Roy F. Weston, Inc.
Suite 400
3 Hawthorn Parkway
Vernon Hills, Illinois 60061-1450
708-918-4000 • Fax 708-918-4055

12 January 1996

Mr. Russell D. Hart
Remedial Project Manager
Remedial Section #3
U.S. EPA, Region V
77 W. Jackson Blvd.
Chicago, IL 60604

Work Order No. 02687-007-002

Re: Moss-American Superfund Site
Milwaukee, Wisconsin

Dear Mr. Hart:

Roy F. Weston, Inc. (WESTON®), on behalf of Kerr-McGee Chemical Corp. (KMCC) has prepared responses, clarification, and supplemental technical information per U.S. EPA's 10 October 1995 letter request.

Enclosed you will find:

- Attachment A — Response to Comments on Focused Remedial Alternatives Evaluation for Soil and Sediment.
- Attachment B — Response to Comments on Preliminary Design for Groundwater Remedial System.
- Attachment C — Report of Preliminary Biotreatability Study for Groundwater Remedial Design.

KMCC/WESTON propose that a meeting between WESTON, KMCC, U.S. EPA, CH2M HILL, and WDNR may be beneficial toward resolution of various technical and work sequence/scheduling issues. I will contact you to arrange such a meeting for late January or early February 1996.

Should you have any initial comments or questions on this transmittal, please contact either of us at (708) 918-4000.

Very truly yours,

ROY F. WESTON, INC.

Gary J. Deigan
Principal Project Manager

Kurt S. Stimpson
Project Director

GJD:KSS/slr
Enclosure (Attachments A, B, C)

cc: Mr. A. Keith Watson
Kerr-McGee Chemical Corporation
Kerr-McGee Center
P.O. Box 25861
Oklahoma City, OK 73125

Mr. Richard Meserve
Covington & Burling
1201 Pennsylvania Avenue N.W.
P.O. Box 7566
Washington, D.C. 20044

Regional Counsel
Attn: Moss-American Site Coordinator (5CS)
U.S. Environmental Protection Agency
77 West Jackson Boulevard
Chicago, IL 60604

cc: Assistant Attorney General
Environment and Natural Resources Division
U.S. Department of Justice
P.O. Box 7611
Ben Franklin Station
Washington, D.C. 20044
Ref. D.J. #90-11-2-590

Section Chief (3 copies)
Environmental Response and Repair Section
Bureau of Solid and Hazardous Waste Management
Wisconsin Department of Natural Resources
101 S. Webster Street
P.O. Box 7921
Madison, WI 53707-7921

Mr. Jim Schmidt (2 copies)
Department of Natural Resources
Southeast District Office
P.O. Box 12436
Milwaukee, WI 53212

ATTACHMENT A

RESPONSE TO COMMENTS ON FOCUSED REMEDIAL ALTERNATIVES EVALUATION FOR SOIL AND SEDIMENT

RESPONSE TO COMMENTS ON FOCUSED REMEDIAL ALTERNATIVES EVALUATION FOR SOIL AND SEDIMENT

U.S. EPA SPECIFIC COMMENTS

***EPA Comment 1**: By copy of this letter to the principal site landowners, U.S. EPA solicits views and discussion of the second paragraph which appears on page 2-4 of the soils and sediment alternatives evaluation. This paragraph states: "...The risk assessment conducted utilizing updated U.S. EPA protocols has determined a soil CPAH cleanup standard for the entire site of 78 mg/kg (benzo[a]pyrene-equivalent concentration), based on industrial land use and a 10-4 cancer risk. Current land use is industrial on the CNW property and recreational on the Milwaukee County property. The cleanup standard based on recreational land use and a 10-4 cancer risk is 610 mg/kg (benzo[a]pyrene-equivalent concentration). Future land use is not expected to differ from current land use. By assuming an industrial cleanup standard for the Milwaukee County property, KMCC/WESTON are not making the assumption that industrial land use is appropriate for this parcel. Rather, the industrial cleanup standard is adequately protective of both industrial and recreational land-use exposures...".*

I should note that U.S. EPA has not officially adopted the point of view expressed by this paragraph; to do so officially would likely require a ROD amendment. Given the Agency's emphasis on administrative reforms and the need to properly assess future site land usage, it is important to review this matter. Appropriate review should also include consideration of pertinent soil standards which may have been adopted by WDNR, NR 720.

Response: As stated above, KMCC/WESTON used current regulatory policy in determining appropriate cleanup standards for the property. We do not anticipate that additional response is requested from KMCC/WESTON at this time.

***EPA Comment 2**: The 1990 ROD for this site noted on its signature page that "...A waiver is justified pursuant to Section 121(d)(4)(B) for the Subtitle C cap and for the State double-liner/leachate collection system requirement, on the basis that an impermeable cap and liner that prevents flushing of the groundwater contaminants will present a greater risk to health and the environment by prolonging the groundwater treatment to greater than 200 years..." If the groundwater remedial design adopted were to inherently recognize that because of the presence of free-product there is a need to address the groundwater question "in perpetuity", then we may need to revisit this reasoning.*

**RESPONSE TO COMMENTS ON
FOCUSED REMEDIAL ALTERNATIVES EVALUATION
FOR SOIL AND SEDIMENT
(CONTINUED)**

Response: KMCC/WESTON concur with U.S. EPA's assessment that variations in soil/ sediment containment design (i.e., cover system permeability) would have little influence on the "groundwater management" period for the site. A higher permeability cover/ containment system would not be expected to appreciably influence removal of DNAPL from a fine-grained, clay-rich subsurface strata via flushing to a groundwater collection and treatment system.

***EPA Comment 3**: Page 3-2 of the soils and sediment alternatives evaluation makes note of the CAMU concept. It is my understanding that this concept may be the subject of proposed rule making. Within a larger context, the whole question of CERCLA reauthorization looms, and one cannot say at this time to what degree concepts such as ARARs and relationship of CERCLA to RCRA LDRs will be maintained. WDNR notes that justification for designating a CAMU under NR 636, Wisconsin Administrative Code, must be provided.*

Response: The Final Rule for the Corrective Action Management Units (CAMU) and Temporary Units, under the RCRA Corrective Action Provisions of Subtitle C became effective on 19 April 1993. However, the second portion of the proposed Hazardous Waste Identification Rule (HWIR) dealing with contaminated media could impact or supersede the Final CAMU Rule.

In general when specifying a CAMU, NR 636.40(3) requires the department to designate a CAMU in accordance with seven criteria. In the event the CAMU rule is an applicable or relevant and appropriate requirement (ARAR) and is not superseded by new rule-making, an overview of how the recommended alternative for the Moss-American site meets these seven criteria are listed below:

NR 636.40(3)(a): *The CAMU shall facilitate the implementation of reliable, effective, protective, and cost-effective remedies.*

Alternative 1d is a cost-effective alternative that consolidates contaminated soil and sediment under a relatively impermeable barrier that is both reliable and effective when maintained properly. The soil and sediment containing constituents above cleanup standards have been proposed to be excavated and contained beneath the cover system, thereby protecting both human health and the environment.

RESPONSE TO COMMENTS ON FOCUSED REMEDIAL ALTERNATIVES EVALUATION FOR SOIL AND SEDIMENT (CONTINUED)

NR 636.40(3)(b): *Waste management activities associated with the CAMU shall not create unacceptable risks to humans or to the environment resulting from exposure to hazardous wastes or hazardous constituents.*

Engineering and administrative controls implemented during the remedial action would effectively eliminate the risks to humans and the environment. Controls such as dust control program during soil excavation and temporary diversion of river water, silt controls, or absorbent booms during hot-spot sediment removal would provide effective protection during implementation of the remedy.

NR 636.40(3)(c): *The CAMU shall include uncontaminated areas of the facility for the purpose of managing remediation wastes, only if including such areas is more protective than management of such wastes at contaminated areas of the facility.*

Under the Alternative 1d conceptual design, the CAMU does not include uncontaminated areas.

NR 636.40(3)(d): *Areas within the CAMU where wastes remain in place after closure shall be managed and contained so as to minimize future releases, to the extent practicable.*

Long-term operation and maintenance (O&M) consisting of an inspection program, cover maintenance, and groundwater monitoring are included as work elements of Alternative 1d. In addition, a groundwater remediation system would be placed downgradient of the soil and sediment containment. The combination of soil/sediment containment and groundwater remediation would minimize future releases, to the extent practicable.

NR 636.40(3)(e): *The CAMU shall expedite the timing of remedial activity implementation, when appropriate and practicable.*

Alternative 1d would require one year to implement, with a 30-year post-closure monitoring and maintenance period. The implementation time of one year expedites the remedy when compared to several of the other alternatives.

**RESPONSE TO COMMENTS ON
FOCUSED REMEDIAL ALTERNATIVES EVALUATION
FOR SOIL AND SEDIMENT
(CONTINUED)**

NR 636.40(3)(f): *The CAMU shall enable the use, when appropriate, of treatment technologies (including innovative technologies) to enhance the long-term effectiveness of remedial actions by reducing the toxicity, mobility, or volume of wastes that will remain in place after closure of the CAMU.*

The ineffectiveness of physical/chemical and biological treatment technologies was demonstrated at the site via rigorous treatability testing.

NR 636.40(3)(g): *The CAMU shall, to the extent practicable, minimize the land area of the facility upon which wastes will remain in place after closure of the CAMU.*

Alternative 1d involves consolidating the contaminated soil and sediment above Area 8. WESTON determined the optimal dimensions (height and area) of the cell by minimizing, to the extent practicable, the height of the cell. The height was minimized so the cell would be compatible with present railroad operations and the surrounding land use. Therefore, the design minimized the land area on which soils would be placed.

EPA Comment 4: *It may be worthwhile for all parties to exchange views on some hypothetical "what if" scenarios involving soils/sediments. If modification of the bioslurry treatment approach were contemplated, then:*

- Since, like other cover alternatives, Alternative 1d involves excavation of outlying soil and sediment areas and contemplates consolidation under a cover over what is now approximately Area 8, would the railroad expect to maintain operations during the time excavation was performed for this alternative?

- Would there be any advantage gained in terms of cost effectiveness if treatment such as thermal desorption were performed on critical site subareas, such as those having free-product above the water table? If such treatment were performed, could the residuals and other untreated soils be consolidated under a RCRA cover as opposed to disposal in a RCRA containment cell? If such treatment were performed, could the residuals and other untreated soils be consolidated under an asphalt cover?

- As above, except substitute the addition of some stabilizing agent for thermal desorption?

RESPONSE TO COMMENTS ON FOCUSED REMEDIAL ALTERNATIVES EVALUATION FOR SOIL AND SEDIMENT (CONTINUED)

- While I do not rule out any alternatives at this point, I do simply observe that after a time asphalt-paved surfaces develop cracks. Therefore, I have reservations about employing an asphalt cover under which are high levels of PAHs and/or free product in soils.

- Setting aside for a moment the fact that the site is an NPL site, what would be the effect on degree of runoff to the river if several acres were to be paved? If this were a commercial development outside the context of Superfund, would there be a need to create some type of retention pond feature?

Response: KMCC/WESTON fully expect that provisions can be made, in cooperation with the railroad, to allow the railroad to maintain operations during and after the remediation. We further believe that Alternative 1d is a compatible remedial alternative for maintaining the railroad operations while being protective of human health and the environment.

KMCC/WESTON do not envision advantages with respect to cost-effectiveness or substantial added environmental protection by performance of thermal desorption on "critical" site subareas. We believe management of any residual product in the vadose zone would be effectively contained by the low-permeability clay strata and a low permeability cover system. Free product in isolated locations below the water table is being managed in the interim by the currently operating free-product recovery system. In the long-term, free-product residual below the water table would be contained/managed by groundwater remediation system components, such as funnel-and-gate or collection/treatment components. KMCC/WESTON are unaware of a stabilizing agent with demonstrated effectiveness on PAHs in soil. We would welcome further information from the U.S. EPA on this concept.

KMCC/WESTON concur that without proper maintenance, asphalt-paved surfaces can develop cracks. Thus, our O&M cost estimate includes periodic maintenance activities to ensure continued integrity of the asphalt cover. Sealant applications, patching, and new overlays are routine, common practices for maintaining effective asphalt surfaces. Future permeability concerns could also be effectively addressed by incorporating a geomembrane beneath the asphalt and aggregate layers.

KMCC/WESTON agree that stormwater runoff controls, including catch basins and retention ponds, would be an integral part of the overall site design. We anticipate that excavated site areas could be regraded and reshaped in a manner that would provide beneficial stormwater controls and an aesthetic natural feature, thus being compatible with surrounding land use.

RESPONSE TO COMMENTS ON FOCUSED REMEDIAL ALTERNATIVES EVALUATION FOR SOIL AND SEDIMENT (CONTINUED)

EPA Comment 5: WDNR has proposed consideration of an alternative which would utilize a 3' soil liner coupled with NR 504 solid waste soil cover. Please develop costs associated with such alternative so that effective comparison can be made. Also, what would be the costs associated with a solvent extraction approach to soils treatment?

Response: WESTON has prepared cost estimates, which are included in Tables A-1 and A-2 of this response document, for the following two additional alternatives requested by U.S. EPA/WDNR:

Alternative 1f: Excavate and Place Soil and Sediment in On-Site Soil-Lined Cell

This alternative includes the following major components:

- Clearing, grubbing, and site preparations.
- Construction of containment cell consisting of a 3-foot clay liner with a 1-foot leachate collection system and an NR 504 cover system.
- Excavation of soil and sediment and placement within the cell.
- Backfilling and landscaping of excavated areas.
- Access restrictions to containment cell.
- Construction of leachate management system.
- Performance of long-term monitoring and maintenance of containment cell.

The total present worth cost estimate for this alternative is $7,262,100.

KMCC/WESTON believe this cost analysis continues to support the recommendations presented in our 31 August 1995 Focused Remedial Alternatives Evaluation.

Alternative 7: Excavate, Perform On-site Solvent Extraction, and Place Treated Soil and Sediment Beneath Soil Cover

This alternative includes the following major components.

**RESPONSE TO COMMENTS ON
FOCUSED REMEDIAL ALTERNATIVES EVALUATION
FOR SOIL AND SEDIMENT
(CONTINUED)**

- Clearing, grubbing, and site preparations.
- Excavation of soil and sediment.
- Treatment of soil via solvent extraction.
- Backfilling of treated soil and sediment.
- Off-site management (commercial incineration) of process residuals.

The total present worth cost estimate for this alternative is $21,991,300.

KMCC/WESTON believe this cost analysis continues to support the recommendations presented in our 31 August 1995 Focused Remedial Alternatives Evaluation.

RESPONSE TO COMMENTS ON FOCUSED REMEDIAL ALTERNATIVES EVALUATION FOR SOIL AND SEDIMENT (CONTINUED)

CH2M HILL'S COMMENTS

CH2M HILL Comment R.1: The recommended alternative requires that the site be designated a CAMU so that LDRs and other RCRA requirements would not be applicable. Has this designation been made? If not, then designation as a CAMU can only be performed by the Regional Administrator after evaluating seven criteria. A brief overview of how the recommended alternative and the site meet these criteria should be provided so that the feasibility of designating the site a CAMU may be evaluated.

Response: A brief overview of how the recommended alternative meets the seven criteria, if applicable, is included in the response to U.S. EPA's Comment 3.

CH2M HILL Comment R.2: The cover alternatives all apparently require placing the excavated material on railroad property. If one of these options is selected, what institutional controls must be implemented and on whose property? Are agreements or restrictive covenants required?

Response: Each of the cover alternatives would involve institutional controls as components of the alternatives. Specifically, land and groundwater use restrictions would be placed within the deed of the railroad property, and groundwater use restrictions would be placed within the deed of the County property. Fencing would be constructed around certain areas of the site that are not already enclosed by a security fence.

KMCC/WESTON do not anticipate that any further agreements or restrictive covenants beyond those envisioned under current agreements would be necessary for these alternate remedies.

CH2M HILL Comment R.3: Although the document's title suggests it might address sediment and soil with an equal level of detail, there is limited discussion on how sediment will be removed, dewatered, and consolidated.

Response: The final disposition of impacted sediment is addressed in the document. KMCC/WESTON propose to further address sediment removal design when alternate proposed sediment/river management approaches are considered by U.S. EPA. We understand that a U.S. EPA BTAG committee has reviewed this aspect of the project and provided recommendations to the RPM.

RESPONSE TO COMMENTS ON FOCUSED REMEDIAL ALTERNATIVES EVALUATION FOR SOIL AND SEDIMENT (CONTINUED)

CH2M HILL Specific Comments

CH2M HILL Comment R.4, Page 2-18: Can some explanation be provided why for some soil samples below the cleanup target of 78 mg/kg, and hence delineated as outside the area to be remediated, free product was observed to be present while sampling?

Response: There are six soil samples in Table 2-1 for which the table notes indicate that "product" was observed. The table notes also indicate that the total CPAHs are below the cleanup target of 78 mg/kg for these six soil samples. These samples include:

- MA1-SSG25-025012-01
- ON-1050E-01
- 75N-600E-01
- 75N-900E-01
- 150N-1350E-01
- MA1-SSG37-1004-01

All these samples were collected at the periphery of the maximally contaminated areas of the site. A review of the WESTON field notes and boring logs indicated that these samples were collected from soil that exhibited minor evidence or limited amounts of product within pore spaces and till fractures. No significant zones of well-defined free product were observed in these borings. Thus, the sample location, field notes, and analytical results provide a consistent picture of the peripheral nature of this contamination.

CH2M HILL Comment R.5, Page 3-6, Paragraph 2: The fill layer is listed as being both 30 inches and 18 inches within the paragraph. Please make consistent.

Response: Alternative 1a would have a fill layer of 30 inches.

CH2M HILL Comment R.6, Page 3-11: Will the area under the asphalt cover be regraded to promote runoff? This construction item was not evident in the cost estimate.

Response: As indicated in Table A-4 of the 31 August 1995 document, the cost item "Soil Excavation" also includes transportation and placement. As the soil is placed within Area 8, the soil would be graded and sloped to promote runoff toward a stormwater collection system. Additional detail (i.e., grading plans, stormwater management, and cover details) would be provided in the Preliminary and Intermediate Design submittals, if this alternative is selected.

RESPONSE TO COMMENTS ON FOCUSED REMEDIAL ALTERNATIVES EVALUATION FOR SOIL AND SEDIMENT (CONTINUED)

CH2M HILL Comment R.7, Page 3-13, Paragraph 1: It is stated that volatiles in the off-gas would condense and the condensate would be treated via oil water separator (if necessary). The next sentence states that the water would then be used to rehydrate the soils and the remaining water would be treated with carbon and discharged. If an oil water separator is not necessary, it appears the condensate will be put right back into the treated soils via untreated water and potentially recontaminate the soil. Please clarify the process in regards to using condensate water to rehydrate the soils.

Response: The condensate would be treated via an oil/water separator and granular activated carbon. The treated water would be utilized either to rehydrate the soil or for dust control.

CH2M HILL Comment R.8, Page 3-13, last paragraph: Please clarify. Will sediments be placed back into the flood plain or river, or will they be consolidated within one of the other areas?

Response: This alternative envisions that the hot-spot sediments would not be placed back within the floodplain or the river, but would be relocated to Area 8, a location outside of the Little Menomonee River floodplain.

CH2M HILL Comment R.9, Page 4-7, Table 4-1: Please confirm the results of the HELP modeling. The asphalt cover is projected to allow less infiltration than either an on-site RCRA cell, RCRA cover, or NR-500 soil cover. These assumptions for runoff and evapotranspiration appear to be overly conservative for an asphalt cover, especially in the long term.

Response: In order to evaluate the performance of the asphalt cover during the long-term, the hydraulic conductivity of the asphalt layer was increased and the HELP model was rerun. The table below summarizes the results.

Water Balance Component	Alternative 1d	Alternative 1d(a)	Alternative 1d(b)
Hydraulic Conductivity of Asphalt (cm/sec)	1×10^{-7}	1.9×10^{-6}	1.7×10^{-5}
Precipitation (inch/year [%])	31.06 (100)	31.06 (100)	31.06 (100)
Runoff (inch/year [%])	24.11 (77.6)	16.12 (51.9)	10.87 (35.0)
Evapotranspiration (inch/year [%])	6.94 (22.3)	14.83 (47.7)	19.39 (62.4)
Lateral Drainage from Cover (inch/year [%])	NA	NA	NA
Percolation through Cover Barrier Layer (inch/year [%])	0.004 (0.01)	0.086 (0.28)	0.80 (2.6)
Volume of Percolation through Barrier Layer (cu. ft./year/acre)	13.3	311.3	2890

**RESPONSE TO COMMENTS ON
FOCUSED REMEDIAL ALTERNATIVES EVALUATION
FOR SOIL AND SEDIMENT
(CONTINUED)**

As shown in the above table, the increase in the hydraulic conductivity would result in an increase in the percolation through the barrier layer. With a hydraulic conductivity of $1.7x10^{-5}$ cm/sec, the asphalt cover would allow a greater amount of percolation through the barrier layer than Alternatives 1a and 1c; however, the asphalt cover would still allow less percolation through the barrier layer than Alternatives 1b and 1e. KMCC/WESTON believe that a hydraulic conductivity of 1×10^{-7} cm/sec is a conservative estimate for new asphalt and that in the event of deterioration through weathering, the asphalt's hydraulic conductivity could increase to 1×10^{-5} cm/sec. However, by annual resealing of the asphalt and resurfacing the asphalt every 5 years, the hydraulic conductivity would likely never be greater than 1×10^{-5} cm/sec during a five-year design life. Therefore, although the asphalt cover system may allow more percolation through the cover during the later part of the asphalt's design life as compared to a RCRA cover, the asphalt cover (hydraulic conductivity of 1×10^{-5} cm/sec) would still be expected to exceed performance standards of either a NR 504 cover (Alternative 1b) or soil cover (Alternative 1e).

The O&M cost estimate for Alternative 1d includes additional costs for periodically maintaining the integrity of the asphalt.

CH2M HILL Comment R.10, Page 4-10, Table 4-1: NR 105 and 102 should also be considered during the remediation of sediments. Releases during construction of toxics and/or oxygen uptake of sediments may cause water quality standards to be violated.

Response: Please refer to Table 3, which summarizes ARARs for each alternative. KMCC/WESTON understand that provisions for the management of water quality standards would be necessary during remediation.

CH2M HILL Comment R.11: Sediment quality criteria would not be met, only the alternative MPB would be met. At the time of the FS, the SQC were considered TBCs. If SQC are now considered ARAR, none of the alternatives will meet this criteria.

Response: As specified in the Consent Agreement executed by KMCC and the United States, we anticipate that maximum probable background (MPB) will continue to be an acceptable alternative to SQC.

CH2M HILL Comment R.12, Ch 147 WI Statutes: The substantive requirements would have to be met for an on-site discharge to POTW.

Response: Please refer to Table 3, which summarizes ARARs for each alternative.

RESPONSE TO COMMENTS ON FOCUSED REMEDIAL ALTERNATIVES EVALUATION FOR SOIL AND SEDIMENT (CONTINUED)

CH2M HILL Comment R.13: NR 340 could be an ARAR, given plans to change (deepen) the stream.

Response: Please refer to Table 3, which summarizes ARARs for each alternative.

CH2M HILL Comment R.14: Listing the site as a CAMU would be considered an ARAR.

Response: Please refer to Table 3, which summarizes ARARs for each alternative.

CH2M HILL Comment R.15: NR 640.10 through 640.16 should be considered in this analysis. Requirements for containers used for permanent and/or temporary storage of waste are identified.

Response: Please refer to Table 3, which summarizes ARARs for each alternative.

CH2M HILL Comment R.16: NR 655 should be considered in this analysis. Requirements for design and use of waste piles is covered.

Response: Please refer to Table 3, which summarizes ARARs for each alternative.

CH2M HILL Comment R.17, Page 4-15, Table 4-3, Alt. 1e: The potential for long-term exposure is different from 1b in that only the sediment will be consolidated. Contamination in areas 5-10 was identified as being covered in place for this alternative.

Response: KMCC/WESTON agree that the potential for future exposure with Alternative 1e may be somewhat greater than with Alternative 1b. However, while the soil would remain in-place within the on-site floodplain, the contaminated soil would be covered with 6 inches of topsoil and protective vegetation. This cover would be maintained throughout the O&M period.

CH2M HILL Comment R.18, 1d: The need for replacement and long-term reliability will be different from 1b. Asphalt is proposed for the cover, not topsoil. The asphalt layer is susceptible to cracking, and since it is the only impermeable layer in the system, the requirement for maintenance is important. The asphalt will probably require complete replacement several times within a 30-year period. Also, PAHs are a component of asphalt. This, along with gasoline and oils from the parking lot, could contribute to degradation of the river if surface water controls are not instituted.

RESPONSE TO COMMENTS ON FOCUSED REMEDIAL ALTERNATIVES EVALUATION FOR SOIL AND SEDIMENT (CONTINUED)

Response: KMCC/WESTON understand that the need for maintenance to ensure long-term reliability of Alternative 1d may be greater than the need for Alternative 1b. However, WESTON included $22,000 per year for maintenance of the asphalt cover, as compared to $9,000 per year for soil cover systems of Alternatives 1a, 1b, and 1c. The higher susceptibility of soil covers to wind and water erosion must also be considered in any comparisons to the more durable asphaltic cover. In addition, Alternative 1d includes the cost for the construction of a stormwater management system ($50,000).

CH2M HILL Comment R.19, Page 4-22, Table 4-6: Expected reductions in toxicity, mobility, and volume Alternatives 1a through 1e state that the criteria is "not applicable." This criterion is specified in the NCP as being applicable. Would the word "none" be more appropriate?

Response: KMCC/WESTON agree that the word "none" may be more appropriate, as long as the administrative record reflects the limited effectiveness demonstrated by KMCC's site-specific treatability work on biological and physical/chemical treatment technologies.

CH2M HILL Comment R.20: No comparative analysis of alternatives is provided. Section 4 provides the detailed analysis of alternatives and Section 5 begins with the recommended alternative. A brief comparison of alternatives should be provided. This would provide the basis for selection of the recommended alternative.

Response: KMCC/WESTON understand that our scope was to present a focused alternatives evaluation for U.S. EPA review. To the degree practical, we followed U.S. EPA guidelines for conducting a feasibility study (FS). We did not intend to conduct a complete FS. We anticipate that the focused evaluation will serve as a basis for the reviewers' informal comparative analysis and technical exchange, as we work together toward selecting and implementing a practicable and timely site remedy.

CH2M HILL Comment R.21: The estimate of O&M for Alternative 1A includes $50,000 for leachate treatment. Given the HELP estimate of infiltration, this equates to more than $30 per gallon.

Response: The HELP model was used as a comparative tool within the context of the focused remedial alternatives evaluation. Because the input parameters for the model are not based on actual field data, the estimated leachate volume should not be compared with WESTON's estimate for O&M. The estimate of $50,000 is based on capital equipment, operator labor, system monitoring, replacement of filters and carbon, utilities, and equipment repairs and replacement. The estimate of $50,000 is appropriate for this conceptual cost estimate, which has a range of accuracy of +50 to -30 percent.

Table A-1

COST SUMMARY FOR ALTERNATIVE 1F
EXCAVATE AND PLACE SOIL AND SEDIMENT IN ON-SITE CONTAINMENT CELL
MOSS-AMERICAN SITE
MILWAUKEE WISCONSIN

ITEM OF WORK	Quantity	Unit Price	Unit	Cost	Subtotal	COMMENTS
DIRECT COSTS						
MOBILIZATION OF CONTRACTORS	Job		Estimate	$100,000	$100,000	
SITE PREPARATION						
Clearing and Grubbing	11.5	$5,000	Acre	$57,500		Includes cell area and excavation areas.
Access Improvements	Job		Estimate	$30,000		Includes road and site security upgrades.
Temporary Fencing	1000	$5	LF	$5,000		Includes temporary fencing during the construction phase.
Temporary Facilities	1		Estimate	$80,000		Includes purchase of trailer and associated equipment.
Utilities Install/Use	16	$6,000	Month	$96,000	$268,500	Includes electrical hookup, and electrical, water and sanitation during project.
SOIL/SEDIMENT EXCAVATION (Dispose at Cell: Includes excavation, transport, and placement)						
Area 5	5,700	$10	CY	$57,000		Assumes excavation depth is approximately 8 feet.
Area 6	2,500	$5	CY	$12,500		Assumes excavation depth is approximately 4 feet.
Area 7	16,100	$10	CY	$161,000		Assumes excavation depth is approximately 10 feet.
Area 8	17,900	$10	CY	$179,000		Assumes excavation depth is approximately 7 feet.
Area 9	12,500	$10	CY	$125,000		Assumes excavation depth is approximately 8.5 feet.
Area 10	600	$5	CY	$3,000		Assumes excavation depth is approximately 4 feet.
Sediments	8,000	$120	CY	$960,000	$1,497,500	Unit price is a weighted average that considers clearing, grubbing, dewatering, haul roads, and other requirements for excavation in river.
LINER CONSTRUCTION: (Includes material, transport, and placement)						
Geotextile Filter Fabric	250,800	$0.20	SF	$50,160		Assumes 6 oz. filter fabric delivered and installed , and 10% additional material due to overlap/scrap.
Drainage Layer (Sand)	9,000	$12	CY	$108,000		Layer is 1' thick with an additional 5% for compaction.
Secondary Liner (Clay)	31,300	$10	CY	$313,000	$471,160	Layer is 3' thick with an additional 15% for compaction.
CAP CONSTRUCTION - NR 504 Cover -(Includes material, transport, and placement)						
Vegetation	6.0	$2,000	Acre	$12,000		Assumes the area is hydroseeded.
Topsoil	4,900	$14	CY	$68,600		Layer is 0.5' thick with an additional 5% for compaction.
Cover Layer	14,100	$8	CY	$112,800		Layer is 1.5' thick with an additional 5% for compaction.
Geotextile Filter Fabric	257,300	$0.20	SF	$51,460		Assumes 6 oz. filter fabric delivered and installed , and 10% additional material due to overlap/scrap.
Drainage Layer (Sand)	8,900	$12	CY	$106,800		Layer is 1' thick with an additional 5% for compaction.
Clay Layer	18,200	$10	CY	$182,000	$533,660	Layer is 2' thick with an additional 15% for compaction.

Table A-1

COST SUMMARY FOR ALTERNATIVE 1F
EXCAVATE AND PLACE SOIL AND SEDIMENT IN ON-SITE CONTAINMENT CELL
MOSS-AMERICAN SITE
MILWAUKEE WISCONSIN

ITEM OF WORK	Quantity	Unit Price	Unit	Cost	Subtotal	COMMENTS
LEACHATE COLLECTION SYSTEM						
NR 500 Cell	2000	$30	LF	$60,000		Assumes one lateral leachate collection pipe in both primary and secondary systems.
					$60,000	
GAS VENTING SYSTEM						
NR500 Cell	Job		Estimate	$50,000		Passive venting system includes lateral collection pipes in gravel trenches with vents.
					$50,000	
STORMWATER MANAGEMENT SYSTEM	Job		Estimate	$30,000		Includes perimeter ditches, sedimentation basin and outfall.
					$30,000	
LEACHATE PRETREATMENT SYSTEM						Assumes maximum flow of 5 gpm.
Treatment Building	1	$20,000	Estimate	$20,000		Assumes pre-engineered building.
Equalization Tank	1	$18,000	Estimate	$18,000		Assumes one 10,000 gallon tank.
Oil/Water Separator	1	$10,000	Estimate	$10,000		
Air Stripper	1	$8,000	Estimate	$8,000		Assumes one low profile air stripper.
Liquid GAC	2	$5,000	Each	$10,000		Assumes two 55-gallon canisters in series.
Electrical/Mechanical	Job		Estimate	$20,000		
Startup/shakedown	Job		Estimate	$10,000		Assumes one week of labor.
Effluent Line Construction	1500	$35	LF	$52,500		
Sampling Manhole/Equipment	1	$10,000	Estimate	$10,000		
					$158,500	
EXCAVATION RESTORATIONS						
Backfilling	66,500	$8	CY	$532,000		Assumes all excavated areas are backfilled with locally available fill soil.
Revegetation	6.0	$2,000	Acre	$12,000		Assumes the area is hydroseeded.
					$544,000	
GROUNDWATER MONITORING WELL						
Monitoring Well Installation	4	$4,500	Well	$18,000		Assumes four monitoring wells (3 downgradient and one upgradient).
Monitoring Well Development	4	$660	Day	$2,640		
					$20,640	
VERIFICATION SAMPLING/LABORATORY ANALYSIS	Job		Estimate	$50,000		Allocation for field lab or fixed off-site commercial laboratory analysis of soil samples.
					$50,000	
FENCE CONSTRUCTION	3000	$12	LF	$36,000		Assumes 6 foot high fence with three strands of barbed wire.
					$36,000	
DEED RESTRICTIONS	Job		Estimate	$10,000		Includes survey plat and deed notice.
					$10,000	
DIRECT COST SUBTOTAL					**$3,829,960**	

Table A-1

COST SUMMARY FOR ALTERNATIVE 1F
EXCAVATE AND PLACE SOIL AND SEDIMENT IN ON-SITE CONTAINMENT CELL
MOSS-AMERICAN SITE
MILWAUKEE WISCONSIN

ITEM OF WORK	Quantity	Unit Price	Unit	Cost	Subtotal	COMMENTS
INDIRECT COSTS						
Engineering/Design	Job		Estimate	$350,000		Includes 30, 60, 90, and 100% Design submittals and related RD Plans.
Contractor Procurements	Job		Estimate	$50,000		
Construction Management						
Resident Engineering	16	$30,000	Month	$480,000		
Surveying	Job		Estimate	$50,000		
QA/QC Testing	6	$5,000	Acre	$30,000		
Health and Safety Monitoring	16	$15,000	Month	$240,000		
Post-Construction Documentation and Certification	Job		Estimate	$60,000		
Site Security	16	$5,000	Month	$80,000		
INDIRECT COST SUBTOTAL					**$1,340,000**	
OPERATIONS AND MAINTENANCE COSTS (POST-CLOSURE)						
GROUNDWATER MONITORING COSTS						
Labor	64	$50	Hour	$3,200		
Analytical	8	$500	Sample	$4,000		
Equipment	2	$300	Day	$600		
LANDFILL MAINTENANCE						
Mowing	1	$4,000	Annual	$4,000		
Cover Repair	Job		Estimate	$5,000		
Leachate Pre-treatment	Job		Estimate	$50,000		Includes Monitoring, O & M, GAC replacement.
Quarterly Inspections	4	$2,000	Quarter	$8,000		
LFG Monitoring	Job		Estimate	$5,000		
Leachate Treatment at POTW	1		Estimate	$26,300		This is a weighted cost over the 30-year period. Leachate production will be greater during years 1 through 5.
ANNUAL O & M COST SUBTOTAL					**$106,100**	
TOTAL PRESENT CAPITAL COST (DIRECT AND INDIRECT COSTS)					$5,170,000	
CONTINGENCY (15%)					$775,500	Assumes 15% contingency on future and present capital costs.
TOTAL CAPITAL COST WITH CONTINGENCY					**$5,945,500**	
PRESENT WORTH OF ANNUALIZED O&M COSTS					$1,316,600	Converts 30 years of annual O & M costs into a present value.
TOTAL PRESENT WORTH					**$7,262,100**	

Table A-2

COST SUMMARY FOR ALTERNATIVE 2
EXCAVATE, SOLVENT EXTRACTION, AND PLACE BENEATH VEGETATIVE COVER
MOSS-AMERICAN SITE
MILWAUKEE WISCONSIN

ITEM OF WORK	Quantity	Unit Price	Unit	Cost	Subtotal	COMMENTS
DIRECT COSTS						
MOBILIZATION OF CONTRACTORS	Job		Estimate	$100,000		
					$100,000	
SITE PREPARATION						
Clearing and Grubbing	4.5	$5,000	Acre	$22,500		Includes excavation areas.
Access Improvements	Job		Estimate	$30,000		Includes road and site security upgrades.
Temporary Fencing	1000	$5	LF	$5,000		Includes temporary fencing during the construction phase.
Temporary Facilities	1		Estimate	$80,000		Includes purchase of trailer and associated equipment.
Utilities Install/Use	8	$6,000	Month	$48,000		Includes electrical hookup, and electrical, water and sanitation during project.
					$185,500	
SOIL/SEDIMENT EXCAVATION (Includes excavation, and transport to solvent extraction unit)						
Area 5	5,700	$10	CY	$57,000		Assumes excavation depth is approximately 8 feet.
Area 6	2,500	$5	CY	$12,500		Assumes excavation depth is approximately 4 feet.
Area 7	16,100	$10	CY	$161,000		Assumes excavation depth is approximately 10 feet.
Area 8	17,900	$10	CY	$179,000		Assumes excavation depth is approximately 7 feet.
Area 9	12,500	$10	CY	$125,000		Assumes excavation depth is approximately 8.5 feet.
Area 10	600	$5	CY	$3,000		Assumes excavation depth is approximately 4 feet.
Sediments	8,000	$120	CY	$960,000		Unit price is a weighted average that considers clearing, grubbing, dewatering, haul roads, and other requirements for excavation in river.
					$1,497,500	
SOLVENT EXTRACTION OF SOIL						Assumes project two construction seasons. Sediments assumed to not require thermal treatment.
Treatability Study/Air Permitting	Job		Estimate	$100,000		
Solvent Extraction of Soils	60,800	$265	CY	$16,112,000		Based on vendor quotes and includes equipment, labor and materials. Three vendor quotes were received at $210, $218, and $315 per CY and a mean cost of approximately $250/CY was used with an additional $15/CY added to the base unit price for disposal of process residuals.
					$16,212,000	
EXCAVATION RESTORATIONS						
Place soil/sediment into excavations	69,600	$4	CY	$278,400		Assumes all excavated areas are backfilled with treated soil. The 8,000 CY of sediment are placed on-site.
Topsoil	3,600	$14	CY	$50,400		Topsoil is imported from off-site.
Revegetation	4.5	$2,000	Acre	$9,000		Assumes the area is hydroseeded.
					$337,800	
VERIFICATION SAMPLING/LABORATORY ANALYSIS	Job		Estimate	$50,000		Allocation for field lab or fixed off-site commercial laboratory analysis of soil samples.
					$50,000	
DIRECT COST SUBTOTAL					**$18,382,800**	

Table A-2

COST SUMMARY FOR ALTERNATIVE 2
EXCAVATE, SOLVENT EXTRACTION, AND PLACE BENEATH VEGETATIVE COVER
MOSS-AMERICAN SITE
MILWAUKEE WISCONSIN

ITEM OF WORK	Quantity	Unit Price	Unit	Cost	Subtotal	COMMENTS
INDIRECT COSTS						
Engineering/Design	Job		Estimate	$200,000		Includes 30, 60, 90, and 100% Design submittals and related RD Plans.
Contractor Procurements	Job		Estimate	$30,000		
Construction Management						
Resident Engineering	8	$30,000	Month	$240,000		
Surveying	Job		Estimate	$30,000		
QA/QC Testing	Job		Estimate	$20,000		
Health and Safety Monitoring	8	$15,000	Month	$120,000		
Post-Construction Documentation and Certification	Job		Estimate	$60,000		
Site Security	8	$5,000	Month	$40,000		
INDIRECT COST SUBTOTAL					$740,000	
OPERATIONS AND MAINTENANCE COSTS (POST-CLOSURE)						
No O & M Costs Related to this Alternative						
ANNUAL O & M COST SUBTOTAL					$0	
TOTAL PRESENT CAPITAL COST (DIRECT AND INDIRECT COSTS)					$19,122,800	
CONTINGENCY (15%)					$2,868,500	Assumes 15% contingency on future and present capital costs.
TOTAL CAPITAL COST WITH CONTINGENCY					$21,991,300	
PRESENT WORTH OF ANNUALIZED O&M COSTS					$0	Converts 30 years of annual O & M costs into a present value.
TOTAL PRESENT WORTH					$21,991,300	

Table A-3

Addendum to Table 4-2 of Focused Remedial Alternatives Evaluation for Soil and Sediment
Compliance with Potential ARARs
Moss-American Site
Milwaukee, Wisconsin

Potential ARAR	Comments	Alternatives									
		1a	1b	1c	1d	1e	2	3	4	5	6
POTENTIAL FEDERAL ARAR											
Action-Specific											
Corrective Action Management Units or Temporary Units; Corrective Action provisions under Subtitle C	40 CFR 264.552. Regulations governing the designation and use of RCRA Corrective Action Management Units.	NA	Y	Y	Y	Y	Y	Y	Y	Y	NA
POTENTIAL STATE ARARs											
Action-Specific											
Ch 147 WI Statutes	Requirements for discharges to POTWs. Landfill leachate generated would be treated and potentially discharge to POTW.	Y	NA	NA	NA	NA	NA	NA	NA	NA	NA
NR 102	Water quality standards for Wisconsin surface waters. During the excavation and removal of sediments, various surface water standards must be maintained.	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
NR 105	Surface water quality criteria for toxic substances. These criteria should not be exceeded during the excavation and removal of sediments.	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

Table A-3

Addendum to Table 4-2 of Focused Remedial Alternatives Evaluation for Soil and Sediment
Compliance with Potential ARARs
Moss-American Site
Milwaukee, Wisconsin
(Continued)

Potential ARAR	Comments	Alternatives									
		1a	1b	1c	1d	1e	2	3	4	5	6
NR 340	Nonmetallic mining and reclamation associated with navigable waterways and adjacent areas. Permit application requirements for excavation and dredging operations within streambeds.	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
NR 636	Corrective action for solid waste management units. Regulations governing the designation and use of RCRA Corrective Action Management Units.	NA	Y	Y	Y	Y	Y	Y	Y	Y	Y
NR 640	Container standards. Regulations apply to facilities that store or treat hazardous waste in containers.	NA	NA	NA	NA	NA	Y	NA	NA	Y	NA
NR 645	Tank system standards. Regulations apply to facilities that store or treat hazardous waste in tank systems.	Y	NA	NA	NA	NA	Y	NA	NA	Y	NA
NR 655	Waste pile standards. Regulations apply to facilities that store or treat hazardous waste in waste piles.	NA	NA	NA	NA	NA	NA	Y	NA	NA	NA

NA - Not applicable.

ATTACHMENT B

RESPONSE TO COMMENTS ON PRELIMINARY DESIGN FOR GROUNDWATER REMEDIAL SYSTEM

RESPONSE TO COMMENTS ON PRELIMINARY DESIGN FOR GROUNDWATER REMEDIAL SYSTEM

U.S. EPA's GENERAL COMMENTS

EPA Comment: *Given the nearly simultaneous receipt of these two documents, I believe there should be an indication made as to which phase of remediation should next be pursued more aggressively into the remedial design/remedial action. My preference is for the groundwater remedial system. I have two main reasons for this: 1) Most fundamentally, stopping the flow of contaminated groundwater into surface water at the site is of basic environmental importance, and 2) The soils/sediments alternatives appear to raise more complex ARARs/ROD amendment questions which will require resolution before detailed design can proceed.*

Response: KMCC/WESTON request a meeting with U.S. EPA/WDNR to invite discussions on the sequence and timing of the various activities and actions necessary to effect a prudent soil and groundwater remedy at the site.

We also must emphasize to U.S. EPA and other reviewers that the groundwater remedial system design is highly interdependent on the selected remedy for on-site soil -- as soil is a contaminant source area to groundwater. As can be observed from predesign groundwater quality data presented in the November 1994 Technical Memorandum, impacted groundwater is limited primarily to areas where groundwater is in contact with contaminated soils that are substantially above cleanup standards. The recommended soil remedy (Alternative 1d) proposes to remove, consolidate, and cover these soils. This would substantially change the configuration of the source areas and would increase the efficiency and effectiveness of the groundwater remediation system. Groundwater system remedial design including groundwater modeling, funnel-and-gate location and configuration, collection trench locations, and other design elements are highly interrelated to the soil remedy and the corresponding final site configuration. Thus, we caution against U.S. EPA's desire to complete groundwater remedial design in advance of soil remedy selection.

U.S. EPA'S SPECIFIC COMMENTS

EPA Comment 1: *The preliminary design presents a choice between a more conventional groundwater collection and treatment system and a "funnel and gate" containment and in-situ treatment system. Until results of the treatability work involving contaminant treatment utilizing microorganisms are available, as well as more detailed descriptions of methods/procedures used in this study are available, U.S. EPA cannot determine whether the in-situ treatment system is acceptable.*

RESPONSE TO COMMENTS ON PRELIMINARY DESIGN FOR GROUNDWATER REMEDIAL SYSTEM (CONTINUED)

Response: Accompanying this response document (as Attachment C) is the "Preliminary Biotreatability Study for Groundwater Remedial Design" prepared by the Waterloo Centre for Groundwater Research, University of Waterloo. The primary goal of the study was to determine if organic contaminants within the site groundwater and soil were subject to biotransformation by indigenous microorganisms. Secondly, the study evaluated the rate and degree of degradation to assess whether biological treatment of site groundwater within a funnel-and- gate system might be explored as a potential remediation technology.

The preliminary biotreatability study of Moss-American site groundwater indicated that site soils and groundwater are microbiologically active, and biotransformation of certain target constituents in groundwater proceeds favorably under aerobic conditions. As expected, the heavier-ring PAH compounds (which are less prevalent or absent in site groundwater) were recalcitrant and less readily degraded by biological processes. The study findings provide continued support for considering a funnel-and-gate technology at the Moss-American site. Please also reference the response to U.S. EPA Comment 4 in Attachment B.

***EPA Comment 2**: I request that your firm, in consultation with your client, develop a detailed schedule showing expected delivery dates for items critical to groundwater remedial system design, including such items as: results/methods/procedures related to the in-situ treatability work, opportunity for consultation with the agencies in arriving at a decision as to whether the design shall be along more conventional lines or will utilize the "funnel and gate"/in-situ treatment approach, receipt/evaluation of groundwater model assumptions/results/design influence, intermediate design package, prefinal/final design package. My expectation at the outset is that like the free product recovery system I am hopeful that the groundwater remedial action can go on line about one year from now.*

Response: Please refer to KMCC's/WESTON's response to U.S. EPA's general comment on Page B-1. KMCC/WESTON anticipate that the work schedule/sequence can be discussed in a forthcoming meeting with U.S. EPA.

***EPA Comment 3**: I note that in the papers attached to the preliminary design, the "funnel and gate"/in-situ treatment groundwater management approach is perceived by the authors as being especially useful for sites involving nonaqueous phase liquids. Given the free product presence at the Moss-American site, it may be appropriate to consider such an approach. However, as will be discussed further in the comments on the soils alternatives, this may bring about the need to revisit certain reasoning in the 1990 ROD concerning appropriate type of cover for soils/sediments.*

RESPONSE TO COMMENTS ON PRELIMINARY DESIGN FOR GROUNDWATER REMEDIAL SYSTEM (CONTINUED)

Response: KMCC/WESTON concur that the U.S. EPA, WDNR, and their technical consultants should utilize current site data, predesign engineering studies, and U.S. EPA technical guidance on DNAPL to revisit reasoning in the 1990 ROD related to cover systems for soil and sediment.

***EPA Comment 4**: Given the results of the treatability work done on site soils, I am somewhat concerned about the ultimate success a biological in-situ treatment approach can bring about. We may find, much like the soils work, that some of the higher molecular weight PAHs may not be treated efficiently. If this is the case, I would urge you to consider treatability study of a more aggressive chemical oxidation approach for in-situ treatment, such as usage of ozone and/or hydrogen peroxide. If an in-situ treatment approach is adopted, it will important for you to work with WDNR in how to accomplish this and yet attain injection concepts within NR 140.*

Response: The results of the "Preliminary Biotreatability Study for Groundwater Remedial Design" (Attachment C) indicated that the 2-ringed PAH compounds (naphthalene, methylnaphthalene, biphenyl) and the monoaromatic hydrocarbons (benzene, toluene, ethylbenzene, and xylene) were rapidly depleted through biodegradation. The 4-ringed PAH compounds (fluoranthene and pyrene), which are quite hydrophobic and relatively immobile, were slowly degraded within the active, nutrient-amended contaminated soil microcosms. Degraded aqueous phase molecules were replaced, however, by new PAH molecules desorbing from the soil.

The funnel-and-gate system seems to be technically feasible because the bulk of PAHs and monoaromatic hydrocarbons likely to enter the treatment gate would be smaller-ringed compounds, since the higher-ringed PAHs are hydrophobic and are relatively immobile. These smaller compounds are likely to be more mobile and are generally more readily degraded. If the higher-ringed PAHs enter the treatment gate, the retardation effect would result in a longer residence time, thereby allowing these PAHs greater opportunity to biodegrade or be contained.

Based on the preliminary biotreatability results, WESTON is encouraged that the design of a funnel-and-gate system may be effective in containing and treating the site groundwater constituents. Per U.S. EPA's request, WESTON would consider the Groundwater Quality Standards (NR 140) when designing the nutrient and oxygen delivery systems.

***EPA Comment 5**: Given the fundamental importance of keeping groundwater contaminants out of surface water, design should also address what means of monitoring will be employed to check on results - especially on water quality after passage through a gate and treatment therein if a funnel/gate approach is adopted.*

RESPONSE TO COMMENTS ON PRELIMINARY DESIGN FOR GROUNDWATER REMEDIAL SYSTEM (CONTINUED)

Response: WESTON/KMCC understand that performance monitoring of the remedial systems will be required. Upon selection of the groundwater remedial alternative, WESTON will provide further details of the monitoring systems in the Intermediate Design (60%) Submittal for the Groundwater Remedial System.

EPA Comment 6: *The matter of passage of possible additional free product into the groundwater system should also be considered. I note the completion of construction of the free product recovery system above what is basically contaminated soil area # 7 as depicted on figures within the documents submitted. However, Figure 2-1 depicts "product presence" findings of Cross Section A-A'. At location TW-01, which appears to correspond to the eastern half of soils Area 9, free product appears to be depicted above the water table. Were a funnel-and-gate type system adopted, what would be the best approach to consider to aid in assuring that certain soil areas do not pose further groundwater source threats? For example, should soil areas 7 and 9 be excavated and treated on-site (e.g., by thermal desorption), or should a system of free product collection trenches be deployed?*

Response: The potential for additional free-product passage into the groundwater remedial system would be considered as the design progresses to intermediate (60%) stages. The gate treatment media can be designed to intercept and collect free-product migration prior to its entering and "fouling" the treatment media. Similarly, a more conventional groundwater collection and treatment system can provide for accumulation and removal of free product prior to its entering the treatment works.

Soil borings, temporary wells, and split-spoon soil samples collected during 1994 predesign investigations provided a basis for generating geological cross-sections and extent- of-contamination mapping (refer to November 1994 Technical Memorandum and 13 July 1995 Response to Comments documents). Further, Predesign Task 3 focused on evaluating the presence and mobility of free product at former process areas of the site. The findings of this predesign task were important in considering remedial measures. The presence of free product in soils of the site is not necessarily indicative of a threat from contaminant mobility or migration. The mobility of a creosote DNAPL in a fine-grained, clay-rich soil is limited. This phenomenon was observed during mobility testing in several of the TW-series wells installed by WESTON. The currently operating free-product recovery and removal system is limited to its present area, based on mobility tests.

RESPONSE TO COMMENTS ON PRELIMINARY DESIGN FOR GROUNDWATER REMEDIAL SYSTEM (CONTINUED)

Thus, we believe that through a combination of soil containment (engineered cover system) and groundwater management (via funnel and gate or collection trench), source areas would be effectively remediated with engineering controls consistent with planned end use for the site. Thermal desorption seems to present a greater short-term risk of introducing contaminants to the air media via excavation and thermal treatment, at a far greater cost.

EPA Comment 7: I note a statement made in the paper entitled "In Situ Remediation of Contaminated Ground Water: The Funnel-and-Gate System": The last paragraph on page 465 notes that "...The upstream wall deflects most ground water around the contaminant source zone..." With that in mind, why does the drawing depicting Alternative 1 on page 3-4 place the upstream wall in what appears to be the middle of the plume? Why not a wall further west/upgradient of the plume? What is the basic rationale for current location choice of Alternative 1 gates and Alternative 2 collection trenches?

Response: Based upon review of the groundwater quality data, WESTON determined that there are two limited source areas contributing to PAH/BTEX groundwater contamination. These source areas include Areas 7 and 8. Based on this information, WESTON has initially located both the funnel-and-gate system (Alternative 1) and the collection trenches (Alternative 2) directly downgradient of these sources areas. We can give additional consideration to an upgradient funnel as we proceed forward in design and, more importantly, as further determination of the soil/sediment remedy is made.

RESPONSE TO COMMENTS ON PRELIMINARY DESIGN FOR GROUNDWATER REMEDIAL SYSTEM (CONTINUED)

CH2M HILL'S COMMENTS

CH2M HILL Comment 1: In general, both concepts appear feasible. The funnel and gate system, a relatively new technology, appears to be the preferred system based upon site hydrogeologic conditions and overall cost. Before concluding that Alternative 1 is clearly the preferred option, several questions should be addressed, including:

- *The bench test results on biodegradation from U-Waterloo were not available for review with this report. While biodegradability is expected to be demonstrated, the ability of the system to degrade compounds of concern within constraints imposed by the system must be demonstrated.*
- *The position of water level and water quality monitoring points as they relate to the engineered controls.*
- *The course of action ("flowchart") proposed to address changes in the system related to changes in water level, water quality, or the injection/extraction systems.*
- *The flexibility in both systems to adjust for hydraulic changes at the site caused by the proposed engineering controls.*
- *The estimated cleanup time comparison for both systems.*

Response: KMCC/WESTON have included the "Preliminary Biotreatability Study for Groundwater Remedial Design" to accompany this response document as Attachment C. While the preliminary treatability results are encouraging, KMCC/WESTON acknowledge the questions raised by CH2M HILL, Inc. We do not expect that steadfast answers to these questions are essential to continuing consideration of this emerging funnel-and-gate technology. Given the challenges posed by remediating DNAPL in a fine-grained, clay-rich hydrogeological setting, we believe similar technical questions and uncertainties exist for the more traditional groundwater collection and ex-situ treatment technologies expressed in the ROD.

RESPONSE TO COMMENTS ON PRELIMINARY DESIGN FOR GROUNDWATER REMEDIAL SYSTEM (CONTINUED)

Funnel and Gate

CH2M HILL Comment G.1: The placement of low-permeability barriers at the site will cause groundwater mounding on the upgradient side of the boundary. This will enhance the potential for lateral migration and, if mounding is severe, may cause contaminated groundwater to migrate around the ends of the low-permeability barrier. We agree with the need to utilize groundwater flow modeling to theoretically evaluate the system design. We suggest that the monitoring plan consider monitoring the groundwater levels and quality near the barrier endpoints and also in and near the gates.

Response: WESTON would conduct groundwater modeling during development of the 60% Intermediate Design. We would consider this comment in preparing a draft monitoring plan detailing both hydraulic and treatment performance monitoring points within the Intermediate Design (60%) submittal.

CH2M HILL Comment G.2: A projection for the estimated cleanup to PALs at the site would help in the comparison of the funnel and gate system with the collection and treatment system.

Response: Both groundwater treatment alternatives are generally passive systems and rely on the groundwater to travel toward the collection systems. Therefore, there would be relatively little difference in projection of "cleanup" times between the two alternatives. Due to the presence of DNAPL or residual DNAPL (contaminant source for dissolved constituents), PALs may not be technically achievable within the groundwater for decades.

CH2M HILL Comment G.3: What potential is there for interferences that could adversely affect in situ treatment operations (e.g., NAPL passing into the gate, iron bacteria growth in the media, or precipitation of iron on media)?

Response: In general, as identified by CH2M Hill, DNAPL could interfere with the treatment gate based on the gate's configuration. WESTON would consider this potential occurrence within the Intermediate Design (60%) phase. One approach to managing DNAPL would be to construct a "sump" on the upgradient side of the gate. The sump would be located beneath the shallow groundwater and would be keyed into the impermeable silty clay unit. An extraction system, similar to the current operating free-product removal system, could be constructed within the sump to remove and manage the DNAPL.

RESPONSE TO COMMENTS ON PRELIMINARY DESIGN FOR GROUNDWATER REMEDIAL SYSTEM (CONTINUED)

The gate design would be constructed of a granular media instead of a reactive metal (iron). Therefore, iron bacteria growth and precipitation of iron would not be a concern with the current design. However, since this system is basically a bioreactor, it could experience the same type of operational problems as a typical biological system (i.e., fouling or clogging of the media). KMCC/WESTON would address operation and maintenance (O&M) of the system within the draft O&M plan that would be submitted concurrently with the Prefinal Design, once a groundwater treatment alternative is selected. Low-cost, effective methods of gate media rejuvenation are available and are expected to be implemented on a periodic basis during system O&M.

CH2M HILL Comment G.4: Figure 2-1 indicates that the gravel fill and silty sand are not continuous. Could this adversely affect the funnel system's ability to capture the plume? Could modifications to the soil on the upgradient side of the barrier significantly improve the collection performance?

Response: Results of predesign groundwater elevation monitoring by WESTON indicate that groundwater flow toward the river is relatively uniform and exhibits very little variability. The presence of discontinuous zones of increased permeability (i.e., gravel fill and silty sand) may act to guide the direction of the contaminant plume. Both free-phase and dissolved-phase contaminants tend to migrate along paths of least resistance; therefore, they should migrate preferentially within the zones of increased permeability. The funnel system can be designed to enhance this phenomenon.

Ultimately, groundwater modeling would be used to simulate the effect that the heterogenous nature of the aquifer would have on the final system design. The stratigraphic variability upgradient of the funnel system should only affect the system component design (i.e., number, length, and location of the funnel system barriers and gates) and should not adversely affect the system's ability to manage the groundwater zone.

CH2M HILL Comment G.5: Page 3-3, Paragraph 2: Will the model also be used to select the number of gates versus just design the gate?

Response: Groundwater modeling would allow WESTON to simulate the effects that various funnel-and-gate configurations have on head pressure within the aquifer, thus predicting the redirection of groundwater flow. Simulating these conditions would allow WESTON to design the funnel system (i.e., barrier length and configuration), and also the number of gates required to maximize the effectiveness of the system.

RESPONSE TO COMMENTS ON PRELIMINARY DESIGN FOR GROUNDWATER REMEDIAL SYSTEM (CONTINUED)

CH2M HILL Comment G.6: Will selection of gate media to maximize permeability adversely affect the radius of influence of the sparge well? Could the use of more adsorptive media (e.g., activated carbon) improve performance by increasing the effective residence time?

Response: The nutrient/addition well is not intended to act as a sparge well. If this alternative is selected, WESTON would evaluate the potential for and magnitude of volatilization occurring during the introduction of oxygen. We may alternately design the system to have a liquid oxygen source (hydrogen peroxide) or a solid-phase oxygen releasing compound. As stated in "Funnel-and-Gate for In-situ Groundwater Plume Containment" (located in Appendix A of "Preliminary Design for Groundwater Remedial System"), current investigations involving methods of chemical addition (nutrients or oxygen) utilize "emitter tubes." The emitter tubes are located within the upgradient zone of the gate. The emitter tubes add chemicals to the gate through diffusion induced by maintaining concentrated solutions within the tube.

During the Intermediate (60%) Design Phase, KMCC/WESTON would evaluate the potential use of more adsorptive media, such as activated carbon mixed with soil as the gate media, if this alternative is selected.

CH2M HILL Comment G.7: The O&M of the funnel and gate alternative includes "gate monitoring." How will samples be collected?

Response: KMCC/WESTON anticipate the use of traditional groundwater monitoring wells to monitor the effluent from the gate. Additional information on the monitoring program would be included with the Intermediate Design (60%) phase if this alternative is selected.

CM2M HILL Comment G.8: As proposed, the gate may simply act as a point of sparging of the more volatile BTEX compounds to the atmosphere. Although the mass emitted may be relatively small, the system may not be in compliance with current WDNR policies on sparging systems since it does not provide for collection of off-gas.

Response: As indicated in the response to Comment G6, KMCC/WESTON do not intend to operate the system as a sparge well. Therefore, the WDNR policies on sparging systems may not be applicable.

Collection and Treatment

CH2M HILL Comment G.9: It is essential that a detailed groundwater monitoring plan be developed to monitor the effectiveness of the capture system.

RESPONSE TO COMMENTS ON PRELIMINARY DESIGN FOR GROUNDWATER REMEDIAL SYSTEM (CONTINUED)

Response: KMCC/WESTON understand that a detailed groundwater monitoring plan should be developed to monitor the system's effectiveness. However, it is our understanding that this information would be contained in the Draft Operation and Maintenance Plan that would be submitted as part of the Prefinal Design submittal.

CH2M HILL Comment G.10: The system, as described, does not appear to allow for sections of the trench system to be monitored and shut down as portions of the groundwater contamination is reduced to below the PALs.

Response: If the collection and treatment system is selected, the trench system would be designed to allow sections of the trench to be shut down as areas of groundwater contamination achieve cleanup levels.

CH2M HILL Comment G.11: A projection for the estimated cleanup to PALs at the site would help in the comparison of the collection and treatment system with the funnel and gate system.

Response: Please see response to Comment G2.

CH2M HILL Comment G.12: O&M costs for Alternative 2 assume 40 hrs/week operator. While it may require this amount of time occasionally, it is unlikely that this amount of time will be required for a physical treatment system. (This change alone, however, will not cause Alternative 2 to be less in cost than Alternative 1.)

Response: KMCC/WESTON would reevaluate the O&M cost estimate for Alternative 2 within the Intermediate Design submittal if this alternative is selected.

CH2M HILL Comment G.13: If we need an oil/water separator for Alternative 2, does this suggest that free product could enter the gates and adversely affect their operation or performance?

Response: An oil/water separator is specified in the preliminary conceptual design for Alternative 2 because the groundwater extracted for treatment may become emulsified by physical/chemical treatment prior to filtration and carbon polishing. The funnel-and-gate system will manage the occurrence of free-phase DNAPL, as outlined in our response to Comment G-3. The presence of LNAPLs are anticipated to be managed by the treatment media.

RESPONSE TO COMMENTS ON PRELIMINARY DESIGN FOR GROUNDWATER REMEDIAL SYSTEM (CONTINUED)

CH2M HILL Comment G.14: What's the advantage of discharging to POTW versus to Menomonee River? Could Alternative 2 discharge to the river?

Response: The preliminary design for Alternative 2 includes the possibility of discharging to the POTW or the Little Menomonee River. If Alternative 2 is selected, WESTON would determine the appropriate discharge alternative within the Intermediate and Prefinal Design submittals. Specifically, the appropriate discharge alternative will be determined based on a detailed comparison of the following key issues: discharge limits; administrative feasibility of each alternative (i.e., WDNR requirements for discharge to the Little Menomonee River versus City of Milwaukee requirements for discharge to the POTW); technical feasibility of treatment alternatives to achieve either discharge standards; and long-term economic issues (i.e., monitoring requirements, permit renewals, and reporting requirements).

ATTACHMENT C

PRELIMINARY BIOTREATABILITY STUDY FOR GROUNDWATER REMEDIAL DESIGN

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 limi

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.

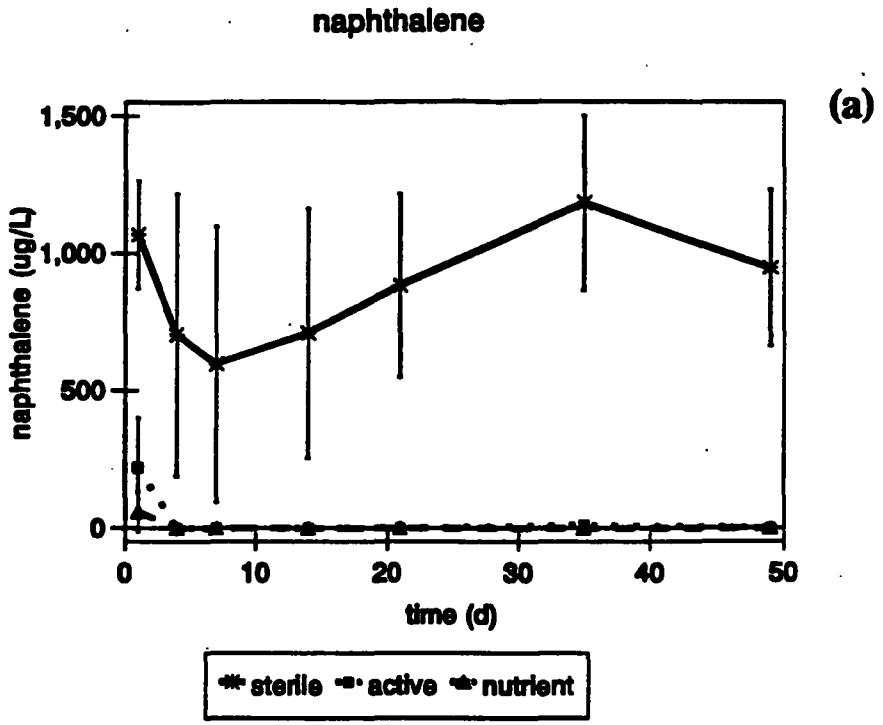
Figures 1-7 depict the aqueous concentrations in contaminated soil-containing microcosms over 49 d. A comparison of the contaminant levels depicted in the Figures with levels in the groundwater used in microcosm preparation (data shown in Appendix II) confirmed that the bulk of the aqueous-phase organics 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

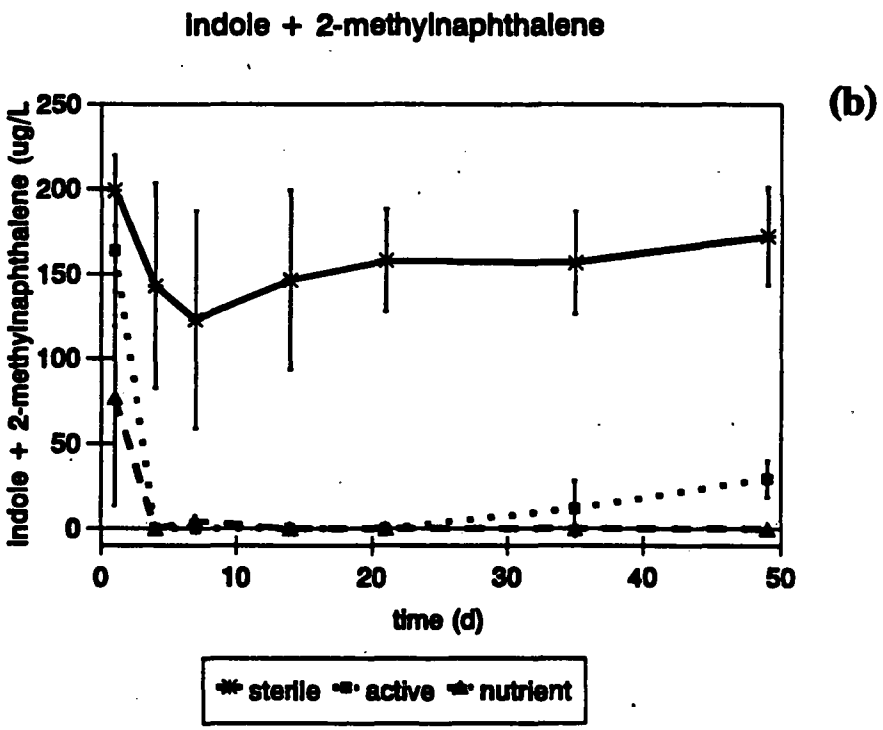
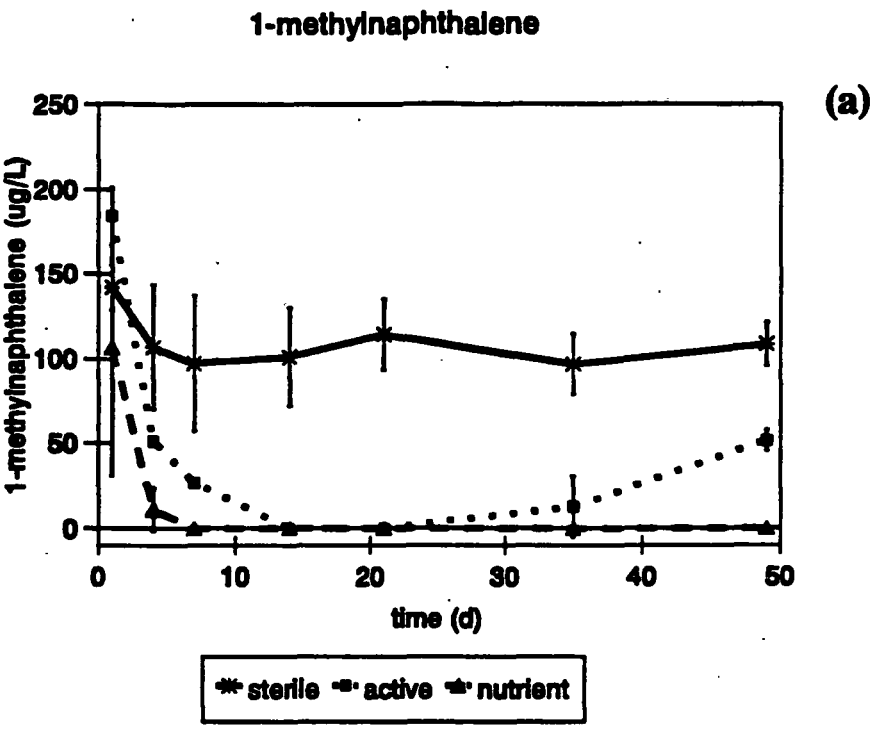

indole + 2-methylnaphthalene
(b)
250
200
150
100
50
0
indole + 2-methylnaphthalene (ug/L
0
10
20
30
40
50
time (d)
sterile
active
nutrient

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

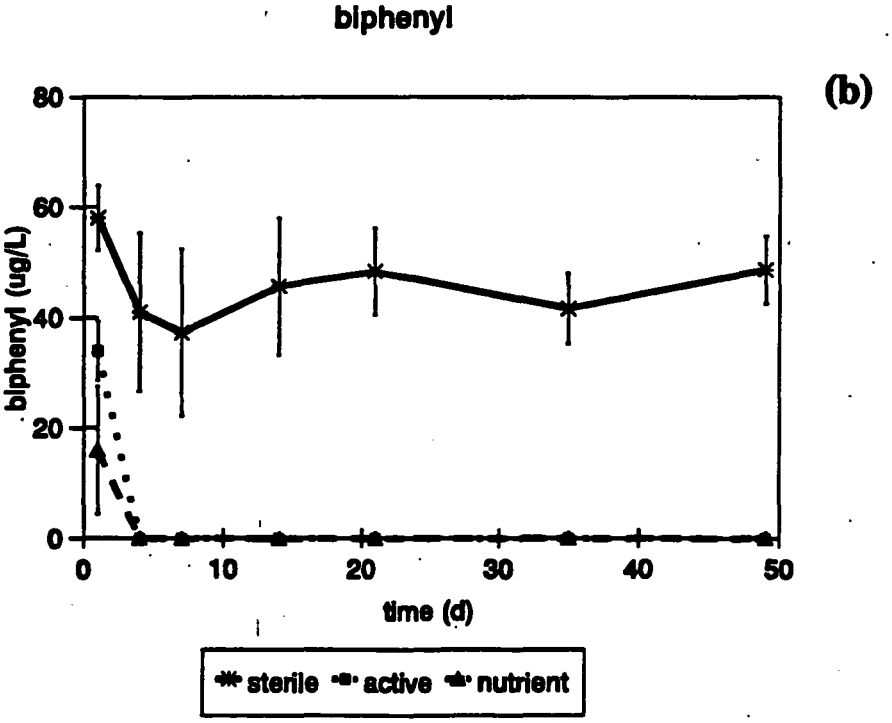
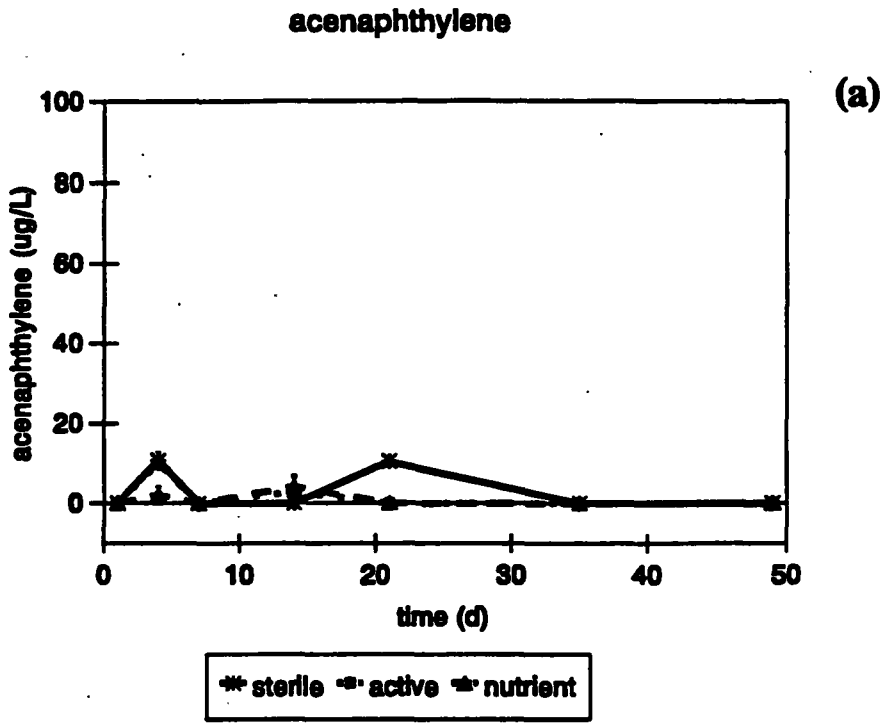

biphenyl
(b)
biphenyl (ug/L)
80
60
40
20
0
0
10
20
30
40
50
time (d)
sterile
active
nutrient

Figure 3


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

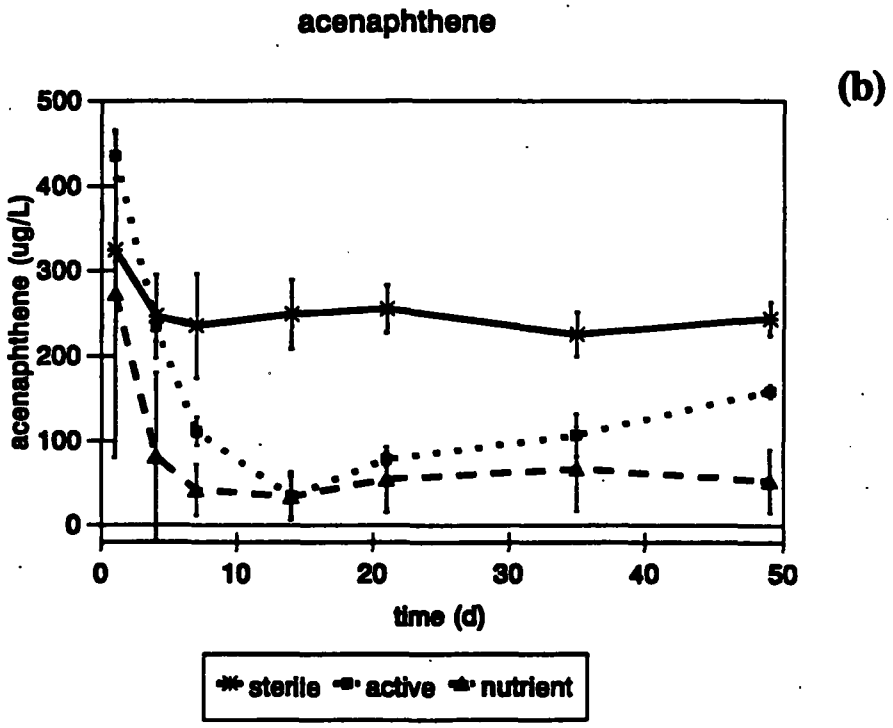
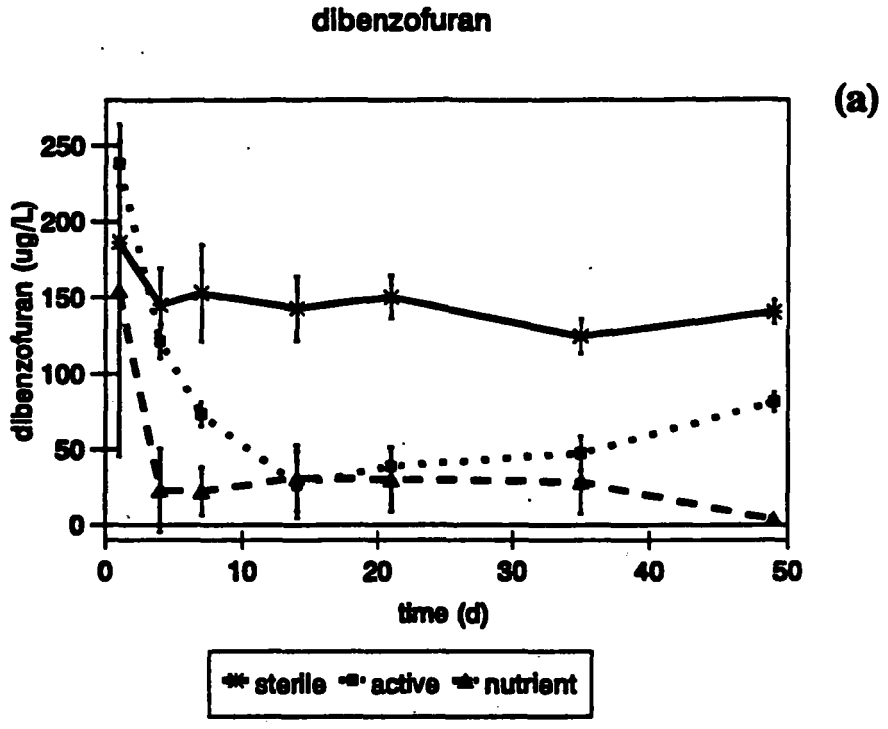

acenaphthene
(b)
acenaphthene (ug/L)
500
400
300
200
100
0
0
10
20
30
40
50
time (d)
sterile
active
nutrient

Figure 4


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

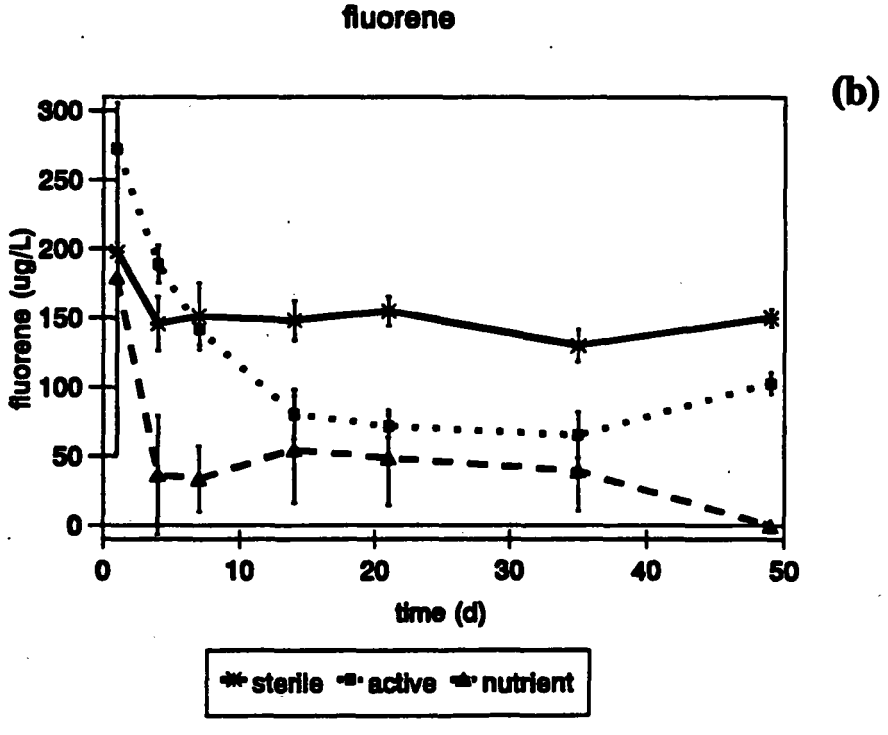
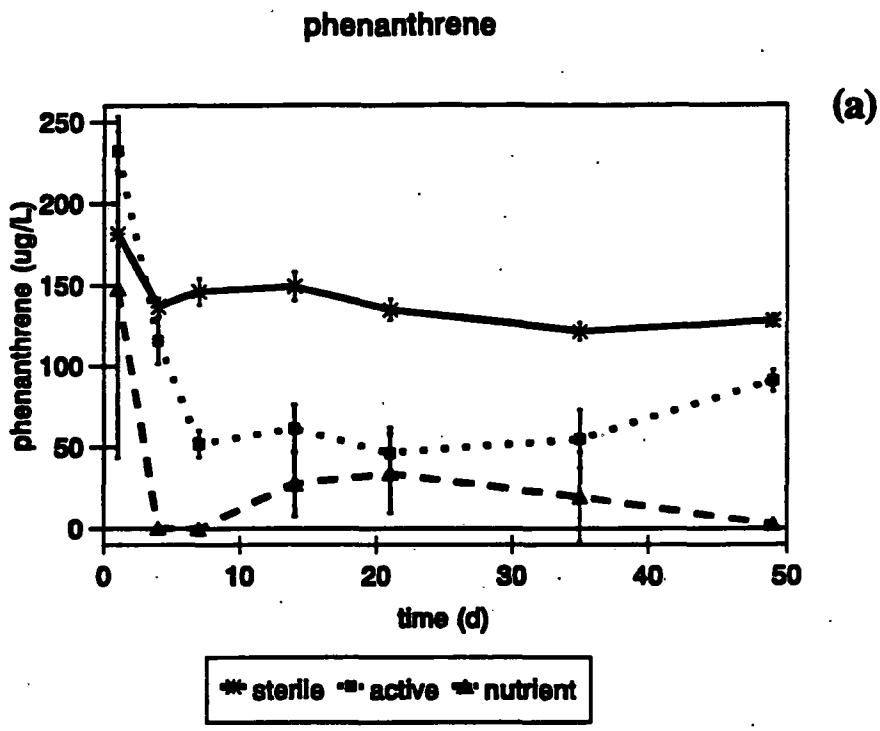

fluorene
(b)
fluorene (ug/L)
300
250
200
150
100
50
0
0
10
20
30
40
50
time (d)
sterile
active
nutrient

Figure 5


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

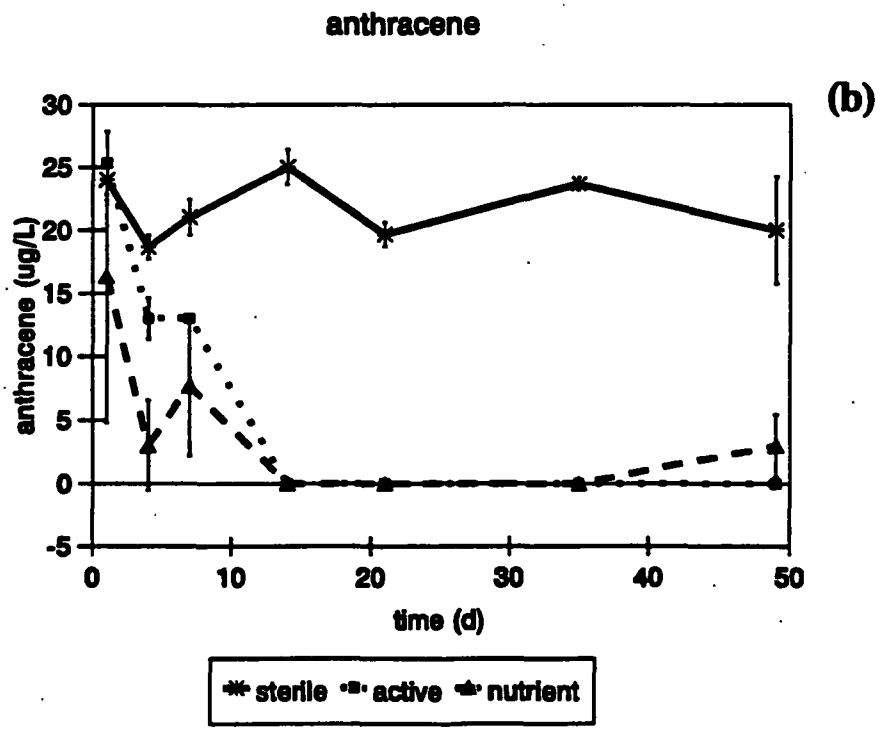
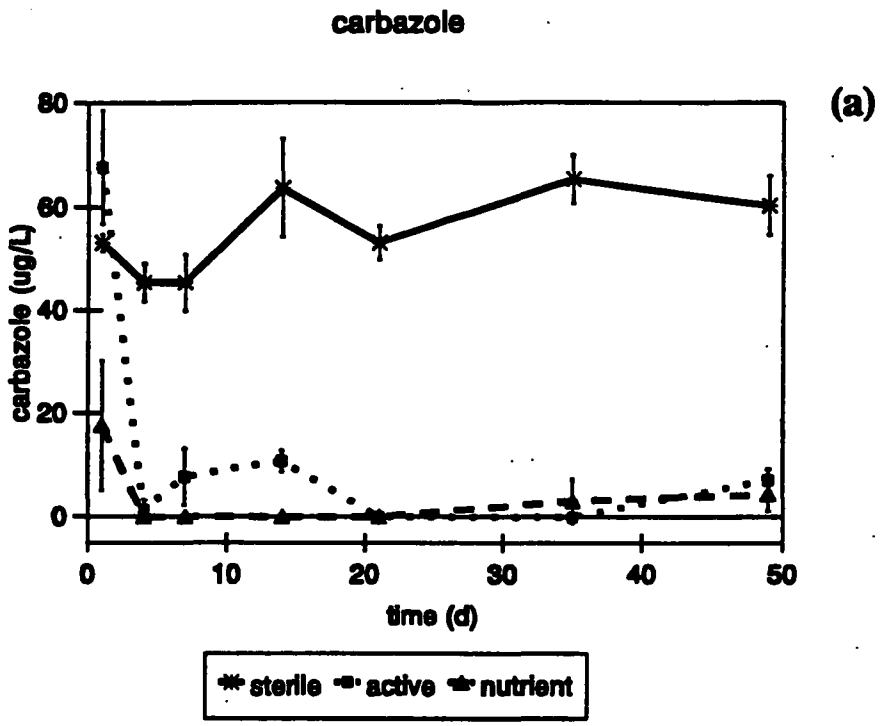

anthracene
(b)
anthracene (ug/L)
30
25
20
15
10
5
0
-5
0
10
20
30
40
50
time (d)
sterile
active
nutrient

Figure 6


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

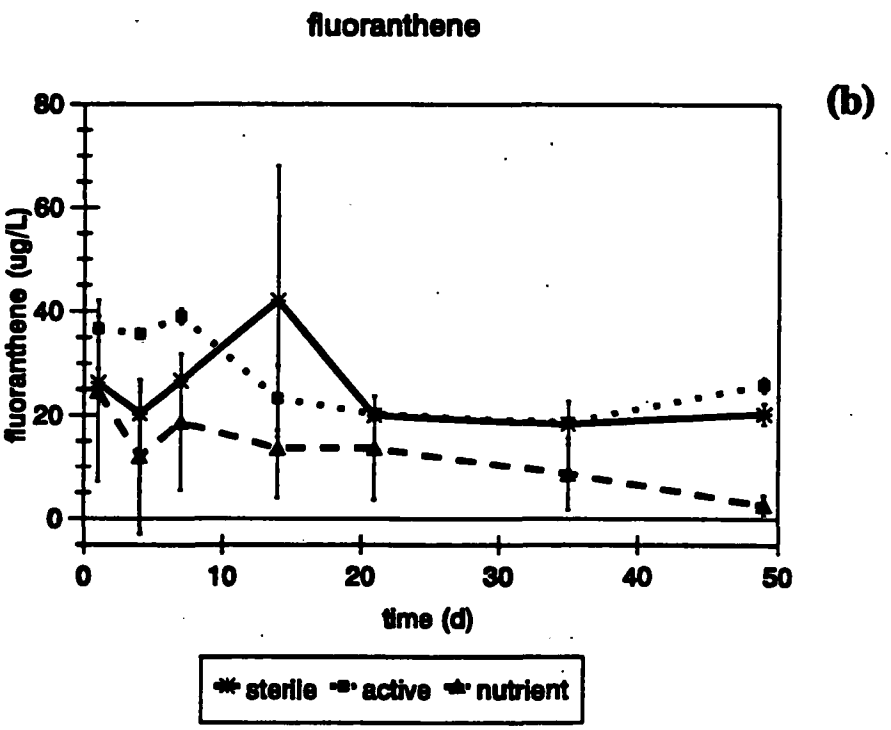
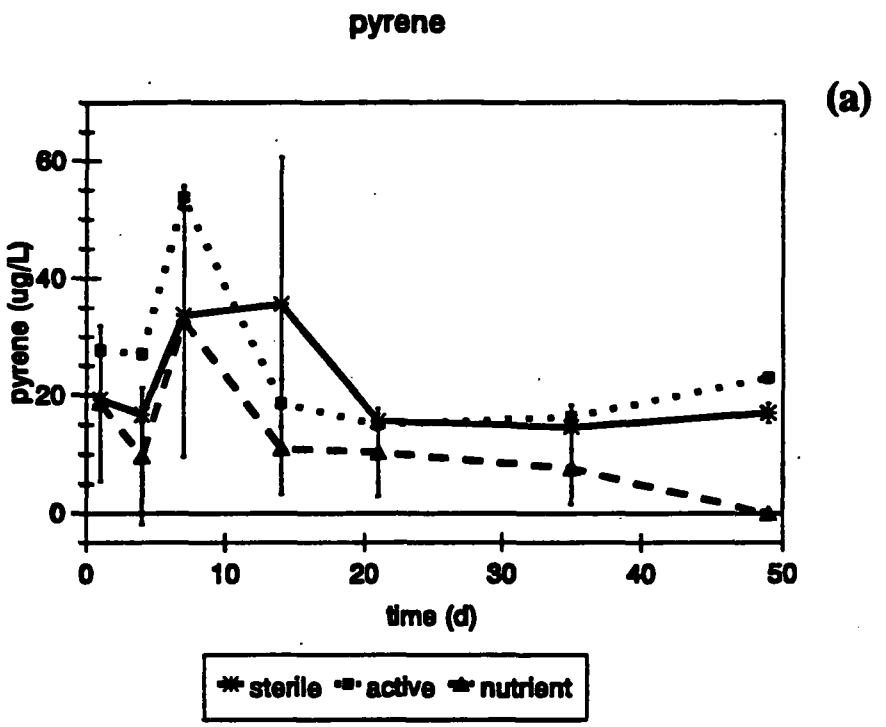
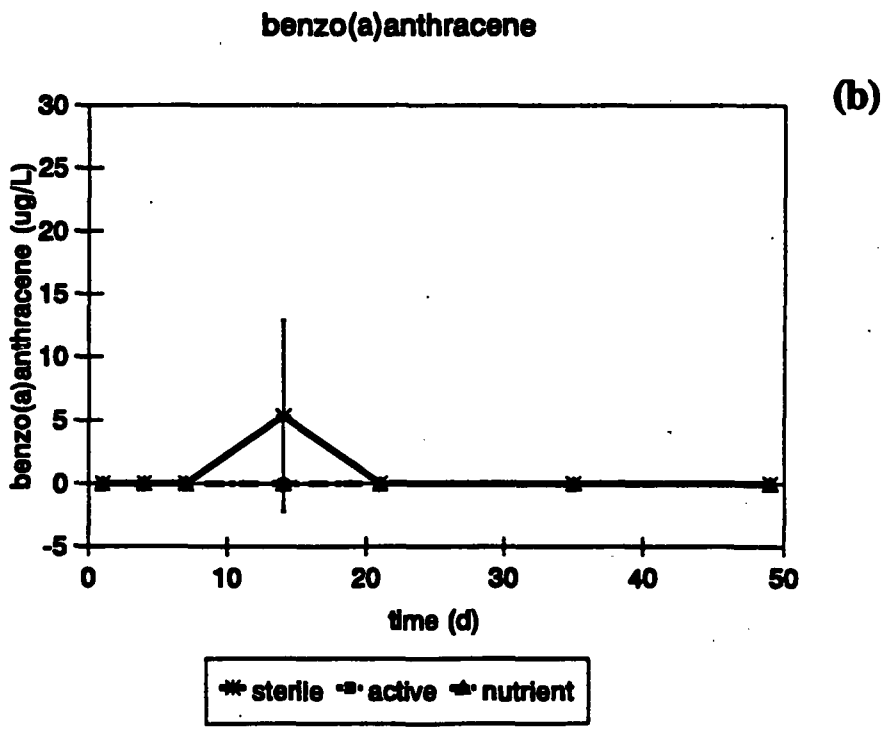

fluoranthene
(b)
fluoranthene (ug/L)
80
60
40
20
0
0
10
20
30
40
50
time (d)
sterile
active
nutrient

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 afore-mentioned 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	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	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 μg/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 $\mu g/g$ 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	4-fluoro-1,1"-biphenyl	23.44	76
(internal	2-fluoro-1,1'-biphenyl *		76
standard)	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

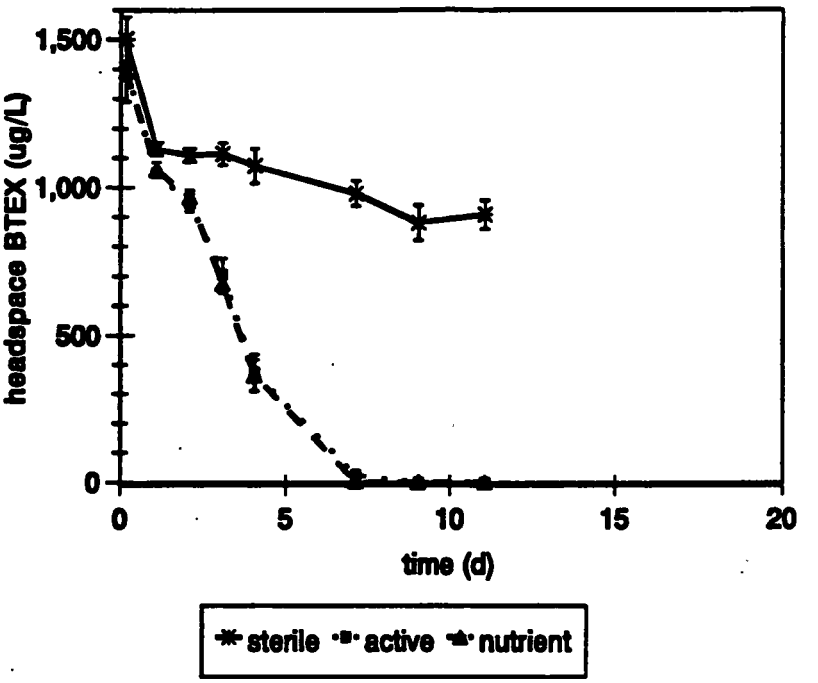
Peak No.	Library/ID	Area(%)	ID quality
active, unamended			
1	4-fluoro-1,1'-biphenyl	51.60	76
(internal	2-fluoro-1,1'-biphenyl *		76
standard)	3,5-dimethyl-1-phenyl-1H-pyrazole		53
2	1,4-dihydro-1,4-ethenonaphthalene	17.37	58
	acenaphthene *		17
	7-chloro-benzofuran		11
3	3,4,5-trimethoxy-benzenamine	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)

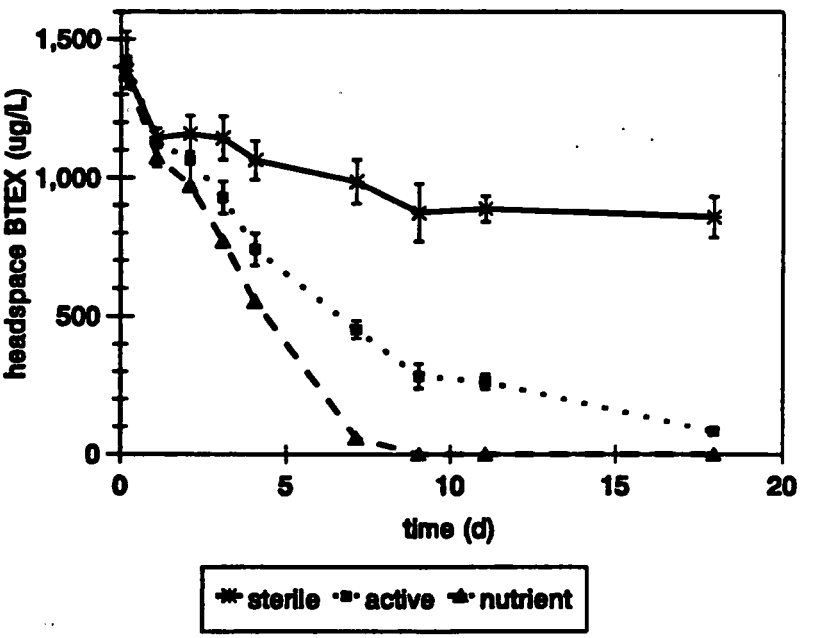
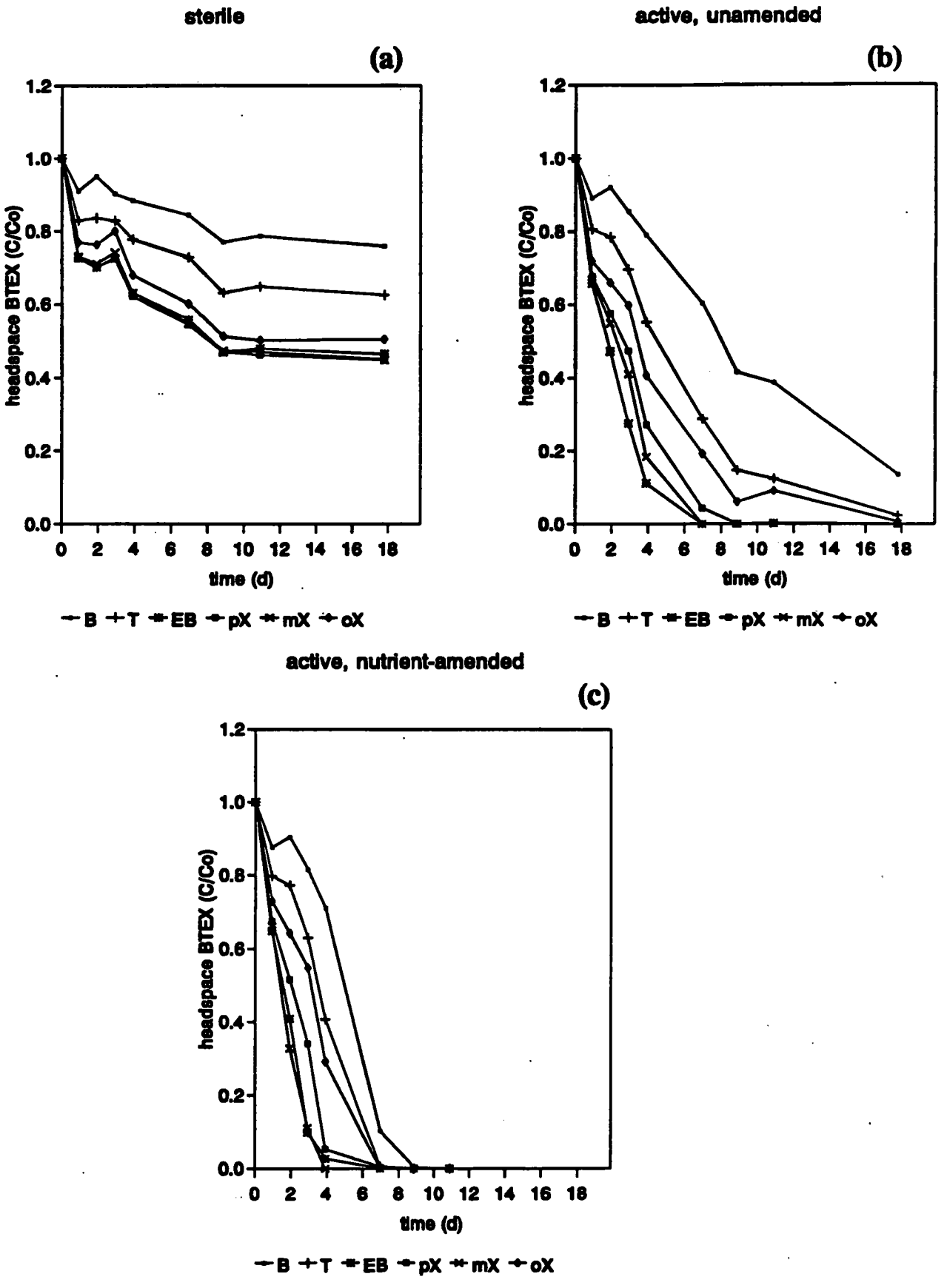


Figure 9


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

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)

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

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

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

$\sim 10^3$-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)

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

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

$\sim 10^3$-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.

9.0 Literature Cited

Alexander, M. 1977. Introduction to Soil Microbiology, 2nd edition. John Wiley & Sons, New York. 467 p.

American Public Health Association, American Water Works Association, and water Pollution Control Federation. 1985. Standard Methods for the Examination of Water and Wastewater, 16th edition. American Public Health Association, Washington, D.C.

Barbaro, S.E., Albrechtsen, H.-J., Jensen, B.K., Mayfield, C.I. and Barker, J.F. 1994. Relationships between aquifer properties and microbial properties in the Borden aquifer. Geomicrobiol. J. 12:203-219.

Bauer, J.E. and Capone, D.G. 1985. Degradation and mineralization of the polycyclic aromatic hydrocarbons anthracene and naphthalene in intertidal marine sediments. Appl. Environ. Microbiol. 50:81-90.

Crocker, F.H. 1992. Survival of psychrotrophic *Pseudomonas putida* strains and stability of the

TOL plasmid in aquifer microcosms. PhD thesis, Department of Biology, University of Waterloo, Waterloo, Ont.

Ehrlich, G.G., Godsy, E.M., Goerlitz, D.F. and Hult, M.F. 1983. Microbial ecology of a creosote-contaminated aquifer at St Louis Park, Minnesota. Dev. Ind. Microbiol. 24:235-245.

Furukawa, K., Simon, J.R. and Chakrabarty, A.M. 1983. Common induction and regulation of biphenyl, xylene/toluene, and salicylate catabolism in *Pseudomonas paucimobilis*. J. Bacteriol. 154:1356-1362.

Godsy, E.M., Goerlitz, D.F. and Grbic-Galic, D. 1992. Methanogenic degradation kinetics of phenolic compounds in aquifer-derived microcosms. Biodegradation 2:211-221.

Hirsch, P. and Rades-Rohkohl, E. 1988. Some special problems in the determination of viable counts of groundwater microorganisms. Microb. Ecol. 16:99-113.

King, M. Malcolmson, H. and Barker, J.F. 1994. Groundwater plume development from a complex organic mixture. In Proc. Petroleum Hydrocarbons and Organic Chemicals in Groundwater: Prevention, Detection and remediation Conference. Nov. 2-4, Houston Tx., API and NGWA. pp. 411-425.

King, W.G., Barker, J.F. and Hamilton, K.A. 1995. Natural attenuation of coal tar organics in groundwater. In Situ and On-Site Bioreclamation, Third International Symp., April 24-27, 1995, San Diego, Calif.

Kuhn, E.P. and Suflita, J.M. 1989. Microbial degradation of nitrogen, oxygen and sulfur heterocyclic compounds under anaerobic conditions: studies with aquifer samples. Environ. Toxicol. Chem. 8:1149-1158.

Lee, M.D., Wilson, J.T. and Ward, C.H. 1984. Microbial degradation of selected aromatics in a hazardous waste site. Dev. Ind. Microbiol. 25:557-565.

Mayou, J. 1976. MPN - Most probable number. In Speck, M.L. (ed), Compendium of Methods for the Microbiological Examination of Foods. American Public Health Association, Inc., Washington, D.C. pp. 152-162.

Mihelcic, J.R. and Luthy, R.G. 1988. Microbial degradation of acenaphthene and naphthalene under denitrification conditions in soil-water systems. Appl. Environ. Microbiol. 54:1938-1942.

Reasoner, D.J. and Geldreich, E.E. 1985. A new medium for the enumeration and subculture of bacteria from potable water. Appl. Environ. Microbiol. 49:1-7.

Shiaris, M.P. 1989. Seasonal biotransformation of naphthalene, phenanthracene, and benzo(a)pyrene in surficial estuarine sediments. Appl. Environ. Microbiol. 55:1391-1399.

Smolenski, W.J. and Suflita, J.M. 1987. Biodegradation of cresol isomers in anoxic aquifers. Appl. Environ. Microbiol. 53:710-716.

Sutherland, J.B., Rafii, F., Kahn, A.A. and Cerniglia, C.E. 1995. Mechanisms of polycyclic aromatic hydrocarbon degradation. In Young, L.Y. and Cerniglia, C.E. (eds), Microbial Transformation and Degradation of Toxic Organic Chemicals. Wiley-Liss, Inc., New York. pp. 269-306.

Wilson, S.C. and Jones, K.C. 1993. Bioremediation of soil contaminated with polynuclear aromatic hydrocarbons (PAHs): a review. Environ. Poll. 81:229-249.

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 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
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 (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	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 (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	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 (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	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 (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	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 (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	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	14
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	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
49	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	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	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	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	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	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	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	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	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	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	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\[illegible]
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