GROUND-WATER FLOW AND SOLUTE TRANSPORT AT A MUNICIPAL LANDFILL SITE ON LONG ISLAND, NEW YORK

Part 1: Hydrogeology and Water Quality

by Eliezer J. Wexler

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(in pocket)

CONVERSION FACTORS AND ABBREVIATIONS

Readers who prefer metric (International System) units to the inch-pound units used in this report may use the following conversion factors:

Multiply inch-pound units	by	To obtain metric units
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	.004	square kilometer (km^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow	
gallon per minute (gal/min)	0.06308	liter per second (L/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)

Equivalent concentration terms

milligrams per liter (mg/L) equals parts per million (ppm)
micrograms per liter (µg/L) equals parts per billion (ppb)

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 both the United States and Canada, formerly called "Mean Sea Level of 1929."

Conversion Factors for Relating Concentration Units.

[Modified from Hem, 1970]

Multiply	by	To obtain
Alkalinity (as HCO_3), in mg/L	0.8202	Alkalinity (as $CaCO_3$), in mg/L
Ammonium (as NH_4), in mg/L	0.7765	Ammonium (as N), in mg/L
Nitrate (as NO_3), in mg/L	0.2259	Nitrate (as N), in mg/L
Nitrite (as NO_2), in mg/L	0.3045	Nitrite (as N), in mg/L
Ammonium (NH_4^+), in mg/L	0.05544	Ammonium, in meq/L
Bicarbonate (HCO_3^-), in mg/L	0.01639	Bicarbonate, in meq/L
Calcium (Ca^{+2}), in mg/L	0.04990	Calcium, in meq/L
Chloride (Cl^-), in mg/L	0.02821	Chloride, in meq/L
Magnesium (Mg^{+2}), in mg/L	0.08226	Magnesium, in meq/L
Nitrate (NO_3^-), in mg/L	0.01613	Nitrate, in meq/L
Potassium (K^+), in mg/L	0.02557	Potassium, in meq/L
Sodium (Na^+), in mg/L	0.04350	Sodium, in meq/L
Sulfate (SO_4^{-2}), in mg/L	0.02082	Sulfate, in meq/L

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ABSTRACT

As part of a study on the transport of contaminants in ground water, the hydrogeology and chemical quality of ground water in a 4-square-mile area surrounding a municipal sanitary landfill in the Town of Brookhaven, Long Island, N.Y., were investigated during 1981-83. The landfill is excavated in glacial-outwash deposits that form part of the upper glacial aquifer and is lined with a polyvinyl chloride membrane. The aquifer in that area consists mostly of highly permeable coarse sand and gravel and is a principal source of water supply for the Town. The saturated thickness of the aquifer ranges from 100 to 120 feet. Ground water moves southeastward at about 1.1 feet per day.

Although the landfill is lined, water samples from wells downgradient contained elevated concentrations of several inorganic ions, which indicates that leachate has entered the aquifer. A leachate plume 3,700 feet long, 2,400 feet wide, and at least 90 feet thick was delineated from specific-conductance data from monitoring-well samples. Water quality in the Magothy aquifer and in Beaverdam Creek, a stream fed by ground water 2,000 ft southeast of the landfill site, does not appear to be contaminated by leachate.

The areal distribution of sodium and chloride is similar to that of specific conductance. Both sodium and chloride appear to be conservative and are attenuated by dispersive mixing only. Bicarbonate, as measured by total alkalinity, is attenuated by several chemical processes, including oxidation of reduced species in leachate. Ammonium concentrations decrease downgradient of the landfill through ion exchange and, along the edges of the plume, by oxidation of ammonium ion to nitrate.

INTRODUCTION

Burial of municipal waste in sanitary landfills is the primary means of solid-waste disposal on Long Island. The high permeability of the glacial outwash deposits in the southern part of Long Island allows leachate from unlined sanitary landfills to easily enter the water-table aquifer. A recent study by Kimmel and Braids (1980) described the degradation of water quality downgradient from two unlined landfills in the Towns of Babylon and Islip (fig. 1).

To minimize the potential for ground-water contamination, newly constructed sanitary landfills on Long Island must be underlain by impermeable

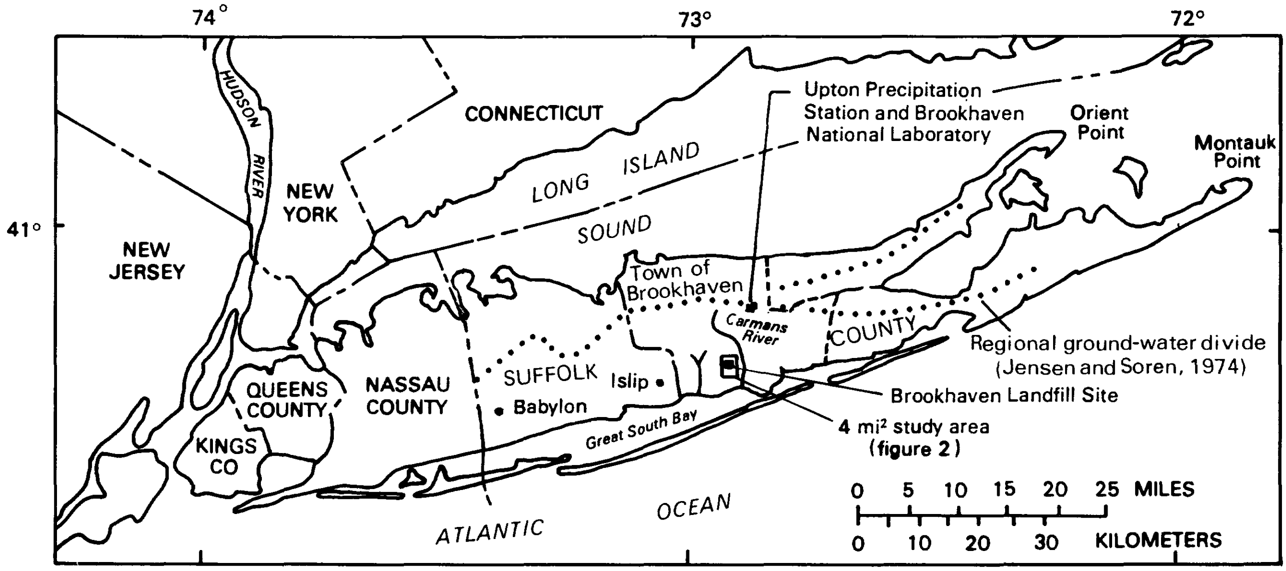
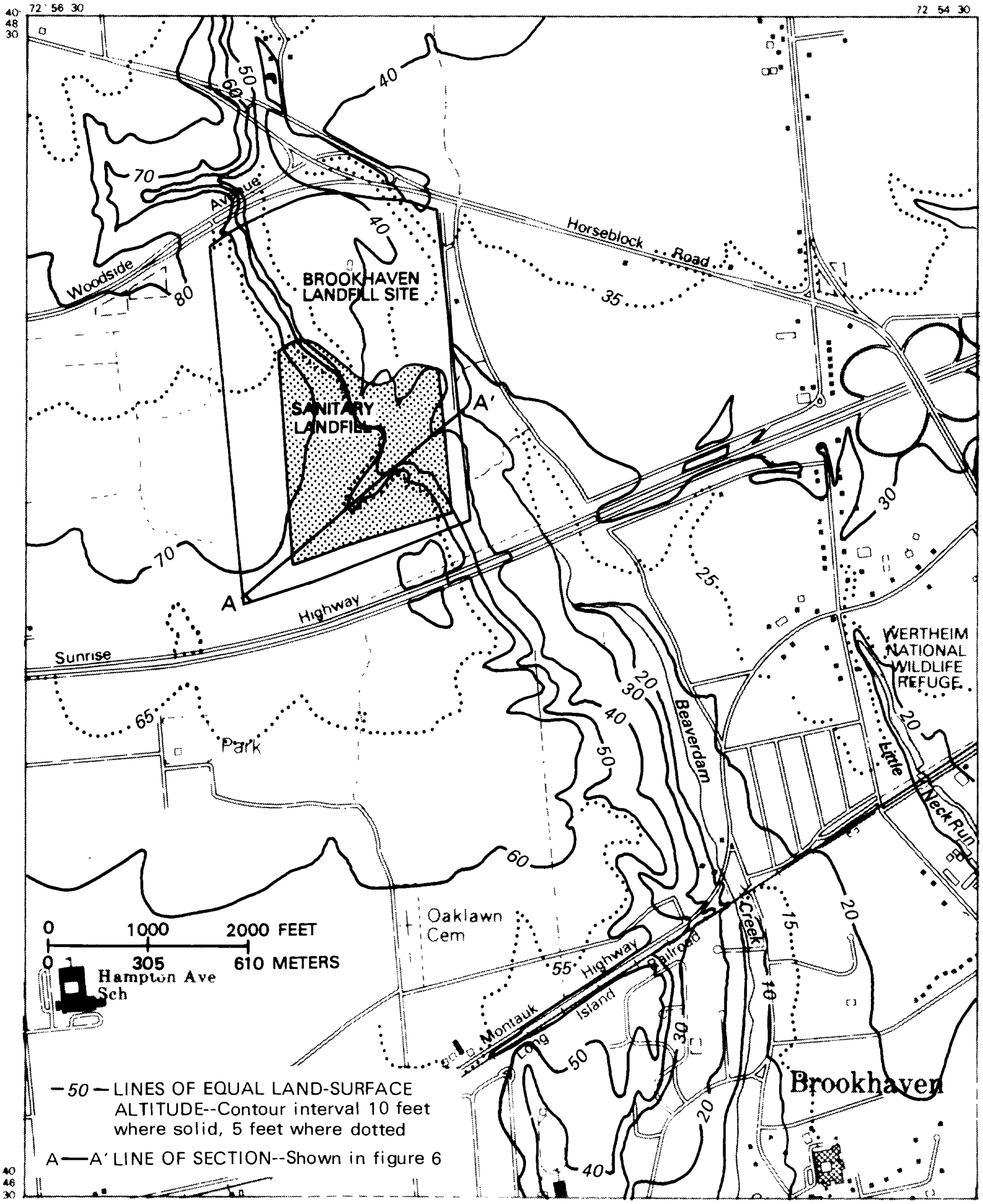


Figure 1.--Location of the Brookhaven landfill site in the Town of Brookhaven, N.Y.

liners. One such lined landfill is in the Town of Brookhaven (fig. 1). All solid waste buried at the site has been placed in an excavation lined with an 0.02-inch thick polyvinyl chloride (PVC) membrane. Approximately 1,100 tons of municipal solid waste per day have been disposed of at the site since operations began in 1974. By 1983, the sanitary landfill covered 60 of the site's 180 acres (fig. 2). The landfill is excavated in outwash deposits that overlie the upper glacial aquifer, a principal source of water supply for the Town of Brookhaven.

In 1981, as part of its continuing investigation of processes that lead to degradation of ground-water quality, the U.S. Geological Survey, in cooperation with the Town of Brookhaven, began gathering data on hydrogeologic conditions and water quality in a 4-mi^2 area surrounding the landfill site (fig. 2). A primary purpose in collecting these data was the development of a predictive ground-water flow and solute-transport model for the area. The model was to be used to identify factors that influence the transport of contaminants in ground water at a typical waste-disposal site on Long Island.

Initial sampling of wells and streams in the study area was done in March, April, and June 1982. Samples from wells downgradient from the landfill had elevated pH, temperature, specific conductance, and chloride and ammonium concentrations. Although elevated specific conductance and chloride concentrations might be attributed to sources other than the landfill, the presence of ammonium in ground water on Long Island is unusual and is considered to be a reliable indicator of contamination by landfill leachate (Kimmel and Braids, 1980).



Base from NYSDOT, Bellport, NY, 1981, 1:24,000

Figure 2.--Topography and major features of the 4-mi² study area surrounding the Brookhaven landfill site. (Location is shown in fig. 1.)

Because leachate contamination of ground water at landfills that are lined had not been reported in the literature, the U.S. Geological Survey and the Town of Brookhaven installed additional monitoring wells in the study area and, in October-December 1982, collected samples from 74 wells and from Beaverdam Creek, a nearby ground-water-fed stream, for laboratory analysis. The analyses provided information on the chemical composition of ground water near the landfill site and were used to delineate the extent of leachate contamination. Additional samples were collected from 16 wells in April 1983 to verify previous results.

Purpose and Scope

This report describes the hydrogeology and ground-water quality in the 4-mi^2 area surrounding the landfill site and contains maps delineating the zone of leachate-contaminated ground water downgradient of the site in 1982. It also contains brief discussions on leachate composition and the physical and chemical mechanisms that control movement of solutes associated with leachate contamination in ground water.

The ground-water-flow and solute-transport models of the landfill-site vicinity, and results of simulations are described in two companion reports (Wexler and Maus, 1988, and Wexler, 1988). Data on organic contaminants in ground water downgradient from the landfill site are given in a report by Pearsall and Wexler (1986).

Acknowledgments

The author thanks Commissioner Vincent Donnelly of the Town of Brookhaven Department of Planning, Environment and Development; Elaine McKibben and James Heil of the Division of Sanitation; and Paul E. Maus, Michael P. Scorca, and David A. Eckhardt of the U.S. Geological Survey in Syosset, N.Y., for their advice and help in the preparation of this report.

GEOLOGIC SETTING

The geology of Suffolk County has been described by Jensen and Soren (1974). The geology and hydrology of central Suffolk County, which includes the Brookhaven landfill site and vicinity, are described by deLaguna (1963) and by Warren and others (1968). A generalized north-south geologic section illustrating the major hydrogeologic units underlying the Town of Brookhaven is given in figure 3.

Geologic data on the Brookhaven landfill site vicinity were obtained through analysis of geologic logs from nearby public-supply wells and test holes. Three additional test wells were drilled through the upper glacial aquifer at or near the site during this investigation and screened in the underlying Magothy aquifer (wells S72812, S72813 and S72814; locations are shown in pl. 1). Geologic logs and cores were used to provide data on the upper glacial aquifer and on the confining units that separate it from the Magothy aquifer. A summary of geologic data from the 4-mi^2 area surrounding the landfill site follows.

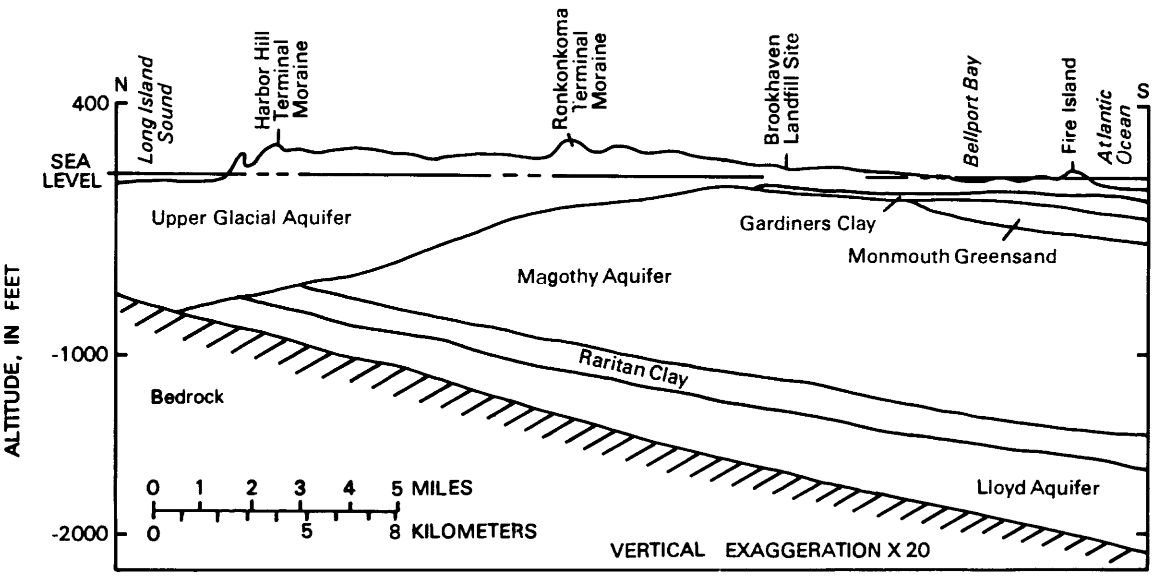


Figure 3.--Generalized geologic section showing major hydrogeologic units underlying the Town of Brookhaven. (Modified from Jensen and Soren, 1974.)

Upper Pleistocene Deposits

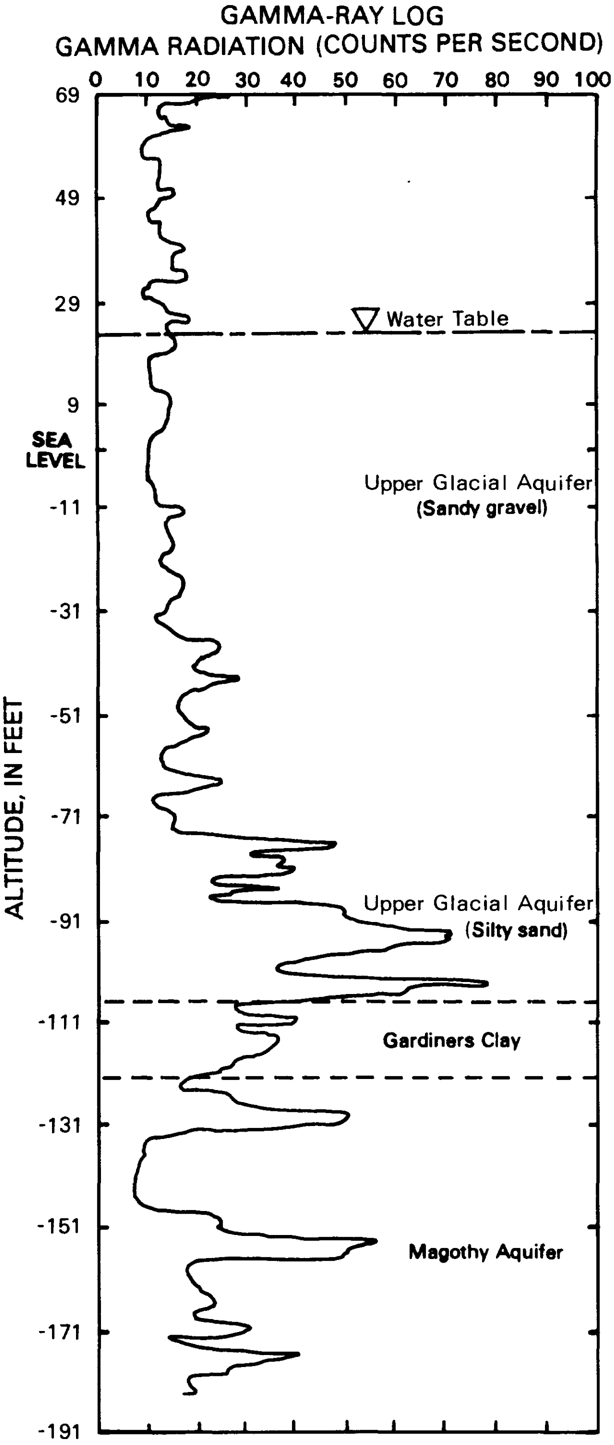
The Brookhaven landfill site lies on unconsolidated deposits of Pleistocene age associated with outwash from the Wisconsin glaciation. These deposits constitute the upper glacial aquifer and consist primarily of stratified sand and gravel containing very little clay or silt. The sand grains are mostly quartz with small amounts of alkali feldspar, mica, amphibole, and other materials (deLaguna, 1963). The quartz grains are typically brown because they have iron oxide or iron hydroxide coatings. Cores from the three test wells showed that the lower 15 to 20 ft of the upper glacial aquifer near the site is composed of micaceous, silty fine sand. The gamma-ray log from well S72813 (fig. 4) shows the position of this unit.

Gardiners Clay

Underlying the upper glacial aquifer is a confining unit identified as the Gardiners Clay of Pleistocene age. Gamma-ray logs and cores from the three test wells showed this formation to be 8 to 15 ft thick (fig. 4). This formation is a sandy facies containing interbedded silt, clay, and some fine gravel (T. P. Doriski, U.S. Geological Survey, written commun., 1982).

Upper Cretaceous Deposits

Underlying the Gardiners Clay is a sequence of Upper Cretaceous deposits that form the Magothy aquifer, the Raritan confining unit, and the Lloyd



LITHOLOGIC LOG[1]

0- 62	Sand, brown, coarse to very coarse grained, mostly quartz with some muscovite mica, feldspar; some gravel.
62-100	Sand, brown, medium to coarse grained, mostly quartz; some gravel.
100-138	Sand, reddish brown to brown, fine to medium grained, silty, mostly quartz with some dark minerals, muscovite mica feldspar; some gravel.
138-142	Sand, brown to orange stained, medium to coarse grained; some silty layers; some gravel. A layer of organic matter occurs around 140 ft.
142-162	Sand, tan, fine to coarse grained, mostly quartz, some feldspar, dark minerals, and organic material.
162-171	Sand, tannish brown, very fine to medium grained, some silt and gravel, mostly quartz and dark minerals.
171-181	Silt, reddish brown, some very fine grained sand, mostly quartz, muscovite mica, and dark minerals.
181-186	Sand, brownish gray, fine grained, quartz, dark minerals; dark gray clay (not greenish).
186-191	Sand, gray, medium to very coarse grained; glauconite; some dark gray clay and lignite.
191-200	Sand, gray, very fine to medium grained; abundant lignite; some dark gray clay.
200-205	Clay, dark gray, solid. Alternating layers of dark gray silty clay with lignite and layers of light gray silty sand.
208-215	Clean sand, light gray, medium to coarse grained, almost all quartz, some muscovite mica and dark minerals.
224	Sand, gray, very fine to medium grained with silty layers; some dark gray clay.
225-238	Sand, gray, medium grained; some clay.
238-248	Clay, black, very sandy.

Note: Gamma-ray log shows a moderate response at 180-183 ft and 185-190 ft. Response is less than for silty layers in glacial outwash (at 158-178 ft) or for clay layers in Magothy aquifer. Cores, ditch samples, and microscopic examination suggest that Gardiners Clay is present here in a sandy facies with some interbedded silt, clay, and gravel.

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[1] T. P. Doriski, U.S. Geological Survey, written commun., 1983.

Figure 4.--Gamma-ray and lithologic logs from well S72813. (Well location is shown on pl. 1.)

aquifer, which rests directly on the bedrock surface. General descriptions of these units are given in table 1. The Monmouth greensand, which overlies the Magothy aquifer along parts of the south shore of Long Island, was not found in the study area.

Table 1.--Generalized description of hydrogeologic units underlying the Town of Brookhaven.

[Modified from Jensen and Soren, 1971]

Hydrogeologic unit	Geologic unit	Description and water-bearing character
Upper glacial aquifer	Upper Pleistocene deposits	Mainly brown and gray sand and gravel of moderate to high hydraulic conductivity; may also include deposits of clayey till and lacustrine clay of low hydraulic conductivity. A major aquifer.
Gardiners Clay	Gardiners Clay	Green and gray clay, silt, clayey and silty sand, and some interbedded clayey and silty gravel. Unit has low hydraulic conductivity and tends to confine water in underlying aquifer.
Monmouth greensand	Monmouth Group, undifferentiated	Interbedded marine deposits of dark gray, olive-green, dark greenish-gray, and greenish-black glauconitic and lignitic clay, silt, and clayey and silty sand. Unit has low hydraulic conductivity and tends to confine water in underlying aquifer. Northern limit of this formation may lie slightly south of the study area.
Magothy aquifer	Matawan Group and Magothy Formation, undifferentiated	Gray and white fine to coarse sand of moderate hydraulic conductivity. Generally contains sand and gravel beds of low to high hydraulic conductivity in basal 100 to 200 ft. Contains much interstitial clay and silt, and beds and lenses of clay of low hydraulic conductivity. A major aquifer although undeveloped in study area.
Raritan clay	Unnamed clay member of the Raritan Formation	Gray, black, and multicolored clay and some silt and fine sand. Unit has low hydraulic conductivity and tends to confine water in underlying aquifer.
Lloyd aquifer	Lloyd Sand Member of the Raritan Formation	White and gray fine-to-coarse sand and gravel of moderate hydraulic conductivity and some clayey beds of low hydraulic conductivity. Not developed as a source of water in study area.
Bedrock	Undifferentiated crystalline rocks	Mainly metamorphic rocks of low hydraulic conductivity; surface generally weathered; considered to be the bottom of the ground-water reservoir.

HYDROLOGIC SETTING

Ground Water

The regional ground-water-flow system of Long Island has been described in detail by Cohen and others (1968) and Franke and McClymonds (1972). The only natural source of recharge to the three principal aquifers is precipitation, which averages 43.4 in/yr (inches per year) over Long Island (Miller and Frederick, 1969). Approximately 50 percent of the precipitation recharges the aquifer; most of the remaining water is lost as evapotranspiration (Cohen and others, 1968). Because the soils are highly permeable, less than 3 percent of precipitation becomes overland runoff to the local streams.

Water entering the aquifers south of the regional ground-water divide, approximately 6.5 mi north of the Brookhaven landfill site (fig. 1), flows southward and discharges to streams or to the Great South Bay and the Atlantic Ocean. Part of the water entering the upper glacial aquifer in the area between the regional divide and the landfill site moves downward to recharge the lower formations. South of the site, water from the Magothy Formation discharges into the upper glacial aquifer as leakage up through the Gardiners Clay.

Precipitation within the study area averages 47.4 in/yr (Wexler and Maus, 1988). Recharge basins in the area augment natural recharge by capturing stormwater runoff. Return flows from irrigation, sewage-treatment plants, and septic systems are additional sources of recharge to the aquifer.

Within the study area, ground water is discharged from the upper glacial aquifer to streams and to private wells for domestic supply, agriculture, and industrial use. Additional discharge may occur through ground-water evapotranspiration in areas where the water table is less than 5 ft below land surface. Two public-supply well fields are located outside the study area, 1 mi west and 1.2 mi northwest of the site.

Ground-Water Flow in Upper Glacial Aquifer

Ground water in the upper glacial aquifer is under water-table conditions. Depth to the water table at the Brookhaven landfill site ranges from 5 to 55 ft, depending on land-surface elevation. Within the study area, depth to water ranges from 0 to 55 feet. The saturated thickness of the upper glacial aquifer ranges from 100 to 120 ft.

The sand and gravel of the upper glacial aquifer is highly permeable. Average hydraulic conductivity in south-central Suffolk County, based on values given by McClymonds and Franke (1972), is 267 ft/d. Warren and others (1968) calculated the hydraulic conductivity for an area near the Brookhaven landfill site to be 187 ft/d by measuring seepage into the Carmans River (fig. 1). Calibration of a ground-water flow model representing a 26-mi^2 area that includes the study area indicates that hydraulic conductivity is about 200 ft/d (Wexler and Maus, 1988).

The aquifer is anisotropic, and estimates of the ratio of horizontal to vertical hydraulic conductivity (K_h/K_v) based on pumping-test data, range from 2:1 to 7:1 (Lindner and Reilly, 1983; Getzen, 1977). Estimates of anisotropy obtained from sensitivity analyses with regional models of Long Island average 10:1 (Reilly and others, 1983).

The porosity of the aquifer material, as measured by Veatch and others (1906), averages 0.33. Estimates of the effective porosity, which indicates the volume of interconnected pore space, range from 0.25 to 0.30 (Kimmel and Braids, 1980; Gureghian and others, 1981) on the south shore of Long Island.

The U.S. Geological Survey installed 51 two-inch diameter wells screened at shallow depths within the upper glacial aquifer in the vicinity of the Brookhaven landfill site. Vertical control was established for these wells, for monitoring wells on the site, and for fire wells in Brookhaven hamlet. Locations of these wells, which constitute the water-level observation network, are shown on plate 1. Physical descriptions of all wells are given in table 4 (at end of report).

Water levels in the observation-well network and stages in nearby streams were measured several times during the study. A water-table map for September 1982, a period of average water levels, is presented in figure 5. The water table slopes to the southeast with a gradient of about 0.0017 (9 ft/mi) in the landfill vicinity. Water-table gradients generally increase southeastward and steepen locally in the vicinity of streams.

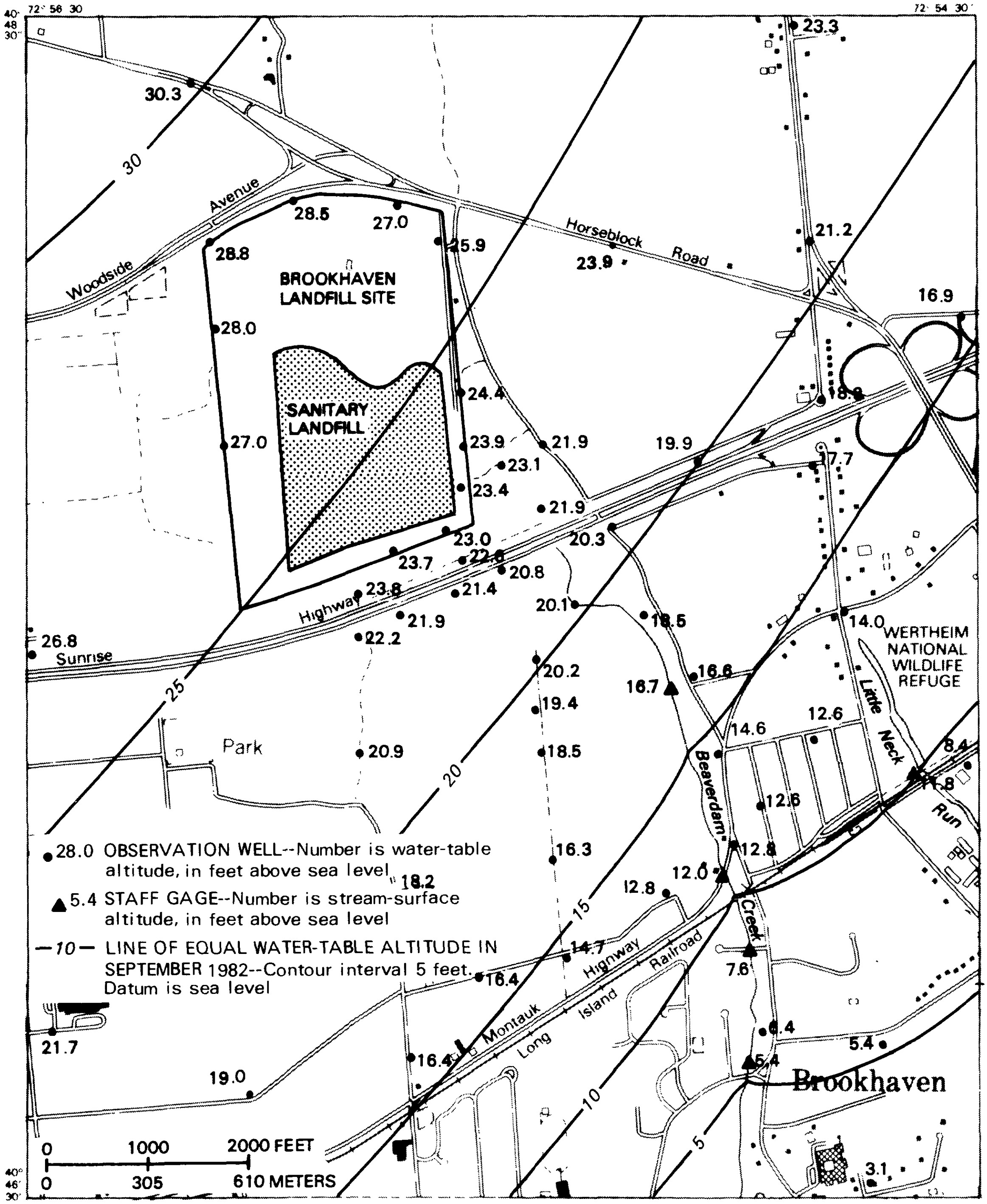
Ground water flows from areas of higher hydraulic head to areas of lower hydraulic head. Flow lines generally are perpendicular to the contours of equal hydraulic head. The average ground-water velocity (pore velocity) was calculated from Darcy's law:

$$v = \frac{K \cdot i}{n}$$

where: v = average ground-water velocity;
K = hydraulic conductivity;
i = hydraulic gradient; and
n = effective porosity.

The average ground-water velocity at the landfill site, based on values of K = 200 ft/d, i = 0.0017, and n = 0.30, is estimated to be 1.1 ft/d. Because of uncertainty in values of aquifer properties, the average ground-water velocity probably is between 0.8 and 1.8 ft/d. Seasonal and annual variations in the rate of recharge and leakage through the Gardiners Clay can affect both the magnitude and direction of ground-water flow in the study area.

Water levels also were measured at several locations having multiple wells with screens set at different depths in the upper glacial aquifer. Significant vertical gradients were not detected, which indicates that flow in the upper glacial aquifer in this area is predominantly horizontal. Continuous recorders placed on wells S73760 and S73763 (locations shown on pl. 1), however, showed that water levels in the shallower well (S73760) respond to precipitation much more rapidly and to a greater degree than those in the deeper well (S73763). This difference in response indicates that vertical gradients may develop for short periods after storms and cause the downward movement of water in the upper glacial aquifer.



Base from NYSDOT, Bellport, NY, 1981, 1:24,000

Figure 5.--Water-table altitude in vicinity of Brookhaven landfill site, September 1982.

Ground-Water Flow in Magothy Aquifer

Ground water in the Magothy aquifer is effectively confined by the Gardiners Clay in the study area. The Magothy aquifer is highly anisotropic because the upper part of the formation contains lenses of fine silt and clay. The average horizontal hydraulic conductivity in the study area has been estimated to be 40 ft/d (McClymonds and Franke, 1972), and the ratio of horizontal to vertical hydraulic conductivity for the formation may range from 30:1 to 100:1 (Lindner and Reilly, 1983).

Recent maps of the potentiometric surface of the Magothy aquifer were compiled in 1975 by Prince (1976) and in 1981 by Donaldson and Koszalka (1983). Flow in the Magothy aquifer beneath the area studied is south-southeastward. All discharge of ground water occurs as upward leakage through the confining units. The three test wells drilled for this study are screened in the upper 50 ft of the Magothy aquifer; heads in the Magothy aquifer are slightly higher (0.1 to 0.5 ft) than heads in the upper glacial aquifer.

Because the Gardiners Clay, which separates the Magothy aquifer from the upper glacial aquifer, has low permeability and because flow through this unit is generally upward, contaminants will probably not move from the upper glacial aquifer into the lower units. Therefore, flow in the Magothy aquifer and the underlying Lloyd aquifer was not studied in this investigation. More detailed discussions of ground-water movement in the Magothy and Lloyd aquifers can be found in Warren and others (1968).

Surface Water

Two streams, Beaverdam Creek and Little Neck Run, lie within the area studied (fig. 5). Flow in both streams is derived primarily from ground-water seepage. Flow in Beaverdam Creek, the larger stream, begins between Sunrise and Montauk Highways. Average base flow at Montauk Highway is estimated to be 1.35 ft^3/s. The creek discharges to Bellport Bay, part of the Great South Bay (fig. 1).

Little Neck Run lies within the Wertheim National Wildlife Refuge (fig. 5). In recent years, its upper reach has become ponded behind a clogged culvert that carried flow beneath the Long Island Railroad right-of-way. Flow gradually resumes south of the railroad tracks. The stream is a tributary to the estuarine part of Carmans River.

Carmans River, one of the largest streams on Long Island, is approximately 5 mi east of the landfill site (fig. 1). Ground-water discharge to the stream is responsible for the eastward component of ground-water flow in the study area. Additional data on streamflow in Carmans River are presented in Warren and others (1968) and in annual water-data reports by the U.S. Geological Survey (1983 and preceding years).

DESCRIPTION OF BROOKHAVEN LANDFILL SITE AND SANITARY LANDFILL

The sanitary landfill lies within the southern half of the 180-acre Brookhaven landfill site; the remaining area contains a storage pile of excavated sand and gravel, maintenance facilities, and a parking area for impounded vehicles. The topography of the area before construction of the sanitary landfill is depicted in figure 2. The western side of the site is 70 to 80 ft above sea level, and the eastern side is 35 to 50 ft above sea level. South and east of the site, several swales contain standing water when ground-water levels are high.

The site is surrounded on all sides by mostly undeveloped land covered by pitch pine and scrub oak forest. Brookhaven hamlet (fig. 2) is approximately 0.9 mi southeast of the site. Additional descriptions of the surrounding area are presented in a report by Environmental Consultants, Inc. (1973).

Landfill Design and History of Operations

The sanitary landfill consists of a single refuse pile in which garbage is placed, compacted, and then covered daily with clean sand and gravel in accordance with sanitary landfilling procedures. The refuse consists mostly of paper, food wastes, glass, metal, plastic, and wood, but also includes bulk material such as construction debris, furniture, appliances, and tires. Dried sludge from nearby sewage-treatment plants and a scavenger-waste (cesspool) treatment facility operated by the Town has also been disposed of at the site. The sanitary landfill has the shape of a truncated pyramid; maximum elevation is 150 ft above sea level.

Landfilling operations began in March 1974 in the southeastern corner of the site and moved westward in stages. In each stage, a section of land approximately 300 ft wide was cleared, and overburden was removed to about 10 ft above the water table. A 2-ft layer of clean sand was placed in the excavation, and a polyvinyl-chloride (PVC) liner 0.02 inches (20 mil) thick was laid on it. The new section of liner was then glued to the edge of a previous section and covered by another 2 ft of sand.

The base and sides of the excavation are sloped to facilitate drainage of leachate to a collection system consisting of slotted PVC pipe placed within the upper sand layer. The collection system feeds into an outlet pipe that passes through the liner on the eastern side of the sanitary landfill. The ends of the liner continue up the sides of the excavation and are buried along the edges of the landfill. By 1983, 60 acres had been excavated and lined (shaded area in fig. 2), and plans call for an additional 25 acres to be lined with a double liner. A typical cross section through the site is shown in figure 6.

Leachate Formation

The chemical processes involved in leachate formation are complex and are discussed only briefly here; recent reports by Baedeker and Back (1979a, 1979b) and Nicholson and others (1983) provide more complete discussions of the geochemical aspects of leachate generation and chemical transformations within ground water.

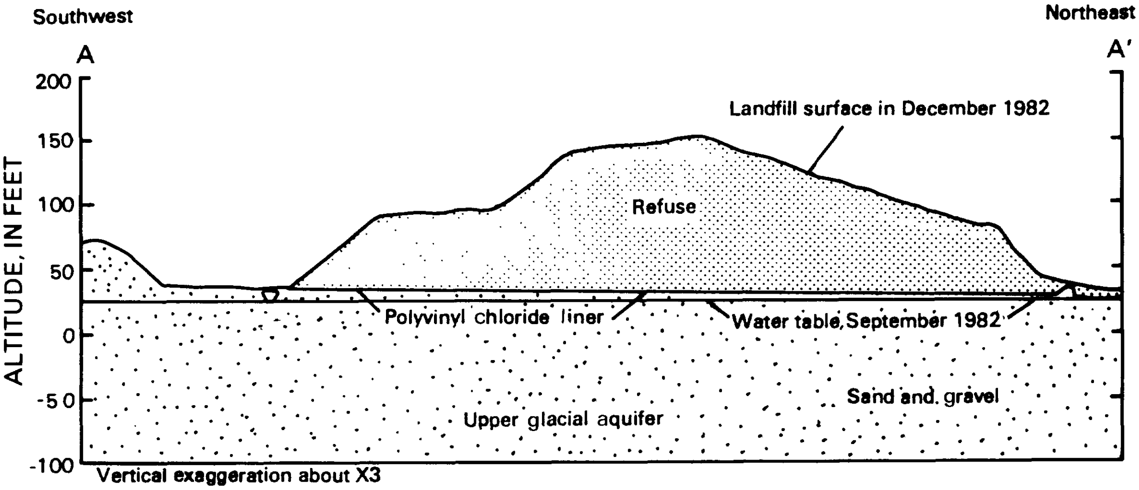


Figure 6.--Section A-A' through Brookhaven landfill site. (Location of section is shown in fig. 2.)

Dissolution

Leachate is the solution formed when precipitation percolates through a landfill and dissolves inorganic and organic constituents in the refuse. Most chloride and sulfate salts of sodium, potassium, calcium, and magnesium have high solubility and are leached directly from the refuse (Nicholson and others, 1983). The concentration of these ions depends on the nature of the waste deposited, the volume of water infiltrating the landfill, and the length of time the water is in contact with the waste (Schneider, 1970). Temperature, pH, and redox potential (Eh) of the leachate also control the rate of leaching of inorganic ions from the refuse.

Biological Degradation

Another major mechanism involved in leachate formation is biological decomposition of organic matter by microorganisms in the refuse. A list of representative oxidation-reduction (redox) reactions that occur during this process is given in table 2.

Aerobic conditions predominate in newly emplaced refuse and in the upper zone of the refuse pile, which is in contact with atmospheric oxygen. Aerobic decomposition of organic matter yields carbon dioxide and ammonium. Dissolution of CO_2 in water yields carbonic acid, which disassociates to produce bicarbonate (HCO_3^-); nitrification of ammonium produces nitrate (NO_3^-).

In most of the refuse pile, the rate of oxygen consumption exceeds the rate of oxygen transport into the waste, and anoxic conditions result. In this environment, facultative microorganisms decompose the organic material in the waste by the fermentation reactions shown in table 2. The reactions result in production of volatile organic acids, ammonia, hydrogen gas, and carbon dioxide.

The facultative microorganisms obtain energy through the reduction of either nitrate, manganese, iron, or sulfate. Reduction of iron and manganese, present in the refuse and as oxide coatings on sand grains used in cover material, yields the more soluble reduced species (Fe^{+2} and Mn^{+2}) of these metals.

Under highly reducing conditions, methanogenic bacteria will break down the volatile organic acids and produce methane gas (CH_4). Reduction of CO_2 also yields methane and consumes hydrogen gas. Methane gas is currently being recovered at the Brookhaven landfill site to generate electric power.

Table 2.--Representative oxidation-reduction reactions occurring in sanitary landfills.

[From Baedeker and Back, 1979b]

Aerobic respiration

$$\underset{\text{glucose}}{C_6H_{12}O_6} + 6O_2 \text{ --> } 6CO_2 + 6H_2O$$

$$\underset{\text{alanine}}{CH_3CH(NH_2)COOH} + O_2 \text{ --> } \underset{\text{acetic acid}}{CH_3COOH} + NH_3 + CO_2$$

Nitrification

$$NH_4^+ + 1.5\ O_2 \text{ --> } 2H^+ + H_2O + NO_2^-$$

$$NO_2 + 0.5\ O_2 \text{ --> } NO_3^-$$

Nitrate Reduction

$$6NO_3^- + 5CH_3OH \text{ --> } 3N_2 + 6OH^- + 7H_2O + 5CO_2$$

Manganese Reduction

$$2MnO_2 + 4H^+ + CH_2O \text{ --> } 2Mn^{2+} + 3H_2O + CO_2$$

Iron Reduction

$$4Fe(OH)_3 + 8H^+ + CH_2O \text{ --> } 4Fe^{2+} + 11H_2O + CO_2$$

Sulfate Reduction

$$SO_4^{-2} + H^+ + 2CH_2O \text{ --> } HS^- + 2CO_2 + 2H_2O$$

Fermentation

$$C_6H_{12}O_6 + 2H_2O \text{ --> } 2CH_3COOH + 2CO_2 + 4H_2$$

$$CH_3CH(NH_2)COOH + 2H_2O \text{ --> } NH_3 + CH_3COOH + CO_2 + 2H_2$$

Methane formation

$$CH_3COOH \text{ --> } CO_2 + CH_4$$

$$CO_2 + 4H_2 \text{ --> } CH_4 + 2H_2O$$

Chemical Composition of Leachate at the Brookhaven Landfill Site

A sample of leachate was withdrawn from the leachate-collection system in December 1982. Analytical results are presented in table 3, and a Stiff diagram (Stiff, 1951) of the sample is presented in figure 7. The leachate contains elevated concentrations of all major cations (sodium, potassium, calcium, and magnesium), and ammonium, iron, and manganese. Chloride and bicarbonate, as measured by total alkalinity, are the anions present in highest concentrations. Not all alkalinity in leachate is due to bicarbonate, although it is likely to be the most significant contributor; organic acids and other weak inorganic acids may also be present.

The concentration of sulfate was only 2 mg/L, even though the construction debris buried in the landfill would be expected to provide a large source of leachable sulfate. Reduction of leached sulfate to sulfide during oxidation of organic matter probably accounts for the low concentration of sulfate in the leachate sample. The concentration of reduced sulfur, however, was not measured.

The leachate sample was also analyzed for several trace constituents including arsenic and six metals. Concentrations of these constituents were well below drinking-water limits set by New York State. Data on organic constituents (priority pollutants) in a later sampling of leachate from the sanitary landfill are given in Pearsall and Wexler (1986).

The chemical composition of leachate, as represented by the December 1982 sample, is not likely to remain constant over time because rates of recharge vary seasonally and from year to year, and new refuse is continually being deposited on top of older material that has already undergone varying rates of leaching and biodegradation. The chemical composition of leachate may also vary from place to place within the landfill because of the heterogeneous composition and age of the refuse. The quality of ground water contaminated by leachate will reflect both the spatial and temporal variability of the contaminant source.

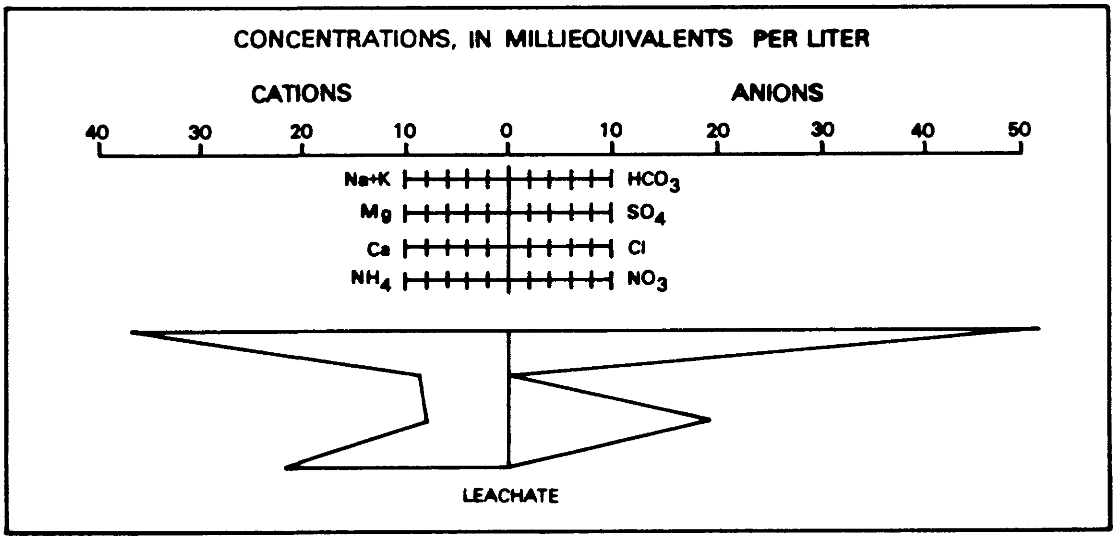


Figure 7.--Stiff diagram of a leachate sample from the sanitary landfill, December 6, 1982.

Table 3.--Chemical analysis of a leachate sample from the sanitary landfill, December 6, 1982

[Analyses by New York Testing, Inc., Westbury, N.Y.; all concentrations are in milligrams per liter except where noted]

Constituent or characteristic	Concentration
pH (units)	7.0
Specific conductance (μS/cm at 20°C)	5,010
Total dissolved solids	2,600
Total alkalinity (as HCO_3)	3,130
Sodium, dissolved	590
Potassium, dissolved	450
Calcium, dissolved	160
Magnesium, dissolved	100
Chloride, dissolved	690
Sulfate, dissolved	2
Ammonium, total (as N)	307
Nitrite, total (as N)	0.03
Nitrate, total (as N)	<0.04
Total kjeldahl nitrogen (as N)	365
Iron, dissolved	26.05
Manganese, dissolved	0.24
Arsenic, dissolved	0.004
Aluminum, dissolved	<0.100
Chromium, hexavalent, dissolved	<0.005
Copper, dissolved	0.084
Lead, dissolved	<0.025
Selenium, dissolved	<0.001
Zinc, dissolved	0.046

Rates of Leachate Generation

Because the surface of the sanitary landfill is not yet capped or covered with vegetation, precipitation can readily infiltrate the landfill. Some of the recharge is absorbed by the refuse or seeps out the sides of the landfill, but most seems to be percolating through the refuse and collecting above the impermeable liner.

Beginning in September 1976, leachate was withdrawn through the collection system in the sand layer above the liner, aerated in a lined lagoon, and then sprayed over the top of the landfill. This practice was continued intermittently until November 1979. Storage of leachate above the impermeable liner continued until August 1982, when the Town began to remove the leachate to an offsite treatment facility. Approximately 375,000 gallons of leachate per week were being removed after August 1982.

The volume of water infiltrating into the sanitary landfill is unknown. Dvirka and Bartilucci (1981) assumed that the increase in recharge that should result from the disturbed soil and lack of vegetation on the landfill is offset by runoff from the steep slopes of the landfill. From the estimated rate of recharge to the surrounding area (24.6 in/yr) and a landfill area of 60 acres, the volume of recharge is estimated to be 770,000 gal/week. The depth of ponded leachate above the liner was measured by the U.S. Geological Survey for 1 year after removal of leachate began and showed no significant long-term decrease. This would indicate that the average rate of leachate generation is at least equal to the 375,000 gallons per week that is removed but must be greater to account for discharge of leachate to the upper glacial aquifer.

Leachate Entry into the Upper Glacial Aquifer

Several mechanisms may be responsible for the entry of leachate into the upper glacial aquifer. The first is leakage through holes in the liner or along incompletely sealed seams between liner sections. Neither the distribution of the leaks nor the volume of leachate flowing through the leaks are known. The volume of flow would depend on several factors, including the size of the leaks, the amount of leachate ponded above the liner, the permeability of the underlying soil, and the rate at which the soil becomes clogged by suspended particles in the leachate.

A second mechanism, referred to as the "bathtub effect" (Cartwright, 1984), occurs when leachate fills the basin formed by the impermeable liner and spills over the sides. Overflow would occur only along the eastern edge of the sanitary landfill, where land-surface altitude is lowest (fig. 6). Because the edge of the liner is buried, the overflow is not visible at land surface. In August 1982, a manometer was placed on the outlet pipe of the leachate-collection system. The manometer showed the fluid level in the landfill to be 38 ft above sea level, which indicates about 8 ft of saturated refuse above the base of the liner (which is about 30 ft above sea level). According to construction drawings, the total depth of the lined basin is about 8 ft; therefore a leachate overflow is likely to have occurred.

A third mechanism is infiltration of landfill runoff that has mixed with leachate emerging from seeps along the sides of the landfill. The runoff has been observed to collect along the eastern boundary of the landfill site. The effects of runoff on water quality are minor compared to overflow and leakage, however.

WATER-SAMPLE COLLECTION AND ANALYSIS

Ground-water samples were collected for laboratory analysis from late October through early December 1982 to distinguish between native water and water affected by leachate or other contaminants and to delineate the extent of leachate contamination. During this period, samples were collected from 72 wells screened in the upper glacial aquifer and two wells screened in the underlying Magothy aquifer. A surface-water sample from Beaverdam Creek was also collected during the sampling period. Physical descriptions of all wells sampled are given in table 4 (at end of report); locations of the wells and surface-water site are shown on plate 1.

Wells in the upper glacial aquifer include 33 monitoring wells installed by the Town of Brookhaven, 35 observation wells drilled by the U.S. Geological Survey, and 4 fire wells in Brookhaven hamlet. These wells were divided into six groups according to the depth of the center of the screen below the water table. Letter codes from A through F were used to designate the various depths and are explained in table 4 (at end of report). The groups containing the greatest number of wells are B (8 to 20 ft below water table), C (20 to 40 ft below water table), and D (40 to 70 ft below water table). The letter code M is used to designate wells screened in the Magothy aquifer.

In April 1983, 16 of the 72 wells in the upper glacial aquifer were resampled to verify the results of the previous testing and to determine whether ground-water quality had changed over the relatively short time interval. Procedures followed in sample collection and analytical results from the two sampling periods are discussed below.

Sampling Procedures

It was impossible to adopt a single standardized sampling procedure because of the diverse physical characteristics of the wells and differences in depth to the water table from land surface. The procedures generally followed were as follows:

(1) 2-inch-diameter wells with a depth of 25 ft or more to water were evacuated with a 1.75-inch-diameter submersible pump. Where the depth to water was less than 25 ft, these wells were evacuated either by the submersible pump or by a pitcher pump. In either case, the sample was extracted by the submersible pump because it has a positive displacement, which minimizes mixing of the sample with air.

(2) The 21 four-inch-diameter wells installed by the Town along the boundary of the landfill site (wells S73750-S73770) were evacuated with a 4-inch-diameter submersible pump, and samples were drawn with the 1.75-inch-diameter submersible pump.

(3) The four fire wells (wells S72149-S72152) and five wells of less than 2-inch diameter (wells S73943-S73948) could not be sampled by the submersible pump and were therefore evacuated and sampled with a centrifugal pump.

All wells were pumped until at least three times the volume of standing water in the casing was evacuated to ensure that water sampled reflected the quality of water in the aquifer. Specific conductance and temperature were monitored at most wells during the evacuation procedure and were found to stabilize after the removal of two to three casing volumes.

Laboratory Analyses and Quality Control

The ground-water, surface-water, and leachate samples collected in October-December 1982 and April 1983 were analyzed by New York Testing, Inc. of Westbury, N.Y., for: (1) pH, specific conductance, total alkalinity, and total dissolved solids (TDS); (2) five major ground-water constituents--

calcium, chloride, magnesium, sodium, and sulfate (SO_4^{-2}); (3) three minor constituents--potassium, iron, and manganese; and (4) the nitrogen series--ammonium, nitrate, nitrite, and kjeldahl nitrogen. (Total kjeldahl nitrogen, TKN, is the sum of organic nitrogen and ammonium ion concentrations.) Temperature, pH, and specific conductance were measured in the field by the U.S. Geological Survey.

New York Testing, Inc. participates in the Standard Reference Water Sample Program, a quality-assurance program instituted by the U.S. Geological Survey. In addition, 13 duplicate samples were collected during the October-December 1982 sampling and sent to the U.S. Geological Survey Laboratory in Atlanta, Ga., for verification. Analytical results from the two laboratories compared favorably.

Sample Preservation

Samples analyzed for dissolved metals by New York Testing, Inc. were vacuum filtered in the field through an 0.45-μ filter and then acidified with nitric acid. Nitrogen-series samples were unfiltered and preserved with sulfuric acid. Samples that were analyzed for dissolved metals by the U.S. Geological Survey Laboratory were filtered in the field and preserved with nitric acid. Nitrogen-series samples were unfiltered, preserved with mercuric chloride, and chilled.

Samples collected for all remaining analyses were not filtered in the field, and no preservatives were added. Analyses for pH, total alkalinity, and specific conductance were made by New York Testing, Inc. upon receipt of samples to minimize changes in these properties over time.

GROUND-WATER QUALITY IN THE BROOKHAVEN LANDFILL-SITE VICINITY

Analytical results for the October-December 1982 and April 1983 sampling periods are presented in tables 5 and 6 (at end of report). Chemical properties of the ground-water samples varied over considerable ranges. Four of the 74 samples exceeded New York State drinking-water standards of 250 mg/L of chloride, nine exceeded the standard of 500 mg/L of total dissolved solids (TDS), and 52 exceeded the limit of 0.5 mg/L for the combined concentration of iron and manganese.

The highest values for specific conductance and concentrations of alkalinity, TDS, sodium, potassium, chloride, ammonium, and total kjeldahl nitrogen (TKN) in October-December 1982 were in samples from wells S73750 and S72817, 180 and 580 ft east of the sanitary landfill, respectively (well locations shown in pl. 1). Maximum concentrations of calcium and magnesium were in well S73759, 200 ft south of the landfill.

A maximum nitrate value of 3.18 mg/L was in well S73752, a deeper well in the same cluster as S73750, 180 ft east of the landfill, and a maximum sulfate concentration of 41 mg/L was in well S44575, a shallow well 450 ft south of the landfill.

Maximum concentrations of most chemical constituents were observed in the April 1983 sample from well S73750, which contained 291 mg/L ammonium, 660 mg/L chloride, and 2,540 mg/L total alkalinity as HCO_3. The specific conductance of the sample was 5,500 µS/cm (microsiemens per centimeter)[1]. These values are almost double those observed in the November 1982 sampling. The high concentrations for most physical and chemical properties for the April samples from wells S72817 and S73759 did not change significantly from those in the earlier sampling.

Some wells showed significant improvement in water quality between the sampling periods. For example, the November 1982 sample from well S73760, 250 ft south of the landfill, had a specific conductance of 2,150 µS/cm and an ammonium concentration of 140 mg/L, whereas the April 1983 sample had a specific conductance of 675 µS/cm and an ammonium concentration of only 0.6 mg/L.

The October-December 1982 analytical results were used to divide the water-quality data into the three general categories: (1) data reflecting native ground water; (2) data reflecting ground water affected by contamination associated with land use other than landfill operations; and (3) data reflecting ground water contaminated by leachate.

Native Ground Water

Under natural (undisturbed) conditions, the chemical quality of ground water reflects both the chemical composition of precipitation and the composition and solubility of material in the soil zone and aquifer. Native water in the upper glacial aquifer generally is soft (low Ca^{+2} and Mg^{+2} concentrations), slightly acidic, and is low in dissolved-solids concentration. Of the wells sampled, 16 had total dissolved solids of 50 mg/L or less. Stiff diagrams for six samples typical of native water quality are presented in figure 8A.

The dominant cations in the native ground water are Na^+, Ca^{+2}, and Mg^{+2}. The cations are byproducts of the slow weathering of alumino-silicate minerals in the aquifer matrix (Freeze and Cherry, 1979). Salty spray from the nearby bay and ocean mixes with precipitation along the south shore and contributes additional amounts of these cations to the ground water (Cohen and others, 1968).

The principal anions in native water are chloride and sulfate. Chloride ion is derived primarily from the salt content of precipitation. Natural levels of chloride in Suffolk County ground water average 10 mg/L (Soren, 1977). Sulfate is often the dominant ion in precipitation away from the nearshore environment (Cohen and others, 1968).

Other ions that may be found in small amounts in native ground water are bicarbonate, nitrate, iron, and manganese. Bicarbonate ion is formed by the disassociation of carbonic acid (H_2CO_3). Carbonic acid is produced by dissolution of atmospheric carbon dioxide gas in precipitation and by aerobic decomposition of organic material in the soil.

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[1] Formerly termed micromhos per centimeter.

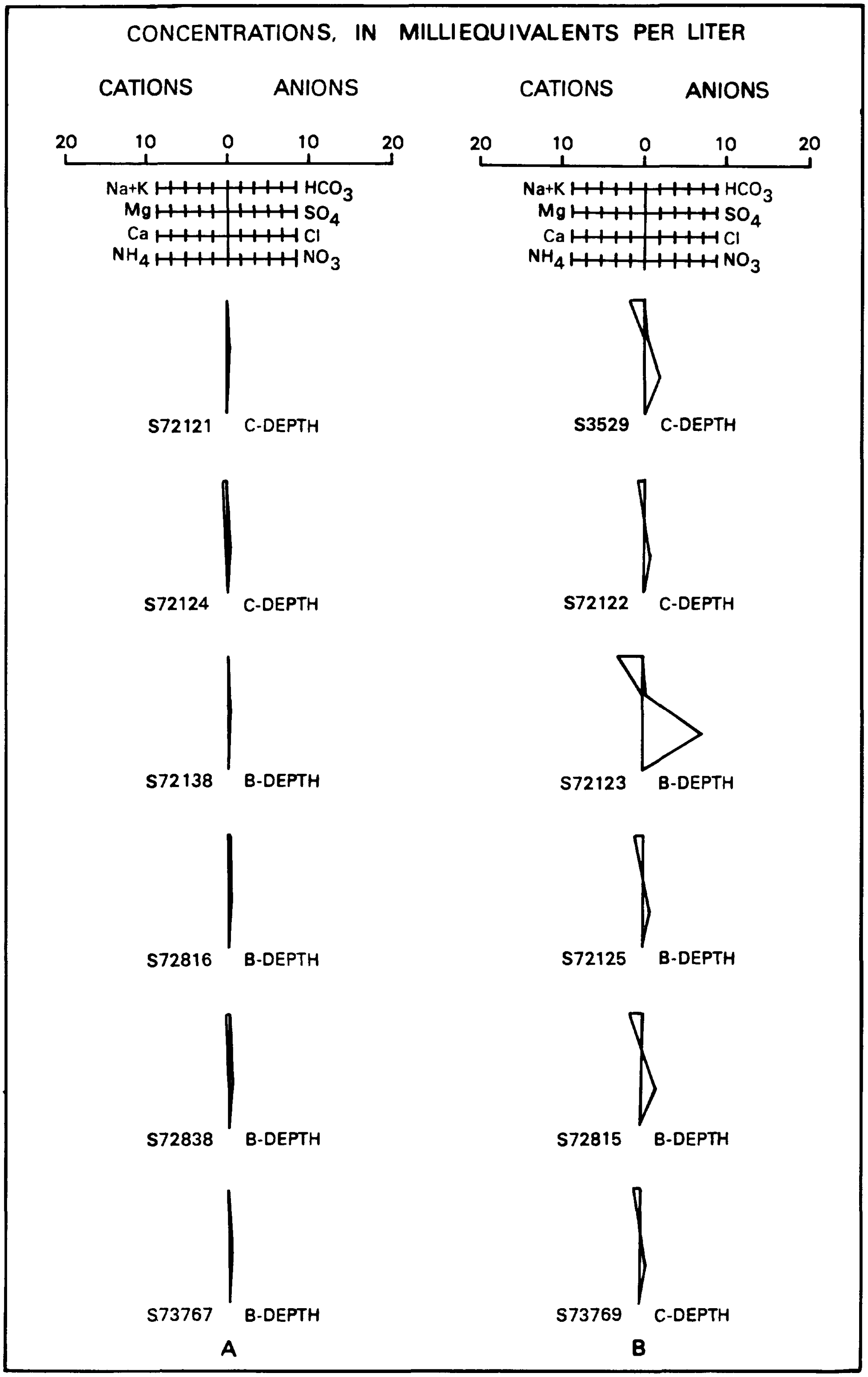


Figure 8.--Stiff diagrams of ground-water samples collected October-November 1982. A. Samples representing native water quality. B. Samples contaminated by road salt. (Well locations shown in pl. 1, depth codes are explained in table 4, at end of report.)

Under natural conditions, organic (amino) nitrogen in decaying vegetation is converted to ammonia in a process called ammonification (Freeze and Cherry, 1979). Ammonium is then converted to nitrate by nitrifying bacteria in the unsaturated zone. The mean level of ammonium in shallow wells in Suffolk County was 0.05 mg/L as N; nitrate concentrations in undeveloped areas of the county ranged from 0.0 to 0.5 mg/L as N (Soren, 1977).

Dissolved iron and manganese concentrations in excess of recommended limits set by New York State are commonly found in ground water along the south shore of Long Island. Of the 16 wells sampled that had a total dissolved-solids concentration of 50 mg/L or less, five exceeded recommended limits for iron and manganese, which indicates that native water in the vicinity of the Brookhaven landfill site is affected by this problem.

Ground Water Affected by Land Uses Other Than Landfill Operations

Samples from several wells near the Brookhaven landfill site are affected by contamination associated with the use of salt for highway deicing. Stiff diagrams for samples from six wells in areas affected by road salt are presented in figure 8B. Wells S3529 and S72123, which show the highest sodium and chloride concentrations, are downgradient of shallow stormwater basins at the intersection of Woodside Avenue and Horseblock Road (pl. 1). Wells S72122, S72815, and S73769 are downgradient of the two deeper stormwater basins along Woodside Avenue. The other well, S72125, is affected, but to a lesser degree, by infiltration of runoff along Sunrise Highway. The slightly elevated calcium concentrations at these wells may be due to calcium chloride in the road-salt mixture or to the release of calcium off ion-exchange sites in the aquifer.

Degradation of ground-water quality on Long Island also has been caused by domestic sewage-disposal systems, which introduce chloride, nitrate, bacteria, viruses, detergents, and other contaminants into the ground water (Pluhowski and Kantrowitz, 1964). Samples collected from fire wells in the northern part of Brookhaven hamlet (wells S72151 and S72152) show slightly elevated levels of bicarbonate but no significant increase in chlorides or nitrates. Domestic wells further south within the hamlet were tested by the Suffolk County Department of Health Services and showed elevated levels of these constituents (Sy F. Robbins, Suffolk County Department of Health Services, written commun., 1982). Kimmel and Braids (1980) note the difficulty in distinguishing ground water contaminated by dilute leachate from that contaminated by domestic waste.

Water Quality at the Southeastern Boundary of Brookhaven Landfill Site

Analytical data from monitoring wells along the southern and eastern borders of the landfill site (wells S73750 through S73765) indicate leachate contamination and suggest that both leakage through the liner and overflow along the eastern edge are occurring. Samples from all wells except S73751 and S73752 had elevated pH, total alkalinity, specific conductance, TDS, sodium, potassium, calcium, magnesium, ammonium, TKN, chloride, and dissolved iron. Sulfate and nitrate concentrations generally were below background levels. Water from these wells had a noticeable odor and contained gases that rapidly exsolved. Samples were pale yellow when first withdrawn but turned orange after exposure to air as a result of oxidation and precipitation of iron. The ground-water samples foamed when agitated, suggesting the possible presence of detergents or other surfactants in the water.

Stiff diagrams for all these samples are presented in figure 9. The diagrams for wells S73750, S73753, S73754, and S73755 (along the eastern boundary of the site) show patterns similar to that of the leachate sample (fig. 7). The elevated concentrations and the general similarity among Stiff diagrams indicate that a concentrated source of leachate--probably leachate overflow--is affecting these wells. The wells may also be affected to a much lesser degree by leachate that seeped out the sides of the landfill and mixed with runoff. Runoff was observed to pond near these wells and near well S44581 (pl. 1).

Samples from wells S73751 and S73752 differ substantially from samples from other wells along the eastern boundary. Well S73751 has been affected by road salt but shows no evidence of leachate contamination, despite the fact that the upper well in the cluster, S73750, has been contaminated to a greater degree than any other well on the site. The sample from well S73752 had elevated calcium, magnesium, and bicarbonate concentrations but also had elevated nitrate and sulfate concentrations, which indicates that this sample, unlike the others, was from an oxidizing rather than a reducing environment. A gamma-ray log shows a 5- to 8-ft-thick layer of fine-grained material at a depth of 30 to 38 ft below land surface (just below the screened zone at well S73750), which probably prevents the downward movement of leachate. A thinner layer of fine-grained material is above the screened zone at well S73752. The lateral extent of these layers is unknown, but they were not observed in logs for wells S72812 and S72813 (locations shown in pl. 1).

All wells along the southern boundary of the site (wells 73756-73765) show evidence of leachate contamination. Ammonium was present in most of the samples, but calcium rather than ammonium was the dominant cation in many. Calcium chloride used during the summer for dust control along the road surrounding the sanitary landfill may contribute calcium, but leachate is still the primary source of this constituent. Bicarbonate, as measured by total alkalinity, was the dominant anion in all samples.

The fact that all wells along the southern side are affected by leachate, even those near relatively new sections of the landfill, implies that leachate is entering the ground water either through many small holes in the liner, thus creating a diffuse source, or through leaks that develop along the seams of the liner, creating a series of linear sources. Local variations in water quality may result from differences in rates of leakage and in chemical composition of leachate at points of leakage.

Specific-conductance data have commonly been used to map leachate plumes (Kimmel and Braids, 1980; Hutchinson and Stewart, 1978). Ground water contaminated by leachate has a high specific conductance resulting from elevated concentrations of dissolved ionic species. Contaminated ground water near the Brookhaven landfill site can easily be distinguished from native ground water, which generally has a specific conductance below 100 µS/cm.

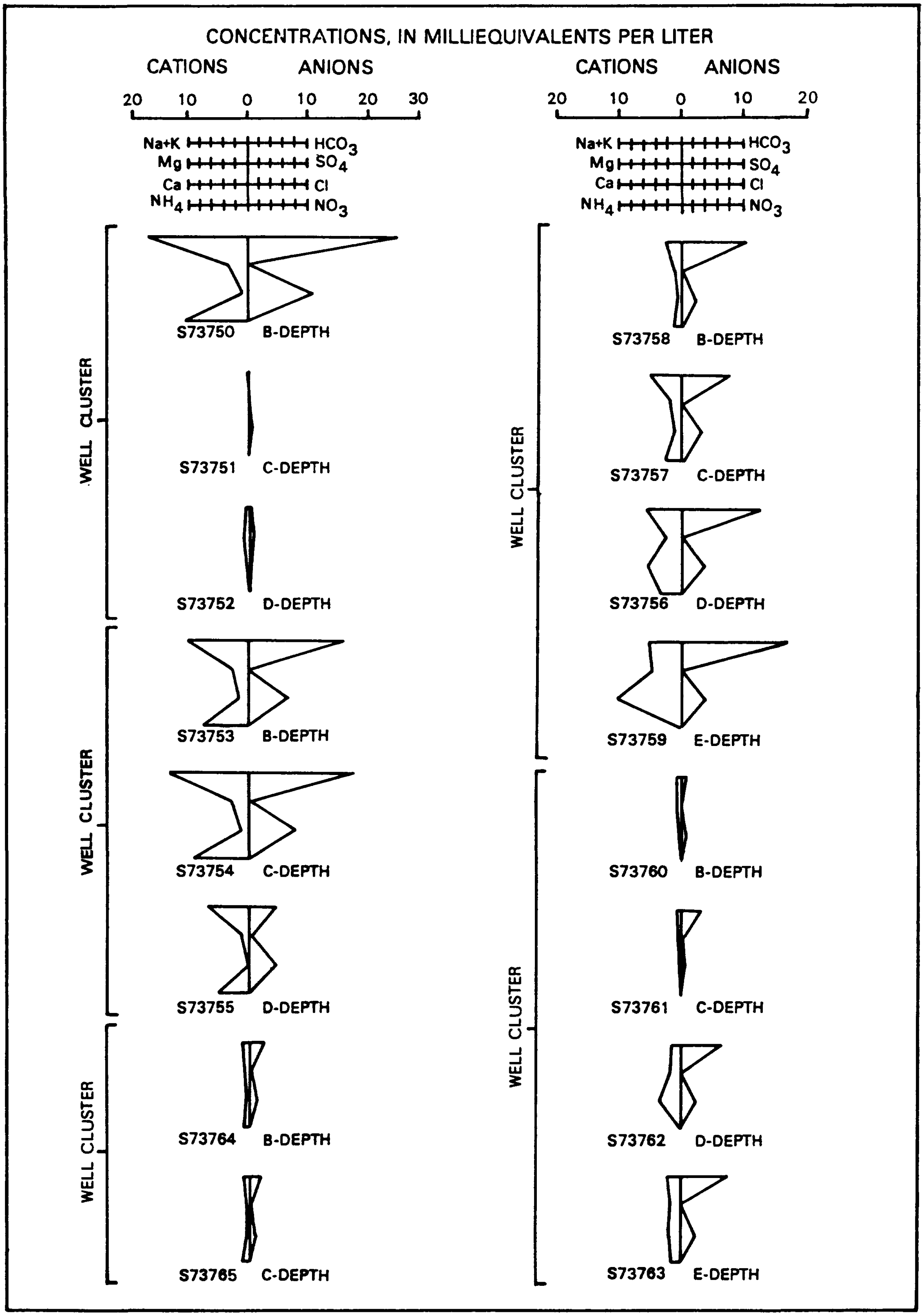
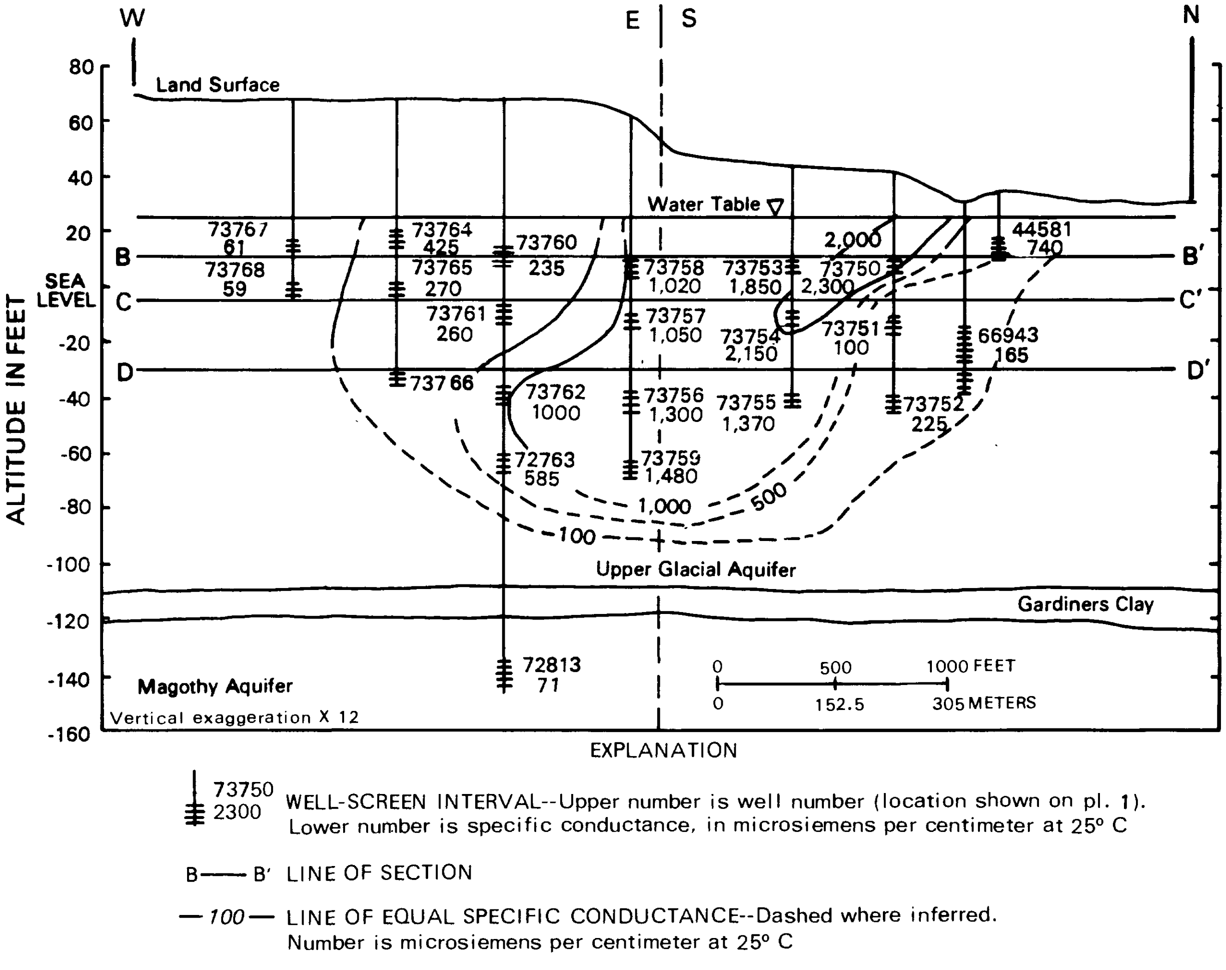


Figure 9.--Stiff diagrams of samples from wells along southeast boundary of Brookhaven landfill site, October-November 1982. (Well locations shown on pl. 1; depth codes are explained in table 4.)

The vertical extent of leachate-contaminated ground water is clearly defined by specific-conductance data from clusters of monitoring wells along the southeastern boundary of the site. A vertical section through these wells showing lines of equal specific-conductance values is given in figure 10.

Elevated specific conductance values extend from shallow depths to 90 ft below the water table. Two deep wells (S73759 and S73763, on the southern boundary of the site) have the highest conductance values in their respective clusters, which indicates that leachate has moved at least 90 ft vertically downward within 200 ft of the sanitary landfill. Possible driving forces for the vertical movement of leachate may be (1) vertical gradients associated with water-table mounding below points of leakage through the liner; (2) transient vertical gradients resulting from recharge events; and (3) density differences between leachate-contaminated water and native ground water. Determination of the extent to which each of these mechanisms contributes to vertical displacement of leachate was beyond the scope of this investigation.



EXPLANATION

73750
2300
WELL-SCREEN INTERVAL--Upper number is well number (location shown on pl. 1). Lower number is specific conductance, in microsiemens per centimeter at 25° C

B —— B' LINE OF SECTION

—*100*— LINE OF EQUAL SPECIFIC CONDUCTANCE--Dashed where inferred. Number is microsiemens per centimeter at 25° C

Figure 10.--Vertical section along southern and eastern boundaries of Brookhaven landfill site showing lines of equal specific conductance, October-November 1982. (Locations of section lines shown in figs. 12, 13, 14.)

Downward movement of leachate has been observed at other (unlined) sanitary landfill sites. Possible causes of vertical movement of leachate at the Babylon, N.Y., and Borden, Ontario, landfills are discussed by Kimmel and Braids (1980) and MacFarlane and others (1983), respectively.

The two deep wells (S73759 and S73763) are screened about 20 ft above the silty fine sand zone at the base of the upper glacial aquifer. The depth to which the contamination has moved beneath these wells is unknown, but the leachate would probably not move far into the silty zone because of its low permeability. Well S72813, also on the southern boundary of the site, is screened in the Magothy aquifer about 25 ft below the Gardiners Clay and shows no evidence of contamination.

Water Quality Downgradient From the Brookhaven Landfill Site

Samples from wells downgradient of the Brookhaven landfill site indicate that leachate-contaminated ground water has migrated beyond the site boundaries. Stiff diagrams for samples from several of the downgradient wells are presented in figure 11. Patterns in these diagrams are similar to those of the leachate sample (fig. 7) and wells at the site (fig. 9).

The highest concentrations of leachate contaminants were in the sample from well S72817, 400 ft east of the site. The sample farthest from the site that showed significant concentrations of ammonium (23.1 mg/L as N) was from well S72824, 1,300 ft southeast of the site. Elevated chloride, bicarbonate, calcium, and magnesium concentrations were detected as far as 3,500 ft southeast of the site in wells S72132, S73955, and S72150. Increasing nitrate concentrations (although less than 3.0 mg/L as N) were detected in samples from downgradient wells S72817, S72825, S73946, S73954,and S73955 (locations shown in pl. 1); these are probably the result of nitrification of ammonium.

Horizontal Extent of Leachate Plume

Specific-conductance data from monitoring wells downgradient of the landfill site were used to delineate the horizontal extent of the contaminant plume. The extent of contaminated ground water as defined by the 100-μS/cm contour varies with depth, as can be seen in the specific-conductance contours for B-, C-, and D-depth wells in figures 12, 13, and 14. The maximum leachate plume migration is within the C depth, in which the plume extends 3,700 ft downgradient from the southeastern corner of the site. The width of the plume, perpendicular to the direction of flow, measures 2,400 ft at the site corner. A slight widening of the plume beyond Sunrise Highway may be the result of road salting.

Vertical Extent of Leachate Plume

Few data are available on the vertical distribution of contaminants downgradient from the landfill, primarily because the observation-well network has only a limited depth distribution. Most of the wells in the landfill vicinity were initially installed for water-level observation and were screened 15 ft below the water table. Later, well clusters were drilled where

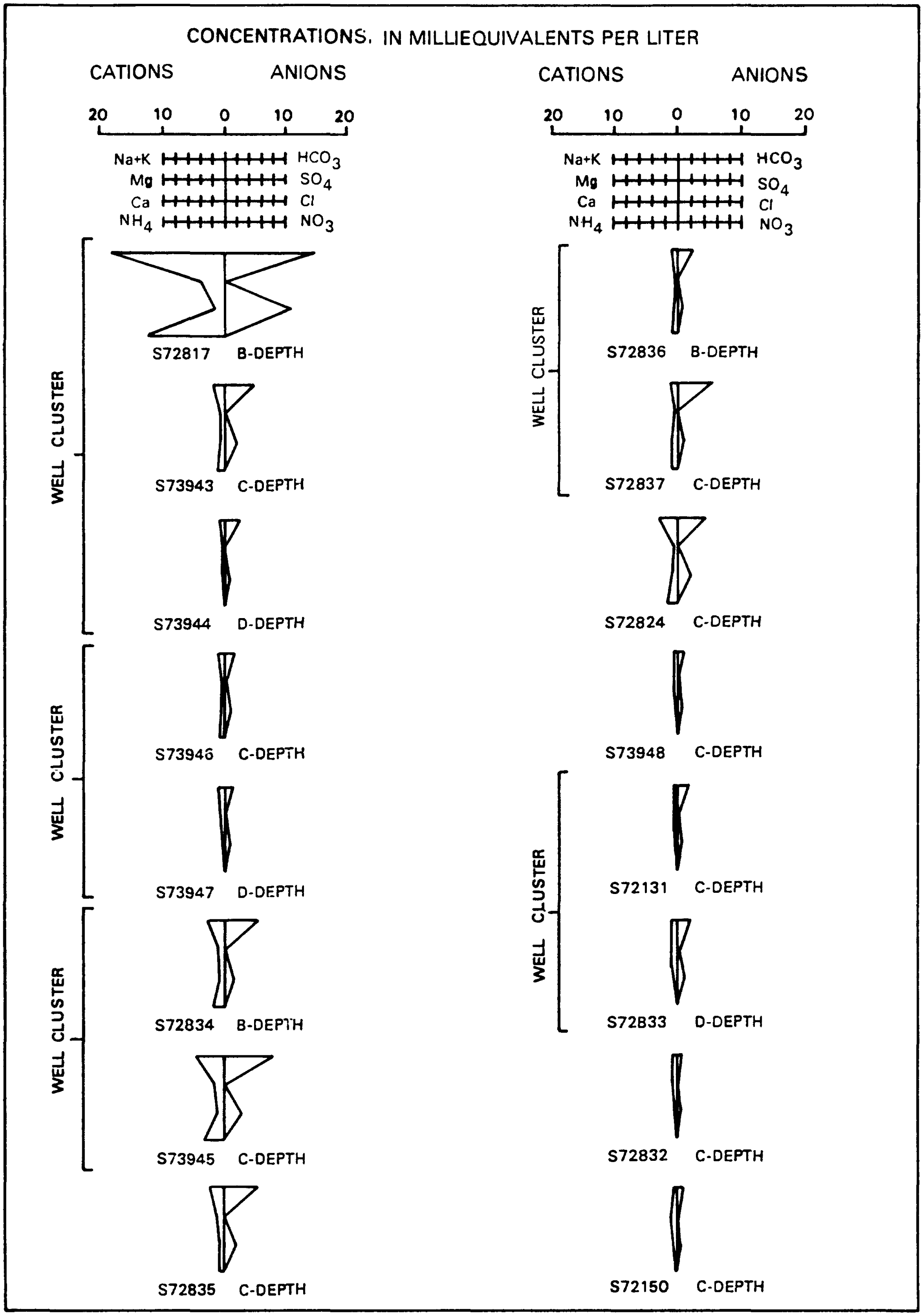
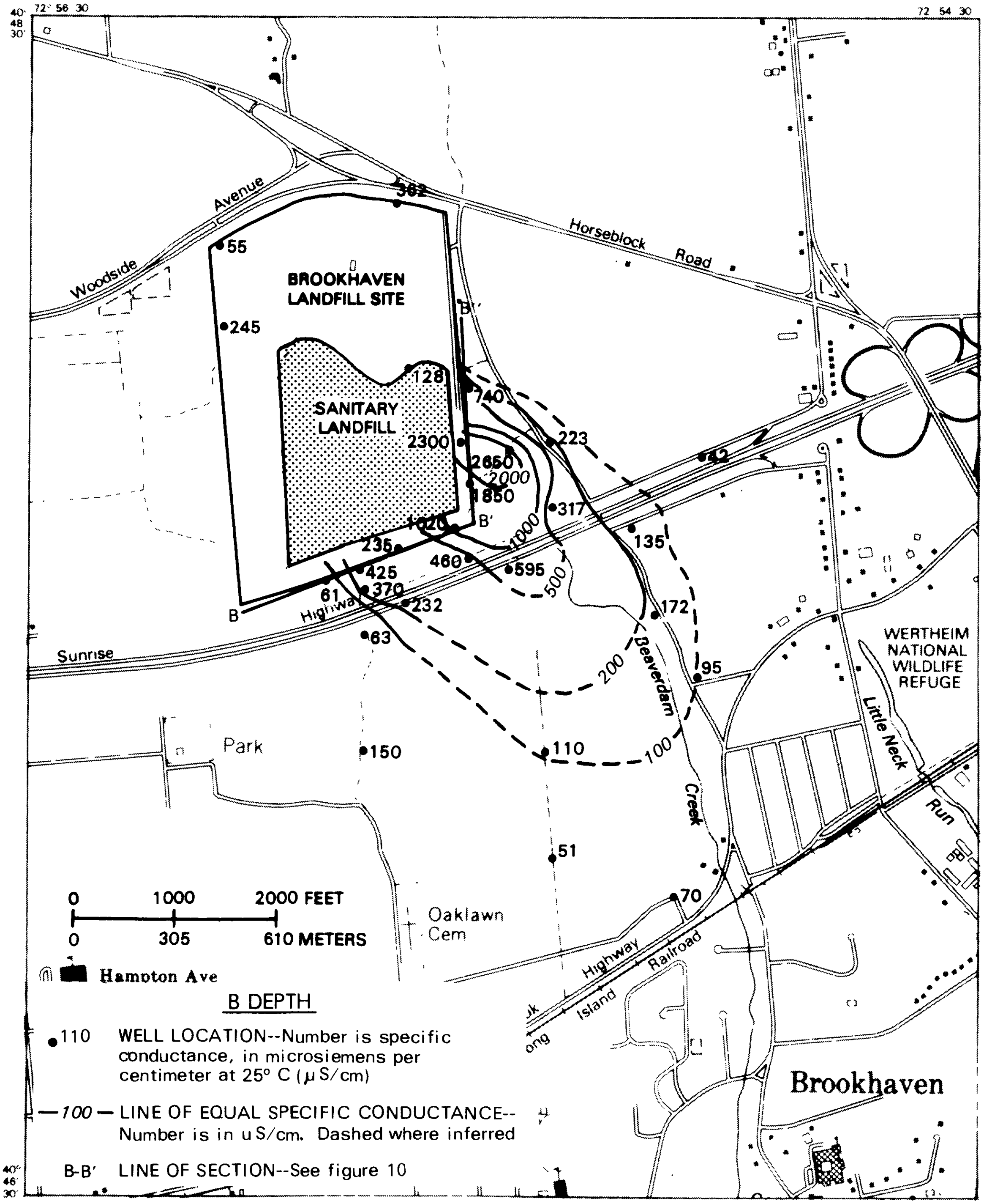


Figure 11.--Stiff diagrams of samples collected from 16 wells downgradient from the landfill site, October-November 1982. (Well locations shown in pl. 1; depth codes explained in table 4.)



Base from NYSDOT, Bellport, NY, 1981, 1:24,000

Figure 12.--Lines of equal specific conductance as indicated by samples from wells screened 8 to 20 ft below water table (B depth), October-December 1982.

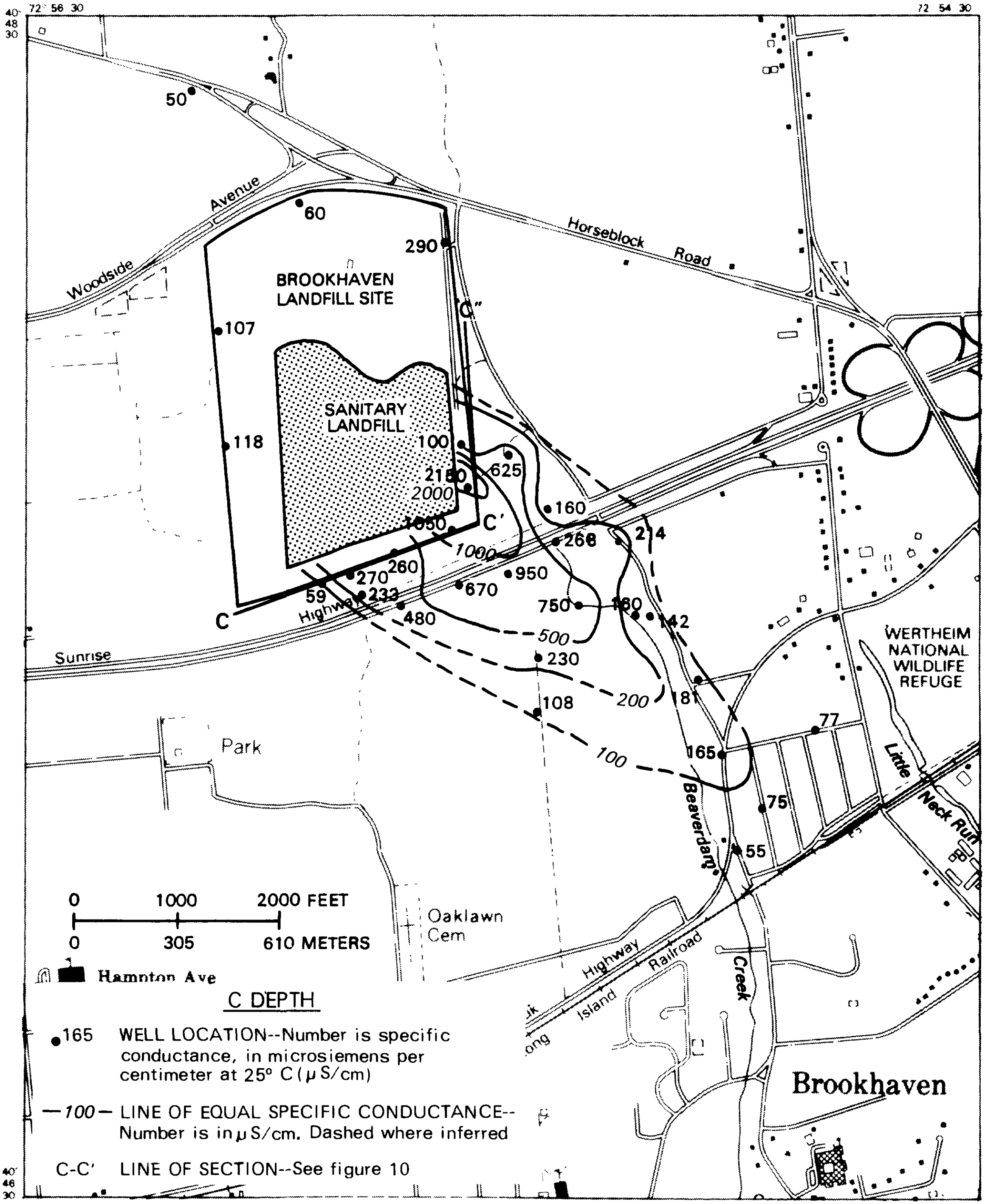


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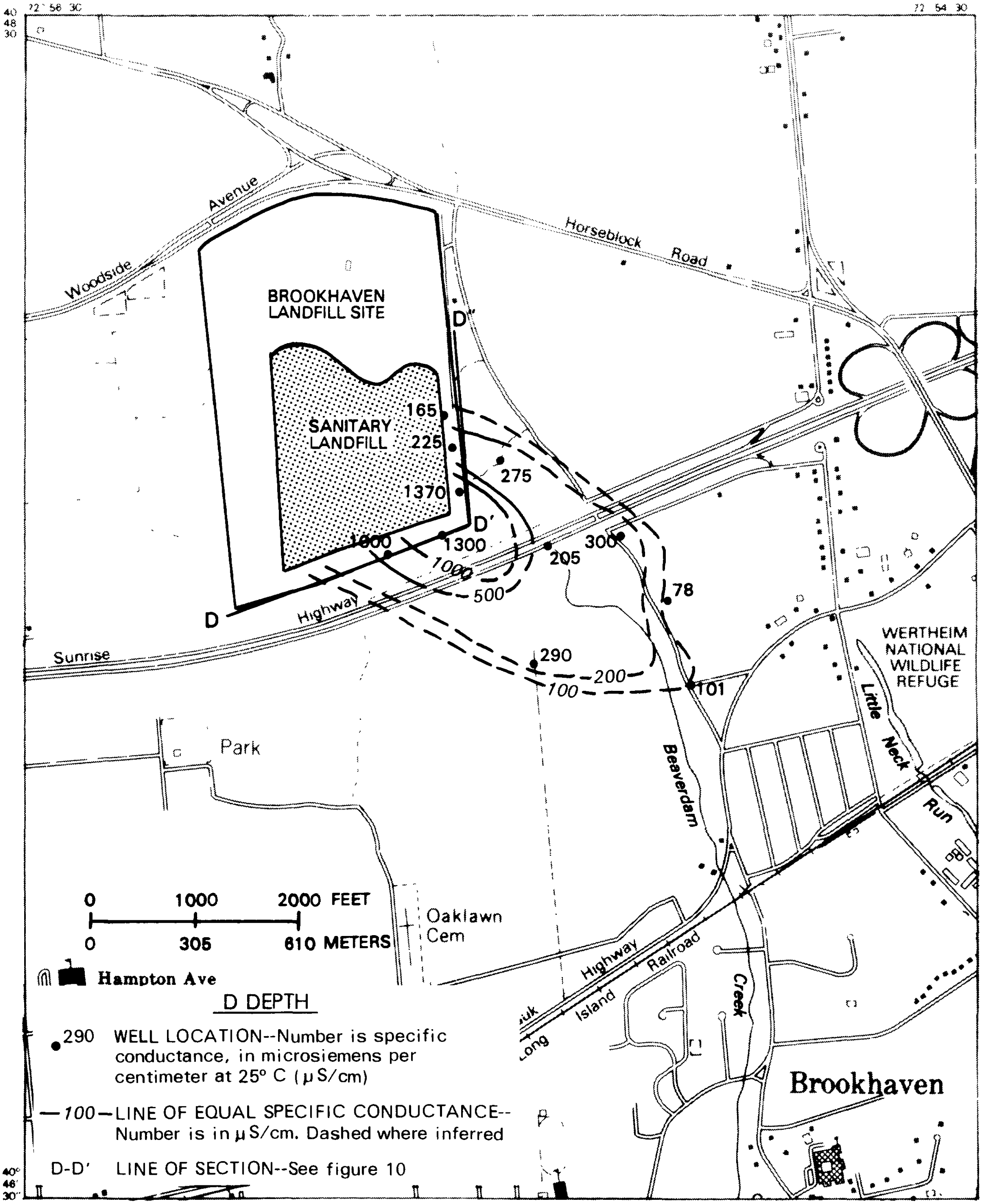
Figure 13.--Lines of equal specific conductance as indicated by samples from wells screened 20 to 40 ft below water table (C depth), October-December 1982.



Base from NYSDOT, Bellport, 1981, 1:24,000

Figure 14.--Lines of equal specific conductance as indicated by samples from wells screened 40 to 70 ft below water table (D depth), October-December 1982.

access was possible in the forested area southeast of the landfill to evaluate the vertical extent of the leachate plume. However, the number of clusters and the depth of penetration into the aquifer are limited. Extension of the monitoring network to provide more complete data on the configuration of the plume downgradient of the site has been planned as part of a continuation of this study.

In general, contaminants spread vertically in an aquifer as the plume moves downgradient. Vertical mixing is not rapid, however, and concentrations downgradient from the Brookhaven landfill site vary considerably with depth. The plume has also been overlain by water from precipitation. A sample from Beaverdam Creek was not affected by leachate contamination, which indicates that the shallow upper zone of ground water that discharges to the upper reach of the stream is uncontaminated.

Areal Distribution of Selected Chemical Species

Sodium and Chloride

Chloride and sodium concentrations measured in the C-depth wells (20 to 40 ft below water table) in October-December 1982 (see fig. 16, p. 34) follow a pattern similar to that of specific conductance (fig. 13). Chloride is generally considered a conservative solute; that is, its concentration in solution is not affected by chemical processes. However, contamination from secondary sources of chloride, such as road salt and septic systems, affect its utility as a tracer for leachate contamination.

Sodium concentrations closely correlate with chloride values (correlation coefficient of 0.99) in samples from wells that tap the leachate plume. A plot of the ratio of sodium to chloride with respect to distance downgradient from the landfill is presented in figure 15A. Although the data show scatter, the line of best fit has a zero slope, which suggests that sodium and chloride behave similarly. Similar results were found by Kimmel and Braids (1980) and LeBlanc (1984). Sodium is probably not subject to ion exchange because other cations in leachate (NH_4^+, Ca^{+2}, Mg^{+2}, and K^+) are adsorbed preferentially.

Bicarbonate

Bicarbonate concentrations at the C depth (20 to 40 ft below the water table) in October-December 1982 as measured by total alkalinity are plotted in figure 17. The zone of elevated bicarbonate concentrations is similar to that delineated by elevated conductance values. Bicarbonate and chloride concentrations did not correlate as well as sodium and chloride (correlation coefficient of 0.86). A plot of the ratio of bicarbonate concentration to chloride concentration with respect to distance downgradient from the landfill (fig. 15B) shows that bicarbonate concentrations generally decrease with distance.

Bicarbonate concentrations are affected by chemical reactions that alter pH of ground water. Oxidation of ammonium ion and sulfide, and reduced forms of iron and manganese lowers the pH and thus, the bicarbonate concentration.

Mixing with native water of lower pH would tend to reduce bicarbonate concentration along the edge of the plume. Outgassing of CO_2 would tend to raise the pH of the contaminated ground water but does not affect the total alkalinity.

Decomposition of weak organic acids that are included in the determination of total alkalinity may be another factor in the decrease in bicarbonate concentration within a short distance of the landfill. Alkalinity determinations may also be subject to analytical error because of changes in pH due to redox reactions during collection and transport of the samples.

Ammonium and Nitrate

Ammonium and nitrate concentrations at the C-depth wells are plotted in figure 18. The ratio of ammonium to nitrate can be used to delineate anaerobic and oxygenated zones in contaminated ground water (Baedeker and Back, 1979a). A high ratio (greater than 100) indicates a reducing zone; lower ratios (less than 0.01) indicate more oxygenated conditions. The highest ratios are found within the center of the plume, where nitrate concentrations are low or below detection limits.

A plot of the ratio of ammonium concentration to chloride concentration with respect to distance downgradient from the sanitary landfill is presented in figure 15C. The data show that ammonium is not conservative and that concentrations drop off sharply with distance from the landfill. A corresponding increase in nitrate within the plume is not evident because nitrifying bacteria require aerobic conditions and are intolerant of high concentrations of organic carbon. Accordingly, most of the ammonium ion in the plume is probably removed by ion exchange rather than nitrification. Along the edges of the plume, nitrate was detected in concentrations of 1 to 3 mg/L. This may reflect mixing with oxygenated ground water and subsequent nitrification of ammonium.

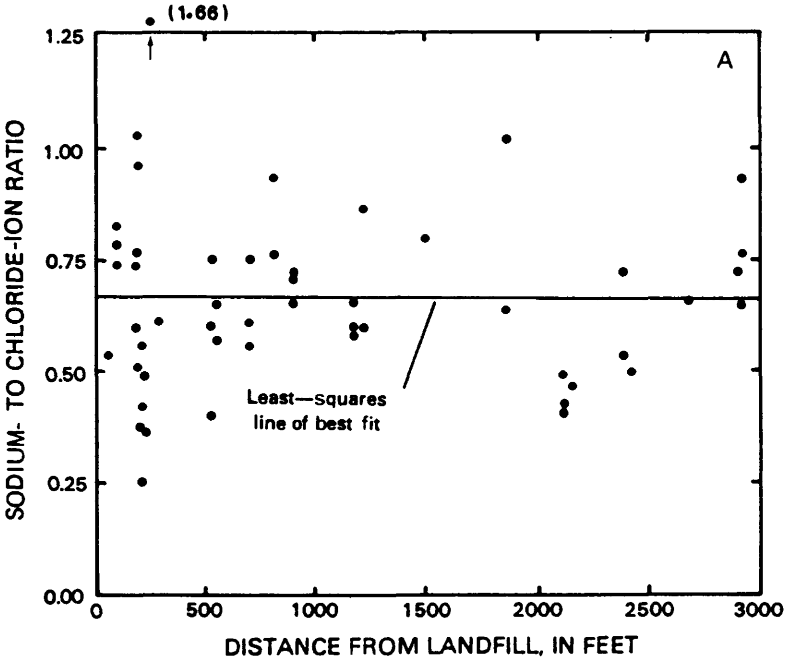


Figure 15A.

Ratio of sodium- to chloride-ion concentration with respect to distance downgradient from the sanitary landfill, October-December 1982.

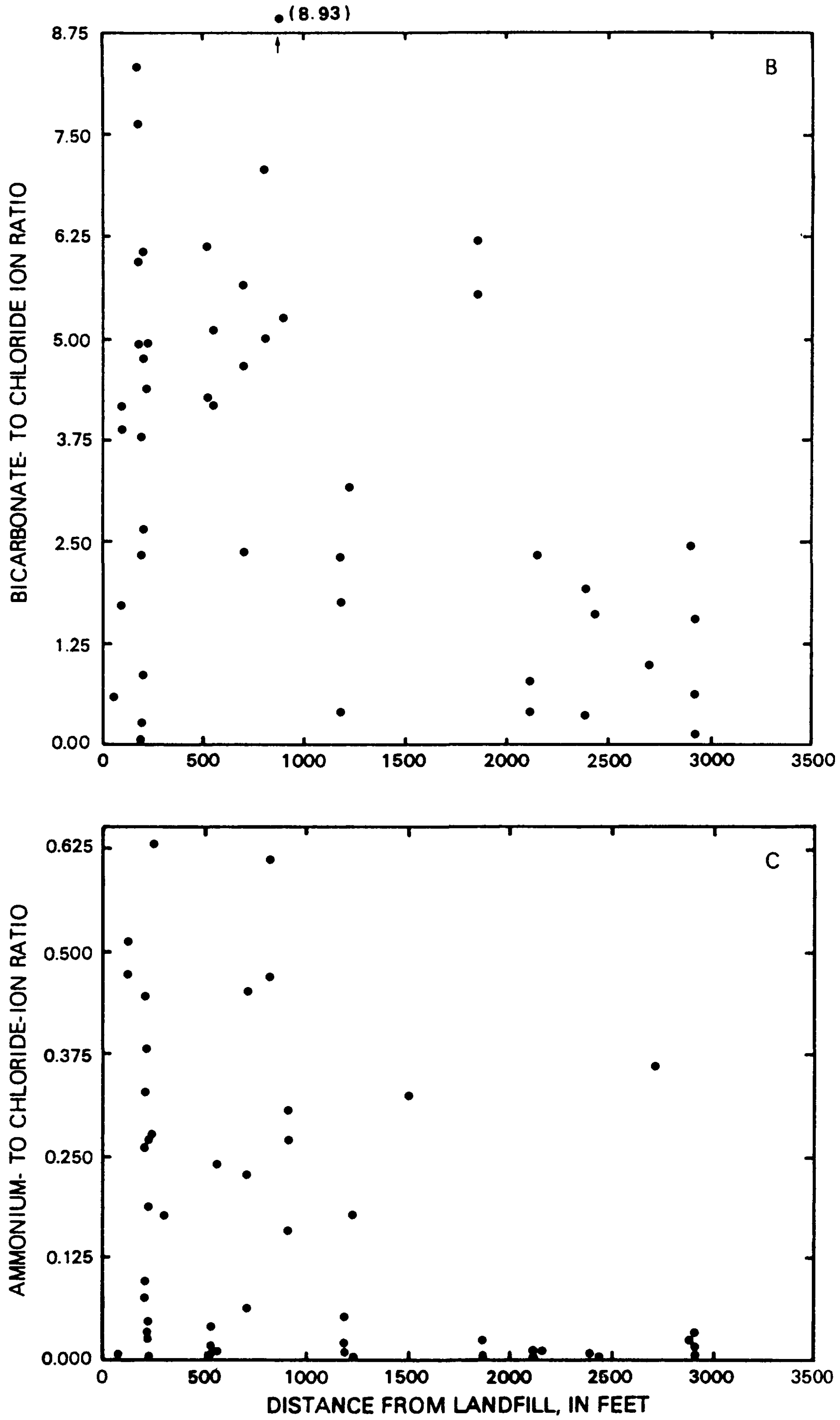
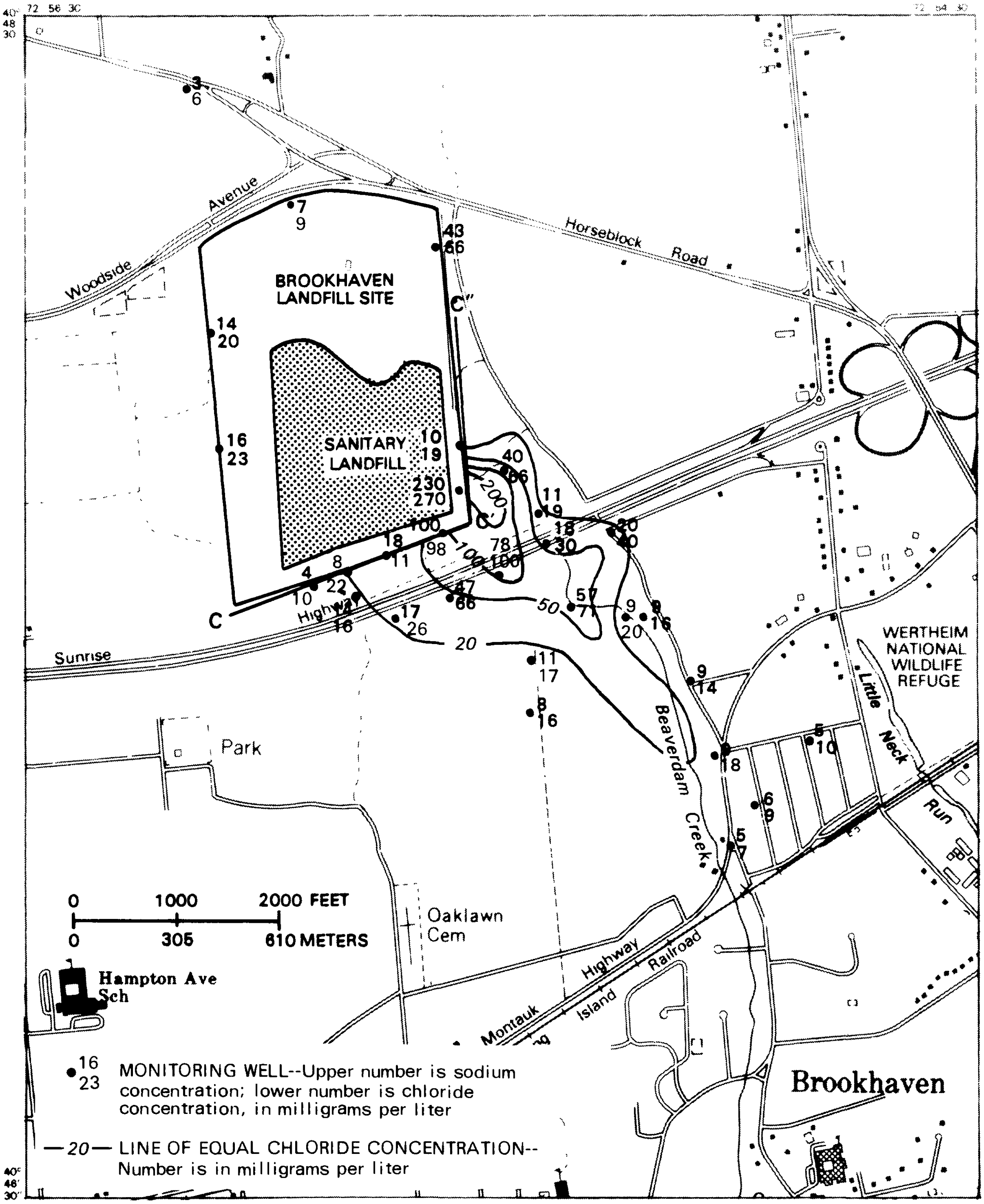
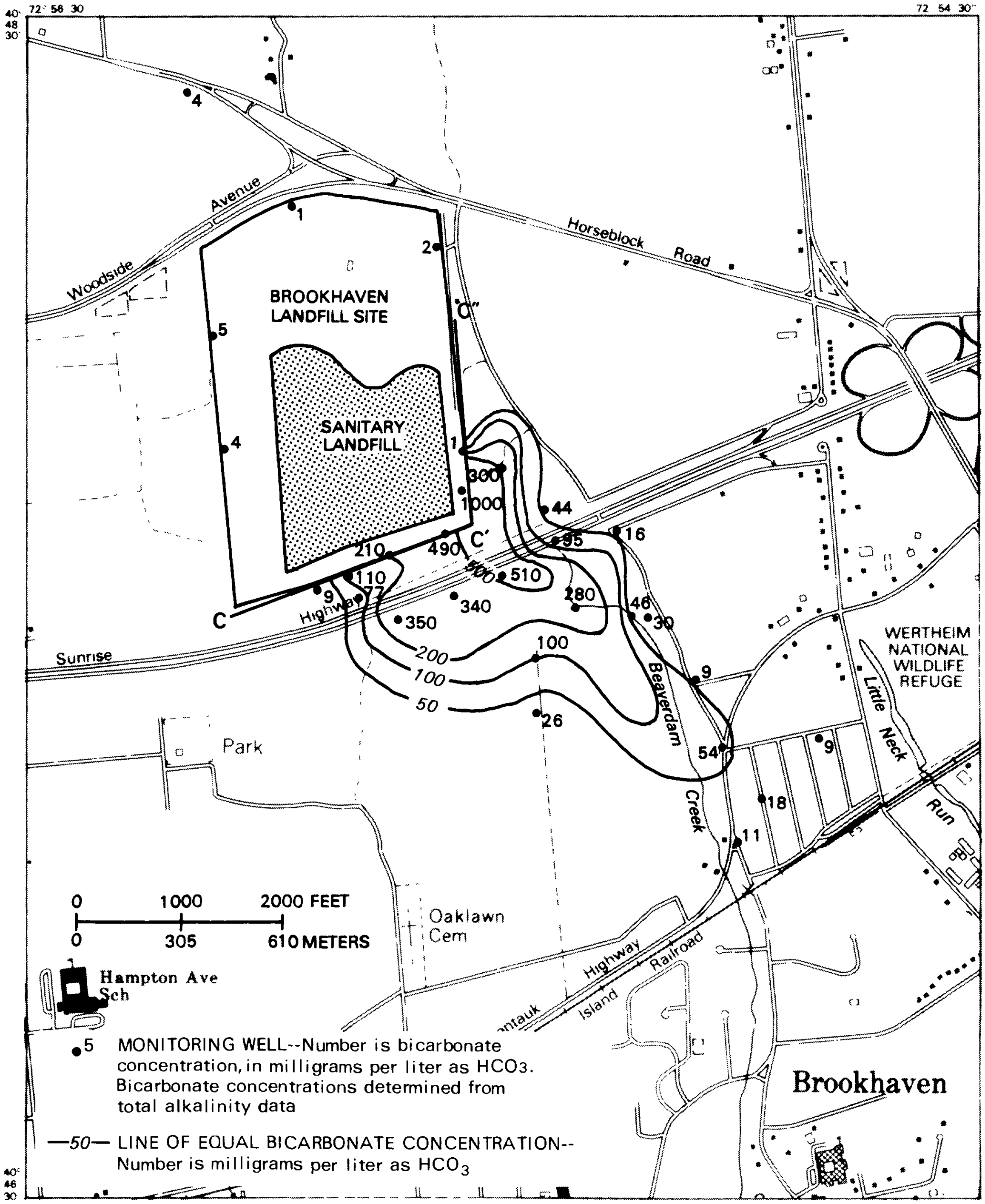


Figure 15 (continued).--Ratio of selected ions to chloride-ion concentration with respect to distance downgradient of sanitary landfill, October-December 1982: B. Bicarbonate-to-chloride ratio. C. Ammonium-to-chloride ratio.



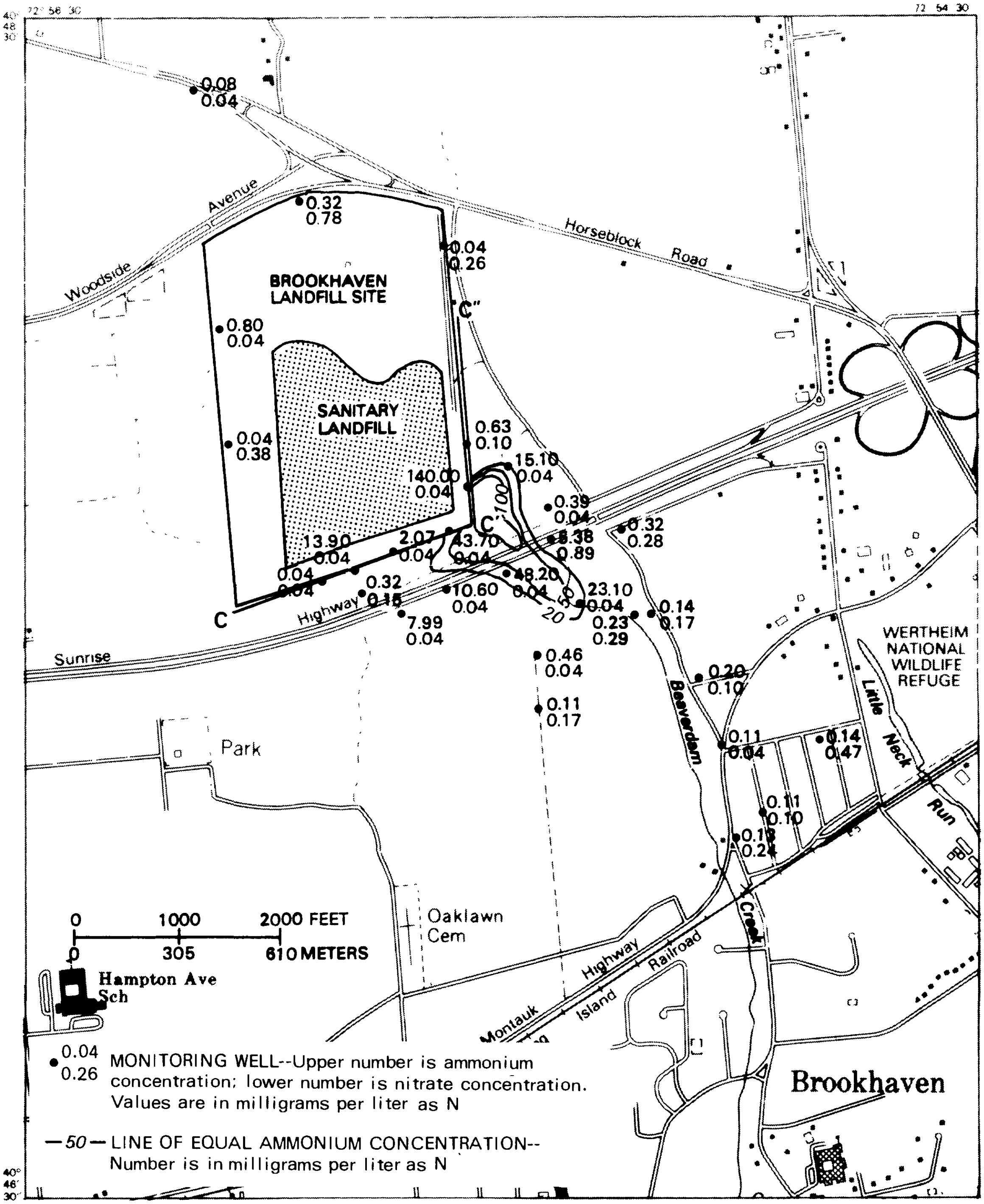
Base from NYSDOT, Bellport, NY, 1981, 1:24,000

Figure 16.--Sodium and chloride concentrations in samples from wells screened 20 to 40 ft below the water table (C depth), October-November 1982.



Base from NYSDOT, Bellport, NY, 1981, 1:24,000

Figure 17.--Bicarbonate concentrations in samples from wells screened 20 to 40 ft below the water table (C depth), October-November 1982.



Base from NYSDOT, Bellport, NY, 1981, 1:24,000

Figure 18.--Ammonium and nitrate concentrations in samples from wells screened 20 to 40 ft below the water table (C depth), October-November, 1982.

FACTORS AFFECTING LEACHATE MIGRATION THROUGH UPPER GLACIAL AQUIFER

Leachate that flows out of the landfill through or over the liner moves downward through the partly saturated sand and gravel that overlies the water table. The thickness of the unsaturated zone beneath the liner and along the east side of the sanitary landfill is generally less than 10 ft. Because of the shallow depth to water and short residence time, the chemical quality of leachate is not altered significantly as it travels through the unsaturated zone.

The distribution of contaminants downgradient of the landfill site is determined by processes that control the transport of solutes in ground water. These include both physical processes, which tend to spread the contaminants in the aquifer, and chemical and biological processes, which tend to retard the movement of certain chemical species (LeBlanc, 1984). A brief discussion of these processes is given below.

Physical Processes

Advection

Advection is a term used to describe the bulk movement of a solute in the mean direction of ground-water flow at a rate equal to the average ground-water (pore) velocity. Direction and rates of flow within the upper glacial aquifer in the vicinity of the Brookhaven landfill site are discussed in a previous section.

Hydrodynamic Dispersion

Hydrodynamic dispersion is the term used to describe the spread of solutes by two different mechanisms--molecular diffusion and mechanical dispersion. Molecular diffusion drives solutes from areas of high concentration within the fluid to areas of lower concentration. Mechanical dispersion is the term used to describe mixing and spreading of solutes by the variations in ground-water velocity. Local ground-water velocities can depart significantly from the average velocity because of differing velocities within each pore, variations in pore size, and the effects of converging and diverging flow (Bear, 1979). Mechanical dispersion is greatly enhanced by variations in ground-water velocity that result from local variations in hydraulic conductivity.

Hydrodynamic dispersion causes contaminants to spread both in the direction of flow (longitudinal) and perpendicular (transverse) to flow, thereby reducing the concentrations of constituents within the plume. Mixing due to hydrodynamic dispersion, however, will cause an earlier arrival of contaminants at a point downgradient from the contaminant source than would be predicted solely from the average ground-water velocity (Anderson, 1984).

Advective transport could cause contaminants to have moved about 2,400 ft by the end of 1982, as calculated from an average ground-water velocity of 1.1 ft/d and assuming that leachate began entering the aquifer in late 1976, when ponding of leachate above the liner was detected. The additional spread of contaminants has most likely been the result of longitudinal dispersion; the lateral spread of the plume transverse to the direction of flow is relatively minor. The predominance of longitudinal dispersion over transverse dispersion has also been noted at other sites on Long Island (Kimmel and Braids, 1980; Gureghian and others, 1981; and Pinder, 1973). A more detailed analysis of movement of contaminants is presented in a report by Wexler (1987), which discusses the results obtained from an advective-dispersive solute-transport model of the area downgradient from the Brookhaven landfill site.

Chemical and Biological Processes

Several chemical and biological processes may also alter the concentration of nonconservative solutes in the leachate plume. These include precipitation, oxidation and reduction, biodegradation, and ion exchange.

Redox processes are important because they can cause changes in the mobility of many inorganic contaminants (Cherry and others, 1984). Leachate entering the ground water contains large amounts of organic material, and biochemical reactions break down much of this material within the aquifer. As an example, reduction of iron and manganese oxides on sand grains during biodegradation of organic matter can add significantly to the dissolved concentrations of these metals (Nicholson and others, 1983).

As leachate-contaminated ground water mixes with recharge from precipitation and native ground water containing dissolved oxygen, the environment at the edge of the plume shifts from anaerobic to aerobic. Oxidation of organic material in the aerobic environment can proceed at an accelerated rate. A rise in redox potential can lead to the oxidation of reduced iron and its precipitation. Reduced manganese (Mn^{+2}) will persist at higher redox potentials and may be transported farther downgradient than iron before oxidizing to a less soluble state (Baedeker and Back, 1979b). Other redox processes such as nitrification of ammonium are discussed in a previous section.

Ion exchange is a process in which certain cations become attached to exchange sites on the aquifer material and thus are removed from solution, while other cations that occupied the exchange sites are released into solution. This process retards the movement of the adsorbed cation relative to that of nonadsorbed species, which move at the average ground-water velocity. Retardation of solute movement depends on the cation-exchange capacity of aquifer materials and the selectivity coefficients for the cations involved.

Selectivity of cations generally increases with higher valence and smaller hydrated radius. Thus, calcium is probably the dominant ion initially on exchange sites. The direction in which cation exchange proceeds also depends on the relationship between concentration ratios of cations in the influent solution and those of the ions initially on exchange sites. Ammonium ions in leachate-contaminated ground water will tend to displace calcium on exchange sites because the ratio of ammonium to calcium is much greater in contaminated water than on the exchange sites.

Most of the upper glacial aquifer contains little silt or clay to provide exchange sites. Faust (1963) found the percentage of silt and clay in core samples from the Brookhaven National Laboratory vicinity (fig. 1) to range between 0.06 and 4.1. Cation-exchange capacities of these samples ranged between 0.4 and 0.6 milliequivalents per 100 grams. Despite these relatively low values, ion-exchange remains a significant process, as evidenced by removal of ammonium within a short distance from the landfill.

SUMMARY AND CONCLUSIONS

The hydrogeologic conditions and chemical quality of water in a 4-mi^2 area surrounding the 180-acre Brookhaven landfill site in the Town of Brookhaven were investigated during 1981-83. A sanitary landfill that contains municipal solid waste covers 60 acres in the southern part of the site. The landfill was begun in 1974 and is lined with an 0.02-inch polyvinyl chloride membrane.

The landfill is excavated in highly permeable outwash deposits that form the upper glacial aquifer. A water-table map for September 1982--a period of average water levels--shows that ground-water flow beneath the site is southeastward. The rate of flow is estimated to be 1.1 ft/d, but because of uncertainty in values for aquifer properties, it may range between 0.8 and 1.8 ft/d. Flow in the upper glacial aquifer in the area studied is predominantly horizontal. The saturated thickness of the upper glacial aquifer at the site ranges from 100 to 120 ft.

Fine-grained material at the base of the upper glacial aquifer and the underlying Gardiners Clay unit confine the Magothy aquifer. Water levels measured in wells screened in the two aquifers indicate that ground water moves upward from the Magothy aquifer into the upper glacial aquifer as leakage through the Gardiners Clay.

Water-quality data collected from October through December 1982 indicate that ground water in the site vicinity can be classified into three general categories: native water; water affected by land use other than landfill operations; and water affected by leachate contamination. Samples of leachate and leachate-contaminated ground water typically had elevated specific conductance, pH, and temperature, and elevated concentrations of sodium, potassium, calcium, magnesium, ammonium, bicarbonate (measured as total alkalinity), chloride, iron, and manganese ions. Concentrations of sulfate and nitrate in leachate and leachate-contaminated water were lower than those in native ground water.

The means of leachate entry into ground water beneath the liner were not identified. Chemical data from monitoring wells along the southeastern boundary of the site indicate that a combination of two mechanisms--leakage through holes or along separated seams of the liner, and overflow of ponded leachate along the eastern edge of the landfill--may be responsible for the observed distribution of contaminants in ground water. After contaminants enter the upper glacial aquifer, their migration is governed by the physical mechanisms of advection and hydrodynamic dispersion. Chemical processes such as dissolution and precipitation, oxidation and reduction, biodegradation, and ion exchange, affect the concentration of nonconservative species.

A leachate plume extending southeastward from the landfill site was delineated from elevated specific-conductance values. At an intermediate depth (20 to 40 ft) below the water table, the plume extends 3,700 feet downgradient from the southeastern corner of the site and is 2,400 ft wide at that corner. The thickness of the plume at the southern boundary of the site is at least 90 ft; data were insufficient to determine its exact depth. The plume appears to be confined to the upper glacial aquifer. A well screened below the Gardiners Clay at the southern boundary of the site shows no evidence of leachate contamination.

Downgradient from the site, the plume is overlain by uncontaminated water from precipitation. Beaverdam Creek, which originates 2,000 ft southeast of the site, probably intersects this shallow uncontaminated zone because the stream sample showed no evidence of leachate contamination.

The lateral distribution of sodium and chloride follows a pattern similar to that of specific conductance. Both sodium and chloride appear to be conservative and are attenuated by dispersive mixing only. Bicarbonate may be attenuated by several processes, including oxidation reactions, that tend to lower the pH. Ammonium concentrations are high near the landfill but are reduced downgradient by ion exchange and, to a lesser extent, by oxidation of ammonium ion to nitrate along the edges of the plume. Changes in the reducing environment within the plume are reflected by changes in the ratios of ammonium to nitrate.

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Table 4.--Physical description of wells in the vicinity of the Brookhaven landfill site

[Well locations are shown in pl. 1.]

Local identifier	Latitude/ Longitude		Seq. no.[1]	Owner[2]	Depth code[3]	Elevation of measuring point (ft)	Land-surface elevation (ft)	Total well depth (ft)	Depth to top of screen (ft)	Screen length (ft)	Well diameter (in)	Water level, Sept. 1982[4] (ft)
S 3529	404801	725538	01	USGS	C	37.11	34	45	41	4	2	25.93
S44574	404728	725548	01	TOB	A	--	69	52	50	2	2	--
S44575	404728	725548	02	TOB	B	--	69	59	57	2	2	--
S44576	404728	725548	03	TOB	C	70.43	69	72	70	2	2	23.82
S44577	404731	725535	01	TOB	A	66.59	65	50	48	2	2	22.64
S44578	404731	725535	02	TOB	B	66.40	65	55	53	2	2	22.63
S44581	404747	725535	01	TOB	B	36.26	35	22	20	2	2	24.39
S47747	404740	725451	01	SCDHS	B	28.89	31	34	22	10	4	17.73
S66943	404745	725536	01	TOB	D	--	39	77	54	21	8	--
S72117	404722	725629	01	USGS	C	63.67	63	64	60	4	2	26.75
S72118	404646	725627	01	USGS	B	54.24	55	52	48	4	2	21.68
S72120	404640	725602	01	USGS	C	48.32	48	52	48	4	2	19.00
S72121	404816	725609	01	USGS	C	70.41	69	66	62	4	2	30.31
S72122	404742	725605	01	USGS	C	76.55	75	72	68	4	2	26.97
S72123	404805	725545	01	USGS	B	30.70	30	23	19	4	2	27.01
S72124	404805	725556	01	USGS	C	44.66	43	43	39	4	2	28.49
S72125	404713	725548	01	USGS	B	67.76	67	64	60	4	2	20.89
S72126	404700	725544	01	USGS	C	58.33	59	63	59	4	2	18.35
S72127	404643	725542	01	USGS	B	55.39	55	54	50	4	2	16.41
S72129	404826	725538	01	USGS	C	42.96	42	44	40	4	2	28.21
S72130	404742	725525	01	USGS	B	27.63	28	23	19	4	2	21.93
S72131	404722	725526	01	USGS	C	47.82	47	55	51	4	2	20.20
S72132	404713	725525	01	USGS	B	64.54	64	62	58	4	2	18.48
S72133	404653	725522	01	USGS	B	57.08	56	61	57	4	2	14.66
S72134	404801	725516	01	USGS	B	36.76	36	34	30	4	2	23.86

Table 4.--Physical description of wells in the vicinity of the Brookhaven landfill site--continued

Local identifier	Latitude/ Longitude	Seq. no.[1]	Owner[2]	Depth code[3]	Elevation of measuring point (ft)	Land-surface elevation (ft)	Total well depth (ft)	Depth to top of screen (ft)	Screen length (ft)	Well diameter (in)	Water level, Sept. 1982[4] (ft)
S72136	404734 725516	03	USGS	D	29.56	29	63	59	4	2	20.31
S72138	404740 725506	01	USGS	B	32.48	32	28	24	4	2	19.91
S72140	404822 725453	01	USGS	C	38.54	39	41	37	4	2	23.27
S72141	404801 725451	01	USGS	B	33.79	34	34	30	4	2	21.15
S72143	404754 725432	01	USGS	B	30.73	29	34	30	4	2	16.89
S72144	404711 725431	01	USGS	B	23.47	20	32	28	4	2	8.38
S72149	404704 725501	01	BFD	C	17.81	17	46	30	15	6	12.78
S72150	404713 725503	01	BFD	C	21.86	20	47	32	15	6	14.60
S72151	404708 725458	01	BFD	C	22.04	21	50	35	15	6	12.57
S72152	404714 725451	01	BFD	C	26.60	25	49	34	15	4	12.58
S72153	404726 725447	01	BFD	C	27.75	27	48	33	15	6	14.05
S72159	404746 725450	01	BFD	C	33.01	32	51	36	15	6	18.82
S72160	404646 725457	01	BFD	C	10.81	8	45	30	15	6	6.43
S72161	404645 725442	01	BFD	C	19.38	18	42	27	15	4	5.40
S72169	404631 725444	01	BFD	C	18.84	16	46	31	15	4	3.11
S72812	404802 725538	01	USGS	M	36.20	36	198	189	5	4	26.00
S72813	404732 725544	05	USGS	M	72.91	69	219	210	5	4	23.52
S72814	404653 725522	02	USGS	M	56.03	56	178	170	5	4	16.37
S72815	404753 725606	01	USGS	B	78.81	78	66	62	4	2	28.01
S72816	404801 725607	01	USGS	B	78.01	79	67	63	4	2	28.83

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[1] Sequence number is used to distinguish between wells having same latitude and longitude

[2] TOB, Town of Brookhaven; SCDHS, Suffolk County Department of Health Services; USGS, U.S. Geological Survey; BFD, Brookhaven Fire Department

[3] Depth of screen setting below average water table: A = 0-8 ft, B = 8-20 ft, C = 20-40 ft, D = 40-70 ft, E = 70-120 ft, M = Magothy aquifer well

[4] Altitude of water level above sea level

Table 4.--Physical description of wells in the vicinity of the Brookhaven landfill site--continued

Local identifier	Latitude/ Longitude	Seq. no.[1]	Owner[2]	Depth code[3]	Elevation of measuring point (ft)	Land-surface elevation (ft)	Total well depth (ft)	Depth to top of screen (ft)	Screen length (ft)	Well diameter (in)	Water level, Sept. 1982[4] (ft)
S72817	404740 725530	01	USGS	B	30.25	29	22	18	4	2	23.07
S72818	404736 725525	01	USGS	A	23.58	23	8	4	4	2	21.91
S72819	404736 725525	02	USGS	B	23.95	23	23	19	4	2	21.88
S72820	404736 725525	03	USGS	C	23.97	23	43	39	4	2	21.89
S72821	404734 725516	01	USGS	B	29.01	29	23	19	4	2	20.35
S72822	404734 725516	02	USGS	C	28.75	29	43	39	4	2	20.34
S72823	404727 725521	01	USGS	B	21.96	21	13	9	4	2	20.11
S72824	404727 725521	02	USGS	C	21.65	21	34	30	4	2	20.11
S72825	404726 725512	01	USGS	B	--	21	24	20	4	2	18.55
S72826	404726 725512	02	USGS	C	21.43	21	43	39	4	2	18.55
S72827	404720 725506	01	USGS	B	20.09	21	14	10	4	2	16.59
S72828	404720 725506	02	USGS	C	20.00	21	33	29	4	2	16.63
S72829	404659 725509	01	USGS	B	34.22	33	33	29	4	2	12.75
S72830	404651 725533	01	USGS	A	59.60	59	53	49	4	2	16.51
S72831	404703 725524	01	USGS	B	61.10	61	56	52	4	2	16.33
S72832	404717 725526	01	USGS	C	54.25	54	72	68	4	2	19.39
S72833	404722 725526	02	USGS	D	46.13	47	72	68	4	2	20.18
S72834	404730 725530	01	USGS	B	40.14	39	34	30	4	2	20.81
S72835	404728 725536	01	USGS	C	54.88	54	64	60	4	2	21.39
S72836	404726 725543	01	USGS	B	62.75	62	54	50	4	2	21.87
S72837	404726 725543	02	USGS	C	62.95	62	73	69	4	2	21.89
S72838	404724 725548	01	USGS	B	66.78	66	64	60	4	2	22.17
S73750	404742 725535	01	TOB	B	38.27	36	34	29	5	4	23.95
S73751	404742 725535	02	TOB	C	38.39	36	55	50	5	4	23.93
S73752	404742 725535	03	TOB	D	39.28	36	85	80	5	4	23.89

Table 4.--Physical description of wells in the vicinity of the Brookhaven landfill site--continued

Local identifier	Latitude/ Longitude	Seq. no.[1]	Owner[2]	Depth code[3]	Elevation of measuring point (ft)	Land-surface elevation (ft)	Total well depth (ft)	Depth to top of screen (ft)	Screen length (ft)	Well diameter (in)	Water level, Sept. 1982[4] (ft)
S73753	404738 725535	01	TOB	B	38.60	37	34	29	5	4	23.38
S73754	404738 725535	02	TOB	C	38.67	37	54	49	5	4	23.38
S73755	404738 725535	03	TOB	D	39.79	37	85	80	5	4	23.39
S73756	404734 725537	03	TOB	D	58.11	55	103	98	5	4	23.16
S73757	404734 725537	02	TOB	C	57.35	55	73	68	5	4	23.17
S73758	404734 725537	01	TOB	B	57.38	55	53	48	5	4	23.18
S73759	404734 725537	04	TOB	E	57.59	55	128	123	5	4	23.22
S73760	404732 725544	01	TOB	B	71.74	69	65	60	5	4	23.73
S73761	404732 725544	02	TOB	C	71.35	69	85	80	5	4	23.71
S73762	404732 725544	03	TOB	D	71.89	69	115	110	5	4	23.71
S73763	404732 725544	04	TOB	E	72.17	69	140	135	5	4	23.16
S73764	404730 725549	01	TOB	B	71.49	69	58	53	5	4	--
S73765	404730 725549	02	TOB	C	72.02	69	78	73	5	4	--
S73766	404730 725549	03	TOB	D	72.41	69	108	103	5	4	--
S73767	404729 725553	01	TOB	B	72.80	69	63	58	5	4	--
S73768	404729 725553	02	TOB	C	72.67	69	79	74	5	4	--
S73769	404753 725606	02	TOB	C	80.13	78	82	77	5	4	--
S73770	404749 725543	01	TOB	B	42.73	42	28	23	5	4	--
S73943	404740 725530	02	TOB	C	--	29	45	43	2	1	--
S73944	404740 725530	03	TOB	D	--	29	65	63	2	1	--
S73945	404730 725530	02	TOB	C	40.03	39	50	48	2	1	--
S73946	404733 725524	01	TOB	C	24.65	23	42	40	2	1	--
S73947	404733 725524	02	TOB	D	24.62	23	60	58	2	1	--
S73948	404726 725514	01	TOB	C	20.18	19	37	35	2	1	--
S73953	404728 725509	01	USGS	C	22.49	22	44	40	4	2	--
S73954	404728 725509	02	USGS	D	22.84	22	64	60	4	2	--
S73955	404720 725506	03	USGS	D	--	21	63	59	4	2	--

[1] Sequence number is used to distinguish between wells having same latitude and longitude

[2] TOB, Town of Brookhaven; SCDHS, Suffolk County Department of Health Services; USGS, U.S. Geological Survey; BFD, Brookhaven Fire Department

[3] Depth of screen setting below average water table: A = 0-8 ft, B = 8-20 ft, C = 20-40 ft, D = 40-70 ft, E = 70-120 ft, M = Magothy aquifer well

[4] Altitude of water level above sea level

Table 5.--*Laboratory analyses of samples from the Brookhaven landfill site vicinity, October-December 1982*
[Well locations shown in pl. 1; analyses by New York Testing, Inc., Westbury, N.Y.]

Local identifier	Latitude/ Longitude		Seq. no.[1]	Date of sample (yr/mo/d)	Temperature (°C)	Specific conductance (µS/cm at 25°C)	pH		Total ammonium as N (mg/L)	Total nitrite as N (mg/L)	Total nitrate as N (mg/L)	Total Kjeldahl nitrogen as N (mg/L)
							field value (units)	lab. value (units)				
S 3529	404801	0725538	01	82-11-02	13.0	290	4.6	5.2	< 0.04	0.01	0.26	0.34
S44574	404728	0725548	01	82-11-03	13.0	400	5.3	5.6	.61	< .01	< .04	3.14
S44575	404728	0725548	02	82-11-03	13.0	370	5.4	5.6	.17	< .01	< .04	2.02
S44576	404728	0725548	03	82-11-03	12.0	233	5.9	5.7	.32	< .01	.15	3.75
S44577	404731	0725535	01	82-11-03	15.0	440	5.5	5.8	.27	< .01	.06	7.73
S44578	404731	0725535	02	82-11-03	14.0	460	5.9	6.3	7.47	< .01	.04	7.78
S44581	404747	0725535	01	82-11-03	15.0	740	5.9	6.3	6.42	< .01	< .04	7.67
S66943	404745	0725536	01	82-11-08	11.0	165	6.5	6.0	.12	.04	1.20	.90
S72121	404816	0725609	01	82-10-26	12.0	50	5.3	5.8	.08	< .01	.04	.84
S72122	404742	0725605	01	82-11-02	12.0	118	6.0	5.4	< .04	< .01	.38	.29
S72123	404805	0725545	01	82-12-09	--	[2]362	--	5.6	.30	< .01	.01	1.29
S72124	404805	0725556	01	82-11-02	12.0	60	5.5	5.9	.32	< .01	.78	.95
S72125	404713	0725548	01	82-11-02	12.0	150	5.6	5.8	.21	.01	.42	.26
S72130	404742	0725525	01	82-10-27	12.0	223	5.3	4.9	.27	< .01	< .04	1.29
S72131	404722	0725526	01	82-11-04	--	230	5.2	5.9	.46	< .01	< .04	.78
S72132	404713	0725525	01	82-11-04	--	110	5.3	5.4	.23	< .01	.72	1.12
S72136	404734	0725516	03	82-10-27	10.0	300	5.2	5.5	.14	< .01	.04	.28
S72138	404740	0725506	01	82-11-03	13.0	42	5.5	6.1	.16	.01	.04	.56
S72149	404704	0725501	01	82-11-05	--	55	6.6	6.0	.13	< .01	.24	1.23
S72150	404713	0725503	01	82-11-04	--	165	6.9	5.3	.11	< .01	.04	1.01
S72151	404708	0725458	01	82-11-05	--	75	6.6	5.7	.11	< .01	.10	.81
S72152	404714	0725451	01	82-10-26	11.0	77	5.5	5.4	.14	< .01	.47	1.96
S72812	404802	0725538	01	82-11-08	11.0	59	5.2	6.6	.16	.04	1.35	.22
S72813	404732	0725544	05	82-11-08	13.0	71	6.2	6.9	.75	.04	.05	.79
S72815	404753	0725606	01	82-11-02	12.0	245	5.4	5.3	< .04	< .01	.54	.32
S72816	404801	0725607	01	82-10-28	11.0	55	4.9	5.7	.06	< .01	< .04	.20
S72817	404740	0725530	01	82-10-27	13.0	2,650	6.8	7.0	181.00	< .01	1.56	184.00
S72818	404736	0725525	01	82-10-28	12.0	131	5.2	5.2	.48	< .01	< .04	1.46
S72819	404736	0725525	02	82-10-28	11.0	317	5.5	5.8	.45	< .01	< .04	.52
S72820	404736	0725525	03	82-10-28	11.0	160	5.9	6.3	.39	< .01	< .04	1.01
S72821	404734	0725516	01	82-10-27	13.0	135	4.3	4.8	.23	< .01	.47	.45
S72822	404734	0725516	02	82-10-27	11.0	214	5.1	5.2	.32	< .01	.28	2.13
S72824	404727	0725521	02	82-11-04	--	750	6.4	6.2	23.10	< .01	< .04	23.70
S72825	404726	0725512	01	82-10-27	12.0	172	4.8	5.0	.23	< .01	1.52	.67
S72826	404726	0725512	02	82-10-27	11.0	142	5.2	5.4	.14	< .01	.17	.22
S72827	404720	0725506	01	82-10-28	13.0	95	4.5	5.6	.34	< .01	< .04	.39
S72828	404720	0725506	02	82-10-28	12.0	131	4.8	5.4	.20	< .01	.10	.24

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[1] Sequence number is used to distinguish between wells hav. same latitude and longitude

[2] Laboratory measurement of specific conductance at 20°C. other specific-conductance data are field values.

Table 5.--Laboratory analyses of samples from the Brookhaven landfill site vicinity, October-December 1982--continued

Local identifier	Date of sample (yr/mo/d)	Alkalinity as HCO_3 (mg/L)	Dissolved calcium (Ca) (mg/L)	Dissolved magnesium (Mg) (mg/L)	Dissolved sodium (Na) (mg/L)	Dissolved potassium (K) (mg/L)	Dissolved chloride (Cl) (mg/L)	Dissolved sulfate (SO_4) (mg/L)	Dissolved iron (Fe) (µg/L)	Dissolved manganese (Mn) (µg/L)	Total dissolved solids (mg/L)
S 3529	82-11-02	2	3.90	1.60	43.00	1.80	66	19	23	510	110
S44574	82-11-03	200	2.80	3.70	6.10	1.70	15	37	1,200	87,800	157
S44575	82-11-03	150	5.00	4.50	14.00	3.50	24	41	94	49,860	130
S44576	82-11-03	77	4.80	4.00	14.00	3.20	18	20	75	16,980	68
S44577	82-11-03	140	5.50	4.10	18.00	8.60	27	29	2,000	38,000	140
S44578	82-11-03	130	9.60	5.30	18.00	12.00	31	6	35,460	8,100	180
S44581	82-11-03	640	21.00	12.00	22.00	24.00	36	21	85,000	5,200	201
S66943	82-11-08	12	5.90	5.00	11.00	1.00	21	21	430	1,600	76
S72121	82-10-26	4	.60	1.40	3.30	.40	6	10	770	<6	50
S72122	82-11-02	4	.90	1.50	16.00	1.00	23	7	49	25	52
S72123	82-12-09	< 1	5.10	1.40	73.00	1.20	260	16	210	470	180
S72124	82-11-02	< 1	1.30	1.70	6.60	.40	9	7	420	41	35
S72125	82-11-02	2	2.90	1.50	21.00	1.30	32	10	75	170	58
S72130	82-10-27	6	1.20	2.00	22.00	2.00	30	38	590	10,170	114
S72131	82-11-04	110	6.00	3.60	11.00	1.80	17	4	90	28,670	81
S72132	82-11-04	27	4.10	2.40	8.00	1.10	11	9	30	150	39
S72136	82-10-27	43	11.00	9.60	23.00	1.60	55	8	210	18	174
S72138	82-11-03	4	1.20	1.00	3.40	.60	6	6	260	120	19
S72149	82-11-05	11	2.10	1.40	4.80	.20	7	4	89	160	20
S72150	82-11-04	54	5.00	7.10	8.50	1.20	18	4	4,800	370	57
S72151	82-11-05	18	2.90	2.30	6.40	.40	9	4	130	200	31
S72152	82-10-26	9	1.70	1.90	4.90	.60	10	4	160	<6	60
S72812	82-11-08	18	3.30	2.10	4.60	.40	7	3	180	36	22
S72813	82-11-08	20	3.70	1.50	4.60	.50	6	3	1,300	180	28
S72815	82-11-02	2	4.80	1.20	36.00	.90	62	4	63	30	111
S72816	82-10-28	< 1	.80	1.50	4.10	.50	7	5	260	14	16
S72817	82-10-27	940	31.00	48.00	300.00	220.00	400	10	14,210	400	1,460
S72818	82-10-28	4	1.10	3.50	5.90	1.20	9	38	2,000	8,600	114
S72819	82-10-28	78	9.30	14.00	26.00	1.50	44	13	320	4,000	148
S72820	82-10-28	44	4.70	7.80	11.00	.80	19	7	300	31	99
S72821	82-10-27	7	3.50	3.20	7.70	1.40	18	17	160	1,700	94
S72822	82-10-27	16	4.00	4.80	20.00	1.40	40	14	140	4,100	146
S72824	82-11-04	280	17.00	7.90	57.00	21.00	71	3	310	26,530	300
S72825	82-10-27	7	3.20	3.40	15.00	1.40	21	24	180	2,100	106
S72826	82-10-27	31	4.20	5.50	8.50	.80	16	9	200	13	108
S72827	82-10-28	< 1	1.20	2.60	10.00	1.30	11	14	2,400	150	99
S72828	82-10-28	9	3.40	4.20	9.10	1.50	14	17	380	140	108

Table 5.--Laboratory analyses of samples from the Brookhaven landfill site vicinity, October-December 1982--continued

Local identi-fier	Latitude/ Longitude	Seq. no.[1]	Date of sample (yr/mo/d)	Temper-ature (°C)	Specific conduct-ance (µS/cm at 25°C)	pH		Total ammonium as N (mg/L)	Total nitrite as N (mg/L)	Total nitrate as N (mg/L)	Total Kjeldahl nitrogen as N (mg/L)
						field value (units)	lab. value (units)				
S72829	404659 0725509	01	82-11-05	--	70	--	5.6	0.13	< 0.01	0.23	1.29
S72831	404703 0725524	01	82-11-04	--	51	5.4	5.6	.11	< .01	.05	2.74
S72832	404717 0725526	01	82-11-04	--	108	5.0	5.3	.11	< .01	.17	.56
S72833	404722 0725526	02	82-11-04	--	290	5.0	5.9	.13	< .01	< .04	.61
S72834	404730 0725530	01	82-10-28	14.0	595	5.7	6.8	29.40	< .01	< .04	30.70
S72835	404728 0725536	01	82-11-03	13.0	670	6.3	6.5	10.60	< .01	< .04	22.50
S72836	404726 0725543	01	82-11-02	12.0	232	5.6	6.3	4.33	< .01	< .04	5.82
S72837	404726 0725543	02	82-11-02	12.0	480	6.1	6.0	7.99	.01	.04	8.46
S72838	404724 0725548	01	82-11-02	12.0	63	4.9	5.7	.23	.01	.30	.78
S73750	404742 0725535	01	82-10-29	14.0	2,300	6.7	7.0	151.00	< .01	< .04	168.00
S73751	404742 0725535	02	82-10-29	12.0	100	7.0	6.7	.63	< .01	.10	.65
S73752	404742 0725535	03	82-10-29	13.0	225	7.0	7.3	1.07	.16	3.18	1.12
S73753	404738 0725535	01	82-10-29	15.0	1,850	6.1	6.7	110.00	< .01	< .04	114.00
S73754	404738 0725535	02	82-10-29	16.0	2,150	6.3	7.4	140.00	< .01	< .04	145.00
S73755	404738 0725535	03	82-10-29	16.0	1,370	6.4	7.1	79.90	< .01	< .04	81.70
S73756	404734 0725537	03	82-11-08	14.0	1,300	6.4	6.7	44.60	< .01	.10	69.20
S73757	404734 0725537	02	82-10-29	16.0	1,050	7.2	6.8	43.70	< .01	< .04	44.30
S73758	404734 0725537	01	82-11-08	14.0	1,020	6.1	6.4	20.20	.04	.10	27.30
S73759	404734 0725537	04	82-11-08	14.0	1,480	6.4	6.7	10.50	.04	.08	12.70
S73760	404732 0725544	01	82-11-08	14.0	235	6.4	6.5	.75	< .01	.14	1.57
S73761	404732 0725544	02	82-10-29	15.0	260	7.0	6.9	2.07	< .01	< .04	4.93
S73762	404732 0725544	03	82-11-08	12.0	1,000	6.1	6.5	4.09	< .01	.32	5.75
S73763	404732 0725544	04	82-11-08	13	585	6.3	6.8	22.20	.04	.08	24.10
S73764	404730 0725549	01	82-11-08	11.5	425	6.7	6.3	9.35	< .01	.37	10.20
S73765	404730 0725549	02	82-11-08	12.0	270	6.5	6.8	13.90	< .01	< .04	16.00
S73767	404729 0725553	01	82-11-08	12.0	61	6.5	6.5	< .04	< .01	2.08	< .04
S73768	404729 0725553	02	82-11-08	11.0	59	6.7	5.9	< .04	< .01	< .04	< .04
S73769	404753 0725606	02	82-10-29	12.0	107	6.3	6.3	.80	< .01	< .04	.83
S73770	404749 0725543	01	82-11-05	--	128	--	5.2	.11	< .01	.17	1.23
S73943	404740 0725530	02	82-11-03	13.0	625	6.3	6.5	15.10	.01	.04	18.30
S73944	404740 0725530	03	82-11-03	12.0	275	6.1	6.8	1.72	< .01	< .04	6.50
S73945	404730 0725530	02	82-10-28	14.0	950	6.5	6.9	48.20	< .01	< .04	48.20
S73946	404733 0725524	01	82-11-03	13.5	268	5.5	6.2	5.38	.02	.89	7.39
S73947	404733 0725524	02	82-11-03	13.0	205	5.5	6.1	< .04	.13	.62	.39
S73948	404726 0725514	01	82-11-03	11.5	160	5.4	5.9	.23	.01	.29	1.68
S73954	404728 0725509	02	82-12-22	--	[2]78	--	6.1	3.64	< .01	2.10	4.48
S73955	404720 0725506	03	82-12-22	--	[2]101	--	6.3	< .04	< .01	3.09	.62
[3]BD CRK	404701 0725503	01	82-10-28	13.0	80	5.1	5.4	.04	< .01	< .04	4.25

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[1] Sequence number is used to distinguish between wells having same latitude and longitude

[2] Laboratory measurement of specific conductance at 20°C. All other specific-conductance data are field values.

[3] Beaverdam Creek at Montauk Highway

Table 5.--Laboratory analyses of samples from the Brookhaven landfill site vicinity, October-December 1982--continued

Local identifier	Date of sample (yr/mo/d)	Alkalinity as HCO_3 (mg/L)	Dissolved calcium (Ca) (mg/L)	Dissolved magnesium (Mg) (mg/L)	Dissolved sodium (Na) (mg/L)	Dissolved potassium (K) (mg/L)	Dissolved chloride (Cl) (mg/L)	Dissolved sulfate (SO_4) (mg/L)	Dissolved iron (Fe) (µg/L)	Dissolved manganese (Mn) (µg/L)	Total dissolved solids (mg/L)
S72829	82-11-05	5	1.20	1.70	5.80	0.40	9	7	66	150	26
S72831	82-11-04	10	1.00	1.50	4.20	.40	7	6	37	190	23
S72832	82-11-04	26	2.40	4.70	8.00	.90	16	3	51	200	40
S72833	82-11-04	120	12.00	12.00	21.00	1.70	21	9	75	260	106
S72834	82-10-28	340	16.00	12.00	45.00	38.00	48	2	13,270	5,300	231
S72835	82-11-03	350	14.00	15.00	47.00	24.00	66	< 1	70,330	10,940	310
S72836	82-11-02	150	8.40	3.00	12.00	6.70	16	1	100	15,750	88
S72837	82-11-02	350	13.00	5.10	17.00	14.00	26	< 1	49,780	9,300	67
S72838	82-11-02	2	1.60	2.00	4.90	.60	11	7	47	100	30
S73750	82-10-29	1,500	17.00	41.00	300.00	170.00	400	1	17,530	1,000	1,410
S73751	82-10-29	< 1	1.70	2.90	9.70	1.90	19	4	1,100	130	65
S73752	82-10-29	26	12.00	9.80	11.00	1.20	11	36	420	47	146
S73753	82-10-29	970	31.00	32.00	170.00	130.00	230	2	33,600	2,300	833
S73754	82-10-29	1,060	23.00	34.00	230.00	160.00	270	4	19,390	3,700	994
S73755	82-10-29	270	6.30	17.00	120.00	78.00	160	8	18,580	5,600	543
S73756	82-11-08	810	110.00	31.00	100.00	52.00	140	3	3,100	34,460	600
S73757	82-10-29	480	29.00	26.00	100.00	54.00	98	1	32,560	6,900	505
S73758	82-11-08	640	19.00	16.00	46.00	35.00	77	< 1	155,700	13,200	500
S73759	82-11-08	1,080	210.00	58.00	110.00	24.00	140	1	23,870	36,530	509
S73760	82-11-08	77	7.40	7.90	7.40	3.00	29	7	11,020	5,300	78
S73761	82-10-29	200	4.50	4.80	18.00	4.40	11	9	11,080	8,900	130
S73762	82-11-08	410	73.00	22.00	32.00	6.70	86	1	34,200	22,070	300
S73763	82-11-08	500	40.00	22.00	46.00	11.00	82	2	30,590	8,200	380
S73764	82-11-08	150	4.70	6.40	17.00	14.00	34	8	24,000	4,400	130
S73765	82-11-08	110	2.30	1.90	8.10	16.00	22	6	4,700	530	81
S73767	82-11-08	4	2.60	2.50	3.60	.70	14	4	95	34	28
S73768	82-11-08	9	2.10	2.30	4.30	.80	10	6	1,100	94	28
S73769	82-10-29	5	1.40	1.10	14.00	1.20	20	8	2,300	230	77
S73770	82-11-05	26	3.80	3.30	5.10	1.70	10	9	3,600	3,300	46
S73943	82-11-03	310	16.00	10.00	40.00	14.00	66	< 1	25,330	9,200	189
S73944	82-11-03	150	8.50	2.90	15.00	3.30	27	1	7,000	20,430	100
S73945	82-10-28	510	21.00	18.00	78.00	56.00	100	1	28,960	3,300	453
S73946	82-11-03	95	3.90	2.80	18.00	6.30	30	18	520	8,300	110
S73947	82-11-03	79	5.70	7.10	22.00	1.40	25	10	530	320	110
S73948	82-11-03	46	8.00	4.80	9.30	1.00	20	7	1,000	270	61
S73954	82-12-22	10	3.00	2.30	6.60	.60	10	6	280	44	52
S73955	82-12-22	17	6.40	3.20	8.40	.70	11	7	240	48	88
[1]BD CRK	82-10-28	< 1	1.50	1.80	7.00	1.40	10	8	600	150	128

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[1] Beaverdam Creek at Montauk Highway

Table 6.--*Laboratory analyses of samples from the Brookhaven landfill site vicinity, April 1983*

[Well locations shown in pl. 1; analyses by New York Testing, Inc., Westbury, N.Y.]

Local identifier	Latitude/ Longitude		Seq. no.[1]	Date of sample (yr/mo/d)	Temperature (°C)	Specific conductance (μS/cm at 25°C)	pH		Total ammonium as N (mg/L)	Total nitrite as N (mg/L)	Total nitrate as N (mg/L)	Total Kjeldahl nitrogen as N (mg/L)
							field value (units)	lab. value (units)				
S72136	404734	0725516	03	83-04-27	13.0	340	--	5.4	0.98	< 0.01	0.22	1.23
S72817	404740	0725530	01	83-04-27	10.0	2,200	--	6.8	89.30	< 0.01	0.07	97.00
S72822	404734	0725516	02	83-04-27	12.0	236	--	5.1	0.95	< 0.01	0.65	0.98
S72826	404726	0725512	02	83-04-27	9.5	115	--	5.5	0.59	< 0.01	0.20	1.06
S72828	404720	0725506	02	83-04-27	14.0	160	--	4.9	0.67	< 0.01	0.07	0.70
S72834	404730	0725530	01	83-04-27	13.5	1,030	--	6.5	49.50	< 0.01	< 0.04	52.00
S72835	404728	0725536	01	83-04-27	12.0	775	--	6.5	16.90	< 0.01	< 0.04	20.10
S72836	404726	0725543	01	83-04-27	12.0	430	--	7.0	7.34	< 0.01	< 0.04	9.35
S73750	404742	0725535	01	83-04-26	11.5	5,500	6.9	7.0	291.00	< 0.01	0.04	308.00
S73754	404738	0725535	02	83-04-26	12.0	675	7.5	7.1	0.59	< 0.01	0.04	2.24
S73757	404734	0725537	02	83-04-26	14.0	750	--	6.8	47.90	< 0.01	0.04	56.50
S73759	404734	0725537	04	83-04-26	13.0	1,100	--	6.9	12.90	< 0.01	0.04	14.60
S73761	404732	0725544	02	83-04-26	12.0	750	--	6.7	17.10	< 0.01	0.04	18.50
S73763	404732	0725544	04	83-04-27	13.5	1,600	--	7.1	37.10	< 0.01	< 0.04	41.20
S73765	404730	0725549	02	83-04-27	12.0	1,100	--	6.4	43.60	< 0.01	0.36	51.70
S73953	404728	0725509	01	83-04-27	10.0	80	--	5.9	0.45	< 0.01	< 0.04	1.46

Local identifier	Date of sample (yr/mo/d)	Alkalinity as HCO_3 (mg/L)	Dissolved calcium (Ca) (mg/L)	Dissolved magnesium (Mg) (mg/L)	Dissolved sodium (Na) (mg/L)	Dissolved potassium (K) (mg/L)	Dissolved chloride (Cl) (mg/L)	Dissolved sulfate (SO_4) (mg/L)	Dissolved iron (Fe) (μg/L)	Dissolved manganese (Mn) (μg/L)	Total dissolved solids (mg/L)
S72136	83-04-27	89	18.00	8.30	38.00	2.50	50	6	770	150	139
S72817	83-04-27	980	41.00	46.00	180.00	140.00	240	11	16,210	600	950
S72822	83-04-27	43	5.50	6.00	25.00	2.30	41	4	50	9,500	106
S72826	83-04-27	68	4.80	4.20	9.40	1.40	18	2	75	20	53
S72828	83-04-27	35	5.40	4.60	14.00	1.40	30	4	71	190	73
S72834	83-04-27	490	15.00	18.00	71.00	60.00	90	5	7,900	10,280	307
S72835	83-04-27	270	15.00	11.00	40.00	28.00	60	<1	85,400	9,900	230
S72836	83-04-27	85	18.00	4.60	14.00	11.00	19	<1	59,900	9,100	74
S73750	83-04-26	2,540	52.00	83.00	500.00	330.00	650	3	26,040	530	2,284
S73754	83-04-26	390	4.80	5.10	51.00	41.00	63	5	4,800	930	224
S73757	83-04-26	460	20.00	12.00	70.00	56.00	90	2	29,650	4,100	342
S73759	83-04-26	950	140.00	57.00	110.00	27.00	140	2	890	16,130	794
S73761	83-04-26	330	18.00	19.00	44.00	12.00	70	3	41,010	21,810	262
S73763	83-04-27	480	47.00	26.00	110.00	37.00	130	<1	30,060	5,100	425
S73765	83-04-27	460	20.00	19.00	70.00	43.00	93	2	51,500	11,550	340
S73953	83-04-27	42	2.90	2.60	7.10	1.10	17	3	94	26	36

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[1] Sequence number is used to distinguish between wells having same latitude and longitude