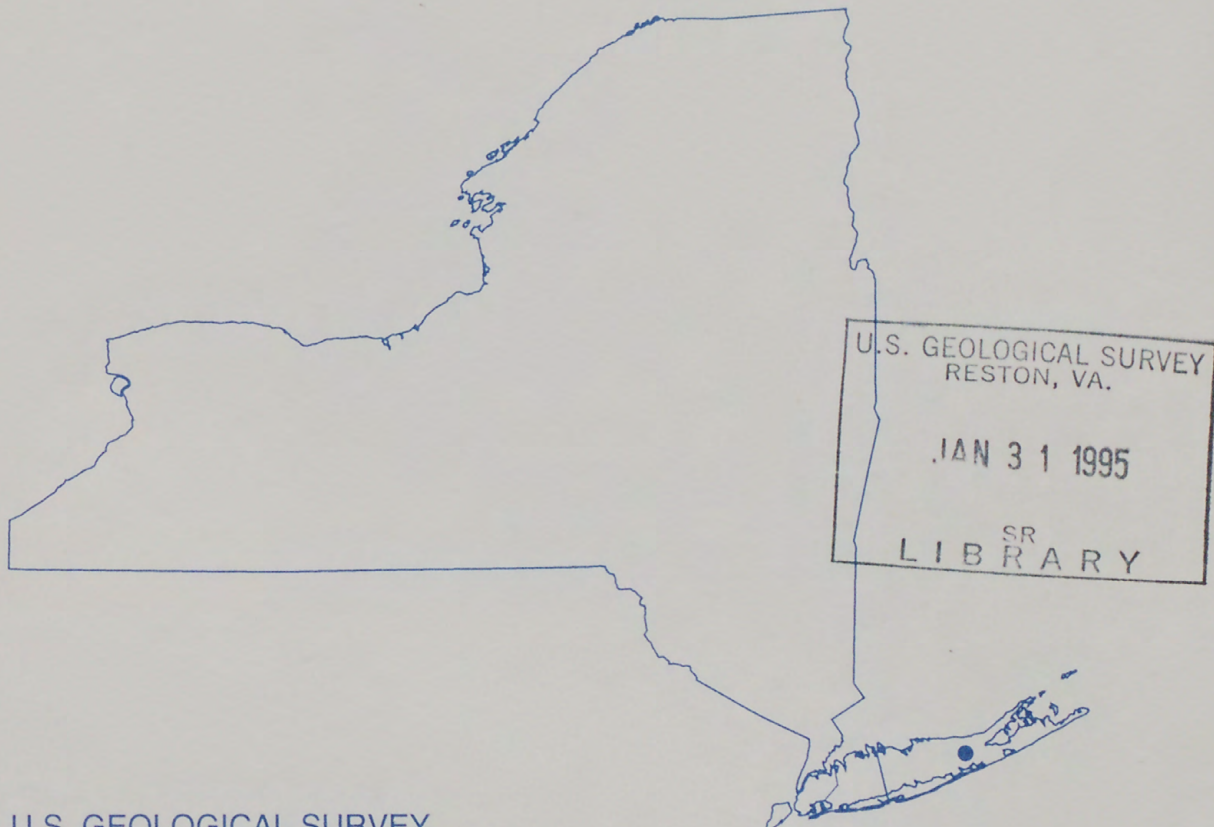


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## Ground-Water Quality and Geochemical Processes at a Municipal Landfill, Town of Brookhaven, Long Island, New York



U.S. GEOLOGICAL SURVEY  
Water-Resources Investigations  
Report 91-4154

Prepared in cooperation with  
NASSAU COUNTY DEPARTMENT OF  
PUBLIC WORKS,  
SUFFOLK COUNTY DEPARTMENT OF  
HEALTH SERVICES,  
and  
SUFFOLK COUNTY WATER AUTHORITY







GROUND-WATER QUALITY AND GEOCHEMICAL PROCESSES AT A MUNICIPAL  
LANDFILL, TOWN OF BROOKHAVEN, LONG ISLAND, NEW YORK

By Kenneth A. Pearsall and Mary Jean Aufderheide

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Syosset, New York

1995

U.S. DEPARTMENT OF THE INTERIOR

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U.S. Geological Survey

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## CONVERSION FACTORS, ABBREVIATIONS, AND VERTICAL DATUM

<i>Multiply</i>	<i>by</i>	<i>To obtain</i>
<i>Length</i>		
inch (in.)	25.4	millimeter
inch (in.)	2.54	centimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
<i>Area</i>		
acre	0.4047	hectare
<i>Flow</i>		
foot per day (ft/d)	0.3048	meter per day
cubic foot per second (ft <sup>3</sup> /s)	28.32	liter per second
million gallons per day (Mgal/d)	0.04381	cubic meter per second

### *Abbreviated Water-Quality Units*

$\mu$ S/cm, microsiemens per centimeter at 25°C (degrees Celsius)  
 mg/L, milligrams per liter  
 $\mu$ g/L, micrograms per liter  
 $\mu$ m, micrometer (filter mesh)

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.





# GROUND-WATER QUALITY AND GEOCHEMICAL PROCESSES AT A MUNICIPAL LANDFILL, TOWN OF BROOKHAVEN, LONG ISLAND, NEW YORK

by Kenneth A. Pearsall and Mary Jean Aufderheide

## Abstract

The principal geochemical process within a plume of leachate-contaminated ground water downgradient from the municipal landfill in the Town of Brookhaven is the oxidation of organic matter. Concurrent reducing processes are the reduction of iron and manganese oxyhydroxides to soluble ferrous and manganous forms, of nitrate and nitrite to nitrogen and ammonia, of sulfate to sulfide (sulfide precipitates from solution as iron and manganese sulfides), and, under extreme conditions, of some organic matter to methane. Secondary processes unrelated to bacterial activity and redox processes are the exchange of dissolved sodium and potassium for calcium and magnesium at ion-exchange sites and the dissolution of calcium and magnesium silicate minerals; these processes cause sodium and potassium concentrations to decrease with depth and with distance from the landfill and cause calcium, magnesium, and silica concentrations to increase.

## INTRODUCTION

The effect of sanitary landfills on Long Island on the underlying aquifer system has become a subject of increasing concern as the demand for ground water, the only source of freshwater in Nassau and Suffolk Counties, has increased. The U.S. Geological Survey (USGS) has conducted several studies of the effects of municipal landfills on Long Island ground water. Kimmel and Braids (1974, 1980) showed that municipal landfills in Babylon and Islip (fig. 1) were sources of contaminant plumes. Studies at the Brookhaven landfill site in the Town of Brookhaven (fig. 1) investigated ground-water quality (Wexler, 1988a; Pearsall and Wexler, 1986) and simulated ground-water flow (Wexler and Maus, 1988) and solute transport (Wexler, 1988b) in the landfill vicinity. In 1985, the USGS, in cooperation with the Nassau County Department of Public Works, Suffolk County Department of Health Services, and Suffolk County Water Authority, began a study to identify major geochemical processes that occur in areas where the Long Island aquifer system is unaffected by human activities, and to compare these processes with those that occur in contaminated ground water. The Brookhaven landfill site was selected for study of the latter and is the subject of this report.

## Purpose and Scope

This report describes aqueous geochemical processes within a sand and gravel aquifer that contains elevated concentrations<sup>1</sup> of organic carbon and

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<sup>1</sup> In this report, "elevated concentrations" refers to concentrations greater than those in ambient ground water unaffected by the landfill.

inorganic constituents and compares these processes with those that occur in uncontaminated areas. The report presents and interprets the results of 51 analyses of samples collected in November and December 1987 from two parallel sections along a plume of contaminated ground water that extends downgradient from the Brookhaven landfill site. Ground-water-quality data collected during previous studies (1982-84) at the same site, and unpublished data collected for a study of natural geochemical processes in the Long Island aquifer system, are used for comparisons.

### Acknowledgments

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

### SITE DESCRIPTION

The Brookhaven landfill site (fig. 1) contains a sanitary landfill that has been used for disposal of municipal refuse since 1974. The site occupies 180 acres south of the intersection of Woodside Avenue and Horseblock Road and north of Sunrise Highway, in the south-central part of the Town of Brookhaven (pl. 1). At the time of construction, the landfill was excavated to within 10 ft of the water table in cells 300 ft wide, each of which was lined with a polyvinyl chloride (PVC) liner. As each liner was laid, it was glued (sealed) to the previously laid, adjacent liners. The resulting liner system is bowl-shaped and intended to retain leachate for collection by a system of buried drains. Collected leachate is trucked to a sewage-treatment facility. Water-quality data obtained in 1982 (Wexler, 1988a) indicate that, despite the

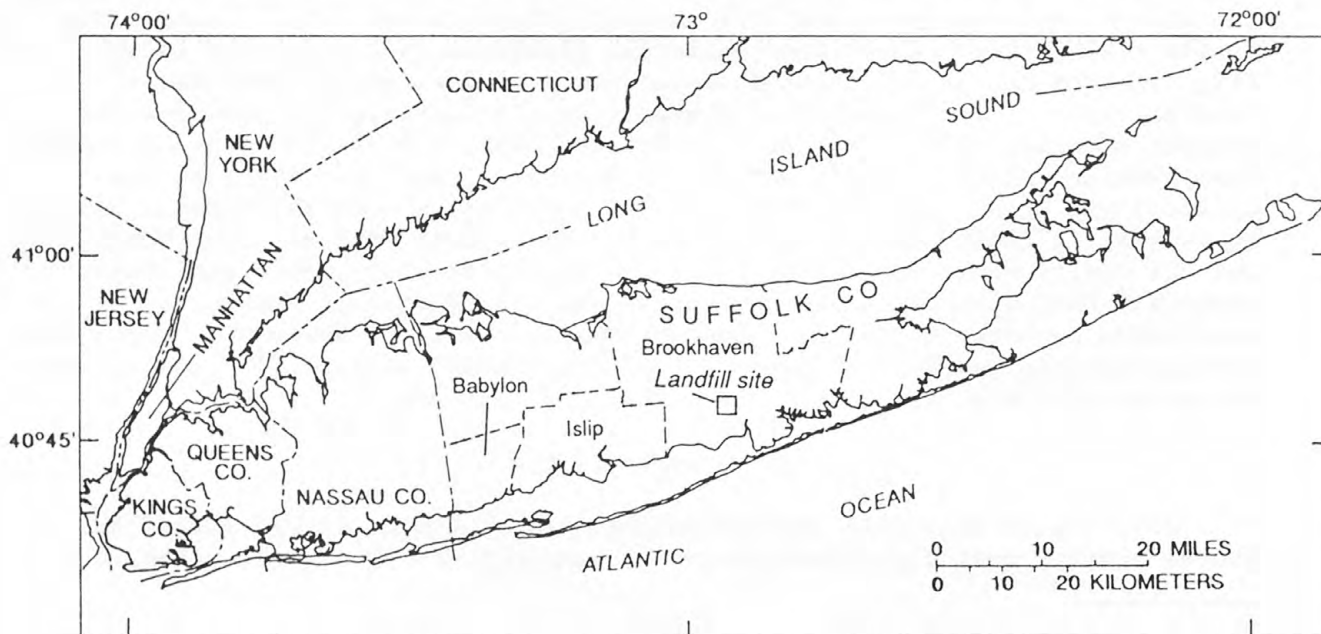


Figure 1. Location of the Brookhaven landfill site in the Town of Brookhaven.



PVC liner and leachate-collection system, leachate has entered and contaminated ground water in the area. A more detailed history of the landfill site and activities is provided by Wexler (1988a).

Terminology used in this report is that used by Wexler (1988a, p. 3 and 12). The terms "landfill" and "sanitary landfill" refer to the area that has been excavated and in which wastes have been deposited. The term "landfill site" refers to the landfill itself plus the surrounding land that has been cleared and fenced (pl. 1).

Ground water near the landfill site has been studied in detail by the USGS in cooperation with the Town of Brookhaven. Analyses of samples collected in 1982 (Wexler, 1988a) indicated the likelihood of leakage from the landfill liner and the extent of ground-water contamination by inorganic constituents. Analyses of ground-water samples collected in 1983 indicated slight contamination by hazardous organic compounds in the vicinity of the landfill site and a correlation between the presence of these compounds and elevated concentrations of dissolved organic carbon (Pearsall and Wexler, 1986). The USGS did additional sampling and analyses for inorganic constituents in 1984 (Scorca, M.P., U.S. Geological Survey, written commun., 1988).

## HYDROGEOLOGIC SETTING

The sanitary landfill is excavated in upper Pleistocene sediments above the upper glacial (water-table) aquifer. In the vicinity of the landfill site, these highly permeable outwash deposits are about 160 ft thick. Sediments are primarily sand with minor amounts of gravel, silt, and clay, and consist predominantly of iron oxyhydroxide-stained quartz, with minor amounts of rock fragments, feldspars, and heavy minerals. Downgradient from the landfill, upper Pleistocene deposits overlie the Gardiners Clay of Pleistocene age--a sand, silt, and clay horizon that forms a semiconfining layer between the upper Pleistocene deposits and the underlying Upper Cretaceous Magothy Formation and Matawan Group, undifferentiated, which form the Magothy aquifer. The extent of the Gardiners Clay has not been determined in detail. The unit is 15 ft thick at one point along the southern edge of the landfill site but appears to thin northward and is not found upgradient from the site. Neither the Magothy Formation and Matawan Group, undifferentiated, nor deeper strata, are discussed in this report.

Ground-water flow in the upper glacial aquifer in the study area is predominantly horizontal and southeastward. North of the landfill site, the upper glacial aquifer is in good hydraulic contact with the underlying Magothy aquifer, but south of the landfill site, hydraulic contact between the aquifers is impeded by the intervening Gardiners Clay. Hydraulic heads in the Magothy aquifer range from several hundredths to several tenths of a foot higher than in the upper glacial aquifer, indicating a potential for upward leakage of water from the Magothy aquifer to the upper glacial aquifer. The 30 water-level measurements made during this study in early November 1987 reflect changes in ambient conditions and averaged about 1.0 ft lower than those reported by Wexler (1988a, p. 10); the flow direction in the area remained essentially unchanged from previous studies.

Precipitation on Long Island averages 44 in/yr, of which about half enters the water-table aquifer as recharge (Miller and Frederick, 1969). Under natural conditions, this recharge would be evenly distributed across the study area, but roads, recharge basins, and the landfill itself redistribute this recharge to some extent. Deposited waste could produce additional recharge at the landfill. The head difference between the upper glacial and Magothy aquifers is smaller along the southern edge of the site than along the northern edge, possibly as a result of additional recharge at the landfill. The hydrogeology of the study area is discussed in detail in Wexler (1988a) and Wexler and Maus (1988).

## GROUND-WATER SAMPLING AND ANALYSES

### Well Network

Samples were collected from wells along two parallel traces used to construct hydrologic sections (pl. 1; fig. 2) along the direction of ground-water flow. Hydrologic section A-A' begins near the southeastern corner of the landfill and extends 1.4 mi downgradient; section B-B' originates along the eastern side of the landfill, downgradient from the leachate-collection-system tap. Section A-A' includes 32 wells at 9 sites; section B-B' includes 18 wells at 8 sites. Well-construction data are provided in table 1; the distribution of the middle of the screened zones along sections A-A' and B-B' is shown in figure 2 (p. 6). The farthest downgradient well (S72162) is included in both sections. Upgradient wells S72121 and S72816 were chosen to represent ambient ground water--that is, water unaffected by the landfill. Wells in this report are identified by a six-character letter-and-number sequence assigned by the New York State Department of Environmental Conservation (beginning with the letter "S" for Suffolk County) or by a two-character letter-number sequence indicating section and site.

### Sampling and Analysis Procedures

Wells were sampled with 1.75- and 3.75-in.-diameter submersible pumps, centrifugal pumps, or peristaltic pumps, depending on well yield, depth to water, casing diameter, and physical access to the well head. Wells were pumped at a rate intended to evacuate three well-casing volumes within 1/4 to 2 hours. After three casing volumes were removed, pH and specific conductance were measured at 10- to 15-minute intervals while pumping continued. The well water was sampled when successive measurements indicated that steady-state conditions had been achieved. Field measurements included temperature, pH, specific conductance, dissolved-oxygen concentration, and alkalinity. Samples were bottled and preserved according to standard procedures (Feltz and others, 1985) and analyzed by the USGS National Water Quality Laboratory in Denver, Colo., according to procedures in Fishman and Friedman (1985). The constituents for which samples were analyzed are listed in table 4 (at end of report). Two samples from wells immediately adjacent to the landfill were also analyzed for the hazardous constituents listed in table 5 (at end of report) according to procedures in the above reference and in Wershaw and others (1987).



Table 1.--Construction data for wells in the Brookhaven landfill site vicinity

[Section, and site locations are shown on pl. 1. Altitude is in feet above sea level. PVC, polyvinyl chloride]

Well number	Latitude	Longitude	Land-surface elevation (feet)	Depth (feet)	Depth of screened interval (feet)		Inside diameter (inches)	Casing material	Site identifier
					Top	Bottom			
S 72121	404816	725609	69	66	62	66	2.0	PVC	Upgradient
S 72136	404734	725516	29	63	59	63	2.0	PVC	B5
S 72150	404713	725503	20	47	32	47	6.0	Steel	A6
S 72151	404708	725458	21	50	35	50	6.0	Steel	A8
S 72152	404714	725451	25	49	34	49	4.0	Steel	B7
S 72162	404653	725426	12	42	27	42	8.0	Steel	Downgradient
S 72816	404801	725607	79	67	63	67	2.0	PVC	Upgradient
S 72817	404740	725530	29	22	18	22	2.0	PVC	B2
S 72818	404736	725525	23	8	4	8	2.0	PVC	B3
S 72819	404736	725525	23	23	19	23	2.0	PVC	B3
S 72820	404736	725525	23	43	39	43	2.0	PVC	B3
S 72821	404734	725516	29	23	19	23	2.0	PVC	B5
S 72822	404734	725516	29	43	39	43	2.0	PVC	B5
S 72823	404727	725521	21	13	9	13	2.0	PVC	A3
S 72834	404730	725530	39	34	30	34	2.0	PVC	A2
S 73750	404742	725535	36	34	29	34	4.0	Steel	B1
S 73751	404742	725535	36	55	50	55	4.0	Steel	B1
S 73752	404742	725535	36	85	80	85	4.0	Steel	B1
S 73756	404734	725537	55	103	98	103	4.0	Steel	A1
S 73757	404734	725537	55	73	68	73	4.0	Steel	A1
S 73758	404734	725537	55	53	48	53	4.0	Steel	A1
S 73759	404734	725537	55	128	123	128	4.0	Steel	A1
S 73943	404740	725530	29	45	43	45	1.5	Steel	B2
S 73944	404740	725530	29	65	63	65	1.5	Steel	B2
S 73945	404730	725530	39	50	48	50	1.5	Steel	A2
S 73946	404733	725524	23	42	40	42	1.5	Steel	B4
S 73947	404733	725524	23	60	58	60	1.5	Steel	B4
S 73953	404728	725509	22	44	40	44	2.0	PVC	B6
S 73954	404728	725509	22	64	60	64	2.0	PVC	B6
S 76380	404711	725503	20	24	19	24	1.0	PVC	A7
S 76381	404711	725503	20	44	39	44	1.0	PVC	A7
S 76382	404711	725503	20	64	59	64	1.0	PVC	A7
S 76383	404711	725503	20	82	77	82	1.0	PVC	A7
S 76384	404711	725503	20	102	97	102	1.0	PVC	A7
S 76385	404711	725503	20	120	115	120	1.0	PVC	A7
S 76386	404721	725520	35	24	19	24	1.0	PVC	A5
S 76387	404721	725520	35	44	39	44	1.0	PVC	A5
S 76388	404721	725520	35	63	58	63	1.0	PVC	A5
S 76389	404721	725520	35	83	78	83	1.0	PVC	A5
S 76390	404721	725520	35	103	98	103	1.0	PVC	A5
S 76391	404721	725520	35	123	118	123	1.0	PVC	A5
S 76392	404725	725523	35	24	19	24	1.0	PVC	A4
S 76393	404725	725523	35	44	39	44	1.0	PVC	A4
S 76394	404725	725523	35	63	58	63	1.0	PVC	A4
S 76395	404725	725523	35	82	77	82	1.0	PVC	A4
S 76396	404725	725523	35	100	95	100	1.0	PVC	A4
S 76397	404725	725523	35	123	118	123	1.0	PVC	A4
S 76398	404730	725530	39	107	102	107	1.0	PVC	A2
S 76399	404730	725530	39	122	117	122	1.0	PVC	A2
S 76400	404730	725530	39	69	64	69	2.0	PVC	A2
S 76401	404730	725530	39	89	84	89	2.0	PVC	A2

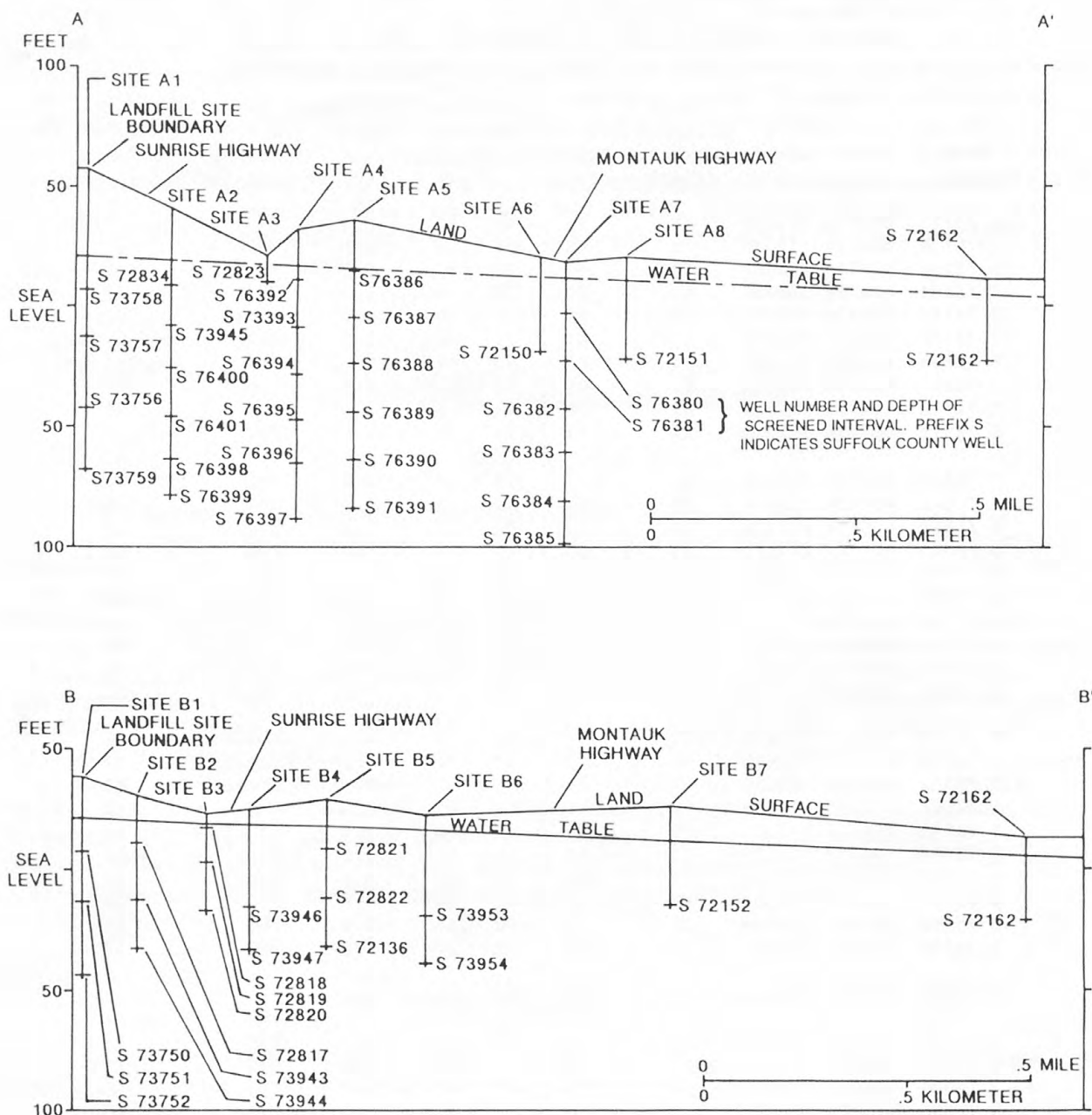


Figure 2. Locations of wells and well screens along hydrologic sections A-A' and B-B'. (Trace of sections is shown on pl. 1.)

## GROUND-WATER QUALITY

Results of analyses of samples collected in November and December 1987 are presented in table 4 (at end of report) and discussed below. Contaminant concentrations are compared with data from December 1982 and August 1984, except for dissolved organic carbon, which is compared with data from July and August 1983. In general, constituent concentrations increased somewhat along section A-A' but decreased slightly along section B-B' since previous samplings.

## Characteristics of Ambient Water

The chemical content of ambient ground water<sup>2</sup> in the landfill-site vicinity is a direct result of the interactions between precipitation that enters the aquifer system and the aquifer materials with which it comes into contact. Ambient ground water in the study area is a slightly acidic (pH 5 to 6) sodium chloride-type water with low specific conductance (less than 50  $\mu\text{S}/\text{cm}$  and low dissolved-solids concentration (less than 50 mg/L). The predominant source of the major cations (calcium, magnesium, sodium, and potassium) in ambient water on Long Island is the weathering of aluminosilicate minerals; a minor source is wet and dry deposition of sea spray from the nearby bays and ocean. Chloride, sulfate, fluoride, and bromide are derived primarily from precipitation and from wet and dry deposition of sea spray.

Iron, manganese, silica, aluminum, lithium, and boron occur naturally in minor amounts in Long Island ground water. The major source of these elements is the weathering of aluminosilicate minerals. Iron and manganese also are present in hydroxide and oxyhydroxide minerals, which also occur in the aquifer material. Bicarbonate is derived from the dissociation of carbonic acid (dissolved carbon dioxide) within the soil and ground-water system, and the carbonic acid is derived from respiration processes, the decomposition of organic material, and atmospheric carbon dioxide. (A detailed explanation is given in a subsequent section on alkalinity.) Nitrate in Long Island ground water is derived from precipitation and biological activity. Phosphorus is present in minor amounts as phosphate and appears to be the limiting nutrient for bacterial growth in the ground-water system.

Two wells upgradient from the landfill site (S72121 and S72816, pl. 1) were sampled to determine ambient water quality in the study area; results of the analyses are listed in table 4 (at end of report) and discussed further on. Before operation of the landfill, the chemical composition of ground water at the site was similar to that at the upgradient wells. (Water samples from these wells reflect oxic conditions and have low concentrations of all constituents.) Water in the upper glacial aquifer throughout the study area is, in general, oxic near the water table, but the redox potential becomes increasingly reducing with depth. Water near the base of the upper glacial aquifer is anoxic (contains little or no dissolved oxygen) in the southern part of the study area, where water from the Magothy aquifer discharges upward.

## Characteristics of Leachate and Leachate-Contaminated Water

Leachate was not sampled in this study, but results of leachate analyses in December 1982 and July 1983 are listed in table 2. Although constituent concentrations changed between the two sampling dates, the proportions of the various ions remained relatively constant. Leachate differs strongly from ambient ground water. The leachate has a pH of 7.0, a high specific conductance (greater than 5,500  $\mu\text{S}/\text{cm}$ ) and a high dissolved-solids concentration (greater than 2,500 mg/L), a distinct odor, and is pale yellow. If leachate is exposed to air, iron dissolved in it oxidizes and forms a bright-orange

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<sup>2</sup> Ambient ground water is ground water at and near the site that was not contaminated by the landfill.

precipitate, indicating that the redox potential of the geochemical environment from which it is derived is strongly reducing. The major ions in the leachate are sodium and bicarbonate.

Leachate-contaminated ground water has many of the leachate's characteristics. Contaminated water has a higher pH, specific conductance, and dissolved-solids concentration than does ambient water. It also is a sodium bicarbonate water, is anoxic, has an odor, and turns orange when exposed to air. Water samples from some wells effervesced.

*Table 2.--Composition of leachate collected at the Brookhaven landfill site, 1982 and 1983*

[Analyses by New York Testing, Inc.<sup>1</sup>, Westbury, N.Y.; all concentrations are in milligrams per liter except where noted. --, no data; °C, degrees Celsius;  $\mu\text{S}/\text{cm}$ , microsiemens per centimeter; <, less than]

Constituent or characteristic	Sampling date	
	<sup>2</sup> 12-6-82	<sup>3</sup> 7-6-83
Temperature (°C)	--	20
pH (units)	7.0	7.0
Specific conductance ( $\mu\text{S}/\text{cm}$ at 25°C)	5,640	5,900
Dissolved solids	2,600	4,420
Total alkalinity (as $\text{CaCO}_3$ )	2,610	3,820
Sodium, dissolved	590	840
Potassium, dissolved	450	640
Calcium, dissolved	160	87
Magnesium, dissolved	100	100
Chloride, dissolved	690	1,100
Sulfate, dissolved	2	<1
Ammonium, total (as N)	307	465
Nitrite, total (as N)	.03	.03
Nitrate, total (as N)	< .04	< .04
Total Kjeldahl nitrogen (as N)	365	520
Iron, dissolved	26.05	15
Manganese, dissolved	.24	.25

<sup>1</sup> The use of firm names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey

<sup>2</sup> Data from Wexler, 1988a, p. 16.

<sup>3</sup> Data from Pearsall and Wexler, 1986, p. 15.

### Extent of Contamination

Water from wells along both vertical sections contained higher concentrations of most constituents than did the ambient ground water. Ambient ground water was found to have a specific conductance of less than 50  $\mu\text{S}/\text{cm}$ . Wexler (1988a, p. 26) used the 100- $\mu\text{S}/\text{cm}$  specific-conductance contour to indicate that leachate contamination had extended roughly to Montauk Highway (pl. 1) by 1983. Application of this criterion to the data collected in 1987 indicates that the leachate plume has extended to the intersection of Railroad Avenue and Chapel Road, about 0.6 mi farther downgradient.



Stiff diagrams of the ground-water samples indicate the presence of several types of water. Figure 3 presents Stiff diagrams of uncontaminated water from the upgradient wells, contaminated water from the plume, and water from downgradient wells that is only slightly contaminated. The principal characteristics of the contaminated water (compared in terms of equivalents) are that (1) alkalinity exceeds the sum of sodium and potassium, (2) chloride concentration is about half the alkalinity, (3) sulfate concentration is less than a tenth of the chloride concentration, (4) sodium plus potassium is twice the sum of calcium plus magnesium, and (5) the concentration of iron plus manganese is much greater than the concentration of sulfate. Samples from sites B6, B7 (more than 1/2 mi from the landfill, pl. 1), and the downgradient well differ sharply from the contaminated-water samples and are more similar to ambient water samples in that: (1) alkalinity is less than the concentration of sodium plus potassium or chloride, (2) sulfate concentration is about half the chloride concentration, (3) sodium plus potassium is roughly equal to calcium plus magnesium, and (4) the concentration of sulfate exceeds that of iron plus manganese. Ground water at the downgradient site and site B7 resembles ambient water in proportions of major ions, but the concentrations are higher than expected for ambient water.

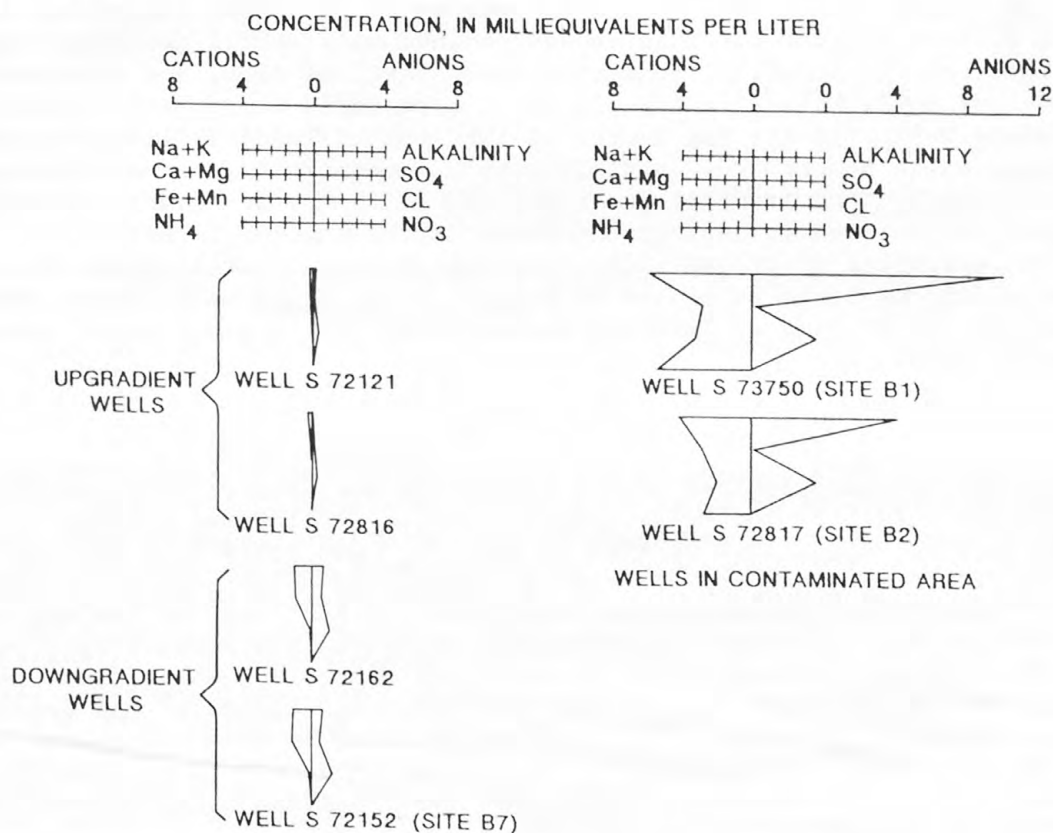


Figure 3. Stiff diagrams showing concentrations of selected constituents in water from upgradient, contaminated, and downgradient wells.

The two sections differ in the distribution of contaminants. Contamination along section B-B' is relatively shallow at site B1 but deepens and diffuses downgradient; the most elevated concentrations of many constituents were found at site B3 (pl. 1). Contamination along this section appears to be from a point source near site B1; this distribution pattern supports the suggestion by Wexler (1988a, p. 17) of overflow of leachate at a low point along the eastern edge of the liner. Because the highest concentrations are no longer at site B1 but at site B3, the magnitude of leachate overflow into the ground-water system (in 1987) probably has decreased since 1982-84.

Contamination along section A-A' is more uniform than along section B-B' and varies less with depth and distance downgradient. Contamination along this section is consistent with the hypothesis of a diffuse source of "leakage through holes in the liner or along incompletely sealed seams between liner sections" (Wexler, 1988a, p. 17). Concentrations of most constituents at some of the deepest wells (S76391 and S76399) are less than at shallower wells.

Results of water-quality analyses indicate that contaminant migration is shallower along section B-B' than along section A-A'. The more uniform vertical mixing and transport of contaminants to greater depths along section A-A' than along section B-B' could be related to processes other than inflow from a diffuse source; possible causes include water-table mounding from recharge from the landfill, density-induced vertical flow, and undetected differences in lithology that would cause more rapid mixing along section A-A' than along B-B'. If (1) the bottom of the leaking landfill liner intersects the water table beneath the landfill either intermittently or continuously, (2) heads within the landfill are high, and (3) hydraulic contact between leachate in the landfill and ground water in the aquifer is sufficient, steep vertical gradients in ground-water flow beneath the landfill might develop. These conditions could be caused by a rise in the water table above levels prevailing at the time of landfill installation, or by mounding of recharge below the liner.

### *Sodium*

Sodium concentrations in ground water near the landfill site in 1987 ranged from 4 mg/L in the ambient-quality wells (S72121 and S72816) to as high as 250 mg/L at well S72819 at site B3 (pl. 1). Concentrations were highest near the landfill along section A-A' and decreased downgradient and with depth. The highest concentrations along section B-B' were at the middle-depth well at site B3. Elevated concentrations extend to the downgradient well (S72162), although contamination at this site probably results from road salt and septic-tank effluent rather than from landfill leachate. The decrease in sodium concentration with depth below land surface is more pronounced in section B-B' than in section A-A'. Most sites in section A-A' indicate a steady increase in concentrations since 1982, whereas sites nearest the landfill in section B-B' indicate a small decrease.

### *Potassium*

Potassium concentrations in the landfill vicinity range from 0.39 and 0.47 mg/L at the upgradient wells to 160 mg/L at the middle-depth well at site B2 (S73943). The 1987 data indicate potassium concentrations are elevated at all wells in both sections, with the possible exception of the two deepest wells

at site A7 (0.4 and 0.6 mg/L). The highest concentrations of potassium in section A-A' were at site A1, but the values decreased downgradient and with depth (fig. 4). Concentrations of potassium increased at all sites in section A-A' after 1982 but decreased at sites B1 and B2 in section B-B'. Concentrations at sites downgradient from site B2 had higher potassium concentrations than in 1982; the concentration was greatest at site B3 and decreased downgradient.

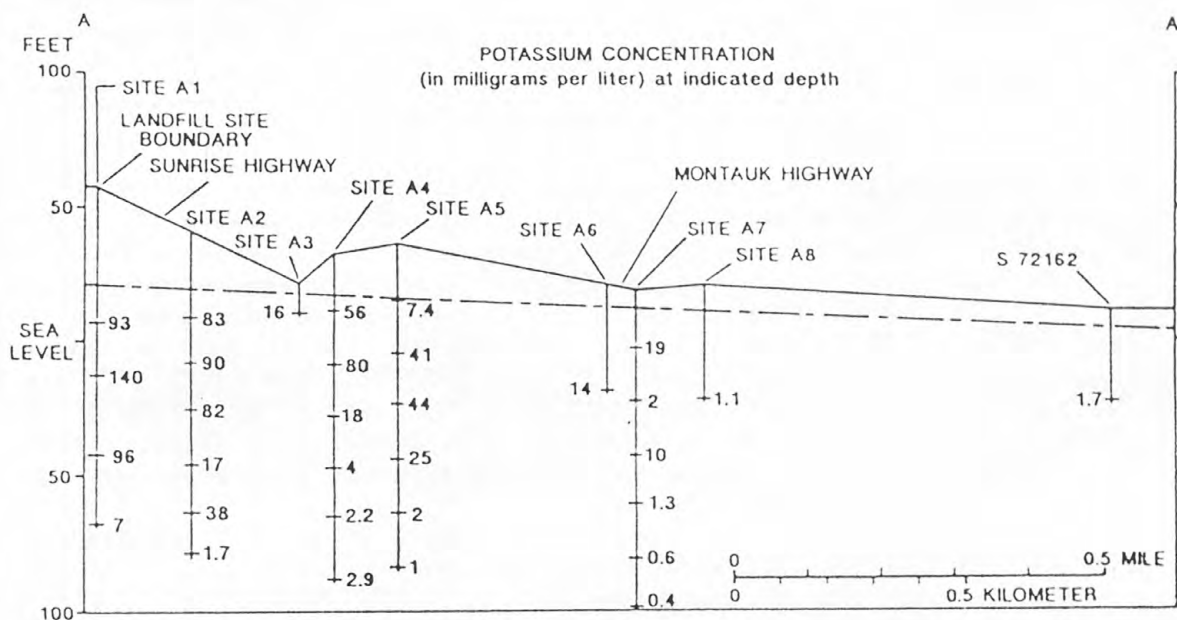


Figure 4. Concentrations of potassium in water from wells along section A-A'.

### Calcium

Calcium concentrations ranged from a low of about 1 mg/L at upgradient wells to 130 mg/L at the deepest well at site A4 (S76397). The 1987 data indicate that water at all wells except the shallow well at site B3 (S72818) contained elevated calcium concentrations, whereas the 1982 and 1984 data for section A-A' and 1982 data for section B-B' include some calcium concentrations less than 2 mg/L (ambient value). Water at site B3 contained both the lowest and highest calcium concentrations along section B-B' (1.1 and 56 mg/L, respectively). Calcium concentrations along section B-B' increased at all sites after 1982. The lowest and highest concentrations along section A-A' in 1987 were 2.7 and 130 mg/L, respectively. The highest concentrations in section A-A' were at the deep wells at sites A4 and A5. Concentrations decreased at all four wells at site A1 after the 1982 sampling but increased at all other sites. Concentrations decreased along section A-A' beyond site A4 and generally increased with depth at sites A1 through A5 (fig. 5). Some of the increase with depth could be attributed to mixing with water from the Magothy aquifer, which has higher calcium concentrations, but the increase from this source probably would be small in relation to the observed concentration. Ion-exchange processes described in a later section are a more likely cause of this phenomenon.

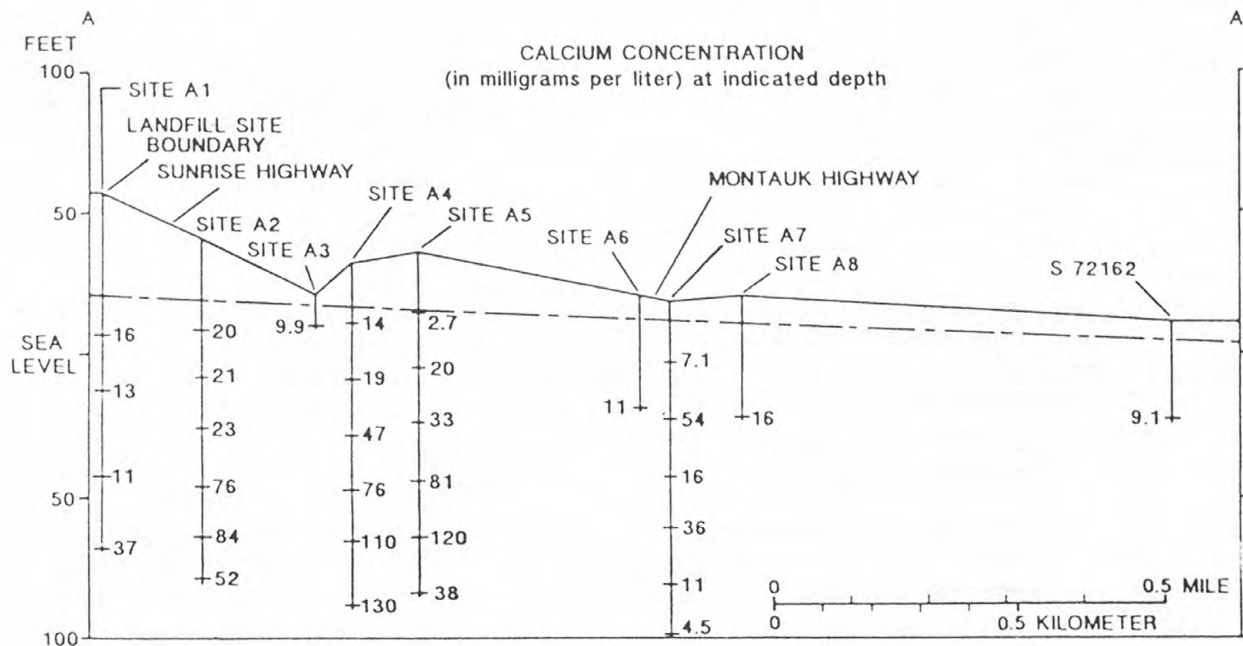


Figure 5. Concentrations of calcium in water from wells along section A-A'.

### Magnesium

The magnesium concentration in water at upgradient well S72121 was 1.5 mg/L. The highest concentration detected (68 mg/L) was in a sample from the deepest well at site A4 (S76397). Concentrations were highest near the midpoints of both sections (sites A4 and B3). Earlier data show that the highest concentrations were closer to the landfill in 1982-84 than in 1987. Concentrations decrease downgradient, although they remain elevated south of Montauk Highway. The highest magnesium concentrations in section A-A' were in samples from the deepest wells at sites A2, A4, and A5. In section B-B', concentrations appear to decrease with depth.

### Chloride

Chloride concentrations in the landfill vicinity ranged from 10 mg/L in the upgradient wells to 450 mg/L at one well at site A1 (S73757). Comparison with 1982-84 data shows that chloride concentrations increased at most sites along section A-A'. Concentrations along section A-A' were highest at the landfill and decrease downgradient. Chloride concentrations at the two deepest wells at site A7 in 1987 were close to background values (less than 10 mg/L); concentrations along section B-B' in 1987 were highest at site B3 and generally decreased downgradient from this site. The highest chloride concentration along section B-B' in 1982 was at site B1, close to the landfill deposits but, by 1987, it had decreased in the shallow wells at sites B1 and B2 to only about one-third the 1982 concentration. Chloride concentrations at the deeper wells at these two sites changed only slightly, however.



Transport of chloride in ground water is commonly considered to be conservative because Long Island aquifer sediments contain no sources or sinks for chloride. The chloride ion generally is nonreactive and thus forms complexes with other ions to only a small extent (less than 0.1 percent) and does not undergo significant ion exchange. The primary source of chloride in the study area appears to be the landfill leachate, although road salt could be increasing the concentration in several shallow wells near major roads, and discharges from cesspools could increase chloride concentrations in the downgradient residential area. These sources appear insignificant in relation to the landfill leachate, however.

### *Alkalinity*

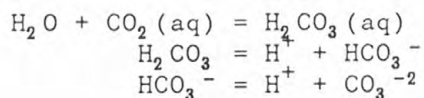
Alkalinity, a measure of the acid-neutralizing capacity of a water sample, is determined through titration of a sample with acid. In the absence of other acid-neutralizing constituents, the alkalinity is the sum of the equivalents of carbonate and bicarbonate, and the proportion of each can be calculated if the pH is known. (For example, when the pH is 7.3 to 9.3, 90 percent or more of the inorganic carbon in solution will be in the bicarbonate form.) Because any acid-neutralizing constituents (weak acids) present in the sample will also be titrated in an alkalinity determination, attribution of all alkalinity to carbonate and bicarbonate will be in error to the extent that weak acids are present.

Uncontaminated Long Island ground water is typically low in alkalinity. Alkalinity concentrations at the upgradient wells near the landfill in 1987 were 3 and 8 mg/L as  $\text{CaCO}_3$  in wells S72816 and S72121, respectively--that is, the alkalinity is equal to the acid-neutralizing capacity of 3 and 8 mg/L of  $\text{CaCO}_3$ . Higher values of 22 and 31 mg/L as  $\text{CaCO}_3$  were observed in uncontaminated samples from two Magothy aquifer wells near the landfill that were sampled in another study (well S78151 and well S84808 in October 1987). These samples were derived from an anoxic environment containing lignitic deposits in which bacterial consumption of the lignite has increased the inorganic carbon concentration in the water. In general, water from wells on Long Island contains only negligible amounts of weak acids other than carbonate species; thus, the alkalinity arises almost entirely from carbonate and bicarbonate (inorganic carbon).

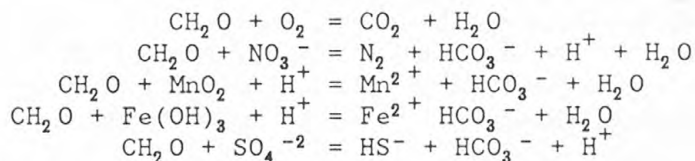
Extremely high values of alkalinity were observed in samples from many wells contaminated by landfill leachate; many of the samples from wells near the landfill effervesced (through the loss of carbon dioxide and other dissolved gases) as they were brought to the surface. The highest alkalinity observed in 1987 was 1,100 mg/L as  $\text{CaCO}_3$  in water from the middle-depth well at site B3 (S72819), and the median alkalinity among all contaminated sites sampled in 1987 was 220 mg/L. Not all of the alkalinity in these samples can be attributed to carbonate and bicarbonate, however, because these measurements include a significant, though undetermined, contribution from organic acids. Presumably, this contribution decreases as the dissolved organic carbon concentration decreases downgradient from the well. Alkalinity decreases with distance from the landfill site along section A-A' but increased at almost all sites along this section from October 1982 through August 1984 and from August 1984 through December 1987. The trend appears to indicate a continually increasing load of inorganic carbon into the system

along section A-A'. In contrast, the highest alkalinity along section B-B' in 1987 was at the middle-depth well at site B3, and alkalinity at sites closer to the landfill decreased from 1982 through 1987.

The principal inorganic carbon species in ground water in the landfill vicinity are dissolved carbon dioxide, carbonic acid, bicarbonate, and carbonate. Only bicarbonate and carbonate react with acid to contribute to the alkalinity; concentrations of carbon dioxide and carbonic acid can be calculated, however, from the alkalinity and equilibrium constants for the following equilibria:



The major source of the inorganic carbon in the ground-water system at the landfill is respiration processes (any of various energy-yielding oxidative reactions in living matter) acting on the organic matter deposited in the landfill. Some respiration processes are:



All these reactions oxidize organic matter and, consequently, reduce inorganic constituents.

### Nitrogen

Nitrogen is present in leachate-contaminated ground water predominantly as ammonia and organic nitrogen (the amine groups in amino acids and proteins). Much smaller amounts of nitrogen as nitrate, and minor to insignificant amounts of nitrite, can be found downgradient from the landfill and in uncontaminated ground water. The average nitrate concentration in the upgradient wells was 0.04 mg/L as N, whereas average ammonia concentrations were 0.02 mg/L as N. (In this report, concentrations of all nitrogen-containing constituents are reported as the equivalent weight of nitrogen.) Nitrate concentrations in leachate-contaminated ground water commonly were below the analytical detection limit, whereas ammonia concentrations ranged broadly, from a minimum less than the detection limit to a maximum value of 90 mg/L along section A-A'. Ammonia concentrations at site A1 (fig. 6) were below the analytical detection limit in 1987, but were elevated in 1982 and 1984. Ammonia concentrations in 1987 were highest at site A2 and decreased downgradient. Concentrations along section B-B' generally were lower than those along section A-A', although the ammonia concentration at the shallow well at site B1 (S73750) was 75 mg/L. Ammonia concentrations in 1987 along section B-B' near the landfill (sites B1 and B2) were lower than those in 1982, whereas concentrations at sites farther downgradient were higher.

Nitrogen in ground water can be found in oxidation states of -3 to +5; the most common oxidation states are -3 (ammonia and amines), 0 (nitrogen gas),

and +5 (nitrate). Nitrogen in leachate-contaminated ground water, however, is found almost entirely as ammonia and amines derived from the organic material deposited in the landfill. In the natural ground-water system, organic nitrogen is converted to ammonia (ammonification) as part of the decomposition of organic matter. This ammonia can be used by bacteria and, if the redox potential is sufficiently oxidizing, ammonia will be oxidized to nitrate (nitrification). If the redox potential is sufficiently reducing, nitrate will be reduced, mostly to nitrogen gas, but a small amount will be reduced to ammonia (denitrification).

In the anoxic environment of the landfill and leachate-contaminated ground water, ammonification processes (conversion of organic nitrogen to ammonia) begin within the landfill deposits and continue in ground water downgradient from the landfill until all organic nitrogen is consumed, but nitrification (oxidation of ammonia to nitrate and nitrite) will not occur. Denitrification--the reduction of nitrate to nitrogen and ammonia in the absence of oxygen--occurs in the leachate plume; this process consumes the available nitrate and results in very low nitrate concentrations (typically near or less than the detection limit of 0.01 mg/L).

Other sources of nitrogen in ground water are insignificant in relation to the landfill leachate. Sinks for nitrogen species are the interconversion processes, including the conversion to nitrogen gas, biological uptake, and cation exchange. Solvated ammonium and potassium ions are roughly the same size, and ammonium ion will substitute readily for potassium in ion-exchange reactions and bind strongly to substrates. Nitrate is an anion that undergoes ion exchange to only a small extent.

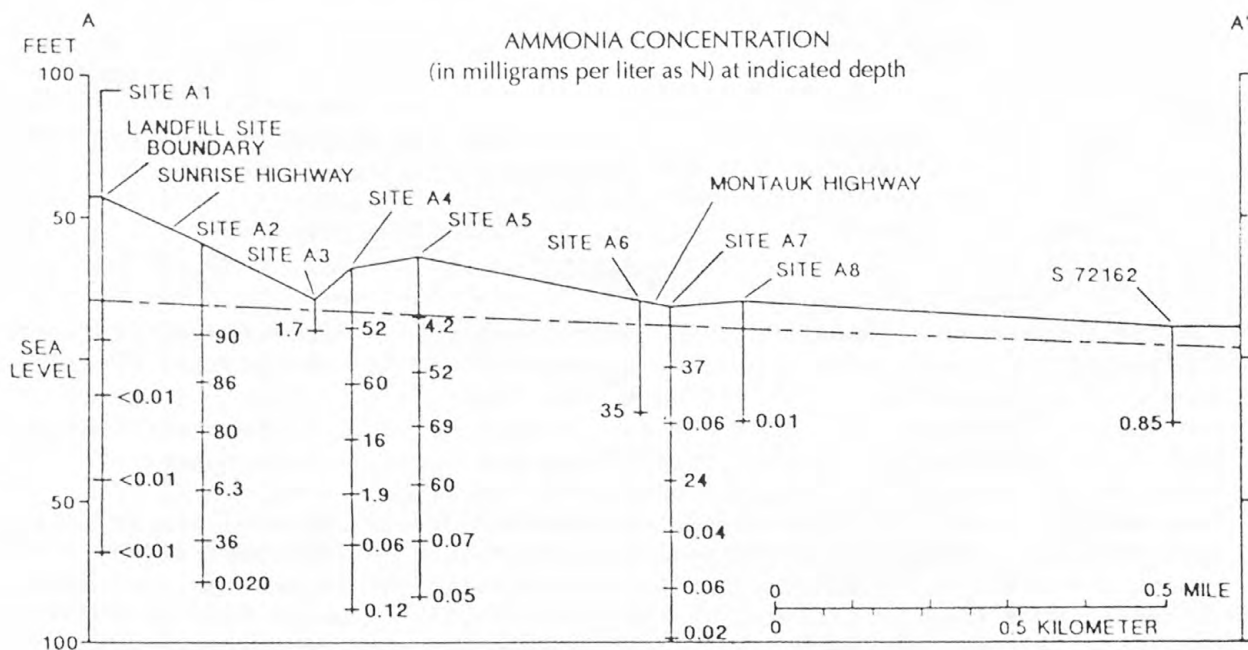


Figure 6. Concentrations of ammonia (as N) in water from wells along section A-A'.

The nitrogen index (Baedecker and Back, 1979, p. 431), the ratio of reduced nitrogen to oxidized nitrogen, indicates the relative degree to which conditions are oxidizing or reducing in the ground-water environment. Along section A-A' (fig. 7), almost all nitrogen is in the form of organic amines at site A1, where the nitrogen index is about 10,000. By the time leachate-contaminated ground water reaches site A2, most of the amines have been converted to inorganic ammonia, and nitrogen indices here average only a few thousand. Farther downgradient, between sites A5 and A7, nitrate concentrations rise slightly, ammonia concentrations decline sharply, and nitrogen indices are variable, with a range of 2,300 to less than 1, indicating that the geochemical environment is less reducing here than farther upgradient.

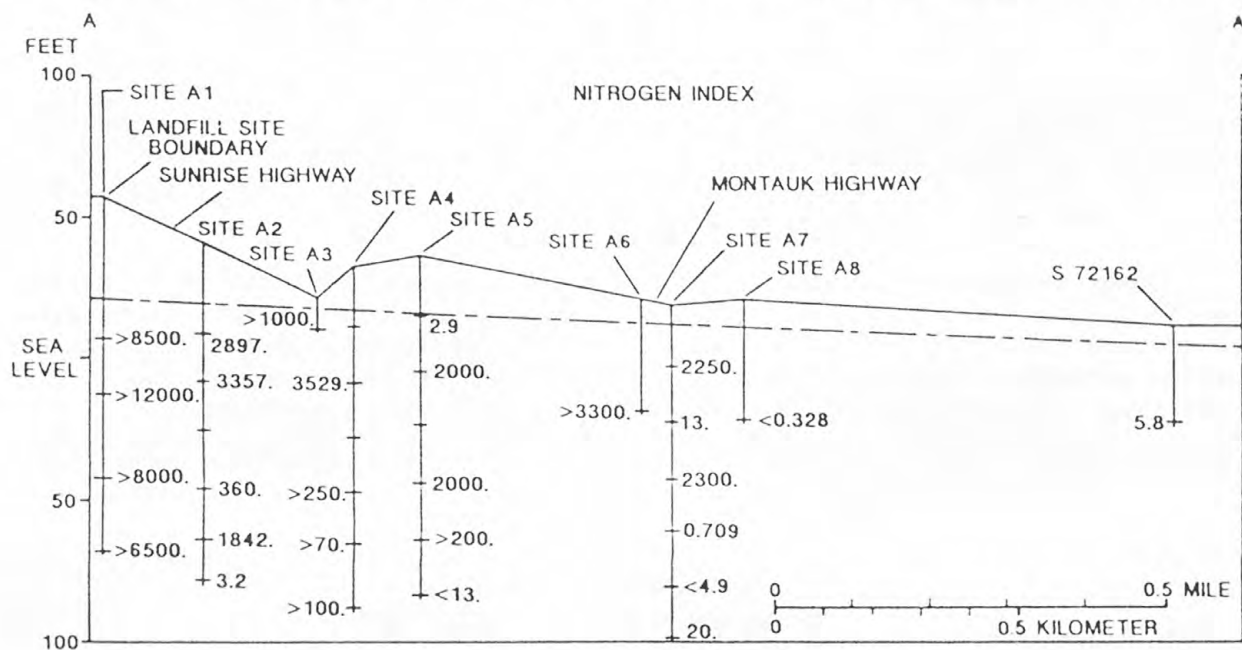


Figure 7. Nitrogen index (ratio of reduced nitrogen to oxidized nitrogen) in water from wells along section A-A'.

### Phosphorus

Concentrations of phosphorus and orthophosphate in most samples of unaffected and leachate-contaminated ground water from the landfill vicinity were near or below the analytical detection limit (mostly 0.01 mg/L as P). Because most analyses indicated the concentrations to be below the detection limit, the distribution of phosphorus among the forms orthophosphate, condensed phosphates, and organic phosphorus could not be determined. Presumably, bacterial growth within the leachate plume has sequestered most of the available phosphorus in biological systems, and the availability of phosphorus could be a limiting factor in bacterial growth and the rate of degradation of organic material in the ground-water system. Data on phosphorus concentrations at this site in previous years are unavailable.

Phosphorus, like nitrogen, can be present in oxidation states of -3 to +5, but the +5 state (orthophosphate, condensed phosphates, and organic phosphorus) is the only one of importance in ground water. Results of two



types of analyses for phosphorus (orthophosphate and total phosphorus) are provided in this report. Orthophosphate analyses provide the sum of phosphorus in the phosphates  $\text{H}_3\text{PO}_4$ ,  $\text{H}_2\text{PO}_4^-$ ,  $\text{HPO}_4^{2-}$ , and  $\text{PO}_4^{3-}$ , whereas phosphorus analyses provide the sum of orthophosphate, condensed phosphates (polyphosphates), and organic phosphorus. Phosphates are weak acids; the extent of their protonation depends upon the pH. At a pH of 7, orthophosphates are approximately half  $\text{HPO}_4^{2-}$  and half  $\text{H}_2\text{PO}_4^-$ . The primary source of phosphorus in leachate-contaminated ground water is the landfill; other sources of phosphorus to the aquifer system probably are insignificant. Phosphorus is an essential nutrient, and its uptake by bacteria is an important sink. The only other major sink is adsorption to iron and manganese oxyhydroxide coatings, but the anoxic nature of the leachate plume probably limits the amount of these coatings on aquifer materials.

### *Sulfur*

Sulfur in ground water can be found in oxidation states of -2 (sulfide) and +6 (sulfate). Sulfide was not detected (detection limit of 0.5 mg/L) in any ground-water samples from the landfill-site vicinity. Median sulfate concentration in water from the upgradient wells was 6.1 mg/L. Along section B-B', water at site B1 (S73752) had the highest sulfate concentration (51 mg/L), and water at site B2 (S72817) had the lowest (5.1 mg/L). Concentrations differed widely along section B-B' and exceeded 30 mg/L at sites B1, B3, B4, and B6. Concentrations at most sites along section B-B' increased during 1982-87. Samples from section A-A' generally had lower sulfate concentrations than samples from section B-B'. The highest concentration (43 mg/L) was found at site A1, and the lowest (1.5 mg/L) at site A2 (S76399). Concentrations generally decreased downgradient and with depth. No overall change in sulfate concentration is evident along section A-A' since 1982.

The main source of sulfate downgradient from the landfill site is the decomposition of sulfur-containing organic matter deposited in the landfill. Because conditions within the landfill are sufficiently reducing to produce methane, some reduction of sulfate to sulfide undoubtedly is occurring within the landfill and in the leachate-contaminated ground-water environment, but elevated iron(II) concentrations and the low solubility of iron sulfides cause most of the available sulfide to be trapped in precipitates and thereby prevent its detection in the analytical procedures used in this study. Equilibrium speciation calculations indicate that up to 15 percent of the sulfate in some of the samples from the leachate plume is complexed with other ions, mainly calcium and magnesium.

### *Iron*

Iron concentrations in the two wells upgradient from the landfill were less than the analytical detection limit (3  $\mu\text{g/L}$ ). Along the sections, iron concentrations ranged from less than 3  $\mu\text{g/L}$  to 82,000  $\mu\text{g/L}$ ; the median concentration was 350  $\mu\text{g/L}$ . Concentrations had a wide range; in 11 samples, concentrations exceeded 10,000  $\mu\text{g/L}$  and in 19 samples were less than 100  $\mu\text{g/L}$  (table 4). Iron concentrations at sites A1 through A4 were highly elevated but decreased sharply at sites downgradient (fig. 8). Along section B-B', the iron distribution differed from that of other constituents in that the highest concentrations were at sites B1 and B2.

Iron is found in both oxidized and reduced forms in the Long Island aquifer system. In anoxic environments, iron is mostly in the +2 oxidation state, a soluble form; in oxic environments, it is present in the slightly soluble +3 oxidation state, mostly as ferric oxyhydroxides and iron oxide coatings on aquifer materials. Because the oxidation of ferrous ion by dissolved oxygen and subsequent precipitation of ferric oxyhydroxides is rapid at near-neutral pH, iron concentrations in the contaminant plume quickly decline where mixing with oxic ground water occurs. Sources of dissolved iron are landfill leachate and the reduction of oxide coatings on aquifer materials and in iron-containing minerals. Dissolved iron in this system is predominantly in the form of the free  $\text{Fe}^{+2}$  ion; a small percentage (less than 3 percent) is complexed with other ions, such as sulfate and hydroxide. The primary sink for iron is oxidation and precipitation of iron oxides and oxyhydroxides, which occurs when the contaminated ground water is mixed with oxic ground water. A second, minor sink is the precipitation of iron sulfides, which occurs when sulfate is reduced to sulfide, where strongly reducing conditions prevail.

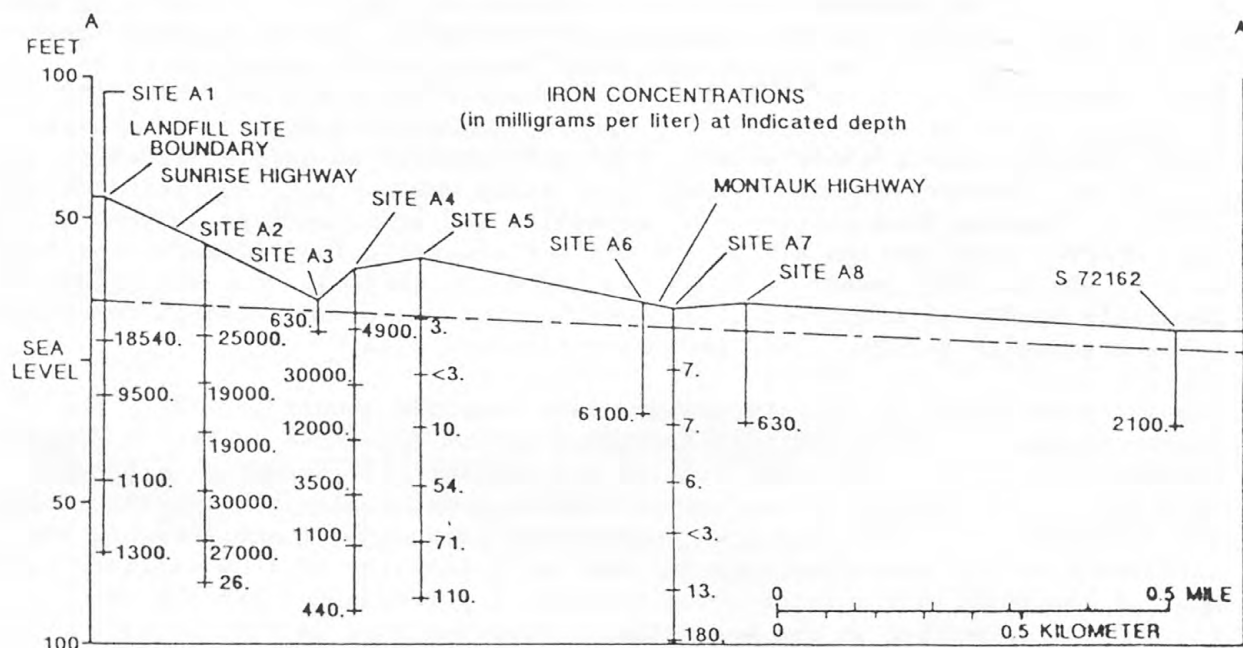


Figure 8. Concentrations of iron in water from wells along section A-A'.

### Manganese

Manganese concentrations in two wells upgradient from and unaffected by the landfill were 11 and 16  $\mu\text{g/L}$ . Manganese concentrations in sections A-A' and B-B' in 1987 ranged from less than 1  $\mu\text{g/L}$  at site B6 (S73954) to 57,000  $\mu\text{g/L}$  at site A5 (S76387); the median concentration was 2,350  $\mu\text{g/L}$ . Concentrations within the sections differed widely; concentrations in 11 samples were less than 100  $\mu\text{g/L}$ , and those in 14 samples exceeded 10,000  $\mu\text{g/L}$ . The lowest concentrations generally were found in the deepest wells or far downgradient; the highest concentrations were found at sites 4 and 5 in both transects (fig. 9). The highest concentrations of manganese encountered in 1987 were

downgradient from the landfill at the sampling sites at Sunrise Highway. In general, concentrations in 1987 were higher than historical values, and peak concentrations were found farther downgradient than in previous studies. Concentrations at site A1 in 1987 were lower than those in 1982, however.

Manganese is present in oxidized and reduced forms in the Long Island aquifer system, depending on the redox potential of the ground-water environment. Manganese is found in solution in the +2 oxidation state as the  $Mn^{+2}$  ion and in the solid phase in the +4 oxidation state as manganese dioxide and as complex oxyhydroxide coatings on aquifer materials. In many respects, manganese chemistry is similar to iron chemistry, except that the rate of oxidation of manganese by dissolved oxygen is slower than for ferrous ion. As with iron, landfill leachate and coatings of manganese oxyhydroxides and oxides on aquifer materials are sources of manganese in the contaminated ground-water plume, although the landfill source probably predominates. The primary sink for manganese, as for iron, is oxidation and precipitation as complex oxyhydroxides and oxides, usually as coatings on aquifer materials. These sink processes will occur in the leachate plume only when ground water containing dissolved oxygen mixes with contaminated ground water and after the oxidation of iron has proceeded to completion. (The oxidation of iron is more rapid than the oxidation of manganese.) Dissolved manganese complexes with anions and organic compounds to a considerable extent. In contrast to iron, speciation calculations indicate that 20 to 30 percent of the manganese complexes with bicarbonate ion when the alkalinity exceeds 400 mg/L. Complexes with other anions could contribute as much as 2 percent to manganese concentrations.

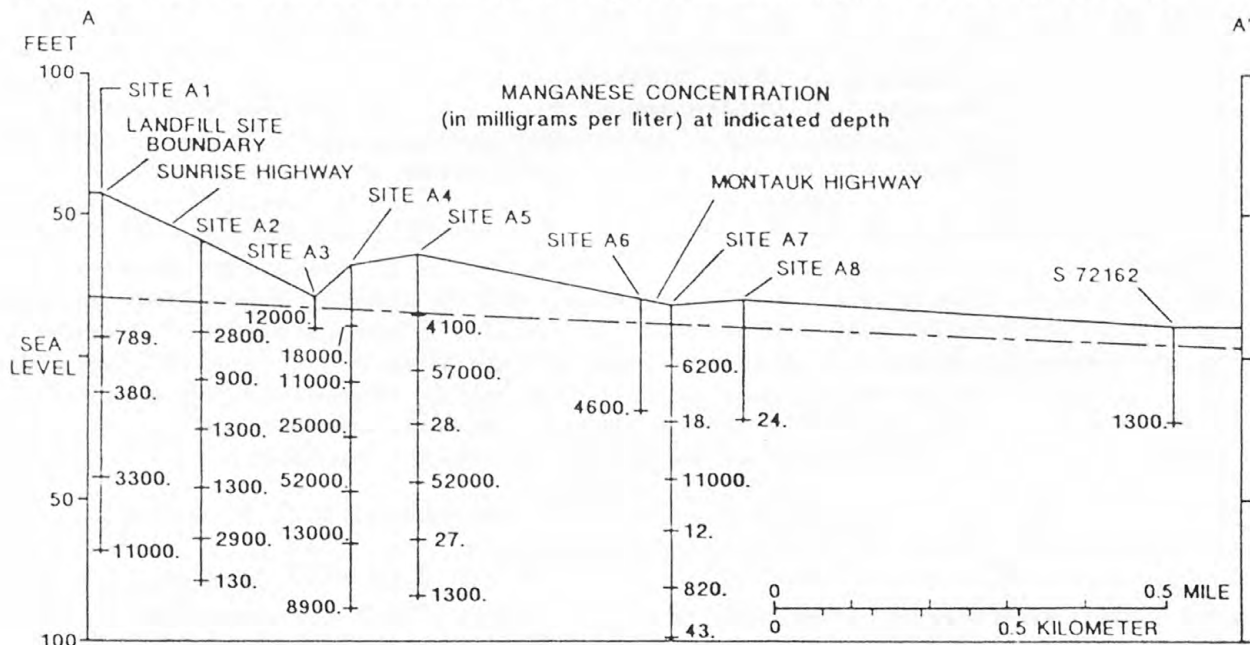


Figure 9. Concentrations of manganese in water from wells along section A-A'.

#### Dissolved Organic Carbon

Dissolved organic carbon (DOC) concentrations in the two upgradient wells were 0.5 and 0.7 mg/L (as carbon) in wells S72121 and S72816, respectively,

and ranged from 0.2 to 0.9 mg/L at other wells screened in the upper glacial and Magothy aquifers in areas unaffected by leachate. DOC concentrations in samples collected from wells along sections A-A' and B-B' in 1987 ranged from 0.4 to 82 mg/L; concentrations were highest in samples from wells most contaminated with other leachate constituents and decreased downgradient. In 1983, the only other year for which DOC-concentration data are available, the maximum DOC concentration was 180 mg/L at well S73750, and the DOC concentration in a leachate sample from the leachate-collection system was 410 mg/L.

Natural sources of DOC in ground water include decomposition and dissolution of organic material at land surface, decomposition of bacteria growing within the aquifer system, and dissolution of organic materials deposited with the aquifer sediments. DOC concentrations arising from these sources are small in relation to the landfill as an organic carbon source, however. Within the landfill, DOC arises from the decomposition and leaching of organic materials deposited as wastes. DOC arising from natural sources typically consists of complex organic molecules, such as humic and fulvic acids. The composition of DOC from the landfill includes the materials from natural sources but also includes simpler organic acids, proteins, starches, sugars, hydrocarbon wastes such as paint thinners and waste oil, and hazardous organic materials such as solvents that were deposited in the landfill. Dissolved organic carbon within the leachate plume in ground water also includes hydrocarbon gases, such as methane, but the analytical procedure for DOC does not detect these compounds. Hazardous materials constitute only a very small percentage of the dissolved organic carbon in the ground water; analyses for these constituents in two samples are described in a later section. A previous study at the Brookhaven Landfill (Pearsall and Wexler, 1986, p. 12) indicated that the presence of organic contaminants within the leachate plume that are listed by the U.S. Environmental Protection Agency as "priority pollutants" correlated well with elevated DOC concentrations (greater than 12 mg/L). This relation was not examined in this study, however.

The persistence of organic compounds within the leachate plume is governed by their susceptibility to use by bacteria in metabolic processes. The transport and fate of organic compounds within the leachate plume depends on the extent of their hydrophobic or hydrophilic characteristics. Hydrophobic compounds tend to partition in an organic phase; hydrophilic compounds tend to partition in the aqueous phase. Hydrophilic compounds, such as organic acids, participate in ion-exchange processes, whereas hydrophobic compounds, such as hydrocarbons, partition on organic surfaces.

### *Dissolved Solids*

Dissolved-solids concentration is a measure of all the dissolved materials in a sample except those that are lost to the gas phase during drying of the sample. The average concentration of dissolved solids in upgradient wells was about 30 mg/L. Concentrations along the two sections ranged from 41 mg/L at site A7 (S76385) to 1,290 mg/L at site B3 (S72819). The distribution of dissolved-solids concentrations along section B-B' is similar to that of other constituents; concentrations were highest at site B3 and decreased farther along the section. The lowest concentration for section B-B' was 74 mg/L at sites B1 and B2. Dissolved-solids concentrations were distributed along section A-A' in a pattern similar to that of other constituents; concentrations



were highest near the landfill and decreased downgradient. The maximum concentration along section A-A' was 915 mg/L at site A2 (S76398); the minimum was 41 mg/L at the deepest well at site A7 (S76385).

### *pH*

The pH values at the two upgradient wells were 5.69 and 5.80. Extreme values for both sections ranged from a low of 5.61 at site B7 to a high of 7.36 at site B2. The highest pH values along section B-B' were at site B2 and decreased steadily downgradient. The pH along section B-B' decreased from 1982 to 1987 at site B1 and in the upper two wells at site B2; the pH at all other sites in section B-B' increased by approximately 1 pH unit, except at site B7, where it increased only slightly. The pH along section A-A' in 1987 ranged from a low of 6.01 at site A8 to a high of 7.19 at site A5. Comparison of 1987 data with 1984 data shows that averages for sites A1, A2, A4, and A7 differed by 0.2 pH units or less; the average for site A5 increased by roughly one-half of a pH unit. The major sink for acidity appears to be the landfill leachate, in which reduction of iron and manganese consumes acid.

### *Silica*

The average concentration of silica in upgradient wells in 1987 was about 7 mg/L. Concentrations along both sections ranged from a low of 3.0 mg/L at site B4 to a high of 26 mg/L at site A2. Unlike most constituents, silica concentration was lowest, rather than highest, at site B3. The concentrations at sites B3, B4, and B5 along section B-B' were less than the upgradient average. Concentrations at other sites were two to three times the ambient concentration. The median concentration along section B-B' in 1987 was 7.5 mg/L. The minimum and maximum silica concentrations along section A-A' in 1987 were 3.5 and 26 mg/L, respectively; the median concentration was 13 mg/L. Silica concentrations tended to increase with depth along section A-A'.

Speciation calculations indicate that silica in solution is in the undissociated form  $\text{Si}(\text{OH})_4$  (silicic acid). The main source of silica in the ground water is the weathering of silicate and aluminosilicate minerals, such as feldspars and clays.

### *Temperature*

Ground-water temperature on Long Island generally ranges from 9 to 16°C. Ground-water temperatures in the two upgradient wells in the November-December sampling period were 10.2 and 10.4°C. The temperature of shallow ground water varies seasonally by several degrees, whereas the temperature of deep ground water is more constant. One major influence on ambient ground-water temperature is the temperature of recharge, and recharge occurs mainly during the nongrowing season.

Ground-water temperatures along the two sections in 1987 ranged from 10.1 to 21.2°C; the temperatures were highest at the first site in both sections (see section A-A' in fig. 10) and decreased steadily downgradient and with depth. Elevated ground-water temperatures in the leachate plume are caused by biological activity within either the landfill or the leachate plume.

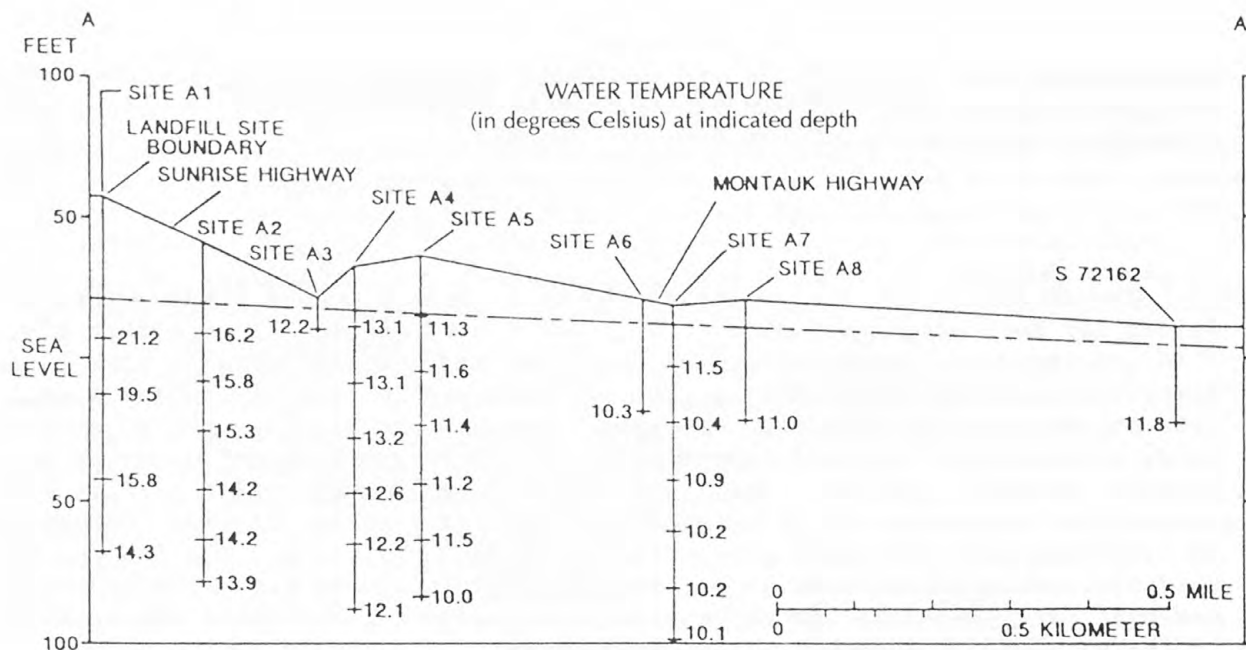


Figure 10. Temperature of ground water from wells along section A-A'.

### Specific Conductance

Specific conductance at both upgradient wells was  $43 \mu\text{S}/\text{cm}$ . Specific conductance along the two sections ranged from a minimum of  $60 \mu\text{S}/\text{cm}$  at the deepest well at site A7 (S76385) to a maximum of  $3,090 \mu\text{S}/\text{cm}$  at the middle-depth well at site B3 (S72819). The distribution of specific conductance values along section B-B' was similar to that of major ions; the highest value was at site B3, and other high values (exceeding  $1,000 \mu\text{S}/\text{cm}$ ) were at the shallow wells at sites B1 and B2 and decreased along the section beyond site B3. Comparison of 1987 data with 1982 data indicates that specific conductance decreased at sites B1 and B2 but increased at sites B3, B4, B5, and B7. Average values along section A-A' generally were higher than those along section B-B'. The maximum value along section A-A' in 1987 was  $2,320 \mu\text{S}/\text{cm}$  at site A1 (S73757); the minimum value was  $60 \mu\text{S}/\text{cm}$  at the deepest well at site A7 (S76385). Specific conductance decreased with depth and with distance along section A-A' from site A1. Comparison of 1987 data with 1982 and 1984 data shows that specific conductance increased at all sites along section A-A'.

### Strontium

Strontium concentration at both upgradient wells in 1987 was  $7 \mu\text{g}/\text{L}$ . The minimum and maximum concentrations along sections A-A' and B-B' were 21 and  $760 \mu\text{g}/\text{L}$ , respectively. The highest concentration along section B-B' was at site B3 ( $350 \mu\text{g}/\text{L}$ ), but no spatial pattern in concentration is apparent along the section. Strontium concentrations generally were higher along section A-A' than along section B-B', and the highest concentration ( $760 \mu\text{g}/\text{L}$ ) was at site A4. Concentrations increased from site A1 to site A4 and decreased farther down-gradient. No historical data for strontium at the landfill site are available.

Strontium is chemically similar to calcium and magnesium. Speciation calculations indicate that most of the strontium in the aquifer system is

present as the free, doubly charged ion  $\text{Sr}^{+2}$ , which complexes with bicarbonate in solution up to about 11 percent and with other ions to a lesser extent.

### *Bromide*

Bromide concentrations in the two upgradient wells in 1987 were 0.043 and 0.029 mg/L. Concentrations in five other nearby wells screened in the Magothy and upper glacial aquifers that were judged to be only minimally affected by human activities ranged from 0.015 to 0.043 mg/L; concentrations in the Magothy aquifer tended to be lower than those in the upper glacial aquifer (S47743 on June 26, 1986; S47224 on June 25, 1986; S52943 on March 3, 1987; S78151 on October 13, 1987; and S84808 on October 13, 1987). Bromide concentrations along the two sections ranged from less than 0.010 to 2.8 mg/L, and most of the higher concentrations were along section A-A'. Of the 32 concentrations measured along section A-A', 18 exceeded 1.0 mg/L, and 6 were equal to or greater than 2.0 mg/L. The 18 highest concentrations were at sites A1 through A5. Concentrations along section A-A' tended to be either very high (sites A1 through A5) or very low, although greater than ambient concentrations (sites A6 through A8). Bromide concentration along section B-B' was 2.8 mg/L at site B3 (S72819) and 0.80 mg/L at site B1 (S73750); at all other sites it was 0.40 mg/L or less. No previous data for bromide are available for comparison.

Bromide, the  $\text{Br}^-$  ion, is a halogen ion and reacts in a manner similar to that of chloride. Bromide transport probably is conservative, and bromide has little tendency to form complexes with other ions or to undergo ion exchange in Long Island ground water. The primary natural source of bromide in Long Island ground water is land deposition of sea spray. The aquifer system has no mineral sources that could contribute more than trace amounts of bromide. The primary source of bromide to the leachate plume is the landfill.

### *Fluoride*

Fluoride is present in very low concentrations in the Long Island aquifer system. The concentration at wells upgradient from the landfill site in 1987 was 0.1 mg/L. Concentrations along section B-B' in 1987 were 0.1 mg/L in 13 wells and 0.2 mg/L in 4 wells. Along section A-A', fluoride concentration was less than 0.1 mg/L (detection limit) in 1 well, 0.1 mg/L in 8 wells, 0.2 mg/L in 16 wells, and 0.3 mg/L in 6 wells. The concentration was 0.3 mg/L at five of the six wells at site A4, possibly because of local lithologic anomalies.

Speciation calculations indicate that, although most fluoride (greater than 90 percent) is present as the free ion, some complexing with calcium, magnesium, and aluminum occurs in conditions that prevail within the leachate plume. Like chloride, fluoride is relatively unreactive. The low concentrations along both sections indicate that the landfill is not a large source of fluoride to ground water.

### *Lithium*

Lithium concentrations in 1987 were less than the detection limit of 4  $\mu\text{g/L}$  at the two upgradient wells and in most samples from both sections. Five

concentrations along section B-B' exceeded the detection limit; the maximum concentration was 10  $\mu\text{g/L}$ . No pattern to the distribution of lithium concentrations is evident, except that the elevated concentrations were in the deep wells. Five concentrations along section A-A' exceeded the detection limit; the highest concentration (16  $\mu\text{g/L}$ ) was found at site A4. In section A-A', as in section B-B', most of the detectable lithium concentrations were in samples from the deep wells. Three of these samples were from site A4; the concentrations possibly reflect local aquifer lithology.

The upper glacial aquifer has no natural sources of lithium except for trace amounts derived from the weathering of lithium-bearing minerals. The landfill does not appear to be a significant source.

### *Aluminum*

The distribution of dissolved aluminum in ground water in the landfill vicinity is difficult to ascertain because (1) the concentrations in most samples were less than the detection limit, and (2) some colloidal aluminum passes through the 0.45- $\mu\text{m}$  filter used to prepare the dissolved fraction and thereby increases the measurements of dissolved aluminum. Of 46 analyses for dissolved aluminum in samples from sections A-A' and B-B' in 1987, concentrations in 37 were less than the analytical detection limit of 10  $\mu\text{g/L}$ . The remaining concentrations were either 10 or 20  $\mu\text{g/L}$ , except for one concentration of 330  $\mu\text{g/L}$ , which is attributed to analytical error.

Although no previous analyses of leachate-plume samples are available for comparison, ground water in the vicinity of the landfill appears to contain little dissolved aluminum, and the landfill probably is not a significant source. Natural sources of aluminum are mostly silicate rocks, such as feldspars and micas, which are abundant in Long Island's upper glacial aquifer. As weathering progresses, however, most of the aluminum in the original substrate is retained in solid-phase weathering products (Hem, 1985, p. 73). The primary control on aluminum solubility in the leachate plume is pH; near pH 6, solubility is at its minimum (slightly less than 10  $\mu\text{g/L}$ ). To the extent that leachate has increased the ground-water pH to above 6, the solubility of aluminum has been increased. Otherwise, aluminum concentrations have probably not been significantly affected by the landfill.

### *Boron*

Boron concentrations at the two upgradient wells in 1987 were less than 10  $\mu\text{g/L}$  and 20  $\mu\text{g/L}$ . Boron concentrations along the two sections ranged from less than 10  $\mu\text{g/L}$  at several sites to 1,200  $\mu\text{g/L}$  at site B3 (S72819). Boron concentrations along section A-A' decreased steadily with distance from the landfill; concentrations along section B-B' peaked at site B3 and decreased in both directions from this site. No previous data are available for comparison.

The Long Island aquifer system has no natural sources of boron that contribute more than trace amounts of the element; the presence of boron generally is considered an indicator of human influences.



## Hazardous Substances

Two of the wells closest to the landfill, S73750 (site B1) and S73758 (site A1), were sampled for trace metals and hazardous organic compounds. Results of trace-metal analyses are given in table 5 (at end of report). Dissolved iron and manganese are included in this table and in table 4 (at end of report) for comparison with total iron and manganese. Iron and manganese are by far the predominant trace metals in this water.

Results of the hazardous-organic-compound analyses are listed in table 5. Very few compounds were detected in either sample. The compounds detected at well S73750 were benzene, chlorobenzene, *trans*-1,2-dichloroethene, and trichloroethene; those detected at well S73758 were toluene, benzene, chlorobenzene, 1,1-dichloroethane, naphthalene, and xylene. Benzene and chlorobenzene concentrations at both wells decreased since July and August 1983 (Pearsall and Wexler, 1986, p. 10). No change was detected in trichloroethene at well S73750 or in toluene at well S73758. Ground-water was not analyzed for 1,1-dichloroethane or xylene in 1983. The naphthalene concentration at well S73758 increased from less than 1  $\mu\text{g/L}$  (detection limit) in 1983 to 7  $\mu\text{g/L}$  in 1987.

## Contaminant-Transport Processes

The major processes that affect concentrations of leachate constituents in ground water are advection, dispersion, density-induced movement, adsorption, and chemical transformation. Advection is the transport of contaminant constituents with the flow of ground water. Dispersion is the dilution that results from mechanical mixing and from molecular diffusion as leachate-contaminated ground water mixes with uncontaminated water. Density-induced movement is the settling or sinking of a heavy fluid (leachate) through a lighter fluid (ground water). Adsorption refers to the retention of dissolved substances on solid-phase surfaces and includes ion-exchange processes and partitioning of nonpolar organic substances on nonpolar solid phases. Adsorption processes do not chemically alter constituents. Advection, dispersion, density-induced movement, and adsorption do not permanently remove constituents from the aquifer system. Chemical transformation includes both biologic and nonbiologic processes and can add and remove constituents from ground water. Biodegradation processes are chemical transformations. Transformation processes affect only those compounds that can be transformed under the conditions present in the aquifer.

Wexler (1988b) developed a two-dimensional solute-transport model for conservative constituents to predict the extent of the chloride plume; results indicated the rate of advective transport beneath the landfill to be about 1.1 ft/d (Wexler, 1988b, p. 22) and longitudinal and transverse dispersivity to be 100 and 20 ft, respectively (Wexler, 1988b, p. 24). The model predictions can be compared with current conditions to provide an indication of the accuracy of the estimates. The model assumes constant leachate composition and does not account for overflow of the liner along the eastern side of the landfill. Because the model is two dimensional, the result is best compared with concentrations averaged over the vertical water column in the upper glacial aquifer. In the following comparison, results are provided for sites that contain at least four wells screened at differing depths. Predicted chloride concentrations at the sampling points in section

A-A' were obtained from the simulation results for 1986 and 1988 (presented in Wexler, 1988b, p. 27), averaged to yield predictions for 1987 to correspond with the actual sampling period. Chloride concentrations, in milligrams per liter, are shown below:

Section A-A' site	Model prediction	1987 observed concentration
A1	145	245
A2	120	140
A4	95	125
A5	75	114
A7	45	40

1987 contaminant concentrations differ from model predictions. Observed concentrations generally were higher than model predictions; discrepancies were largest nearest the source but decreased downgradient, and concentrations agreed at site A7. Sources of error that could contribute to these discrepancies include the simulation of three-dimensional flow and transport with a two-dimensional model, an insufficient number of sampling points within the vertical profile to establish a reliable average, temporal changes in the chloride concentration in leachate, and temporal changes in the volume of leachate entering the aquifer system. Most discrepancies probably result from the variability of leachate inflow and constituent concentrations, and from the model's neglect of leachate overflow, rather than from error in the estimates of advection and dispersion. Wexler noted that the errors in model predictions were highest on the eastern side of the plume, probably as a result of leachate overflow that was not represented in the model (Wexler, 1988b, p. 25). Model predictions and observed concentrations converge downgradient from the landfill, indicating that the overflow, which began several years after landfilling began, has affected downgradient points the least and accounts for most of the discrepancies between simulated and measured chloride concentrations near the landfill.

No direct measurements of the adsorptive capacity of aquifer sediments were made in this study. Effects of adsorption can be inferred from the following comparisons of constituent concentrations with those of chloride--a conservative constituent. The ratio of sodium to chloride decreases with depth in section A-A' but does not change significantly or increase or decrease with distance downgradient along either section. The ratio of bromide to chloride varies little along section B-B', whereas ratios along section A-A' at sites A1 through A5 are somewhat higher than ratios along section B-B'. The ratio of potassium to chloride in both sections decreases by as much as a factor of 10 vertically and downgradient from the landfill, indicating adsorption of potassium by aquifer materials. The ratios of calcium and magnesium to chloride in both sections increase with distance from the landfill, indicating that geochemical processes supply these elements. For calcium, this increase with distance is pronounced in all data sets; for magnesium, the effect is most noticeable in the 1987 data from section A-A'. Processes that could account for these increases include displacement and release of previously adsorbed calcium and magnesium in ion-exchange reactions, and weathering of calcium- and magnesium-containing minerals (clays and feldspars).

## GEOCHEMICAL PROCESSES

The entry of landfill leachate into the ground-water environment affects almost all geochemical processes that occur there under normal conditions. Most constituent concentrations are greater in leachate than in ambient ground water, and the large amount of dissolved organic carbon in the leachate intensifies bacterial activity and results in strongly reducing conditions. Some of the physical characteristics of leachate and contaminated ground water (odor, effervescence, and orange color on exposure to air) are caused by this biological activity.

Most geochemical processes that affect major-ion constituents are direct or indirect results of bacterial mediation of the oxidation of organic matter within the aquifer. Many chemical reactions in ground water that are thermodynamically favored are kinetically hindered and occur only to the extent that bacteria mediate or catalyze the process. Bacterial metabolic processes obtain energy from the oxidation of organic matter. Aerobic bacteria use oxygen as the electron acceptor in the oxidation processes. When all the oxygen in the system is consumed, anaerobic bacteria mediate transformations by using nitrate, nitrite, manganese dioxide, ferric oxyhydroxides, and eventually sulfate and carbon dioxide as electron acceptors in oxidation reactions as the redox potential of the ground-water environment becomes more reducing.

The following section describes the geochemical processes in the leachate plume at well sites along section A-A'.

### Landfill Leachate

Analyses of leachate samples collected in 1982 and 1983 (table 2, p. 8) indicate that conditions within the landfill deposits are strongly reducing. Elevated iron and manganese concentrations indicate that oxidized forms of these metals have been used as electron acceptors (oxidizing agents) in oxidation reactions. The absence of nitrate and nitrite indicates the occurrence of denitrification processes; nitrogen is found almost entirely as ammonia and organic amines. Leachate samples contained high concentrations of dissolved organic carbon, which fuels biological activity, and high concentrations of alkalinity, which is indicative of extensive oxidation of organic matter. Small electrical generators at the landfill are fueled by a methane-collection system--a clear demonstration that reducing conditions within the deposits are severe enough to allow methanogenesis. Leachate samples have a strong odor of sulfur gases but contain negligible sulfate concentrations--indicators that sulfate reduction has occurred.

When landfill leachate overflows or leaks from the landfill liner, it can become slightly aerated if it passes through the unsaturated zone before reaching the water table and also loses some carbon dioxide and other dissolved gases. When leachate enters the water table, it is exposed to additional oxygen as it becomes diluted with oxic ground water. The dissolved oxygen that enters the leachate during percolation through the unsaturated zone or by mixing with oxic ground water reacts rapidly with reduced iron and is consumed. The effects of the added oxygen probably are transitory, however. The resulting oxidized iron probably is reduced again within a short time as anaerobic bacterial processes use the oxidized iron as an oxidizing agent in the oxidation of organic matter.

## Site A1

Site A1 is near the southeastern corner of the landfill site (at the landfill fence line), about 250 ft downgradient from the southern edge of the landfill deposits. This location has four wells (S73758, S73757, S73756, and S73759) screened at 48 to 53, 68 to 73, 98 to 103, and 123 to 128 ft, respectively, below land surface. The top of the Gardiners Clay is about 160 ft below land surface at this site.

Ground water at site A1 is heavily contaminated with landfill leachate as a result of its having passed beneath the landfill deposits. The contamination extends from the water table to below the well screen of the deepest well but decreases with depth. The contaminated water is characterized by an absence of dissolved oxygen, elevated pH, and elevated concentrations of metal ions, chloride, alkalinity, and organic carbon; nitrogen is found only in the form of organic amines, and phosphorus concentrations are low enough that they could limit biological activity. (Ambient ground water generally can be characterized as a low-dissolved-solids, sodium chloride type of water, whereas the contaminated water is sodic, with bicarbonate as the predominant anion, and has 200 times the dissolved-solids concentration of ambient ground water.) Elevated iron, DOC, and alkalinity concentrations, and the absence of dissolved oxygen, indicate strongly reducing conditions. Elevated sulfate concentrations indicate that conditions are less reducing than within the landfill deposits, however.

Concentrations differed significantly among the four wells at site A1. Sodium concentration had no trend with depth, whereas potassium concentration in the deepest well was very low (7.0 mg/L). Calcium was highest (37 mg/L) in the deepest well, but magnesium was evenly distributed with depth. Iron concentrations decreased by a factor of 14, and manganese concentrations increased by a factor of 14, from the shallowest well to the deepest well. Ground-water temperature decreased with depth, averaging 20°C in the two shallow wells and 15°C in the two deep wells. Stiff diagrams of the four wells (fig. 11, p. 30-31) indicate that the samples from the four wells are chemically similar but at different stages of dilution. Chloride was disproportionately elevated at well S73757. In general, the extent of dilution by oxic water increases with depth.

The primary geochemical process at site A1 is the anaerobic oxidation of organic carbon. Elevated ground-water temperatures observed at site A1 reflect the intensity of this biological activity. The main geochemical reactions that result from this biological activity are (1) the reduction and dissolution of oxidized iron and manganese mineral phases in aquifer sediments, (2) consumption of hydrogen ion (pH increase) in these reactions, (3) conversion of organic nitrogen to ammonia, and (4) bacterial consumption of nutrients (nitrogen and phosphorus). Presumably, additional processes include the retardation of the movement of cations to some extent by ion-exchange and adsorption processes, and the partitioning of hydrophobic organic constituents in organic phases and on organic surfaces. Odors in ground water from site A indicate some reduction of sulfate to sulfide, and solubility indices indicate the potential for precipitation of iron sulfides within aquifer sediments.

The 1987 data indicate that sodium, potassium, chloride, sulfate, DOC, organic nitrogen, and pH increased since 1982-84 (pH only slightly), and



calcium, magnesium, ammonia, and manganese decreased. Iron concentrations have been variable during this time, but the median concentration remained virtually unchanged. These results indicate that the inflow of leachate was still continuing in 1987. Bacterial activity appears to have increased, and bacteria now appear to be using inorganic nitrogen as fast as it becomes available from the degradation of organic nitrogen.

## Site A2

Site A2 is along Sunrise Highway about 40 ft south of the eastbound lanes and about 710 ft downgradient from the southeastern corner or edge of the landfill deposits. Site A2 consists of six wells (S72834, S73945, S76400, S76401, S76398, and S76399) screened at 30 to 34, 48 to 50, 64 to 69, 84 to 89, 102 to 107, and 117 to 122 ft below land surface, respectively. Water at five of the six wells is contaminated.

The major differences between water quality at site A2 and site A1 are that some dilution has occurred between site A1 and site A2, and that most organic nitrogen has been converted to ammonium ion at site A2. Comparison of the ratios of contaminant concentrations to chloride concentration at sites A1 and A2 indicate that processes other than dilution are causing a decrease in concentrations of potassium, DOC, and sulfate and an increase in concentrations of calcium, magnesium, iron, and silica between the two sites. Sodium concentrations at site A2 are greater than at site A1 in the shallowest wells and are about the same as at site A1 in the deep wells. From site A1 to site A2, manganese concentrations have increased at shallow depths and decreased in deep wells. Iron concentrations along section A-A' reach their maximum at site A2 and decrease thereafter; manganese concentrations peak farther downgradient. Ground-water temperature at the shallow wells at site A2 is substantially lower than at shallow wells at site A1.

In general, the distribution of concentrations among the upper five wells at site A2 is more uniform than at site A1, except that the deepest well at site A2 shows little evidence of contamination. Alkalinity and concentrations of iron, manganese, chloride, DOC, and sulfate do not change with depth. Concentrations of sodium, potassium, and ammonia decrease with depth, whereas concentrations of calcium, magnesium, and silica increase with depth. Ground-water temperature decreases with depth. Stiff diagrams (fig. 5) indicate that the distribution of the major ions at site A1 is the same as at site A2 except that disproportionately small amounts of monovalent cations (sodium and potassium) and large amounts of divalent cations (calcium and magnesium) are present at some wells; the ratio of divalent cations to monovalent cations increases with depth. Also, the organic nitrogen observed at site A1 appears as ammonia in the Stiff diagram for site A2.

The same geochemical processes operate at site A2 as at site A1. Mixing with ambient oxidizing ground water continues to lower contaminant concentrations; consequently, conditions are less reducing at site A2 than at site A1. In addition, an increase in the ratio of divalent cations to monovalent cations with depth first becomes apparent at site A2 and is much more evident at sites farther downgradient. This change in cation distribution probably results from two processes: (1) ion exchange involving the substitution of monovalent cations for previously adsorbed divalent cations in a process

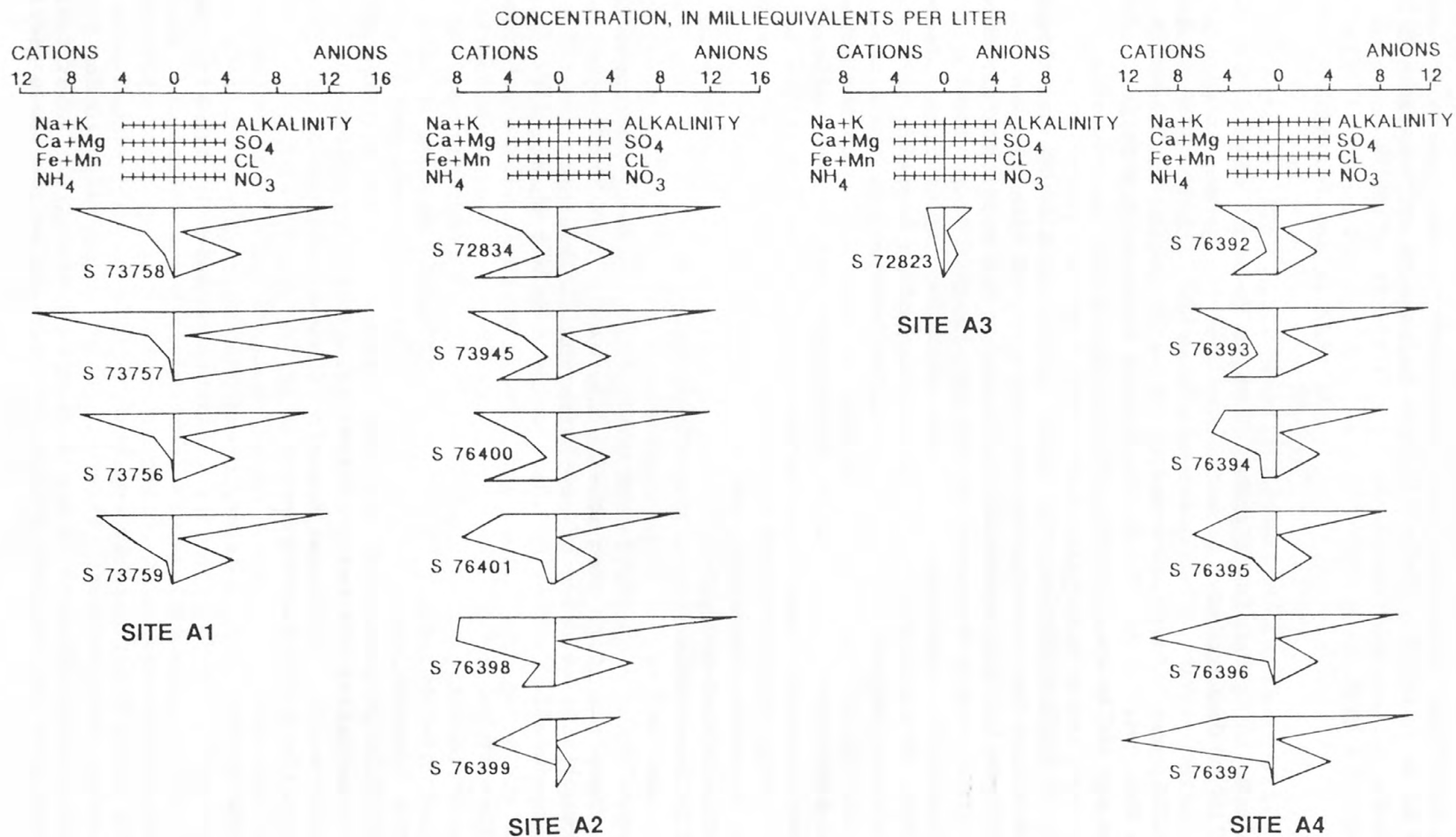


Figure 11. Stiff diagrams of samples from wells along hydrogeologic section A-A', sites A1 through A4.

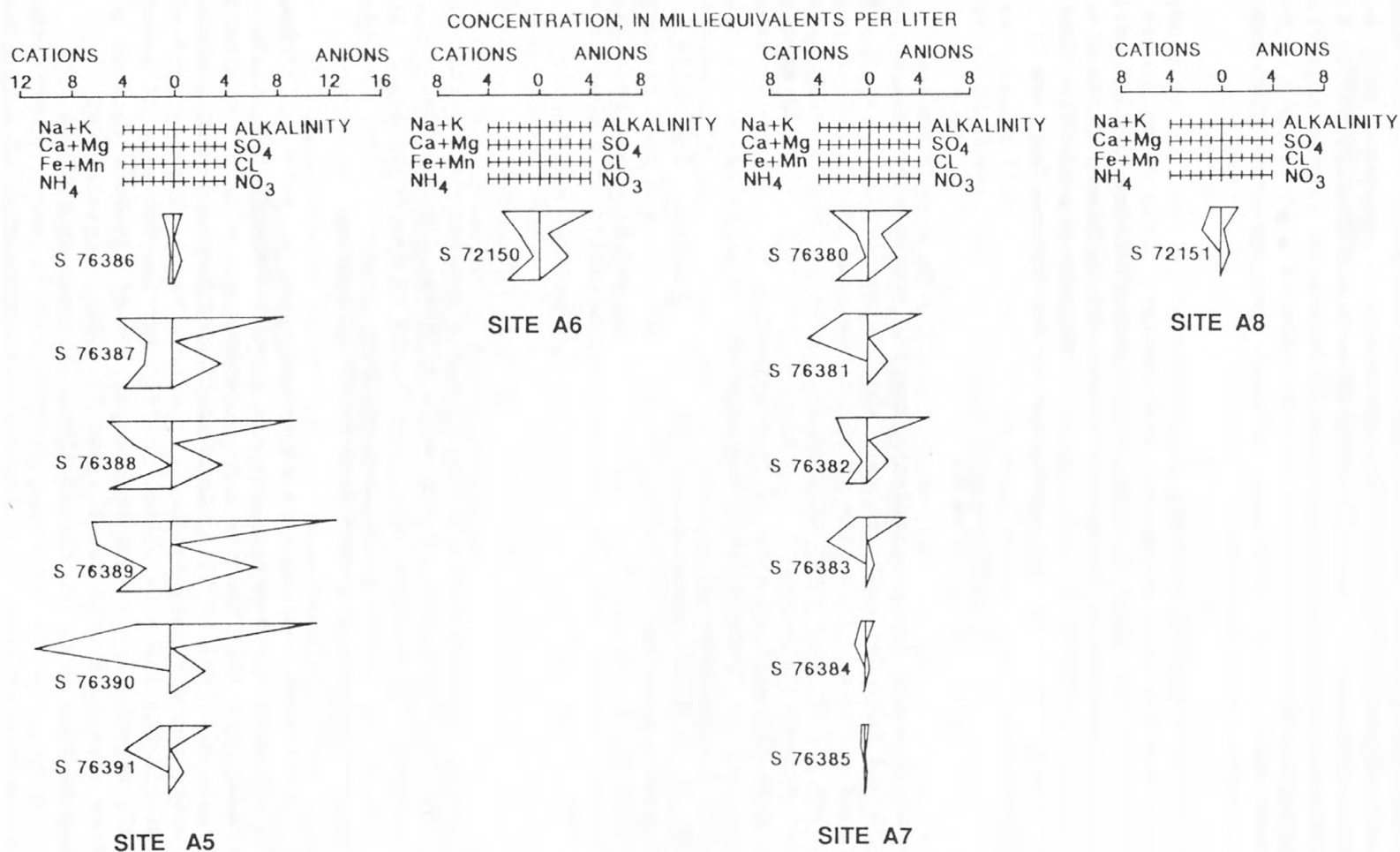


Figure 11. Stiff diagrams of samples from wells along hydrogeologic section A-A', sites A5 through A8.

similar to the change in ion distribution observed when seawater intrudes into a freshwater aquifer, and (2) the alteration of calcium and magnesium silicate minerals, which results in some dissolution of calcium, magnesium, and silica. The solubility of calcium and magnesium aluminosilicates increases with increasing partial pressure of carbon dioxide (Freeze and Cherry, 1979, p. 107). The ratios of calcium and magnesium to silica show no trends, however, indicating a common generative process. The effects of both processes increase with contact time and, although less apparent, also are evident in the downgradient direction.

Since the 1982-84 sampling periods, concentrations of sodium, calcium, chloride, ammonia, and DOC have increased, and concentrations of manganese and sulfate have decreased. Iron and magnesium concentrations in 1987 were similar to those found in 1984. Potassium concentrations have increased at shallow depths and decreased at deeper depths. Phosphorous concentrations are at or below the analytical detection limit, and no historical data are available for comparison.

### Site A3

Site A3 is about 1,480 ft downgradient from the southeastern corner of the landfill deposits and includes only one very shallow well, S72823, screened 9 to 13 ft below land surface. This site is about the same distance downgradient as site A4 but lies 200 ft northeast of site A4. Water from the well at site A3 shows some contamination, but much less than water from the wells at site A4, possibly because the well at site A3 is screened so near the water table that it intercepts mostly recharge that has entered the water table south of the landfill. The ground-water temperature at site A3 is lower than at site A2, and the water at site A3 resembles ambient water quality. The Stiff diagram for the sample from well S72823 (fig. 5) indicates a higher proportion of divalent cations ( $\text{Ca}^{+2}$ ,  $\text{Mg}^{+2}$ ,  $\text{Fe}^{+2}$ , and  $\text{Mn}^{+2}$ ) than was observed in other leachate-contaminated samples, and the ammonia concentration is proportionately lower than at other nearby sites.

### Site A4

Site A4 is about 1,480 ft downgradient from the southeastern corner of the landfill deposits and consists of six wells (S76392, S76393, S76394, S76395, S76396, and S76397) screened at 19 to 24, 39 to 44, 58 to 63, 77 to 82, 95 to 100, and 118 to 123 ft below land surface, respectively. The site lies along a fire road within a wooded area south of Sunrise Highway.

Concentrations of most constituents in ground water at site A4 are lower than at site A2. Manganese concentrations are greater by a factor of 13, however, and peak at site A4. Calcium concentrations are slightly greater at site A4 than at site A2. Well S76393 shows little evidence of mixing with ambient ground water and probably is the most nearly vertically centered of all wells screened within the leachate plume. Stiff diagrams for site A4 resemble those for site A2, especially in that the proportion of divalent cations to monovalent cations increases with depth (fig. 5). Concentrations of constituents at this site are higher than those observed in 1982-84.

Iron concentrations indicate that the rate of consumption of oxidants by bacterial processes at site A4 (at all wells except S76393) has slowed to less



than the rate at which dissolved oxygen is added to the leachate plume (by mixing with oxic ground water); bacterial activity has slowed to the point at which mixing with ambient water provides excess dissolved oxygen to oxidize some iron and remove it from solution. A decrease in ground-water temperature of 2 to 3°C from site A2 to site A4 also could indicate decreased biological activity. Manganese concentrations remain high because the reaction of oxygen with iron is much faster than with manganese; the iron scavenges available oxygen before the manganese can react with it.

### Site A5

Site A5 is about 2,030 ft downgradient from the southeastern corner of the landfill deposits and consists of six wells (S76386, S76387, S76388, S76389, S76390, and S76391) screened at 19 to 24, 39 to 44, 58 to 63, 78 to 83, 98 to 103, and 118 to 123 ft below land surface, respectively. This site lies along a fire road within the same wooded area as site A4 (south of Sunrise Highway), but is farther downgradient.

Concentrations of all constituents at site A5 are lower than those at upgradient sites, although they are higher than those found in the 1982-84 sampling periods. Iron concentrations are considerably less than at upgradient sites, indicating mixing with oxic water in excess of the requirements for aerobic biological activity. Manganese concentrations also are considerably less at some wells, although the concentrations remain high in wells S76387 and S76389 (fig. 9). Site A5 is the first site in the downgradient direction at which iron concentrations increase with depth. Although iron concentrations remain slightly elevated at some wells, the increase with depth results from the mixing of oxic upper glacial aquifer water with anoxic, iron-containing water from the Magothy aquifer and reflects the upward leakage of water from the Magothy through the Gardiners Clay rather than the effects of landfill leachate.

The primary geochemical process at site A5 is the bacterial oxidation of organic matter, as at the sites farther upgradient. DOC concentrations remain elevated and average 21 mg/L in the four middle-depth wells. Other processes include the conversion of organic nitrogen to ammonia, bacterial consumption of nutrients, cation-exchange processes, and partitioning of hydrophobic organic constituents in organic phases and on organic surfaces. The loss of iron and manganese from solution indicates that the reduction of oxidized iron and manganese mineral phases in aquifer sediments does not occur at this site.

If a flow rate of 1.1 ft/d is assumed (Wexler, 1988a, p. 9), ground water at site A1 in August 1983 would have reached site A5 in December 1987. Table 3 lists concentrations of major constituents at site A1 in 1983 and those at site A5 in 1987. The changes were calculated from the average of constituent concentrations among all wells at each site.

### Site A6

Site A6 is a fire well, S72150, about 3,480 ft downgradient from the southeastern corner of the landfill deposits and screened at 32 to 47 ft below land surface. This well is on the western side of the intersection of Montauk Highway and Old Town Road, about 160 ft north of site A7.

*Table 3.--Percent difference between average constituent concentrations in ground-water samples collected at site A1 in August 1983 and site A5 in December 1987*

[Site locations are shown on pl. 1.]

Constituent	Percent difference
Sodium	- 30
Potassium	- 68
Calcium	+ 43
Magnesium	- 7
Chloride	- 17
Sulfate	+300
Ammonia + organic-N	- 48
Iron	-100
Manganese	- 47
Dissolved solids	- 19
Alkalinity	- 29
Dissolved organic carbon	- 45

A Stiff diagram of the composition of water from well S72150 (fig. 5) shows the proportions of major ions to be similar to those in water from shallow wells screened in the leachate plume nearer the landfill site. Iron concentrations are 100 to 1,000 times higher than at sites A5 and A7, and manganese concentrations also are elevated. Sulfate concentrations at most wells in section A-A' are less than 10 mg/L; only water from well S72150 at site A6, the wells at site A1, the shallow well at site A7 (S76380), and the downgradient well (S72162) contains sulfate concentrations greater than 20 mg/L. The geochemical environment is anoxic, but less reducing than farther upgradient. The concentration of monovalent cations exceeds the concentration of divalent cations.

### Site A7

Site A7 is the farthest downgradient cluster of observation wells-- 3,510 ft from the southeastern corner of the landfill deposits. The site consists of six wells (S76380, S76381, S76382, S76383, S76384, and S76385) screened at 19 to 24, 39 to 44, 59 to 64, 77 to 82, 97 to 102, and 115 to 120 ft below land surface, respectively. The site is west of Montauk Highway, about 160 ft south of site A6, and the intersection of Montauk Highway and Old Town Road.

Contaminant concentrations in ground water at site A7 are lower than at sites upgradient but are higher than in 1982-84. Ground-water temperatures are not substantially different from ambient temperatures. Manganese, ammonia, and alkalinity concentrations are elevated (no discernible pattern) in some wells at site A7. Samples from well S76385 contain very low concentrations of most constituents and resemble ambient ground water.

The geochemical processes operating at sites farther upgradient in the section also operate at site A7. The importance of bacterial activity has decreased, however, because much of the DOC present at sites farther upgradient has been consumed. DOC concentrations remain higher than ambient concentrations but have decreased by a factor of 10 from those at site A1 and are less than half the concentrations at site A5. Iron concentrations increase with depth because water discharging upward from the Magothy aquifer contains high iron concentrations. After the water from the Magothy aquifer passes through the Gardiners Clay, it mixes with water in the upper glacial aquifer, which contains comparatively low iron concentrations and creates a concentration gradient with depth.

### Site A8

Site A8 is a fire well, S72151, about 4,110 ft downgradient from the southeastern corner of the landfill deposits; it is screened 35 to 50 ft below land surface. The well is on the western side of Seeley Street, about 600 ft south of Carman Boulevard.

Water from well S72151 has the same general pattern of contamination as do samples from leachate-contaminated wells, but concentrations of most constituents are lower. In addition, most of the deviation from ambient water quality could result from the site's proximity to a residential area and the effects of road salting and leaching from cesspools.

### Downgradient Well S72162

Well S72162 is a fire well about 6,860 ft downgradient from the southeastern corner of the landfill deposits and is screened 27 to 42 ft below land surface on the western side of Railroad Avenue, about 200 ft south of Chapel Road. The sample from well S72162 is a mixed type of water (cations are 49 percent sodium, anions are 47 percent chloride); its quality appears to be intermediate between that of ground water affected by leachate from the landfill and that of ambient water. Although constituent concentrations exceed ambient levels, the proportions of constituents, as plotted in a Stiff diagram (fig. 3), do not resemble those of water from contaminated wells; the alkalinity is low in relation to the concentrations of monovalent cations and chloride, and the sulfate concentration is elevated in relation to the concentrations of the other anions. These discrepancies cause water from well S72162 to plot apart from water from the other wells along section A-A' with respect to the anion and composite fields of a trilinear diagram (fig. 12). The quality of water from well S72162 does not closely resemble that of ambient water from wells upgradient from the landfill because it is intermediate between that of the leachate plume and ambient water, and (or) because the well is in a residential area, where ground water is affected by road salting and cesspool effluent. No historical data for well S72162 are available for comparison.

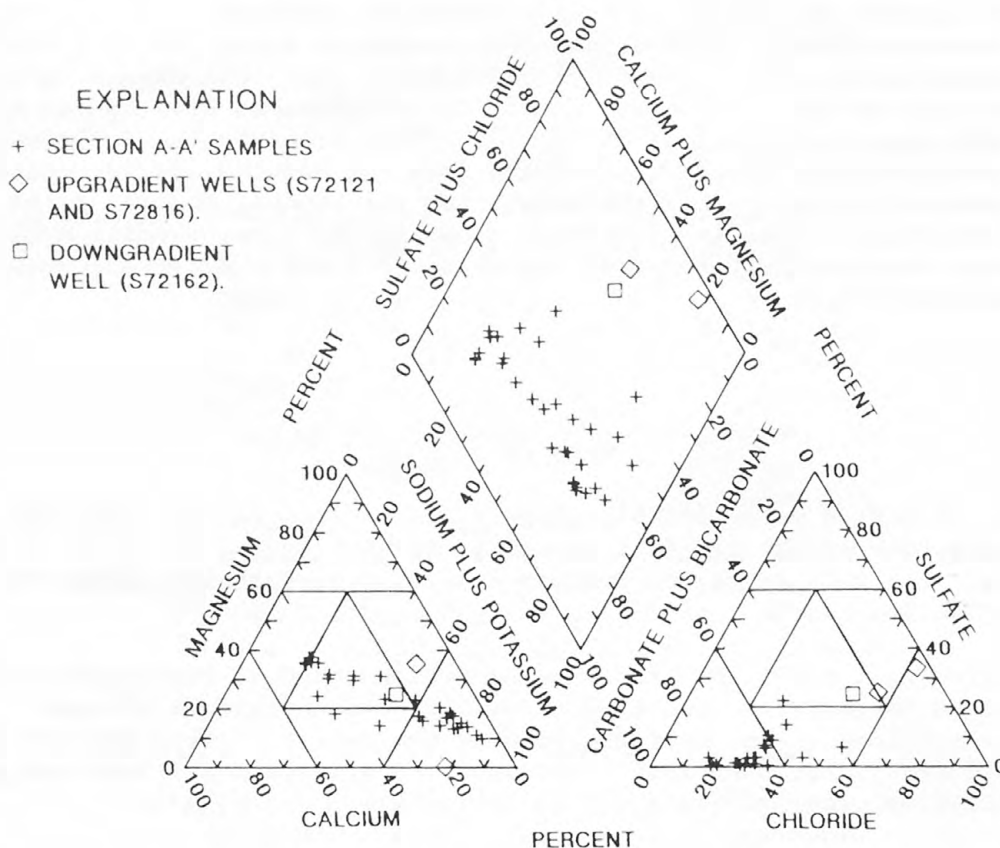


Figure 12. Trilinear diagram of results of ground-water analyses for section A-A'. (Locations are shown in pl. 1.)

## SUMMARY AND CONCLUSIONS

Ground water was sampled at sites along two vertical sections through the leachate-contaminated plume of ground water downgradient from the Brookhaven Landfill. Fifty-one samples collected in November and December 1987 were analyzed by the National Water Quality Laboratory of the USGS. The analytical results were used to identify geochemical processes within the contaminated aquifer system and to compare these processes with those that occur under natural conditions.

The introduction of landfill leachate into ground water affects the ambient geochemical environment in several ways. The concentrations of inorganic and organic chemicals in the ground water increase sharply. The increased inorganic chemical content drives ion-exchange processes to new equilibria that, in turn, cause changes in constituent proportions and presumably cause much greater adsorption of ions onto the solid phase than is usual for Long Island sediments. The organic material and nutrients support bacterial activity that consumes dissolved oxygen and creates strongly



reducing redox conditions. Under these conditions, anaerobic bacteria use oxidized forms of nitrogen, iron, manganese, sulfur, and carbon as electron acceptors in metabolic processes, causing these elements to appear in reduced forms. As the contaminated ground water moves downgradient, nutrients and dissolved organic carbon are consumed, dilution with ambient ground water occurs, bacterial activity decreases, and geochemical processes that prevailed before contamination gradually are restored.

The primary processes that affect constituent concentrations in the leachate-contaminated ground water are dilution and the oxidation of organic matter. Wexler (1988b) estimated rates of advection and dispersion (dilution processes) in a transport model and predicted the future extent of the contaminant plume in the aquifer system at the landfill. The concentrations predicted by the model are less than those found during this investigation but generally support Wexler's estimates for rates of advection and dispersion.

The oxidation of organic matter is intrinsic to most geochemical transformation within the leachate plume. In contaminated ground water near the landfill, bacteria mediate the oxidation of organic matter and the reduction of (1) iron and manganese oxyhydroxides to soluble ferrous and manganous forms; (2) nitrate and nitrite to nitrogen and ammonia (denitrification); (3) some sulfate to sulfide (the sulfide precipitates from solution as iron and manganese sulfides); and (4) under extreme conditions, some organic matter to methane (methanogenesis). Farther downgradient, mixing with oxic ambient ground water reoxidizes many of these reduced forms.

A secondary process unrelated to bacterial activity and redox processes is the exchange of dissolved sodium and potassium for calcium and magnesium adsorbed on ion-exchange sites; this exchange results in a decrease in concentrations of monovalent cations and an increase in concentrations of divalent cations with depth and distance from the landfill.

Several observations indicate that the strongly reducing conditions within the leachate plume near the landfill become less reducing as the water moves downgradient and as nutrients and organic compounds are consumed and diluted. Advective and dispersive processes dilute leachate with the more oxidizing ambient ground water. Nitrogen is present almost entirely in the form of organic amines at site A1 but is present as ammonia farther downgradient. The nitrogen index decreases by a factor of 1,000 from site A1 to site A8 along section A-A'. Methane from methanogenic processes at the landfill and a strong odor of sulfur gases in leachate and in samples from site A1 are absent from contaminated wells farther downgradient. Lastly, oxidized iron and manganese mineral phases in aquifer sediments apparently no longer function as oxidizers at sites A4 and A5 because dissolved iron concentrations have decreased sharply from those at sites A1, A2, and A3.

Contaminant concentrations have increased at all sites along section A-A' since 1982; contaminant concentrations along section B-B' peak at site B3, indicating a recently reduced inflow of leachate constituents upgradient from section B-B'. The vertical distribution of contaminants along section A-A' differs sharply from that along section B-B'; the vertical distribution of contaminants along section A-A' is relatively uniform, whereas the plume along

section B-B' is more shallow, indicating a difference in the sources of contamination along the two sections. The previously proposed source of contamination along section B-B' is overflow of leachate along the eastern edge of the landfill liner (a point source), whereas the source of contamination along section A-A' probably is leakage through the liner (a diffuse source). The source of contaminants along section A-A' does not account for the depth to which contaminants have penetrated along the section, nor the uniformity of contaminant concentrations with depth. Density differences between leachate and ground water and (or) mounding of the water table could cause increased vertical head gradients and a potential for increased vertical movement of contaminants.

One water sample from a well at the origin (site 1) of each section was analyzed for hazardous constituents. No significant changes from concentrations or types of hazardous constituents reported in earlier (1983) studies were found.

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Table 4.--Results of analyses of ground-water samples collected at the Brookhaven landfill site vicinity in November and December, 1987

[°C, degrees Celsius;  $\mu$ S/cm, microsiemens per centimeter at 25 degrees Celsius; <, less than; mg/L, milligrams per liter;  $\mu$ g/L, micrograms per liter; --, no data. Well and site locations shown in fig. 2 and pl. 1]

Well number	Date	Section and site identifier	Specific conductance ( $\mu$ S/cm)	pH (standard units)	Water temperature (°C)	Oxygen, dissolved (mg/L)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Alkalinity, total field (mg/L as CaCO <sub>3</sub> )
S72121	11-17-87	Upgradient	43	5.8	10.4	12	0.89	1.5	4.0	0.39	8
S72136	11-16-87	B5	286	6.2	10.3	<1	20	14	16	1.5	97
S72150	11-30-87	A6	741	6.1	10.3	<1	11	11	59	14	208
S72151	11-30-87	A8	233	6.0	11.0	<1	16	8.4	19	1.1	70
S72152	11-30-87	B7	244	5.6	11.0	<1	9.9	6.9	23	1.4	31
S72162	12-01-87	Downgradient	231	5.6	11.8	1	9.1	5.5	21	1.7	32
S72816	12-14-87	Upgradient	43	5.7	10.2	13	1.1	0.01	4.3	.47	3
S72817	12-14-87	B2	1,160	6.6	11.2	<1	35	12	65	47	406
S72818	12-10-87	B3	153	6.1	9.4	<1	1.1	1.5	12	13	25
S72819	12-10-87	B3	3,090	6.8	11.1	<1	56	52	250	160	1,100
S72820	12-10-87	B3	336	6.5	10.9	<1	9.4	12	29	3.6	78
S72821	11-16-87	B5	576	6.1	12.7	<1	15	10	39	14	173
S72822	11-16-87	B5	324	6.0	10.9	<1	8.3	5.2	16	10	102
S72823	11-19-87	A3	386	6.4	12.2	<1	9.9	5.6	23	16	112
S72834	12-08-87	A2	1,740	7.0	16.2	<1	20	22	120	83	645
S73750	12-21-87	B1	1,650	6.5	14.3	--	27	17	89	78	705
S73751	12-21-87	B1	121	5.9	12.2	--	2.1	2.3	16	.90	5
S73752	12-21-87	B1	204	6.1	11.4	--	16	8.3	7.4	.80	8
S73756	12-28-87	A1	1,630	6.8	15.8	--	11	12	110	96	529
S73757	12-28-87	A1	2,320	7.1	19.5	--	13	16	170	140	777
S73758	12-28-87	A1	1,830	7.0	21.2	--	16	18	130	93	618
S73759	12-28-87	A1	1,710	7.0	14.3	--	37	18	130	7.0	608
S73943	12-14-87	B2	535	7.1	11.1	<1	14	6.7	38	12	177
S73944	12-14-87	B2	145	7.4	11.0	<1	3.1	.84	10	3.1	23
S73945	12-04-87	A2	1,730	7.0	15.8	<1	21	23	110	90	627
S73946	12-01-87	B4	587	6.5	12.2	<1	8.3	5.7	48	21	136
S73947	12-01-87	B4	390	6.6	12.9	<1	5.7	3.1	32	13	77
S73953	11-17-87	B6	139	6.1	10.7	3	3.6	3.1	19	.90	25
S73954	11-17-87	B6	183	6.0	10.6	8	12	6.6	10	.90	12
S76380	11-23-87	A7	761	6.2	11.5	<1	7.1	7.4	59	19	177
S76381	11-23-87	A7	637	6.4	10.4	<1	54	26	43	2.0	220
S76382	11-23-87	A7	625	6.6	10.9	<1	16	12	51	10	255
S76383	11-23-87	A7	366	6.5	10.2	<1	36	17	17	1.3	158
S76384	11-23-87	A7	--	6.2	10.2	<1	11	3.4	7.2	.60	39
S76385	11-23-87	A7	--	6.3	10.1	<1	4.5	1.1	3.9	.40	14
S76386	12-07-87	A5	180	6.3	11.3	1	2.7	1.8	15	7.4	33
S76387	12-07-87	A5	1,200	6.7	11.6	<1	20	11	77	41	436
S76388	12-07-87	A5	1,420	6.7	11.4	<1	33	17	91	44	487
S76389	12-07-87	A5	1,720	7.0	11.2	<1	81	21	130	25	640
S76390	12-07-87	A5	1,220	7.2	11.5	<1	120	56	60	2.0	568
S76391	12-07-87	A5	420	6.6	10.0	<1	38	20	19	1.0	162
S76392	12-09-87	A4	1,140	6.9	13.1	<1	14	11	82	56	415
S76393	12-09-87	A4	1,630	7.0	13.1	<1	19	20	110	80	595
S76394	12-09-87	A4	1,080	6.9	13.2	<1	47	35	84	18	436
S76395	12-09-87	A4	1,030	6.7	12.6	<1	76	34	59	4.0	430
S76396	12-09-87	A4	1,130	6.6	12.2	<1	110	54	59	2.2	480
S76397	12-09-87	A4	1,390	6.7	12.1	<1	130	68	81	2.9	558
S76398	12-04-87	A2	1,950	7.0	14.2	<1	84	43	150	38	726
S76399	12-04-87	A2	553	6.8	13.9	<1	52	28	27	1.7	251
S76400	12-08-87	A2	1,580	6.9	15.3	<1	23	19	100	82	608
S76401	12-08-87	A2	1,200	6.9	14.2	<1	76	44	86	17	486



Table 4.--Results of analyses of ground-water samples collected at the Brookhaven landfill site vicinity in November and December, 1987--continued

Well number	Sulfide, total (mg/L as S)	Sulfate, dis- solved (mg/L as SO <sub>4</sub> )	Chlo- ride, dis- solved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Bromide dis- solved (mg/L as Br)	Silica, dis- solved (mg/L as SiO <sub>2</sub> )	Dis- solved solids, residue at 180 °C (mg/L)	Nitro- gen, nitrite dis- solved (mg/L as N)	Nitro- gen, NO <sub>2</sub> +NO <sub>3</sub> dis- solved (mg/L as N)	Nitro- gen, ammonia dis- solved (mg/L as N)
S72121	<0.5	6.1	10	0.10	0.043	7.1	24	0.003	0.020	0.012
S72136	< .5	13	25	.10	.36	6.1	148	.030	.069	.270
S72150	< .5	30	81	.10	.17	6.3	278	.010	< .010	35.0
S72151	< .5	12	24	< .10	.20	16	132	.028	.610	.010
S72152	< .5	20	42	.10	.32	12	150	.014	.290	.030
S72162	< .5	25	35	.10	.26	11	121	.005	.190	.850
S72816	< .5	7.3	10	.10	.029	6.6	35	< .001	.059	.030
S72817	< .5	5.1	130	.10	.037	14	464	.002	< .010	37.0
S72818	< .5	32	12	.10	< .010	4.1	91	.004	< .010	4.00
S72819	< .5	23	390	.20	2.8	4.9	1,290	.006	.076	--
S72820	< .5	8.7	56	.10	.35	4.7	162	.001	< .010	4.70
S72821	< .5	23	60	.10	.40	5.2	244	< .001	< .010	20.0
S72822	< .5	16	27	.10	.20	4.8	143	< .001	< .010	7.90
S72823	< .5	10	39	.10	.091	6.2	171	.005	< .010	1.70
S72834	< .5	11	160	.20	1.3	12	676	.012	.029	90.0
S73750	< .5	12	130	.20	.80	19	--	.004	< .010	75.0
S73751	< .5	7.0	27	.10	.054	8.2	74	< .001	.150	< .010
S73752	< .5	51	12	.10	.047	13	127	< .001	5.20	< .010
S73756	< .5	26	170	.20	2.0	14	591	.003	< .010	< .010
S73757	< .5	43	450	.20	2.8	11	860	.005	< .010	< .010
S73758	< .5	26	190	.20	2.3	12	--	.014	< .010	--
S73759	< .5	23	170	.20	1.6	13	691	.002	< .010	< .010
S73943	< .5	11	56	.20	.023	11	230	.002	< .010	12.0
S73944	< .5	9.7	26	.20	.15	9.0	74	.001	< .010	3.80
S73945	< .5	13	150	.20	1.3	13	655	.012	.028	68.0
S73946	< .5	30	66	.10	.33	5.0	258	.006	4.30	25.0
S73947	< .5	27	45	.10	.19	3.0	174	.006	5.00	16.0
S73953	< .5	16	19	.10	.13	6.7	78	.001	.522	< .010
S73954	< .5	35	16	.10	.12	13	106	< .001	3.80	.010
S76380	< .5	46	81	.10	.24	3.5	280	.004	.016	37.0
S76381	< .5	3.4	56	.10	.35	12	343	.005	.016	.060
S76382	< .5	4.1	61	.10	.34	5.4	257	.005	.010	24.0
S76383	< .5	5.5	21	.10	.15	20	207	.031	.282	.040
S76384	< .5	4.2	13	.10	.074	18	80	.012	.041	.060
S76385	< .5	5.8	5.2	.10	.029	14	41	.005	< .010	.020
S76386	< .5	5.2	27	.20	.19	5.2	83	.006	1.50	4.20
S76387	< .5	6.0	140	.20	1.8	3.8	509	.010	.024	52.0
S76388	< .5	5.3	140	.20	2.0	4.1	556	--	--	69.0
S76389	< .5	6.4	240	.20	2.3	8.3	798	.011	.030	60.0
S76390	< .5	5.2	99	.30	1.5	12	762	.004	< .010	.070
S76391	< .5	3.5	40	.20	.29	21	264	.008	.016	.050
S76392	< .5	7.4	110	.30	1.4	6.8	449	--	--	52.0
S76393	< .5	12	140	.30	2.2	9.4	622	.029	.017	60.0
S76394	< .5	6.6	120	.30	1.7	13	577	--	--	16.0
S76395	< .5	3.6	100	.30	1.3	18	624	.005	< .010	1.90
S76396	< .5	3.6	120	.30	1.5	19	683	.005	< .010	.060
S76397	< .5	4.2	160	.20	1.8	18	856	.004	< .010	.120
S76398	< .5	10	220	.20	1.8	25	915	.013	.038	36.0
S76399	< .5	1.5	38	.20	.28	16	313	.013	.093	.020
S76400	< .5	10	150	.20	1.3	14	612	.010	.022	80.0
S76401	< .5	4.6	120	.20	.95	26	655	.011	.025	6.30

Table 4.--Results of analyses of ground-water samples collected at the Brookhaven landfill site vicinity in November and December, 1987--continued

Well number	Nitrogen, ammonia + organic dissolved (mg/L as N)	Phosphorous, dissolved (mg/L as P)	Phosphorous, ortho, dissolved (mg/L as P)	Aluminum, dissolved (μg/L as Al)	Boron, dissolved (μg/L as B)	Iron, dissolved (μg/L as Fe)	Lithium, dissolved (μg/L as Li)	Manganese, dissolved (μg/L as Mn)	Strontium, dissolved (μg/L as Sr)	Carbon, organic dissolved (mg/L as C)
S72121	<0.20	<0.005	<0.001	20	<10	<3	<4	16	7	0.5
S72136	.20	.020	.010	<10	80	33	5	35	110	2.3
S72150	33	.010	<.010	<10	300	6,100	<10	4,600	170	9.7
S72151	<.20	.020	.010	<10	80	630	<4	24	88	1.5
S72152	.20	.010	<.010	10	40	1,500	<4	1,400	89	2.6
S72162	1.1	<.010	.010	10	40	2,100	<4	1,300	63	2.0
S72816	.40	<.005	<.002	<10	20	<3	<4	11	7	.7
S72817	47	<.010	<.010	<10	380	51,000	<4	1,600	220	17
S72818	4.0	<.010	.010	330	100	350	<4	1,900	13	12
S72819	--	.030	--	<10	1,200	50	10	29,000	350	66
S72820	4.5	<.010	<.010	<10	50	280	<4	1,700	87	2.9
S72821	17	<.010	<.010	<10	190	4	<4	19,000	110	5.8
S72822	7.2	<.010	<.010	<10	90	3	5	22,000	70	2.6
S72823	10	<.010	<.010	<10	140	630	<4	12,000	79	3.2
S72834	84	.010	.010	<10	740	25,000	<4	2,800	150	35
S73750	68	.010	<.010	--	580	82,000	<4	4,200	210	36
S73751	<.20	<.010	<.010	<10	<10	76	<4	11	21	.6
S73752	<.20	<.010	<.010	<10	20	55	8	6	85	.7
S73756	80	--	<.010	<10	530	1,100	<4	3,300	110	43
S73757	120	--	<.010	<10	990	9,500	10	380	110	82
S73758	85	--	--	--	760	19,000	<4	790	140	63
S73759	65	--	<.010	<10	800	1,300	<4	11,000	240	52
S73943	12	<.010	.010	<10	110	31,000	<4	7,300	99	7.6
S73944	3.5	.400	.190	<10	20	2,500	<4	4,800	33	1.0
S73945	94	.010	.050	<10	730	19,000	<4	900	180	33
S73946	21	.030	<.010	10	190	270	<4	12,000	91	7.5
S73947	15	.010	<.010	10	140	180	<4	7,300	37	4.1
S73953	<.20	<.010	<.010	<10	30	<3	<4	6	28	1.0
S73954	.40	.010	<.010	<10	10	<3	6	<1	66	.8
S76380	36	.010	<.010	<10	280	7	<4	6,200	140	9.6
S76381	.20	.020	.010	<10	220	7	<4	18	240	4.8
S76382	23	.020	<.010	<10	260	6	<4	11,000	220	6.3
S76383	.20	.010	<.010	<10	20	<3	<4	12	150	1.6
S76384	<.20	.070	.050	<10	<10	13	<4	820	52	1.0
S76385	<.20	.100	.080	<10	<10	180	<4	43	24	.4
S76386	4.3	.020	<.010	20	60	3	<4	4,100	33	1.8
S76387	48	.010	<.010	<10	380	<3	<4	57,000	120	19
S76388	70	<.010	.020	10	490	10	<4	28	400	21
S76389	60	<.010	<.010	<10	680	54	<4	52,000	590	32
S76390	2.0	<.010	<.010	<10	280	71	5	27	440	13
S76391	<.20	<.010	<.010	<10	20	110	<4	1,300	170	3.7
S76392	51	<.010	.010	<10	500	4,900	<4	18,000	87	18
S76393	60	.010	.040	<10	720	30,000	<4	11,000	140	30
S76394	12	.060	.040	<10	470	12,000	<4	25,000	760	20
S76395	2.5	.020	.020	<10	320	3,500	16	52,000	500	14
S76396	.70	.020	.010	<10	190	1,100	10	13,000	430	14
S76397	1.0	.020	.010	<10	330	440	9	8,900	550	22
S76398	70	.010	.040	10	740	27,000	<4	2,900	480	43
S76399	.30	<.010	<.010	<10	20	26	<4	130	250	3.1
S76400	--	.010	.170	10	580	19,000	<4	1,300	280	29
S76401	9.0	.010	.040	10	420	30,000	<4	1,300	340	17

Table 5.--Concentrations of trace metals and organic compounds in two ground-water samples from the Brookhaven landfill site, 1987

[All values are in micrograms per liter; <, less than]

Constituent	Well S73750 (site B1 on pl. 1)	Well S73758 (site A1 on pl. 1)
Heavy Metals		
Arsenic, dissolved	12	12
Arsenic, total	12	16
Cadmium, dissolved	4	<1
Cadmium, total	<1	<1
Chromium, dissolved	2	2
Chromium, total	3	6
Cobalt, dissolved	10	6
Cobalt, total	10	6
Copper, dissolved	1	1
Copper, total	2	8
Iron, dissolved	82,000	19,000
Iron, total	80,000	20,000
Lead, dissolved	<5	<5
Lead, total	<5	<5
Manganese, dissolved	4,200	790
Manganese, total	3,700	270
Mercury, dissolved	< .1	< .1
Mercury, total	< .10	< .10
Selenium, dissolved	<1	<1
Zinc, dissolved	16	5
Zinc, total	20	<10
Volatile Organic Compounds		
Bromodichloromethane	< .20	< .20
Carbon tetrachloride	< .20	< .20
1,2-Dichloroethane	< .20	< .20
Bromoform	< .20	< .20
Chlorodibromomethane	< .20	< .20
Chloroform	< .20	< .20
Toluene	< .20	.60
Benzene	2.7	1.8
Chlorobenzene	7.2	2.0
Chloroethane	< .20	< .20
Ethylbenzene	< .20	< .20
Methyl bromide	< .20	< .20
Methyl chloride	< .20	< .20
Methylene chloride	<0.20	<0.20
Tetrachloroethene	< .20	< .20
Fluorotrichloromethane	< .20	< .20
1,1-Dichloroethane	< .20	.60
1,1-Dichloroethene	< .20	< .20
1,1,1-Trichloroethane	< .20	< .20
1,1,2-Trichloroethane	< .20	< .20
1,1,2,2-Tetrachloroethane	< .20	< .20
1,2-Dichlorobenzene	<5.0	<5.0
1,2-Dichloropropane	< .20	< .20
trans-1,2-Dichloroethylene	1.0	< .20
1,3-Dichloropropene	< .20	< .20

Table 5.--Concentrations of trace metals and organic compounds in  
two ground-water samples from the Brookhaven landfill  
site, 1987--continued

Constituent	Well S73750 (site B1 on pl. 1)	Well S73758 (site A1 on pl. 1)
Volatile Organic Compounds--continued		
1,3-Dichlorobenzene	<5.0	<5.0
1,4-Dichlorobenzene	<5.0	<5.0
2-Chloroethyl vinyl ether	< .20	< .20
Dichlorodifluoromethane	< .20	< .20
<i>trans</i> -1,3-Dichloropropene	< .20	< .20
<i>cis</i> -1,3-Dichloropropene	< .20	< .20
1,2-Dibromoethane	< .2	< .2
Vinyl chloride	< .20	< .20
Trichloroethylene	.2	< .2
Styrene	< .2	< .2
Xylene	< .2	4.3
Pesticides		
Aldrin	< .01	< .01
Chlordane	< .1	< .1
DDD	< .01	< .01
DDE	< .01	< .01
DDT	< .01	< .01
Diazinon	< .01	< .01
Dieldrin	< .01	< .01
Endosulfan	< .01	< .01
Endrin	< .01	< .01
Ethion	< .01	< .01
Heptachlor	<0.01	<0.01
Heptachlor epoxide	< .01	< .01
Lindane	< .01	< .01
Malathion	< .01	< .01
Methoxychlor	< .01	< .01
Methyl parathion	< .01	< .01
Methyl trithion	< .01	< .01
Mirex	< .01	< .01
Naphtahlenes, polychlorinated	< .10	< .10
Parathion	< .01	< .01
Biphenyls, polychlorinated	< .1	< .1
Perthane	< .1	< .1
Toxaphene	<1	<1
Trithion	< .01	< .01
Acid and Base-Neutral Extractable Organic Compounds		
Acenaphthylene	<5.0	<5.0
Acenaphthene	<5.0	<5.0
Anthracene	<5.0	<5.0
Benzo(b)fluoranthene	<10.0	<10.0
Benzo(k)fluoranthene	<10.0	<10.0



Table 5.--Concentrations of trace metals and organic compounds in  
two ground-water samples from the Brookhaven landfill  
site, 1987--continued

Constituent	Well S73750 (site B1 on pl. 1)	Well S73758 (site A1 on pl. 1)
Acid and Base-Neutral Extractable Organic Compounds--continued		
Benzo(a)pyrene	<10.0	<10.0
bis(2-Chloroethyl) ether	<5.0	<5.0
bis(2-Chloroethoxy) methane	<5.0	<5.0
bis(2-Chloroisopropyl) ether	<5.0	<5.0
<i>n</i> -Butyl benzyl phthalate	<5.0	<5.0
Chrysene	<10.0	<10.0
Diethyl phthalate	<5.0	<5.0
Dimethyl phthalate	<5.0	<5.0
Fluoranthene	<5.0	<5.0
Fluorene	<5.0	<5.0
Hexachlorocyclopentadiene	<5.0	<5.0
Hexachloroethane	<5.0	<5.0
Indeno(1,2,3-cd)pyrene	<10.0	<10.0
Isophorone	<5.0	<5.0
<i>N</i> -Nitrosodi- <i>n</i> -Propylamine	<5.0	<5.0
<i>N</i> -Nitrosodiphenylamine	<5.0	<5.0
<i>N</i> -Nitrosodimethylamine	<5.0	<5.0
Nitrobenzene	<5.0	<5.0
<i>p</i> -Chloro- <i>m</i> -cresol	<30.0	<30.0
Phenanthrene	<5.0	<5.0
Pyrene	<5.0	<5.0
Benzo(g,h,i)perylene	<10.0	<10.0
Benzo(a)anthracene	<5.0	<5.0
1,2-Dichlorobenzene	<5.0	<5.0
1,2,4-Trichlorobenzene	<5.0	<5.0
Dibenzo(a,h)anthracene	<10.0	<10.0
1,3-Dichlorobenzene	<5.0	<5.0
1,4-Dichlorobenzene	<5.0	<5.0
2-Chloronaphthalene	<5.0	<5.0
2-Chlorophenol	<5.0	<5.0
2-Nitrophenol	<5.0	<5.0
Di- <i>n</i> -octyl phthalate	<10.0	<10.0
2,4-Dichlorophenol	<5.0	<5.0
2,4-Dimethylphenol	<5.0	<5.0
2,4-Dinitrotoluene	<5.0	<5.0
2,4-Dinitrophenol	<20.0	<20.0
2,4,6-Trichlorophenol	<20.0	<20.0
2,6-Dinitrotoluene	<5.0	<5.0
4-Bromophenyl phenyl ether	<5.0	<5.0
4-Chlorophenyl phenyl ether	<5.0	<5.0
4-Nitrophenol	<30.0	<30.0
4,6-Dinitro- <i>o</i> -cresol	<30.0	<30.0
Phenol	<5.0	<5.0
Naphthalene	<5.0	<7.0
Pentachlorophenol	<30.0	<30.0
bis(2-Ethylhexyl) phthalate	<5.0	<5.0
Di- <i>n</i> -butyl phthalate	<5.0	<5.0
Hexachlorobenzene	<5.0	<5.0
Hexachlorobutadiene	<5.0	<5.0





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