United States
Environmental Protection
Agency

Hazardous Waste Engineering
Research Laboratory
Cincinnati OH 45268

Research and Development

EPA/600/S2-86/074 Dec. 1986

EPA

Project Summary

Testing and Evaluation of Permeable Materials for Removing Pollutants from Leachates at Remedial Action Sites

James E. Park

In order to better understand the potential effectiveness of permeable treatment systems, four readily available, low-cost permeable materials — limestone, coal, fly ash, and a soil containing clay — were bench-tested to determine their ability to remove organic pollutants from two simulated hazardous waste leachates. The capabilities of various sequentially ordered layers of these materials were evaluated with respect to their ability to retain total organic carbon (TOC) and twelve selected priority pollutants. As a result of testing, the most effective ordering of materials was found to be a layer of fly ash, followed by a layer of coal, followed by a layer of limestone. Conceptual designs for three field-scale permeable treatment systems were developed using the results of the bench-scale experiments.

This Project Summary was developed by EPA's Hazardous Waste Engineering Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

As the number of hazardous waste sites requiring remedial action increases, technological alternatives that not only enclose sites, but mitigate contamination will become increasingly popular. One such alternative might use permeable materials in systems designed for the retention of pollutants from hazardous waste leachates. These permeable treatment systems could be designed as vertical treatment walls or horizontal treatment beds. In the former case, the treatment wall would partially or totally encircle a site in a manner similar to a slurry trench, retaining pollutants as leachates moved through the wall. In the latter case, the treatment bed would be used to pretreat pumped leachate prior to its release to an industrial or municipal wastewater treatment plant.

In order to determine the feasibility of the above remedial action alternative, a study was initiated by the U.S. Environmental Protection Agency. Two goals were set for this study. The first was to test four readily available, low-cost permeable materials — limestone, coal, fly ash, and a soil containing clay — for their ability to retain the organic pollutants in two simulated hazardous waste leachates. Various combinations of the materials, ordered in sequential layers, were tested, and their interactions with selected organic pollutants were measured to determine individual and collective performance characteristics of the materials. The second goal of the study was to develop conceptual designs for three field-scale permeable treatment systems.

Procedure

The choice of permeable materials was based on their estimated ability to retain pollutant concentrations, as well as their local availability. Natural or waste materials were judged to have an apparent cost ad-

vantage over such man-made materials as activated carbon or ion exchange resins. For this reason, readily available, low-cost materials were tested. Coal was obtained from a mine near Stinson, KY, limestone from a local dealer, fly ash from the Miami Fort Power Plant near Harrison, OH, and soil from northern Hamilton County near Cincinnati, OH. The particle size distributions for each of these materials are shown in Figure 1.

The materials were placed in twelve 20.3 cm x 20.3 cm cross-sectional columns. Layer thicknesses were chosen for comparative purposes of volume, 20 cm being twice the volume of 10 cm; 6 cm layers were used mostly for limestone. The total height of all columns was 36 cm. The layer orderings used for both experimental runs are shown in Figure 2. The feed for each run was common to all columns. Porous stones connected to external sample ports were placed between each layer and at the bottom of each column. These allowed the TOC concentration to be monitored daily as the simulated hazardous waste leachate flowed through the materials in the 12 columns.

Two different simulated leachates were used in the test. Since organics were of primary concern, total organic carbon (TOC) analysis was used as a measure of their presence in both Runs #1 and #2. Gas chromatographic (GC) analysis for 12 spiked priority pollutants was performed on the effluents from Run #2 to provide an indication of their relative mobilities. The first simulated leachate consisted of experimental solid waste lysimeter leachate spiked with phenol and dichlorobenzene at 400 mg/L and 80 mg/L, respectively. The TOC level for Run #1 began at 2500 mg/L and decreased to 400 mg/L by the end of the run. Average column feed concentrations for this run, based on daily feed volume and average daily TOC concentration ranged from 1115 mg/L to 1596 mg/L. The simulated leachate for Run #2 was prepared daily and consisted of 0.1N$CaSO_4$, 850 mg/L potassium hydrogen phthalate (KHP), 100 mg/L toluene and the priority pollutants listed in Table 1. The average TOC was 421 mg/L.

Calculations of the retentive capacities were made from the breakthrough curves for each column. Retention was interpreted as the amount of the pollutants, in this case represented by TOC, that remained on a given amount of material (mg/kg dry wt.). Knowing the total TOC input and output, the difference is retained by the permeable materials. Typical

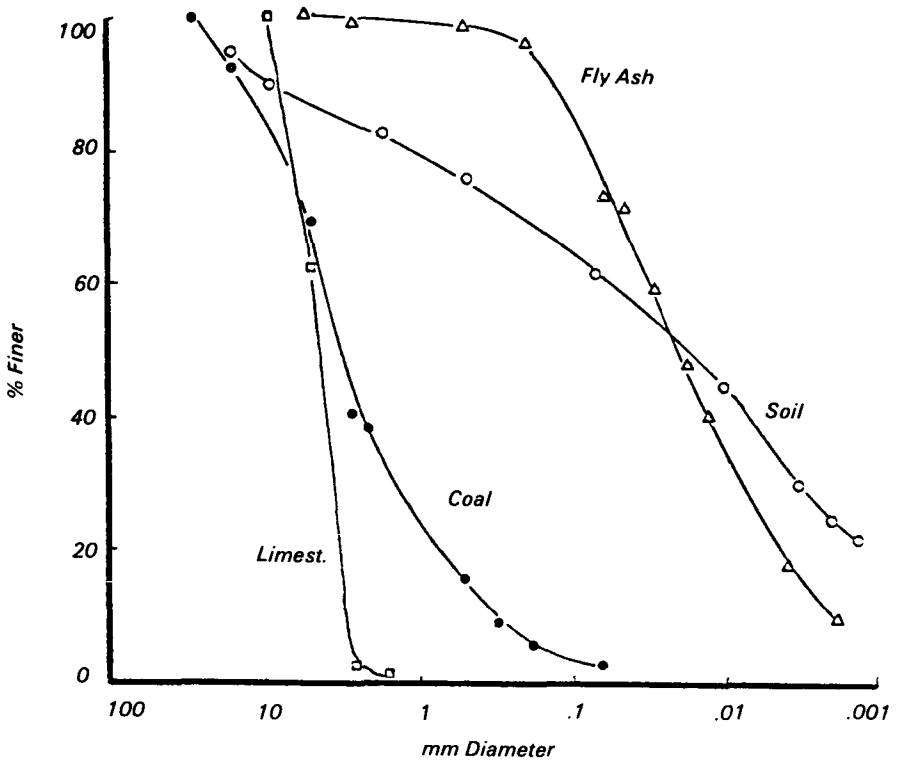

Figure 1. *Particle size distributions for permeable materials.*

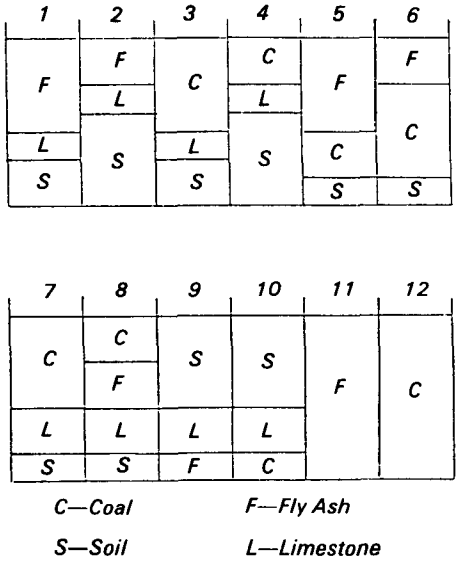

Figure 2. *Orderings of materials in columns.*

examples of breakthough curves are shown in Figures 3 and 4. The cumulative flow volume and the TOC concentration were normalized to the total flow for each column and the maximum TOC concentration for each experiment. The areas between each curve are proportional to the amount of TOC retained by each layer of the column. The total amount of pollutants

Table 1. *Priority Pollutants in Feed #2*

	Actual Con (μg/l)
Bis(2-ethylhexyl)Phthalate	*163*
Di-N-Butyl Phthalate	*128*
1,4 Dichlorobenzene	*192*
2,4 Dichlorophenol	*109*
Ethylbenzene	*261*
Fluoranthene	*129*
Isophorone	*120*
*Pentachlorophenol**	*136*
*Phenanthrene**	
Phenol	*115*
Pyrene	*135*
Naphthalene	*137*

**These two compounds could not be distinguished in the analytical procedure.*

retained was found by summing the re tangular areas between data points.

The overall effectiveness of the orde ings of materials were comparted by ran ing four column results: 1) The number days until 50% breakthrough, 2) the tot TOC retained, 3) the linear flow veloci and 4) the calculated permeability coeff cient. The first two results are measure of retention, while the last two are inc cative of flow. The most effective colum then should have both high retention ar flow.

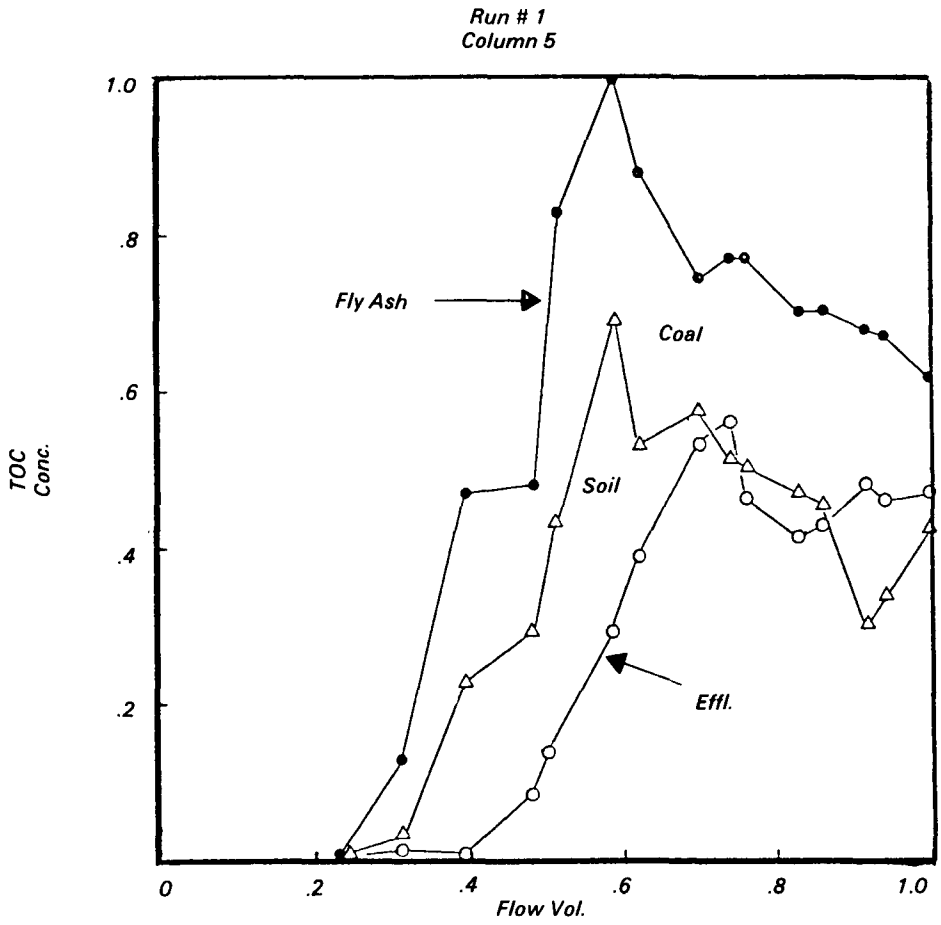

Figure 3. *Typical breakthrough curve, Run #1, Column 5.*

Results and Discussion

The retentive capacity results for the individual permeable material layers are shown in Figure 5. The range and average values for the pollutants retained during the two simulated leachate runs are presented in Table 2. Coal retained the most TOC per unit weight in both runs. The soil, containing about 20% clay-sized particles retained a large amount of pollutants in Run #1 and slightly less in Run #2. The fly ash retention results are similar for both runs, indicating its retentive capacity may not be related to strong adsorption reactions. Limestone retained very little of the organic pollutants, although it did precipitate iron eluted from the coal. Rust colored layers in the limestone were clearly visible when a coal layer was located above a limestone layer.

Batch elution tests were run using 300 ml of 0.1N$CaSO_4$ and 50 g of the concentration-saturated materials from Run #2. The elution values (mg/kg dry wt.) are included in Figure 5, in parentheses. In the case of fly ash, all the retained TOC was eluted, supporting the contention that fly ash is not a strong adsorber. The coal held as much as half the retained TOC following elution, while the soil elution results were mixed, most samples eluting all the retained TOC with a few holding up to 30%. Thus, coal was the only material exhibiting relatively strong adsorbtion capabilities.

The rate of flow through the layers influenced retention by the permeable materials. The porosity of the coal layers allowed rapid movement of TOC. Columns 3 and 7, with 20 cm of coal on the top in Run #1, provided less retention than the coal layers in the other columns. Limiting the flow through the coal by a less permeable layer above it, as in Column 6, appeared to increase the retentive capability of coal. The 20 cm layers of soil in Columns 2 and 4 inhibited flow, while the fly ash in Columns 1 and 5 only moderated the flow. In order to better understand the permeability of the materials used, permeameter tests were run and the results are shown in Table 3 for coal, fly ash, and soil. Limestone was not tested in the permeameter since it was a uniformly distributed granular material that was not expected to effect liquid flow rates when in combination with the other materials.

The results of the GC analyses for Run #2 are presented in Table 4. The majority of the occurrences of the 12 priority pollutants in the effluents were at lower levels than in the simulated leachate feed. Generally, even when a compound was detected at a concentration greater than 100 μg/L in a sample, it would not be detected in the subsequent sample. The detected compounds appeared predominately in discrete cases. Phenanthrene, fluoranthene, dichlorophenol, pyrene and pentachlorophenol were either undetected or appeared at concentrations less than 20 μg/L. These compounds would be less likely to migrate than the other compounds listed in Table 1.

The four criteria used for evaluating column performance were: 1) the number of days to 50% breakthrough, 2) the total TOC retained, 3) the linear flow velocity, and 4) the calculated permeability coefficient. As previously mentioned, the first two results are measures of retention, while the last two results are indicative of flow. The best performing column then would have both high retention and high flow. The overall rankings for performance were found by assigning numerical values (1 through 12) to each of the columns for each of the four results. For example, in Run #1 Column 12 retained the most TOC so it was given a "1" ranking, while Column 7 retained the least and received a rank of "12." The four ranked results were then added and the totals ranked again, 1 through 12. The original rankings were also multiplied together; these products were then ranked. The additive and multiplicative rankings were then added together. The overall rankings were determined from these numbers. The additive and muitiplicative methods were combined in order to afford better resolution when two or more columns were closely ranked. The results are presented in Tables 5 and 6. The overall rankings are indicative of the responses of the columns to the simulated leachates used in the two runs. Since the soil used in the test hindered flow, especially in Columns 2 and 4, these columns received lower rankings despite long times

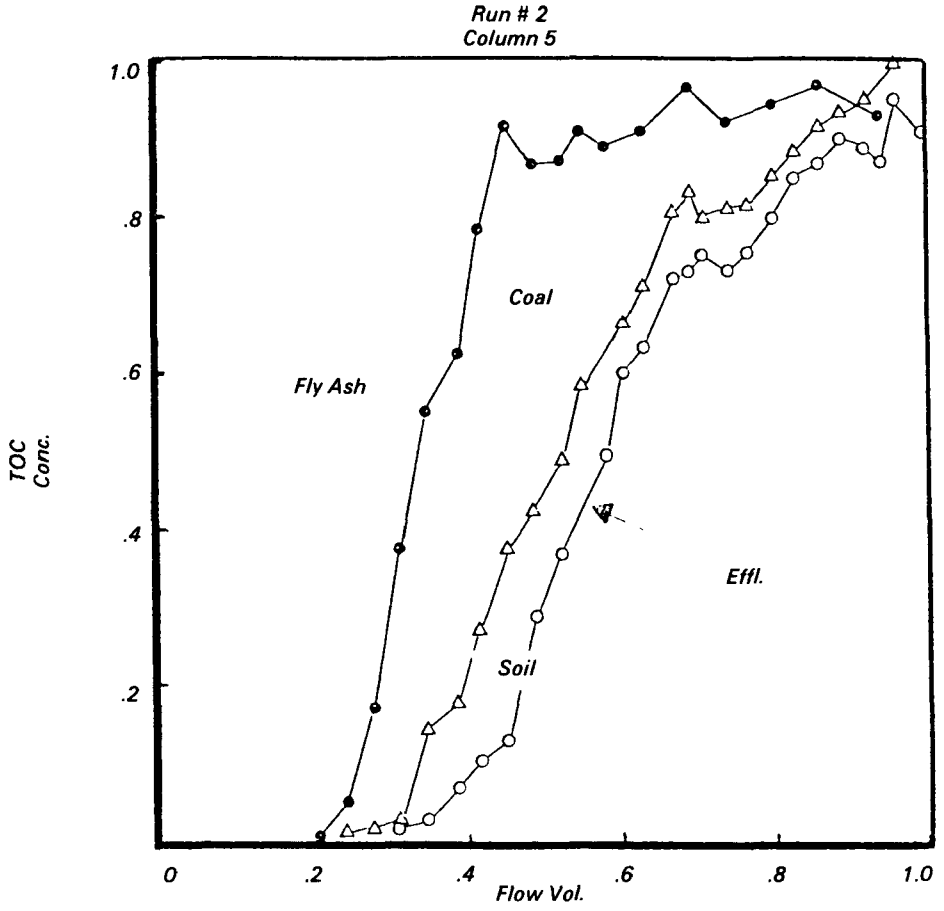

Figure 4. *Typical breakthrough curve, Run #2, Column 5.*

to breakthrough. Columns 3 and 7, with 20 cm coal layers, performed poorly in Run #1 due to high permeability and possible channelling.

Considering the results of Run #2, the most appropriate layer orderings were found in Columns 5 and 6, with fly ash above a coal layer. Ranked next was Column 3, which did not repeat its performance from Run #1. Column 8 also ranked high, and exhibited the least occurrences of priority pollutants in its effluent. Based on the results of Run #2 and indications from Run #1, the most appropriate ordering of these materials would be a top layer of fly ash for flow moderation, followed by a coal layer as the primary retaining material, then a limestone layer to adjust pH and precipitate the iron leached from the coal.

Conceptual Designs

The secondary goal of this project was to develop conceptual designs for applying the permeable materials concept to a field site. Three such conceptual designs were developed. The site utilized for this exercise was a National Priority List (NPL) site in the Pacific Northwest which had been characterized both geologically and hydrologically and for which a reasonable amount of background environmental data was available. This site, however, should not necessarily be construed to be a candidate for installation of a permeable treatment system.

The first conceptual design was a downgradient permeable treatment barrier intended to retain all pollutants. The second and third designs make use of a downgradient collection system. The second design incorporates the ability to flush contaminants from the permeable material, while the third design is a modular, replaceable permeable treatment system. Only the first conceptual design is presented in this summary.

The goal of this design is to intercept the contaminated ground water from the site with a vertical barrier of permeable materials for a specified time. Two years wa chosen based on the large ground-wate flow and the likelihood of rapid flushing c organics.

The primary design calculation was tha of the thickness of the permeable barrie Since the design is for the treatment c organics, and coal was determined in th laboratory tests to retain the most orgar ics (as TOC), the assumption was mad that the coal portion of the barrier mus retain the full organic load for 2 years. Th other materials would then serve to pr vide a margin of safety.

The TOC load per day/m^2 was found b multiplying the flow times the concer tration:

34.5 L/day/m^2 (flow per day) x
40 mg/L (average TOC conc.) =
1380 mg TOC/day/m^2

Coal's retentive capacity = 400 mg TO per Kg coal

Dividing the load by the retentive capacit

$$= \frac{1380 \text{ mg TOC/day/m}^2}{400 \text{ mg TOC/kg coal}} =$$

3.45 kg coal used per day

Coal's density in a barrier would b approximately 900 kg/m^3 or 9.0 kg p linear cm in a cubic meter.

Dividing the daily coal usage by the line density:

$$\frac{3.45 \text{ kg coal/day}}{9.0 \text{ kg/cm}} = .38 \text{ cm/day}$$

This is the amount of coal completel used in retention each day. Over two yea then, 2.8 m of coal would be required (73 days x .0038 m).

Figure 6 shows a plan view of the si with the location of the permeable trea ment barrier. A cross-sectional schemat shows the design dimensions chose Allowing a margin of safety, 3.0 m of co would be used. The fly ash serves t moderate the flow as well as provic additional retention. The limestone w increase the pH of the groundwater as passes from the coal. The thicknesses c the fly ash and limestone are proportion to the layers that were tested in the bencl scale project.

The permeable materials would be plac in a trench 5.0 m deep with approximate 2.0 m of freeboard to allow for rises in th water table and yet still provide treatmen Calculations based on in-place densiti indicated the weights of the three mat rials needed would be: coal, 6.7 x 10^6 k limestone, 5.5 x 10^6 kg and fly ash, 3.9 10^6 kg. It would also be advisable t cover the barrier with an impermeab layer to prevent infiltration.

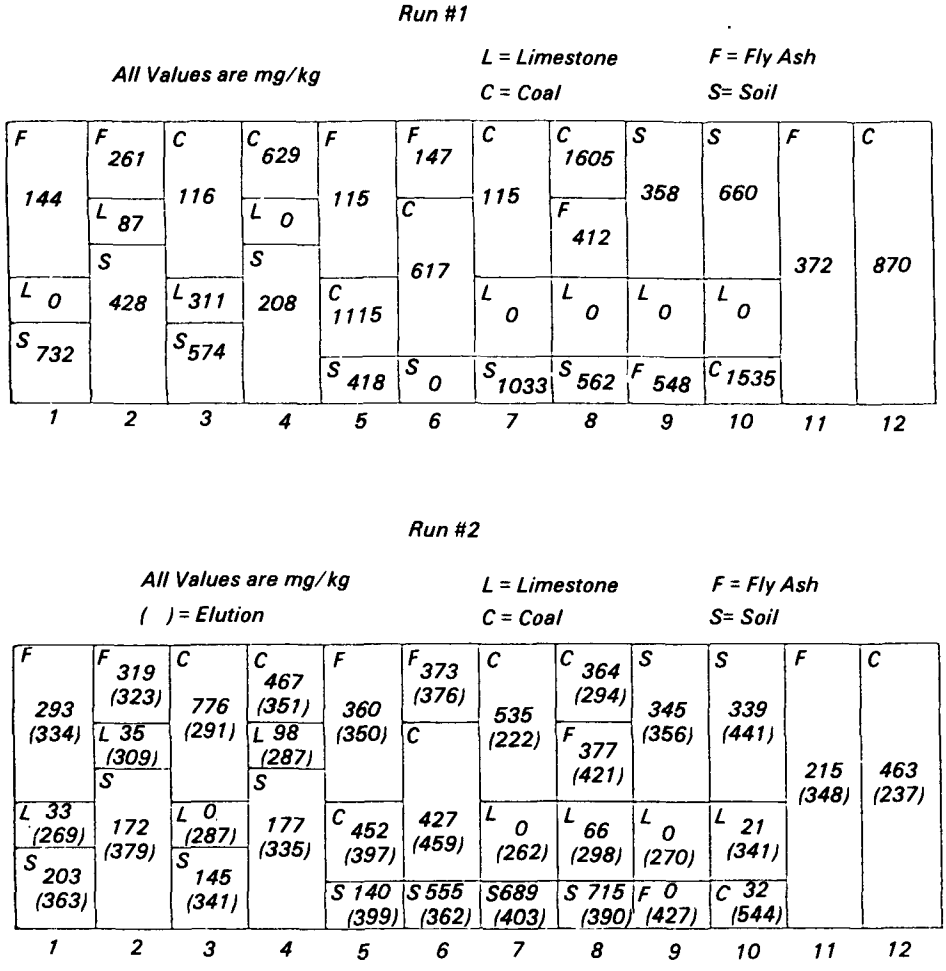

Figure 5. *Retention and elution results, Runs 1 and 2.*

Table 2. *Average Retention Capacities*

Run #1 (2500-400 mg/l TOC)

		RANGES
Coal	813 mg/kg	(1267 - 473)
Limestone	0	(87 - 0)
Fly ash	286 mg/kg	(548 - 115)
Soil	552 mg/kg	(1033 - 208)

Run #2 (421 mg/l TOC)

		RANGES
Coal	498 mg/kg	(776 - 364)
Limestone	32 mg/kg	(98 - 0)
Fly ash	323 mg/kg	(377 - 215)
Soil	348 mg/kg	(715 - 140)

Table 3. *Permeability Results (cm/sec)*

Coal	$1.8 - 5.6 \times 10^{-4}$
Fly Ash	$5.3 - 7.0 \times 10^{-5}$
Soil	$1.7 \times 10^{-4} - 3.5 \times 10^{-5}$

Conclusions and Recommendations

- The results of this project showed that low-cost permeable materials such as coal, limestone, fly ash, and soil containing clay can retain contaminants from simulated hazardous waste leachates. Using total organic carbon (TOC) as an indication of the presence of organic contaminants, coal retained 498-813 mg TOC/kg, fly ash 286-323 mg TOC/kg, limestone 0-98 TOC/kg, and a soil containing clay 348-522 mg TOC/kg.
- The priority pollutants spiked into the feed of Run #2 exhibited various relative mobilities. Dichlorophenol, phenanthrene, pentachlorophenol, fluoranthene and pyrene had limited mobility, while Bis (2-ethylhexyl) phthalate, Di-N-Butyl phthalate, phenol, 1,2, dichlorobenzene, isophorene, napthalene and ethylbenzene moved through the columns at the same rates as measured by the TOC data.
- The most effective ordering sequence considering the permeable materials and the simulated hazardous waste leachate used was a layer of fly ash, followed by a layer of coal, followed by a layer of limestone.
- The experiments helped establish the efficacy of the concept of using permeable materials, but the test apparatus is inefficient for rigorous testing. The second run lasted 47 days and consumed almost 700 L of feed.

Given the results and the observations made during this project, the following recommendations are offered.

- A scaled-down, bench test system should be developed that would provide results faster than the 30-47 days required for the experiments performed for this project. The results from this new system should be verified by comparison with the previously performed work.
- Various solutions for flushing contaminants from the retentive materials should be tested followed by an assessment of the flushed permeable materials' retentive capacities. This would provide information on the utility of flushable permeable treatment systems.
- The design and testing procedures for permeable materials should be demonstrated by installing and evaluating a pilot-scale or larger permeable treatment system. Installation at a remedial action site should be considered.

Table 4. *Run #2 Priority Pollutant G.C. Analyses*

Column	Total Occurences	Occurences >100 μg/L	Compounds >100 μg/L
1	30	2	Dibutylphthalate, Phenol
2	25	1	Phenol
3	21	1	Bis(2-ethylhexyl) Phthalate
4	13	1	Phenol
5	17	1	Bis(2-ethylhexyl) Phthalate
6	16	3	Phenol (2), Bis(2-ethylhexyl) Phthalate
7	20	5	Phenol (2), 1, 2 Dichlorobenzene, Bis(2ethyl. . .) Dibutylphthalate
8	10	0	
9	21	5	Bis(2-ehtylhexyl) Phthalate (2), Phenol, Isophorone, Dibutylphthalate
10	14	3	Napthalene, Dibutylphthalate, Ethylbenzene
11	14	4	Bis(2-ethyl. . .), Dibutylphthalate (2), Ethylbenzene
12	13	3	Bis(2-ethyl. . .), Dibutylphthalate (2)

( ) Indicates more than one occurrence.

Table 5. *Run #1 Column Performance*

Column	Total Flow (L)	Total TOC Retained (mg)	Days to 50% Breakthrough	Linear Velocity (cm/day)	Permeability (cm/day)	Overall Ranking
1	7.18	6377	16	19.3	.78	8
2	6.66	7839	18	17.2	.73	6
3	6.79	5709	9	10.2	.96	11
4	3.93	5247	19	7.5	.41	10
5	8.95	7299	11	18.8	.98	4
6	7.74	6103	12	12.4	.85	9
7	6.47	5177	7	9.2	.91	12
8	9.22	10493	11	21.4	1.01	2
9	6.21	6567	12	27.8	.68	7
10	9.23	11683	18	23.5	.95	1
11	8.08	7900	19	9.4	.84	5
12	8.92	12274	7	22.2	.97	3

Table 6. *Run #2 Column Performance*

Column	Total Flow (L)	Total TOC Retained (mg)	Days to 50% Breakthrough	Linear Velocity (cm/day)	Permeability (cm/day)	Overall Ranking
1	15.86	4448	26	34.5	.84	5
2	12.38	3857	39	21.7	.52	9
3	25.78	7064	30	13.8	1.12	3
4	11.86	4310	47	8.8	.50	8
5	23.99	6146	16	60.5	1.47	2
6	24.02	7525	37	41.2	1.01	1
7	26.12	6810	19	14.8	1.10	7
8	28.40	7006	20	16.0	1.19	4
9	14.35	3796	13	23.3	1.36	11
10	16.12	3911	14	25.9	1.00	12
11	17.00	4374	28	31.1	.77	6
12	29.44	6533	15	8.2	1.23	10

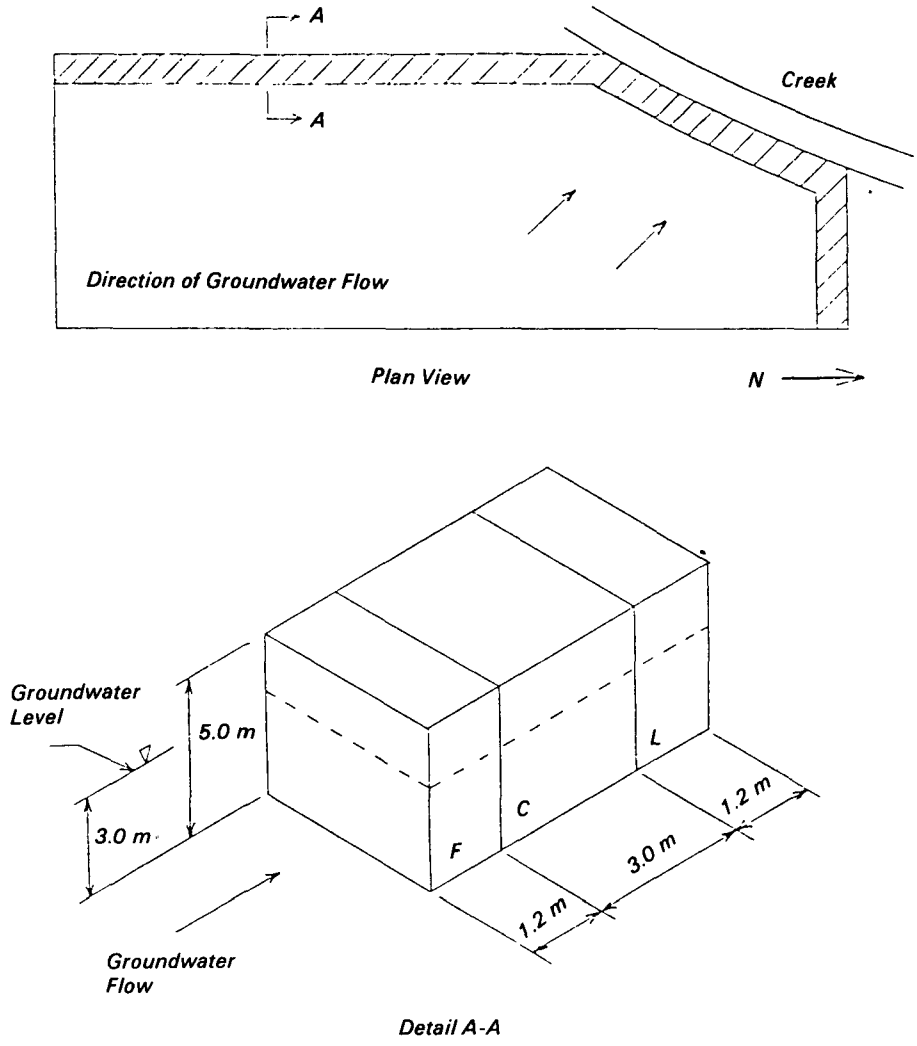

Figure 6. *Conceptual design 1: boundary barrier.*

James E. Park is with the University of Cincinnati, Cincinnati, OH 45221.
***Jonathan G. Herrmann** is the EPA Project Officer (see below).*
The complete report, entitled "Testing and Evaluation of Permeable Materials for Removing Pollutants from Leachates at Remedial Action Sites," (Order No. PB 86-237 708/AS; Cost: $11.95, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650
The EPA Project Officer can be contacted at:
Hazardous Waste Engineering Research Laboratory
U.S. Environmental Protection Agency
Cincinnati, OH 45268

United States
Environmental Protection
Agency

Center for Environmental Research
Information
Cincinnati OH 45268

Official Business
Penalty for Private Use $300

EPA/600/S2-86/074

U.S. OFFICIAL M
CINCINNATI OHIO FEB 10 '87
PENALTY FOR PRIVATE USE $300
U.S. POSTA
0 3 2

0000329 PS

U S ENVIR PROTECTION AGENCY
REGION 5 LIBRARY
230 S DEARBORN STREET
CHICAGO IL 60604