Kerr-McGee Chemical Corporation
Oklahoma City, Oklahoma

INTERMEDIATE (60 PERCENT) DESIGN FOR GROUNDWATER REMEDIAL SYSTEM

Moss-American Site
Milwaukee, Wisconsin

VOLUME 1—DESIGN REPORT

4 September 1996

WESTON®
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4 September 1996

Mr. Russell D. Hart (HSRW-6J)
Remedial Project Manager
U.S. Environmental Agency - Region V
77 W. Jackson Blvd.
Chicago, IL 60604

Work Order No. 02687-007-002-0022

Re: Intermediate (60 Percent) Design for
Groundwater Remedial System
Moss-American Site, Milwaukee, Wisconsin

Dear Mr. Hart:

Roy F. Weston, Inc. (WESTON®) has prepared this transmittal on behalf of Kerr-McGee Chemical Corporation (KMCC). The enclosed design documents provide the Intermediate (60 percent) Design for the Groundwater Remedial System at the Moss-American Site. The design documents are presented in two volumes: Volume 1 - Design Report and Volume 2 - Technical Specifications.

KMCC and WESTON look forward to U.S. EPA's review and concurrence with the design approach for the groundwater remedial system so we may continue progress toward a final design. Please contact the undersigned at (847) 918-4000 with any comments or questions on this transmittal.

Very truly yours,

ROY F. WESTON, INC.

Gary J. Deigan
Principal Project Manager

Kurt S. Stimpson
Project Director

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INTERMEDIATE (60 PERCENT) DESIGN FOR GROUNDWATER REMEDIAL SYSTEM

MOSS-AMERICAN SITE
Milwaukee, Wisconsin

September 1996

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VOLUME I—DESIGN REPORT
TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

Appendix

SECTION 1
INTRODUCTION

This document presents the intermediate (60 percent) design for the "funnel and gate" groundwater containment and in situ treatment system. The document was prepared by Roy F. Weston, Inc. (WESTON®) on behalf of Kerr-McGee Chemical Corporation (KMCC). The design submittal is presented in two volumes. Volume I includes the design report and the intermediate design drawings. Volume 2 includes the technical specifications. This submittal was prepared in accordance with WESTON's 23 May 1996 letter to the United States Environmental Protection Agency (U.S. EPA), which outlined the proposed approach/scope and the schedule for design of the groundwater treatment system. WESTON/KMCC submitted a 30 percent groundwater remedial design to the U.S. EPA on 6 September 1995. The U.S. EPA subsequently commented on the design and provided concurrence with the funnel and gate technology selection for the Moss-American Site during a 15 February 1996 meeting. This intermediate design addresses certain review comments prepared by the U.S. EPA and its review contractor, CH2M HILL, Inc. Review comments related to the gate treatment system will be further addressed in subsequent design submittals.

Following completion of the November 1995 preliminary treatability study, the University of Waterloo (under contract to WESTON) recommended that a pilot-scale system be constructed at the site prior to full-scale implementation to demonstrate the short-term (1 to 2 years) performance of the treatment system and to provide improvements, as necessary, prior to full-scale design. The pilot-scale system would assist in determining oxygen addition, nutrient amendment, and treatment zone configuration design parameters. Because the pilot-scale system evaluation is an integral and a necessary part of the design and the ultimate success of this innovative in situ treatment technology, WESTON/KMCC is in the process of developing a groundwater remedial design that is a combination of both pilot-scale and full-scale design. Thus, this document includes the intermediate design for the funnel (barrier) system, as well as the approach for the preparation of a detailed pilot-scale system for the subsequent design of the gate (treatment) system.

Section 1 summarizes the site location and history and provides a description of the current site groundwater conditions. Section 2 provides a discussion of how this design would comply with applicable or relevant and appropriate requirements (ARARs) established by the U.S. EPA and the Wisconsin Department of Natural Resources (WDNR). Section 3 presents the design approach for the funnel and gate system and describes the proposed pilot-scale work plan. The various construction documents that would be prepared as part of the final design are identified in Section 4, and Section 5 presents a project schedule.

1.1 SITE BACKGROUND

The Moss-American site is the location of a former wood-preserving facility that treated railroad ties with a creosote and fuel oil mixture. The site operated from 1921 to 1976 and was closed after being acquired by KMCC.

The U.S. EPA, pursuant to Section 105 of the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA), placed the Moss-American site on the National Priorities List in 1983. The U.S. EPA conducted a remedial investigation/ feasibility study (RI/FS) for the Moss-American site and issued the corresponding RI/FS report in 1990.

A Consent Decree (CD) incorporating the Statement of Work (SOW) was signed by KMCC in 1991. This CD directs KMCC to lead in developing and implementing the remedial design and remedial action plan for the Moss-American site. KMCC implemented a predesign phase to further evaluate site conditions and to complete various engineering studies before remedial design/remedial action was initiated.

In 1995, KMCC initiated groundwater and soil remediation at the site by designing, installing, and operating a free product recovery and removal system. The system extracts free phase creosote from subsurface soil and groundwater.

1.2 SITE LOCATION

The Moss-American site (also referred to as the facility) is located in the northwestern section of the City of Milwaukee, County of Milwaukee, State of Wisconsin, at the southeast corner of the intersection of Brown Deer and Granville Roads, at 8716 Granville Road. The CD defined the following areas as the facility:

- The former Moss-American wood-preserving plant site.
- Approximately 5 miles of the Little Menomonee River.
- Portions of the Little Menomonee floodplain.

The Little Menomonee River flows through the eastern portion of the former wood-preserving plant site and continues through the Milwaukee County Parkway to its confluence with the Menomonee River, about 5 miles south. Milwaukee County owns 51 acres of the former wood-preserving plant site; this parcel is undeveloped recreational-use park land, much of which is in the 100-year floodplain of the Little Menomonee River. Union Pacific, formerly Chicago and Northwestern Transportation Company, owns and uses 23 acres of the site for a loading and storage area for automobile transport (industrial use).

The site is located in a moderately populated suburban area of mixed light industrial, commercial, residential, and recreational uses. Population in the nearby area is an estimated 2,036 persons per square mile. A general location map of the site is presented as Figure 1-1.

1.3 SITE GROUNDWATER CONDITIONS

Site groundwater conditions were evaluated during the RI by the U.S. EPA's contractor and were further evaluated by WESTON/KMCC during several tasks of the predesign phase. This section summarizes groundwater conditions at the Moss-American site and provides a basis for the intermediate design of the groundwater containment and treatment system.

1.3.1 Geology/Hydrogeology

1.3.1.1 Subsurface Geology

WESTON evaluated data collected during the RI and the remedial design phase investigations to define the site stratigraphy and depositional history of the subsurface soil. The site stratigraphy and the relationship between various stratigraphic deposits will dictate the direction and rate of groundwater flow and the migration of any free- and dissolved-phase contamination. A detailed understanding of the stratigraphy underlying the site assists in designing remedial measures. WESTON's interpretation of the available data is presented in the following paragraphs.

The soil encountered at the site varies depending upon location and can consist of soil deposited by man-made, lacustrine, fluvial, and glacial processes. In the vicinity of the former wood-preserving plant's main process area, which is now the Union Pacific automobile transport area, the surface is covered by gravel and asphalt. East of the automobile transport area and west of the river, the surface is covered by varying thickness of clay, aggregate, topsoil, and natural vegetation.

Throughout the area on the west side of the river, the surficial deposits described above are underlain by man-made fill deposits that range between 2- and 12-feet thick; however, the fill averages approximately 2-feet thick throughout much of the site. The fill consists of gravel, cinders, wood chips, railroad ties, river dredgings, and other miscellaneous debris.

The fill material is underlain by soil that has been deposited by lacustrine, fluvial, and glacial processes. These deposits average approximately 5-feet thick and comprise the uppermost groundwater-bearing formation at the site. The occurrence and thickness of each type of deposit are dependant upon the distance from the river. Further from the river, in the topographically higher portions of the site, the fill material is underlain by deposits ranging from lower-permeability silty clay to moderately permeable silt and silty sand. This soil has been interpreted to be silt, sand, and possibly weathered or reworked (eroded and redeposited) glacial tills that have been deposited by lacustrine and fluvial processes.

Nearer to the river, in the topographically lower portions of the site, the fill material is underlain by soil ranging from fine-grained clay and silty clay to more permeable sand and gravel. These deposits have been interpreted to be the result of overbank flood-type deposition and alluvial channel-type deposition, respectively. Of particular interest to the investigation and remedial design at the site is the area occurring within the site grid coordinates of 300 N to 900 N and 1,200 E to 1,800 E (shown in Appendix A, Drawing A-2). Within this area, a moderate-to-high-permeability alluvial sand and gravel deposit was encountered ranging from approximately 2- to 5-feet thick. Ascending from the river flood plain to the topographically higher portion of the site, this deposit may be associated with a small backfilled drainage channel that previously flowed to the river. On the river flood plain, however, this deposit has been interpreted to be an alluvial channel deposit that may be associated with a past configuration of the Little Menomonee River. Figures 1-2 and 1-3 present geological cross-sections in two directions across the site. The locations of the cross-sections are shown on the groundwater contour map (Drawing A-2). These cross-sections were developed from numerous borings and wells advanced and logged during the RI and the predesign phases.

The more permeable lacustrine/alluvial deposits are underlain by a glacial till deposit. This deposit is described as consisting of a very fine-grained, relatively plastic silty clay. Based on geotechnical testing, the glacial till is very impermeable, with an average vertical hydraulic conductivity measurement of 2×10^{-7} cm/sec. Table 1-1 presents the geotechnical properties of the glacial till, as measured by laboratory testing of Shelby tube samples collected at various depths within the deposit. Based on the measured geotechnical parameters and the observations made of the till during the investigation, the glacial till unit acts as an impermeable barrier below the overlying, more permeable deposits.

1.3.1.2 Hydrogeological Conditions

Based on information obtained from soil borings and monitoring wells completed at the site, the uppermost groundwater at the site occurs within the silt and silty sand deposits and the sand and gravel deposits. Water levels in wells located in the topographically higher

portions of the site extend above these permeable units, into the much less permeable silty clay and fill deposits, indicating that within this area of the site the groundwater exists under confined conditions. However, in the immediate vicinity of the river, where the overlying silty clay deposit is absent, groundwater levels occur within the sand and gravel deposit. This suggests that groundwater in the immediate vicinity of the river is not confined. Therefore, the uppermost groundwater occurring at the site exists under semiconfined conditions. On the west side of the river, in the topographically higher portions of the site, groundwater occurs at an average depth of 4 feet below ground surface (bgs). In the river floodplain area of the site, the groundwater occurs at an average depth of 2 feet bgs; however, groundwater in this area is present at the ground surface during times of high precipitation.

Groundwater on both the east and the west sides of the river flows toward and discharges into the Little Menomonee River. This groundwater flow pattern has been confirmed by several years of seasonal groundwater elevation measurements. On the west side of the river, groundwater flow is relatively uniform within the topographically higher portions of the site. Nearer to the river, in the river floodplain area, groundwater flow is dictated by the presence and configuration of the more permeable sand and gravel deposits. Drawing A-2 presents a groundwater elevation contour map that was drawn based on groundwater elevations collected on 9 September 1994. As this figure shows, groundwater is directed toward the area where the sand and gravel deposit is more prevalent. As a result, a natural groundwater barrier is present just south of where the more permeable deposits occur.

The results of hydraulic conductivity measurements completed on 11 shallow site wells indicate the average hydraulic conductivity of the groundwater-bearing zone is 7.4×10^{-4} cm/sec (approximately 2.1 feet/day). Based on measurements taken from the groundwater elevation contour map (Drawing A-2), the horizontal hydraulic gradients in the topographically higher portion of the site, in the floodplain area where the fluvial channel deposits occur, and in the floodplain area where the fluvial channel deposits do not occur are 0.030 feet per foot (ft/ft), 0.016 ft/ft, and 0.024 ft/ft, respectively. Using these hydraulic gradients, the average site hydraulic conductivity, and an assumed effective porosity of 30

percent, the velocity of groundwater flow was calculated to be approximately 0.2 feet/day in the topographically higher portion of the site and in the floodplain area where the fluvial channel deposits do not occur, and approximately 0.1 feet/day in the floodplain area where the fluvial channel deposits are present.

Based on a review of groundwater measurements collected over several years, groundwater flow from the west side of the river averages approximately 4,200 gallons per day (1.5 million gallons per year) during periods of normal precipitation, and approximately 1,700 gallons per day (620,000 gallons per year) during periods of low precipitation.

Since the vertical hydraulic conductivity of the silty clay glacial till deposit is very low (approximately 2 x 10^{-7} cm/sec), downward groundwater flow from the uppermost groundwater-bearing deposit into the glacial till deposit is very limited. Groundwater will primarily flow within the overlying sand and gravel deposit, toward the river.

1.3.1.3 Area Groundwater Use

During the predesign phase, KMCC/WESTON completed a survey of area groundwater utilization (*Predesign Task 8 Technical Memoranda*, 4 February and 1 September 1992, WESTON). The availability of a treated municipal water supply (using Lake Michigan water) and the low yield of shallow groundwater have nearly eliminated the area's reliance upon groundwater resources. The nearest active groundwater well in the vicinity of the site is nearly 3 miles away from the Moss-American site and is constructed at a depth of 100 feet bgs. There are no active residential, municipal, or industrial groundwater pumping wells within a 2.5-mile radius of the Moss-American site.

1.3.2 Nature and Extent of Groundwater Contamination

New groundwater monitoring well installations (during 1992 and 1994 predesign work) and existing RI monitoring wells were sampled and analyzed to determine the nature and extent of groundwater contamination at the Moss-American site.

The location of shallow groundwater exceeding State of Wisconsin NR 140 enforcement standards is shown in Drawing A-4. Table 1-2 presents the ranges of concentrations of the constituents in site groundwater compared to the groundwater remedial action objectives. Based on the RI groundwater sampling and analyses, the primary constituents of concern in site groundwater are benzene, toluene, ethylbenzene and xylene (BTEX) and polycyclic aromatic hydrocarbons (PAHs). The presence of these constituents is consistent with the wood-treating operations formerly employed at the site. Thus, predesign phase groundwater analyses focused on these parameters. The groundwater investigations defined a localized plume of elevated BTEX and PAH concentrations in the shallow groundwater overlying the low-permeability silty clay till unit, limited to an area west of the Little Menomonee River.

Groundwater quality impacts on the former wood treating site are limited to site areas where soil with high PAH concentrations and/or free product is in contact with shallow groundwater. Groundwater immediately downgradient of these "source" areas is also affected. The groundwater quality has not been impacted by activities east of the Little Menomonee River. Any source material (contaminated soil) present at the northeast landfill has not affected the groundwater quality east of the river.

1.4 REMEDIAL ACTION OBJECTIVES FOR GROUNDWATER

The objectives for remediation of groundwater at the site are to prevent the discharge of creosote, BTEX, and dissolved PAHs to the Little Menomonee River and to attain ARARs for groundwater quality.

The U.S. EPA's CD, executed by KMCC, further stated this objective by requiring the following statement of work to address groundwater:

> *"KMCC shall design and install a groundwater collection and treatment system that will meet groundwater cleanup standards, and that will meet effluent discharge standards. The groundwater collection/treatment system shall include a cut-off wall between the system and the river, a collection trench running parallel to the river downgradient of suspected source areas, a collection sump, and a treatment system...unless at predesign it can be demonstrated that an alternative collection and treatment system will be equally effective and reliable... KMCC shall operate the collection/treatment system until the NR 140 standards are met."*

The remedial action objectives for site groundwater are based on preventive action limits (PALs), enforcement standards (ESs), and maximum contaminant levels (MCLs). The CD established groundwater cleanup objectives for BTEX, at PAL concentrations, as presented in Table 1-2. If the U.S EPA determines it is not technically or economically feasible to achieve the PALs within the groundwater, then Wisconsin alternative concentration limits (WACLs) may be established. The CD further stated that other site-related constituents (specifically PAHs) shall not exceed other applicable standards or MCLs.

The funnel and gate treatment system would provide an alternative groundwater management system designed to be equally effective and reliable as the groundwater collection/treatment system identified within the CD. Following review of a 30 percent design submittal, the U.S. EPA and the WDNR provided concurrence with conceptual plans for the funnel and gate system.

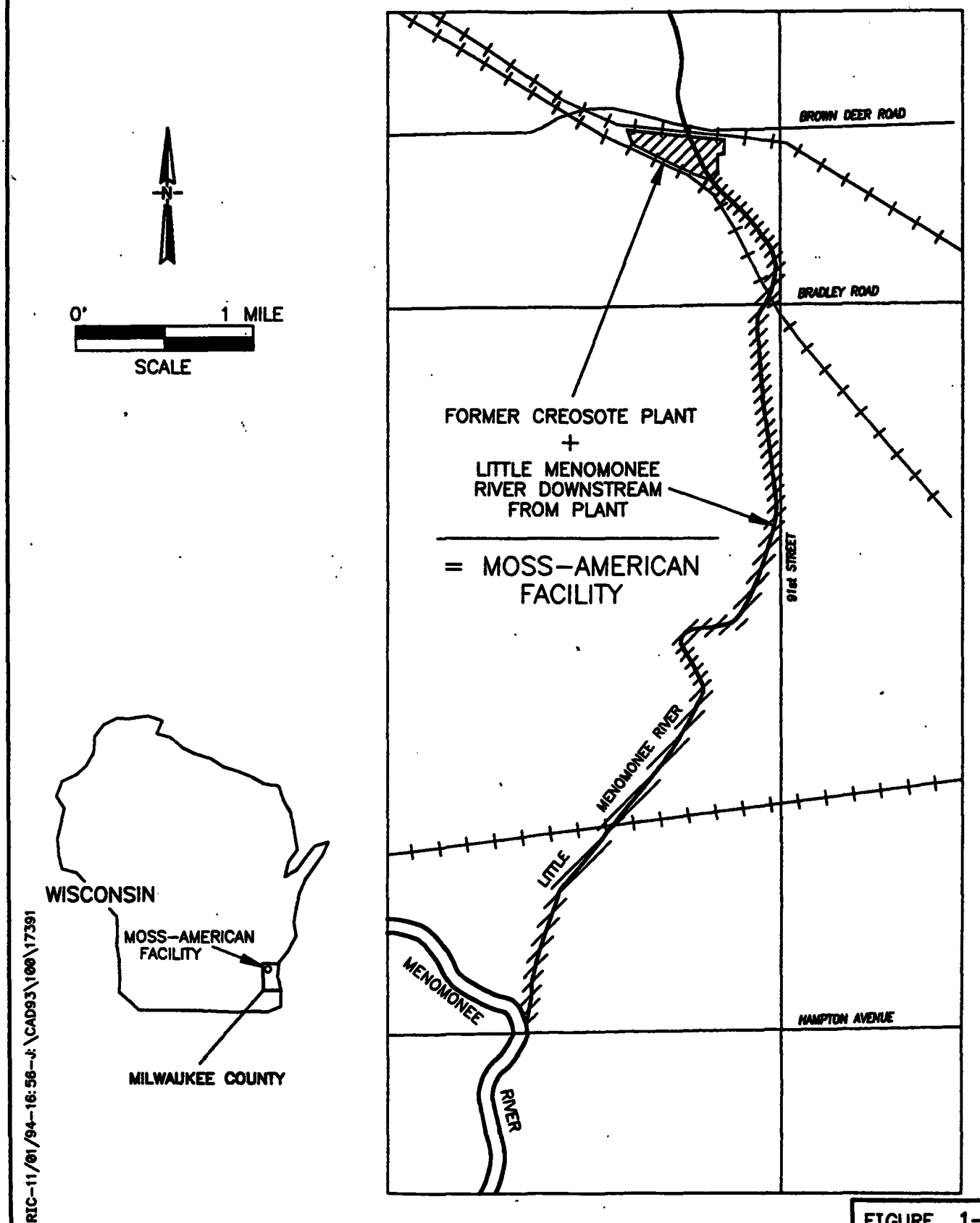

FIGURE 1-1

WESTON MANAGERS DESIGNERS/CONSULTANTS	Three Hawthorn Parkway Vernon Hills, Illinois 60061	FACILITY LOCATION MAP MOSS-AMERICAN SITE Milwaukee, Wisconsin

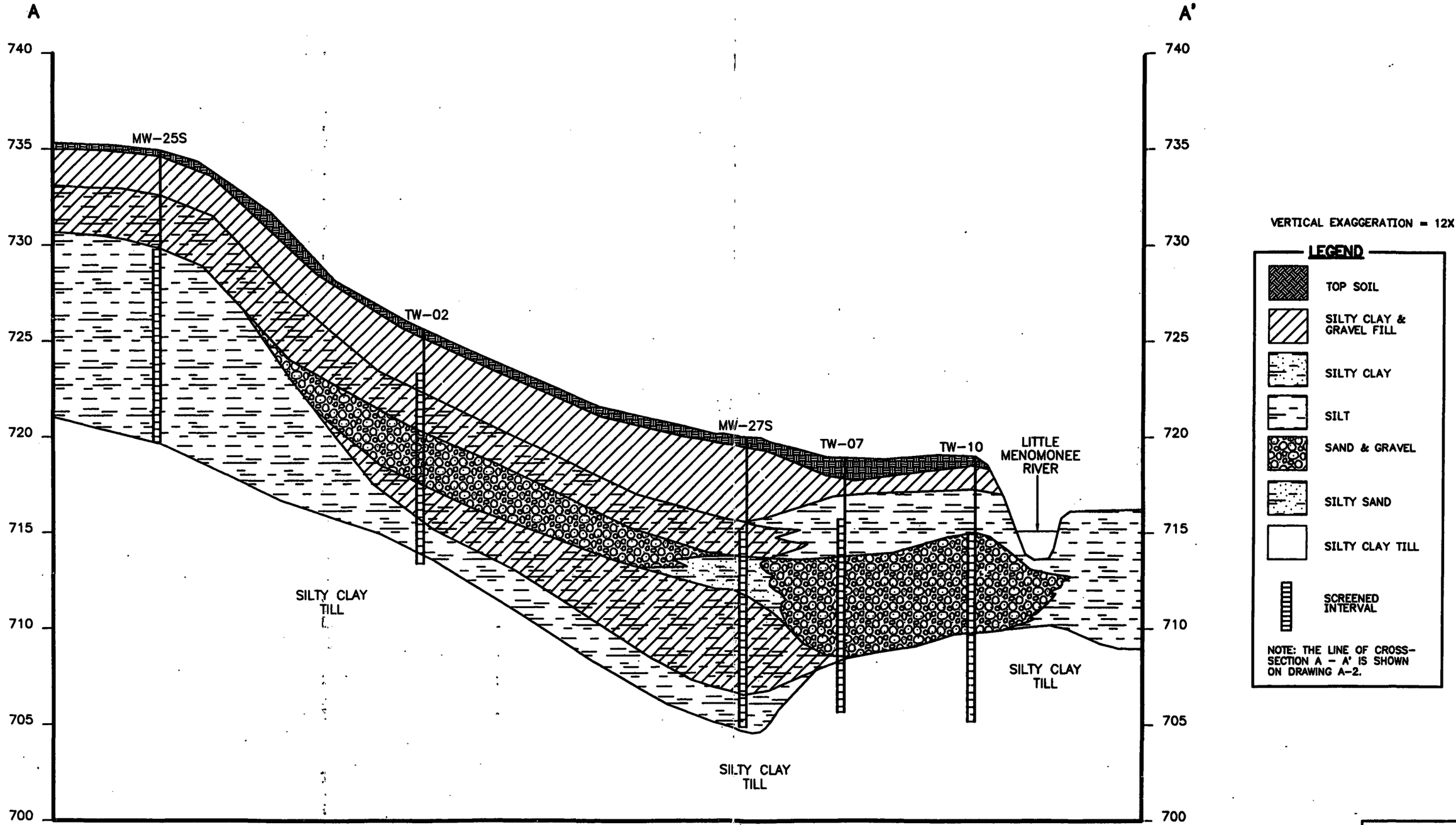

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FIGURE 1-2

WESTON MANAGERS DESIGNERS/CONSULTANTS

Three Hawthorn Parkway
Vernon Hills, Illinois
60061

GEOLOGIC CROSS-SECTION A - A'

MOSS-AMERICAN SITE
Milwaukee, Wisconsin

B

B'

MW-7I & 7S

TW-10

MW-8I & 8S

MW-9I & 9S

720

715

710

705

700

695

690

685

680

675

SILTY CLAY TILL

SILTY CLAY TILL

SILTY CLAY TILL

SILTY CLAY TILL

SILTY CLAY TILL

SILTY CLAY TILL

5'

VERTICAL

0'

60'

HORIZONTAL

VERTICAL EXAGGERATION = 12X

LEGEND

- TOP SOIL
- SILTY CLAY & GRAVEL FILL
- SANDY SILT
- SILT
- SAND
- SAND & GRAVEL
- LAMINATED CLAY & SILT
- INTERBEDDED, SILT SAND & CLAY
- SILTY CLAY TILL
- SCREENED INTERVAL

NOTE: THE LINE OF CROSS-SECTION B – B' IS SHOWN ON DRAWING A-2.

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FIGURE 1-3

WESTON MANAGERS DESIGNERS/CONSULTANTS

Three Hawthorn Parkway
Vernon Hills, Illinois
60061

GEOLOGIC CROSS-SECTION B – B'

MOSS-AMERICAN SITE
Milwaukee, Wisconsin

Table 1-1

Summary of Geotechnical Index Properties on the Silty Clay Till Unit
Moss-American Site
Milwaukee, Wisconsin

Grid Location*	Boring No.	Depth (feet)	% Passing #200 Sieve	% Clay (.005 mm)	USCS Class	Cation Exchange Capacity (meq/100g)	Permeability (cm/sec)
10+71N 28+40E	MA-65	16-18	78.0	76.3	CL	11	2.3 x 10E-8
615N 900E	MA-53	8-9.5	75.0	43.5	CL	14	2.4 x 10E-7
0+00N 1+50E	MA-05	8-10	75.1	40.0	CL	14	1.2 x 10E-7
9+00N 27+00E	MA-61	12-14	98.0	61.7	CL	13	1.4 x 10E-7

United Soil Classification System (USCS) classifications:

CL - Silty clay.

* Grid locations originally referenced in 1994 Technical Memorandum for predesign phase work (WESTON, November 1994).

Table 1-2

Comparison of Groundwater Concentrations and Remedial Action Objectives
Moss-American Site
Milwaukee, Wisconsin
(All Concentrations in μg/L)

Constituent	Range of Site Groundwater Concentrations	Groundwater Remedial Action Objectives		
		NR 140.10 PALS	NR 140.10 ES	U.S. EPA MCLs
Benzene	4-6	0.5	5	5
Naphthalene	1,100-3,000	8	40	---
Benz(a)anthracene	9.4-23.8	---	---	0.1
Chrysene	14-26	---	---	0.2
Benzo(b)fluoranthene	13-15	---	---	0.2
Benzo(k)fluoranthene	3.3-6.1	---	---	0.2
Benzo(a)pyrene	5.7-8.3	0.0003	0.003	2
Indeno(1,2,3-cd)pyrene	1-4	---	---	0.4

Notes:

--- - Not specified.
PALS - Preventive Action Limits. These limits are the concentrations of the constituents in groundwater that shall be achieved at the site in accordance with the Consent Decree, unless an alternate concentration limit is approved.
ES - Enforcement Standards. If the U.S. EPA determines it is not technically or economically feasible to achieve the PAL, than a Wisconsin Alternative Concentration Limit (WACL) may be established. The WACL may not exceed the enforcement standard.
MCLs - Maximum Contaminant Level. This level is the maximum permissible level of a contaminant in water that is delivered to any user of a public water system.

SECTION 2
DESIGN CRITERIA AND APPLICABLE REGULATIONS

This section identifies the ARARs and discusses the attainment of ARARs applicable during the construction and operation and maintenance of the funnel and gate groundwater treatment system. This section also discusses compliance with the SOW requirements.

The FS prepared by CH2M HILL identified several ARARs as being applicable during the remediation of groundwater at the Moss-American site. Table 2-1 lists the ARARs identified in the FS. The identification of ARARs was based upon an evaluation conducted by the U.S. EPA and the WDNR following their review of the proposed collection and treatment groundwater treatment system.

The CD SOW provides for selecting an alternative groundwater remedial system that is equally effective and reliable as the groundwater collection/treatment system identified within the CD. Consequently, KMCC implemented a predesign phase to further evaluate the site conditions and to complete the necessary engineering studies before remedial design/remedial action was initiated. Based on the engineering studies conducted as part of the predesign phase and on U.S.EPA/WDNR review, the newly developed funnel and gate groundwater treatment system was selected as an appropriate alternative for managing groundwater at the site.

The ARARs originally proposed in the FS as being applicable were reevaluated based on the planned design and operation of the funnel and gate technology. Those ARARs that are no longer applicable are shaded in Table 2-1 and not considered in the reevaluation process. Based on this evaluation, a revised list of ARARs applicable during the construction and the operation and maintenance of the funnel and gate groundwater treatment system was prepared. Tables 2-2 and 2-3 show the federal and State ARARs applicable during the construction and the operation and maintenance of the funnel and gate groundwater treatment system, respectively, and provides a discussion of the compliance methods for attaining the ARARs. Table 2-2 includes specific requirements

under 40 CFR 264 that would be applicable to the proposed remedial action. These federal requirements would encompass the NR 181 (hazardous waste management) requirements that were identified as ARARs within the FS.

Table 2-3 identifies two additional ARARs WESTON has determined to be applicable to the Moss-American site. Specifically, they include NR 670, which requires an operating license be obtained, and NR 680, which requires the facility to be inspected on a routine basis.

Table 2-1

Originally Proposed Federal and State ARARs
Groundwater Collection and Treatment System
Moss-American Site
Milwaukee, Wisconsin

Type of ARAR	ARAR Category	Specific Requirement	Citation
Federal	Location-Specific	Facility within a 100-year floodplain must be designed, constructed, operated, and maintained to avoid washout.	40 CFR 264.18 (b)
		Action within floodplains to avoid adverse effects, to minimize potential harm, and to restore and preserve beneficial values.	Executive Order 11988. Protection of Flood Plains (40 CFR 6, Appendix A).
		Action to minimize the destruction, loss, or degradation of wetlands.	Executive Order 11990. Protection of Wetlands (40 CFR 6, Appendix A).
		Avoid taking or assisting in action that will have direct adverse effects on scenic rivers.	Scenic Rivers Act (16 U.S. C. 1271 et. seq., Section 7[a]): 40 CFR 6.302 (e)
State	Location-Specific	Requires and establishes standards for municipal floodplain zoning ordinances.	Wisconsin Adm. Code NR-116
Federal	Action-Specific	The proposed action must be consistent with regional water quality management plans developed under Section 208 of the Clean Water Act.	Federal Water Pollution Control Act, as amended by the Clean Water Act of 1977: Section 205 (b)
		National Pollutant Discharge System (NPDES) permit regulations.	40 CFR 122
		The site operator shall develop a best management practice (BMP) program and shall incorporate it into the operations plan or the NPDES permit application if required.	40 CFR 125.100

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ARAR is not applicable to funnel and gate technology; therefore, it has not been carried forward for reevaluation.

Table 2-1

Originally Proposed Federal and State ARARs
Groundwater Collection and Treatment System
Moss-American Site
Milwaukee, Wisconsin
(Continued)

Type of ARAR	ARAR Category	Specific Requirement	Citation
Federal	Action-Specific (Cont.)	The BMP must establish procedures for managing potential spills, predict spill flow, and ensure RCRA management of spilled waste.	40 CFR 125.104
		States are granted enforcement jurisdiction over direct discharges and may adopt reasonable standards to protect or enhance the uses and qualities of surface water bodies in the state.	40 CFR 131
		Requires adherence to sample preservation procedures, including container materials and sample holding times.	40 CFR 136.1 - 136.4
		Standards for environmental performance of miscellaneous treatment units.	40 CFR 264 Subpart X
		Requires wastes to be properly treated prior to discharge to a publicly owned treatment works (POTW) facility.	40 CFR 403.5
State	Action-Specific	Establishes limits for toxic substances to protect public health from consumptive use of fish from surface waters.	Wisconsin Adm. Code NR-105(8)&(9)
		Establishes surface water quality criteria for toxic substances.	Wisconsin Adm. Code NR-102, NR-105
		Establishes procedures for calculating effluent limitations for toxic substances.	Wisconsin Adm. Code NR-106

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ARAR is not applicable to funnel and gate technology; therefore, it has not been carried forward for reevaluation.

Table 2-1

Originally Proposed Federal and State ARARs
Groundwater Collection and Treatment System
Moss-American Site
Milwaukee, Wisconsin
(Continued)

Type of ARAR	ARAR Category	Specific Requirement	Citation
State	Action-Specific (cont.)	WDNR to review all plans and specifications for wastewater treatment facilities and groundwater monitoring systems.	Wisconsin Adm. Code NR-108
		Specifies construction standards for well and pump installations and abandonment of wells.	Wisconsin Adm. Code NR-112
		Establishes requirements for the identification of hazardous waste and standards for the storage, transport, and disposal of hazardous waste.	Wisconsin Adm. Code NR-181
		Discharge permit is required for discharges to surface water and to land areas where water may percolate to groundwater.	Wisconsin Adm. Code NR-200
		Prohibits discharges to POTWs that pass through or interfere with the operation or performance of the POTW, thereby causing a POTW to violate its NPDES permit or preventing municipal sludge use or disposal by the POTW's selected method of sludge disposal.	Wisconsin Adm. Code NR-211
		Monitoring conducted for meeting NPDES permits must comply with analytical test methods, Preservation procedures and other laboratory requirements specified.	Wisconsin Adm. Code NR-219

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ARAR is not applicable to funnel and gate technology; therefore, it has not been carried forward for reevaluation.

Table 2-1

Originally Proposed Federal and State ARARs
Groundwater Collection and Treatment System
Moss-American Site
Milwaukee, Wisconsin
(Continued)

Type of ARAR	ARAR Category	Specific Requirement	Citation
State	Action-Specific (cont.)	Requires WDNR to establish effluent limits for uncategorized point sources to base those limits on best practicable control technology currently available or best available control technology economically achievable.	Wisconsin Adm. Code NR-220
		Requires point source discharges to obtain a permit from WDNR	CH 147. stats—Pollution Discharge Elimination
State	Chemical-Specific	Establishes groundwater quality standards.	Wisconsin Adm. Code NR-140

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ARAR is not applicable to funnel and gate technology; therefore, it has not been carried forward for reevaluation.

Table 2-2

Revised Federal ARARs and Compliance Methods
Funnel and Gate Groundwater Treatment System
Moss-American Site
Milwaukee, Wisconsin

Citation	Requirement	Compliance Method
Location-Specific ARARs		
40 CFR 264.18 (b)[1]	Facility within a 100-year floodplain must be designed, constructed, operated, and maintained to avoid washout of hazardous wastes.	The primary components of the gate and funnel system would be installed below ground surface. Therefore, these components would not be affected by the washout conditions. All aboveground components such as buildings and related ancillaries would be installed in areas outside the 100-year floodplain.
Executive Order 11988. Protection of Flood Plains (40 CFR 6, Appendix A).[1]	Action within floodplains to avoid adverse effects, to minimize potential hazards, and to restore and preserve beneficial values.	The funnel and gate groundwater treatment system will be designed, constructed, operated, and maintained to avoid adverse effects and to minimize potential hazards. Since the major components of the system will be installed below ground surface, beneficial values of the floodplain will remain the same.
Executive Order 11990. Protection of wetlands (40 CFR 6, Appendix A).[1]	Action to minimize the destruction, loss, or degradation of wetlands.	Construction of the funnel and gate system would have a minimal impact on the wetlands present at the site because the system would be installed belowground.
Scenic Rivers Act (16 U.S.C. 1271, et. seq., Section 7[a]): 40 CFR 6.302(e)	Avoid taking or assisting in action that will have direct adverse effects on scenic rivers.	The system would not have direct adverse effects on the Little Menomonee River. Engineering controls during construction would aid in further preventing adverse effects.
Action-Specific ARARs		
40 CFR 125[1]	Requires development of a best management program (BMP).	This ARAR will be attained by developing an operation and maintenance (O&M) plan for the funnel and gate groundwater treatment system.
40 CFR 136[1]	Requires adherence to sample preservation procedures, including container materials and sample holding time.	Compliance with this ARAR will be achieved by developing an O&M plan and a construction quality assurance plan (CQAP). The O&M plan would encompass sampling requirements, including sampling and preservation procedures, container materials, and sample holding times during facility operation. The CQAP would include sampling requirements during construction of the treatment system.

Table 2-2

Revised Federal ARARs and Compliance Methods
Funnel and Gate Groundwater Treatment System
Moss-American Site
Milwaukee, Wisconsin
(Continued)

Citation	Requirement	Compliance Method
40 CFR 264.14[2]	Requires that the site be secured to prevent unauthorized access.	As specified in the SOW, major portions of the site are currently secured by a fence and a locked gate. The primary components of the gate and funnel groundwater treatment system would be installed below ground surface and in areas already secured by a fence and a locked gate. In accordance with this ARAR and as specified in the SOW, all aboveground system components such as buildings and related ancillaries would be secured by a fence and a locked gate.
40 CFR 264.15[2]	Requires that the facility be inspected on a routine basis for deterioration, operator errors, and discharges.	Periodic inspections of the facility will be conducted to achieve compliance with this ARAR. Detailed facility inspection procedures will be included in the O&M plan.
40 CFR 264.16[2]	Requires facility personnel to be properly trained.	In order to achieve compliance with this ARAR, a health and safety program will be implemented in accordance with the health and safety plan (HASP) included in the construction specifications.
40 CFR 264.31[2]	Requires that facilities be designed, constructed, maintained, and operated to minimize the threat to human health or the environment.	The funnel and gate groundwater treatment system will be designed, constructed, maintained, and operated in a way that will minimize the threat to human health or the environment.
40 CFR 264.32[2]	Requires emergency and health and safety equipment.	In order to achieve compliance, emergency equipment such as internal alarms, telephones, fire extinguishers, spill containment kits, and decontamination equipment will maintained at the site in accordance with the HASP and the O&M plan.
40 CFR 264.33[2]	Requires that the emergency equipment at the site be regularly tested and maintained.	Emergency equipment at the site will be regularly tested and maintained in accordance with the HASP and the O&M plan.
40 CFR 264.34[2]	Requires that facility personnel have easy access to electronic communications and alarm systems.	Trained facility personnel will have access to an alarm system and a telephone in order to comply with this ARAR.

Table 2-2

Revised Federal ARARs and Compliance Methods
Funnel and Gate Groundwater Treatment System
Moss-American Site
Milwaukee, Wisconsin
(Continued)

Citation	Requirement	Compliance Method
40 CFR 264.37[2]	Requires arrangements with local authorities.	To achieve compliance, local police, fire department, and emergency response teams will be familiarized with the facility and its related hazards in accordance with the HASP and the O&M plan.
40 CFR 264.53[2]	Requires that copies of the contingency plan be maintained at the site.	Copies of the HASP and the O&M Plan will be maintained at the site to achieve compliance with this ARAR.
40 CFR 264.56[2]	Requires establishment of emergency procedures.	Emergency procedures will be defined in the HASP and the O&M plan.
40 CFR 264.73[2]	Requires maintenance of operating records.	The operating records will be maintained in accordance with the O&M plan.
40 CFR 264.74[2]	Requires availability, retention, and disposition of records.	All records will be made available at all reasonable times for inspections.
40 CFR 264.75[2]	Requires submittal of biennial report.	A biennial report will be submitted.
40 CFR 264.92[2]	Action to achieve groundwater protection standards.	The funnel and gate groundwater treatment system will achieve groundwater protection standards.
40 CFR 264.93[2]	Requires establishment of hazardous constituents.	Hazardous constituents have been established in the SOW.
40 CFR 264.94[2]	Requires establishment of concentration limits.	Concentration limits have been established in the SOW.
40 CFR 264.95[2]	Requires establishment of point of compliance.	Points of compliance will be established downstream of the treatment system.
40 CFR 264.96[2]	Requires establishment of compliance period.	Compliance periods have been established in the SOW.
40 CFR 264.97[2]	Requires establishment of general groundwater monitoring requirements.	Groundwater monitoring requirements have been established in the SOW and will be included in the O&M plan.
40 CFR 264.98[2]	Requires establishment of a detection monitoring program.	RIs have been conducted at the site. Requirements for the compliance monitoring program are included in the SOW. These requirements will be included in the O&M plan.

Table 2-2

Revised Federal ARARs and Compliance Methods
Funnel and Gate Groundwater Treatment System
Moss-American Site
Milwaukee, Wisconsin
(Continued)

Citation	Requirement	Compliance Method
40 CFR 264.99[2]	Requires establishment of a compliance monitoring program.	Requirements for the compliance monitoring program are included in the SOW.
40 CFR 264.100[2]	Requires a corrective action program.	Groundwater remediation will be conducted once the funnel and gate groundwater treatment system is installed.
40 CFR 264.601[1]	Requires environmental performance standards.	The requirements in this section will be met as specified in the SOW.
40 CFR 264.602[1]	Requires monitoring, analysis, inspection, response, reporting, and corrective action.	The requirements in this section will be met as specified in the SOW.

[1] ARAR identified in the FS.
[2] Specific requirements under 40 CFR 264 that would require compliance.

Table 2-3

Revised State ARARS and Compliance Methods
Funnel and Gate Groundwater Treatment System
Moss-American Site
Milwaukee, Wisconsin

Citation	Requirement	Compliance Method
Location-Specific ARARs		
NR 116[1]	Requires and establishes standards for municipal floodplain zoning ordinances.	Construction and operation and maintenance of the funnel and gate groundwater treatment will meet the standards of the municipal ordinances specified in NR 116.
Action-Specific ARARs		
NR 108[1]	Requires that all plans and specifications for wastewater treatment facilities and groundwater monitoring systems be reviewed by the WDNR.	Plans and specifications associated with the funnel and gate groundwater treatment system will be submitted to the WDNR for review.
NR 112[1]	Specifies construction standards for wells and pump installations and abandonment of wells.	Monitoring wells will be constructed to these standards.
NR 181[1]	Establishes requirements for the identification of hazardous waste and standards for the storage, treatment, and disposal of hazardous waste.	These requirements will be achieved as described in Table 2-2 under the applicable sections of 40 CFR 264 regulations.
NR 670[2]	Requires that an operating license be obtained prior to operating a facility.	Compliance with this ARAR will be attained by obtaining an operating license from the WDNR.
NR 680[2]	Requires that the facility be inspected on a routine basis for deterioration, operator errors, and discharges.	Routine inspections of the facility will be conducted to achieve compliance with this ARAR. Detailed facility inspection procedures will be included in the O&M plan.
Chemical-Specific ARARs		
NR 140[1]	Establishes groundwater quality standards.	The funnel and gate groundwater treatment system will be designed to meet the groundwater quality standards specified in NR 140 and the SOW.

[1] ARAR identified in the FS.
[2] Newly identified ARAR.

SECTION 3
DESIGN AND ANALYSIS

3.1 DESIGN OVERVIEW

The design of the groundwater remedial system addresses both pilot-scale and full-scale design. Specifically, the design of the funnel (barrier) system is a full-scale design, while the design and operation of the treatment gate specifies a period of pilot-scale operations prior to final design. Further rationale for this design approach is presented in Subsection 3.4.3. The full-scale design of the funnel involved modeling groundwater flow through the site and subsequently locating the funnels and determining the number of gates required to capture the plume. In addition, an evaluation was conducted to determine the most technically and economically feasible barrier material. The modeling results and the alternatives analysis for the barrier material are presented within this section.

3.2 GROUNDWATER MODELING

To design the funnel and gate system for the site, it was necessary to obtain a detailed understanding of the groundwater flow system within the uppermost aquifer underlying the site. This includes understanding the groundwater flow system during natural steady-state flow conditions and understanding how installation of the funnel and gate system will affect the aquifer. Once these conditions can be predicted by the model, the funnel and gate configuration can be modified to achieve the design objectives. To provide an understanding of the groundwater flow system, WESTON has completed modeling of the groundwater flow. The results of these modeling efforts are described in the following subsections and explain the type of groundwater model used to model groundwater flow, the model geometry and hydraulic input parameters used to complete the model, and the modeling results and conclusions.

3.2.1 Model Design

The groundwater modeling program used to construct the Moss-American site model is the United States Geological Survey (USGS) Three-Dimensional Modular Finite Difference Groundwater Flow Model (MODFLOW) (McDonald and Harbaugh, 1988). This is a three-dimensional groundwater modeling program that is used to calculate the head distribution of a specified area based on known site conditions that are input into the program. The model uses a finite difference approach to determine groundwater head distributions. The MODFLOW program can be used to simulate many aquifer conditions; however, the model constructed for the Moss-American site simulates unconfined steady state groundwater flow.

The Moss-American model is a one-layer model that simulates groundwater flow within the uppermost 15 feet of soil underlying the site (the soil above the relatively impermeable glacial till deposit). Initially, a larger grid area was modeled using a larger grid cell spacing (130 by 130 feet). This larger model was completed in order to determine the size of the area that would be affected by the placement of the funnel and gate system. The results of this large area model were used to determine that an area measuring 2,800 by 2,800 feet would be adequate to model groundwater flow within the area where the funnel and gate system will be installed without any appreciable boundary effects that would adversely affect the model. Known aquifer geometry and hydraulic parameters are input into each individual cell to represent the specific area the grid cell encompasses. The modeling program then calculates the resulting hydraulic head value for each cell. The Moss-American model contains a total of 4,500 cells that vary in size from 20 by 20 feet to 200 by 200 feet. The size of the individual cells depends upon where the cells occur within the modeled area. In the central portion of the model, where the funnel and gate system is to be installed, the cells are 20 by 20 feet square to provide greater detail in which to manipulate the location of the funnel and gates. Moving away from the center of the model, the cells will not contain the funnels and gates; they will contain only head measurements. Therefore, less detail is necessary, and the cells become larger (at a rate of 1.5 times the preceding cell or less).

The model grid is orientated southwest to northeast, which is parallel to the dominant direction of groundwater flow. This orientation allows the northwest and southeast sides of the model to be defined as no-flow boundaries, where water flows perpendicularly to the model boundaries. The northeast side of the model is a constant head boundary that corresponds to the elevation of the water in the Little Menomonee River. The southwest side of the model is a constant head boundary that is parallel to the groundwater equipotential lines, and it is based on the hydraulic head, calculated based on the site's natural hydraulic head gradient. The bottom of the model (15 feet below ground surface) is a no-flow boundary condition that simulates no flow between the uppermost aquifer and the underlying glacial till deposit. Drawing A-1 (Appendix A) presents a map that shows in plan view the grid design of the model and its boundary conditions.

3.2.2 Model Input Parameters

3.2.2.1 Input

All the cells in the model that are on the west side of the river contain data and are therefore considered to be active. The cells that are located on the northeast side of the river do not contain data and are considered to be inactive. The cells on the northeast side of the river were made inactive, since groundwater flow on the northeast side of the river will not impact the design of the funnel and gate remedial system. The cells located within the river were given a constant head of 714 feet, which is an average river-stage elevation based on past gauging information. The cells on the southwest border of the model were given a constant head value of 751 feet, which was extrapolated using the natural hydraulic head gradient and measured groundwater elevations from site wells.

The hydraulic conductivity of the modeled area was defined by using two different sets of average values. First, in the areas where the uppermost aquifer is composed of silty sand and clayey silt material, an average value of 1.3×10^{-5} cm/sec (0.04 feet/day) was used. This is an estimated value, based on the assumption that the horizontal hydraulic conductivity is two orders of magnitude higher than the vertical hydraulic conductivity (1.3×10^{-7} cm/sec) measured by falling head permeability tests conducted on soil samples. In the area that has

been interpreted as consisting of fluvial channel deposits composed of silty sand and gravel, an average value of 7.4 x 10^{-4} cm/sec (2.1 feet/day) was used. This value is based on the average of results of hydraulic conductivity slug testing conducted at the site.

3.2.2.2 Model Calibration

The first step to completing the Moss-American site model was to construct a model of the natural static groundwater flow conditions that could be calibrated to match the groundwater elevation contours generated from groundwater levels measured at the site. The model was run without including any funnel or gate configurations. The individual cell input parameters were then adjusted, and the model was run through several iterations in order to calibrate it by ensuring that the natural head distribution at the site (shown in Drawing A-2) was properly represented by the model. The extent of the sand and gravel zones or higher permeable zones was adjusted as necessary during calibration in order to obtain a calibrated model. A map showing the head distribution of the calibrated model is provided as Drawing A-3 for comparison with the naturally occurring head distribution map Drawing A-2). WESTON is confident the calibrated groundwater model reasonably represents site groundwater conditions; thus, the model is an appropriate evaluation tool for designing the funnel and gate system.

3.2.2.3 Funnel and Gate Simulation

The funnels were simulated by giving the cells that will make up the funnels a hydraulic conductivity equal to that of sheetpiling material. The vendor specifications on the sheetpiling material give the common range of 1 x 10^{-10} cm/sec (2.8 x 10^{-7} feet/day) hydraulic conductivity for a joint-sealed steel or high density polyethylene (HDPE) sheetpiling (*A New Type of Steel Sheet Piling with Sealed Joints for Groundwater Pollution Control* [Starr, Cherry, and Vales, 1992]).

The gates were simulated by giving the cell or cells a hydraulic conductivity value one order of magnitude higher than that of the surrounding soil, as was presented in *In Situ*

Remediation of Contaminated Groundwater: The Funnel and Gate System (Starr and Cherry, 1994).

The cells that make up the funnels were given a hydraulic conductivity value of 1×10^{-10} cm/sec (2.8×10^{-7} feet/day) and are 20 by 20 feet in area. The cells that make up the gates were given a hydraulic conductivity value of 7.4×10^{-3} cm/sec (21 feet/day) and are 20 by 20 feet in area.

3.2.3 Results and Conclusions

Two different plan-view maps were generated to show the results of the groundwater modeling effort; they are presented in Appendix A. Drawing A-3 presents the model-simulated groundwater contours of the calibrated model, representing the typical static groundwater flow system without the addition of the funnel and gate system. As this drawing shows, the model successfully approximates the groundwater contours that were drawn based on actual measured groundwater elevations collected on 9 September 1994 (Drawing A-2); therefore, the model does represent actual groundwater flow conditions that are present at the site.

Drawing A-4 presents the simulated groundwater flow that occurs as a result of the installation of the funnel and gate system. This drawing shows the simulation of the two proposed funnels: Funnel No. 1 located in the southwest, topographically higher portion of the site and Funnel No. 2 located in the northeast portion of the site adjacent to the river. Two gates (G1 and G2) were simulated in Funnel No. 1, and three gates (G3, G4, and G5) were simulated in Funnel No. 2. As Drawing A-4 shows, the installation of the funnel and gate system has affected the groundwater flow system. Careful review of the groundwater contours shown in Drawing A-4 shows that the contours bend inward toward the simulated gates at a point that is outside of the limits of the contaminant plume. This indicates that the groundwater flow outside of the limits of the contaminant plume is inward toward the gate; therefore, the entire extent of the contaminated groundwater is being directed inward.

To assist in completing the design of the actual treatment gate configurations, WESTON has calculated the anticipated volumes and velocities of groundwater that will flow through the gates once they are installed. The volume of water that will flow through a gate installed in Funnel No. 1 can be estimated using the cross sectional area of the gate (20 feet wide times 15 feet of saturated thickness), the hydraulic gradient induced by the presence of the gate (approximately 0.05 ft/ft), and the hydraulic conductivity of the gate material (21.0 feet/day). Based on these data, the volume of groundwater that will flow through a gate installed in Funnel No. 1 will be approximately 2,500 gallons per day. The velocity of groundwater flow through the gates calculated using the hydraulic conductivity of the gate material, the induced hydraulic gradient, and an estimated effective porosity of 30 percent, is 3.5 feet/day. Using the hydraulic gradient induced by a gate installed in Funnel No. 2 (0.04 ft/ft), the volume and velocity of water flowing through a gate installed in Funnel No. 2 are calculated to be approximately 1,900 gallons/day and 2.9 feet/day, respectively.

Using the results of these calculations, the volume flowing through the two gates in Funnel No. 1 would be approximately 5,000 gal/day. The volume flowing through the three gates in Funnel No. 2 would be approximately 5,700 gallons/day. The absolute discharge, defined by the volume of water that could flow through the area occupied by the funnel under the same hydraulic conditions created by the funnel (i.e. hydraulic gradient of 0.05 ft/ft), is a measure of how much water should flow through the area occupied by the funnel if the funnel were not in place. Using the area of Funnel No. 1 (6,900 ft^2), the hydraulic gradient induced by the funnel (0.05 ft/ft), and the average hydraulic conductivity of the aquifer (2.1 ft/day), the absolute discharge is calculated to be approximately 5,400 gal/day. Using the area of Funnel No. 2 (10,000 ft^2), the hydraulic gradient induced by the funnel (0.04 ft/ft), and the average hydraulic conductivity of the aquifer (2.1 ft/day), the absolute discharge through Funnel No. 2 area is 6,400 gallons/day. These discharge calculations are representative of the results of the groundwater model, since the model shows a relatively small amount of water flowing around the edges of the funnels instead of through the treatment gates.

As these results show, this funnel configuration will capture and contain the contaminant plume. The configuration of the gates will result in groundwater flowing through the funnel and gate system at a rate that will allow clean groundwater to flow around the funnel edges and direct the contaminant plume inward toward the gates.

This analysis of groundwater hydraulics will be utilized as a basis for proceeding with the next level of design completion for the gate treatment system and for development of the pilot-scale treatability demonstration work plan. Initially, the gate geometry and proposed gate media permeability may be modified in an iterative design process to meet the goals for residence time/treatment efficacy. This would be the first step in the next level of design.

3.3 DEVELOPMENT OF FUNNEL DESIGN

The overall design objective of the funnel and gate treatment system is to provide a system that can contain or limit the flow of contaminated groundwater, redirect the groundwater to discrete openings in the funnel walls, and direct the water through a suitable media designed to remove and/or treat the contaminants of concern. The funnel barrier must be designed to function under differing subsurface groundwater conditions, while still effectively containing and redirecting the groundwater flow through the treatment gates. The length and orientation of the barrier system along with the optimal gate width has been determined through groundwater modeling. The depth of the barrier must be sufficient to tie into a zone of significantly lower permeability acting as an aquitard, limiting the vertical movement of groundwater. The barrier material must be such that it can be installed to a maximum depth of 20 feet, corresponding to the low-permeability clay layer underlying the site. In addition, the barrier material must be chemically compatible with the contaminants of concern to ensure the barrier maintains its structural and hydraulic stability throughout the design life of the treatment system. Alternative materials considered for design of the funnel and gate structural components are discussed in the following sections.

3.3.1 Description of Barrier Wall Alternatives

WESTON evaluated three different alternative materials of construction for installation of a subsurface barrier consistent with the funnel and gate remediation approach. These barrier walls include steel sheetpiling using the Waterloo Barrier method of joint sealing, installation of a HDPE sheeting by vibrating the panels into the subgrade, and trenching followed by automatic installation of HDPE panels.

Waterloo Barrier Sheetpiling

A common barrier wall used in the funnel and gate treatment approach is steel sheetpiling driven into place with sealed joints. Installation of the panels takes place in the same manner as for sheeting used for excavation support or breakwater construction. This method of driving piles is applicable for soil containing minimal cobbles or boulders. When soil is nonhomogeneous, leading edge attachments can be used on the sheeting to allow the piles to break through cobbles with minimal resistance. The panels are made of a specially designed pile configuration that creates a connection that can be sealed. Once the panels are installed, the interstitial space is pressure-jetted to remove any soil or debris in the void, and the connection is grouted using a tremmie pipe placement method.

During installation, the contractor implements a quality control program to ensure the seal and panels are installed correctly. The steel sheeting is patented and is manufactured by Canadian Metal Rolling Mills located in Cambridge, Ontario. The connection joint between two sheetpile sections form a hollow cavity, which can be sealed with a grout mixture to make the joint watertight. A foot plate is welded at the bottom edge of each pile to limit the migration of soil and debris into this sealable cavity during driving of the piles. The sealing process was developed by the University of Waterloo and requires a certified seal installer and inspector to be present during installation of the barrier grout. This field staffing approach ensures the field inspection and installation will be consistent with the Waterloo-patented product specifications.

Gundwall HDPE Sheetpiling

A second subsurface barrier alternative—Gundwall HDPE Sheetpiling—was evaluated, which consists of an HDPE sheetpile barrier wall in place of the standard structural steel sheetpiling. Gundwall sheetpiling was developed by GSE Lining Technology of Houston, Texas, for use in environmental applications as a subsurface barrier to groundwater migration. Gundwall sheetpiling consists of 4-foot wide panels made of 80-mil HDPE. Each panel has a sheetpile-type interlock connection and is installed one panel at a time. The panel connection is sealed by feeding a cord of bentonite-based material (Hypertite) into the joint, which subsequently swells when it comes into contact with groundwater, creating a watertight seal. Quality control is employed during the panel installation to ensure the Hypertite sealant is installed along the full vertical length of the panel joint.

Gundwall sheetpiling is installed in a "pulling" action as opposed to typical sheetpiling, which is "pushed" into the underlying material. The HDPE panels are attached to a drive plate of the same dimensions as the Gundwall panels. The drive plate is advanced through the soil by vibrating the drive plate and relocating the soil. The HDPE panel is attached to the bottom of the drive plate and is pulled into position. Once in position, the drive plate is removed, and the next panel is readied for installation.

Gundwall Sheetpiling Installed with One Pass Trencher

As a modification to the driven Gundwall method of installation, the HDPE barrier panels can also be installed by a one pass trencher machine. The equipment consists of a specially designed tracked excavator with a trencher attachment. The unit cuts a trench approximately 18 inches wide to the required installation depth. The trencher is outfitted with vertical steel panels that act as a trench box to maintain the stability and to eliminate collapse of the trench sidewalls. The Gundwall panels are installed within the liner compartment. Once a complete panel is installed, the unit trenches another five feet, and the panel installation and sealing process is repeated. The liner compartment allows the installer to backfill general fill soil or granular fill on the upgradient side of the wall to

increase groundwater flow across the wall face. Depending on the native soil condition and results of groundwater modeling, this option can provide efficient control and capture of the groundwater plume by reducing the reliance on native soil permeabilities to transport the plume to each gate location.

3.3.2 Constructability

Each alternative was evaluated for potential difficulties that could be encountered during construction and installation of each type of barrier system at the Moss-American site.

Installation of Waterloo Barrier steel sheetpiling is typically limited to soil without boulders or rock outcroppings. Sheetpiling can be readily driven into a clayey soil. Based on the subsurface investigations conducted at the Moss-American site, suitable soil conditions are present to allow the sheeting to be driven into a confining layer and function as intended. Bends, turns, and angles can be installed by producing the appropriate angle piles in the mill. Installation of the gate sidewalls can be achieved using the same installation process as for the funnel walls.

GSE Lining Technologies was consulted to determine the constructability of the Gundwall barrier alternative with respect to the on-site soil types. Based on their recommendation and on the fact that the soil is a cohesive clayey material, it was determined that Gundwall sheetpiling could not be installed to the depths required to ensure an adequate hydraulic barrier to groundwater flow. The cohesive soil would reduce the effectiveness of the vibrating drive plate, significantly reducing the achievable depth.

The one pass trencher method of installation allows the HDPE barrier to be installed while overcoming the cohesive soil limitations. However, significant volume of soil is generated from excavation of the 18-inch trench and the soil would subsequently require management. The one pass trencher machine would not be able to construct the gate sidewalls because the unit cannot turn 90 degrees and still maintain installation consistency.

3.3.3 Cost Evaluation

WESTON evaluated the costs associated with the installation of each of the barrier alternatives described in Subsection 3.3.1. Waterloo Barrier steel sheetpiling can be installed in granular or clayey soil and is installed in a manner that does not produce excavated soil. The sheetpiles are installed with standard pile driving equipment that would require a stable level platform along the length of the installation route. The preliminary estimated cost for installation of the Waterloo Barrier is approximately $19.00 per square foot of barrier wall.

The Gundwall HDPE sheetpiling is installed in generally the same manner as the steel sheeting. The HDPE panels are pulled into the subgrade using a vibratory plate. This installation method does not produce any excavated soil and requires a flat stable platform on which to install the panels. The preliminary estimated cost to install the Gundwall panels would be approximately $14.00 per square foot. Based on the previous evaluation, the soil is not suited for this installation, thus removing this alternative from continued design consideration.

Installation of Gundwall using the one pass trenching method can be conducted in the soil types present across the site, but this alternative will generate a significant volume of excavated soil requiring further management. Installation of 90° turns are not possible, limiting the effectiveness of the gate installation. The preliminary estimated cost of using the one pass trenching method for installation of Gundwall HDPE sheetpile is approximately $13.00 per square foot.

Based on the above evaluation, Waterloo Barrier steel sheetpiling has been selected as the appropriate groundwater barrier component for use in constructing the funnel and gate sidewalls at the Moss-American site. The following design reflects this material of construction. Steel sheetpiling shall be provided by Canadian Metal Rolling Mills of Cambridge, Ontario, or by any other approved manufacturer under license from Waterloo Barrier, Inc. The joints of the sealable sheetpiling shall be manufactured with a foot plate

welded to the base of each joint to prevent material from entering the joint as the pile is driven. At a minimum, each sheetpile section shall have these properties:

Thickness	0.295 inch
Depth	8.17 inches
Nominal Width	22.25 inches
Section Area	10.5 square inches
Weight	35.6 lbs/linear foot
	19.2 lbs/square foot
Moment of Inertia (I)	64.8 inches^4/LF
Radius of Gyration	3.39 inches
Section Modulus	15.9 inches^3/LF

The piles shall be driven with an air hammer or a vibratory hammer appropriate for the specific soil conditions encountered. Joints shall be sealed with Waterloo Barrier grout sealant. The grout will be placed using a tremie hose inserted into the base of the sealable cavity. The hose shall be withdrawn progressively up as the sealant fills the space below. The sealant shall have a hydraulic conductivity of less than or equal to 1 x 10^{-7} cm/sec.

Specifications and drawings for the construction of the funnel are discussed in Section 5 and are included as appendices to this document.

3.4 DEVELOPMENT OF GATE TREATMENT DESIGN

The groundwater treatment system design consists of openings in the containment barrier that hydraulically funnel groundwater and contaminants through a treatment media. In this manner, in situ groundwater treatment occurs. A conceptual design of a typical treatment gate is presented in Drawing B-3. The development of the final gate design for the Moss-American site groundwater remediation system will encompass six design and construction steps:

Step 1 Complete a preliminary bench-scale treatability evaluation (this step was completed in November 1995, and the findings report is presented in Appendix C of this Intermediate [60 percent] Design Report).

Step 2 Conduct groundwater flow modeling and a detailed evaluation of site hydrogeology to design gate locations. (The groundwater flow modeling has been completed and is included in this Intermediate [60 percent] Design Report. Additional evaluation on the gate configuration to achieve residence time/treatment efficacy will be completed prior to the 95 percent design submittal).

Step 3 Construct the funnel and two of the gates at the site by installing the sheetpile sections in accordance with the approved 95 percent design plans. Develop a pilot-scale treatability demonstration work plan for operation of the two initial treatment gates.

Step 4 Implement the Pilot-Scale Treatability Demonstration Work Plan.

Step 5 Specify the final design and O&M for the gates based on data and engineering evaluations conducted during the pilot-scale work.

Step 6 Install and operate each of the gates in accordance with the final design plans.

This six-step approach to development of the final gate design provides for timely construction of the groundwater remedial system components, while integrating the engineering evaluation into the early stages of operation of this emerging in situ treatment technology.

3.4.1 Preliminary Treatability Study

In November 1995, The University of Waterloo Institute of Groundwater Research, under contract to WESTON, conducted a preliminary treatability study using groundwater and site soil. The scope of this preliminary testing included an evaluation of indigenous microbial communities' ability to degrade site constituents. The study evaluated:

- Site groundwater and clean site soil.
- Site groundwater and contaminated site soil.

The focus of the study was on aqueous phase components. However, site soil was included as a source of contaminants to site groundwater and may be the primary host for microorganisms that would inoculate an installed gate reactor.

The preliminary study indicated that Moss-American site soil and groundwater are microbiologically active and that biotransformation of site groundwater contaminants proceeds favorably under aerobic conditions. As expected, the two- and three-ring PAH compounds and BTEX were more rapidly biodegraded than the heavier four-ring PAHs such as fluoranthene and pyrene. The addition of nutrients generally enhanced contaminant biotransformation, but is not yet viewed as a necessity for this process. The study preliminarily concluded a potential gate residence time on the order of 15 to 20 days to effect maximal contaminant depletion. WESTON and the University of Waterloo recognize the limitations and utility of this preliminary residence time prediction and will address this issue with additional certainty as the design proceeds.

Appendix C presents a reference copy of the University of Waterloo's preliminary treatability study, previously transmitted to the U.S. EPA and the WDNR.

3.4.2 Gate Design Locations/Anticipated Treatment System Configuration

WESTON's groundwater modeling, the results of which are presented in Appendix A and discussed in Subsection 3.2, further evaluated groundwater hydraulics at the Moss-American site. The model was run using a two-tiered funnel system and gates positioned at five locations in the groundwater flow regime of the site. This intermediate plan view of the funnel and gate system is illustrated in Drawing A-4.

Anticipated gate configuration and treatment system components that will continue to be evaluated and refined as the gate design proceeds include:

- Through an iterative design process, the gate geometry and proposed gate media permeability may be modified to meet the goals for residence time/ treatment efficacy.

- An engineered treatment medium consisting of sand and gravel. This medium would be placed within excavated cavities of each gate to a depth of approximately 12 feet bgs. Approximately 100 cubic yards (cu yd) of treatment media would be placed at each gate. Soil excavated to place the treatment media would be characterized for carcinogenic PAH content and would be managed according to the remedial plans developed for soil and sediment.

- A gate that would introduce oxygen (air bubbles) and nutrients (nitrogen and phosphorous) within the upgradient zone of the treatment gate.

- A nutrient addition system consisting of a nutrient storage/supply tank, nutrient injection/dispersion wells located within the treatment medium, and supporting pump and process piping components. The storage/supply tank would be installed in an equipment enclosure centrally located within the funnel and gate system. The nutrient storage and pump system would be sized to supply sufficient nutrients to all gates in the system, based on future pilot-scale treatability demonstration results.

- An oxygen addition system consisting of an air supply compressor and associated filter regulators, process piping, and pressure control instrumentation. The air injection lines would be co-located within the nutrient addition wells. The air compressor and controls would be co-located within the equipment enclosure. The compressor would be sized to supply sufficient oxygen to all gates within the system, based on future pilot-scale treatability demonstration results.

- A year-round operation design for the equipment enclosure, to include insulation and heating units. The enclosure would contain a control logic center that could be operated from a remote location, which would control the operation of the nutrient/oxygen addition system and monitor the performance of the equipment. An autodialer system would be provided to alert the remote operator of a potential problem with the functioning of the system.

3.4.3 Pilot-Scale Treatability Demonstration Work Plan

Steps 3 and 4 in the development of the final gate design propose implementation of a pilot-scale treatability demonstration work plan after installation of the full-scale funnel system. This pilot-scale operation is consistent with recommendations developed by the University of Waterloo. WESTON and the University of Waterloo are currently transferring information on current pilot-scale work and gate designs at other sites to develop an

approach to the pilot-scale design. The pilot-scale operation will assist in determining the following design and operating parameters:

- Oxygen Addition
  - Minimal sparging of air or oxygen to add oxygen to the groundwater with minimal off-gas generation.
  - Suspension of solid oxygen-releasing compounds (ORCs).
- Nutrient Amendment
  - Inclusion of solid slow-release fertilizer in the gate material.
  - Release of ammonia gas via diffusion through plastic tubing.
  - Periodic addition of liquid nutrient solution into the gate.
  - Inclusion of ammonium-doped cement in the gate material.
- Treatment Zone
  - Solid material backfill such as pea gravel.
  - Removable physical growth supports.
  - Control of residence time.

The treatability demonstration work is anticipated to be conducted immediately following the installation of the funnel and will use two of the five treatment gates. The two "study" gates will be constructed with a treatment medium, a means for oxygen and nutrient addition, and monitoring points. The three inactive gates that are not subject to study will be monitored during the pilot-scale operation for hydraulics and groundwater chemistry. Because there is a low hydraulic conductivity at the site, it is anticipated that the pilot-scale operation will require 18 to 24 months to conduct. This period will provide for seasonal evaluations and will allow an adequate volume of water to move through the system to effect the evaluation.

Pilot-scale operations will be conducted in accordance with a work plan. An outline for the proposed work plan is presented in Table 3-1. WESTON/KMCC proposes to submit the draft Work Plan for U.S. EPA/WDNR review concurrently with the prefinal design submittal. The Work Plan would then be implemented following construction of the full-scale funnels and work would continue thereafter for approximately 1.5 to 2 years.

Section 5 of this intermediate design report further outlines the anticipated schedule of deliverables and target construction schedule.

Table 3-1

**Outline of Pilot-Scale Treatability Demonstration Work Plan
for Gate Treatment System
Moss-American Site
Milwaukee, Wisconsin**

1 INTRODUCTION
- 1.1 Site Background
- 1.2 Objectives and Scope of Pilot-Scale Operations

2 OVERVIEW OF TREATMENT SYSTEM DESIGN
- 2.1 Description of Pilot-Scale Funnel and Gate Design
- 2.2 Treatment Media
  - 2.2.1 Crushed Rock
  - 2.2.2 Removal Physical Growth Supports
- 2.3 Potential Operational Problems
  - 2.3.1 Organic Overloading
  - 2.3.2 Biofouling
- 2.4 Treatment Enhancement
  - 2.4.1 Nutrient Amendment
  - 2.4.2 Oxygen Addition
- 2.5 Buildings and Utilities
- 2.6 Monitoring System
  - 2.6.1 Treatment Monitoring System
  - 2.6.2 Flow Monitoring System

3 PILOT-SCALE OPERATION AND MAINTENANCE
- 3.1 Description of Operating Procedures
- 3.2 Influent Flow Monitoring
- 3.3 Effluent Flow Monitoring
- 3.4 Monitoring of Treatment Bed Conditions

4 TREATABILITY DEMONSTRATION SAMPLING AND ANALYSIS PLAN
- 4.1 Sampling Objectives
- 4.2 Sample Location and Frequency
- 4.3 Field Procedures for Collecting Samples
- 4.4 Sample Designation
- 4.5 Field Documentation

Table 3-1

**Outline of Pilot-Scale Treatability Demonstration Work Plan
for Gate Treatment System
Moss-American Site
Milwaukee, Wisconsin
(Continued)**

4.6 Shipping and Handling of Field Samples
- 4.5.1 Procedures to Prevent Cross-Contamination
- 4.5.2 Sample Packaging
- 4.5.3 Field Chain-of Custody Procedures

4.7 Testing Parameters and Objectives

4.8 Laboratory Custody Procedures
- 4.8.1 Laboratory Documentation
- 4.8.2 Sample Labels

5 SCHEDULE AND SEQUENCE
- 5.1 Installation
- 5.2 Start-up
- 5.3 Reporting and Deliverables

SECTION 4
CONSTRUCTION DOCUMENTS

In accordance with the SOW and as outlined in KMCC/WESTON's groundwater remedial design scope and schedule letter to the U.S. EPA dated 23 May 1996, the following construction documents would be prepared during the various design phases for the groundwater containment and treatment system:

- Design drawings.
- Technical specifications.
- Capital O&M cost estimate.
- O&M plan.
- Construction quality assurance plan (CQAP).
- Construction HASP.

The following subsections provide a brief description and the schedule for submittal of the documents.

4.1 DESIGN DRAWINGS

Drawings associated with the intermediate design of the groundwater containment and treatment system are presented in Appendix B. The drawings included with the intermediate design include plans and details of the funnel system and a conceptual drawing detail for the gate(s). Additional details for the gate design would be provided with the prefinal design submittal and following completion of pilot-scale operation. Final versions of these drawings would be submitted with the final design submittals.

4.2 TECHNICAL SPECIFICATIONS

Technical specifications for the intermediate design of the groundwater containment and treatment system are presented as Volume 2 of this intermediate design submittal. The

technical specifications include both *Division 1—General Requirements* and *Division 2—Site Work*. The technical specifications include the site work requirements, with the exception of the gate construction.

4.3 COST ESTIMATE

Cost estimates are developed to ensure the availability of the financial resources necessary to construct and implement the remedial action. Because the pilot-scale work has not been defined, the cost estimate prepared for the preliminary design report has not been revised and is not included with this intermediate design submittal. Therefore, a revised cost estimate will be included with the prefinal design submittal and will include both capital and operation and maintenance costs during both the pilot-scale testing and full-scale operation.

4.4 O&M PLAN

Following implementation and completion of the pilot scale work plan, an O&M plan will be prepared to cover both implementation and long-term maintenance of the groundwater containment and treatment system. It will, at a minimum, consist of the following elements:

- An overview of the proposed system and the basic components and their purpose.
- A description of routine O&M.
- A description of potential operating problems and troubleshooting procedures.
- A description of routine monitoring and laboratory testing.
- An inspection and maintenance plan.
- A corrective action plan.
- A safety plan.
- A description of equipment.
- Treatment (gate) media evaluation and regeneration.

- A groundwater monitoring plan.
- Records and reporting mechanisms required.

The outline for the O&M plan will be submitted with the prefinal design submittal. A draft O&M plan will be submitted during implementation of the pilot scale system. The final version will be submitted following completion of the pilot-scale system.

4.5 CQAP

A CQAP will be prepared to ensure, with a reasonable degree of certainty, that the completed groundwater containment and treatment system meets or exceeds the requirements of the design plans and the technical specifications. The plan will cover the following elements:

- Responsibility and authority.
- Personnel qualifications.
- Inspection activities.
- Sampling requirements.
- Sheetpile installation quality assurance.
- Waterloo Barrier installation quality assurance.
- Construction documentation.

The sheetpile installation quality assurance program will provide the minimum acceptable installation tolerances pertaining to horizontal and vertical deflection and the overall integrity of the sheet materials. Procedures will be outlined in the plan directing the installer to repair or replace sheet sections that become damaged during installation.

The Waterloo Barrier installation quality assurance plan will describe the installation guidelines required to properly install the joint sealant in accordance with the Waterloo Barrier specifications. In addition, the plan will require the Waterloo Barrier installation

contractor to be certified by the University of Waterloo, in accordance with their licensing program.

A draft CQAP for construction of the funnel system and the pilot-scale system will be submitted with the prefinal design. The final CQAP will be submitted concurrently with the final design submittal.

4.6 CONSTRUCTION HASP

An outline of the requirements for the HASP is presented in Section 01390 of the specifications (Volume 2). The construction contractor will prepare a HASP for site-specific activities anticipated during the construction activities. The HASP will be prepared in accordance with the Occupational Safety and Health Act (OSHA) requirements outlined in 29 CFR 1910 and 1926 and with the SOW.

SECTION 5
SCHEDULE AND DELIVERABLES

WESTON has revised the project schedule for the design phase of the groundwater containment and treatment system. Specifically, WESTON has included the schedule for the pilot-scale work plan to be completed prior to the submittal of the prefinal design. It should be noted that the overall schedule of the design phase has not changed and still indicates completion of the final design during January 1997. Figure 5-1 presents a project schedule for groundwater design at the Moss-American site. Table 5-1 identifies the components of the prefinal and final design submittals. As indicated in Table 5-1, the draft and final pilot-scale work plans would be submitted concurrently with the prefinal and final design submittals, respectively.

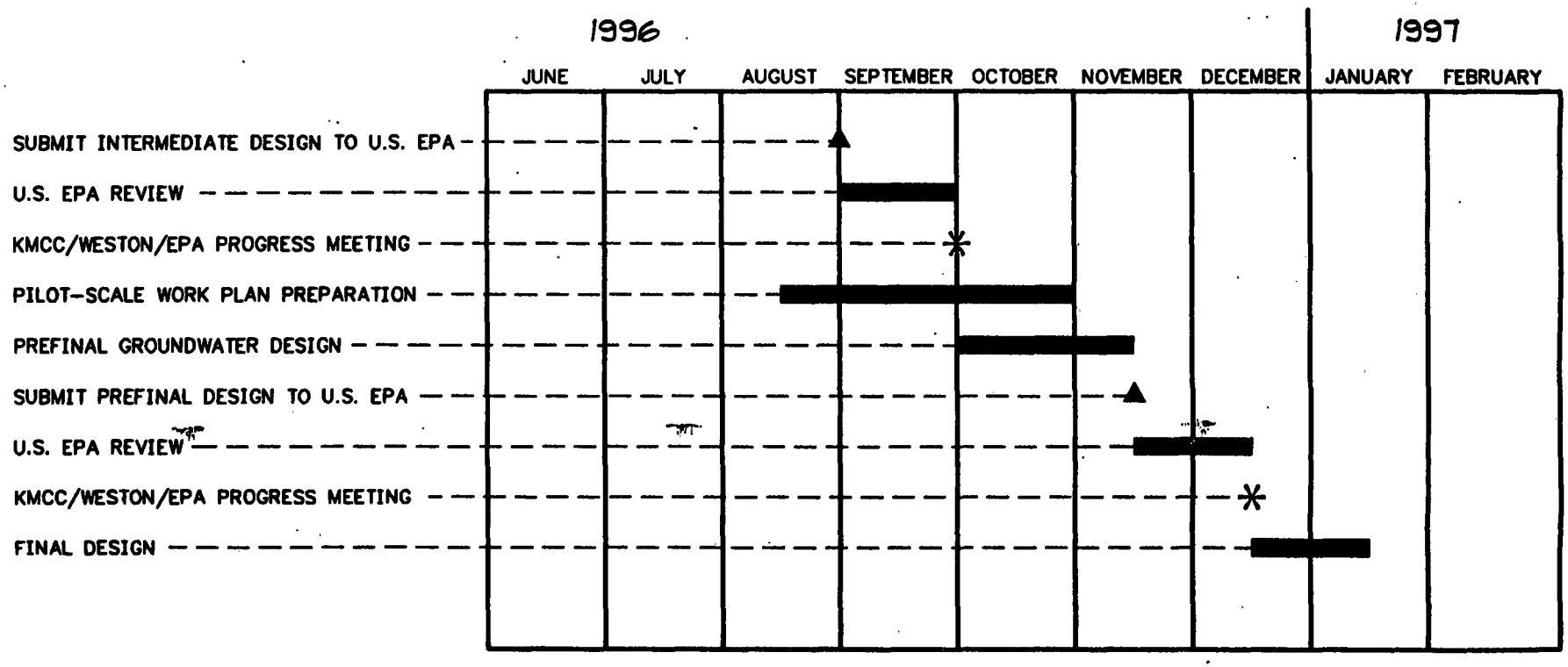


FIGURE 5-1

PROJECT SCHEDULE FOR GROUNDWATER DESIGN

MOSS – AMERICAN SITE
Milwaukee, Wisconsin

WESTON MANAGERS DESIGNERS/CONSULTANTS

Three Hawthorn Parkway
Vernon Hills, Illinois
60061

RON-08/08/96-08:48-J:\CAD93\200\20096

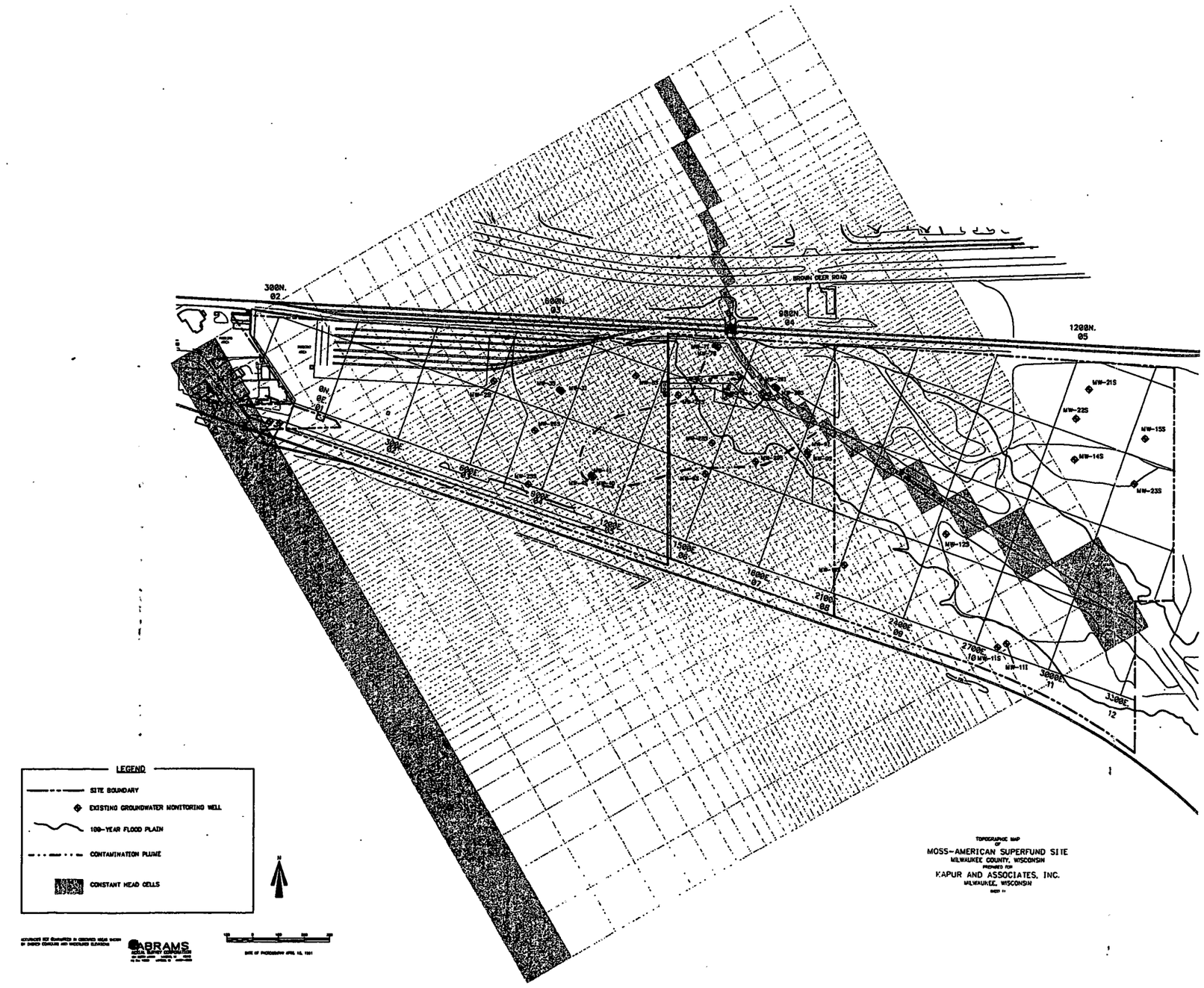
Table 5-1

Components of Design Submittals
Moss-American Site
Milwaukee, Wisconsin

Prefinal Design	Final Design
1. Design Report—The report would be revised based on U.S. EPA comments on the intermediate design. - Draft Pilot-Scale Work Plan - Detailed Cost Estimate 2. Project Manual (Revised based on U.S. EPA comments). - Draft Specifications (Includes HASP) - Drawings 3. Draft O&M Plan Outline. 4. Draft CQAP.	1. Design Report—The report would be revised based on U.S. EPA comments on the prefinal design. - Final Pilot-Scale Work Plan - Final Cost Estimate 2. Project Manual (Revised based on U.S. EPA comments). - Final Specifications - Final Drawings 3. Final O&M Plan Outline. 4. Draft CQAP.

APPENDIX A

RESULTS OF GROUNDWATER MODELING



NO.	DATE	APPR.	REVISION
NO.	DATE	APPR.	REVISION

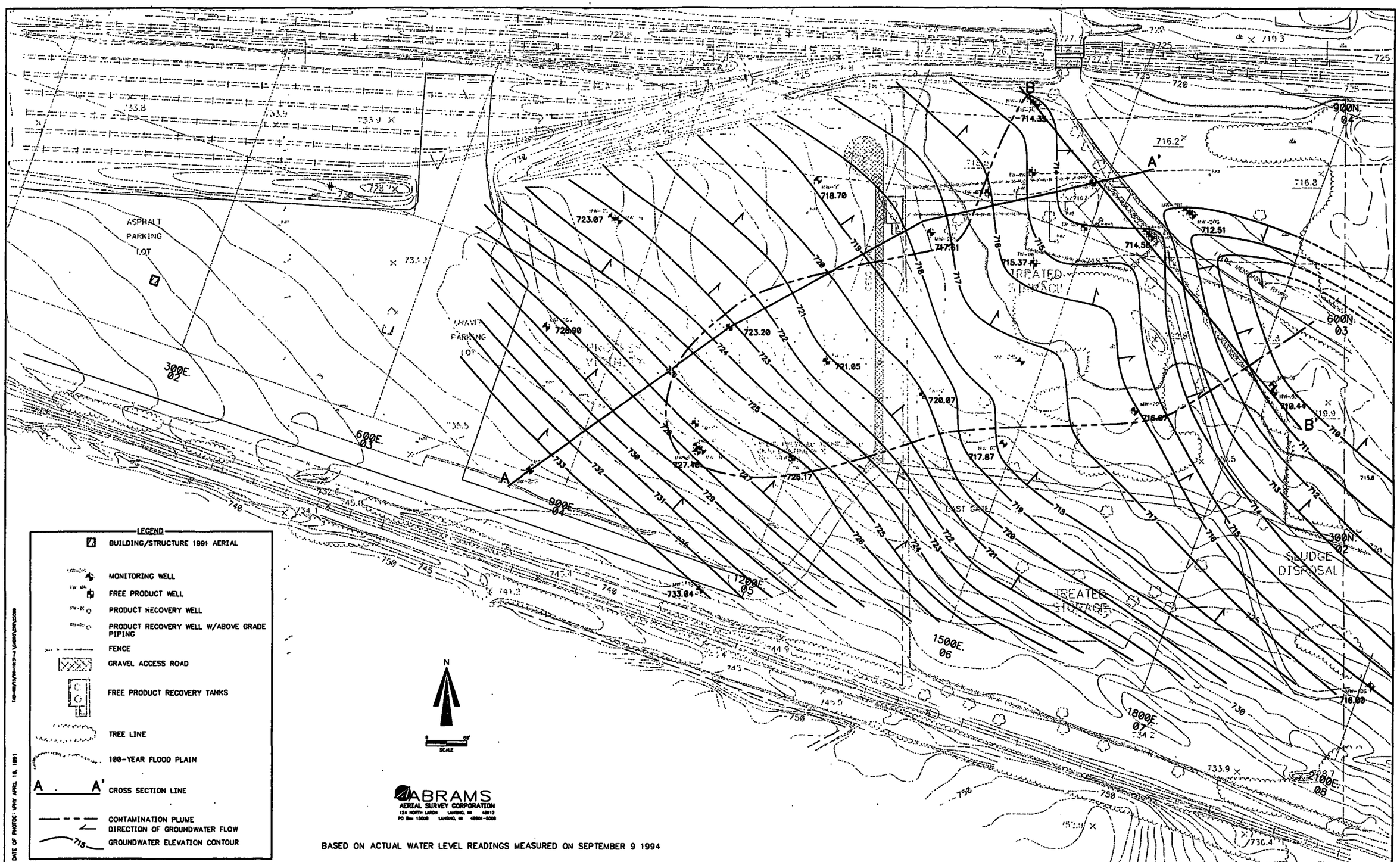
MOSS – AMERICAN SITE
Milwaukee, Wisconsin

WESTON MANAGERS DESIGNERS/CONSULTANTS
VERNON HILLS ILLINOIS

CHECKED	DATE	CLIENT APPROVALS	DATE
DES. ENG.			
PROJ. ENG.			
PROJ. MGR.			
APPROVED			
APPROVED "		ISSUED FOR	DATE

MODELED AREA AND
GRID CONFIGURATION

DRWN T.A.D.	DATE 13 AUG 96	DWG. NO. A-1	REV. NO.
SCALE 1" = 200'	W.O. NO. 02687007002002200	SHT. ____ OF ____	



LEGEND

- BUILDING/STRUCTURE 1991 AERIAL
- MONITORING WELL
- FREE PRODUCT WELL
- PRODUCT RECOVERY WELL
- PRODUCT RECOVERY WELL W/ABOVE GRADE PIPING
- FENCE
- GRAVEL ACCESS ROAD
- FREE PRODUCT RECOVERY TANKS
- TREE LINE
- 100-YEAR FLOOD PLAIN
- A . A' CROSS SECTION LINE
- CONTAMINATION PLUME
- DIRECTION OF GROUNDWATER FLOW
- 715 GROUNDWATER ELEVATION CONTOUR

N

SCALE 0 60'

ABRAMS
AERIAL SURVEY CORPORATION
124 NORTH LARCH LANSING, MI 48912
PO Box 15008 LANSING, MI 48901-5008

DATE OF PHOTO: APRIL 16, 1991

BASED ON ACTUAL WATER LEVEL READINGS MEASURED ON SEPTEMBER 9 1994

NO.	DATE	APPR.	REVISION

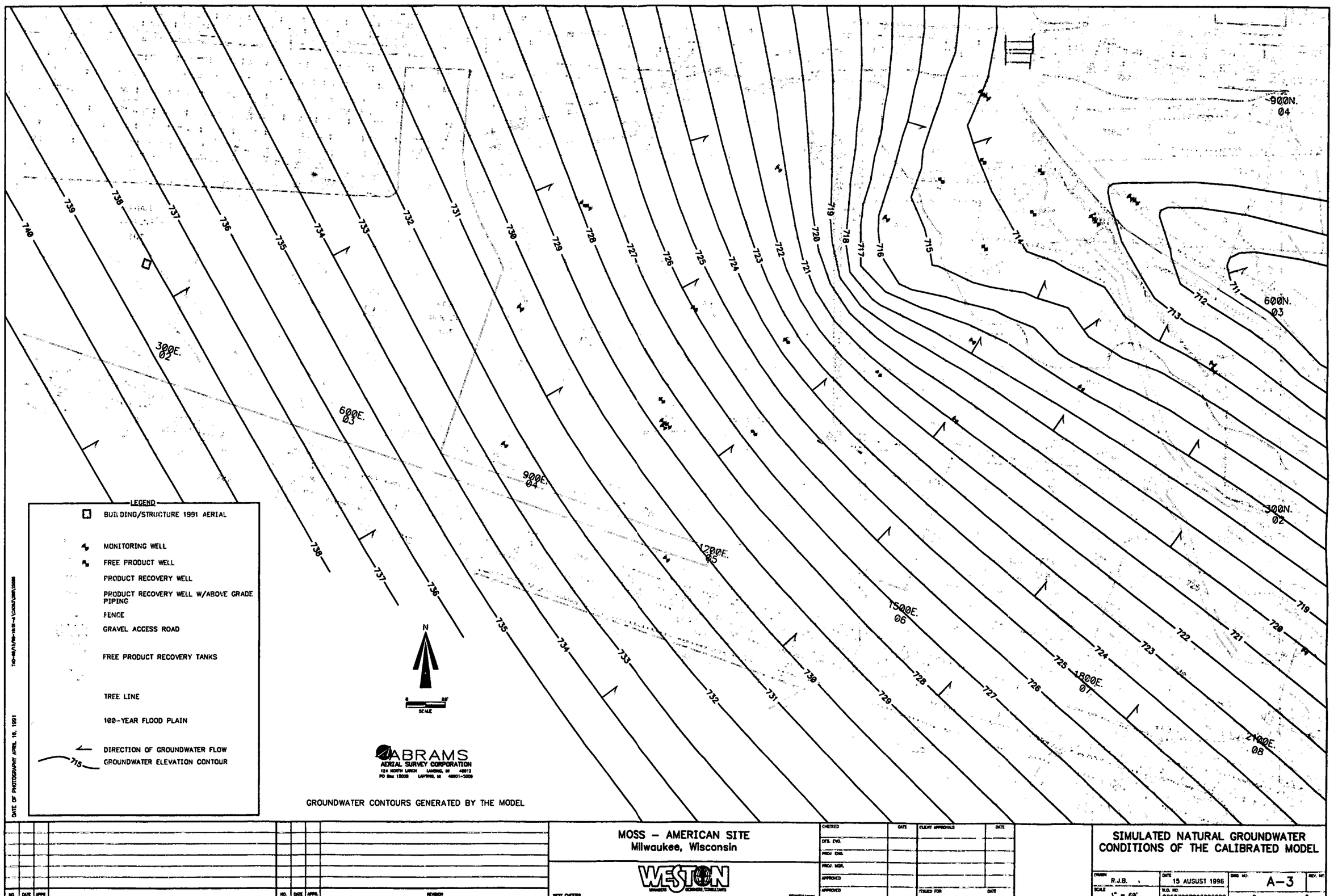
MOSS – AMERICAN SITE
Milwaukee, Wisconsin

WESTON DESIGNERS/CONSULTANTS
WEST CHESTER PENNSYLVANIA

CHECKED	DATE	CLIENT APPROVALS	DATE
DES. ENG.			
PROJ. ENG.			
PROJ. MGR.			
APPROVED			
APPROVED		ISSUED FOR	DATE

GROUNDWATER ELEVATION CONTOUR MAP SEPTEMBER 9 1994

DRAWN R.J.B.	DATE 15 AUGUST 1996	DWG. NO. A-2	REV. NO.
SCALE 1" = 60'	W.O. NO. 02687007002002200	SHT. 2 OF 3	



NO	DATE	APPR	NO.	DATE	APPR.	REVISION

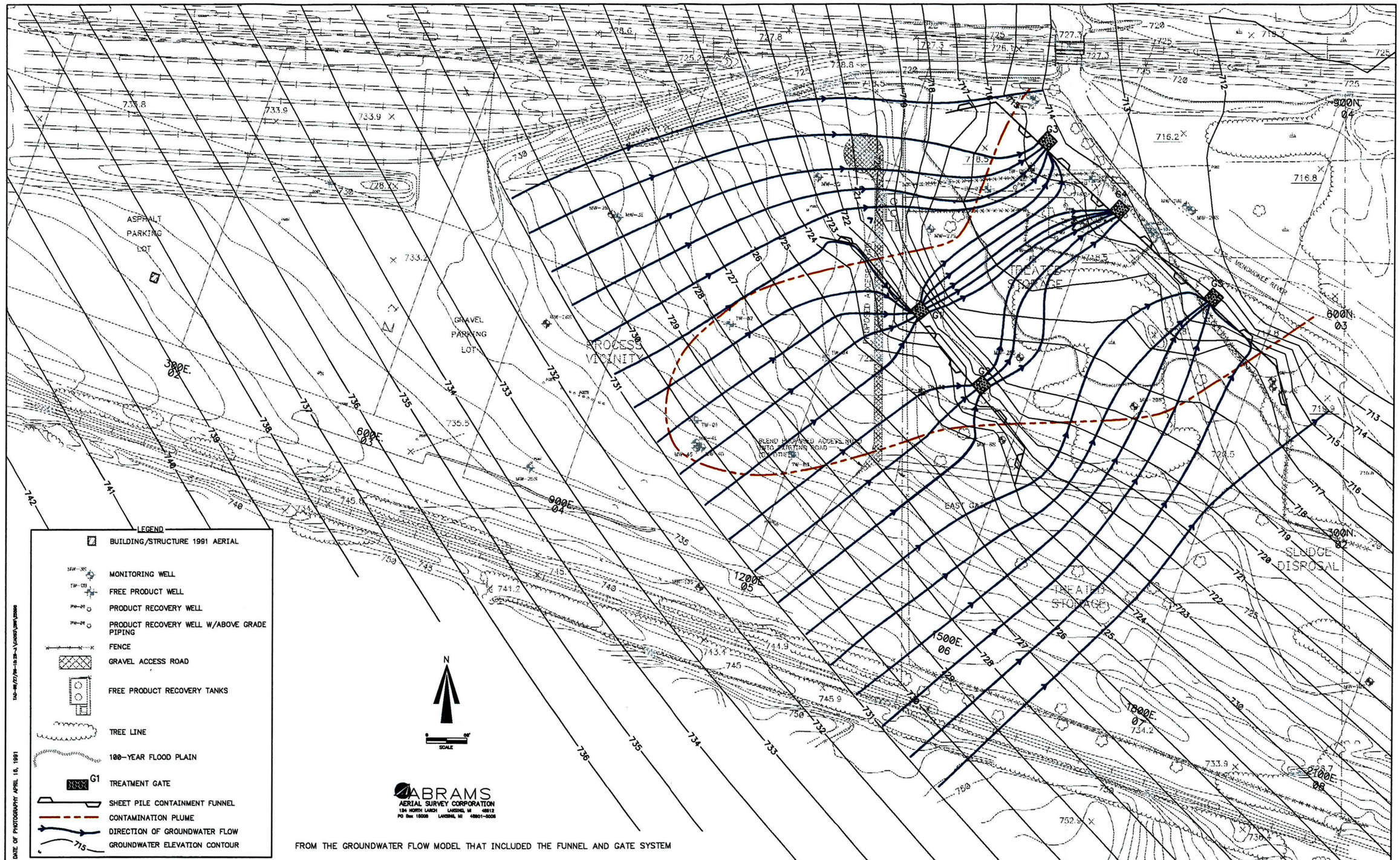
MOSS – AMERICAN SITE
Milwaukee, Wisconsin

WESTON
WEST CHESTER PENNSYLVANIA

CHECKED	DATE	CLIENT APPROVALS	DATE
DES. ENG.			
PROJ. ENG.			
PROJ. MGR.			
APPROVED			
APPROVED		ISSUED FOR	DATE

SIMULATED NATURAL GROUNDWATER CONDITIONS OF THE CALIBRATED MODEL

DRAWN	DATE	DWG NO.	REV. NO.
R.J.B.	15 AUGUST 1996	A-3	
SCALE 1" = 60'	W.O. NO. 02657007007202200	SHT 2 OF 3	



NO.	DATE	APPR.	REVISION

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Milwaukee, Wisconsin

WESTON MANAGERS ENGINEERS/CONSULTANTS
WEST CHESTER PENNSYLVANIA

CHECKED	DATE	CLIENT APPROVALS	DATE
DES. ENG.			
PROJ. ENG.			
PROJ. MGR.			
APPROVED			
APPROVED		ISSUED FOR	DATE

FUNNEL AND GATE SIMULATED GROUNDWATER CONTOUR MAP

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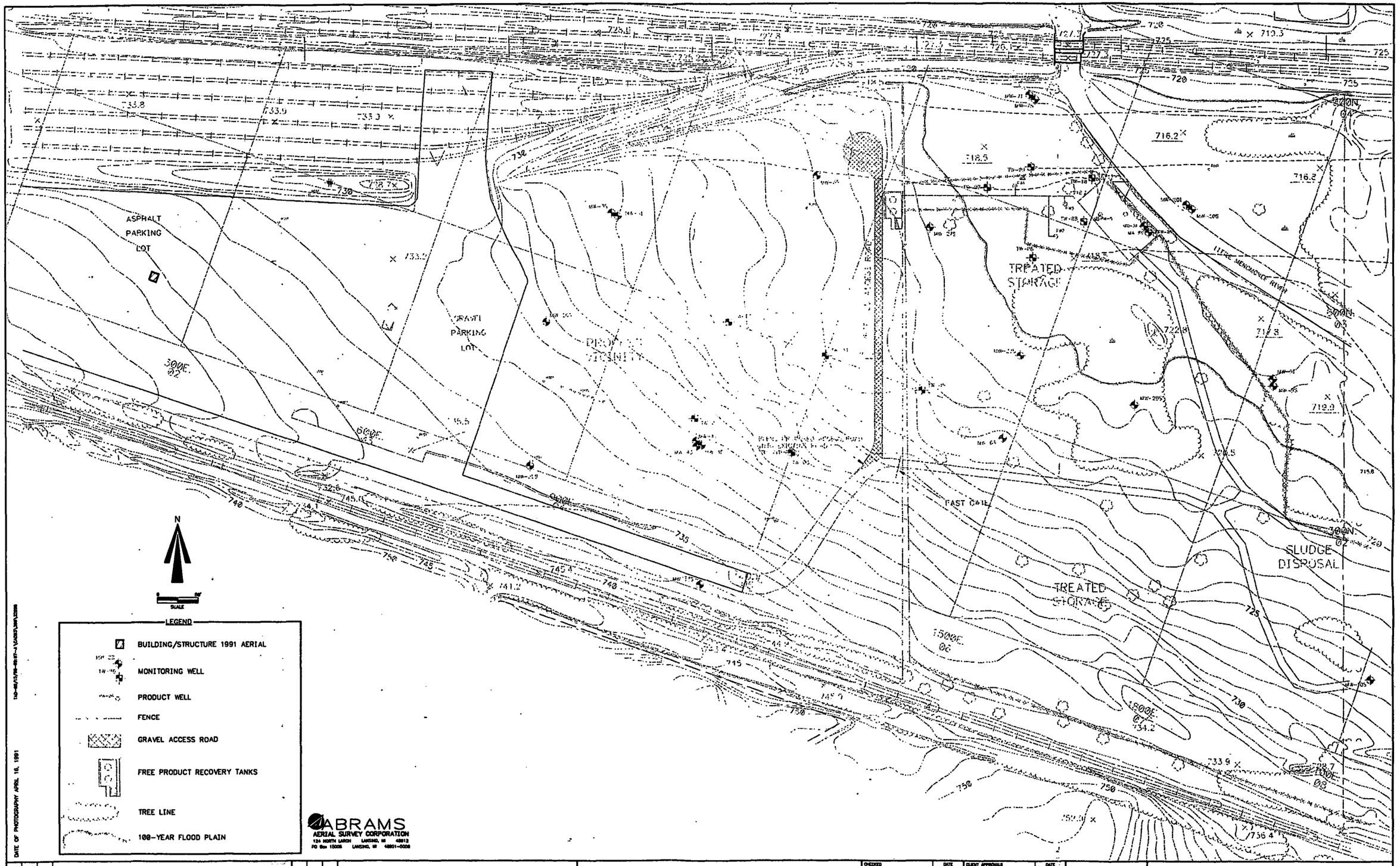
SCALE 1" = 60'	W.O. NO. 02687907002002200	SHT. 2 OF 3	

APPENDIX B

DESIGN DRAWINGS



NO.	DATE	APPR.	REVISION

MOSS – AMERICAN SITE
Milwaukee, Wisconsin

WESTON MANAGERS DESIGNERS/CONSULTANTS
WEST CHESTER PENNSYLVANIA

CHECKED	DATE	CLIENT APPROVALS	DATE
DES. ENG.			
PROJ. ENG.			
PROJ. MGR.			
APPROVED			
APPROVED		ISSUED FOR	DATE

EXISTING SITE CONDITIONS

DRAWN	DATE	ORIG. NO.	REV. NO.
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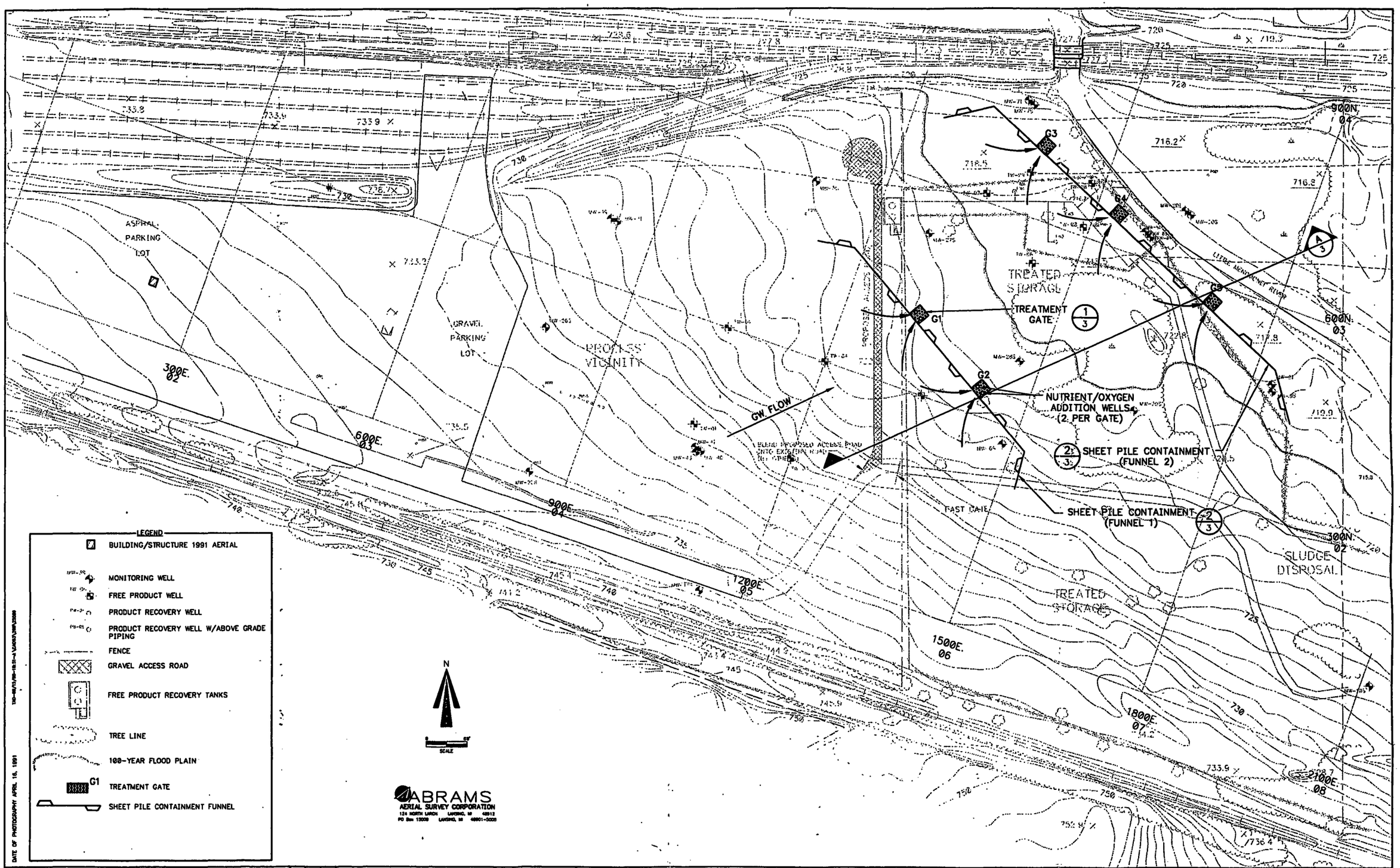

NO.	DATE	APPR.	REVISION

MOSS – AMERICAN SITE
Milwaukee, Wisconsin

WESTON ENGINEERS DESIGNERS/CONSULTANTS
WEST CHESTER PENNSYLVANIA

CHECKED	DATE	CLIENT APPROVALS	DATE
DES. ENG.			
PROJ. ENG.			
PROJ. MGR.			
APPROVED			
APPROVED		ISSUED FOR	DATE

PLAN VIEW FUNNEL AND GATE CONTAINMENT & TREATMENT SYSTEM

DRAWN R.J.B.	DATE 15 AUGUST 1996	DWG. NO. B-2	REV. NO.
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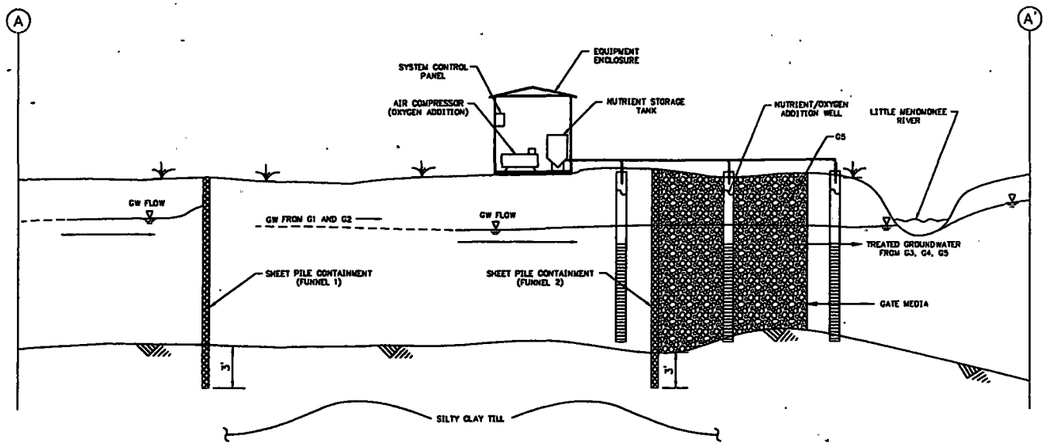

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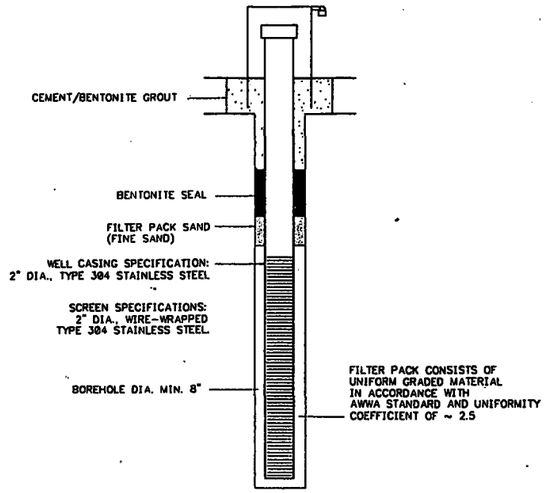
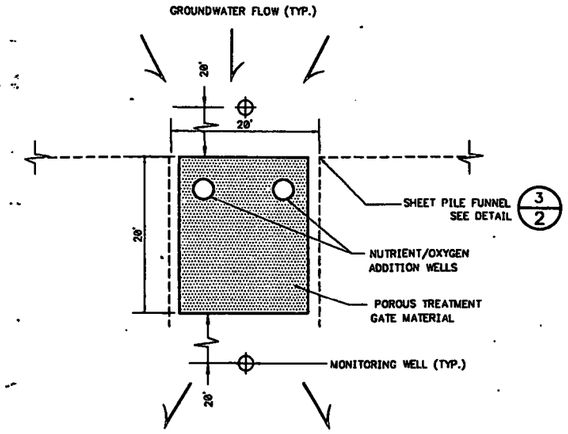


MONITOR WELL (TYPICAL)
NTS



TREATMENT GATE DETAIL 1/3
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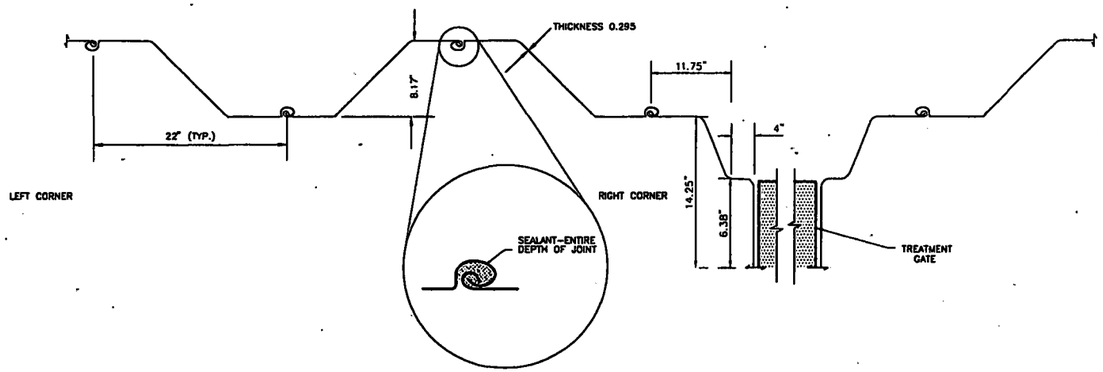

INTERNAL CAVITY SEALABLE JOINT SHEET PILE 2/3
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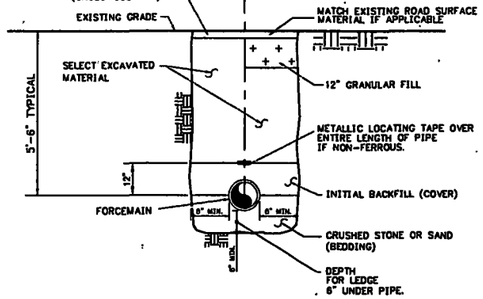

NUTRIENT/OXYGEN ADDITION PIPE TRENCH DETAIL (TYPICAL)
NTS

~ RESERVE FOR GATE COMPONENT DETAILS ~

NO.	DATE	APPR.	REVISION	NO.	DATE	APPR.	REVISION

MOSS – AMERICAN SITE
Milwaukee, Wisconsin

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VERNON HILLS ILLINOIS

CHECKED	DATE	CLIENT APPROVALS	DATE
DES. ENG.			
PROJ. ENG.			
PROJ. MGR.			
APPROVED			
APPROVED		ISSUED FOR	DATE

STANDARD DETAILS

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SCALE AS NOTED	W.O. NO. 02687007002002200	SHT. 3 OF 3	

APPENDIX C

PRELIMINARY BENCH-SCALE TREATABILITY EVALUATION RESULTS

Preliminary Biotreatability Study for Groundwater Remedial Design

Wisconsin Site of Roy F. Weston, Inc.

Barbara J. Butler and James F. Barker
Waterloo Centre for Groundwater Research
University of Waterloo, Waterloo, Ontario, Canada N2L 3G1

WRI Award No. 2428901

Prepared for

Roy F. Weston, Inc.
Suite 400
3 Hawthorn Parkway
Vernon Hills, Illinois, USA 60061-1450

November 3 1995

Preliminary Biotreatability Study for Groundwater Remedial Design

Wisconsin Site of Roy F. Weston, Inc.

Barbara J. Butler and James F. Barker
Waterloo Centre for Groundwater Research
University of Waterloo, Waterloo, Ontario, Canada N2L 3G1

WRI Award No. 2428901

Prepared for

Roy F. Weston, Inc.
Suite 400
3 Hawthorn Parkway
Vernon Hills, Illinois, USA 60061-1450

November 3 1995

Preliminary Biotreatability Study for Groundwater Remedial Design
Wisconsin Site of Roy F. Weston, Inc.

Executive Summary

The biotreatability study indicated that the Wisconsin site materials are microbiologically active, and biotransformation of some target contaminants proceeds quite rapidly under aerobic conditions. Complete depletion of compounds in the aqueous phase of active, clean soil-containing microcosms occurred within 7 days, whereas, contaminants persisted in parallel controls which had been sterilized to destroy microbial activity. Site groundwater contributed little contaminant to the microcosm environments. Contaminants were introduced into clean soil-containing microcosms by spiking the groundwater with a number of polynuclear aromatic hydrocarbons (PAHs) and heterocyclics. The groundwater was quite active, biologically, so that a significant proportion of the contaminant spike had disappeared during the time required for microcosm construction. Naphthalene, for example, was added to the groundwater at ~5 mg/L but was undetectable the next day.

In contaminated soil-containing microcosms, compounds leached from the soil into the microcosm aqueous phase constituted the bulk of the contaminant present. Rapid, biologically-mediated depletion of 2-ringed compounds (naphthalene, methylnaphthalene, biphenyl) was observed in contaminated soil-containing microcosms. These compounds were largely undetectable in active microcosms after 7-14 d at 10°C. Acenaphthene, dibenzofuran, fluorene, phenanthrene, anthracene and carbazole were also subject to biotransformation, although compound loss was in general slower, and lower, residual levels of these compounds tended to persist in the aqueous phase of active microcosms. Persistence may have resulted, in part, from either oxygen limitation and/or inorganic nutrient (N, P) limitation in the microcosms towards the end of the experiment. After some microcosms were opened on day 40 to add additional N and P and (as an unavoidable consequence) atmospheric oxygen, residual contaminant levels had clearly declined in these microcosms by day 49.

The 4-ring PAHs fluoranthene and pyrene appeared recalcitrant in contaminated soil-containing microcosms, on the basis of aqueous phase analyses, although the compounds were biotransformed in clean soil-containing microcosms. Soils analyses revealed that soil levels of fluoranthene and pyrene in active, nutrient-amended, contaminated soil-containing microcosms dropped over time. Taken together, the aqueous phase and soils data suggest that these 4-ringed compounds, which are quite hydrophobic, were slowly degrading in the active, nutrient-amended, contaminated soil microcosms, but degraded aqueous phase molecules were replaced by new PAH molecules desorbing from the soil.

Although monoaromatic hydrocarbons were not present in the site materials examined, benzene has been detected on site. When microcosms constructed with site materials were amended with benzene, toluene, ethylbenzene and xylene (BTEX), biodegradation of the hydrocarbons was readily initiated. In the presence of added N and P, initial levels (~16-17 mg/L, if all BTEX is assumed in the aqueous phase) were completely biodegraded within 9 days.

Addition of N and P generally enhanced contaminant biotransformation, affecting both the rate and extent of compound loss. However, significant biotransformation was also observed in the absence of added inorganic nutrients.

Analysis of microcosm liquid by GC/MS revealed no compounds obviously identifiable as hazardous byproducts of PAH degradation. Indeed, results suggested that few biotransformation intermediates accumulated in the aqueous phase, and those that did were likely not persistent.

Microbial numbers were clearly elevated in Wisconsin site groundwater, compared with typical pristine groundwaters. Significant numbers of microorganisms able to grow on three test substrates (naphthalene, phenanthrene and dibenzofuran) were recovered from site soils and groundwater. No evidence to suggest inhibition of microbial activity due to contaminant presence was obtained, rather, part of the subsurface microbial population (i.e., cells able to use the invading organics) was likely stimulated by contaminant influx. This population is likely actively degrading contaminants *in situ*, when environmental conditions (e.g., available oxygen) allow, and would serve as an inoculum for a gate "bioreactor" if one was installed.

This biotreatability study indicates that the smaller contaminants (2-4-ringed) present at the site - those found in the site groundwater - are biodegradable, although the smallest ones were more readily depleted than the 4-ringed compounds. If a funnel-and-gate were to be installed, and if conditions similar to those in the contaminated soil-containing microcosms were established in the gate, a gate residence time on the order of 15-20 days may be sufficient to effect maximal contaminant depletion. This question is complicated by the fact that movement of all contaminants will be retarded relative to groundwater movement, but to different degrees. The retardation effects should, however, generally act in a positive sense with respect to bioremediation. Those compounds likely to be most mobile are the ones most readily degraded. The more recalcitrant ones would take longer to traverse the gate.

Biodegradation of both benzene and naphthalene should be sufficient to meet the potential regulatory objectives of Weston, as judged by the results of this study. No comment may be made for the other compounds for which cleanup objectives were given, as they were not routinely detected in microcosm waters.

Table of Contents

List of Tables

List of Figures

Preliminary Biotreatability Study for Groundwater Remedial Design
Wisconsin Site of Roy F. Weston, Inc.

1.0 Purpose of Study

This laboratory study was initiated to determine if organic contaminants within soil and groundwaters from the Wisconsin site were subject to biotransformation by indigenous microorganisms. Further, if biotransformation does occur, are the rate and degree of degradation such that biological treatment of site groundwater within a funnel-and-gate system might be explored as a potential remediation technology?

The study consisted of batch microcosm experiments, using soil and groundwater obtained from the Wisconsin site for microcosm construction. Enumeration of some microbial populations indigenous to the site materials was also conducted. The intent of the study was to address the following questions:

1. Will biodegradation of the contaminants occur within the treatment gate using indigenous microorganisms and environmental conditions?
2. Is the subsurface environment inhibitory to microbial life?
3. How can biodegradation of the contaminants be improved by changing the microbial populations or subsurface conditions within the treatment gate?
4. How fast will biodegradation occur within the treatment gate under the present conditions?
5. Will biological processes meet regulatory standards set for the site at the effluent end of the treatment gate?
6. Will the biodegradation process produce any hazardous byproducts?,

and these will be dealt with in this report.

2.0 Introduction and Background Information

We have not been apprised of the exact nature of the source material contributing to the contaminant plume(s) at the Wisconsin site, if this is in fact known, but the organic compounds detected in our studies and listed in field data received from Roy F. Weston, Inc.[1] indicate that some phenols, polynuclear aromatic hydrocarbons (PAHs), monoaromatic hydrocarbons, and

[1] The Roy F. Weston, Inc. data referred to in this report were provided to us by M. Kleiner of Weston, via letters (8 May, and 18 May 1995) to R. Jowett of Waterloo Groundwater Control Technologies, Inc.

heterocyclic compounds are emitted, i.e., compounds typical of coal tar, creosotic and gas plant-type wastes. For convenience then, we will speak in terms of "creosotic compound" contamination in this report. Many of the chemicals found at the site are known to be subject to biotransformation, and so the contaminated groundwater at the site is potentially amenable to bioremediation if suitable environmental conditions prevail. Use of an appropriate funnel-and-gate system would allow delivery of oxygen, and inorganic nutrients, if necessary, to the contaminated water within the treatment gate.

PAHs degrade most readily under aerobic conditions, so that oxygen availability is highly desirable. The potential for anaerobic PAH metabolism has not been extensively investigated; although Mihelcic and Luthy (1988) reported naphthalene and acenaphthene biotransformation under denitrifying conditions, generally PAHs are believed to persist indefinitely in anaerobic soils and sediments (Shiaris, 1989; Bauer and Capone, 1985). Phenolics and heterocyclic compounds, too, are far more amenable to aerobic biodegradation, although some single-ringed N- and O-heterocyclic compounds at least are also degraded anaerobically (Kuhn and Suflita, 1989). Degradation of phenolic compounds in anoxic aquifers has also been reported (e.g., Smolenski and Suflita, 1987; Godsy et al., 1992).

The biodegradability of each compound will depend on its chemical and physical properties. These will affect a compound's natural susceptibility to enzymatic attack and its bioavailability to microorganisms. Naphthalene, for example, is fairly readily biodegraded, but if sorbed to the soil matrix, maybe unavailable to degrader cells. Other factors such as soil type, presence of nutrients, makeup of the microbial community, presence of toxicants, pH, and temperature also affect biodegradative activity. Information on mechanisms of PAH degradation, particularly with reference to detoxification pathways, has recently been summarized by Sutherland et al. (1995). Most bacteria oxidize PAH rings via dioxygenase enzyme activity, forming *cis*-dihydrodiols, which are further transformed to diphenols, and then other products. This type of metabolic pathway can support microbial growth. In contrast, many fungi, and a few bacteria, use monooxygenases, forming *trans*-dihydrodiol intermediates. The *trans*-dihydrodiol pathways may sometimes serve to detoxify the parent PAH, but do not enable the microorganism to utilize the PAH as a carbon source (Sutherland et al., 1995). In mammals, cytochrome P_{450} monooxygenase activity may lead to activation of precarcinogens, as is known

for benzo(a)pyrene.

In general, more is known about lower molecular weight PAHs such as naphthalene, phenanthrene and anthracene, all of which may serve as sole carbon and energy sources for a number of aerobic microorganisms and are known to be metabolized, although not necessarily completely degraded, by a wide variety of microorganisms. Information on the microbiological fate of larger PAHs is more limited, but these compounds are of concern because their probable role as carcinogens. Benzo(a)pyrene, for example, binds DNA, RNA and proteins if metabolically activated, causing carcinogenic and genotoxic effects. Fluorene, acenaphthene, fluoranthene, pyrene, benz(a)anthracene, chrysene and benzo(a) pyrene oxidation have all been documented. The compounds do not necessarily serve as a sole source of carbon and energy but are often cometabolized, hence production of intermediates is possible, and even likely in some instances. In it unclear, at present, whether microorganisms with ability to affect the larger PAHs are relatively rare, or simply less investigated. At any rate, PAHs with more than 3 rings are certainly relatively resistant to microbial degradation, and 5- and 6-ringed compounds are quite recalcitrant, with turnover times often on the order of years (e.g., summary in Table 8 of Shiaris, 1989).

A recent review by Wilson and Jones (1993) summarizes the state of bioremediation of PAH-contaminated soils. They conclude that on-site landfarming has been reasonably successful for PAHs with 3 rings or fewer, but that bioreactors are most effective for soils because of the ease with which environmental conditions can be adjusted to enhance degradation. They note, however, that more development of bioreactor technology is required before routine use is a reality. Most tellingly, perhaps, they conclude that degradation of the more recalcitrant high molecular weight PAHs in soils has not been particularly successful to date.

Groundwater biotreatment, however, would seem to have some chance of success, because the bulk of the PAHs likely to enter the treatment gate will be smaller compounds, since the large PAHs are so hydrophobic and relatively immobile. The gate of the funnel-and-gate functions essentially as an *in situ* bioreactor. One advantage of the technology is that it allows delivery of oxygen and/or other additives directly into an area through which the contaminant plume is forced to pass, thereby enhancing biodegradation, but also restricting the need to alter *in situ* environmental conditions to a relatively small area.

3.0 Soil and Groundwater Samples

Soil and groundwater samples delivered by Roy F. Weston, Inc. were received at the University of Waterloo (UW) within 24 hours of shipping and stored at 4°C until required. The samples consisted of ten 4-L plastic jugs of groundwater from a monitoring well (MW-043), and six 1-L glass jars containing soil. Three jars were composite samples of "clean" soil collected at site MA2-TS03 (approximately 400 N, 750 E), the other three jars contained composite samples designated "300 mg/kg", from site MA2-TS01 (150 N, 1050 E). Both soils were visibly nonhomogeneous, the clean being noticeably drier, containing small soil clumps (~ 1-2 mm dia) plus some stones, ranging up to ~20 mm dia. The fraction of organic carbon (f_{oc}) of the clean soil was measured as 1.27%. The contaminated soil (f_{oc} = 1.66%) was wetter, and contained bands of greyish and of black material. To reduce the nonhomogeneity of the soils, each soil type was pooled in a sterile bucket and mixed thoroughly by hand . Mixing was conducted in a sterile containment hood, and exposure of the soils to the atmosphere was minimized to avoid loss of volatiles. The contaminated soil proved to be extremely plastic and sticky, therefore, neither soil type was sieved prior to use, but objects (stones, corroded metal, wood, etc.) too large to pass through the neck of a hypovial were excluded from the test microcosms.

4.0 Preliminary Analyses

Preliminary analyses of sample materials were conducted before initiating the biotreatability test, to determine the contaminants present and their approximate levels. The groundwater contained fine particulate material, so three jugs (arbitrarily labelled groundwaters (gw) #1, #2 and #3 in Table 1) containing a medium amount, relatively little, and a large amount of fines were tested. The waters were shaken to resuspend the fines, settled for 5-10 min, and then used to fill glass 160-mL hypovials. The hypovials were sealed with teflon-faced silicon septa and aluminum crimp seals, and settled overnight at 4°C. Soil-water test systems were also constructed, in duplicate, from the clean and the contaminated soil and gw#1. These were composed of 25 g soil plus 110 mL groundwater. The soil + water-containing hypovials were shaken at 175 rpm for 1 h at room temperature, then settled overnight at 4°C. Two aliquots of water were decanted from each experimental hypovial into clean vials, then analyzed for BTEX, and for phenolics, PAHs and heterocyclics (analytical methods are described in Section 5.2

Table 1 Preliminary analyses, Wisconsin site groundwater and soils

compound	This study: gw #1	gw #2	gw #3	contam rep 1	contam rep 2	clean rep 1	clean rep 2	Weston information: concentration range	NR 140.10 PALS*	NR 140.10 ES*	NR 140.10 MCLS*	mdl
benzene	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	4-6	0.5	5		5-10
m-xylene	0	0	0	0	0	0	0					32
phenol	0	0	0	0	0	0	0					110
o-cresol	0	0	0	0	0	0	0					58
p+m-cresol	0	0	0	0	0	0	0					44
2,6-dmp	0	0	0	0	0	0	0					41
2,4+2,5-dmp	0	0	0	0	0	0	0					6
2,3-dmp	0	0	0	0	0	0	0					68
3,5-dmp	0	0	0	0	0	0	0					40
naphthalene	0	0	0	1323	1842	0	0	1100-3000	8	40		6
indole+2-mn	0	0	33	224	350	0	0					11
1-mnaph	0	0	31	141	206	0	0					10
biphenyl	0	0	0	59	91	0	0					10
acenaphthylene	0	0	0	0	0	0	0					6
acenaphthene	47	34	322	282	456	0	0					7
dibenzofuran	0	0	129	160	270	0	0					10
fluorene	5	0	193	182	275	0	0					14
phenanthrene	0	0	168	175	270	0	0					5
anthracene	13	13	26	7	18	0	0					4
carbazole	0	0	0	74	103	0	0					26
fluoranthene	54	19	97	29	43	0	0					5
pyrene	51	17	74	23	33	0	0					7
B(a)anthracene	9	0	0	0	0	0	0	9.4-23.8	-	-	0.1	6
chrysene	9	0	0	0	0	0	0	14-26	-	-	0.2	5
B(b)fluoranth	6	0	0	0	0	0	0	13-15	-	-	0.2	6
B(k)fluoranth	0	0	0	0	0	0	0	3.3-6.1	-	-	0.2	6
B(a)pyrene	0	0	0	0	0	0	0	5.7-8.3	0.003	0.003	-	6
indeno+dibenzo	0	0	0	0	0	0	0	1-4 (indeno)	-	-	0.4	16

all µg/L. gw = groundwater, contam = contaminated soil + gw#1, clean = clean soil + gw#1. * = potential cleanup objectives. mdl = method detection limit

below). No BTEX were detected in any of the samples. Table 1 gives results of the phenolics, PAHs, heterocyclics analysis (hereafter, termed creosotic compound analysis), and also includes information provided by Weston concerning monitoring well concentration ranges for some of the organic contaminants, plus potential cleanup objectives, for comparison.

Little contaminant was present in the groundwater (Table 1), although the levels detected appeared correlated with the amount of fines in the water, since gw#3, the most contaminated, also contained the most particulate matter. Some proportion of the contaminants originally present was likely lost through sorption to the sample jugs and volatilization through the plastic, during shipping and storage. Biological activity would also continue, slowly, at 4°C.

Results from the clean soil + groundwater system (Table 1) suggest that those contaminants present in gw#1 sorbed to the soil during shaking and settling, leaving levels below detection in the water phase. Results from the contaminated soil + groundwater system (Table 1) indicated that relatively high contaminant levels were present in the soil matrix, and upon mixing with groundwater, these partitioned into the water to some degree. Contaminants detectable were comprised largely of 2-4-ringed PAHs, heterocyclic compounds (dibenzofuran, carbazole and possibly indole) and biphenyl, but no phenolics were detected (Table 1).

On the basis of this preliminary experiment, and after consultation with Mark Kleiner of Weston, it was decided to spike microcosms containing clean soil plus groundwater with a contaminant mixture, to obtain information on the degradative ability of microorganisms indigenous to the clean soil. As well, investigation of the microcosm soil phase was evidently desirable, since partitioning of compounds from soil into groundwater would constitute the major source of contaminants in microcosms containing the contaminated soil. This was not part of the experimental plan originally envisioned, so given the time constraints of the study, microcosms were prepared and the experiment initiated with water-only analyses. Soils from the sacrificed microcosms were frozen to allow later analysis. Because no BTEX were detected in the soils or groundwater, experimental microcosms were monitored only by the creosotic compound analytical procedure. A separate experiment (see Section 5.1.2 below) was initiated with BTEX-spiked microcosms, to investigate the fate of these compounds.

5.0 Experimental Methods

5.1 Microcosm preparation

5.1.1 Microcosms for creosotic analysis

Five jugs of groundwater (gw#1, #2, #3, plus two others) were pooled in a sterile 18-L glass carboy, to provide a consistent water source for microcosm preparation. The carboy contents were stirred for 30 min then allowed to settle for 2 h. The water was then decanted (leaving much of the fine material behind) and split into two aliquots, one used in contaminated soil microcosms, the other spiked with a contaminant mixture (as described below) for microcosms containing clean soil.

Microcosm construction was similar for both clean and contaminated soil microcosms and aseptic technique was used during all phases of microcosm construction. The experimental conditions tested, for both clean and contaminated soil systems were:

(1) sterile controls: autoclaved soil + groundwater + 1 mL of a 10% Na azide solution,

(2) active, unamended: soil + groundwater + 1 mL sterile MilliQ water,

(3) active, nutrient-amended: soil + groundwater + 1 mL nutrient stock solution.

Twenty g of soil were allocated into 160-mL glass hypovials, the soil was amended with Na azide, water, or a stock solution of NH_4Cl and KH_2PO_4, as required, and 100 mL of groundwater were then added. Groundwater was continuously stirred during dispensing to evenly distribute the remaining particulates. The hypovials were closed with septa and crimp seals, and then hand-shaken to disperse the soil and groundwater. Sterile controls were prepared by autoclaving sealed hypovials of soil for 1 h on three successive days, then adding the groundwater and azide solution. Nutrient-containing microcosms initially contained 13 mg added NH_4-N/L and 0.5 mg added PO_4-P/L; those nutrient-amended microcosms remaining on day 40 were treated with a second 1-mL aliquot of nutrient stock solution at that time. Up until day 21, microcosms were incubated horizontally, without shaking, in the dark at 10°C. The evening prior to a sampling event, microcosms to be sacrificed were briefly hand-shaken, then placed upright to allow soil settling. After day 21, the remaining microcosms were hand-shaken once/week, in addition to the pre-analysis shaking.

At each sampling event, three microcosms of each experimental condition were sacrificed. Periodically, extra microcosms were sacrificed to measure the dissolved oxygen (DO)

content of groundwater, using the azide modification of the Winkler technique (APHA, 1985). Decanting water from the hypovials had proved exceedingly difficult in the preliminary tests, because of the fines, so glass syringes fitted with large-bore metal cannulae were used to withdraw water without disturbing the settled soil. Sixty-mL hypovials were filled with microcosm water, and sent to the Organic Geochemistry Laboratory at UW for analysis. Water samples were not azide-preserved, as this affects analytical results (M. King, pers. commun.), but were stored at 4°C until extracted. Except in the case of unavoidable equipment failure, water samples were extracted and analyzed on the day of collection.

Microcosm soils and residual liquid were stored at -20°C until near experiment completion. After thawing, each soil slurry was dewatered by vacuum suction before extraction.

Groundwater used for the clean soil-containing microcosms was prepared as follows: Approximately 8 L of groundwater, contained in a foil-wrapped flask (total vol = 8.8 L) was amended with 0.045 g naphthalene, 0.04199 g 1-methylnaphthalene, 0.0149 g dibenzofuran, 0.0025 g fluorene, 0.00209 g phenanthrene, 0.00189 g anthracene, 0.00136 g carbazole, 0.00160 g fluoranthene, 0.00028 g pyrene and 0.00024 g benzo(a)anthracene. The flask was closed with a teflon tape-covered stopper, and allowed to stir at room temperature for 5 h. Then the flask was filled to capacity, resealed, and stirred for 12 h more before dispensing. Two samples of amended groundwater were taken for analysis, immediately before and after dispensing the water into microcosms. Nominal (based on chemical mass added) and actual (based on analysis of the 2 samples) contaminant concentrations in the amended groundwater are recorded in Table 2. As is apparent from Table 2 data, actual contaminant levels in the amended groundwater bore little resemblance to nominal, calculated concentrations. Losses were expected because of sorption to the vessel walls and the particulates, but complete loss of a relatively water-soluble compound such as naphthalene, which was added at a relatively high concentration, indicates a high degree of biodegradative activity during the time allowed for mixing and microcosm construction. Initial contaminant levels in clean soil microcosms were thus less than intended, but, evidence of biodegradation in site groundwater was certainly clear.

5.1.2 Microcosms for BTEX analysis

Although BTEX were not detected during the preliminary analyses, benzene has been

Table 2 Amended groundwater

compound	nominal concentration (μg/L)	actual concentration gw sample 1 (μg/L)	gw sample 2 (μg/L)	mdl (μg/L)
naphthalene	5159.1	0	0	6
1-methylnaphthalene	4771.6	605	319	10
dibenzofuran	1693.2	1164	588	10
fluorene	284.1	476	294	14
phenanthrene	2296.5	76	48	5
anthracene	214.8	10	9	4
carbazole	154.5	0	0	26
fluoranthene	181.8	96	89	5
pyrene	31.8	43	47	7
B(a)anthracene	27.3	0	0	6

gw sample 1: taken immediately prior to dispensing water into microcosms.
gw sample 2: taken immediately after dispensing water into microcosms.
Both samples stored overnight at 4°C before analysis.
mdl = method detection limit

recorded during Weston's field sampling. Therefore, investigation of the potential for BTEX biodegradation was deemed expedient. An experiment wherein a series of BTEX-amended microcosms were repeatedly sampled over time was conducted, as insufficient soil was available to construct a second series of sacrificial microcosms. The conditions tested were those described for the creosotic compound microcosms in section 5.1.1. The BTEX microcosms consisted of 100-mL bottles containing 10 g of either clean or contaminated soil plus 50 mL of groundwater and 0.5 mL of either 10% Na azide solution, sterile water, or nutrient stock solution, as required. A new (sixth) jug of groundwater, with the bulk of the fines removed, as above, was used. The bottles were sealed with screw-cap mininert valves. Each microcosm was then amended with 1 μL of a neat BTEX stock solution (3:2:1:1:1:1 of benzene:toluene:ethylbenzene:*p*-xylene:*m*-xylene:*o*-xylene, by volume) giving an initial level of 871 μg BTEX per hypovial ($\sim$17 mg/L liquid in clean soil-, $\sim$16 mg/L in contaminated soil-microcosms if all BTEX is considered to be in the liquid phase). Microcosms were incubated at 10°C in the dark. A 400 μL aliquot of headspace gas was removed from each microcosm with a 1-mL gas-tight syringe for GC analysis. The microcosms were maintained in an ice bucket of 10°C water on the lab bench during this procedure, then returned to the 10°C incubator after sampling.

Complete data sets for the treatability experiments are provided in Appendix I (creosotic microcosms) and Appendix II (BTEX microcosms).

5.2 Analytical procedures

5.2.1 Creosotic analysis

This analytical method was developed by the Organic Geochemistry Laboratory, UW, for a large field study presently being conducted at UW (King et al., 1994; King et al., 1995). An advantage of the protocol is that it allows analysis of small sample volumes for a suite of compounds simultaneously, and large numbers of samples can be processed relatively quickly (King collects 100's of samples per sampling event). The compounds monitored represent the main groups of compounds (phenolics, PAHs, heterocyclics) found in a creosote mixture. *m*-xylene is also included as a representative petroleum hydrocarbon. The entire group of compounds detected is listed in Table 3. A disadvantage is that the protocol is a compromise,

Table 3 **Method detection limits, creosotic compounds in water**

compound	method detection limit (μg/L)
m-xylene	32
phenol	110
o-cresol	58
p-+m-cresol	44
2,6-dimethylphenol	41
2,4-+2,5-dimethylphenol	6
2,3-dimethylphenol	68
3,5-dimethylphenol	40
naphthalene	6
indole+2-methylnaphthalene	11
1-methylnaphthalene	10
IS (2-fluorobiphenyl)	-
biphenyl	10
acenaphthylene	6
acenaphthene	7
dibenzofuran	10
fluorene	14
phenanthrene	5
anthracene	4
carbazole	26
fluoranthene	5
pyrene	7
benzo(a)anthracene	6
chrysene	5
benzo(b)fluoranthene	6
benzo(k)fluoranthene	6
benzo(a)pyrene	6
indeno(1,2,3-c,d)pyrene +dibenzo(a,h)anthracene	16
benzo(g,h,i)perylene	8

rather than best-available-method for each individual compound. The phenolic compounds are most poorly recovered. However, compounds of this group were not detected in Wisconsin site materials.

Groundwater samples (60 mL) were prepared by adding 9 g NaCl to promote partitioning of all analytes, and 1.0 mL 1N HCl to enhance partitioning of phenolic compounds. After the salt had dissolved, 2 mL of dichloromethane (containing 7 ppm of the internal standard 2-fluorobiphenyl) was added, and then samples were shaken for 20 min at 300 rpm on a rotary shaker. About 1 mL of the solvent extract was transferred by syringe to an autosampler vial, and solvent extracts were injected into a Hewlett Packard 5890 GC equipped with an HP7673A autosampler, 30 m DB-5 column and flame ionization detector (FID). Calibration is by the external standard method, using standards prepared as in Appendix III. The method detection limits determined for the present project are listed in Table 3. Co-elution of compounds occurs, as indicated. The co-elution most pertinent to the present study is that of indole and 2-methylnaphthalene.

Soil samples were extracted by shaking a known weight of moist soil with 60 mL of methylene chloride for 20 min at 300 rpm. The solvent was then poured off and the procedure repeated three more times. All the methylene chloride extracts for each sample were combined in an amber bottle and dried over anhydrous sodium sulfate. Using a Kuderna-Danish evaporator, the solvent was reduced to 5 mL, transferred to a volumetric flask, and made up to 10 mL in methylene chloride. The solvent extract was then analyzed by GC.

5.2.2 GC/MS scans

GC/MS library scans were conducted on extracts of water from contaminated soil microcosms sacrificed on day 49. Liquid from three microcosms was pooled to provide a 250-mL composite sample for each experimental condition (i.e., sterile, active unamended, and active nutrient-amended) which was then extracted with dichloromethane as in section 5.2.1. Dichloromethane extracts were analyzed with a HP 5890 GC coupled to a HP 5970 mass selective detector to separate and determine the possible identity
of any unknown compounds. The mass spectrometer was placed in a scanning mode with a range of 30-300 amu and a 2-μL injection was separated on a DB-5 capillary column over a

temperature range of 40°-300°C changing at a rate of 15°C per min. There is a 3.0 min solvent delay before the mass spectrometer can activated, therefore, compounds that may elute from the GC during this delay are not be detected. The mass spectra of all eluted peaks were compared to spectra in a 54,000 compound library and the top three matches are reported. The complete GC/MS reports are found in Appendix IV.

5.2.3 BTEX analysis

Preliminary BTEX analyses were conducted with a Hewlett Packard 5890 gas chromatograph equipped with a photoionization detector (PID) and a Varian Genesis headspace autosampler. The peak areas were measured by a HP 3392A integrator and an external standard method of calibration was used. Detection limits for BTEX compounds range from 5 ppb to 10 ppb with this system. However, this automated system was not suitable for repeated analysis of microcosms. Accordingly, BTEX-amended microcosms were analyzed manually with a Shimadzu GC-9A equipped with a 60 m Supelcowax 10 capillary column, FID and Shimadzu C-R3A integrator. Helium was the carrier gas, and detector and injector temperatures were maintained at 200°C and the column at 105°C during analysis. Each headspace gas sample was introduced on-column via a sample loop.

5.2.4 Microbial enumeration

Site water and soils were assessed for viable aerobic, heterotrophic microorganisms by plate count on R2A agar (Reasoner and Geldreich, 1985) and for most-probable-number (MPN) of aerobic naphthalene-, phenanthrene- and dibenzofuran-degrading microorganisms, using three-tube series of mineral salts medium (MSM) amended with the aforementioned compounds as carbon sources. MPN tubes were scored for turbidity and/or the development of pigmented breakdown products (brown-coloured products were formed in some tubes) and MPNs were calculated using the 3-tube MPN table in Mayou (1976).

Ten mL of groundwater or 10 g (wet wt) of soil were diluted in 90 mL of 0.1% Na pyrophosphate solution and shaken for 10 min at ~400 rpm on a rotary shaker. Further dilutions were made in phosphate-buffered saline solution, then 0.1-mL aliquots of appropriately diluted sample were spread onto triplicate plates of R2A agar, and 0.75-mL aliquots were dispensed into

triplicate tubes of naphthalene-MSM, phenanthrene-MSM and dibenzofuran-MSM. Inoculated media were incubated at room temperature, in the dark, for 3 weeks. The MSM contained 4.3 g K_2HPO_4, 3.4 g KH_2PO_4, 2.0 g $(NH_4)_2SO_4$, 0.34 g $MgCl_2 \cdot 6H_2O$, 0.026 g $CaCl_2 \cdot 2H_2O$, 0.0006 g $FeSO_4 \cdot 7H_2O$, 0.001 g $MnCl_2 \cdot 4H_2O$ and 0.002g $NaMo_4 \cdot 2H_2O$ per L, adjusted to pH 7.0 (Furukawa et al., 1983). Each carbon source was prepared as a 0.2 g/mL stock solution in filter-sterilized acetone, and 5 μL of stock was added per tube MSM, to give 0.01% carbon source. Carbon source manipulation was carried out under dim lighting (near dusk with room lights off) to minimize photolytic alteration of the PAHs. After inoculation, tubes were left loosely sealed for 1.5 h to permit volatilization of the solvent carrier, then tightly sealed with screw caps to prevent loss of volatile substrates. Negative controls of uninoculated tubes, and inoculated acetone-only tubes were prepared. Known PAH-degrading bacterial strains were unavailable, so to provide positive controls, a series of tubes was inoculated with an in-house enrichment culture that has been growing on creosote-amended MSM for ~3 years. The presence of naphthalene-, phenanthrene- or dibenzofuran-degrading cells in this enrichment culture had not been previously determined, but there was some likelihood that such cells were present. The raw enumeration data are given in Appendix V.

5.2.5 Moisture content

Triplicate aliquots of the soils were dispensed into pre-dried aluminum pans and dried overnight at 100°C. The loss of moisture upon drying was determined gravimetrically. The clean soil contained 11.6% moisture (s.d.= 2.0), the contaminated soil contained 28.3% moisture (s.d. = 1.2). Values in this report are per mass of dry soil.

6.0 Study Results

Several of the compounds monitored were never detected in the Wisconsin groundwater provided or in microcosm waters (unless these were amended). These included BTEX, all the phenolics, benzo(k)fluoranthene, benzo(a)pyrene, and indeno(1,2,3-c,d)pyrene + dibenzo(a,h)anthracene, and benzo(g,h,i)perylene. Benzo(b)fluoranthene was detected, at the MDL, in gw#1 during the preliminary analyses (Table 1). Benzo(a)anthracene and chrysene were recorded only twice, in gw#1 during preliminary analyses (Table 1) and in a single contaminated

soil sterile control microcosm; even though the former compound was spiked into groundwater used in the clean soil microcosms, it was not detected, either in the spiked groundwater (Table 2) or in microcosm water (Table 4). The lower molecular weight PAHs monitored (2-3 ring) plus pyrene and fluoranthene, biphenyl, and the heterocyclics dibenzofuran, carbazole and possibly indole (which co-elutes with 2-methylnaphthalene) were detectable in experimental materials. Field data provided by Weston (see Table 1) indicates that measurable benzo(k)fluoranthene, benzo(a)pyrene and indeno(1,2,3-cd)pyrene have also been recorded in site water, although levels were near or below our MDL. Weston data also indicate "phenol" (which may/may not include phenol-like compounds such as cresols, etc., depending upon assay technique) in some site waters over a concentration range of 2-510 μg/L.

6.1 Microcosms for creosotic analysis

Contaminant biotransformation was observed in both clean soil + (spiked) groundwater and contaminated soil + groundwater-containing microcosms. Complete compound loss occurred within 7 d in active, clean soil-containing microcosms (Table 4) but contaminants persisted in sterile microcosm waters. This indicates that the compound loss was biologically-mediated, and not simply due to sorption onto solid phases, although sorption effects are seen as a decline in aqueous phase concentrations over time in the sterile controls (Table 4). Compound depletion in the biologically-active microcosms was so rapid that it is difficult to ascertain whether inorganic nutrient addition increased biodegradative activity. Fluoranthene and pyrene did persist in active, unamended day 4 microcosms but not in their nutrient-amended counterparts, but neither compound was detected under either treatment, by day 7. The clean soil microcosms were not monitored further.

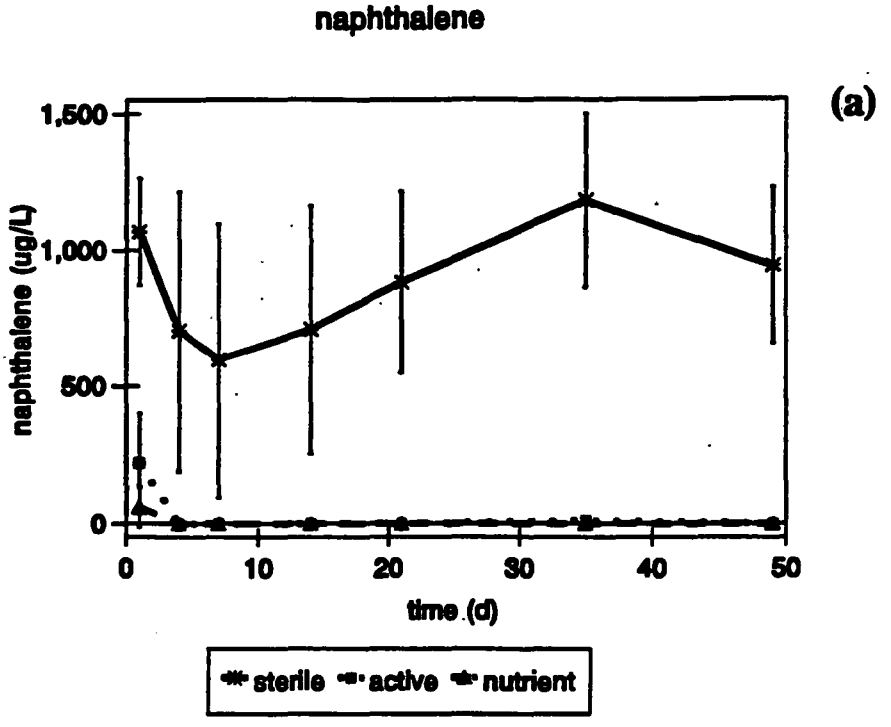
Figures 1-7 depict the aqueous concentrations in contaminated soil-containing microcosms over 49 d. A comparison of the contaminant levels depicted in the Figures with levels in the groundwater used in microcosm preparation (data shown in Appendix II) confirmed that the bulk of the aqueous-phase organics in the microcosms was derived from the soil phase, presumably as a result of desorption, not the groundwater. This was expected, from the preliminary tests (Table 1). Rapid biologically-mediated depletion of 2-ringed compounds (naphthalene, indole + 2-methylnaphthalene, 1-methylnaphthalene, biphenyl) was observed (Fig. 1, 2). Naphthalene and

Table 4 Clean soil-spiked water microcosms

time (d)	naph* (µg/L)	in + 2-mn (µg/L)	1-mn* (µg/L)	biphen (µg/L)	acen-y (µg/L)	acen (µg/L)	dibenzo* (µg/L)	fluor* (µg/L)	phen* (µg/L)	anth* (µg/L)	carb* (µg/L)	fluoran* (µg/L)	pyrene* (µg/L)	b(a)anth* (µg/L)
sterile control														
1	0	0	230.0	0	0	37.3	228.0	176.7	20.7	7	(3.3)	19.3	12.33	0
4	0	0	104.3	0	0	25.0	106.3	141.3	16.0	0	(4.7)	8.7	13.7	0
7	0	0	90.7	0	0	19.7	92.7	138.3	10.7	0	(1.0)	10.0	9.0	0
active, unamended														
1	0	0	56.7	0	0	17.0	141.3	128.7	0	(2)	(4.7)	17.0	12.0	0
4	0	0	0	0	0	0	0	0	16.0	0	0	11.0	9.0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0
active, N,P-amended														
1	0	0	28.7	0	0	10.7	68.7	72.3	0	0	(2.7)	9.0	7.0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0
mdl	6	11	10	10	6	7	10	14	5	4	26	5	7	6

all values are mean aqueous concentrations of three replicate microcosms. ( ) = < mdl.
* = spiked into groundwater before microcosm construction (see Table 2).
mdl = method detection limit

Figure 1


naphthalene
(a)
1,500
1,000
500
0
naphthalene (ug/L)
0
10
20
30
40
50
time (d)
sterile
active
nutrient

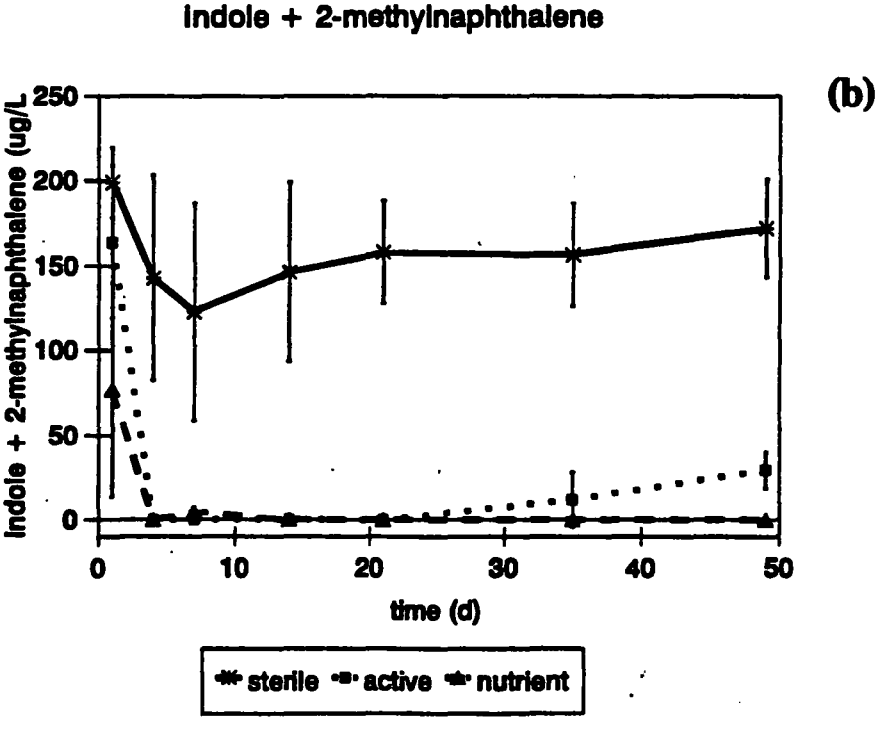
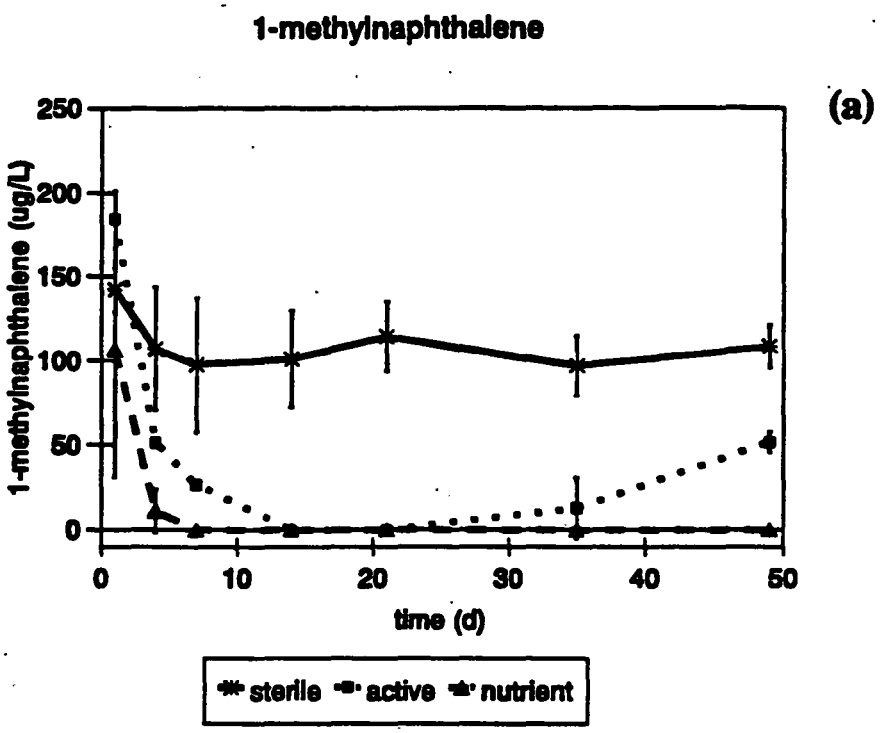

Indole + 2-methylnaphthalene
(b)
250
200
150
100
50
0
Indole + 2-methylnaphthalene (ug/L
0
10
20
30
40
50
time (d)
sterile
active
nutrient

Figure 2


1-methylnaphthalene
(a)
1-methylnaphthalene (ug/L)
250
200
150
100
50
0
0
10
20
30
40
50
time (d)
sterile
active
nutrient

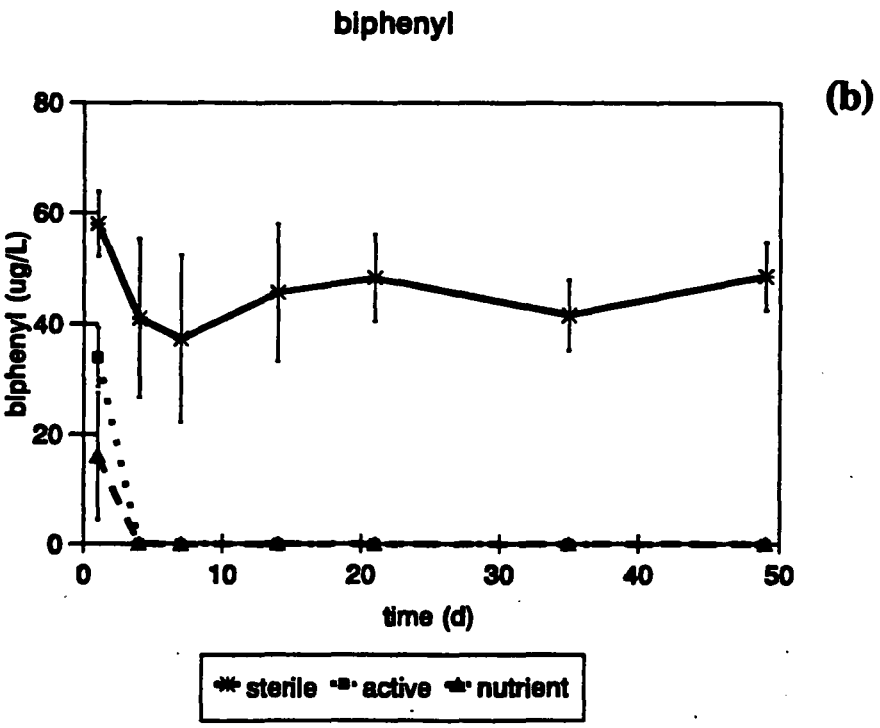
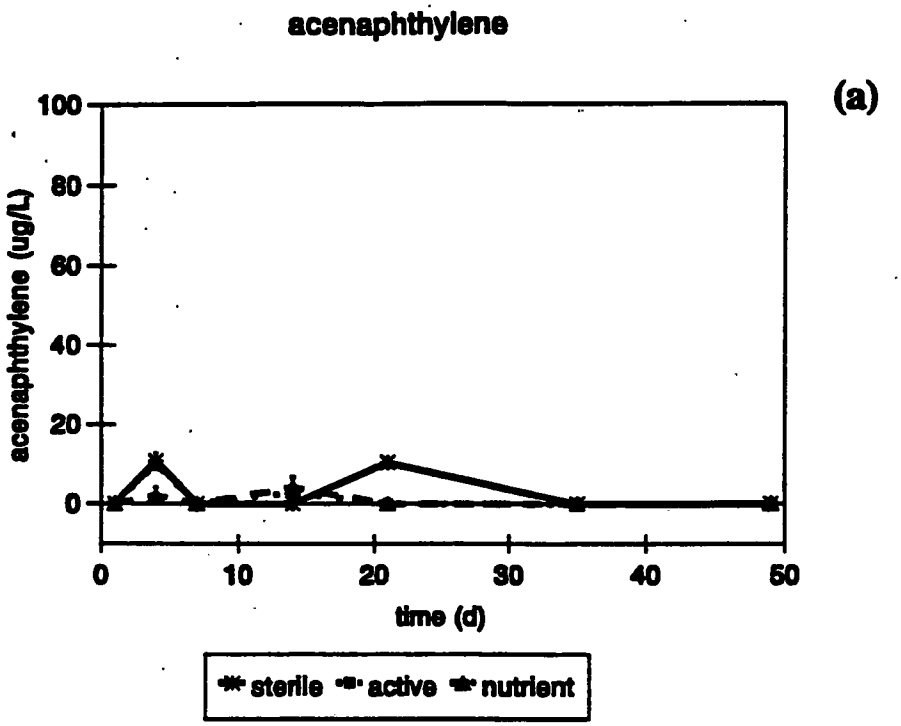

biphenyl
(b)
biphenyl (ug/L)
80
60
40
20
0
0
10
20
30
40
50
time (d)
sterile
active
nutrient

Figure 3


acenaphthylene
(a)
acenaphthylene (ug/L)
100
80
60
40
20
0
0
10
20
30
40
50
time (d)
sterile
active
nutrient

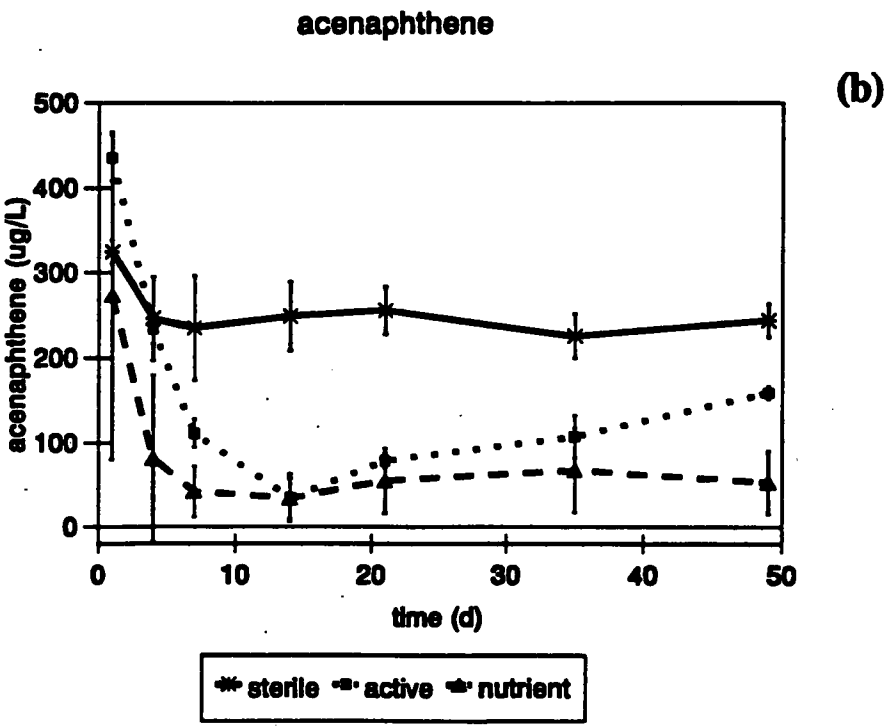
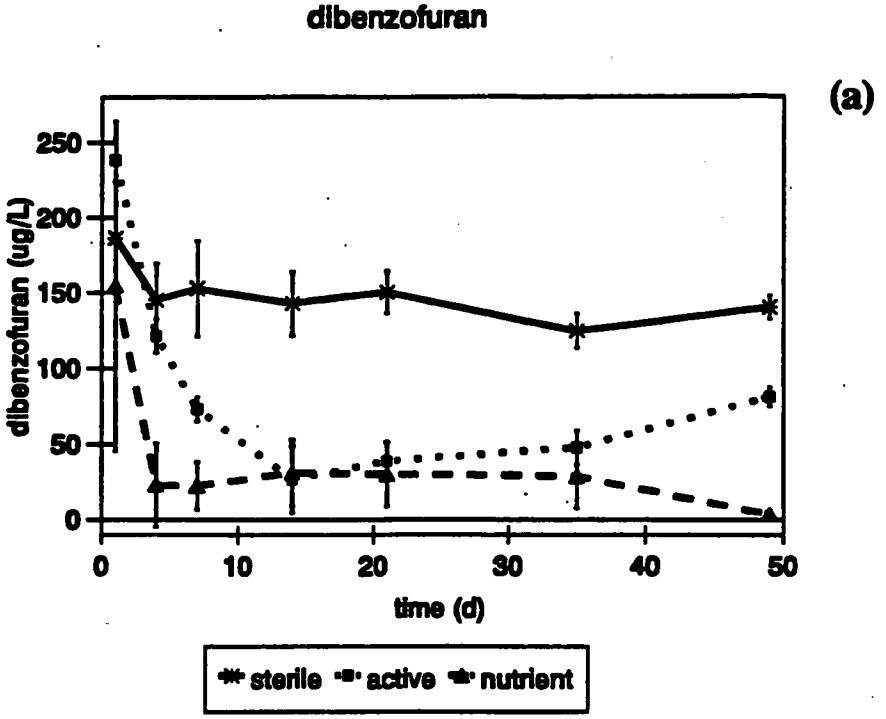

acenaphthene
(b)
acenaphthene (ug/L)
500
400
300
200
100
0
0
10
20
30
40
50
time (d)
sterile
active
nutrient

Figure 4


dibenzofuran
(a)
dibenzofuran (ug/L)
250
200
150
100
50
0
0
10
20
30
40
50
time (d)
sterile
active
nutrient

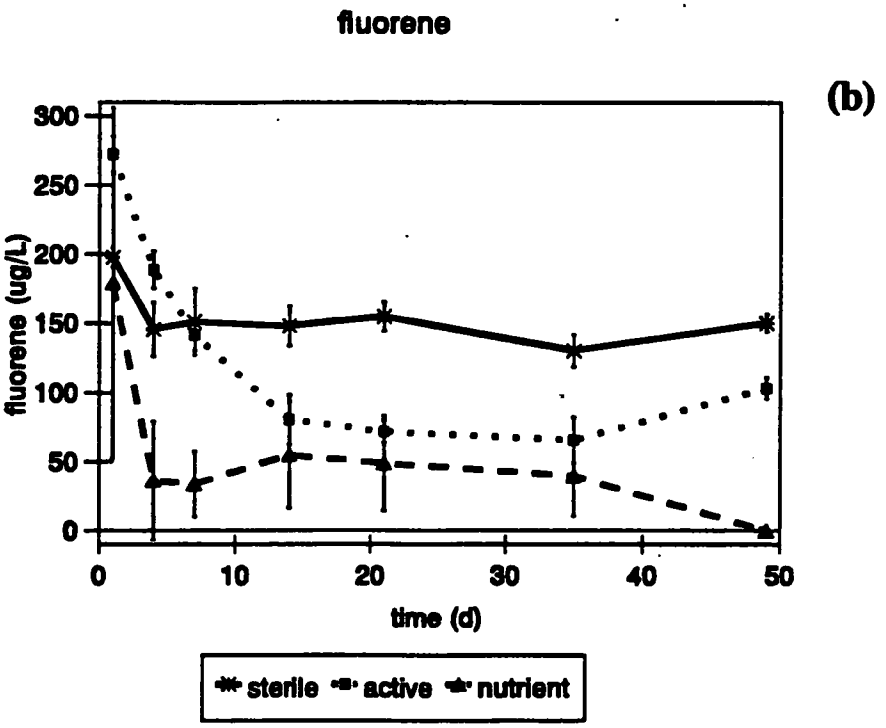
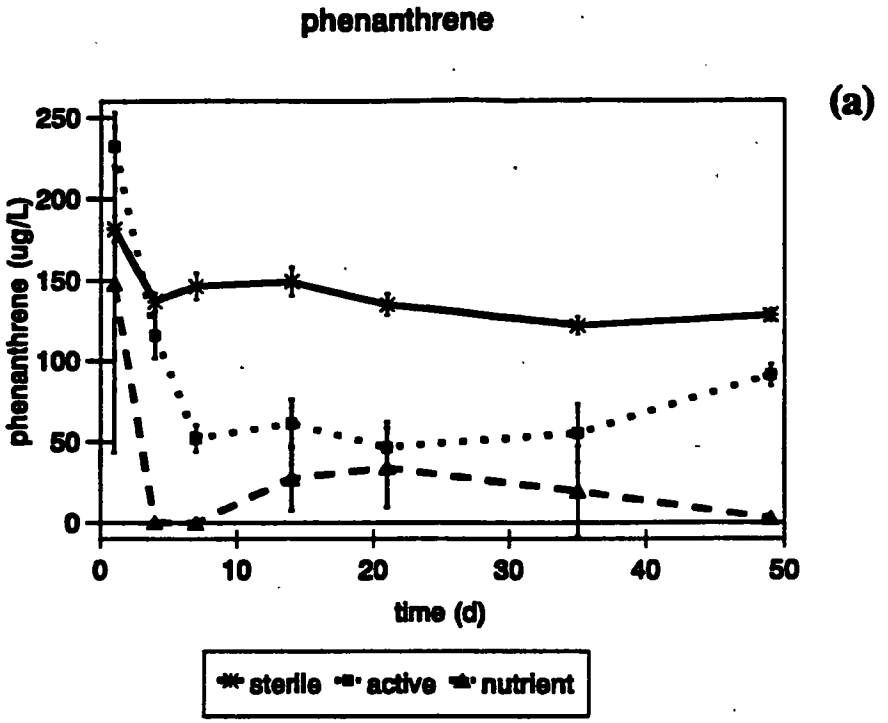

fluorene
(b)
fluorene (ug/L)
300
250
200
150
100
50
0
0
10
20
30
40
50
time (d)
sterile
active
nutrient

Figure 5


phenanthrene
(a)
phenanthrene (ug/L)
250
200
150
100
50
0
0
10
20
30
40
50
time (d)
sterile
active
nutrient

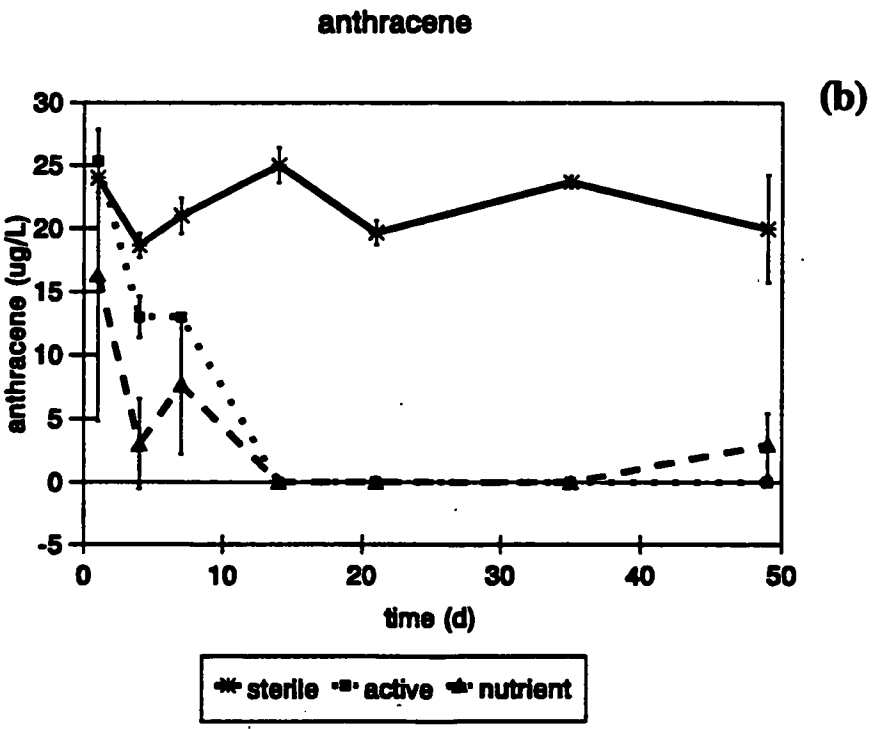
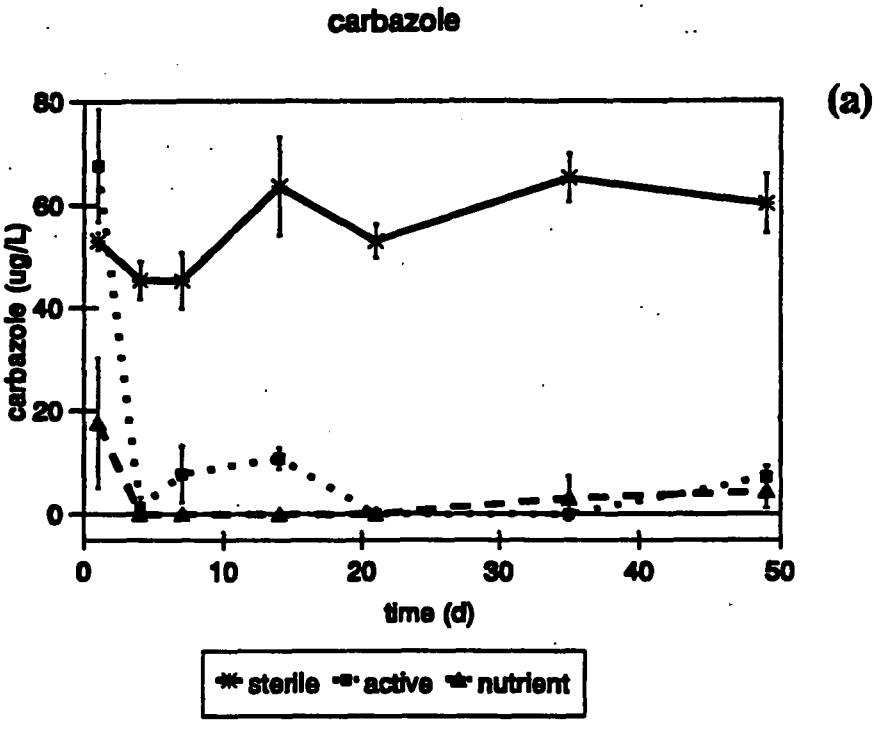

anthracene
(b)
anthracene (ug/L)
30
25
20
15
10
5
0
-5
0
10
20
30
40
50
time (d)
sterile
active
nutrient

Figure 6


carbazole
(a)
carbazole (ug/L)
80
60
40
20
0
0
10
20
30
40
50
time (d)
sterile
active
nutrient

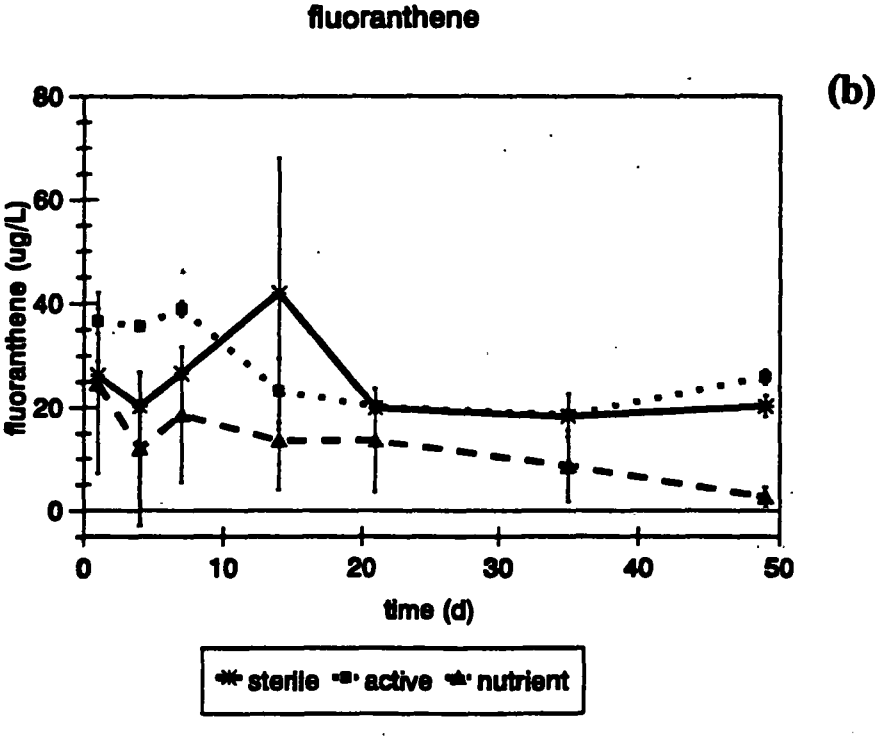
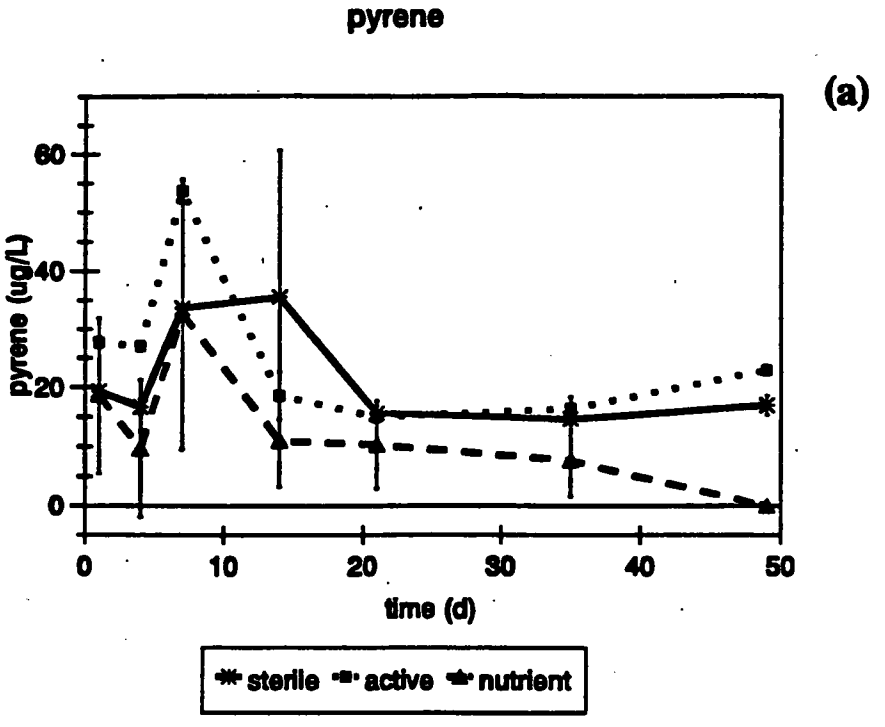
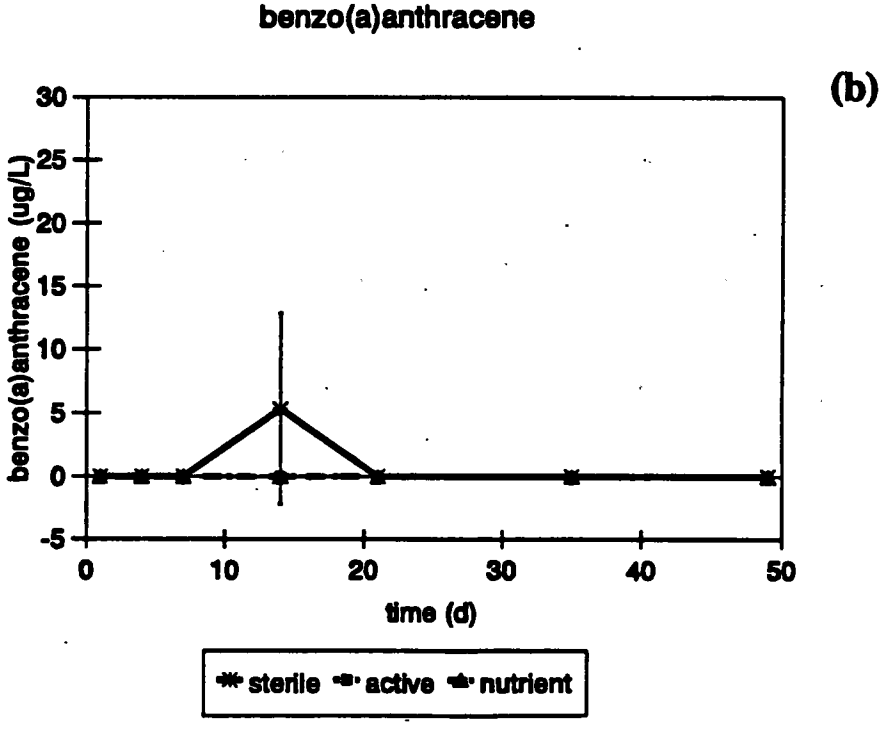

fluoranthene
(b)
fluoranthene (ug/L)
80
60
40
20
0
0
10
20
30
40
50
time (d)
sterile
active
nutrient

Figure 7


pyrene
(a)
pyrene (ug/L)
60
40
20
0
0
10
20
30
40
50
time (d)
sterile
active
nutrient


benzo(a)anthracene
(b)
benzo(a)anthracene (ug/L)
30
25
20
15
10
5
0
-5
0
10
20
30
40
50
time (d)
sterile
active
nutrient

biphenyl were never detected after day 1 in active, unamended or active, nutrient-amended microcosms, with the exception of a single active, unamended microcosm (replicate c) sacrificed on day 35. This anomaly could represent a "hot spot" in the soil of that microcosm, or, alternatively, less-than-average microbial activity in that soil aliquot. The latter explanation appears more likely, because levels of other, recalcitrant compounds (fluoranthene and pyrene) in the microcosm were "typical" (see data in Appendix II). Indole + 2-methylnaphthalene depletion was similarly quick, although near-detection-level peaks were recorded on day 7 under nutrient-amended conditions. Loss of 1-methylnaphthalene was also quite rapid. This compound was not detected in nutrient-amended microcosms after day 4, although depletion was somewhat slower in unamended microcosms, where the compound was present on day 7 but not day 14 (Fig. 2a). These compounds were metabolized so rapidly that significant loss occurred between microcosm construction and day 1 in the active microcosms. However, if similar initial concentrations in active and sterile microcosms is assumed, then one may conclude that nutrient amendment increased the rate at which these short-lived contaminants degraded. Day 1 levels in nutrient-amended microcosms were lower than levels in unamended microcosms for all 4 compounds (Fig. 1, 2). A reappearance of indole + 2-methylnaphthalene and 1-methylnaphthalene in unamended microcosms at the last two sampling events may be related to weekly agitation of the microcosms (discussed below).

Acenaphthene (Fig. 3b), dibenzofuran and fluorene (Fig. 4), phenanthrene and anthracene (Fig. 5) and carbazole (Fig. 6a) were all subject to biotransformation, although it should be noted that levels of carbazole recorded in active microcosms were almost always below the level (26 μg/L) at which the compound could be reliably detected. Loss of these compounds was slower than 2-ring compound degradation, and except for anthracene, lower, residual levels of the compounds persisted in both unamended and nutrient-amended, active microcosms, after initial biotransformation. Phenanthrene was essentially undetected in nutrient-amended microcosms on day 4 and day 7, but subsequent aqueous phase levels rose and reached a plateau at ~20-30 μg/L (Fig. 5a). Residual levels of acenaphthene, dibenzofuran and fluorene were on the order of 35-65, 20-30, and 35-55 μg/L, respectively, under nutrient-amended conditions. More acenaphthene remained in the water on d 49 than any other compound. As with the 2-ring compounds, the depletion of this group of slower-biodegrading compounds was enhanced by N

and P addition. In all cases, residual contaminant levels were lower in nutrient-containing microcosms, and rates of dibenzofuran, fluorene, phenanthrene and possibly anthracene depletion were slower in the absence of added inorganic nutrients (Fig. 4 & 5). The rate of acenaphthene depletion appeared little-affected by nutrient addition, although higher residual levels were observed in unamended microcosms (Fig. 3b). Interpretation of carbazole data is necessarily tentative, but results suggest more rapid depletion had occurred under conditions of nutrient addition, so that little carbazole remained by day 1 compared to the unamended treatment.

Neither fluoranthene (Fig. 6a) or pyrene (Fig. 7a), two 4-ring PAHs, were biotransformed appreciably during the experiment, except in the nutrient-amended microcosms between day 35 and day 49, perhaps as a result of the second nutrient amendment on day 40. Benzo(a)anthracene (Figure 7a) and chrysene (not shown) were detected in the aqueous phase of only one sterile control microcosm during the experiment, so that no comment may be made upon the potential for biotransformation of these compounds.

Low levels of acenaphthylene were periodically detected after day 1, with no discernable pattern to its occurrence (Fig. 3a). This compound was not detected during the preliminary analyses. Its occurrence here may reflect a patchy distribution of this compound in contaminated soil, although contaminated soil analyses completed to date have not detected acenaphthylene, or it might be a consequence of some abiotic reaction producing acenaphthylene from the acenaphthene in the soil, over time. The appearance of acenaphthylene was not biologically-mediated, as it occurred in sterile controls as well.

An estimate of oxygen availability in contaminated soil microcosms was conducted. Using a concentration of 300 mg contaminant mass/kg soil, as listed on the soil jars, with all contaminant assumed to be naphthalene for the purpose of calculation, about 110% of the oxygen required for complete contaminant mineralization to CO_2 was available. Complete mineralization is not expected, since some carbon is likely to be assimilated into biomass, but it is conceivable that oxygen limitation became a factor towards the end of the experiment. The contaminated soil-containing microcosms were incubated under quiescent conditions for the first 21 days, but thereafter they were agitated weekly to encourage mass transfer of oxygen to the aqueous and soil phases, while still simulating the limited degree of mixing that would occur *in situ*. DO content of the microcosm water was typically low (Table 5). The anoxic condition of one of the

Table 5 Dissolved oxygen content of microcosm waters

Condition	Dissolved oxygen (mg/L) day 1	day 14	day 49
contaminated soil microcosms			
sterile control	2.7	1.5	1.1
active, unamended	3.8	1.2	0
active, nutrient-amended	3.0	1.1	0.6
clean soil microcosms			
sterile control	3.4		2.9
active, unamended	not tested		not tested
active, nutrient-amended	6.9		1.0

test hypovials on day 49 supports the hypothesis of oxygen limitation late in the experiment. A second, unforeseen, consequence of microcosm agitation may be evident at post-day 21 sampling times in some of Figs. 1-7, where aqueous concentrations rise again in active microcosms. A possible explanation is that the agitation helped to release previously unexposed contaminant from the soil into the water. If conditions had become biologically limiting in active microcosms by experiment's end, the released contaminant would persist.

On day 40, the remaining active, nutrient-amended microcosms were re-amended with nitrogen and phosphorus. Results indicate that this manipulation was beneficial. The aforementioned late rise in contaminant levels was most often evident in active, unamended microcosms, but not nutrient-amended, although anthracene was exceptional. Dibenzofuran and fluorene (Fig. 4), phenanthrene (Fig. 5a), fluoranthene (Fig. 6b) and pyrene (Fig. 7a) levels clearly declined in nutrient-amended microcosms between days 35 and 49. A necessary consequence of the re-addition of N and P to the nutrient-amended microcosms was a brief exposure of the microcosm headspace to the open atmosphere. It must be noted, then, that one cannot identify O_2 addition or N,P addition (or both) as the key benefit.

6.1.1 Soil samples

The soils analyses were planned when it became apparent that the soil would be the primary source of dissolved contamination in the contaminated soil microcosms. Our concern was that residual NAPL might be in the soil, and biodegradation of contaminants might not be apparent, even if occurring, by monitoring only the microcosm aqueous phase. In fact, this was not the case, biodegradation was detectable by aqueous phase analyses.

Results of the soil analyses conducted on active, nutrient-amended, contaminated soil-containing microcosms (Table 6) generally indicate a depletion of contaminants in the soil, over time. Most notably, there seemed to be some loss of fluoranthene and pyrene, the two compounds relatively persistent in the aqueous phase. Little change was evident in levels of compounds to the right of pyrene in Table 6; these compounds were rarely (benzo(a)anthracene and chrysene) or never detected in aqueous phase analyses.

The same downward trend in soil contaminant level was not nearly as apparent in active, unamended, contaminated soil microcosms, with the exception of naphthalene levels, and

Table 6 Soil analyses, contaminated soil microcosms, days 1, 21 and 49

time (d)	naph	in + 2-mn	l-mn	biphen	aceny	acen	dibenz	fluor	phen	anth	carb	fluoran	pyrene	b(a)anth	chry	b(b)flu	b(k)flu	b(a)pyr	in + dib	benzo
sterile control																				
1	24.7	8.7	7.0	3.0	0.3	25.3	19.3	26.0	63.7	14.7	3.3	35.3	27.7	6.0	10.0	3.0	2.0	2.7	0.3	0.3
	(9.0)	(4.1)	(1.4)	(2.4)	(0.5)	(7.4)	(8.2)	(8.2)	(20.4)	(3.7)	(4.0)	(11.0)	(9.6)	(2.4)	(3.3)	(2.4)	(1.4)	(1.2)	(0.5)	(0.50)
21	9.7	3.0	4.0	0	0	12.7	8.7	11.7	31.7	7.7	0	18.3	14.0	3.0	5.3	1.7	1.3	1.0	0	0
	(7.1)	(2.2)	(1.4)	(0)	(0)	(4.7)	(4.0)	(4.7)	(12.7)	(2.6)	(0)	(6.6)	(4.5)	(1.4)	(0.9)	(1.7)	(1.8)	(0.8)	(0)	(0)
49	18.7	6.7	4.0	3.0	0.7	18.7	15.7	20.0	56.0	11.7	6.0	33.0	27.0	2.9	3.8	1.7	0.5	0.9	0.5	0
	(5.0)	(1.2)	(0.8)	(0)	(0.5)	(0.9)	(0.9)	(2.2)	(5.9)	(1.7)	(0.8)	(7.3)	(6.5)	(2.9)	(3.9)	(1.7)	(0.5)	(0.9)	(0.5)	(0)
active, unamended																				
1	15.0	5.0	3.3	2.0	0	12.7	10.7	13.0	34.7	6.0	2.3	18.3	16.0	3.3	5.0	3.3	0	2.0	1.0	0.3
	(7.3)	(2.4)	(1.2)	(0.8)	(0)	(5.3)	(4.9)	(5.7)	(13.1)	(2.9)	(1.2)	(6.9)	(5.7)	(1.2)	(1.6)	(1.2)	(0)	(0.8)	(0)	(0.5)
21	9.7	3.0	4.7	0	0	16.3	9.3	16.3	41.0	12.7	0.3	28.3	20.3	5.0	10.3	0	6.3	3.0	0	0
	(3.9)	(1.6)	(1.7)	(0)	(0)	(5.6)	(3.7)	(6.3)	(13.4)	(5.2)	(0.5)	(11.3)	(6.1)	(2.2)	(4.0)	(0)	(2.6)	(1.4)	(0)	(0)
49	4	2.7	2.0	1.7	0	11.0	9.0	11.0	32.3	8.3	2.0	22.0	18.3	5.7	9.0	4.0	3.0	3.7	3.0	1.7
	(0.8)	(0.5)	(0)	(0.5)	(0)	(0.8)	(0.8)	(0.8)	(2.4)	(0.9)	(1.4)	(2.2)	(1.7)	(1.2)	(2.4)	(2.2)	(0.8)	(1.2)	(1.6)	(1.2)
active, nutrient-amended																				
1	24.3	8.3	5.0	3.3	0	19.7	17.0	21.0	53.0	11.7	5.3	29.0	24.7	5.0	8.3	3.7	1.0	2.3	1.0	1.0
	(1.9)	(1.2)	(0)	(0.5)	(0)	(3.1)	(2.2)	(2.9)	(8.0)	(1.7)	(0.9)	(4.5)	(4.1)	(0.8)	(1.2)	(0.5)	(1.4)	(0.5)	(0)	(0)
21	7.7	3.0	4.0	0	0	12.7	8.3	12.3	35.0	9.0	0	21.3	15.7	3.7	7.7	0	4.0	2.0	0	0
	(0.5)	(0)	(0)	(0)	(0)	(0.9)	(0.5)	(0.5)	(2.2)	(2.2)	(0)	(1.2)	(1.7)	(0.5)	(0.5)	(0)	(0)	(0)	(0)	(0)
49	1.7	1.7	1.0	1.0	0	7.0	6.0	7.7	24.7	6.7	2.0	17.7	15.0	4.7	7.7	3.7	2.7	3.3	1.7	1.0
	(0.5)	(0.5)	(0)	(0)	(0)	(0.8)	(0.8)	(1.2)	(2.9)	(1.2)	(0)	(1.2)	(0.8)	(0.5)	(0.9)	(0.9)	(0.5)	(0.5)	(0.9)	(0)

mean (s.d.) of triplicate microcosms. All data are $\mu g/g$ dwt.

perhaps other of the smaller compounds (indole + 2-methylnaphthalene, 1-methylnaphthalene, biphenyl, dibenzofuran).

Although the contaminants detectable in the aqueous phase of clean soil microcosms were primarily those added by spiking the groundwater with a contaminant mix, soil analyses were also conducted for these microcosms (Table 7), because of an interest in the fates of fluoranthene and pyrene. By reliance on aqueous phase analyses only, these compounds appeared relatively persistent in contaminated soil microcosms, but biodegraded in active clean soil microcosms.

Results of the analyses of clean soils (Table 7) were quite curious. As would be expected, little of the smaller contaminants (e.g., naphthalene, methylnaphthalene, biphenyl, etc.) was ever detected on the soils. However, the heavy compounds benzo(a)anthracene, chrysene, benzo(b)fluorene, benzo(k)fluorene, benzo(a)pyrene, indenopyrene + dibenzoanthracene, and benzoperylene, were apparently present at higher levels in this clean soil
than in the contaminated soil (Table 6). One suspects this is unlikely to be so. The odd finding may be a consequence of misidentification of other, nontarget, components extracted from the soil. The analyst reported that clean soil extracts were dark brown to black in colour, so that initially, extracts were diluted in the belief that they must contain extremely high contaminant levels that would overwhelm the capabilities of the GC. This was not the case, but if many different compounds were present in the extracts, the chances of co-elution are much increased, and some unknown, nontarget compounds may have been misidentified as target compounds. Development and use of suitable fractionation protocols during soil extraction, and perhaps analysis by GC/MS, would be required to alleviate this problem.

The fluoranthene and pyrene data for the clean soil microcosms (Table 7) are also dubious, for the reasons cited above. If it is assumed that the magnitude of the datum only is affected, then the tentative conclusion may be made that the downward trend in fluoranthene and pyrene levels between days 1 and 7 in both types of active microcosms, compared with the upward trend (perhaps indicative of compound sorption to the soil) in sterile control microcosms, suggests fluoranthene and pyrene biodegradation. This concurs with the conclusions made from aqueous phase data. Unfortunately, a stronger conclusion cannot be made.

Table 7 Soil analyses, clean soil microcosms, days 1 and 7

time (d)	naph	in + 2-mn	1-mn	biphen	aceny	acen	dibenz	fluor	phen	anth	carb	fluoran	pyrene	b(a)anth	chry	b(b)flu	b(k)flu	b(a)pyr	in + dib	benzo
sterile control																				
1	1.3	0	0	0	0	1.0	0	0	0	1.0	0	4.0	4.7	1.3	3.3	6.3	0	3.0	1.0	1.0
	(0.5)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0.8)	(0.9)	(0.5)	(0.9)	(1.7)	(0)	(0.8)	(0)	(0)
7	1.0	0	0.3	0	0	1.3	2.3	1.7	5.3	2.3	0	7.0	6.0	2.7	3.7	6.0	2.7	3.0	2.0	1.7
	(1.4)	(0)	(0.5)	(0)	(0)	(1.2)	(1.9)	(0.9)	(4.8)	(1.9)	(0)	(2.8)	(1.6)	(0.5)	(0.5)	(1.4)	(0.5)	(1.4)	(1.4)	(1.2)
active, unamended																				
1	1.3	0	0	0	0	1.0	0	0	3.3	3.0	1.0	17.7	17.7	7.7	12.7	16.7	0	10.0	3.7	3.3
	(0.5)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0.5)	(0.8)	(0.8)	(5.3)	(3.9)	(1.2)	(2.4)	(2.1)	(0)	(1.4)	(1.7)	(1.2)
7	1.0	0.7	0	0	0.7	1.3	0.7	0.7	4.3	3.0	1.3	12.3	14.0	7.0	10.0	13.7	4.7	9.7	7.0	4.3
	(0)	(0.5)	(0)	(0)	(0.5)	(0.5)	(0.5)	(0.5)	(1.2)	(0.8)	(1.2)	(1.9)	(2.9)	(1.6)	(0.8)	(4.2)	(3.3)	(2.5)	(4.5)	(2.1)
active, nutrient-amended																				
1	1.0	0	0	0	0.3	1.0	0	0	3.3	2.3	0.3	13.3	13	5.3	9.7	14.3	0	8.0	5.0	4.3
	(0)	(0)	(0)	(0)	(0.5)	(0)	(0)	(0)	(0.9)	(0.5)	(0.5)	(2.6)	(1.6)	(2.1)	(3.7)	(4.9)	(0)	(3.3)	(2.4)	(3.7)
7	0	0	0	0	1.0	0.7	0.3	0.3	3.3	3.3	4.7	10.7	12.7	6.3	8.3	14.7	2.7	8.0	4.0	2.0
	(0)	(0)	(0)	(0)	(0)	(0.5)	(0.5)	(0.5)	(1.2)	(1.2)	(3.3)	(4.1)	(4.1)	(2.1)	(2.9)	(5.4)	(2.5)	(2.4)	(3.3)	(1.6)

mean (s.d.) of triplicate microcosms. All data are μg/g dwt.

6.1.2 GC/MS scans

The results of the GC/MS library scans are summarized in Tables 8 & 9. Relatively few peaks were detected in any sample. Nine peaks (excluding the internal standard) were detected in the sterile control, but only 5 in the active, unamended sample, and just 2 peaks were observed in the active, nutrient-amended sample. This suggests that few intermediates of biotransformation accumulated in the aqueous phase, and those that did were not persistent, as those in the unamended sample were gone in the nutrient-amended sample.

The last column of Tables 8 & 9 is an indication of the quality of the match between library spectra and the spectra of sample peaks. A "good" match for a compound is usually considered to be ≥ 80 (out of 100), but even known identities in the present scans (e.g., the internal standard) do not reach this level. This is because we supplied no limiting parameters at all to the search-and-match function (spectra of authentic standards, likely compound types, etc.). Some peaks (denoted by asterick) were identified as parent compounds with some certainty, because their GC retention times are known. A couple peaks may be oxidized intermediates of fluorene degradation. Peak 6 of the unamended sample may be a derivative of a longchain aliphatic hydrocarbon, or a propanoic acid derivative. Peak 3 of the nutrient-amended sample is quite a good match for histidine, an amino acid. This is an odd finding, but it could be an excreted microbial product. None of the possible compound identities generated is obviously identifiable as a highly hazardous byproduct.

6.2 Microcosms for BTEX analysis

Figure 8 summarizes results of the BTEX degradation experiment. An example (the contaminated soil microcosms) to show the fate of individual compounds is given in Figure 9. Little difference was observed between the nutrient-amended and unamended condition, in the clean soil microcosms (Fig. 8a). All added contaminants were depleted by day 7, except benzene, which was gone by day 9. Contaminant loss was nearly as rapid in the microcosms containing contaminated soil, if nutrient-amended, but the rate of BTEX depletion was considerably slower in the unamended, contaminated soil microcosms (Fig. 8b). Significant benzene, and some toluene and *o*-xylene remained under this condition, at day 18 (Fig. 9c). Our experience is that these will slowly degrade, so the microcosms were not monitored further.

Table 8 Summary of GC/MS library scan results - sterile control

Peak No.	Library/ID	Area(%)	ID quality
1	3,6-bis(benzyl)-tetrazine	2.60	22
	(chloromethyl)ethenyl-benzene		18
	1,3,4-tri-O-acetyl-2,5-di-O-methylribitol		14
2	1-methylene-1H-indene	29.56	87
	azulene		78
	[4.2.2]propella-2,4,7,9-tetraene		72
3	3a,10b-dihydro-3a,10b-dimethylthiepino-[3,2-e]isobenzofuran-1,3-dione	2.79	43
	2,4,6-trifluoropyrimidine		38
	1,4-benzenedicarboxaldehyde		38
4	1,4-dihydro-1,4-methanonaphthalene	3.83	86
	1-ethylidene-1H-indene		68
	benzocycloheptatriene		43
5	1-ethylidene-1H-indene	4.21	90
	2-methylnaphthalene *		86
	1-methylnaphthalene *		86
6 (internal standard)	4-fluoro-1,1"-biphenyl	23.44	76
	2-fluoro-1,1'-biphenyl *		76
	4-(2-hydroxyphenyl)pyrimidine		47
7	acenaphthene *	13.98	47
	1,3,5-trimethyl-2,4(1H,3H)-pyrimidineione		22
	2-ethenyl-naphthalene		17
8	dibenzofuran *	5.54	72
	3-chloro-benzo[b]thiophene		42
	3-methyl-1,1'-biphenyl		42
9	4,6-dihydroxy-2,3-dimethyl-benzaldehyde	6.88	72
	fluorene-9-methanol		64
	9H-fluorene-9-carboxylic acid		43
10	9-methylene-9H-fluorene	7.17	72
	phenanthrene *		72
	1,1'-(1,2-ethynediyl)bis-benzene		64

* most likely identification, based on GC retention times for parent compounds

Table 9 Summary of GC/MS library scan results - active microcosms

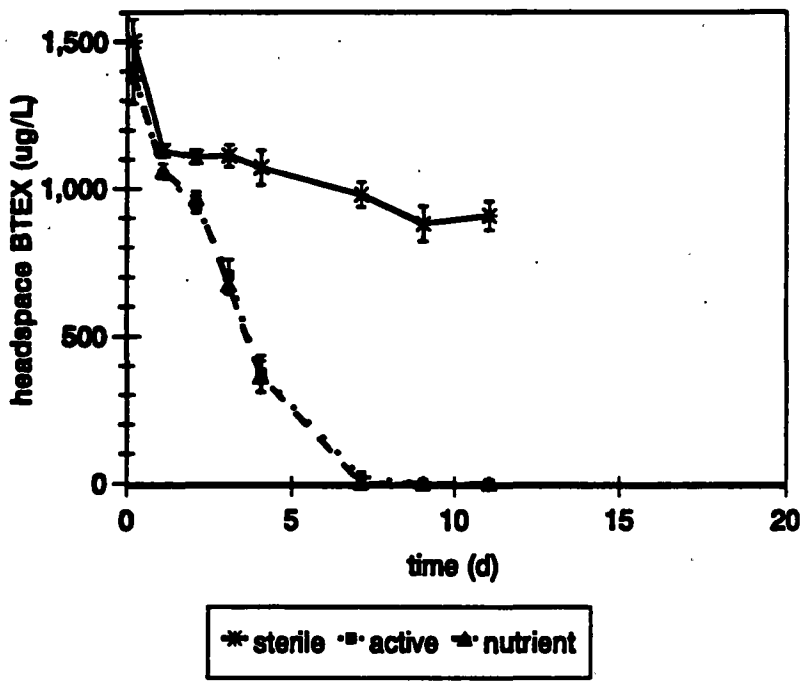
Peak No.	Library/ID	Area(%)	ID quality
active, unamended			
1	4-fluoro-1,1'-biphenyl	51.60	76
(internal	2-fluoro-1,1'-biphenyl *		76
standard)	3,5-dimethyl-1-phenyl-1H-pyrazole		53
2	1,4-dihydro-1,4-ethenonaphthalene	17.37	58
	acenaphthene *		17
	7-chloro-benzofuran		11
3	3,4,5-trimethoxy-benzenamine	4.68	12
	3-methyl-1-isoquinolinecarbonitrile		12
	N-(trifluoroacetyl)-, 1 methyl propyl ester, (S)-ß-alanine		10
4	1H-phenalene	8.72	64
	fluorene-9-methanol		59
	2,4-dihydroxy-3,6-dimethyl-benzaldehyde		50
5	phenanthrene *	8.57	83
	9-methylene-9H-fluorene		72
	anthracene		72
6	4,8,12,-trimethyl-3,7,11-tridecatrienenitrile	9.06	49
	2-methyl-, 3,7-dimethyl-2,6-octadienyl ester, (E) propanoic acid		47
	3,7,11-trimethyl-, acetate, (E,E) 2,6,10-dodecatrien-1-ol		38
active, nutrient-amended			
1	4-fluoro-1,1'-biphenyl	81.19	76
(internal	2-fluoro-1,1'-biphenyl *		76
standard)	3,5-dimethyl-1-phenyl-1H-pyrazole		53
2	1,4-dihydro-1,4-ethenonaphthalene	12.28	53
	2,5-etheno[4.2.2]propella-3,7,9-triene		36
	acenaphthene *		27
3	L-histidine	6.52	74
	15-octadecenal		64
	1-histidine, ethyl ester		64

* most likely identification, based on GC retention times for parent compounds

Figure 8

clean soil + groundwater

(a)



contaminated soil + groundwater

(b)

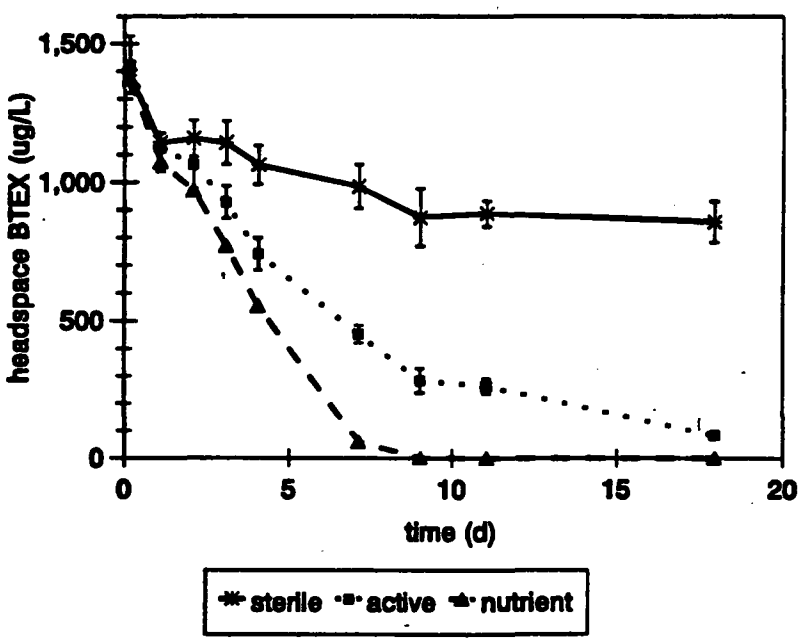
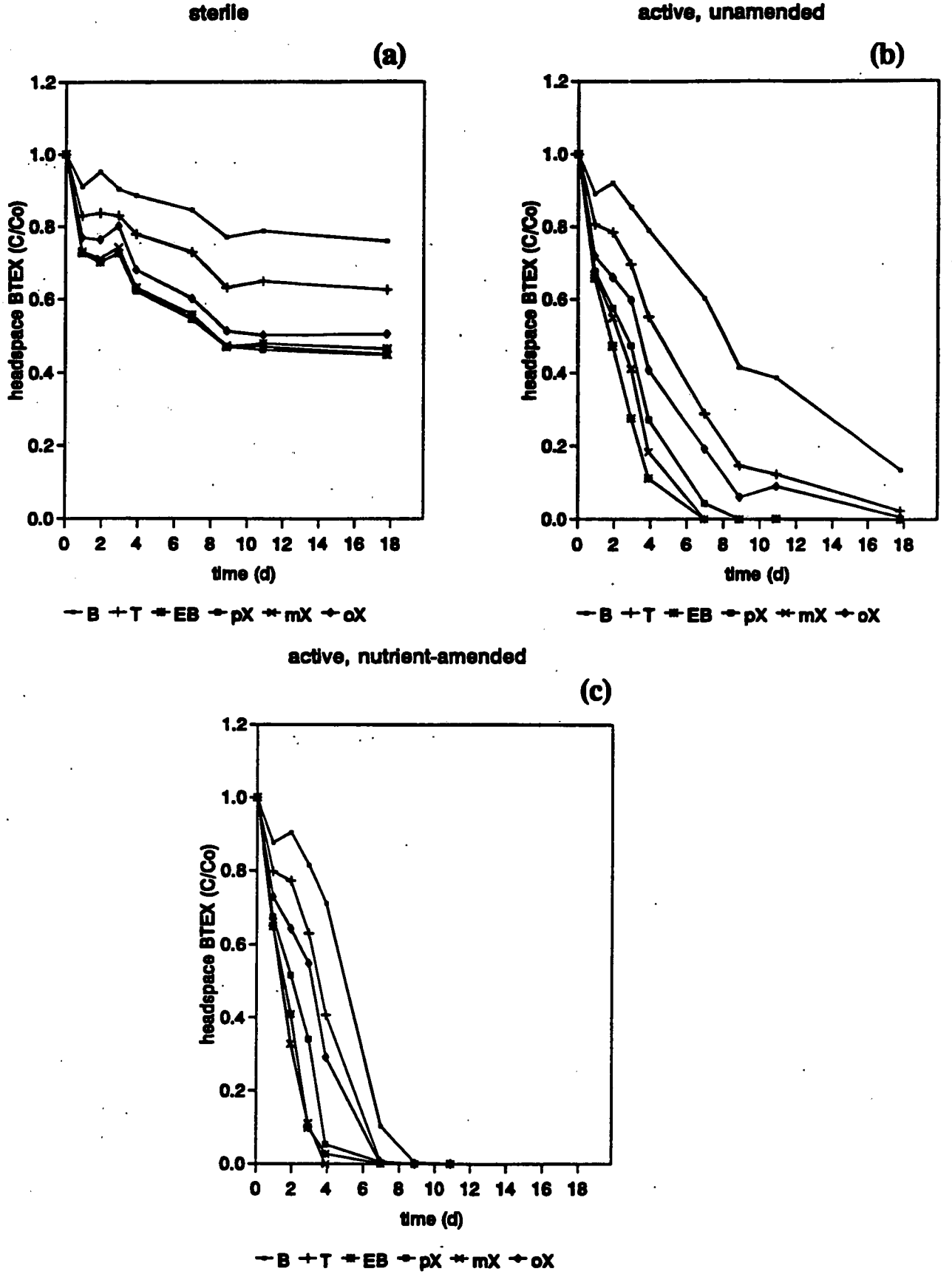


Figure 9


sterile
(a)
active, unamended
(b)
headspace BTEX (C/Co)
time (d)
B T EB pX mX oX
active, nutrient-amended
(c)

6.3 Microbial enumeration

The results of microbial enumerations of Wisconsin groundwater and soils are shown in part (a) of Table 10. To provide some comparison, heterotrophic plate count data (or an equivalent MPN procedure in one instance) for other source materials - pristine and contaminated - are given in part (b) of Table 10. Clearly, microbial numbers in the Wisconsin site groundwater are highly elevated, compared with clean water systems. This would be expected in the event of an influx of usable organic nutrients into the subsurface, and suggests that (part of) the indigenous subsurface microbial population was stimulated, not inhibited, by contaminant influx. Similarly, the number of microorganisms recovered from the soils on R2A medium suggest a large, active microbial community, not conditions of microbial inhibition. The MPN data support this hypothesis. Microorganisms capable of growth on all three test substrates, but particularly the PAHs, were readily detected in contaminated and clean site materials but enriched in the former materials. Degrading populations in the groundwater are particularly important with respect to a funnel-and-gate technology, as these will serve to inoculate the gate matrix after installation.

7.0 Interpretation of Results with Respect to Funnel-and-Gate Technology

The biotreatability study indicated that the site materials are microbiologically active, and biotransformation of some target contaminants proceeds quite rapidly under aerobic conditions.

Inorganic nutrient addition enhanced biotransformation activity, generally shortening the time required to reach nondetectable levels of degrading contaminant in the aqueous phase. This was particularly evident in contaminated soil-containing microcosms, especially so in the experiment where BTEX degradation was monitored (Fig. 8). More potentially metabolizable carbon was likely present in the contaminated soil microcosms than in the clean soil microcosms, hence a greater demand for inorganic N and P existed in the contaminated soil microcosms. In the BTEX-amended microcosms, where N and P addition was most notably required, this condition was exacerbated because a significant metabolizable BTEX mass was added to the organic contaminant load already present in the soil.

The finding of an inorganic nutrient requirement for optimal contaminant degradation cannot be transferred directly to requirements in a gate installation, because only contaminated

Table 10 Microbial enumerations

(a) Wisconsin site materials

sample	R2A plate count CFU/mL or g dwt mean (std dev)	most-probable-number of degraders/mL or g dwt naph-degraders	phen-degraders	dibenz-degraders
groundwater	4.6×10^6 (2.1×10^5)	3.2×10^5	57	32
clean soil	9.0×10^7 (1.4×10^7)	5.2×10^5	$>2.7 \times 10^6$	170
contaminated soil	1.6×10^8 (5.8×10^6)	$>3.4 \times 10^6$	$>3.4 \times 10^6$	1.3×10^4

(b) Some comparative plate count (or MPN) data:

(i) waters

4.3×10^3 CFU/mL (mean R2A count, 10 water distribution system samples) (Reasoner and Geldreich, 1985)

~ 10^3 CFU/mL (CFB Borden aquifer, a shallow sandy aquifer near Alliston, Ontario) (Crocker, 1992)

~ 10^3-10^4/mL (7 wells, in sandy sediment underlying Segeberg Forest, Germany) (Hirsch and Rades-Rohkohl, 1988)

~ 10^3-10^5 MPN aerobes/mL (uncontaminated wells near creosote-contaminated aquifer) (Ehrlich et al., 1983)

~ 10^3-10^6 MPN aerobes/mL (well waters from a creosote-contaminated aquifer) (Ehrlich et al., 1983)

(ii) soils

undetectable - 10^4 CFU/g (CFB Borden aquifer, a shallow sandy aquifer) (Barbaro et al., 1994)

~ 10^5-10^8 CFU/g (typical range for surface soil plate counts) (Alexander, 1977)

~ 10^4-10^5 CFU/g (uncontaminated subsurface, creosoting plant disposal pit, Conroe, Tx) (Lee et al., 1984)

~ 10^3-10^6 CFU/g (contaminated subsurface, creosoting plant disposal pit, Conroe, Tx) (Lee et al., 1984)

groundwater will enter the gate, whereas the microcosms were soil + groundwater water ecosystems. This question would have to be addressed by experimentation simulating gate conditions, if and when such an installation was designed. However, one speculates that inorganic nutrient addition to the gate environment may be desirable. The present study suggests a high degree of biological activity will be occurring within the contaminated area at the site, wherever there is any available oxygen. Indeed, anaerobic biological activity is also not precluded, as some of the compounds present (i.e., the heterocyclic compounds) may be anaerobically biotransformable. That being the case, it is plausible that groundwater flowing through source areas and downgradient to a gate installation may be depleted in inorganic nutrients. On the other hand, significant biotransformation was observed in this study in the absence of added inorganic nutrient. Circumstantial evidence of rapid contaminant depletion in a groundwater-only system was inadvertently obtained during the attempt to introduce contaminants into groundwater by amendment (Table 2).

One difficulty, with respect to a reliance on biotransformation for groundwater contaminant cleanup, is that certain compounds in the groundwater (pyrene, fluoranthene) appeared rather recalcitrant in contaminated soil microcosms. They were, however, depleted to levels below detection in active microcosms containing clean soil and spiked groundwater. Although contaminant compound sorption was clearly discernable over time in clean soil microcosms (Table 4), this alone cannot account for apparent pyrene and fluoranthene loss, because both compounds remained at detectable levels in the aqueous phase of the sterile, but not the active microcosms. The soil analyses for the nutrient-amended contaminated soil microcosms indicate that these compounds were lost from the soil phase during the course of the experiment. This, taken together with the aqueous phase data for these microcosms suggests the "recalcitrance" was only apparent. These 4-ringed compounds, which are quite hydrophobic, were slowly degrading in the active, contaminated soil microcosms, but aqueous phase concentrations remained relatively constant because degraded aqueous phase molecules were replaced by new molecules desorbing from the soil.

Compound degradation profiles obtained in this study indicate that a residence time on the order of 15-20 days within a gate would be required to effect maximal contaminant depletion in a groundwater having a makeup similar to the aqueous phase in the contaminated soil

microcosms if the gate environment resembled microcosm conditions. Complete loss of 2-ringed compounds was observed in the microcosm study, and would therefore be expected in a gate treatment. However, while biotransformation of all the 3-ring compounds detected did occur, residual levels of some remained at the end of the study. The residual concentrations remaining may exceed site cleanup targets. On the other hand, if biologically-limiting conditions in the microcosms towards the end of the experiment were the cause of the residuals, avoidance of this problem may be feasible in a treatment gate, which could lower or even eliminate the residuals. The literature indicates that maintenance of an available oxygen supply for gate microorganisms would be critical for adequate biotreatment.

A final non-biological point should be made with respect to the fines in the water, in case it may have practical relevance. The "hands-on" experience was that the fine, silty material in the groundwater took in excess of 6 h to settle suspension by gravity, hence the overnight settling period adopted prior to water sampling. Further, it was noted that the fines in the initial dilution bottles used in microbial enumeration tests (which were agitated at 400 rpm for 10 min) failed to settle even after standing overnight, suggesting behaviour like a colloidal suspension. This is mentioned as it may be of relevance with respect to the possibility of clogging in a treatment gate due to transport of fines into the gate.

8.0 Summary and Conclusions

We conclude that the subsurface environment at the Wisconsin site is not innately inhibitory to microbial life. Results of microbial enumerations simply reveal information about the presence of viable cells, not whether or not they are active. Still, very large numbers of cells were recovered from the site materials. Groundwater numbers in particular exceeded the norm at pristine sites, and naphthalene-, phenanthrene- and dibenzofuran-degrading populations were readily demonstrated. Furthermore, evidence of microbial transformation of site contaminants abounded in this study; hence it may be readily concluded that biodegradation of the contaminants will occur within the treatment gate using indigenous microorganisms. However, if plume water entering the gate was anoxic, this environmental condition would have to be altered. Introduction of inorganic N and P into a treatment gate would likely improve contaminant degradation, increasing reaction rate and/or decreasing residual levels of some

compounds. The optimal level of inorganic nutrient addition (as well as oxygen addition) would be best determined in a soil-free system which simulates anticipated gate conditions. Under conditions similar to those in the contaminated soil microcosms, a gate residence time on the order of 15-20 d may be sufficient to effect maximal contaminant depletion, although this question is complicated by the fact that movement of all the contaminants will be retarded relative to groundwater movement, but to different degrees. One can generalize that retardation effects should act in a positive sense. The compounds likely to be most mobile, generally, are the ones most readily degraded. The more recalcitrant ones will take longer to traverse the gate. Biodegradation of both benzene and naphthalene should be sufficient to meet the potential regulatory objectives of Weston (Table 1), as judged by study results. No comment may be made for the other compounds for which cleanup objectives were given, as they were not routinely detected in microcosm waters. Finally, an exhaustive search for biotransformation byproducts was beyond the scope of the treatability study as well as outside our area of expertise. Nevertheless, the GC/MS library scans conducted suggest that relatively few byproducts were produced, and those that were may be further biodegraded.

Acknowledgment. The excellent work of K.A. Hamilton is gratefully acknowledged.

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Appendix I Creosotic data

- note that if values <MDL were obtained they are recorded, but bracketed. A value of zero indicates no peak was integrated for that compound

Weston uncontaminated

spiked
groundwater

	naph	in+2-mn	1-mn	biphen	aceny	acenaph	dibenz	fluor	phen	anth	carb	fluoran	pyrene	B(a)anth
	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
gw1	0	0	605	0	0	53	1164	476	76	10	0	96	43	0
gw2	0	0	319	0	0	49	588	294	48	9	0	89	47	0

con stera

time	naph	in+2-mn	1-mn	biphen	aceny	acenaph	dibenz	fluor	phen	anth	carb	fluoran	pyrene	B(a)anth
(d)	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
1	0	0	233	0	0	39	221	147	17	7	0	19	12	0
4	0	0	109	0	0	26	117	133	18	0	(4)	8	14	0
7	0	0	90	0	0	18	95	141	8	0	(3)	9	9	0

con sterb

time	naph	in+2-mn	1-mn	biphen	aceny	acenaph	dibenz	fluor	phen	anth	carb	fluoran	pyrene	B(a)anth
(d)	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
1	0	0	217	0	0	35	208	198	22	8	(6)	17	12	0
4	0	0	97	0	0	26	97	152	18	0	(5)	11	16	0
7	0	0	76	0	0	19	78	130	11	0	0	12	10	0

con sterc

time	naph	in+2-mn	1-mn	biphen	aceny	acenaph	dibenz	fluor	phen	anth	carb	fluoran	pyrene	B(a)anth
(d)	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
1	0	0	240	0	0	38	255	185	23	6	(4)	22	13	0
4	0	0	107	0	0	23	105	139	12	0	(5)	7	11	0
7	0	0	106	0	0	22	105	144	13	0	0	9	8	0

con act1a

time	naph	in+2-mn	1-mn	biphen	aceny	acenaph	dibenz	fluor	phen	anth	carb	fluoran	pyrene	B(a)anth
(d)	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
1	0	0	66	0	0	17	143	142	0	0	(5)	15	10	0
4	0	0	0	0	0	0	0	0	48	0	0	33	27	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0

con act1b

time	naph	in+2-mn	1-mn	biphen	aceny	acenaph	dibenz	fluor	phen	anth	carb	fluoran	pyrene	B(a)anth
(d)	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L

1	0	0	49	0	0	16	140	119	0	(3)	(4)	18	13	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0

con act1c

time (d)	naph ug/L	in+2-mn ug/L	1-mn ug/L	biphen ug/L	aceny ug/L	acenaph ug/L	dibenz ug/L	fluor ug/L	phen ug/L	anth ug/L	carb ug/L	fluoran ug/L	pyrene ug/L	B(a)anth ug/L
1	0	0	55	0	0	18	141	125	0	(3)	(5)	18	13	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0

con nut1a

time (d)	naph ug/L	in+2-mn ug/L	1-mn ug/L	biphen ug/L	aceny ug/L	acenaph ug/L	dibenz ug/L	fluor ug/L	phen ug/L	anth ug/L	carb ug/L	fluoran ug/L	pyrene ug/L	B(a)anth ug/L
1	0	0	40	0	0	15	101	109	0	0	(4)	11	10	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0

con nut1b

time (d)	naph ug/L	in+2-mn ug/L	1-mn ug/L	biphen ug/L	aceny	acenaph ug/L	dibenz ug/L	fluor ug/L	phen ug/L	anth ug/L	carb ug/L	fluoran ug/L	pyrene ug/L	B(a)anth ug/L
1	0	0	46	0	0	17	105	108	0	0	(4)	16	11	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0

con nut1c

time (d)	naph ug/L	in+2-mn ug/L	1-mn ug/L	biphen ug/L	aceny	acenaph ug/L	dibenz ug/L	fluor ug/L	phen ug/L	anth ug/L	carb ug/L	fluoran ug/L	pyrene ug/L	B(a)anth ug/L
1	0	0	46	0	0	18	121	95	0	0	(5)	20	13	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Weston contaminated
all remaining bottles handshaken immed after d21 sampling, 1/week thereafter
re-add nutrients to nut bottles on d 40

groundwater

	naph ug/L	in+2-mn ug/L	1-mn ug/L	biphen ug/L	aceny ug/L	acenaph ug/L	dibenz ug/L	fluor ug/L	phen ug/L	anth ug/L	carb ug/L	fluoran ug/L	pyrene ug/L	B(a)anth ug/L
initial	0	0	0	0	0	83	35	80	41	15	0	41	34	0
d1gwa	0	0	0	0	0	13	36	63	22	10	0	39	36	0
d2gwb	0	0	0	0	0	13	28	43	(5)	17	0	43	38	0

con ster a

time (d)	naph ug/L	in+2-mn ug/L	1-mn ug/L	biphen ug/L	aceny ug/L	acenaph ug/L	dibenz ug/L	fluor ug/L	phen ug/L	anth ug/L	carb ug/L	fluoran ug/L	pyrene ug/L	B(a)anth ug/L
1	1247	210	147	60	0	320	186	190	174	24	53	24	18	0
4	1402	218	151	58	13	299	169	165	141	18	45	21	17	0
7	1281	207	150	56	0	309	191	180	156	22	53	28	34	0
14	1351	221	142	63	0	306	173	168	154	27	76	23	19	0
21	1342	196	140	57	11	287	165	165	141	19	57	20	17	0
35	735	114	72	33	0	189	109	114	114	24	67	18	14	0
49	541	132	91	40	0	216	129	141	133	26	68	23	17	0

con ster b

time (d)	naph ug/L	in+2-mn ug/L	1-mn ug/L	biphen ug/L	aceny ug/L	acenaph ug/L	dibenz ug/L	fluor ug/L	phen ug/L	anth ug/L	carb ug/L	fluoran ug/L	pyrene ug/L	B(a)anth ug/L	chrys
1	794	170	124	50	0	310	183	196	179	22	51	30	20	0	
4	184	70	61	23	8	181	112	119	129	18	41	21	18	0	
7	96	51	53	19	0	159	113	121	136	19	41	26	34	0	
14	386	106	80	35	0	220	130	140	157	24	62	79	71	16	1
21	557	122	89	38	9	219	131	140	126	19	49	19	14	0	
35	1370	174	106	44	0	240	134	134	125	23	59	19	16	0	
49	1131	196	122	53	0	259	146	156	126	17	54	20	15	0	

con ster c

time (d)	naph ug/L	in+2-mn ug/L	1-mn ug/L	biphen ug/L	aceny ug/L	acenaph ug/L	dibenz ug/L	fluor ug/L	phen ug/L	anth ug/L	carb ug/L	fluoran ug/L	pyrene ug/L	B(a)anth ug/L
1	1164	217	155	64	0	343	190	207	192	26	55	25	20	0
4	525	141	109	42	11	259	155	153	141	20	50	19	15	0
7	411	111	89	37	0	238	155	152	147	22	42	26	33	0
14	390	112	81	39	0	220	126	136	137	24	53	24	17	0
21	747	156	114	50	11	259	155	159	138	21	53	21	16	0
35	1442	182	113	48	0	247	132	142	126	24	70	18	14	0
49	1161	189	112	53	0	256	146	153	125	17	59	18	19	0

con act a

time (d)	naph ug/L	in+2-mn ug/L	1-mn ug/L	biphen ug/L	aceny ug/L	acenaph ug/L	dibenz ug/L	fluor ug/L	phen ug/L	anth ug/L	carb ug/L	fluoran ug/L	pyrene ug/L	B(a)anth ug/L
1	467	226	206	40	0	459	259	280	237	26	79	35	27	0
4	0	0	49	0	8	220	114	178	102	15	(4)	35	27	0
7	0	0	28	0	0	113	80	138	59	13	(11)	37	53	0
14	0	0	0	0	0	12	(9)	59	44	0	(8)	15	13	0
21	0	0	0	0	0	90	42	83	68	0	0	20	16	0
35	0	0	0	0	0	74	33	42	32	0	0	13	14	0
49	0	23	53	0	0	170	90	113	100	0	(10)	27	24	0

con act b

time (d)	naph ug/L	in+2-mn ug/L	1-mn ug/L	biphen ug/L	aceny ug/L	acenaph ug/L	dibenz ug/L	fluor ug/L	phen ug/L	anth ug/L	carb ug/L	fluoran ug/L	pyrene ug/L	B(a)anth ug/L
1	155	145	164	27	0	398	226	254	216	22	53	35	27	0
4	0	0	51	0	11	224	113	180	110	11	0	36	26	0
7	0	0	26	0	0	131	78	157	57	13	0	40	52	0
14	0	0	0	0	0	16	13	79	60	0	(11)	25	21	0
21	0	0	0	0	0	71	37	66	32	0	0	21	15	0
35	0	0	0	0	0	111	49	73	59	0	0	20	16	0
49	0	21	43	0	0	151	79	102	87	0	(5)	27	23	0

con act c

time (d)	naph ug/L	in+2-mn ug/L	1-mn ug/L	biphen ug/L	aceny ug/L	acenaph ug/L	dibenz ug/L	fluor ug/L	phen ug/L	anth ug/L	carb ug/L	fluoran ug/L	pyrene ug/L	B(a)anth ug/L
1	44	121	183	35	0	449	230	283	244	28	71	40	29	0
4	0	0	54	0	11	258	137	208	136	13	0	36	28	0
7	0	0	26	0	0	90	62	130	41	13	(12)	40	56	0
14	0	0	0	0	8	74	58	103	80	0	(13)	30	22	0
21	0	0	0	0	0	73	37	66	40	0	0	20	14	0
35	33	35	38	0	0	136	61	81	75	0	0	23	19	0
49	0	45	58	0	0	156	75	94	85	0	(6)	24	22	0

con nut a

time (d)	naph ug/L	in+2-mn ug/L	1-mn ug/L	biphen ug/L	aceny ug/L	acenaph ug/L	dibenz ug/L	fluor ug/L	phen ug/L	anth ug/L	carb ug/L	fluoran ug/L	pyrene ug/L	B(a)anth ug/L
1	166	155	169	27	0	415	235	275	223	24	(24)	36	28	0
4	0	0	29	0	(5)	221	62	97	0	8	0	33	26	0
7	0	(8)	0	0	0	54	32	52	0	12	0	28	49	0
14	0	0	0	0	6	57	48	82	36	0	0	20	16	0
21	0	0	0	0	0	77	43	70	45	0	0	17	14	0
35	0	0	0	0	0	121	50	69	59	0	(9)	17	15	0
49	0	0	0	0	0	79	(5)	0	(3)	(3)	(5)	(4)	0	0

con nut b

time (d)	naph ug/L	in+2-mn ug/L	1-mn ug/L	biphen ug/L	aceny- ug/L	acenaph ug/L	dibenz ug/L	fluor ug/L	phen ug/L	anth ug/L	carb ug/L	fluoran ug/L	pyrene ug/L	B(a)anth ug/L
1	16	75	150	21	0	403	229	263	222	25	29	38	28	0
4	0	0	(4)	0	(1)	23	(7)	(12)	(1)	(1)	0	(3)	(3)	0
7	0	(5)	0	0	0	71	35	49	0	11	0	28	49	0
14	0	0	0	0	6	44	45	82	47	0	0	21	17	0
21	0	0	0	0	0	86	47	76	57	0	0	24	17	0
35	0	0	0	0	0	80	36	49	0	0	0	9	8	0
49	0	0	0	0	0	79	(6)	0	5	6	(8)	(4)	0	0

con nut c

time (d)	naph ug/L	in+2-mn ug/L	1-mn ug/L	biphen ug/L	aceny ug/L	acenaph ug/L	dibenz ug/L	fluor ug/L	phen ug/L	anth ug/L	carb ug/L	fluoran ug/L	pyrene ug/L	B(a)anth ug/L
1	246	207	203	38	0	451	259	291	238	27	82	37	29	0
4	0	0	46	0	0	247	87	142	26	12	0	36	28	0
7	0	(6)	0	0	0	144	68	107	0	18	0	33	53	0
14	0	0	0	0	8	56	55	89	50	0	0	25	19	0
21	0	0	0	0	0	74	41	71	47	0	0	18	14	0
35	0	0	0	0	0	79	22	38	0	0	(5)	14	11	0
49	0	0	0	0	0	101	0	0	12	0	(7)	(4)	0	0

lab H20 blank

time (d)	naph ug/L	in+2-mn ug/L	1-mn ug/L	biphenylacen-y ug/L	ug/L	acenaph ug/L	dibenzo ug/L	fluor ug/L	phen ug/L	anth ug/L	carbaz ug/L	fluoran ug/L	pyrene ug/L	B(a)anth ug/L
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0
49	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Weston soils

contaminated microcosms

sterile controls

ster a

time (d)	naph ug/gdwt	in+2-mn ug/g	1-mn ug/g	biphen ug/g	aceny ug/g	acenaph ug/g	dibenz ug/g	fluor ug/g	phen ug/g	anth ug/g	carb ug/g	fluoran ug/g	pyrene ug/g
1	36	14	8	6	1	34	30	36	89	19	9	49	41
21	17	5	5	0	0	16	12	15	38	9	0	22	19
49	12	5	3	3	0	20	17	23	64	14	7	43	36

ster b

time (d)	naph ug/gdwt	in+2-mn ug/g	1-mn ug/g	biphen ug/g	aceny ug/g	acenaph ug/g	dibenz ug/g	fluor ug/g	phen ug/g	anth ug/g	carb ug/g	fluoran ug/g	pyrene ug/g
1	14	4	5	0	0	16	10	16	39	10	0	22	19
21	0	0	2	0	0	6	3	5	14	4	0	9	8
49	20	7	4	3	1	18	15	19	54	11	6	30	24

ster c

time (d)	naph ug/gdwt	in+2-mn ug/g	1-mn ug/g	biphen ug/g	aceny ug/g	acenaph ug/g	dibenz ug/g	fluor ug/g	phen ug/g	anth ug/g	carb ug/g	fluoran ug/g	pyrene ug/g
1	24	8	8	3	0	26	18	26	63	15	1	35	23
21	12	4	5	0	0	16	11	15	43	10	0	24	15
49	24	8	5	3	1	18	15	18	50	10	5	26	21

act a

time (d)	naph ug/gdwt	in+2-mn ug/g	1-mn ug/g	biphen ug/g	aceny ug/g	acenaph ug/g	dibenz ug/g	fluor ug/g	phen ug/g	anth ug/g	carb ug/g	fluoran ug/g	pyrene ug/g
1	15	5	3	2	0	13	10	13	34	5	2	18	16
21	8	3	4	0	0	14	9	14	37	10	0	23	16
49	3	2	2	1	0	10	8	10	29	7	0	19	16

act b

time (d)	naph ug/gdwt	in+2-mn ug/g	1-mn ug/g	biphen ug/g	aceny ug/g	acenaph ug/g	dibenz ug/g	fluor ug/g	phen ug/g	anth ug/g	carb ug/g	fluoran ug/g	pyrene ug/g
1	6	2	2	1	0	6	5	6	19	3	1	10	9
21	15	5	7	0	0	24	14	25	59	20	1	44	29
49	5	3	2	2	0	12	10	12	34	9	3	24	20

act c

time (d)	naph ug/gdwt	in+2-mn ug/g	1-mn ug/g	biphen ug/g	aceny ug/g	acenaph ug/g	dibenz ug/g	fluor ug/g	phen ug/g	anth ug/g	carb ug/g	fluoran ug/g	pyrene ug/g
1	24	8	5	3	0	19	17	20	51	10	4	27	23
21	6	1	3	0	0	11	5	10	27	8	0	18	16
49	4	3	2	2	0	11	9	11	34	9	3	23	19

nut a

time (d)	naph ug/gdwt	in+2-mn ug/g	1-mn ug/g	biphen ug/g	aceny ug/g	acenaph ug/g	dibenz ug/g	fluor ug/g	phen ug/g	anth ug/g	carb ug/g	fluoran ug/g	pyrene ug/g
1	23	8	5	3	0	18	16	20	50	11	6	28	24
21	7	3	4	0	0	12	8	12	33	6	0	21	14
49	1	1	1	1	0	6	5	6	21	5	2	16	14

nut b

time (d)	naph ug/gdwt	in+2-mn ug/g	1-mn ug/g	biphen ug/g	aceny ug/g	acenaph ug/g	dibenz ug/g	fluor ug/g	phen ug/g	anth ug/g	carb ug/g	fluoran ug/g	pyrene ug/g
1	23	7	5	3	0	17	15	18	45	10	4	24	20
21	8	3	4	0	0	12	8	12	34	10	0	20	18
49	2	2	1	1	0	8	7	9	28	8	2	19	16

nut c

time (d)	naph ug/gdwt	in+2-mn ug/g	1-mn ug/g	biphen ug/g	aceny ug/g	acenaph ug/g	dibenz ug/g	fluor ug/g	phen ug/g	anth ug/g	carb ug/g	fluoran ug/g	pyrene ug/g
1	27	10	5	4	0	24	20	25	64	14	6	35	30
21	8	3	4	0	0	14	9	13	38	11	0	23	15
49	2	2	1	1	0	7	6	8	25	7	2	18	15

Weston soils

contaminated microcosms

sterile controls

ster a

time (d)	B(a)anthchry ug/g		B(b)flu ug/g	B(k)flu ug/g	B(a)pyr ug/g	in+dib ug/g	benzo ug/g
1	9	14	3	3	4	1	1
21	4	6	4	0	1	0	0
49	9	11	9	3	6	2	1

ster b

time (d)	B(a)anthchry ug/g		B(b)flu ug/g	B(k)flu ug/g	B(a)pyr ug/g	in+dib ug/g	benzo ug/g
1	3	6	0	3	1	0	0
21	1	4	1	0	0	0	0
49	2	2	6	2	4	1	1

ster c

time (d)	B(a)anthchry ug/g		B(b)flu ug/g	B(k)flu ug/g	B(a)pyr ug/g	in+dib ug/g	benzo ug/g
1	6	10	6	0	3	0	0
21	4	6	0	4	2	0	0
49	6	9	5	2	4	1	1

act a

time (d)	B(a)anthchry ug/g		B(b)flu ug/g	B(k)flu ug/g	B(a)pyr ug/g	in+dib ug/g	benzo ug/g
1	3	5	3	0	2	1	0
21	4	8	0	5	2	0	0
49	4	6	2	2	2	1	0

act b

time (d)	B(a)anthchry ug/g		B(b)flu ug/g	B(k)flu ug/g	B(a)pyr ug/g	in+dib ug/g	benzo ug/g
1	2	3	2	0	1	1	0
21	8	16	0	10	5	0	0
49	6	9	7	3	4	3	2

act c

time (d)	B(a)anthchry ug/g		B(b)flu ug/g	B(k)flu ug/g	B(a)pyr ug/g	in+dib ug/g	benzo ug/g
1	5	7	5	0	3	1	1
21	3	7	0	4	2	0	0
49	7	12	3	4	5	5	3

nut a

time (d)	B(a)anthchry ug/g		B(b)flu ug/g	B(k)flu ug/g	B(a)pyr ug/g	in+dib ug/g	benzo ug/g
1	5	7	4	0	2	1	1
21	4	7	0	4	2	0	0
49	5	7	3	3	4	3	1

nut b

time (d)	B(a)anthchry ug/g		B(b)flu ug/g	B(k)flu ug/g	B(a)pyr ug/g	in+dib ug/g	benzo ug/g
1	4	8	4	0	2	1	1
21	3	8	0	4	2	0	0
49	4	7	5	2	3	1	1

nut c

time (d)	B(a)anthchry ug/g		B(b)flu ug/g	B(k)flu ug/g	B(a)pyr ug/g	in+dib ug/g	benzo ug/g
1	6	10	3	3	3	1	1
21	4	8	0	4	2	0	0
49	5	9	3	3	3	1	1

clean soil microcosms

sterile controls

ster a

time (d)	naph ug/gdwt	in+2-mn ug/g	1-mn ug/g	biphen ug/g	aceny ug/g	acenaph ug/g	dibenz ug/g	fluor ug/g	phen ug/g	anth ug/g	carb ug/g	fluoran ug/g	pyrene ug/g
1	2	0	0	0	0	1	0	0	0	1	0	5	6
7	0	0	1	0	0	0	1	1	1	1	0	5	4

ster b

time (d)	naph ug/gdwt	in+2-mn ug/g	1-mn ug/g	biphen ug/g	aceny ug/g	acenaph ug/g	dibenz ug/g	fluor ug/g	phen ug/g	anth ug/g	carb ug/g	fluoran ug/g	pyrene ug/g
1	1	0	0	0	0	1	0	0	0	1	0	4	4
7	0	0	0	0	0	1	1	1	3	1	0	5	6

ster c

time (d)	naph ug/gdwt	in+2-mn ug/g	1-mn ug/g	biphen ug/g	aceny ug/g	acenaph ug/g	dibenz ug/g	fluor ug/g	phen ug/g	anth ug/g	carb ug/g	fluoran ug/g	pyrene ug/g
1	1	0	0	0	0	1	0	0	0	1	0	3	4
7	3	0	0	0	0	3	5	3	12	5	0	11	8

act a

time (d)	naph ug/gdwt	in+2-mn ug/g	1-mn ug/g	biphen ug/g	aceny ug/g	acenaph ug/g	dibenz ug/g	fluor ug/g	phen ug/g	anth ug/g	carb ug/g	fluoran ug/g	pyrene ug/g
1	2	0	0	0	0	1	0	0	3	3	1	24	23
7	1	1	0	0	1	2	1	1	4	3	1	11	13

act b

time (d)	naph ug/gdwt	in+2-mn ug/g	1-mn ug/g	biphen ug/g	aceny ug/g	acenaph ug/g	dibenz ug/g	fluor ug/g	phen ug/g	anth ug/g	carb ug/g	fluoran ug/g	pyrene ug/g
1	1	0	0	0	0	1	0	0	4	4	2	18	16
7	1	0	0	0	0	1	0	0	3	2	0	11	11

act c

time (d)	naph ug/gdwt	in+2-mn ug/g	1-mn ug/g	biphen ug/g	aceny ug/g	acenaph ug/g	dibenz ug/g	fluor ug/g	phen ug/g	anth ug/g	carb ug/g	fluoran ug/g	pyrene ug/g
1	1	0	0	0	0	1	0	0	3	2	0	11	14
7	1	1	0	0	1	1	1	1	6	4	3	15	18

nut a

time (d)	naph ug/gdwt	in+2-mn ug/g	1-mn ug/g	biphen ug/g	aceny ug/g	acenaph ug/g	dibenz ug/g	fluor ug/g	phen ug/g	anth ug/g	carb ug/g	fluoran ug/g	pyrene ug/g
1	1	0	0	0	1	1	0	0	4	3	1	17	15
7	0	0	0	0	1	0	0	0	3	3	9	10	12

nut b

time (d)	naph ug/gdwt	in+2-mn ug/g	1-mn ug/g	biphen ug/g	aceny ug/g	acenaph ug/g	dibenz ug/g	fluor ug/g	phen ug/g	anth ug/g	carb ug/g	fluoran ug/g	pyrene ug/g
1	1	0	0	0	0	1	0	0	4	2	0	12	11
7	0	0	0	0	1	1	1	1	5	5	4	16	18

nut c

time (d)	naph ug/gdwt	in+2-mn ug/g	1-mn ug/g	biphen ug/g	aceny ug/g	acenaph ug/g	dibenz ug/g	fluor ug/g	phen ug/g	anth ug/g	carb ug/g	fluoran ug/g	pyrene ug/g
1	1	0	0	0	0	1	0	0	2	2	0	11	13
7	0	0	0	0	1	1	0	0	2	2	1	6	8

clean soil microcosms

sterile controls

ster a

time (d)	B(a)anthchry ug/g	ug/g	B(b)flu ug/g	B(k)flu ug/g	B(a)pyr ug/g	in+dib ug/g	benzo ug/g	
1	2	4	7	0	3	1	1	
7	3	4	7	3	4	3	2	

ster b

time (d)	B(a)anthchry ug/g	ug/g	B(b)flu ug/g	B(k)flu ug/g	B(a)pyr ug/g	in+dib ug/g	benzo ug/g	
1	1	4	8	0	4	1	1	
7	3	4	7	3	4	3	3	

ster c

time (d)	B(a)anthchry ug/g	ug/g	B(b)flu ug/g	B(k)flu ug/g	B(a)pyr ug/g	in+dib ug/g	benzo ug/g	
1	1	2	4	0	2	1	1	
7	2	3	4	2	1	0	0	

act a

time (d)	B(a)anthchry ug/g	ug/g	B(b)flu ug/g	B(k)flu ug/g	B(a)pyr ug/g	in+dib ug/g	benzo ug/g	
1	8	11	17	0	9	6	5	
7	7	9	8	7	9	6	4	

act b

time (d)	B(a)anthchry ug/g	ug/g	B(b)flu ug/g	B(k)flu ug/g	B(a)pyr ug/g	in+dib ug/g	benzo ug/g	
1	9	16	19	0	12	2	3	
7	5	10	15	0	7	2	2	

act c

time (d)	B(a)anthchry ug/g	ug/g	B(b)flu ug/g	B(k)flu ug/g	B(a)pyr ug/g	in+dib ug/g	benzo ug/g	
1	6	11	14	0	9	3	2	
7	9	11	18	7	13	13	7	

nut a

time (d)	B(a)anthchry ug/g	ug/g	B(b)flu ug/g	B(k)flu ug/g	B(a)pyr ug/g	in+dib ug/g	benzo ug/g	
1	8	14	20	0	12	8	9	
7	6	8	13	6	8	8	4	

nut b

time	B(a)anthchry		B(b)flu	B(k)flu	B(a)pyr	in+dib	benzo
(d)	ug/g	ug/g	ug/g	ug/g	ug/g	ug/g	ug/g
1	3	5	8	0	4	2	0
7	9	12	22	0	11	0	0

nut c

time	B(a)anthchry		B(b)flu	B(k)flu	B(a)pyr	in+dib	benzo
(d)	ug/g	ug/g	ug/g	ug/g	ug/g	ug/g	ug/g
1	5	10	15	0	8	5	4
7	4	5	9	2	5	4	2

Checks - creosotic compound analysis

all ug/L

lab number 950616
June 22, prelim analysis

compound	chk conc	low chk 1	low chk 2	% theor 1	% theor 2
m-xylene	42	39	42	92.9	100.0
phenol	74	49	64	66.2	86.5
o-cresol	77	0	69	0.0	89.6
p+m-cresol	58	84	39	144.8	67.2
2,6-dmp	54	63	91	116.7	168.5
2,4+2,5-dmp	63	44	47	69.8	74.6
2,3-dmp	45	0	0	0.0	0.0
3,5-dmp	46	0	23	0.0	50.0
naphthalene	37	61	48	164.9	129.7
indole+2-mn	66	36	36	54.5	54.5
1-mnaphthalene	40	55	53	137.5	132.5
biphenyl	41	36	32	87.8	78.0
acenaphthylene	37	37	38	100.0	102.7
acenaphthene	37	37	36	100.0	97.3
dibenzofuran	44	36	42	81.8	95.5
fluorene	37	38	34	102.7	91.9
phenanthrene	37	32	34	86.5	91.9
anthracene	37	43	44	116.2	118.9
carbazole	81	62	75	76.5	92.6
fluoranthene	37	36	38	97.3	102.7
pyrene	37	36	41	97.3	110.8
b(a)anthracene	37	25	31	67.6	83.8
chrysene	37	39	42	105.4	113.5
b(b)fluoranthene	37	26	32	70.3	86.5
b(k)fluoranthene	37	43	44	116.2	118.9
b(a)pyrene	37	24	29	64.9	78.4
indeno+dibenzo	74	47	65	63.5	87.8

lab number 950704
July 7 samples, contam d 1

compound	chk conc	low chk 1	low chk 2	low chk 3	% theor 1	% theor 2	% theor 3
m-xylene	83	70	74	67	84.3	89.2	80.7
phenol	147	46	31	113	31.3	21.1	76.9
o-cresol	154	166	162	161	107.8	105.2	104.5
p+m-cresol	115	83	87	83	72.2	75.7	72.2
2,6-dmp	109	117	111	108	107.3	101.8	99.1
2,4+2,5-dmp	126	128	126	126	101.6	100.0	100.0
2,3-dmp	90	28	35	32	31.1	38.9	35.6
3,5-dmp	93	75	77	77	80.6	82.8	82.8
naphthalene	74	97	90	88	131.1	121.6	118.9
indole+2-mn	131	79	78	76	60.3	59.5	58.0
1-mnaphthalene	80	101	96	96	126.3	120.0	120.0
biphenyl	82	85	87	87	103.7	106.1	106.1

acenaphthylene	74	82	78	79	110.8	105.4	106.8
acenaphthene	74	80	79	79	108.1	106.8	106.8
dibenzofuran	88	100	96	95	113.6	109.1	108.0
fluorene	74	83	84	83	112.2	113.5	112.2
phenanthrene	74	72	72	74	97.3	97.3	100.0
anthracene	74	89	87	91	120.3	117.6	123.0
carbazole	163	153	154	157	93.9	94.5	96.3
fluoranthene	74	76	77	79	102.7	104.1	106.8
pyrene	74	81	85	82	109.5	114.9	110.8
b(a)anthracene	74	68	70	72	91.9	94.6	97.3
chrysene	74	90	90	94	121.6	121.6	127.0
b(b)fluoranthene	74	68	68	70	91.9	91.9	94.6
b(k)fluoranthene	74	88	86	84	118.9	116.2	113.5
b(a)pyrene	74	81	84	86	109.5	113.5	116.2
indeno+dibenzo	147	140	148	140	95.2	100.7	95.2

lab number 950708
July 10 samples, contam d 4; uncontam d 1

compound	chk conc	low chk 1	low chk 2	low chk 3	% theor 1	% theor 2	% theor 3
m-xylene	83	85	79	66	102.4	95.2	79.5
phenol	147	128	135	82	87.1	91.8	55.8
o-cresol	154	153	156	154	99.4	101.3	100.0
p+m-cresol	115	92	88	86	80.0	76.5	74.8
2,6-dmp	109	108	107	105	99.1	98.2	96.3
2,4+2,5-dmp	126	133	134	131	105.6	106.3	104.0
2,3-dmp	90	48	45	44	53.3	50.0	48.9
3,5-dmp	93	77	79	78	82.8	84.9	83.9
naphthalene	74	90	91	88	121.6	123.0	118.9
indole+2-mn	131	117	116	107	89.3	88.5	81.7
1-mnaphthalene	80	101	101	98	126.3	126.3	122.5
biphenyl	82	84	85	85	102.4	103.7	103.7
acenaphthylene	74	68	68	68	91.9	91.9	91.9
acenaphthene	74	84	83	83	113.5	112.2	112.2
dibenzofuran	88	99	94	93	112.5	106.8	105.7
fluorene	74	78	77	77	105.4	104.1	104.1
phenanthrene	74	74	73	73	100.0	98.6	98.6
anthracene	74	69	84	73	93.2	113.5	98.6
carbazole	163	153	152	152	93.9	93.3	93.3
fluoranthene	74	80	81	78	108.1	109.5	105.4
pyrene	74	78	80	80	105.4	108.1	108.1
b(a)anthracene	74	77	77	75	104.1	104.1	101.4
chrysene	74	78	74	73	105.4	100.0	98.6
b(b)fluoranthene	74	71	72	70	95.9	97.3	94.6
b(k)fluoranthene	74	82	82	79	110.8	110.8	106.8
b(a)pyrene	74	83	84	74	112.2	113.5	100.0
indeno+dibenzo	147	129	147	140	87.8	100.0	95.2
benzo	74	81	82	78	109.5	110.8	105.4

lab number 950713
July 13 samples, uncontam d 4

compound	chk conc	low chk 1	low chk 2	low chk 3	% theor 1	% theor 2	% theor 3
m-xylene	83	83	84	86	100.0	101.2	103.6
phenol	147	47	145	141	32.0	98.6	95.9
o-cresol	154	151	149	153	98.1	96.8	99.4
p+m-cresol	115	79	83	85	68.7	72.2	73.9
2,6-dmp	109	120	113	115	110.1	103.7	105.5
2,4+2,5-dmp	126	125	124	128	99.2	98.4	101.6
2,3-dmp	90	27	38	38	30.0	42.2	42.2
3,5-dmp	93	74	82	83	79.6	88.2	89.2
naphthalene	74	98	92	91	132.4	124.3	123.0
indole+2-mn	131	114	118	116	87.0	90.1	88.5
1-mnaphthalene	80	107	103	104	133.8	128.8	130.0
biphenyl	82	85	84	86	103.7	102.4	104.9
acenaphthylene	74	81	79	80	109.5	106.8	108.1
acenaphthene	74	82	82	83	110.8	110.8	112.2
dibenzofuran	88	108	98	97	122.7	111.4	110.2
fluorene	74	86	91	83	116.2	123.0	112.2
phenanthrene	74	81	88	82	109.5	118.9	110.8
anthracene	74	92	92	90	124.3	124.3	121.6
carbazole	163	149	151	154	91.4	92.6	94.5
fluoranthene	74	83	87	82	112.2	117.6	110.8
pyrene	74	83	89	87	112.2	120.3	117.6
b(a)anthracene	74	77	77	76	104.1	104.1	102.7
chrysene	74	81	81	74	109.5	109.5	100.0
b(b)fluoranthene	74	75	73	73	101.4	98.6	98.6
b(k)fluoranthene	74	89	82	82	120.3	110.8	110.8
b(a)pyrene	74	77	80	79	104.1	108.1	106.8
indeno+dibenzo	147	65	71	64	44.2	48.3	43.5
benzo	74	81	80	75	109.5	108.1	101.4

lab number 950715
July 14 samples, contam d 7 **

compound	chk conc	low chk 1	low chk 2	% theor 1	% theor 2
m-xylene	83	62	61	74.7	73.5
phenol	147	34	57	23.1	38.8
o-cresol	154	142	151	92.2	98.1
p+m-cresol	115	69	79	60.0	68.7
2,6-dmp	109	118	120	108.3	110.1
2,4+2,5-dmp	126	126	135	100.0	107.1
2,3-dmp	90	29	40	32.2	44.4
3,5-dmp	93	67	77	72.0	82.8
naphthalene	74	94	93	127.0	125.7
indole+2-mn	131	106	118	80.9	90.1
1-mnaphthalene	80	107	106	133.8	132.5
biphenyl	82	80	86	97.6	104.9
acenaphthylene	74	81	83	109.5	112.2
acenaphthene	74	81	86	109.5	116.2
dibenzofuran	88	110	96	125.0	109.1
fluorene	74	92	95	124.3	128.4
phenanthrene	74	77	81	104.1	109.5

anthracene	74	92	94	124.3	127.0
carbazole	163	146	162	89.6	99.4
fluoranthene	74	84	90	113.5	121.6
pyrene	74	150	165	202.7	223.0
b(a)anthracene	74	77	85	104.1	114.9
chrysene	74	78	78	105.4	105.4
b(b)fluoranthene	74	76	83	102.7	112.2
b(k)fluoranthene	74	90	89	121.6	120.3
b(a)pyrene	74	83	90	112.2	121.6
indeno+dibenzo	147	61	76	41.5	51.7
benzo	74	72	87	97.3	117.6

** extract samples in autosampler over weekend because of power failure

lab number 950716
July 13 samples, uncontam d 7 ***

compound	chk conc	low chk 1	low chk 2	% theor 1	% theor 2
m-xylene	83	64	62	77.1	74.7
phenol	147	135	115	91.8	78.2
o-cresol	154	141	253	91.6	164.3
p+m-cresol	115	88	165	76.5	143.5
2,6-dmp	109	112	189	102.8	173.4
2,4+2,5-dmp	126	116	183	92.1	145.2
2,3-dmp	90	26	32	28.9	35.6
3,5-dmp	93	63	98	67.7	105.4
naphthalene	74	91	133	123.0	179.7
indole+2-mn	131	99	121	75.6	92.4
1-mnaphthalene	80	97	125	121.3	156.3
biphenyl	82	87	84	106.1	102.4
acenaphthylene	74	75	84	101.4	113.5
acenaphthene	74	79	90	106.8	121.6
dibenzofuran	88	99	104	112.5	118.2
fluorene	74	78	84	105.4	113.5
phenanthrene	74	73	67	98.6	90.5
anthracene	74	90	86	121.6	116.2
carbazole	163	144	155	88.3	95.1
fluoranthene	74	75	72	101.4	97.3
pyrene	74	79	79	106.8	106.8
b(a)anthracene	74	73	59	98.6	79.7
chrysene	74	78	74	105.4	100.0
b(b)fluoranthene	74	72	58	97.3	78.4
b(k)fluoranthene	74	89	81	120.3	109.5
b(a)pyrene	74	82	66	110.8	89.2
indeno+dibenzo	147	130	115	88.4	78.2
benzo	74	67	59	90.5	79.7

*** delay in analysis because of sample-backup due to power failure; stored @ 4 C

lab number 950720

July 21 samples, contam d 14

compound	chk conc	low chk 1	low chk 2	low chk 3	% theor 1	% theor 2	% theor 3
m-xylene	83	80	79	69	96.4	95.2	83.1
phenol	147	178	183	0	121.1	124.5	0.0
o-cresol	154	144	144	28	93.5	93.5	18.2
p+m-cresol	115	77	56	188	67.0	48.7	163.5
2,6-dmp	109	123	109	25	112.8	100.0	22.9
2,4+2,5-dmp	126	113	116	130	89.7	92.1	103.2
2,3-dmp	90	21	0	180	23.3	0.0	200.0
3,5-dmp	93	53	76	54	57.0	81.7	58.1
naphthalene	74	94	98	100	127.0	132.4	135.1
indole+2-mn	131	105	103	98	80.2	78.6	74.8
1-mnaphthalene	80	93	93	94	116.3	116.3	117.5
biphenyl	82	86	84	87	104.9	102.4	106.1
acenaphthylene	74	77	78	73	104.1	105.4	98.6
acenaphthene	74	80	83	83	108.1	112.2	112.2
dibenzofuran	88	93	95	88	105.7	108.0	100.0
fluorene	74	76	84	81	102.7	113.5	109.5
phenanthrene	74	68	70	72	91.9	94.6	97.3
anthracene	74	83	86	89	112.2	116.2	120.3
carbazole	163	163	182	184	100.0	111.7	112.9
fluoranthene	74	81	79	84	109.5	106.8	113.5
pyrene	74	82	86	85	110.8	116.2	114.9
b(a)anthracene	74	67	69	69	90.5	93.2	93.2
chrysene	74	89	88	91	120.3	118.9	123.0
b(b)fluoranthene	74	63	66	68	85.1	89.2	91.9
b(k)fluoranthene	74	91	87	98	123.0	117.6	132.4
b(a)pyrene	74	79	81	82	106.8	109.5	110.8
indeno+dibenzo	147	54	137	81	36.7	93.2	55.1
benzo	74	77	81	80	104.1	109.5	108.1

lab number 950725

July 28 samples, contam d 21

compound	chk conc	low chk 1	low chk 2	% theor 1	% theor 2
m-xylene	83	71	82	85.5	98.8
phenol	147	152	153	103.4	104.1
o-cresol	154	149	151	96.8	98.1
p+m-cresol	115	89	87	77.4	75.7
2,6-dmp	109	108	106	99.1	97.2
2,4+2,5-dmp	126	136	139	107.9	110.3
2,3-dmp	90	48	48	53.3	53.3
3,5-dmp	93	71	77	76.3	82.8
naphthalene	74	93	94	125.7	127.0
indole+2-mn	131	114	119	87.0	90.8
1-mnaphthalene	80	99	100	123.8	125.0
biphenyl	82	89	89	108.5	108.5
acenaphthylene	74	79	79	106.8	106.8
acenaphthene	74	83	81	112.2	109.5
dibenzofuran	88	99	101	112.5	114.8
fluorene	74	90	89	121.6	120.3

phenanthrene	74	77	76	104.1	102.7
anthracene	74	85	84	114.9	113.5
carbazole	163	169	170	103.7	104.3
fluoranthene	74	79	78	106.8	105.4
pyrene	74	88	86	118.9	116.2
b(a)anthracene	74	75	75	101.4	101.4
chrysene	74	91	90	123.0	121.6
b(b)fluoranthene	74	69	69	93.2	93.2
b(k)fluoranthene	74	87	86	117.6	116.2
b(a)pyrene	74	85	78	114.9	105.4
indeno+dibenzo	147	169	147	115.0	100.0
benzo	74	84	119	113.5	160.8

lab number 950802
Aug 11 samples, contam d 35

compound	chk conc	low chk 1	low chk 2	low chk 3	% theor 1	% theor 2	% theor 3
m-xylene	83	67	64	65	80.7	77.1	78.3
phenol	147	n.r.	n.r.	n.r.	0.0	0.0	0.0
o-cresol	154	n.r.	n.r.	n.r.	0.0	0.0	0.0
p+m-cresol	115	n.r.	n.r.	n.r.	0.0	0.0	0.0
2,6-dmp	109	n.r.	n.r.	n.r.	0.0	0.0	0.0
2,4+2,5-dmp	126	n.r.	n.r.	n.r.	0.0	0.0	0.0
2,3-dmp	90	n.r.	n.r.	n.r.	0.0	0.0	0.0
3,5-dmp	93	n.r.	n.r.	n.r.	0.0	0.0	0.0
naphthalene	74	78	69	70	105.4	93.2	94.6
indole+2-mn	131	74	70	64	56.5	53.4	48.9
1-mnaphthalene	80	81	73	77	101.3	91.3	96.3
biphenyl	82	76	68	74	92.7	82.9	90.2
acenaphthylene	74	51	47	49	68.9	63.5	66.2
acenaphthene	74	69	66	67	93.2	89.2	90.5
dibenzofuran	88	84	80	82	95.5	90.9	93.2
fluorene	74	72	68	69	97.3	91.9	93.2
phenanthrene	74	62	60	61	83.8	81.1	82.4
anthracene	74	74	71	73	100.0	95.9	98.6
carbazole	163	162	166	157	99.4	101.8	96.3
fluoranthene	74	71	67	69	95.9	90.5	93.2
pyrene	74	73	73	73	98.6	98.6	98.6
b(a)anthracene	74	57	54	57	77.0	73.0	77.0
chrysene	74	81	75	78	109.5	101.4	105.4
b(b)fluoranthene	74	57	54	58	77.0	73.0	78.4
b(k)fluoranthene	74	87	84	83	117.6	113.5	112.2
b(a)pyrene	74	70	65	69	94.6	87.8	93.2
indeno+dibenzo	147	38	132	42	25.9	89.8	28.6
benzo	74	66	74	65	89.2	100.0	87.8

n.r.: results not recorded on lab data sheet

lab number 950823
Aug 25 samples, contam d 49

compound	chk conc	low chk 1	% theor 1
m-xylene	83	72	86.7
phenol	147	116	78.9
o-cresol	154	137	89.0
p+m-cresol	115	81	70.4
2,6-dmp	109	111	101.8
2,4+2,5-dmp	126	24	19.0
2,3-dmp	90	159	176.7
3,5-dmp	93	17	18.3
naphthalene	74	89	120.3
indole+2-mn	131	82	62.6
1-mnaphthalene	80	56	70.0
biphenyl	82	86	104.9
acenaphthylene	74	75	101.4
acenaphthene	74	89	120.3
dibenzofuran	88	102	115.9
fluorene	74	92	124.3
phenanthrene	74	69	93.2
anthracene	74	63	85.1
carbazole	163	159	97.5
fluoranthene	74	83	112.2
pyrene	74	94	127.0
b(a)anthracene	74	69	93.2
chrysene	74	100	135.1
b(b)fluoranthene	74	65	87.8
b(k)fluoranthene	74	104	140.5
b(a)pyrene	74	32	43.2
indeno+dibenzo	147	88	59.9
benzo	74	62	83.8

Soil samples - Aug 29-31

compound	chk conc	low chk 1	low chk 2	low chk 3	low chk 4	%theor 1	%theor 2	%theor 3	%theor 4
m-xylene	1038	825	885	825	954	79.5	85.3	79.5	91.9
naphthalene	921	975	840	833	937	105.9	91.2	90.4	101.7
indole+2-mn	1640	813	732	787	927	49.6	44.6	48.0	56.5
1-mnaphthalene	1000	1220	993	1197	1285	122.0	99.3	119.7	128.5
biphenyl	1020	779	787	810	927	76.4	77.2	79.4	90.9
acenaphthylene	921	992	822	889	931	107.7	89.3	96.5	101.1
acenaphthene	921	1104	972	1031	1069	119.9	105.5	111.9	116.1
dibenzofuran	1102	1300	1107	1218	1282	118.0	100.5	110.5	116.3
fluorene	921	1141	881	961	1047	123.9	95.7	104.3	113.7
phenanthrene	922	854	704	737	809	92.6	76.4	79.9	87.7
anthracene	922	1321	1047	1112	1132	143.3	113.6	120.6	122.8
carbazole	2034	1872	1801	1942	2083	92.0	88.5	95.5	102.4
fluoranthene	921	1077	865	923	966	116.9	93.9	100.2	104.9
pyrene	921	1126	928	981	1014	122.3	100.8	106.5	110.1

b(a)anthracene	921	708	731	728	8063	76.9	79.4	79.0	875.5
chrysene	921	1483	1188	1268	1272	161.0	129.0	137.7	138.1
b(b)fluoranthene	921	710	630	612	6570	77.1	68.4	66.4	713.4
b(k)fluoranthene	920	1401	1148	1187	1093	152.3	124.8	129.0	118.8
b(a)pyrene	921	989	713	741	722	107.4	77.4	80.5	78.4
indeno+dibenzo	1843	1849	1393	1129	1182	100.3	75.6	61.3	64.1
benzo	921	1197	905	757	766	130.0	98.3	82.2	83.2

Soil samples - 2nd listing

compound	chk conc	additional chk	%theor 1
m-xylene	1038	955	92.0
naphthalene	921	835	90.7
indole+2-mn	1640	903	55.1
1-mnaphthalene	1000	1097	109.7
biphenyl	1020	875	85.8
acenaphthylene	921	932	101.2
acenaphthene	921	1007	109.3
dibenzofuran	1102	1106	100.4
fluorene	921	980	106.4
phenanthrene	922	821	89.0
anthracene	922	1116	121.0
carbazole	2034	2122	104.3
fluoranthene	921	986	107.1
pyrene	921	1003	108.9
b(a)anthracene	921	1424	154.6
chrysene	921	1534	166.6
b(b)fluoranthene	921	736	79.9
b(k)fluoranthene	920	1509	164.0
b(a)pyrene	921	919	99.8
indeno+dibenzo	1843	1988	107.9
benzo	921	1143	124.1

Appendix II BTEX data

Weston BTEX

uncontaminated soil

uncon ster a

time (h)	time (d)	B ug/L	T ug/L	eB ug/L	pX ug/L	mX ug/L	oX ug/L	BTEX ug/L
4	0.166667	542.4865	323.9	168.1072	142.0239	135.1472	93.831	1405.496
26	1.083333	488.7875	266.9463	116.8953	97.8162	92.8389	70.5321	1133.816
50	2.083333	519.4619	263.5772	105.8964	89.227	86.2903	65.3677	1129.821
74	3.083333	500.0945	270.1265	111.3047	91.9039	89.9063	70.6307	1133.967
97.5	4.0625	505.6669	267.8034	104.8372	87.6426	85.0536	67.4801	1118.484
171	7.125	474.2771	241.3059	87.4971	72.4793	69.7629	54.568	999.8903
217	9.041667	445.7321	226.5269	81.2112	67.348	64.3518	47.6563	932.8263
265.5	11.0625	452.0004	222.055	75.8434	61.8427	59.7708	44.8595	916.3718

uncon ster b

time (h)	time (d)	B ug/L	T ug/L	eB ug/L	pX ug/L	mX ug/L	oX ug/L	BTEX ug/L
4	0.166667	584.9272	368.8965	198.8418	166.6212	162.7929	109.2448	1591.324
26	1.083333	486.4314	271.2	121.5152	103.0228	100.5573	72.1445	1154.871
50	2.083333	504.6247	266.5733	108.505	90.9152	88.8722	64.7394	1124.23
74	3.083333	493.0914	274.0616	115.3175	97.1625	94.5578	71.4057	1145.597
97.5	4.0625	493.5	267.2461	106.4771	90.3196	87.6432	65.1763	1110.362
171	7.125	467.7716	247.5773	94.116	77.6196	75.1552	57.4453	1019.685
217	9.041667	436.9707	220.7238	79.2183	65.0424	61.7917	47.3345	911.0814
265.5	11.0625	464.1452	235.1916	82.2815	67.0651	63.4728	51.3318	963.488

uncon ster c

time (h)	time (d)	B ug/L	T ug/L	eB ug/L	pX ug/L	mX ug/L	oX ug/L	BTEX ug/L
4	0.166667	559.7065	349.832	183.9248	156.3335	150.5204	105.3142	1505.631
26	1.083333	470.8151	261.0293	114.4706	96.5258	92.9529	68.4132	1104.207
50	2.083333	482.7788	255.1533	103.7356	87.1645	85.1858	62.9309	1076.949
74	3.083333	461.9332	254.8182	105.5087	88.49	85.799	65.3179	1061.867
97.5	4.0625	456.7618	233.5282	92.3594	76.6095	72.7432	57.0971	989.0992
171	7.125	427.9751	223.735	83.3717	69.2611	66.2008	50.9885	921.5322
217	9.041667	394.7409	194.8292	66.9842	52.6629	47.9162	40.5894	797.7228
265.5	11.0625	406.8784	204.1591	73.6687	59.5894	59.1009	41.241	844.6375

uncon act a

time (h)	time (d)	B ug/L	T ug/L	eB ug/L	pX ug/L	mX ug/L	oX ug/L	BTEX ug/L
4	0.166667	565.306	352.108	188.0364	159.8184	155.3901	108.0616	1528.721
26	1.083333	462.0398	255.3619	103.2494	92.3899	88.6052	66.3674	1068.014
50	2.083333	466.9443	240.506	67.9768	82.1863	71.0861	59.9692	988.6687
74	3.083333	415.0964	188.3231	13.6726	66.53	40.6611	57.5747	781.8579
97.5	4.0625	311.3004	94.8261	0	20.822	0	31.7777	458.7262
171	7.125	46.1612	1.2567	0	0	0	0	47.4179
217	9.041667	0.5474	0	0	0	0	0	0.5474
265.5	11.0625	0	0	0	0	0	0	0

uncon act b

time (h)	time (d)	B ug/L	T ug/L	eB ug/L	pX ug/L	mX ug/L	oX ug/L	BTEX ug/L
4	0.166667	514.9738	319.7284	167.192	143.2576	137.0892	95.6374	1377.878
26	1.083333	444.6816	246.8075	104.3925	94.3523	86.7124	65.7758	1042.722
50	2.083333	446.1714	225.3853	54.1198	76.831	62.4362	57.7932	922.7369
74	3.083333	375.2827	158.4862	10.7619	50.8268	28.2773	45.7319	669.3668
97.5	4.0625	252.3478	68.7881	0	12.1583	0	9.9676	343.2618
171	7.125	8.1295	0	0	0	0	0	8.1295
217	9.041667	0	0	0	0	0	0	0
265.5	11.0625	0	0	0	0	0	0	0

uncon act c

time (h)	time (d)	B ug/L	T ug/L	eB ug/L	pX ug/L	mX ug/L	oX ug/L	BTEX ug/L
4	0.166667	503.8185	298.8276	144.4003	124.359	120.6197	84.2389	1276.264
26	1.083333	448.2213	247.0305	101.1832	92.4791	85.1429	64.2525	1038.31
50	2.083333	449.4299	228.151	54.0503	78.8448	64.1476	57.2358	931.8594
74	3.083333	361.0935	153.4667	14.154	54.4933	34.1391	48.1641	665.5107
97.5	4.0625	212.0115	68.7519	0	16.3017	0	19.7108	316.7759
171	7.125	12.0255	0	0	0	0	0	12.0255
217	9.041667	0	0	0	0	0	0	0
265.5	11.0625	0	0	0	0	0	0	0

uncon N,P a

time (h)	time (d)	B ug/L	T ug/L	eB ug/L	pX ug/L	mX ug/L	oX ug/L	BTEX ug/L
4	0.166667	544.0472	326.9667	167.72	142.0031	136.1429	91.2354	1408.115
26	1.083333	465.2923	255.5984	105.7951	94.0507	88.107	68.3965	1077.24
50	2.083333	473.9404	243.9468	66.4261	83.0796	70.5632	61.4942	999.4503
74	3.083333	404.9112	168.6743	12.8089	52.2846	30.7141	46.1538	715.5469
97.5	4.0625	307.8943	82.876	0	17.4905	0	27.567	435.8278
171	7.125	3.4937	0	0	0	0	0	3.4937
217	9.041667	0	0	0	0	0	0	0
265.5	11.0625	0	0	0	0	0	0	0

uncon N,P b

time (h)	time (d)	B ug/L	T ug/L	eB ug/L	pX ug/L	mX ug/L	oX ug/L	BTEX ug/L
4	0.166667	526.476	318.3644	157.8991	134.6134	126.9889	88.2645	1352.606
26	1.083333	453.1078	243.163	97.713	87.9375	81.2094	60.3605	1023.491
50	2.083333	464.3818	235.0911	55.7287	79.0097	61.8268	55.7393	951.7774
74	3.083333	381.5289	148.0572	4.1726	45.0306	22.0965	41.2002	642.086
97.5	4.0625	231.2629	51.9639	0	3.7877	0	18.9519	305.9664
171	7.125	0	0	0	0	0	0	0
217	9.041667	0	0	0	0	0	0	0
265.5	11.0625	0	0	0	0	0	0	0

uncon N,P c

time (h)	time (d)	B ug/L	T ug/L	eB ug/L	pX ug/L	mX ug/L	oX ug/L	BTEX ug/L
4	0.166667	537.8342	330.0195	171.6596	144.8183	139.787	93.3974	1417.516
26	1.083333	466.518	259.4829	104.531	95.3099	87.9903	66.0835	1079.916
50	2.083333	456.2998	229.6996	58.7094	78.4831	65.663	57.4995	946.3544
74	3.083333	384.7318	155.5761	4.223	49.9034	25.8782	44.6463	664.9588
97.5	4.0625	249.9876	68.0699	0	5.9338	0	25.0021	348.9934
171	7.125	0	0	0	0	0	0	0
217	9.041667	0	0	0	0	0	0	0
265.5	11.0625	0	0	0	0	0	0	0

contaminated soil

contam ster a

time	time	B	T	eB	pX	mX	oX	BTEX

(h)	(d)	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
4	0.166667	566.3352	328.5795	150.2476	126.1625	120.4401	83.5626	1375.328
26	1.083333	513.5372	276.8932	116.4945	99.9643	95.3303	70.1767	1172.396
50	2.083333	544.6348	281.447	112.6651	97.5437	94.149	70.085	1200.525
74	3.083333	531.0083	294.3506	125.0389	104.8702	99.311	74.7268	1229.306
97.5	4.0625	520.6054	277.4456	107.9518	90.3741	85.5698	62.6482	1144.595
171	7.125	494.3364	253.6592	95.3148	78.149	75.3541	56.383	1053.197
217	9.041667	471.782	243.1788	91.071	76.9285	74.1859	58.2297	1015.376
265.5	11.0625	469.9394	227.6151	77.5197	60.7524	58.2364	43.6436	937.7066
431	17.95833	457.1335	227.8156	81.9719	67.5784	64.6815	50.5972	949.7781

contam ster b

time (h)	time (d)	B ug/L	T ug/L	eB ug/L	pX ug/L	mX ug/L	oX ug/L	BTEX ug/L
4	0.166667	537.3814	325.5651	164.7256	139.0304	130.8187	90.1372	1387.658
26	1.083333	480.8748	260.068	111.0638	93.3416	88.5837	64.7125	1098.644
50	2.083333	482.8763	253.3795	102.0564	85.39	81.4345	61.2958	1066.433
74	3.083333	452.173	244.9504	103.4766	87.951	86.0674	65.3573	1039.976
97.5	4.0625	442.0549	232.6616	92.6241	76.1134	73.914	55.8752	973.2432
171	7.125	415.3548	216.0317	76.7995	62.6465	59.0379	44.5804	874.4508
217	9.041667	374.1076	179.9607	63.8423	54.1248	51.0447	42.0341	765.1142
265.5	11.0625	388.0891	198.3939	73.4899	60.6881	59.2609	44.5671	824.489
431	17.95833	374.388	185.5998	66.2196	52.5856	48.851	39.0247	766.6687

contam ster c

time (h)	time (d)	B ug/L	T ug/L	eB ug/L	pX ug/L	mX ug/L	oX ug/L	BTEX ug/L
4	0.166667	549.5542	330.7404	159.6714	134.1386	126.4116	88.8919	1389.408
26	1.083333	508.6697	278.7407	117.5402	96.8919	92.3426	67.1589	1161.344
50	2.083333	543.8707	287.8789	118.053	97.8574	92.9571	68.9526	1209.57
74	3.083333	507.7317	276.5384	116.0078	96.8898	94.6382	70.055	1161.861
97.5	4.0625	498.8471	255.6983	98.831	81.7468	78.8438	59.9536	1073.921
171	7.125	484.204	247.7535	92.1836	76.2955	72.257	56.9886	1029.682
217	9.041667	427.4566	198.369	67.9787	56.6003	53.4573	34.2804	838.1423
265.5	11.0625	443.5489	212.7322	76.5154	63.2541	60.381	43.3464	899.778
431	17.95833	424.5405	202.8426	72.3067	58.6841	55.8761	42.7325	856.9825

contam act a

time (h)	time (d)	B ug/L	T ug/L	eB ug/L	pX ug/L	mX ug/L	oX ug/L	BTEX ug/L
4	0.166667	537.0834	316.8589	150.1404	125.1678	120.9946	82.9915	1333.237
26	1.083333	490.3487	266.0156	108.6934	94.5341	88.2967	66.994	1114.883

50	2.083333	492.6388	246.8389	74.1482	74.4168	66.7396	58.5335	1013.316
74	3.083333	460.1814	229.5364	51.1133	67.766	56.1125	57.0417	921.7513
97.5	4.0625	416.4206	174.0158	19.1456	35.3331	23.3251	34.6992	702.9394
171	7.125	326.9912	101.6709	0	6.1193	0	20.6898	455.4712
217	9.041667	228.9208	51.6536	0	0	0	3.301	283.8754
265.5	11.0625	213.1076	46.1044	0	0	0	10.3047	269.5167
431	17.95833	58.4916	7.2195	0	0	0	0	65.7111

contam act b

time (h)	time (d)	B ug/L	T ug/L	eB ug/L	pX ug/L	mX ug/L	oX ug/L	BTEX ug/L
4	0.166667	588.5076	364.8689	191.5488	162.3855	154.9598	108.1725	1570.443
26	1.083333	513.614	287.6856	121.716	103.7981	98.1663	72.5997	1197.58
50	2.083333	542.79	291.8812	98.1216	96.2352	90.0233	70.3003	1189.352
74	3.083333	497.6106	253.4768	53.1181	73.9921	63.9153	62.0237	1004.137
97.5	4.0625	462.4576	206.9483	24.5005	48.4591	33.9947	45.7073	822.0675
171	7.125	348.8231	107.3649	0	9.8408	0	23.1228	489.1516
217	9.041667	263.2605	62.2371	0	0	0	11.2774	336.775
265.5	11.0625	235.6905	46.6324	0	0	0	10.1215	292.4444
431	17.95833	88.0948	9.0737	0	0	0	1.7864	98.9549

contam act c

time (h)	time (d)	B ug/L	T ug/L	eB ug/L	pX ug/L	mX ug/L	oX ug/L	BTEX ug/L
4	0.166667	527.0883	319.875	161.7541	136.8666	129.8814	92.0533	1367.519
26	1.083333	466.9054	254.5372	101.0684	89.4455	84.6117	64.2049	1060.773
50	2.083333	484.8941	247.3582	65.5535	73.4972	65.7183	58.1181	995.1394
74	3.083333	453.4113	215.0999	34.6108	59.1612	46.5224	50.2161	859.0217
97.5	4.0625	427.6174	171.0861	12.0359	31.7541	16.7348	34.9495	694.1778
171	7.125	320.2956	79.7272	0	2.1653	0	10.6605	412.8486
217	9.041667	193.8296	32.3024	0	0	0	2.3733	228.5053
265.5	11.0625	189.5686	29.9046	0.9584	0	0	5.0829	225.5145
431	17.95833	75.7319	6.9303	0	0	0	0	82.6622

contam N,P a

time (h)	time (d)	B ug/L	T ug/L	eB ug/L	pX ug/L	mX ug/L	oX ug/L	BTEX ug/L
4	0.166667	568.3937	338.4936	166.3316	140.9068	133.1729	90.9977	1438.296
26	1.083333	496.6035	269.8106	109.5913	93.7814	87.3304	65.4233	1122.541
50	2.083333	503.5196	264.0358	74.0403	77.7536	47.9116	61.4123	1028.673
74	3.083333	455.9791	211.8516	21.7359	45.5713	11.864	50.2599	797.2618

97.5	4.0625	399.7009	138.2762	1.2035	9.2666	0	27.1305	575.5777
171	7.125	75.0838	2.0935	0	0.2929	0	0.2355	77.7057
217	9.041667	3.6125	0	0	0	0	0	3.6125
265.5	11.0625	0	0	0	0	0	0	0

contam N,P b

time (h)	time (d)	B ug/L	T ug/L	eB ug/L	pX ug/L	mX ug/L	oX ug/L	BTEX ug/L
4	0.166667	524.6166	312.1305	150.2191	125.2171	118.0613	83.6512	1313.896
26	1.083333	457.5959	250.2015	100.7525	89.5091	84.7624	65.3589	1048.18
50	2.083333	broken						

contam N,P c

time (h)	time (d)	B ug/L	T ug/L	eB ug/L	pX ug/L	mX ug/L	oX ug/L	BTEX ug/L
4	0.166667	528.1979	319.5255	162.6651	136.7237	129.4457	91.107	1367.665
26	1.083333	466.1865	253.9852	100.7287	88.5296	79.1647	62.9951	1051.59
50	2.083333	474.0202	235.6163	56.7393	61.1492	35.3124	52.4773	915.3147
74	3.083333	425.8141	195.5745	9.8207	46.0105	16.1866	46.9743	740.3807
97.5	4.0625	368.6173	125.1562	7.4303	5.1207	0	24.5477	530.8722
171	7.125	36.5432	2.0502	0.2642	0.9555	0	0	39.8131
217	9.041667	0	0	0	0	0	0	0
265.5	11.0625	0	0	0	0	0	0	0

BTEX Checks

July 31/95
time= 4 h 4:00 pm

	chk		rpt		rpt		mid		end	
	ug/L	%theor	ug/L	%theor	ug/L	%theor	ug/L	%theor	ug/L	%theor
B	442.8815	105.1451	436.894	103.7236	444.2923	105.48	441.0226	104.7037	439.8439	104.4239
T	453.9172	109.2329	442.0722	106.3824	450.8457	108.4937	445.9139	107.3069	443.2513	106.6662
eB	258.7442	124.51	246.7562	118.7413	254.6278	122.5291	247.6782	119.1849	242.2055	116.5514
pX	257.5788	124.7959	243.134	117.7975	250.7045	121.4654	247.3684	119.849	240.0922	116.3237
mX	250.7712	121.0636	236.9315	114.3823	245.5933	118.5639	240.6438	116.1745	234.5605	113.2377
oX	259.6731	123.0795	245.0206	116.1345	251.6035	119.2547	251.31	119.1156	238.1983	112.9009

Aug 1/95
time= 26 h 2:00 pm; rm=26 C

	chk		rpt		rpt		mid		end	
	ug/L	%theor	ug/L	%theor	ug/L	%theor	ug/L	%theor	ug/L	%theor
B	452.4972	107.4279	453.8945	107.7597	449.9505	106.8233	451.6247	107.2208	444.4282	105.5123
T	457.6965	110.1423	465.0317	111.9075	461.224	110.9912	459.1011	110.4804	447.3967	107.6637
eB	254.5888	122.5104	257.665	123.9907	254.4125	122.4255	250.3873	120.4886	241.3319	116.131
pX	253.463	122.8018	254.3372	123.2254	252.5889	122.3783	249.167	120.7204	237.6477	115.1394
mX	245.9346	118.7287	248.0533	119.7515	246.8241	119.1581	242.2973	116.9727	232.5183	112.2518
oX	252.268	119.5696	254.5243	120.6391	252.8442	119.8427	247.246	117.1893	237.5338	112.5859

50
Aug 2/95
time= 50 h 2:00 pm; diff (not gastight) 10 uL syringe

	chk		rpt		rpt		mid		end	
	ug/L	%theor	ug/L	%theor	ug/L	%theor	ug/L	%theor	ug/L	%theor
B	503.0155	119.4215	488.7274	116.0294	492.8524	117.0087	449.4822	106.7121	451.351	107.1558
T	515.927	124.1552	496.3335	119.4401	496.9418	119.5865	448.6735	107.971	451.3545	108.6162
eB	281.4382	135.4305	267.5419	128.7435	263.0588	126.5862	232.8336	112.0416	240.6316	115.794
pX	280.6717	135.9844	265.3428	128.5576	258.6307	125.3056	227.8096	110.3729	237.9602	115.2908
mX	273.2458	131.9136	257.2589	124.1957	251.9217	121.619	223.7189	108.0037	232.6345	112.3079
oX	280.136	132.7785	263.0004	124.6566	251.9533	119.4205	223.9798	106.1616	240.4851	113.9848

74
Aug 3/95
time= 73 h 2:00 pm

	chk		rpt		rpt		mid		end	
	ug/L	%theor	ug/L	%theor	ug/L	%theor	ug/L	%theor	ug/L	%theor
B	451.4201	107.1722	448.8382	106.5592	445.3482	105.7307	440.3867	104.5528	440.6975	104.6266
T	461.7267	111.1122	460.9718	110.9305	455.4039	109.5906	444.2479	106.906	446.6619	107.4869
eB	259.3552	124.804	257.2297	123.7812	254.0305	122.2417	241.8964	116.4027	241.2937	116.1127
pX	257.496	124.7558	252.9888	122.5721	253.6257	122.8807	238.2468	115.4297	235.0982	113.9042
mX	253.4258	122.3452	250.5172	120.941	247.8468	119.6518	231.2754	111.6517	230.9356	111.4877
oX	261.3499	123.8743	256.5592	121.6036	255.8263	121.2562	238.9012	113.2341	238.9754	113.2692

97.5
Aug 4/95
time= 97.5 h 1:30 pm

	chk		rpt		rpt		mid		end	
	ug/L	%theor	ug/L	%theor	ug/L	%theor	ug/L	%theor	ug/L	%theor
B	465.7764	110.5806	469.7055	111.5134	466.7275	110.8064	notdone	0	460.9166	109.4268
T	474.3786	114.1568	482.1698	116.0317	472.5162	113.7086	notdone	0	456.0113	109.7368
eB	259.6023	124.9229	258.282	124.2876	254.1796	122.3135	notdone	0	239.9419	115.4622
pX	258.6249	125.3028	255.1064	123.5981	251.5114	121.8563	notdone	0	236.7824	114.7202

mX	252.1703	121.7391	248.7162	120.0715	248.8891	120.155	notdone	0	230.3161	111.1886
oX	259.9049	123.1894	253.4179	120.1147	252.7458	119.7961	notdone	0	233.3064	110.5822

171
Aug 7/95
time= 171 h 3:00 pm

	chk		rpt		rpt		mid		end	
	ug/L	%theor	ug/L	%theor	ug/L	%theor	ug/L	%theor	ug/L	%theor
B	415.9373	98.7482	416.8184	98.95738	419.4314	99.57774	406.7565	96.56858	406.6499	96.54327
T	416.4344	100.2128	419.358	100.9164	427.3874	102.8486	400.9785	96.49344	404.8979	97.43663
eB	224.3929	107.9798	227.6467	109.5456	233.4819	112.3535	210.909	101.4913	217.0982	104.4696
pX	224.2665	108.6563	226.7409	109.8551	235.3954	114.0482	209.1308	101.3231	216.4083	104.849
mX	217.1566	104.8357	221.1364	106.757	231.3623	111.6937	202.3795	97.7018	210.0855	101.422
oX	221.6297	105.0477	225.9063	107.0747	234.8439	111.311	208.6261	98.8843	215.7664	102.2687

217
Aug 9/95
time= 217 h 1:00 pm

	chk		rpt		rpt		mid		end	
	ug/L	%theor	ug/L	%theor	ug/L	%theor	ug/L	%theor	ug/L	%theor
B	429.9265	102.0694	427.7696	101.5573	429.5317	101.9757	409.2065	97.15023	406.85	96.59077
T	440.4538	105.993	428.7711	103.1816	439.7037	105.8125	415.642	100.0221	413.5893	99.52817
eB	241.3822	116.1552	232.4788	111.8708	236.9875	114.0405	218.6906	105.2358	216.9005	104.3744
pX	242.0166	117.2561	228.8433	110.8737	233.6807	113.2174	215.1689	104.2485	211.1551	102.3038
mX	235.4874	113.6851	227.7932	109.9706	228.2623	110.1971	209.3162	101.0506	204.9219	98.92918
oX	238.0316	112.8219	232.4326	110.1681	230.1237	109.0737	211.8708	100.4222	207.5388	98.36894

265.5
Aug 11/95
time= 265.5 h 1:30 pm

	chk		rpt		rpt		mid		end	
	ug/L	%theor	ug/L	%theor	ug/L	%theor	ug/L	%theor	ug/L	%theor
B	421.2528	100.0102	429.3462	101.9316	436.6759	103.6718	notdone	0	424.8187	100.8567
T	417.966	100.5814	426.5501	102.6471	444.1885	106.8917	notdone	0	414.915	99.84719
eB	216.1286	104.003	228.0517	109.7405	239.8231	115.405	notdone	0	218.0838	104.9438
pX	217.0086	105.1398	226.83	109.8983	237.1122	114.8799	notdone	0	214.352	103.8527
mX	212.5791	102.6258	218.805	105.6315	232.3774	112.1837	notdone	0	210.8251	101.779
oX	215.0576	101.9327	223.4637	105.917	233.9442	110.8845	notdone	0	213.4176	101.1554

431
Aug 18/95
time= 431 h 11:00 am; rm=24.5 C

	chk		rpt		rpt		mid		end	
	ug/L	%theor	ug/L	%theor	ug/L	%theor	ug/L	%theor	ug/L	%theor
B	438.9976	104.223	442.0401	104.9453	446.4153	105.984	notdone	0	447.7643	106.3043
T	445.6699	107.2482	449.7705	108.235	457.2755	110.041	notdone	0	452.208	108.8216
eB	239.6755	115.334	243.6364	117.24	243.0752	116.9699	notdone	0	234.9211	113.0461
pX	240.4007	116.4732	242.5151	117.4976	242.8491	117.6594	notdone	0	234.0083	113.3761
mX	235.438	113.6613	236.2569	114.0566	237.3433	114.5811	notdone	0	224.8602	108.5547
oX	241.8146	114.6149	239.4303	113.4848	242.806	115.0848	notdone	0	231.3619	109.6606

Appendix III Preparation of standards for creosotic analysis

Two stock solutions are prepared. Stock A is prepared by adding 10.0 mg of each solid (or 10 μL if a liquid) phenol, cresol and dimethylphenol compound listed in Table 3 to a 50-mL volumetric flask. Fifteen mL of methanol are added, and the mixture sonicated to dissolve the compounds. Additional methanol is added to give 50.0 mL, and the stock solution (about 200 μg of each compound/mL) is stored at -20°C in a tightly sealed amber bottle. Stock B is prepared by combining a number of commercial standard preparations with 4.0 mg each of biphenyl, 16-methylnaphthalene, carbazole, and indole in a 50-mL volumetric flask. The commercial preparations include 2 mL of PAH mix #US-106 (2000 μg/mL, purchased from Ultra Scientific) 4 mL of *m*-xylene (1000 μg/mL, from NSI Environmental), 1 mL of dibenzofuran (5000 μg/mL, from NSI Environmental) and 4 mL of 2-methylnaphthalene (5000 μg/mL, from NSI Environmental). Thirty-five mL of methylene chloride are added, and the contents of the flask mixed by sonication, then additional methylene chloride is added to give 50.0 mL. This gives a stock solution of approximately 80 μg of each compound/mL. The stock B solution is divided into 50 1-mL amber ampoules which are sealed and stored at -20°C. To prepare calibration standards, 150 μL of stock A and 150 μL of stock B are diluted in water, then extracted according to normal protocol. Check standards are prepared at 1/10th the concentration. A method blank is prepared the same way except that no standards are added to the water.

Appendix IV GC/MS Library Scans

Information from Data File:
File : C:\HPCHEM\1\DATA\BARB1.D
Operator :
Acquired : 29 Aug 95 11:50 am using AcqMethod KIMCREO
Sample Name: weston, sterile 8a,8b,8c
Misc Info : 2ul inj
Vial Number: 1

Search Libraries: C:\DATABASE\nbs54k.l Minimum Quality: 0

Unknown Spectrum: Apex minus baseline at 18 minutes
Integration Params: AutoIntegrate

Pk#	RT	Area%	Library/ID	Ref#	CAS#	Qual
1	6.14	2.60	C:\DATABASE\NBS54K.L			
			3,6-Bis(benzyl)-tetrazine	30811	014141-65-2	22
			Benzene, (chloromethyl)ethenyl-	8819	030030-25-2	18
			1,3,4-Tri-O-acetyl-2,5-di-O-methylrib	37091	084925-31-5	14
2	7.83	29.56	C:\DATABASE\NBS54K.L			
			1H-Indene, 1-methylene-	4532	002471-84-3	87
			Azulene	4530	000275-51-4	78
			[4.2.2]Propella-2,4,7,9-tetraene	4533	088090-34-0	72
3	7.93	2.79	C:\DATABASE\NBS54K.L			
			Thiepino[3,2-e]isobenzofuran-1,3-dion	30437	055044-57-0	43
			Pyrimidine, 2,4,6-trifluoro-	5243	000696-82-2	38
			1,4-Benzenedicarboxaldehyde	5323	000623-27-8	38
4	9.01	3.83	C:\DATABASE\NBS54K.L			
			1,4-Methanonaphthalene, 1,4-dihydro-	7016	004453-90-1	86
			1H-Indene, 1-ethylidene-	7017	002471-83-2	68
			Benzocycloheptatriene	7018	000264-09-5	43
5	9.19	4.21	C:\DATABASE\NBS54K.L			
			1H-Indene, 1-ethylidene-	7017	002471-83-2	90
			Naphthalene, 2-methyl-	7019	000091-57-6	86
			Naphthalene, 1-methyl-	7015	000090-12-0	86
6	9.67	23.44	C:\DATABASE\NBS54K.L			
			1,1'-Biphenyl, 4-fluoro-	13567	000324-74-3	76
			1,1'-Biphenyl, 2-fluoro-	13566	000321-60-8	76
			4-(2-Hydroxyphenyl)pyrimidine	13454	068535-55-7	47
7	10.87	13.98	C:\DATABASE\NBS54K.L			
			Acenaphthene	9558	000083-32-9	47
			2,4(1H,3H)-Pyrimidinedione, 1,3,5-tri	9192	004401-71-2	22

			Naphthalene, 2-ethenyl-	9559	000827-54-3	17
8	11.17	5.54	C:\DATABASE\NBS54K.L			
			Dibenzofuran	12597	000132-64-9	72
			Benzo[b]thiophene, 3-chloro-	12347	007342-86-1	42
			1,1'-Biphenyl, 3-methyl-	12711	000643-93-6	42
9	11.76	6.88	C:\DATABASE\NBS54K.L			
			Benzaldehyde, 4,6-dihydroxy-2,3-dimet	12019	002990-31-0	72
			Fluorene-9-methanol	18673	024324-17-2	64
			9H-Fluorene-9-carboxylic acid	21568	001989-33-9	43
10	13.42	7.17	C:\DATABASE\NBS54K.L			
			9H-Fluorene, 9-methylene-	14817	004425-82-5	72
			Phenanthrene	14815	000085-01-8	72
			Benzene, 1,1'-(1,2-ethynediyl)bis-	14818	000501-65-5	64

Wed Aug 30 09:01:03 1995

Information from Data File:
File : C:\HPCHEM\1\DATA\BARB2.D
Operator :
Acquired : 29 Aug 95 2:06 pm using AcqMethod KIMCREO
Sample Name: weston, active 8a,8b,8c
Misc Info : 2ul inj
Vial Number: 1

Search Libraries: C:\DATABASE\nbs54k.l Minimum Quality: 0

Unknown Spectrum: Apex minus baseline at 18 minutes
Integration Params: AutoIntegrate

Pk#	RT	Area%	Library/ID	Ref#	CAS#	Qual
1	9.68	51.60	C:\DATABASE\NBS54K.L			
			1,1'-Biphenyl, 4-fluoro-	13567	000324-74-3	76
			1,1'-Biphenyl, 2-fluoro-	13566	000321-60-8	76
			1H-Pyrazole, 3,5-dimethyl-1-phenyl-	13553	001131-16-4	53
2	10.88	17.37	C:\DATABASE\NBS54K.L			
			1,4-Ethenonaphthalene, 1,4-dihydro-	9557	007322-47-6	58
			Acenaphthene	9558	000083-32-9	17
			Benzofuran, 7-chloro-	8759	024410-55-7	11
3	11.21	4.68	C:\DATABASE\NBS54K.L			
			Benzenamine, 3,4,5-trimethoxy-	15829	024313-88-0	12
			1-Isoquinolinecarbonitrile, 3-methyl-	12566	022381-52-8	12
			.beta.-Alanine, N-(trifluoroacetyl)-,	27229	055133-79-4	10
4	11.78	8.72	C:\DATABASE\NBS54K.L			
			1H-Phenalene	12193	000203-80-5	64
			Fluorene-9-methanol	18673	024324-17-2	59
			Benzaldehyde, 2,4-dihydroxy-3,6-dimet	11981	034883-14-2	50
5	13.44	8.57	C:\DATABASE\NBS54K.L			
			Phenanthrene	14815	000085-01-8	83
			9H-Fluorene, 9-methylene-	14817	004425-82-5	72
			Anthracene	14816	000120-12-7	72
6	20.03	9.06	C:\DATABASE\NBS54K.L			
			3,7,11-Tridecatrienenitrile, 4,8,12-t	25586	006006-01-5	49
			Propanoic acid, 2-methyl-, 3,7-dimeth	24327	002345-26-8	47
			2,6,10-Dodecatrien-1-ol, 3,7,11-trime	31142	004128-17-0	38

Wed Aug 30 08:58:19 1995

File : C:\HPCHEM\1\DATA\BARBSPD1BRP.TXT
Operator :
Acquired : 29 Aug 95 2:45 pm using AcqMethod KIMCREO
Sample Name: weston, nutrients 8a,8b,8c
Misc Info : 2ul inj
Vial Number: 1

Search Libraries: C:\DATABASE\nbs54k.l Minimum Quality: 0

Unknown Spectrum: Apex minus baseline at 20 minutes
Integration Params: AutoIntegrate

Pk#	RT	Area%	Library/ID	Ref#	CAS#	Qual
1	9.68	81.19	C:\DATABASE\NBS54K.L			
			1,1'-Biphenyl, 4-fluoro-	13567	000324-74-3	76
			1,1'-Biphenyl, 2-fluoro-	13566	000321-60-8	76
			1H-Pyrazole, 3,5-dimethyl-1-phenyl-	13553	001131-16-4	53
2	10.89	12.28	C:\DATABASE\NBS54K.L			
			1,4-Ethenonaphthalene, 1,4-dihydro-	9557	007322-47-6	53
			2,5-Etheno[4.2.2]propella-3,7,9-trien	9555	088090-38-4	36
			Acenaphthene	9558	000083-32-9	27
3	11.80	6.52	C:\DATABASE\NBS54K.L			
			L-Histidine	9573	000071-00-1	74
			15-Octadecenal	31476	056554-93-9	64
			l-Histidine, ethyl ester	15817	007555-06-8	64

Wed Aug 30 08:54:01 1995

Appendix V Microbial enumeration data

dilution	R2A plates			naph			phen			dibenz		
	gw	uncon	con	gw	uncon	con	gw	uncon	con	gw	uncon	con
undil a					+			+			+	
undil b					+			+			+	
undil c					+			+			+	
10^{-1}a				+	+	+	+	+	+	+	+	+
10^{-1}b				+	+	+	+	+	+	+	+	+
10^{-1}c				+	+	+	+	+	+	+	+	+
10^{-2}a	tntc	tntc	tntc	+	+	+	-	+	+	-	-/+	+
10^{-2}b	tntc	tntc	tntc	+	+	+	-	+	+	-	+	+
10^{-2}c	tntc	tntc	tntc	+	+	+	+	+	+	-	+	+
10^{-3}a	tntc	tntc	tntc	+	+	+	-	+	+	-	-	+
10^{-3}b	tntc	tntc	tntc	+	+	+	-	+	+	-	-	+
10^{-3}c	tntc	tntc	tntc	+	+	+	-	+	+	-	+	+
10^{-4}a	249	tntc	tntc	+	+	+	-	+	+	-	-	+
10^{-4}b	335	tntc	tntc	+	+	+	-	+	+	-	-	+
10^{-4}c	363	tntc	tntc	+	+	+	-	+	+	-	-	-
10^{-5}a	45	323sp	269sp	+	+	+	-	+	+	-	-	-
10^{-5}b	48	283sp	339	+	+	+	-	+	+	-	-	-
10^{-5}c	44	475	349	+	+	+	-	+	+	-	-	-
10^{-6}a	3	113	69	-	-	+	-	+	+	-	-	-
10^{-6}b	8	121	76	-	-	+	-	+	+	-	-	-
10^{-6}c	4	115	93	-	+	+	-	+	+	-	-	-
10^{-7}a	0	22	20									
10^{-7}b	0	19	10									
10^{-7}c	0	23	19									

acetone only; all uninoc controls	-
inoc, substrate-free MSM	-
"+ve" control (creosote-grown enrichment)	+ on naph, + on dibenz, - on phen

blank: dilution not tested; tntc: too numerous to count; sp: spreader colonies on plate;
+: turbid &/or brown metabolite formed; -: no turbidity or colour