

ORGANIC COMPOUNDS IN GROUND WATER NEAR A
SANITARY LANDFILL IN THE TOWN OF BROOKHAVEN,
LONG ISLAND, NEW YORK

By Kenneth A. Pearsall and Eliezer J. Wexler

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations
Report 85-4218

Prepared in cooperation with the
TOWN OF BROOKHAVEN



Syosset, New York

1986

UNITED STATES DEPARTMENT OF THE INTERIOR

DONALD PAUL HODEL, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information write to:

U.S. Geological Survey
5 Aerial Way
Syosset, New York 11791
(516) 938-8830

Copies of this report may be
purchased from:

U.S. Geological Survey
Books and Open-File Reports
Federal Center, Bldg. 41
Box 25425
Denver, Colorado 80225
(303) 236-7476

CONTENTS

	Page
Abstract.	1
Introduction.	1
Purpose and scope.	1
Acknowledgments.	2
Description of landfill site.	2
Ground-water sampling and analyses.	3
Monitoring wells	3
Sampling procedures.	5
Water-quality analyses	6
Quality assurance.	8
Accuracy of measurements	8
Results of chemical analyses.	9
Priority pollutants.	9
Dissolved organic carbon	11
Inorganic constituents	14
Vertical distribution of contaminants	18
Fate of organic compounds	18
Dissolved organic carbon	18
Priority pollutants.	19
Summary and conclusions	20
References cited.	21

ILLUSTRATIONS

Figure 1. Map showing location of Brookhaven landfill site in Town of Brookhaven	2
2. Map showing well locations and ground-water levels in vicinity of Brookhaven landfill site in September 1982, a period of average water levels	4
3. Map showing dissolved organic carbon concentrations in ground water in vicinity of Brookhaven landfill site, July and August 1983.	13
4. Graph showing relationship between dissolved organic carbon and chloride concentrations in ground water in vicinity of Brookhaven landfill site	14
5. Stiff diagrams of inorganic constituent concentrations in leachate and ground water in vicinity of Brookhaven landfill site, July and August 1983	16

TABLES

	Page
Table 1. Descriptions of wells sampled in vicinity of Brookhaven landfill site	5
2. Priority pollutants analyzed for in this study.	7
3. Organic "priority pollutants" detected in leachate and ground water in vicinity of Brookhaven landfill site, July and August 1983	10
4. Organic nonpriority pollutants detected in landfill leachate in vicinity of Brookhaven landfill site, July 6, 1983	10
5. Organic nonpriority pollutants identified in ground-water samples collected in vicinity of Brookhaven landfill site, July 6, 1983.	12
6. Concentrations of inorganic constituents detected in leachate and ground water in vicinity of Brookhaven landfill site, July and August 1983.	15

Conversion Factors and Abbreviations

<u>Multiply inch-pound unit</u>	<u>by</u>	<u>To obtain SI (metric) unit</u>
<u>Length</u>		
inch (in)	25.40	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
<u>Area</u>		
acre	4,047	square meter (m ²)
<u>Volume</u>		
ounce, fluid (fl. oz)	0.02957	liter (L)
gallon (gal)	3.785	liter (L)
<u>Flow</u>		
foot per day (ft/d)	0.3048	meter per day (m/d)
<u>Temperature</u>		
degree Fahrenheit (°F)	°C = 5/9 (°F-32)	degree Celsius (°C)

ORGANIC COMPOUNDS IN GROUND WATER NEAR A SANITARY LANDFILL IN THE TOWN OF BROOKHAVEN, LONG ISLAND, NEW YORK

By Kenneth A. Pearsall and Eliezer J. Wexler

Abstract

Landfill leachate and ground water near the Brookhaven landfill site were analyzed for volatile, acid-extractable, and base/neutral-extractable organic compounds classified by the U.S. Environmental Protection Agency as "priority pollutants," and for dissolved organic carbon (DOC) and inorganic constituents. Thirteen priority pollutants were detected, including benzene, chlorobenzene, ethylbenzene, and naphthalene. The most commonly detected priority pollutant, benzene, was found in the landfill leachate and in five ground-water samples. The concentration of ethylbenzene was the highest of all organic compounds detected--55 $\mu\text{g/L}$ (micrograms per liter) in the leachate. Three samples downgradient from the site contained detectable levels of priority pollutants; two of these, from wells 2,000 feet downgradient from the site, contained trace amounts of chloroform, and the other, from a well 500 feet downgradient, contained four priority pollutants in concentrations totaling less than 20 $\mu\text{g/L}$. DOC concentrations ranged from 410 mg/L (milligrams per liter) in the leachate to 0.8 mg/L, which is considered background level for ground water upgradient of the landfill site. Samples from downgradient wells contained less than 8 mg/L DOC except at two wells 500 feet from the site, which contained 21 and 16 mg/L.

INTRODUCTION

Solid-waste-disposal sites can be sources of ground-water contamination, especially where the underlying material is permeable, as on Long Island, New York. In 1981, the U.S. Geological Survey, in cooperation with the Town of Brookhaven, began a study of the hydrogeologic conditions and chemical quality of ground water near the Brookhaven landfill site (fig. 1). Water samples from monitoring wells downgradient of the site were analyzed for inorganic constituents and were found to contain high concentrations of bicarbonate, chloride, ammonium, and other major cations, which indicated ground-water contamination by landfill leachate. In 1983, the Town of Brookhaven expanded the study to identify organic compounds in the contaminated ground water and to determine their concentrations at wells downgradient of the landfill.

Purpose and Scope

This report describes (1) the chemical quality of leachate at the landfill and of ground water in the vicinity of the landfill, (2) the vertical distribution of contaminants in the ground water, (3) the probable fate of organic compounds in ground water, and (4) the procedures used for ground-water sampling and analysis of volatile, acid-extractable, and base/neutral-extractable organic compounds, dissolved organic carbon (DOC), and major inorganic constituents.

Acknowledgments

Thanks are extended to the Sanitation Division of the Town of Brookhaven Department of Planning, Environment, and Development for their assistance in the sampling program during this study.

DESCRIPTION OF LANDFILL SITE

The Brookhaven landfill site occupies a 180-acre area in the south-central part of the Town of Brookhaven (fig. 1). A sanitary landfill in the southern part of the site has been used for the disposal of municipal solid wastes since 1974. By the summer of 1984, the landfill covered approximately 60 acres. All refuse has been deposited in an excavation lined with a 0.02-inch-thick polyvinyl chloride (PVC) liner. A slotted PVC-pipe leachate-collection system was installed in a sand layer above the liner to collect leachate for offsite treatment and disposal. Water-quality data obtained in 1982 (Wexler, in press) indicate that despite the PVC liner and leachate-collection system, leachate has entered and contaminated ground water in the area.

The sanitary landfill was excavated in highly permeable outwash sand and gravel from the Wisconsin glaciation. The outwash deposits form the upper glacial aquifer, which is under water-table conditions. The saturated thickness of the aquifer beneath the site is approximately 125 ft. The Gardiners Clay, of Pleistocene age, which is 10 to 15 ft thick, forms a semiconfining layer between the upper glacial aquifer and the underlying Magothy aquifer in the upper Cretaceous Matawan Group and Magothy Formation, undifferentiated. Additional data on the hydrogeology of the surrounding area are given in Wexler (in press).

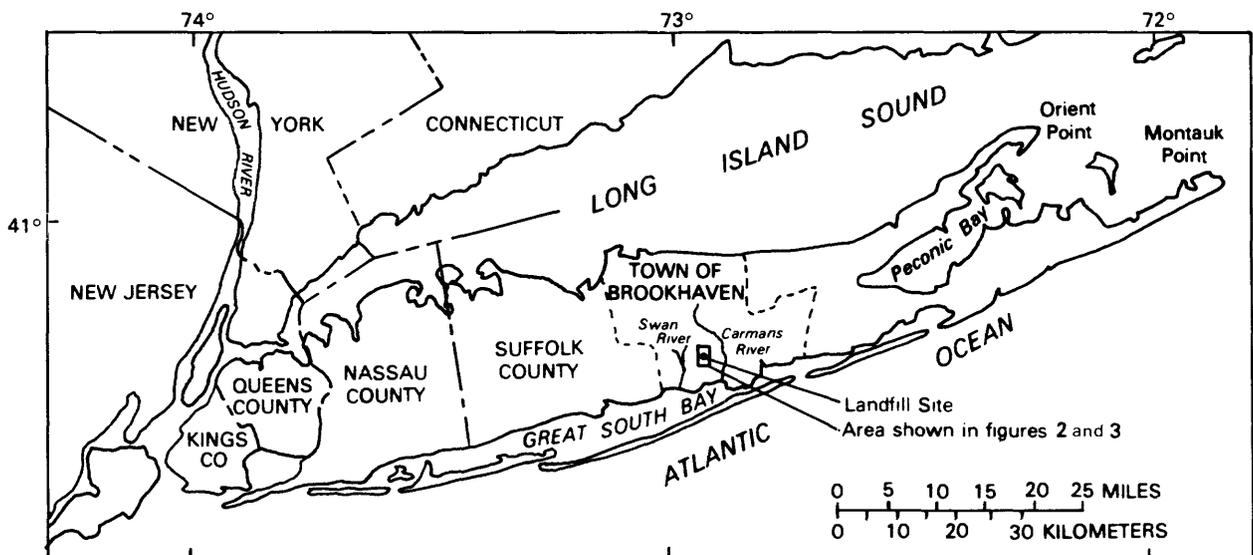


Figure 1.--Location of Brookhaven landfill site in Town of Brookhaven.

The water-table altitude in September 1982, a period of average water levels, is depicted in figure 2. Ground-water flow in the upper glacial aquifer is predominantly horizontal, and water in the area moves southeastward from higher to lower altitudes, perpendicular to the contour lines. Ground-water velocities in the landfill-site vicinity are estimated to be between 0.8 and 1.8 ft/d.

GROUND-WATER SAMPLING AND ANALYSES

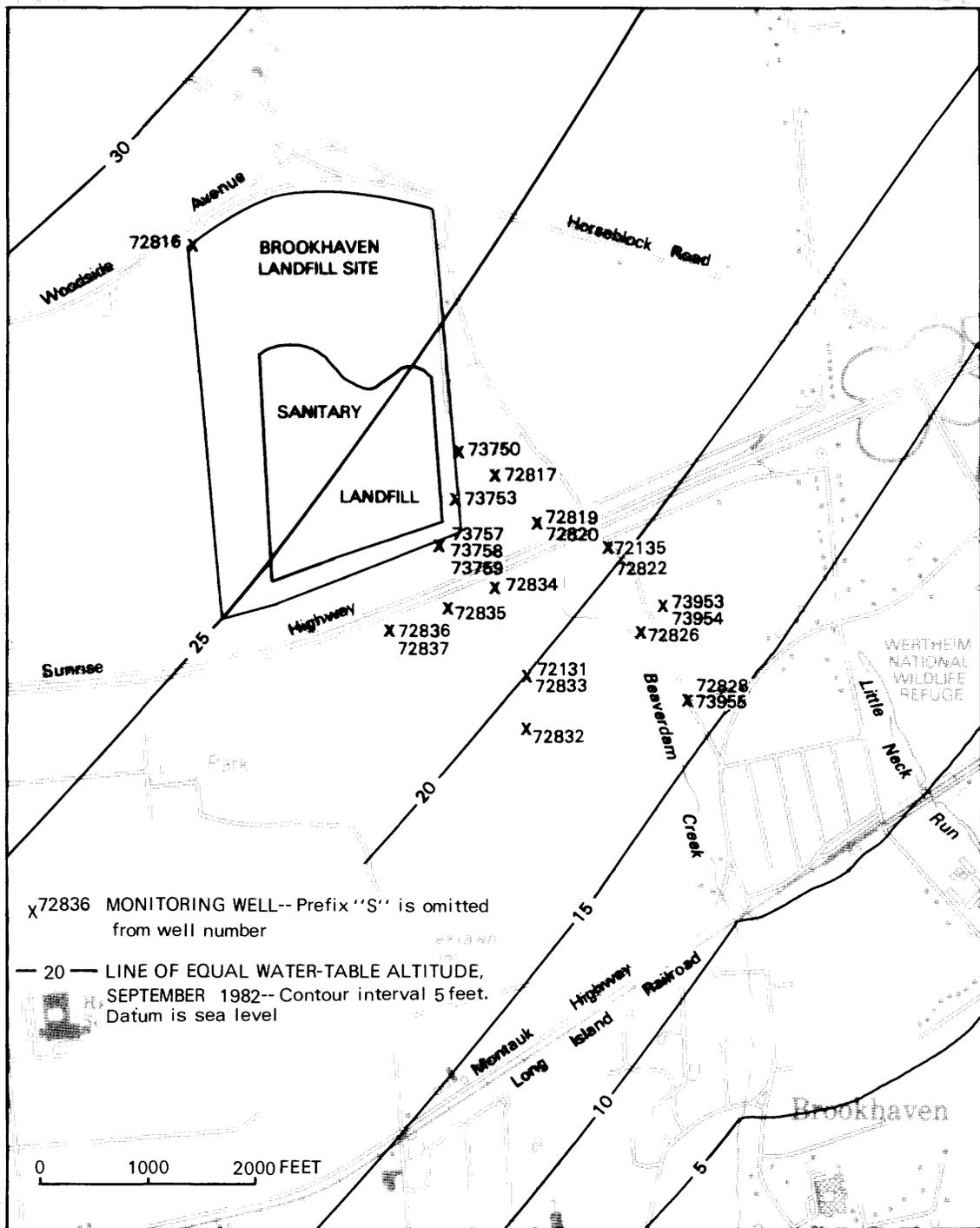
Ground-water samples were collected from 23 wells near the landfill site in July and August 1983. A sample of leachate and ground-water samples from nine wells were analyzed for volatile, acid-extractable, and base/neutral-extractable organic "priority pollutants" and for dissolved organic carbon (DOC). Samples from the remaining wells were analyzed for DOC. All samples were analyzed for the major inorganic constituents as part of a continuing effort to monitor the extent of inorganic contamination by landfill leachate.

Monitoring Wells

Samples for organic chemical analyses were collected at several wells installed during the previous phase of the study. Descriptions of these wells are given in table 1; their locations are shown in figure 2. The wells were selected to provide a representative distribution of sampling sites through the affected area and to include wells that had contained high concentrations of inorganic constituents indicative of leachate contamination during the previous sampling.

Well S73750, on the eastern boundary of the landfill site (fig. 2), contained the highest concentrations of inorganic constituents in previous studies. Wells S72826, S72832, and well clusters S72819 and S72820, S72136 and S72822, S73953 and S73954, S72828 and S73955, S72131 and S72833, and S72836 and S72837 are downgradient from the site and roughly outline the plume as defined by previous inorganic chemical data (Wexler, in press). Well clusters were installed at some locations, with each well screened at a different depth to provide a measure of the vertical distribution of contaminants within the aquifer. Individual wells S72834 and S72835, well clusters S72136 and S72822, and S72836 and S72837 represent a cross section of the plume along Sunrise Highway, approximately 500 ft south of the site, or 1/2 mi downgradient from well S73750. Well S72816, at the northwestern corner of the site, is upgradient of the landfill and provided background water-quality data for the study. Wells S73757, S73758, and S73759 form a cluster at the southeast corner of the landfill site.

Wells on the site boundaries are constructed of 4-inch-diameter threaded steel. Wells downgradient of the site are constructed of 2-inch diameter cemented PVC. The 4-inch wells were driven by the cable-tool method; 2-inch wells were installed by hollow-stem auger.



Base from New York State Department of Transportation
 1:24,000 scale, Bellport, 1981

Hydrology by E.J. Wexler and M.P. Scorca, 1982

Figure 2.--Well locations and ground-water levels in vicinity of Brookhaven landfill site in September 1982, a period of average water levels. (Location is shown in fig. 1.)

Table 1.--Descriptions of wells sampled in vicinity of Brookhaven landfill site.

[Well locations are shown in fig. 2]

Local identifier	Latitude/ Longitude	Sequence no. ¹	Land-surface altitude (ft above sea level)	Total well depth (ft below land surface)	Depth of screen (ft) to top	Screen length (ft)	Well diameter (in)	Casing material
S72131	404722 725526	1	47	55	51	4	2	PVC
S72136	404734 725516	3	29	63	59	4	2	PVC
S72816	404801 725607	1	79	67	63	4	2	PVC
S72817	404740 725530	1	29	22	18	4	2	PVC
S72819	404736 725525	2	23	23	19	4	2	PVC
S72820	404736 725525	3	23	43	39	4	2	PVC
S72822	404734 725516	2	29	43	39	4	2	PVC
S72826	404726 725512	2	21	43	39	4	2	PVC
S72828	404720 725506	2	21	33	29	4	2	PVC
S72832	404717 725526	1	54	72	68	4	2	PVC
S72833	404722 725526	2	47	72	68	4	2	PVC
S72834	404730 725530	1	39	34	30	4	2	PVC
S72835	404728 725536	1	54	64	60	4	2	PVC
S72836	404726 725543	1	62	54	50	4	2	PVC
S72837	404726 725543	2	62	73	69	4	2	PVC
S73750	404742 725535	1	36	34	29	5	4	Steel
S73753	404738 725535	1	37	34	29	5	4	Steel
S73757	404734 725537	2	55	73	68	5	4	Steel
S73758	404734 725537	1	55	53	48	5	4	Steel
S73759	404734 725537	4	55	128	123	5	4	Steel
S73953	404728 725509	1	22	44	40	4	2	PVC
S73954	404728 725509	2	22	64	60	4	2	PVC
S73955	404720 725506	3	21	63	59	4	2	PVC

¹ Sequence number is used to distinguish wells with identical latitude and longitude.

Sampling Procedures

All wells were sampled with a Johnson-Keck¹ 2-inch-diameter positive displacement screw-type submersible sampling pump. This pump is made of stainless steel with an ethylene propylene rubber (EPDM) stator. Teflon tubing was used to transmit the pumped water to land surface. The method used to evacuate the well casing and obtain the sample depended upon the diameter of the well; 2-inch-diameter wells were evacuated with the sampling pump,

¹Use of brand names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

whereas 4-inch-diameter wells were first evacuated with a 4-inch submersible pump, and then a sample was withdrawn with the 2-inch sampling pump. During sampling of 2-inch wells, the sampling pump was placed about 10 ft below the water-level surface, generally about 5 ft above the well screen. In 4-inch wells, the sampling pump was usually placed just above the well screen. The usual sampling procedure was to evacuate the casing volume at least three times before collecting samples.

Sample bottles were prepared and supplied by the analyzing laboratory. Samples for organic compound analysis were collected in glass bottles and sealed with Teflon-lined caps or septa. These bottles were previously prepared by baking at 350°C to remove organic residues. All samples for inorganic constituent analyses were collected in containers supplied with preservatives added by the analyzing laboratory.

Dissolved organic carbon samples were pressure filtered through a 0.45- μ m silver filter. (A very small amount of silver from the filter dissolves in the sample and inhibits bacterial growth, preserving the sample.) Sample containers for volatile organic compounds were always filled in a manner that minimized aeration. Samples for dissolved inorganic constituents were filtered through a 0.45- μ m cellulose filter, and samples for metals analysis were preserved by acidification with nitric acid. Nutrient samples were preserved by addition of sulfuric acid. All samples were stored with ice in a cooler for preservation during transport.

The sampling pump was flushed with 2 to 5 gallons of clean water after each well was sampled. Samples of the flush water were collected and scanned for volatile organic compounds by gas chromatography with flame ionization detection (GC/FID) at the U.S. Geological Survey office in Syosset, N.Y., to verify the cleanliness of the sampling equipment.

Water-Quality Analyses

Ground-water samples from nine wells were analyzed for volatile, acid-extractable, and base/neutral-extractable organic compounds on the U.S. Environmental Protection Agency priority pollutant list. (Volatile or purgeable organic compounds (VOCs) are generally defined as low-molecular-weight hydrocarbons or halogenated hydrocarbons having less than 2-percent solubility in water and boiling points lower than 150°C.) The volatiles or VOCs considered in this study are those determined by U.S. Environmental Protection Agency Method 624 (Federal Register, 1979) and are listed in table 2.

The acid-extractable and base/neutral-extractable compounds analyzed for, also listed in table 2, are the organic compounds that can be solvent-extracted from water samples as described in EPA Method 625 (Federal Register, 1979). The acid-extractable compounds are the 11 phenols and cresols on the U.S. Environmental Protection Agency priority pollutant list that can be solvent-extracted from an acidified water sample; the base/neutral-extractable compounds are those that can be solvent-extracted from a neutral or basic solution. Most of the latter are aromatic or contain aromatic functional groups. Compounds that can be detected by these analyses include vinyl chloride and 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD), chemicals of frequent public concern at landfill sites. Pesticides and polychlorinated

biphenyls are not detected in acid-extractable and base/neutral-extractable analyses. Samples to be analyzed for organic constituents were sent to the U.S. Geological Survey Water Quality Laboratory in Atlanta, Ga., for analysis by U.S. Environmental Protection Agency procedures as described in Wershaw and others (1982).

In addition to acid-extractable and base/neutral-extractable compounds, landfill leachate and ground-water samples from 23 wells were analyzed for dissolved organic carbon (DOC). Much of the organic carbon in municipal-landfill leachate is not detected in U.S. Environmental Protection Agency priority pollutant analyses because only a small fraction of the organic compounds in leachate are priority pollutants. Other compounds are organic acids, short-chain hydrocarbons, and related intermediate decomposition products, and it is usually impractical to identify each of these compounds. DOC, which measures the total dissolved carbon concentration, is a relatively inexpensive analysis that has been used successfully at other landfills to

Table 2.--Priority pollutants analyzed for in this study.

A. Volatile organic compounds		
Benzene	Dichlorodifluoromethane	Methylene chloride
Bromoform	1,1-Dichloroethane	1,1,2,2-Tetrachloroethane
Carbon tetrachloride	1,2-Dichloroethane	Tetrachloroethylene
Chlorobenzene	1,1-Dichloroethylene	Toluene
Chlorodibromomethane	1,2-trans-Dichloroethylene	1,1,1-Trichloroethane
Chloroethane	1,2-Dichloropropane	1,1,2-Trichloroethane
2-Chloroethyl vinyl ether	1,3-Dichloropropene	Trichloroethylene
Chloroform	Ethylbenzene	Trichlorofluoromethane
Dichlorobromomethane	Methylbromide	Vinyl chloride
B. Acid-extractable organic compounds		
4-Chloro-3-methylphenol	4,6-Dinitro-2-methylphenol	Pentachlorophenol
2-Chlorophenol	2,4-Dinitrophenol	Phenol
2,4-Dichlorophenol	2-Nitrophenol	2,4,6-Trichlorophenol
2,4-Dimethylphenol	4-Nitrophenol	
C. Base/neutral-extractable organic compounds		
Acenaphthene	Chrysene	Hexachlorobenzene
Acenaphthylene	Dibenz (a,h) anthracene	Hexachlorobutadiene
Anthracene	1,2-Dichlorobenzene	Hexachlorocyclopentadiene
Benzidine	1,3-Dichlorobenzene	Hexachloroethane
Benzo (a) anthracene	1,4-Dichlorobenzene	Indeno (1,2,3-cd) pyrene
Benzo (b) fluoranthene	3,3'-Dichlorobenzidine	Isophorone
Benzo (k) fluoranthene	Diethyl phthalate	Napthalene
Benzo (g,h,i) perylene	Dimethyl phthalate	Nitrobenzene
Benzo (a) pyrene	Di-n-butyl phthalate	n-Nitrosodimethylamine
4-Bromophenyl phenyl ether	2,4-Dinitrotoluene	n-Nitrosodiphenylamine
Butyl benzyl phthalate	2,6-Dinitrotoluene	n-Nitrosodi-n-propylamine
bis (2-Chloroethoxy) methane	Di-n-octyl phthalate	Phenanthrene
bis (2-Chloroethyl) ether	bis (2-Ethylhexyl) phthalate	Pyrene
bis (2-Chloroisopropyl) ether	Fluoranthene	2,3,7,8-Tetrachlorodibenzo-
2-Chloronaphthalene	Fluorene	p-dioxin
4-Chlorophenyl phenyl ether		1,2,4-Trichlorobenzene

delineate the extent and concentration of organic contamination (Hughes and others, 1974). Samples to be analyzed for DOC were sent to the U.S. Geological Survey National Water Quality Laboratory in Atlanta, Ga., and were analyzed by standard procedures as described in Goerlitz and Brown (1972).

All samples were collected in duplicate or triplicate and additionally analyzed for pH, specific conductance, total alkalinity, total dissolved solids (TDS), ammonia, nitrate, nitrite, total Kjeldahl nitrogen (TKN), chloride, sulfate, calcium, iron, magnesium, manganese, potassium, and sodium. Samples for inorganic constituent analysis were analyzed by New York Testing Laboratories, Inc., in Westbury, N.Y., by established procedures outlined in U.S. Environmental Protection Agency (1974) or the American Public Health Association (1975) (Remo Gigante, New York Testing Laboratories, Inc., oral commun., 1984).

Quality Assurance

All samples to be analyzed for volatiles were collected in duplicate, and one sample was scanned by GC/FID for quality control at the U.S. Geological Survey office in Syosset, N.Y. Acid- and base/neutral-extractable surrogate spiking compounds were added to all samples before extraction as a quality-control check of the extraction procedure. The U.S. Geological Survey National Water Quality Laboratory and New York Testing Laboratories participate in the Standard Reference Water Sample (SRWS) Program, a quality-assurance program administered by the U.S. Geological Survey.

Accuracy of Measurements

A degree of error is inherent in any measurement, and an understanding of the possible magnitude of the error is necessary to correctly interpret that measurement. The process of ground-water sampling and analysis allows several possible sources of error, as described below.

Any analytical procedure is subject to some degree of error. The magnitude of this error is dependent upon the procedure chosen and is usually well characterized for that procedure. Analyses for specific organic compounds dissolved in water at extremely low (parts per billion) concentrations involve new and complex technology that measures lower concentrations than could be achieved previously, and the magnitude of error associated with these procedures is not yet well characterized but is considered large. Sources of error include the complexity of the technology itself and the very low concentration levels being measured. The U.S. Environmental Protection Agency has concluded that "the practical (lower) limit for measuring organic priority pollutants is about 10 $\mu\text{g/L}$ " (Dowd, 1983), yet many concentrations reported in this study are below this level.

Additional error arises from variable recovery efficiencies for organic compounds in aqueous solution at very low concentrations. When organic compounds are solvent extracted, acceptable recovery efficiencies for surrogate spiking compounds can range from 30 to 130 percent (Wershaw and others, 1982).

The quality of the numerical data is further constrained by the difficulty in obtaining samples that are truly representative of the water in

the aquifer. This, together with the problems inherent in storing unstable samples, limits the representativeness of a water sample even before it enters the laboratory. Thus, despite the quality-control procedures described above, concentrations reported as representative of ground-water quality at a specific site must be interpreted with caution.

RESULTS OF CHEMICAL ANALYSES

Ground-water samples were collected during three periods in July and August 1983. On July 6, four samples, including one of landfill leachate, were obtained for analysis for DOC and all organic and inorganic constituents discussed previously. On August 9 and 10, 14 samples were obtained for analysis for DOC and inorganic constituents only. On August 24 and 25, eight samples were obtained for analysis for all constituents.

Leachate was sampled from a tap on the leachate-collection system. The leachate is pale yellow and has a strong odor. Ground-water samples from the most contaminated wells were somewhat discolored and had a similar odor. The ground-water samples bubble like carbonated water when brought to the surface and release large quantities of gas, presumably decomposition products of organic material in the landfill. Leachate and contaminated ground-water samples turn bright orange when exposed to air as a result of the formation of oxidized iron precipitates, indicating the absence of dissolved oxygen and high concentrations of dissolved iron in a reduced state.

Priority Pollutants

One sample of landfill leachate, collected on July 6, 1983, was analyzed for volatile, acid-extractable, and base/neutral-extractable priority pollutants. Chemical data for this analysis and for each of the wells sampled for priority pollutants during the study are given in table 3. Five organic priority pollutants were detected in the leachate; they were: benzene, 9 µg/L; chlorobenzene, 23 µg/L; ethylbenzene, 55 µg/L; toluene, 4 µg/L; and naphthalene, 19 µg/L. The analyzing laboratory additionally reported all nonpriority pollutant organic compounds that were extractable from samples collected on July 6, 1983; those detected in the leachate are listed in table 4. Concentrations of all organic compounds were lower at and downgradient of the site than in the leachate, but several samples contained constituents that were not found in the leachate.

The volatile priority pollutants identified in the samples from monitoring wells are the aromatic compounds benzene, chlorobenzene, ethyl benzene, and toluene, and the halogenated compounds methylene chloride, trichloroethylene, and chloroform. Each of these compounds has been identified as toxic and potentially carcinogenic (National Academy of Sciences, 1977). Volatile organic compounds are commonly found in solvents and degreasers, paints, paint thinners, and paint products, and in some household cleaners, including some types of drain cleaners, disinfectants, and oven cleaners (Mackay and others, 1979). These products and their containers are commonly disposed of in household and commercial refuse and are ultimately deposited in landfills.

Table 3.--Organic "priority pollutants" detected in leachate and ground water in vicinity of Brookhaven landfill site, July and August 1983.

[Well locations are shown in fig. 2]

Constituent	Sampling date											
	7-6-83			8-24-83			8-25-83					
	Leachate	S72817	S73750	S73759	S72826	S72834	S73750	S73753	S73759	S73954	S73757	S73758
<u>Volatile organic compounds</u>												
Benzene (µg/L)	9	<1	9	<1	<1	3	13	5	<1	<1	4	9
Chlorobenzene (µg/L)	23	<1	21	<1	<1	<1	23	7	<1	<1	<1	8
Ethylbenzene (µg/L)	55	<1	27	<1	<1	6	34	7	<1	<1	<1	28
Toluene (µg/L)	4	<1	3	<1	<1	<1	<1	<1	<1	<1	<1	<1
Methylene chloride (µg/L)	<1	<1	2	<1	<1	<1	28	<1	<1	<1	<1	17
Trichloroethylene (µg/L)	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	11
Chloroform (µg/L)	<1	<1	1	<1	4	<1	<1	<1	<1	5	<1	<1
<u>Base/neutral-extractables</u>												
Napthalene (µg/L)	19	<1	5	<1	<1	<1	8	<1	<1	<1	<1	<1
1,4-Dichlorobenzene (µg/L)	<1	<1	<1	<1	<1	2	5	2	<1	<1	<1	7
Diethyl phthalate (µg/L)	<1	<1	18	13	<1	<1	4	<1	10	<1	5	<1
2-Ethylhexyl phthalate (µg/L)	<1	<1	20	<1	<1	8	<1	<1	<1	<1	<1	<1
Di-n-butyl phthalate (µg/L)	<1	<1	7	<1	<1	<1	<1	<1	<1	<1	<1	<1
n-Nitrosodimethylamine (µg/L)	<1	<1	6	<1	<1	<1	<1	<1	<1	<1	<1	<1
Dissolved organic carbon (mg/L)	410	36	180	16	32	21	160	53	13	3.4	35	31

Table 4.--Organic nonpriority pollutants detected in landfill leachate in vicinity of Brookhaven landfill, July 6, 1983.

Compound	Concentration (µg/L)
1,2-Dimethylbenzene	11.0
1,7,7-Trimethylbicyclo(2.2.1)heptan-2-one	178.0
1,3-Isobenzofurandione	23.6
3,5-Dimethylbenzoic acid	212.0
N-(1,1-Dimethylethyl)-4-methylbenzamide	83.6
4-Methylbenzenesulfonyl chloride	35.0
3-[(3,5-Dimethyl-4-isoxazolyl)methyl]-2,4-pentanedione	77.2
2(3H)-Benzothiazolone	430.0

The most hazardous compounds that can be detected by volatiles analyses are vinyl chloride and benzene. Both have been identified as human carcinogens (U.S. Department of Health and Human Services, 1982). Benzene, the most frequently detected priority pollutant in this study, was found in five wells and in the landfill leachate. The New York State guideline for benzene in drinking water is 5 µg/L; the leachate and samples from wells at the eastern and southeastern boundaries of the site (S73750 and S73758) exceeded this limit (table 3). Benzene was detected mostly in wells on the site. About 500 ft downgradient of the site, 3 µg/L of benzene was found in well S72834 at Sunrise Highway, but not in wells S72826 and S73954, 1,000 ft further downgradient and south of Sunrise Highway (see fig. 2). Vinyl chloride was not detected in any of the analyses for this study (at 1 ppb detection limit). Trichloroethylene was identified only in well S73758 at the southeastern boundary, at 11 µg/L. Chloroform was detected at 1 ppb in one of the two analyses of well S73750 and at 4 and 5 ppb in wells S72826 and S73954, respectively. The isolated occurrence of chloroform in wells S72826 and S73954 is anomalous, and no potential sources for this contamination have been identified. These wells are approximately 350 ft apart and 2,000 ft downgradient of the site, and chloroform was not detected upgradient in samples from any wells at Sunrise Highway (fig. 2).

The extractable priority pollutants identified in this study include naphthalene, 1,4-dichlorobenzene, diethyl phthalate, bis (2-ethylhexyl) phthalate, di-n-butyl phthalate, and n-nitrosodimethylamine (table 3). Naphthalene and 1,4-dichlorobenzene are components of mothballs and are frequently disposed of in sanitary landfills. Both are potential carcinogens. Phthalates are plasticizers and are frequently used as additives in polymerization processes to control certain characteristics of plastic polymers. Their occurrence is generally scattered and unpredictable, and they were not detected in the leachate. No 2,3,7,8,-tetrachlorodibenzo-*p*-dioxin (TCDD) was detected in any of the samples (at 1 µg/L detection limit).

The extractable organic compounds appear limited to wells at the boundary of the Brookhaven landfill site, although well S72834, 500 ft downgradient at Sunrise Highway, contained trace amounts of priority pollutants. Toluene, chloroform, bis (2-ethylhexyl) phthalate, di-n-butyl phthalate, and n-nitrosodimethylamine were detected in the July 6 sample from well S73750 at the eastern boundary of the site, but not in the sample on August 24. 1,4-Dichlorobenzene was detected in the second sample but not in the original sample. Both samples from well S73759 at the southeastern boundary of the site were consistent, and only diethyl phthalate was detected. Additional extractable compounds not on the acid- and base/neutral-extractable schedules were identified in the July 6 samples from three wells at and near the southeastern boundary of the facility (S72817, S73750, and S73759) and are listed in table 5. No other nonpriority pollutants were detected in the other samples from the July 6 sampling.

Dissolved Organic Carbon

High levels of dissolved organic carbon are typical in leachate-contaminated ground water. DOC values measured in this study ranged from 410 mg/L in the leachate to 0.8 mg/L in background well S72816, upgradient of the landfill (fig. 2). High DOC concentrations correlate well with the

presence of priority pollutants. Ground-water samples with DOC concentrations less than 8 mg/L contained low levels of priority pollutants and were generally from monitoring wells more than 500 ft from the edge of the sanitary landfill. All samples with DOC values greater than 12 mg/L contained significant levels of priority pollutants. The maximum observed DOC concentration in ground water was in the July 6 sample from well S73750, at the eastern boundary of the site, which contained 180 mg/L. This value was exceeded only by the leachate sample.

The procedure for a DOC analysis involves purging dissolved carbon dioxide from the sample before the analysis for organic carbon. During this process, any purgeable organic compounds present will also be lost, and this can cause a downward bias in DOC values for samples containing volatile hydrocarbons. The results of GC/FID scans for purgeables indicated small amounts of volatile hydrocarbons in the more highly contaminated samples. Thus, the higher reported DOC values will be slightly low because of purging.

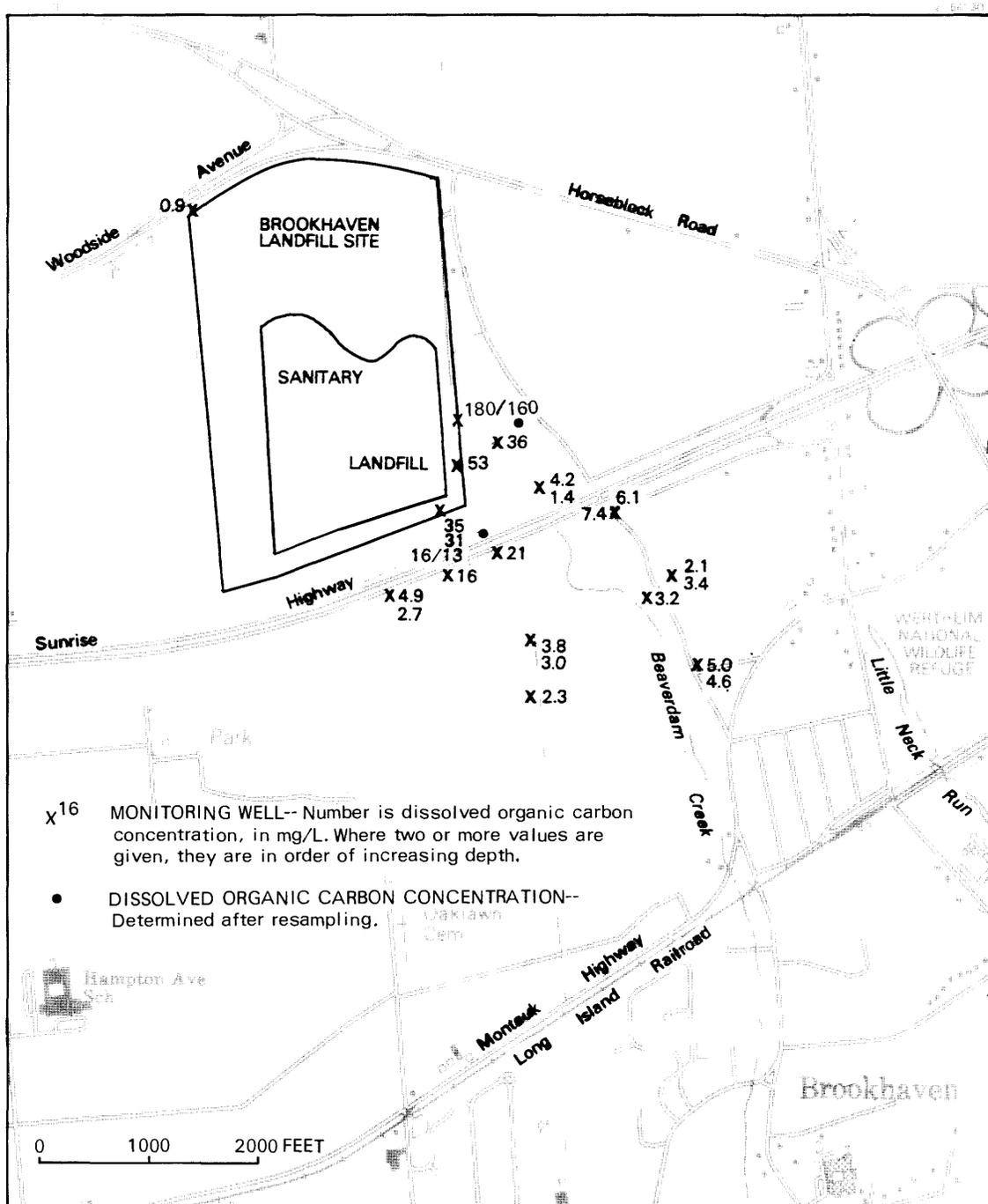
Results of DOC analyses are plotted in figure 3. The areal extent of elevated DOC is similar to that of chloride and other inorganic constituents reported by Wexler (in press), although the DOC concentrations decrease more rapidly with distance from the sanitary landfill than the inorganic constituents. A graph relating DOC concentration to chloride concentration is given in figure 4. The nonlinearity of this relationship suggests that the

Table 5.--Organic nonpriority pollutants identified in ground-water samples collected in vicinity of Brookhaven landfill site, July 6, 1983.

[Locations of wells are shown in fig. 2]

Well no.	Compound	Concentration (µg/L)
S72817	1,7,7-Trimethylbicyclo (2.2.1) heptan-2-one	2.7
	2(3H)-Benzothiazolone	21.3
S73750	Diphenylhydrazine	5.9
	1,2-Dimethylbenzene	4.8
	1,3-Dimethylbenzene	6.5
	1,4-Dimethylbenzene	3.0
	1,2,4-Trimethylbenzene	2.4
	1,3,3-Trimethylbicyclo (2.2.1) heptan-2-one	39.3
	1,7,7-Trimethylbicyclo (2.2.1) heptan-2-one	102.0
	4-Acetylmorpholine	24.8
	1-(2-Ethoxypropoxy)-2-propanol	16.2
	1-(2-(2-ethoxy-1-methylethoxy)-1 methylethoxy)-2-propanol	14.2
S73759	1-Chloro-2-ethenyl-1-methylcyclopropane	10.6
	2-(2-Methoxypropoxy)-1-propanol	16.9
	1,3-Isobenzofurandione	11.7
	2,3-Dimethylbenzoic acid	11.3
	2,5-Dimethylbenzoic acid	65.2
	N-(1,1-Dimethylethyl)-4-methylbenzamide	49.0
	2-Methylbenzenesulfonyl chloride	18.8
	2(3H)-Benzothiazolone	221.0
	9,10-Dimethoxy-1-methyl lycorenan	7.6

movement of DOC is not conservative in ground water. DOC concentrations at two wells 1/2 mile downgradient of the landfill site (S72834, 21 mg/L, and S72835, 16 mg/L), are roughly 1/10 the concentrations detected in well S73750, at the eastern boundary of the site.



Base from New York State Department of Transportation
1:24,000 scale, Bellport, 1981

Figure 3.--Dissolved organic carbon concentrations in ground water in vicinity of Brookhaven landfill site, July and August 1983. (Well-identification numbers are shown in fig. 2.)

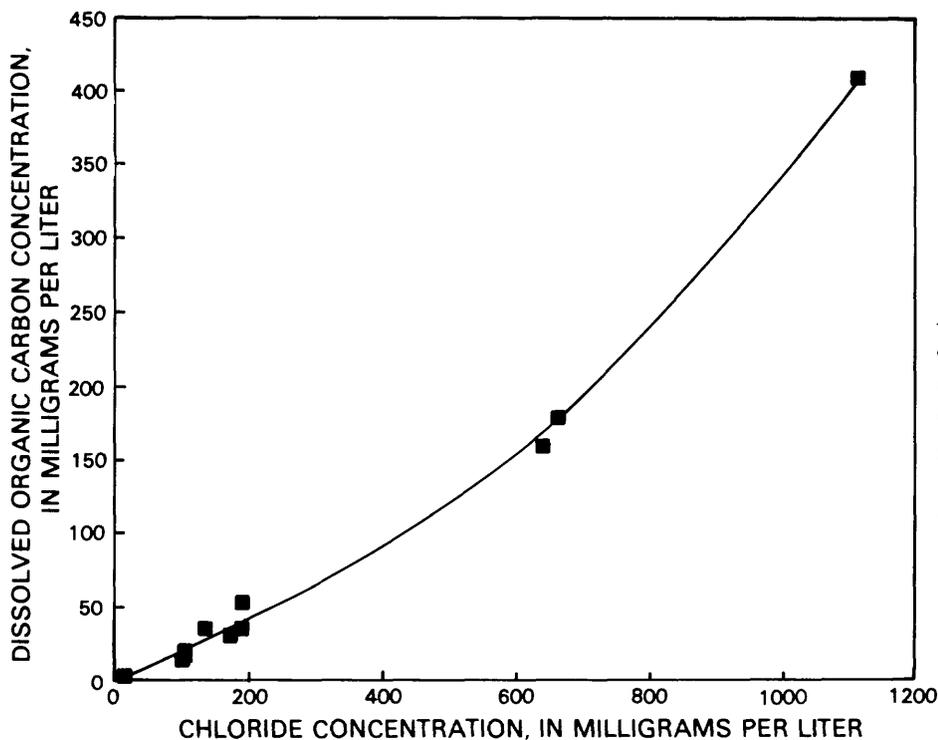


Figure 4

Relationship between dissolved organic carbon and chloride concentrations in ground water in vicinity of Brookhaven landfill site.

Inorganic Constituents

Each monitoring well was sampled for inorganic constituents to establish the extent of contamination by landfill leachate. Results for both the leachate and ground-water samples are presented in table 6. The leachate sample contained elevated levels of chloride and the metal ions--sodium, potassium, calcium, magnesium, iron, and manganese, which are dissolved out of the refuse. In addition, the leachate contained elevated levels of alkalinity and ammonium ion. Bicarbonate alkalinity arises from the reaction of water and carbon dioxide produced by decomposition of the organic matter in the waste. Additional alkalinity may be due to weak organic acids or inorganic acids such as silicic, phosphoric, and boric acids. Ammonium ion is a product of anaerobic decomposition within the reducing environment of the landfill and leachate plume. Nitrate and sulfate concentrations are below detection limits because the nitrogen and sulfur compounds occur in the reduced forms of ammonium and sulfide. The concentrations (in milliequivalents per liter) of nine ions in leachate and ground-water samples are plotted as computer-generated Stiff diagrams in figure 5. (Bicarbonate concentrations were calculated from the total alkalinity values).

Water from several wells downgradient of the Brookhaven landfill site shows similar patterns in which bicarbonate, ammonium, chloride, and the metals are above the background concentrations at the upgradient well S72816. Well S73750, at the eastern boundary of the site, had bicarbonate, chloride, ammonium, sodium, and potassium concentrations ranging from 60 to 75 percent of the values in the leachate sample.

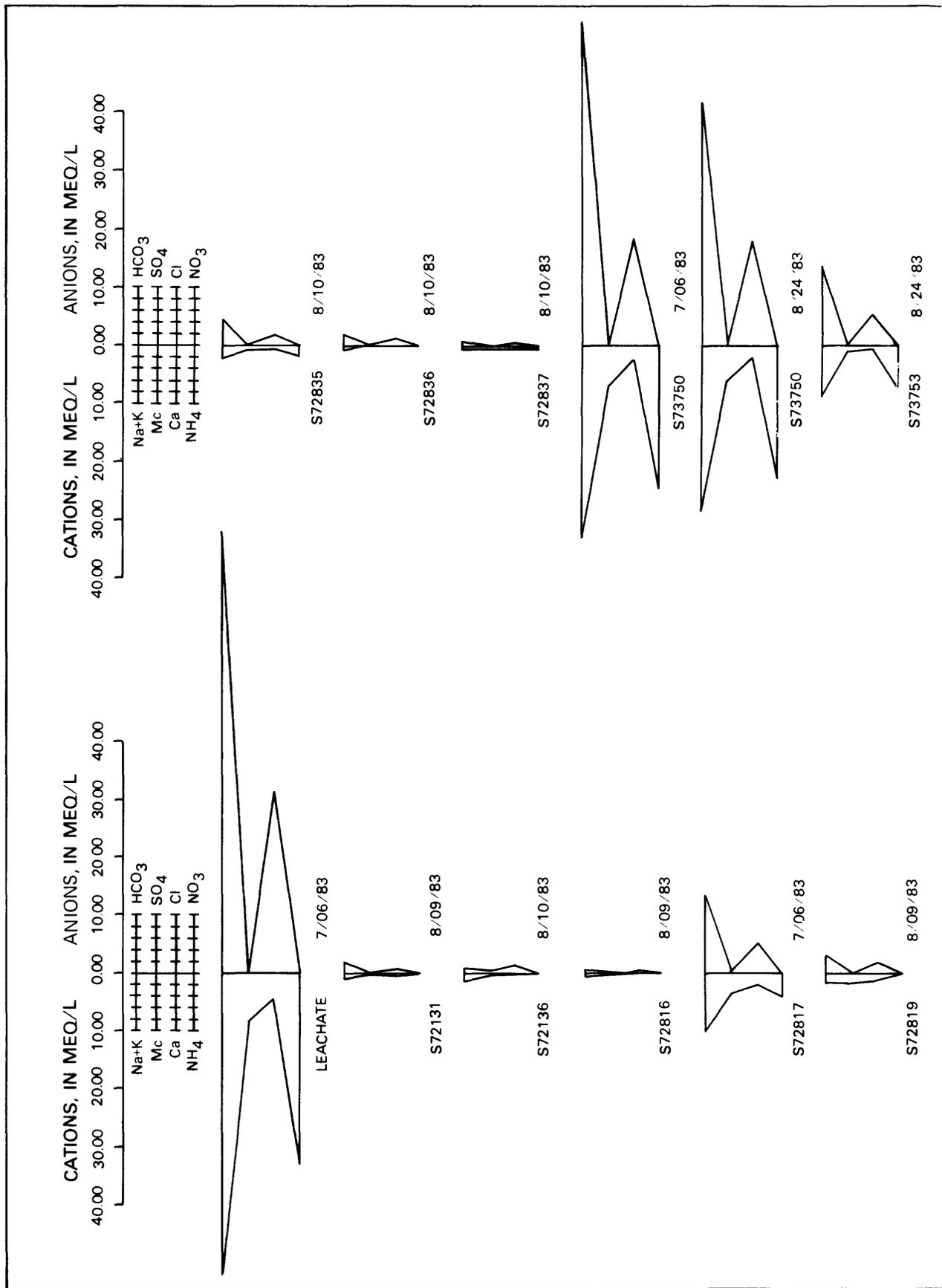
Table 6.--Concentrations of inorganic constituents detected in leachate and ground water in vicinity of Brookhaven landfill site, July and August, 1983.

[Well locations shown in fig. 2]

Local identifier	Latitude/longitude	Sequence no.	Date of sample	Temperature (°C)	Specific conductance (µmho at 25°C)	pH field value (units)	pH lab. value (units)	Alkalinity as CaCO ₃ (mg/L)	Total ammonium as N (mg/L)	Total nitrite as N (mg/L)	
Leachate	404745	0725538	1	83-07-06	20.0	^a 5900	7.0	7.41	3820	465.	0.03
S72131	404722	0725526	1	83-08-09	12.0	240	5.9	5.42	100	0.17	< 0.01
S72136	404734	0725515	3	83-08-10	11.0	260	--	5.33	39	< 0.04	< 0.01
S72816	404801	0725607	1	83-08-09	14.0	< 50	4.9	5.33	16	< 0.04	< 0.01
S72817	404741	0725530	1	83-07-06	14.0	^a 960	6.9	6.70	675	61.2	< 0.01
S72819	404736	0725525	2	83-08-09	13.0	400	6.4	6.01	153	< 0.04	< 0.01
S72820	404736	0725525	3	83-08-09	13.0	220	6.3	6.09	61	< 0.04	< 0.01
S72822	404734	0725515	2	83-08-10	11.0	220	--	5.00	19	< 0.04	< 0.01
S72826	404726	0725512	2	83-08-24	11.0	80	5.5	5.87	25	< 0.04	< 0.01
S72828	404720	0725506	2	83-08-09	12.0	70	6.0	5.03	16	< 0.04	< 0.01
S72832	404717	0725526	1	83-08-09	12.5	120	5.1	5.16	31	< 0.04	< 0.01
S72833	404722	0725526	2	83-08-09	13.0	220	6.0	6.07	109	0.08	0.05
S72834	404730	0725530	1	83-08-24	14.0	975	6.6	7.01	477	58.2	< 0.01
S72835	404729	0725536	1	83-08-10	12.5	675	--	6.72	235	27.0	0.03
S72836	404727	0725543	1	83-08-10	12.5	290	--	5.85	101	5.74	< 0.01
S72837	404727	0725543	2	83-08-10	12.5	135	--	6.55	34	4.09	< 0.01
S73750	404742	0725536	1	83-07-06	16.0	^a 3100	6.8	6.93	2810	350.	0.02
do.	do.		1	83-08-24	14.0	5500	6.5	7.06	2110	318.	< 0.01
S73753	404738	0725535	1	83-08-24	16.0	1800	6.5	7.12	695	104.	< 0.01
S73757	404734	0725537	2	83-08-25	17.0	1200	6.3	7.04	530	68.8	< 0.01
S73758	404734	0725537	1	83-08-25	17.0	1800	5.7	6.44	482	56.5	< 0.01
S73759	404734	0725537	4	83-07-06	18.0	^a 920	6.6	6.77	691	33.9	< 0.01
do.	do.			83-08-24	14.5	800	6.5	7.48	623	31.1	< 0.01
S73953	404728	0725509	1	83-08-10	11.5	80	--	5.35	15	< 0.04	< 0.01
S73954	404728	0725509	2	83-08-24	11.0	90	6.0	6.49	6	< 0.04	< 0.01
S73955	404720	0725506	3	83-08-09	12.0	220	6.1	5.88	77	< 0.04	< 0.01

Local identifier	Total nitrate as N (mg/L)	Total Kjeldahl nitrogen as N (mg/L)	Dissolved calcium (Ca) (mg/L)	Dissolved magnesium (Mg) (mg/L)	Dissolved sodium (Na) (mg/L)	Dissolved potassium (K) (mg/L)	Dissolved chloride (Cl) (mg/L)	Dissolved sulfate (SO ₄) (mg/L)	Dissolved iron (Fe) (mg/L)	Dissolved manganese (Mn) (mg/L)	Total dissolved solids (mg/L)
Leachate	< 0.04	520.	87.	100.	840.	640.	1100	< 1	15.	0.25	4420
S72131	< 0.04	2.9	4.9	3.0	13.	2.2	24	2	0.058	29.	103
S72136	< 0.04	< 0.04	6.7	6.1	31.	1.7	52	17	0.18	0.020	117
S72816	< 0.04	0.25	1.2	1.4	6.1	0.48	11	4	0.089	0.018	22
S72817	0.07	66.	41.	43.	150.	140.	190	8	23.	0.77	945
S72819	< 0.04	0.95	26.	22.	37.	2.1	68	3	0.053	6.3	232
S72820	< 0.04	< 0.04	9.2	13.	15.	0.84	35	4	0.44	0.35	104
S72822	1.04	< 0.04	2.6	4.6	20.	1.4	39	36	0.077	12.	97
S72826	0.08	< 0.04	2.2	2.8	6.8	0.68	18	5	< 0.020	0.024	49
S72828	< 0.04	< 0.04	3.2	3.4	10.	0.78	21	11	0.075	0.13	59
S72832	< 0.04	< 0.04	2.2	5.0	13.	0.87	23	8	0.079	0.035	62
S72833	0.13	0.45	17.	15.	17.	1.0	22	3	0.051	0.046	121
S72834	< 0.04	59.	19.	22.	69.	64.	110	3	16.	5.9	476
S72835	< 0.04	32.	12.	9.8	37.	26.	63	1	51.	9.8	263
S72836	< 0.04	6.3	2.7	2.5	14.	6.4	52	7	18.	21.	126
S72837	< 0.04	8.0	2.6	1.0	4.3	5.0	19	2	12.	1.9	39
S73750	< 0.04	370.	47.	86.	530.	400.	670	1	23.	0.59	2580
do.	< 0.04	340.	39.	73.	460.	340.	640	2	18.	0.50	2210
S73753	< 0.04	110.	14.	12.	140.	120.	190	6	14.	0.70	711
S73757	< 0.04	76.	21.	23.	97.	80.	140	1	26.	3.6	550
S73758	< 0.04	58.	13.	15.	110.	70.	170	1	100.	80.	561
S73759	< 0.04	36.	92.	40.	94.	38.	110	2	2.4	23.	807
do.	< 0.04	44.	69.	30.	75.	36.	100	3	1.6	25.	713
S73953	0.20	< 0.04	2.0	2.5	7.5	0.68	14	3	0.066	0.022	30
S73954	1.62	0.73	2.7	2.3	6.8	0.62	14	5	0.069	0.036	42
S73955	2.63	< 0.04	15.	8.6	12.	0.91	21	10	0.058	0.015	119

^a Lab value; all other specific conductance measurements are field values.



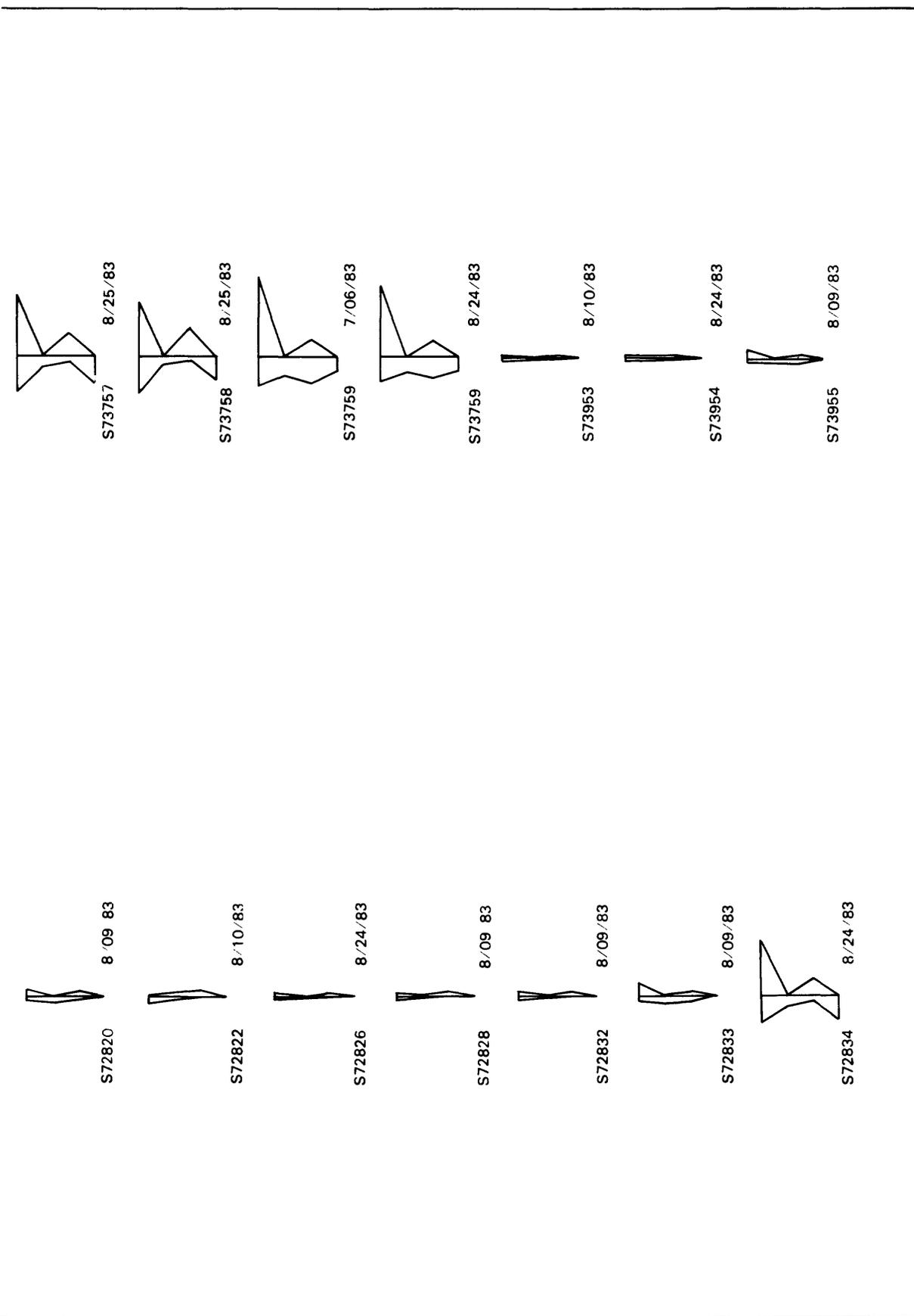


Figure 5.--Stiff diagrams of inorganic constituent concentrations in leachate and ground water in vicinity of Brookhaven landfill site, July and August 1983. (Well locations are shown in fig. 2.)

The Stiff diagrams for well S72817, 300 ft east of the landfill site, for wells along Sunrise Highway (S72834-S72837), and all wells on the site boundaries (S73750, S73753, and S73757-S73759) show configurations similar to that for the leachate. Several wells further downgradient (S72136, S72819, S72820, S72131, S72833, S72832, S72822, S73955, and S72828) show elevated levels of most constituents except ammonium. Nitrate appears in concentrations above 1 mg/L in three wells along the east edge of the plume (S72822, S73954 and S73955), which may indicate that some nitrification of ammonium ion takes place as oxygenated ground water mixes with water in the plume. Stiff diagrams for two wells at the edge of the site (S73750 and S73759), which were each sampled twice, show little change in concentrations of inorganic constituents over the 2-month sampling period.

VERTICAL DISTRIBUTION OF CONTAMINANTS

At several locations at the Brookhaven landfill site, clusters of wells were installed with screens set at different depths to obtain data on the vertical distribution of contaminants.

The three wells at the southeast corner of the site (S73758, S73757, and S73759) screened at 50, 70, and 125 ft, respectively, were sampled to provide a vertical profile of ground water leaving the site. The shallowest well (S73758), 50 ft deep, contained six priority pollutants in significant concentrations. The intermediate well (S73757), 70 ft deep, contained only benzene and diethyl phthalate, both in low concentrations. The deepest well (S73759), 125 ft deep, contained only diethyl phthalate, but at an elevated concentration (18 µg/L on July 6 and 10 µg/L on August 24, 1983). The vertical distribution of DOC values at these wells was 31, 35, and 13 mg/L (August 24-25 samples) at 50-, 70-, and 125-ft depths, respectively. This indicates that although the priority pollutants are attenuated with depth, organic compounds and their decomposition products have penetrated to at least 125 ft below land surface at the site boundary. At wells downgradient of the site, contaminant concentrations generally decreased with depth, although no clear pattern is evident.

FATE OF ORGANIC COMPOUNDS

Dissolved Organic Carbon

The principal influences on DOC concentrations are advection, dispersion, adsorption, chemical degradation, and biodegradation. Advection and dispersion are processes whereby contaminants move with the flow of ground water. Advection refers to the transport of contaminants at the same rate as the average velocity of ground water (Anderson, 1984); dispersion refers to the scattering of contaminants by local variations in ground-water velocities. Dispersion causes mixing with uncontaminated ground water and thus is a mechanism for dilution (Anderson, 1984). Both advection and dispersion are nondestructive--that is, the contaminants spread over a wider area and are diluted but not altered or destroyed.

Adsorption is the physical attachment of a contaminant to a solid surface. Ion exchange is adsorption to charged surfaces and can be significant for hydrophilic or polar compounds (organic acids and inorganic ions). Hydrophobic or nonpolar compounds (hydrocarbons) will have an affinity for an organic or hydrocarbon phase in preference to the aqueous (or ground-water) phase. The strength of this affinity can be approximated by an octanol:water partition coefficient, and published values of these coefficients are available for many organic compounds. The significance of adsorption processes for hydrophobic compounds in ground water is related to the amount of organic material in the aquifer system. In general, the upper glacial aquifer deposits on Long Island contain a very small percentage of organic carbon. However, a landfill-leachate plume typically contains sufficient nutrients to support extensive bacterial growth, which provides organic surfaces upon which adsorption can occur. Not enough is known about this process to quantify its importance, however. Adsorption is also nondestructive, and the compound can later be desorbed or released.

Organic compounds are subject to decomposition as a result of inherent instability in chemical structure, and to chemical alteration and degradation by hydrolysis, reaction with the natural components of the ground-water system, and reaction with other leachate constituents. Also, they are subject to biological degradation when used as a nutrient or energy source by bacteria. Ground-water samples from highly contaminated wells along the boundary of the Brookhaven landfill site released significant amounts of carbon dioxide, a product of biodegradation of organic materials, as they were brought to the surface. Thus, biodegradation is an active process within ground water near the site. Both chemical and biological degradation are destructive processes that alter or degrade contaminants.

The collective influence of advection and dispersion on DOC concentrations can be separated from the influences of adsorption, chemical degradation, and biodegradation. Both chloride and DOC are subject to advection and dispersion, but chloride is not subject to adsorption, chemical degradation, or biodegradation. Thus, the combined effects of these processes upon DOC can be observed in the plot in figure 4 (p. 14). If chloride and DOC both decreased at the same rate, a graph of DOC in relation to chloride concentrations would be linear. The upward concavity of this plot, however, indicates that DOC concentrations decrease more rapidly than chloride concentrations as leachate moves from the sanitary landfill toward well S73750, and from there southeastward toward other monitoring wells.

Priority Pollutants

The fate of the priority pollutants identified in this study has been reviewed by Overcash and others (1982) and Callahan and others (1979). Neither volatilization, physical degradation, nor chemical degradation appear to be significant loss processes for these compounds in ground water. However, biodegradation processes have been identified or proposed for each of the priority pollutants. Evidence from recent research suggests that all nonpolymerized organic compounds are biodegradable, although refractory compounds are degraded at very slow rates.

Wilson and others (1983) have demonstrated aerobic bacterial degradation of benzene and toluene. Parsons and others (1984) have demonstrated microbial degradation of trichloroethylene. Bailey (1983) has reviewed the research literature that describes the microbial degradation of chlorobenzenes. Insufficient information is available at present, however, to quantify the importance of biodegradation in attenuating the concentrations of these compounds in ground-water systems.

Nonaromatic, nonhalogenated organic compounds are generally the most readily degraded. Nonhalogenated aromatic compounds are less readily degraded, and halogenated aromatic compounds are the most persistent. Specifically, the nonhalogenated compounds benzene, toluene, ethylbenzene, naphthalene, and phthalates are gradually biodegraded at low concentrations in aquatic systems, but chlorobenzene and dichlorobenzene are regarded as extremely persistent and are degraded only very slowly.

SUMMARY AND CONCLUSIONS

Landfill leachate and ground-water samples in the vicinity of the Brookhaven landfill site were analyzed for U.S. Environmental Protection Agency priority pollutant volatile, acid-extractable, and base/neutral-extractable organic compounds, dissolved organic carbon (DOC), and selected inorganic constituents. Thirteen priority pollutants were detected, including benzene, chlorobenzene, ethylbenzene, and naphthalene. The most commonly detected compound was benzene, which was found in the leachate and in samples from five wells. The priority pollutant having the highest concentration--55 µg/L in landfill leachate--was ethylbenzene. No TCDD (dioxin) or vinyl chloride were detected in any samples (1 µg/L detection limit).

Samples from well S73750, at the eastern boundary of the site, were the most contaminated of all samples tested. Eleven priority pollutants and the highest DOC concentration of all wells were found in the July 6 sample from this well. Other wells along the eastern and southern boundaries of this site also contained detectable concentrations of priority pollutants. A sample from one well (S72834), 500 ft south and downgradient of the site, contained priority-pollutant concentrations totaling less than 20 µg/L. Samples from two wells 2,000 ft downgradient of the site contained trace amounts of chloroform, but this is not believed to be associated with the sanitary landfill. DOC concentrations decrease rapidly downgradient and approach background values within 1/2 mi of the site.

REFERENCES CITED

- American Public Health Association, 1975, Standard methods for the examination of water and wastewater, 14th ed.: Washington, D.C., 1193 p.
- Anderson, M. P., 1984, Movement of contaminants in groundwater--groundwater transport-advection and dispersion, in Studies in geophysics, groundwater contamination: National Academy Press, p. 37-45.
- Bailey, R. E., 1983, Comment on "Chlorobenzenes in sediments, water, and selected fish from Lakes Superior, Huron, Erie, and Ontario": Environmental Science and Technology, v. 17, no. 8, p. 504.
- Callahan, M. A., Slimak, M. W., Gable, N. W., May, I. P., Fowler, C. F., Freed, J. R., Jennings, P., Durfee, R. L., Whitmore, F. C., Maestri, B., Mabey, W. R., Holt, B. R., and Gould, C., 1979, Water-related environmental fate of 129 priority pollutants: U.S. Environmental Protection Agency publication EPA-440/4-79-029b, 714 p.
- Dowd, R. M., 1983, Effluent guidelines for organic chemicals, plastics, and synthetic fibers: Environmental Science and Technology, v. 17, no. 10, p. 473A.
- Federal Register, 1979, Test procedures for the analysis of pollutants: v. 44, no. 233, December 3, p. 69463-69575.
- Goerlitz, D. F., and Brown, Eugene, 1972, Methods for analysis of organic substances in water: Techniques of Water-Resources Investigations of the U.S. Geological Survey, Laboratory analysis, book 5, chapter A3, p. 4-6.
- Hughes, J. L., Eccles, L. A., and Malcolm, R. M., 1974, Organic contamination in ground water near Barstow, California: Groundwater, v. 12, no. 5, p. 283-290.
- Mackay, S. L., Fleisher, M. B., and Cusumano, R. D., 1979, Inventory of consumer products for "Report on survey of consumer products containing or suspected of containing harmful organic chemicals and having the potential of contaminating the groundwater of Nassau County, New York": Mineola, N.Y., Nassau County Department of Health, 39 p.
- National Academy of Sciences, 1977, Drinking water and health: Washington, D.C., Safe Drinking Water Committee, 939 p.
- Overcash, M. R., Weber, J. B., and Miles, M. L., 1982, Behavior of organic priority pollutants in the terrestrial system--di-n-butyl phthalate ester, toluene, and 2,4-dinitrophenol: Water Resources Research Institute of the University of North Carolina Report no. 171, 94 p.
- Parsons, Frances, Wood, P. R., and DeMarco, Jack, 1984, Transformations of tetrachloroethene and trichloroethene in microcosms and groundwater: Journal Americal Water Works Association, v. 76, no. 2, p. 56-59.

REFERENCED CITED (Continued)

U.S. Department of Health and Human Services, Public Health Service, 1982, Third annual report on carcinogens, December 1982: Publication PB 83-135855, 327 p.

U.S. Environmental Protection Agency, 1974, Methods for chemical analysis of water and wastes: Cincinnati, Ohio, Methods Development and Quality Assurance Laboratory, National Environmental Research Center, U.S. Environmental Protection Agency, EPA-625/6-74-003, 298 p.

Wershaw, R. L., Fishman, M. J., Grabbe, R. R., and Lowe, L. E., 1982, eds., Methods for the determination of organic substances in water and fluvial sediments: U.S. Geological Survey Open-File Report 82-1004, 173 p.

Wexler, E. J., Ground-water flow and solute transport at the Brookhaven landfill site, Long Island, New York, Part 1--Hydrogeology and ground-water quality near the Brookhaven landfill site: U.S. Geological Survey Water-Resources Investigations Report 86-4070 (in press).

Wilson, J. T., McNabb, J. F., Balkwill, D. L., and Ghiorse, W. C., 1983, Enumeration and characterization of bacteria indigenous to a shallow water-table aquifer: Groundwater, v. 21, no. 2, p. 134-142.