GROUND-WATER QUALITY NEAR A SCAVENGER-WASTE-DISPOSAL FACILITY IN MANORVILLE, SUFFOLK COUNTY, NEW YORK 1984-85

By Michael P. Scorca

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MANUEL LUJAN JR., Secretary

U.S. GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information
write to:

U.S. Geological Survey
5 Aerial Way
Syosset, NY 11791

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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 unit	by	To obtain metric unit
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
acre	0.0040	square kilometer (km^2)
square mile (mi^2)	2.590	square kilometer (km^2)
foot per day (ft/d)	0.3048	meter per day (m/d)
gallon (gal)	0.003785	cubic meter (m^3)
gallons per day (gal/d)	0.003785	cubic meter per day (m^3/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 "sea level datum of 1929."

Conversion Factors for Relating Concentration Units

[Modified from Hem, 1985]

Multiply	by	To obtain
Alkalinity, in mg/L (as HCO_3^-)	0.8202	Alkalinity, in mg/L (as $CaCO_3$)
Ammonium, in mg/L (as NH_4^+)	0.7765	Ammonium, in mg/L (as N)
Nitrate, in mg/L (as NO_3^-)	0.2259	Nitrate, in mg/L (as N)
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	0.08229	Magnesium, in meq/L
Potassium (K^+), in mg/L	0.02558	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

Sludge from sewage-treatment plants and septic tanks was discharged to unlined infiltration basins at a scavenger-waste-disposal facility in Manorville, in south-central Suffolk County, during 1964-82, and solid waste was accepted during 1960-72. Three test borings were made at the site and ground-water samples collected in 1984 and 1985 to examine the effects of the waste on local ground-water quality in the upper glacial aquifer.

The test borings reveal that 180 to 205 feet of well-sorted glacial outwash sediments overlie deposits of the Matawan Group and Magothy Formation, undifferentiated. A sandy facies of the Gardiners Clay may be present in the southern half of the 0.88-square-mile study area.

Observation wells were installed in clusters along flow lines hydraulically downgradient from the facility, and water samples were collected from 29 wells in 1984 and from 63 wells in 1985. Geochemical data indicate that a 1,300-foot-wide plume of contaminated water has moved 4,700 feet downgradient from the disposal site. Samples of plume water had higher specific conductance, lower dissolved-oxygen concentrations, and higher concentrations of dissolved solids, chloride, sodium, calcium, potassium, magnesium, and chlorobenzene than did samples from uncontaminated areas. The median background dissolved-solids concentration of 23 mg/L (milligrams per liter) in water from wells in areas unaffected by the plume is considerably lower than the median concentration of 190 mg/L for plume water, which indicates that dissolved-solids concentration and specific conductance are useful indicators of the plume's extent. Dissolved-iron concentrations in ground water are elevated for at least 1,400 feet downgradient from the site as a result of chemical (oxidation-reduction) alteration to the more soluble ferrous state. The geochemical condition of ground water near this facility shows general similarities and particular differences to previously studied landfills located in glacial outwash deposits.

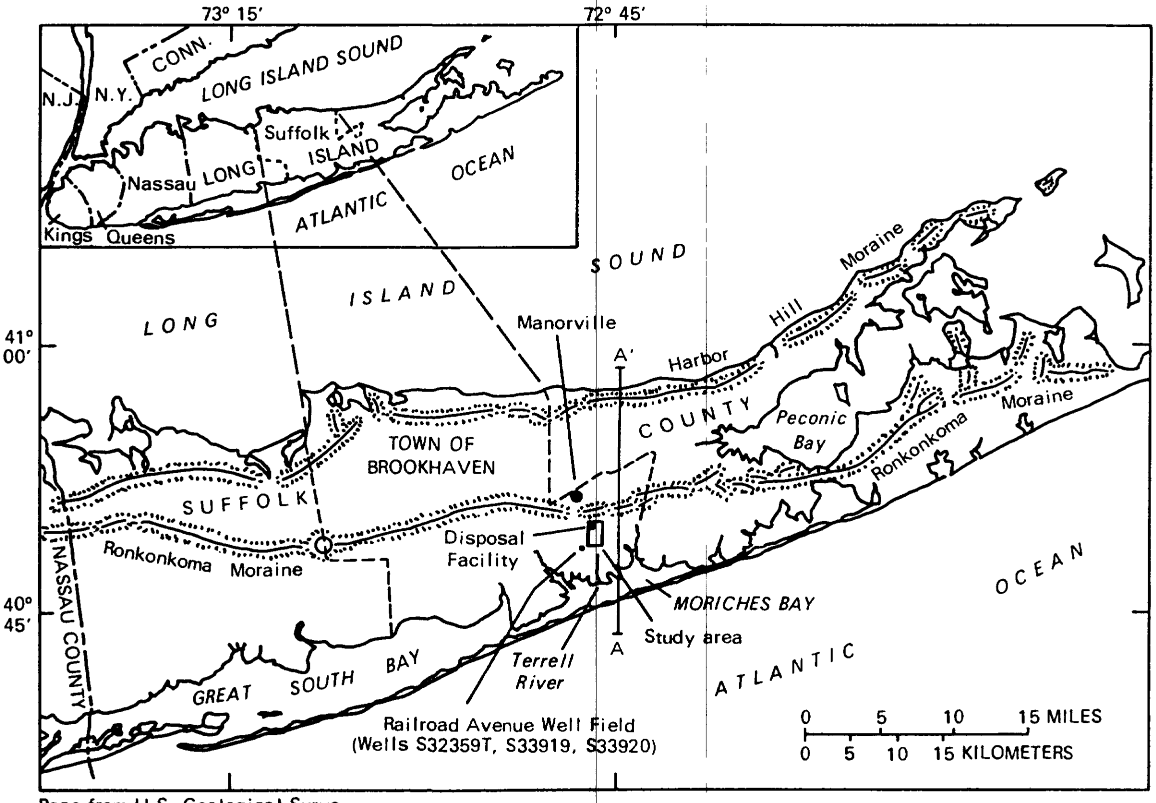
INTRODUCTION

Most of the wastes generated by the domestic and industrial activities on Long Island are treated and disposed of at municipal facilities, where they may affect the quality of water in the underlying aquifer system. Ground water is the sole source of freshwater for Nassau and Suffolk Counties, which have a combined population of approximately 2.6 million. Planning for future development of the ground-water resource requires information on the effects of waste-disposal sites on ground-water quality.

Solid-waste-disposal practices at several landfills on Long Island have affected the local ground-water quality (Wexler, 1988a; Kimmel and Braids, 1980). The movement of precipitation through solid waste dissolves chemical substances out of the materials and transports them into the aquifer system. Similarly, the ponding of liquid sewage in unlined infiltration basins can introduce dissolved contaminants to the aquifers (LeBlanc, 1984).

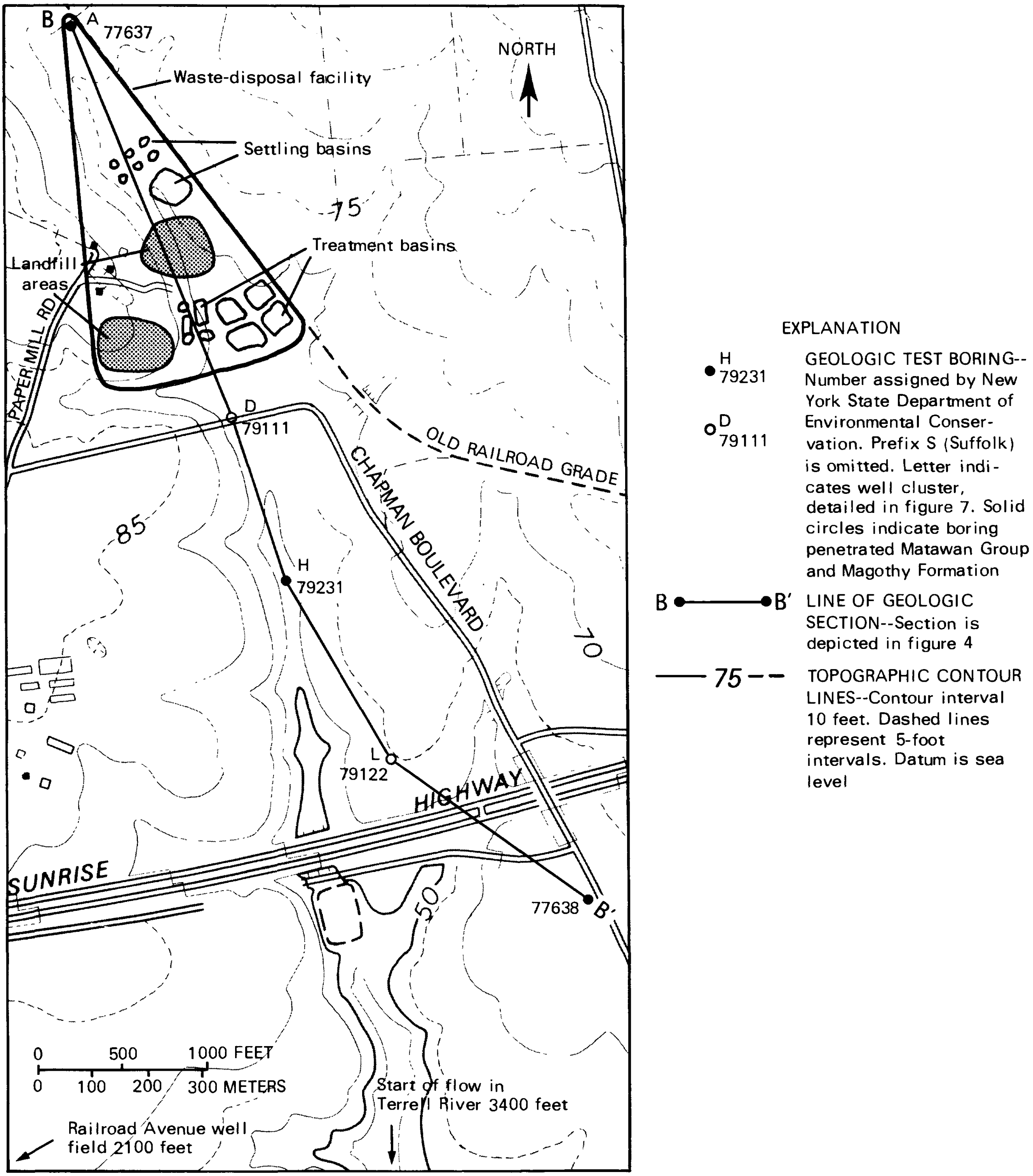
A disposal facility in Manorville (fig. 1) accepted scavenger waste (wastes from cesspools or septic tanks and sludge from municipal sewage-treatment plants) for treatment and disposal from 1964 until 1982. Solid wastes were accepted at the site during 1960-72. The facility's waste-disposal areas consisted of solid-waste landfills and several unlined liquid-waste basins excavated in glacial-outwash deposits (fig. 2). This facility and the aforementioned landfills are located on the glacial outwash deposits of permeable sand and gravel that form one of the aquifers used for water supply.

In 1983, the Town of Brookhaven entered into a cooperative agreement with the U.S. Geological Survey to examine and evaluate the effects of waste disposal at the facility on ground water in the upper glacial aquifer. The project was done between October 1983 and September 1986 and included establishing a precipitation gage and a ground-water-level recorder, expanding the observation-well network downgradient of the site, and collecting ground-water samples during two periods.



Base from U.S. Geological Survey
State Base map, 1974, 1:500,000

Figure 1.--Location of 0.88-square-mile study area near Manorville in Town of Brookhaven. (Section A-A' is depicted in fig. 3).



Base from U.S. Geological Survey
Moriches, 1967, 1:24,000

Figure 2.--Location of waste-disposal facility, test-borings, selected well borings, and section B-B′ in study area. (Geologic section B-B′ is depicted in fig. 4.)

Purpose and Scope

This report describes the local hydrogeology and water quality of the upper glacial aquifer within the 0.88-mi^2 (square-mile) area around the facility and, briefly, that of the upper part of the Magothy aquifer at the site. Data are presented in tables of the chemical quality of the groundwater samples collected in August 1984 and June 1985, and in maps, cross sections, and diagrams showing concentrations of selected chemical constituents in the upper glacial aquifer in June 1985.

Location and Site Operation

The 0.88-mi^2 area of study extends about 5,000 ft (feet) south of the south border of the disposal facility (fig. 2). Tree nurseries and woodlands surround the facility, but some residential housing is fairly close by. The woodlands consist mainly of scrub oak and pine, which are typical of that part of Long Island (Krulikas, 1986). The dry upper reach of the Terrell River stream channel (fig. 1) dissects the southward sloping land surface near the center of the study area (fig. 2).

The disposal facility first began receiving solid waste in 1960, and landfill operations continued until 1972. From 1964 through 1982, the facility accepted treated sludge from the Town of Brookhaven's sewage-treatment plants and wastes from private holding tanks. These wastes were placed in unlined basins (fig. 2) for disinfection, aeration, settling, and infiltration to the aquifer (Dvirka and Bartilucci, 1981; Eckhardt and Wexler, 1986). The facility was designed to handle about 50,000 gal/d (gallons per day) of liquid scavenger wastes but commonly received more during its latter stage of operation (Dvirka and Bartilucci, 1981). After the facility ceased operation in 1982, operations were begun to remove material that had settled on the floor of each basin and transport it to another landfill.

The basins for liquid sewage and sludge disposal are north and south of a solid-waste landfill area. The western part of the facility contains a second solid-waste landfill. The waste-disposal areas covered about 80 percent of the facility's 35-acre property.

Previous Investigations

Kimmel and Braids (1980) studied the effects of municipal-waste-disposal sites on ground-water quality at two Long Island landfills that are hydrogeologically similar to the Manorville area, and LeBlanc (1984) reported on a sewage-treatment site in a similar hydrogeologic setting on Cape Cod, Mass. The U.S. Geological Survey (Wexler 1988a, b; Wexler and Maus, 1988; Pearsall and Wexler, 1986) investigated a sanitary landfill about 8 mi west of the Manorville facility and developed a ground-water flow model and a solute-transport model to predict the extent and rates of contaminant migration.

The Geological Survey's initial investigation of the scavenger-waste facility measured water-table altitudes in a 36-mi^2 area around the facility (Eckhardt and Wexler, 1986). A surface-geophysical survey (electromagnetic terrain conductivity) was conducted as a part of a related study; results are given by Mack and Maus (1987). The concentrations of chemical constituents in one of the liquid-waste-disposal basins are given by Dvirka and Bartilucci (1981).

Acknowledgments

The author thanks Elaine McKibben and Joseph Lapienski, Division of Sanitation of the Town of Brookhaven, for their cooperation during field projects, and also the Bernstein and Eberhard families, for their cooperation in allowing access to wells during this study. The author also thanks E. J. Wexler, the first project chief of this study, for his assistance in project planning, selection of well sites, and the installation and sampling of the first set of monitoring wells.

GEOLOGIC SETTING

The scavenger-waste-disposal facility is on the glacial-outwash plain of Long Island, south of the Ronkonkoma terminal moraine (fig. 1). The outwash deposits overlie unconsolidated sediments of Cretaceous through Quaternary age that thicken south-southeastward along the dip of the underlying bedrock surface. A generalized hydrogeologic section of Long Island is shown in figure 3; the lithologic and water-bearing characteristics of the units are summarized in table 1. Further discussions of the geology of Long Island are given by Suter and others (1949) and Jensen and Soren (1971, 1974).

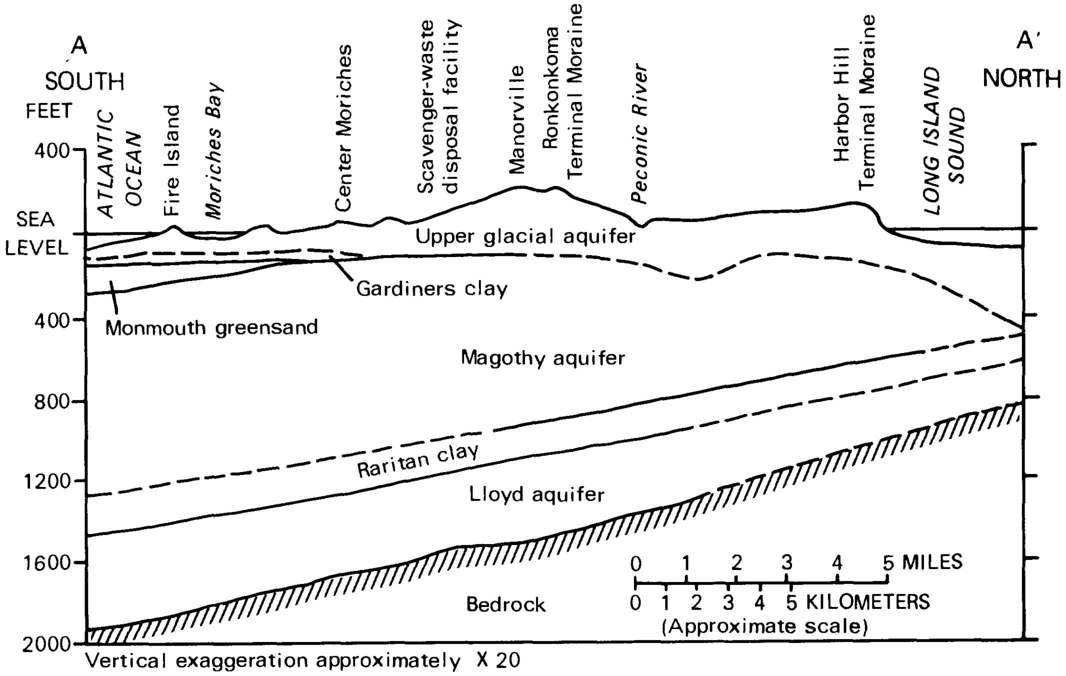


Figure 3.--Relative positions of major hydrogeologic units on Long Island. (Modified from Jensen and Soren, 1974.)

Table 1.--Generalized description of Hydrogeologic units underlying the Town of Brookhaven, N.Y.

[Modified from Jensen and Soren, 1971, table 1]

Hydrogeologic unit	Geologic unit	Description and water-bearing character
Upper glacial aquifer	Upper Pleistocene deposits	Mainly brown and gray sand and gravel deposits 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.

Additional geologic investigations within the Town of Brookhaven were conducted by deLaguna (1963), Wexler (1988a), and Koszalka (1984).

The U.S. Geological Survey drilled three test borings in the study area (fig. 2) in October 1984 and March 1985 by the mud-rotary method and used geologic cores and gamma-ray logs to distinguish the sedimentary units. A north-south geologic section through the study area, drawn from data from the test borings and from gamma-ray logs of monitoring-well borings, is shown in figure 4.

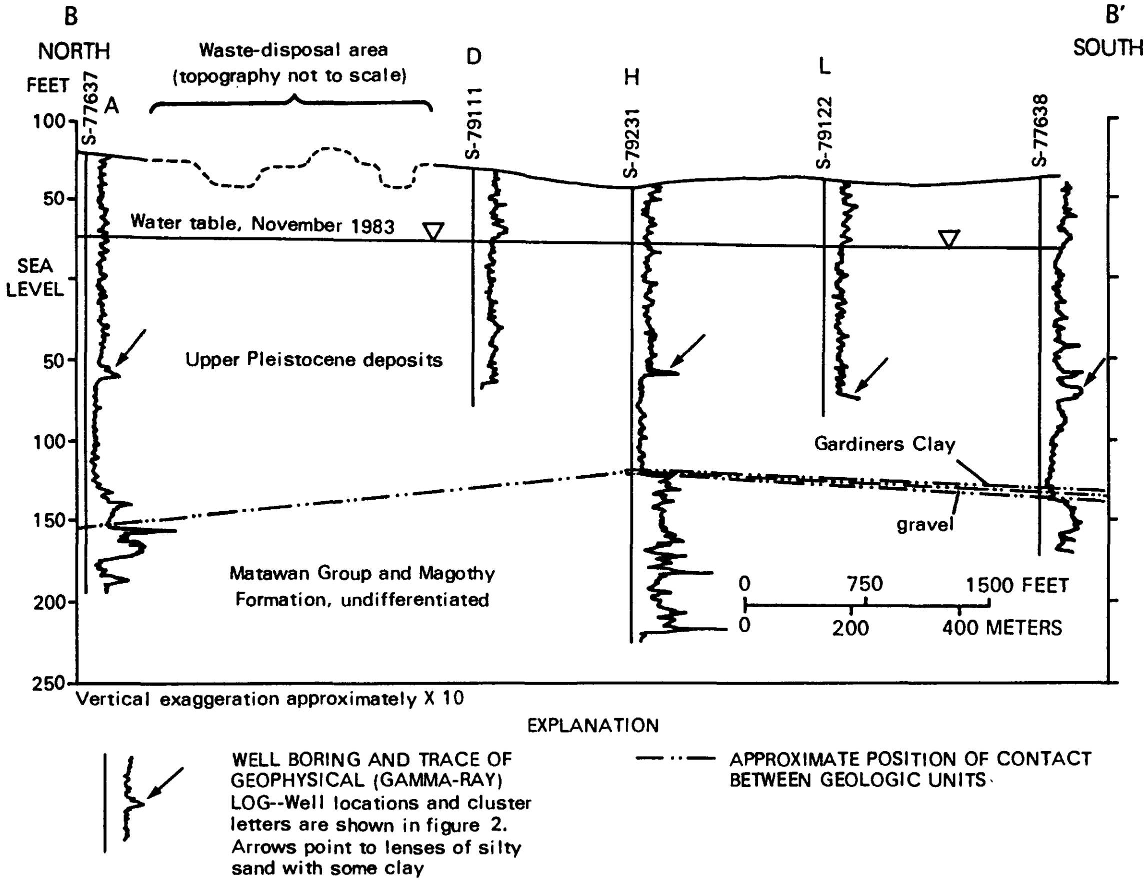


Figure 4.--Geologic units and gamma-ray logs from well borings along geologic section B-B'. (Line of section is shown on fig. 2.)

Pleistocene Sediments

Glacial-Outwash Deposits

The stratified glacial-outwash deposits at the three test borings around the waste-disposal site are 180 to 205 ft thick. The outwash unit contains three divisions, as indicated by lithology and grain-size distribution.

The basal part of the outwash is well-sorted, light-brown, fine to medium quartz sand that ranges in thickness from about 50 ft at well S77638 near the south end of section B-B' to 65 ft at well S77637 at the north end of section B-B'. Grains of glauconite are scattered throughout this sand, but the bottom of this zone at well S77638 is noticeably greener because it contains minor amounts of interstitial green clay. This layer may represent a transitional sandy facies of the Gardiners Clay or, more likely, a deposit of reworked Gardiners Clay eroded from deposits north of the study area.

Above the basal sand unit lies a discontinuous layer of silty and clayey sand ranging from 4 ft thick at well S79231 to about 13 ft thick at well S77638. It is distinguished on geophysical logs by higher gamma radiation (fig. 4). This fine-grained layer may have been deposited in a proglacial lake or during a short-term rise in sea level during an interglacial period. This layer may correlate with the "20-foot" clay (Doriski and Wilde-Katz, 1983) because it separates the basal, finer grained outwash from the upper, coarser grained outwash. The gamma-radiation log of monitoring well S79111, about 400 ft south of the site border, indicates this layer to be absent in the area just downgradient of the facility.

The uppermost 116 to 140 ft of sediment is glacial outwash associated with the latest stage of Wisconsin glaciation. This division contains well-sorted brown and tan, fine to coarse sand and gravel with little clay or silt. Thin, discontinuous layers of micaceous sediments or silt and clay are indicated by gamma-radiation logs. The most common constituents are quartz, feldspar, and rock fragments. These deposits are believed to have been laid down by sediment-laden streams of glacial meltwaters from the ice sheet (Koszalka, 1984).

Gardiners Clay

The Gardiners Clay is believed to be a marine deposit laid down during a period of temporary glacial retreat (Suter and others, 1949). It is typically 10 to 20 ft thick and ranges from silty to sandy with glauconite. It locally contains discontinuous sand beds. The southward slope of the base of the Gardiners during deposition, together with subsequent erosional processes, resulted in an irregular surface and partial removal of this unit at its northern extent.

The Gardiners Clay was found only in wash samples in the south and central borings but not in the northern boring. The unit in the study area consists of green, clayey sand with quartz and glauconite grains. It overlies a layer of partly cemented gravel that rests upon the Matawan Group and Magothy Formation, undifferentiated. The clay layer and the gravel layer were not detectable on gamma-ray logs. These layers combined are less than 5 ft thick and apparently pinch out just north of boring S79231. The sand layers within the Gardiners Clay in the study area were probably deposited nearer to the shore than were the more clayey layers commonly found at other sites (Doriski and Wilde-Katz, 1983).

Cretaceous Sediments

The Matawan Group and Magothy Formation, undifferentiated, contains sedimentary deposits from a river delta system of Late Cretaceous age. As a result of its manner of deposition, the composition and texture of sediments vary laterally and vertically, with lenticular clay and sandy clay layers interbedded with fine to medium lignitic quartz sand. This unit is estimated to be more than 900 ft thick in the study area (Jensen and Soren, 1974).

The three test borings drilled in this study penetrated the upper part of the unit. Sand layers of this unit consist of gray, fine to medium quartz sand with some interstitial silt and clay and some laminated clay beds. Lignite, locally associated with pyrite and marcasite, also is common. Black and gray sandy clay beds locally are present between sand layers.

Before the test-boring program, few test holes had been drilled into this unit in this part of Suffolk County, and little information was available about the altitude of the contact between the Matawan Group and Magothy Formation and overlying post-Cretaceous deposits. The altitude of the upper surface varies throughout Long Island because the depositional surface was irregular and was further altered later on by stream-channel formation during post-Cretaceous erosion. The contact between Pleistocene and Cretaceous units in the study area ranges between 125 and 160 ft below sea level (fig. 4).

Above the Matawan Group and Magothy Formation is a zone of post-Cretaceous stream-reworked sediment, especially in boring S77637, at the north end of the facility. Geologic samples contain orange-stained quartz grains with a few grains of glauconite and some lignite. A similar zone may exist in S32359, the test boring at the Railroad Avenue well field (fig. 1), about 1 mi southwest of the site.

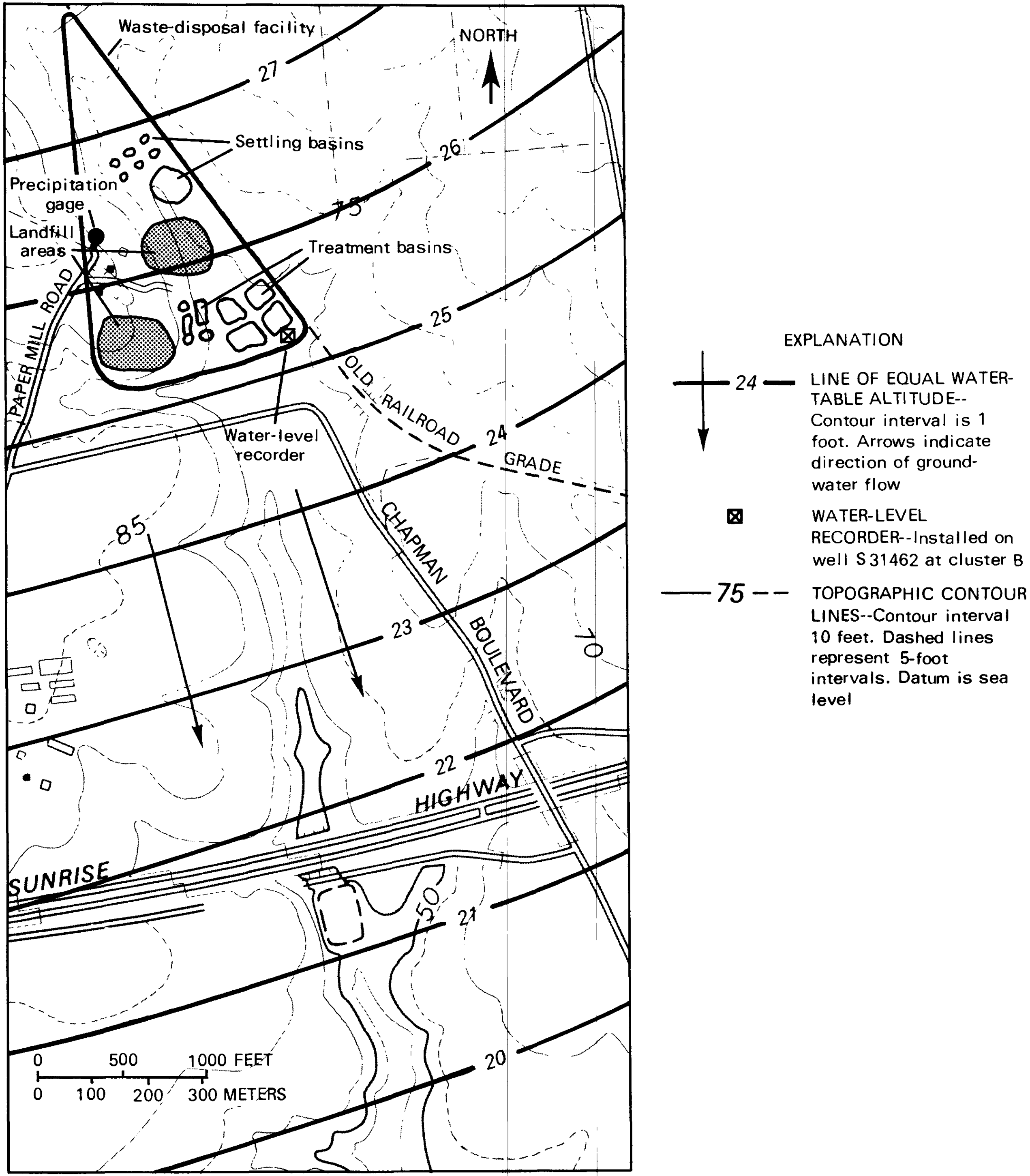
The Monmouth Group, which overlies the Matawan Group-Magothy Formation along parts of southern Long Island, consists of marine silty sand and clay. It was not detected in the three test borings; thus, its northern extent in the study area is unknown.

HYDROLOGY

Water supplies for Suffolk County are obtained from the upper glacial, Magothy, and Lloyd aquifers. The hydrology of Long Island's aquifer system is described by McClymonds and Franke (1972) and Cohen and others (1968). Warren and others (1968) described the hydrology (precipitation, evapotranspiration, and recharge) of the Brookhaven area. Hydrologic characteristics of the upper glacial aquifer in the Manorville area are given in a report by Eckhardt and Wexler (1986), which includes a water-table map. The following sections describe the hydrogeology of the upper glacial aquifer and the upper part of the Magothy aquifer in the 0.88-mi^2 study area as indicated by test drilling done for this study.

Upper Glacial Aquifer

The water table in the study area is in the upper glacial aquifer, which has a saturated thickness of 140 to 170 ft. A map showing the water-table altitude in November 1983 (fig. 5) indicates the direction of ground-water flow to be south-southeastward. Thickness of the unsaturated zone in the study area ranges from about 55 ft in the north to about 14 ft in the nonflowing part of the stream channel of the Terrell River (fig. 1). The start of flow in the Terrell River channel was about 8,000 ft (1.5 mi) south of the disposal facility's southern border in April 1983.



Base from U.S. Geological Survey
Moriches, 1967, 1:24,000

Figure 5.--Water-table altitude in November 1983. (Modified from Eckhardt and Wexler, 1986.)

Ground-Water Movement

The horizontal hydraulic conductivity of the upper glacial aquifer in the study area has been estimated to be between 220 and 430 ft/d (feet per day) (Eckhardt and Wexler, 1986). A ground-water flow model of a 26-mi^2 area centered 9 mi west of the Manorville disposal facility indicated that the average hydraulic conductivity is 200 ft/d (Wexler and Maus, 1988). Eckhardt and Wexler (1986), using specific-capacity data from supply wells in the upper glacial aquifer, estimated a maximum horizontal hydraulic conductivity of 430 ft/d and calculated the average horizontal ground-water velocity to range from 1.0 to 1.7 ft/d. McClymonds and Franke (1972) calculated the average hydraulic conductivity of the upper glacial aquifer in south-central Suffolk County to be 254 ft/d.

The anisotropy (ratio of horizontal to vertical hydraulic conductivity) of the upper glacial aquifer averages about 10:1 (Reilly and others, 1983). Eckhardt and Wexler (1986) used vertical gradients measured during November 1983 with estimates of vertical hydraulic conductivity to obtain an average vertical ground-water velocity of 0.02 ft/d.

Disposal operations at the facility altered the natural recharge conditions. Liquid scavenger wastes applied to the basins infiltrated almost continuously during operations, which caused near-saturated conditions beneath the basins. The nearly continuous percolation of liquid waste caused a mounding of the water table beneath the basins that increased the downward ground-water flow gradient and allowed the fluid to move deeper into the aquifer system than it would have under natural conditions.

Recharge and Water-Table Fluctuations

Precipitation is the only natural source of freshwater recharge to Long Island's ground-water system. Warren and others (1968) indicate that 50 percent of the average annual precipitation (45 inches) reaches the ground-water system; the rest is lost by evapotranspiration and, to a lesser degree, as direct runoff to streams. Recharge occurs primarily during the nongrowing season, from October to May. The amount of recharge is influenced by the frequency and amount of precipitation, evapotranspiration rate during the growing season, and the soil-moisture deficit in the unsaturated zone at the time of precipitation.

The study area receives recharge from two sources--subsurface inflow along the north and west boundaries of the area and precipitation at land surface. The direction of ground-water flow is south-southeastward through the study area to the south shore of Long Island, where it discharges at points near East Moriches and beneath Moriches Bay (Eckhardt and Wexler, 1986).

The U.S. Geological Survey established a precipitation gage on the west side of the disposal facility in 1983 and installed a water-level recorder at the same time on well S31462 at the southeast corner of the facility (locations shown in fig. 5) to evaluate the effects of natural recharge on the water table. In addition, the Survey measured water levels quarterly at several well sites in the Town of Brookhaven, including the Railroad Avenue well field, about 1 mi southwest of the site (fig. 1). One well at this site

(S33919) is screened in the upper glacial aquifer, and another in the Magothy aquifer (S33920). Hydrographs showing water-level fluctuations at these two wells and at the recorder well (S31462) from October 1983 through May 1986 are shown in figure 6 with the monthly rainfall recorded at the precipitation gage.

A period of high precipitation from October 1983 to July 1984 produced nearly record-high water levels in much of Suffolk County. This was followed by a period of below-normal monthly rainfall from August 1984 to April 1985. The hydrographs show that water levels declined about 4.5 ft during this period and continued to decline, but at a slower rate, for the next 10 months, even though monthly precipitation was close to normal.

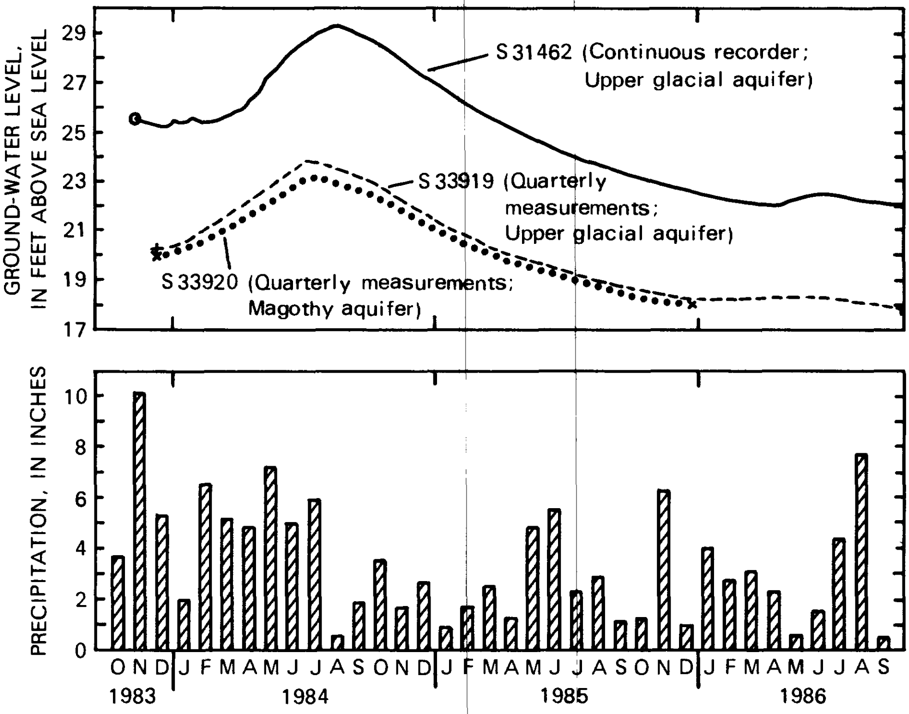


Figure 6.--Water levels in three wells near disposal site and monthly precipitation, October 1983 through September 1986. (Precipitation-gage and well locations are shown in figs. 1 and 5.)

Gardiners Clay

The Gardiners Clay is a confining unit along parts of the south shore of Long Island. Hydraulic conductivity of the clay in areas in which it occurs has been estimated to be 0.01 ft/d horizontally and 0.001 ft/d vertically (Franke and Cohen, 1972).

The Gardiners Clay is absent in the northern half of the study area and is sandy and only a few feet thick in the southern half of the area (fig. 4). Although hydraulic conductivity was not measured, its characteristics indicate that it may be ineffective as a confining unit in this area. The absence of the Gardiners Clay directly beneath the disposal facility suggests a hydraulic connection between the upper glacial and Magothy aquifers and a potential for the downward movement of leachate from the disposal facility into the Magothy aquifer.

Magothy Aquifer

The sediments of the Matawan Group and Magothy Formation, undifferentiated, make up the Magothy aquifer (table 1). The deposits are of varying composition, thickness, and extent, which makes estimation of average hydraulic conductivity difficult. Layers of silty fine sand and lenses of clay are more prevalent in the Magothy aquifer than in the upper glacial aquifer and thus restrict ground-water flow to a greater extent. Average horizontal and vertical hydraulic conductivities of the Magothy aquifer in this part of Long Island have been estimated to be about 48 ft/d (McClymonds and Franke, 1972) and 1.4 ft/d (Franke and Cohen, 1972), respectively. Sandy parts of the Magothy aquifer have higher hydraulic conductivity and higher flow rates than the estimated average values, however.

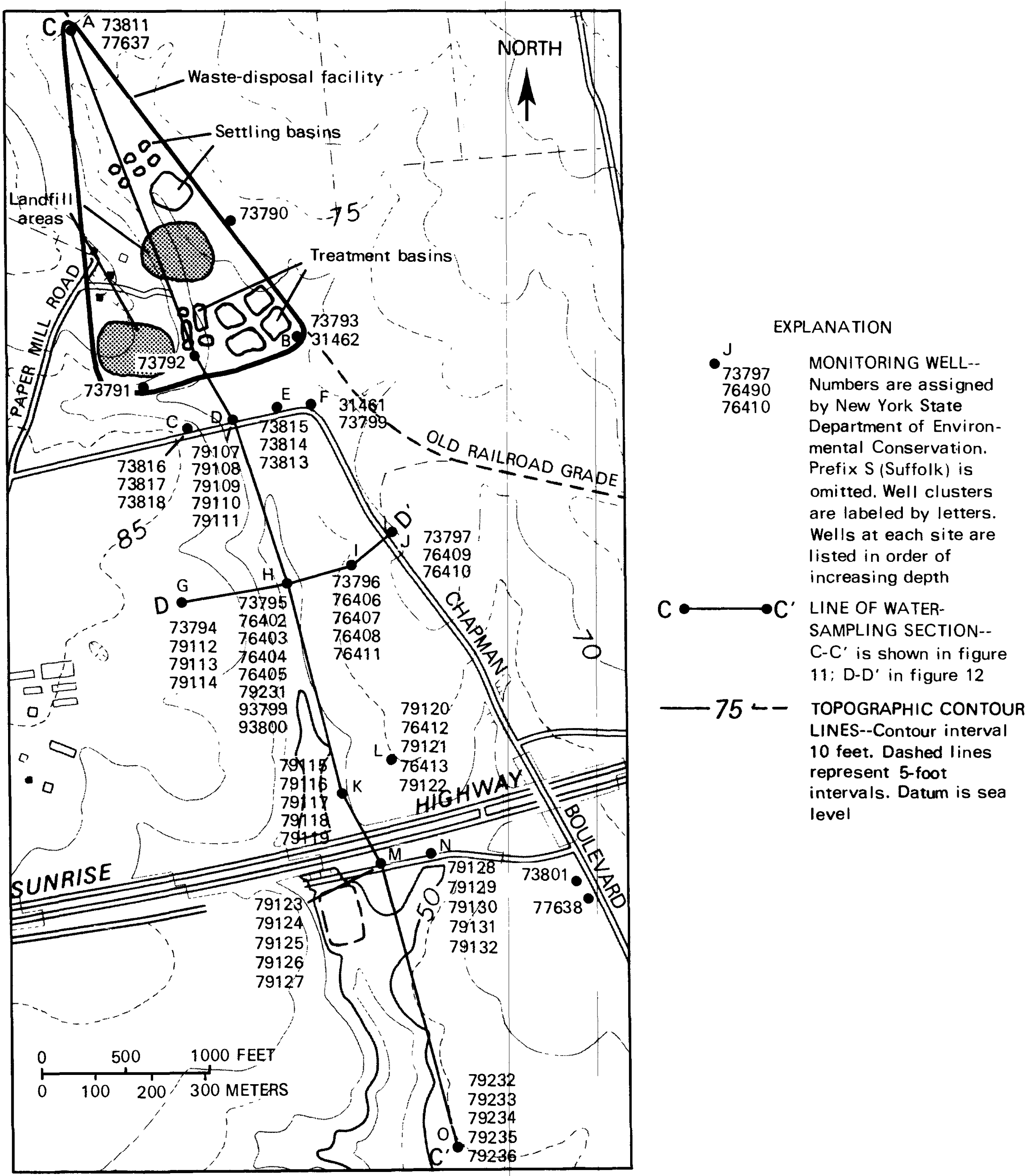
Ground-water levels in the upper glacial and Magothy aquifers are presented in figure 6. The difference between water levels in the two aquifers at the well cluster (S33919 and S33920) at the Railroad Avenue well field was larger (0.6 ft) during the summer of 1984, a period of high water levels, than in late 1985 (0.2 ft), a period of low water levels. The greater vertical hydraulic gradient during the rainy period indicates that (1) recharge to deeper sections of the aquifer system varies with precipitation and climatic conditions, and (2) above-average precipitation, which causes high water levels in the upper glacial aquifer, is not immediately transmitted to the Magothy aquifer but is slightly retarded by the lower hydraulic conductivity of the Magothy aquifer and its local confining clay beds.

Although clay beds in the Magothy aquifer can act as confining layers, they are not extensive beneath the disposal facility. Thus, the absence of the Gardiners Clay and extensive Magothy clay layers (fig. 4) beneath the facility allows a hydraulic connection between the upper glacial and Magothy aquifers. This, in addition to the water-table mounding that developed during disposal operations, resulted in contamination of the upper part of the Magothy aquifer (discussed later on). The lower hydraulic conductivity of Magothy sediments than of upper glacial sediments in this area probably would make solute transport slower than in upper glacial deposits, however.

GROUND-WATER QUALITY

Methods of Investigation

A network of 66 water-quality-monitoring wells, including 18 steel-cased wells from a previous network used by Eckhardt and Wexler (1986) was established in stages in the area of the disposal facility. In March 1984, 12 2-inch-diameter monitoring wells were installed by a hollow-stem auger drill rig, and in March 1985, 31 additional 2-inch-diameter monitoring wells were installed. One well screened in the Magothy aquifer was installed in each of the three geologic test borings. Two additional wells screened in the upper glacial aquifer were installed in test boring S79231. Wells installed during these phases of the project were constructed of solvent-welded PVC (polyvinyl chloride) casing. Locations of wells are shown in figure 7; physical descriptions of wells used in the study are given in table 2.



Base from U.S. Geological Survey
Moriches, 1967, 1:24,000

Figure 7.--Observation well network and locations of sections C-C' and D-D'.

Table 2.--Physical description of wells used in the study.

[Locations are shown in figs. 5 and 7. Ft, feet; in., inches]

Well number	Latitude	Longitude	Aquifer	Total depth (ft)	Depth to screen (ft) Top	Bottom	Screen length (ft)	Cluster designation	Casing material	Diameter (in.)
S 31461	404956	724642	Glacial	68	62	68	6	F	Steel	4
S 31462[a]	405000	724643	Glacial	73	67	73	6	B	Steel	4
S 73790	405007	724648	Glacial	61	58	61	3		Steel	2
S 73791	404957	724655	Glacial	61	58	61	3		Steel	2
S 73792	404959	724651	Glacial	61	58	61	3		Steel	2
S 73793	405000	724643	Glacial	56	53	56	3	B	Steel	2
S 73794	404945	724652	Glacial	73	70	73	3	G	Steel	2
S 73795	404946	724644	Glacial	47	44	47	3	H	Steel	2
S 73796	404947	724639	Glacial	55	52	55	3	I	Steel	2
S 73797	404949	724635	Glacial	57	54	57	3	J	Steel	2
S 73799	404956	724642	Glacial	101	98	101	3	F	Steel	2
S 73801	404929	724622	Glacial	50	47	50	3		Steel	2
S 73811	405014	724657	Glacial	85	80	85	5	A	Steel	4
S 73813	404956	724645	Glacial	88	83	88	5	E	Steel	4
S 73814	404956	724645	Glacial	68	63	68	5	E	Steel	4
S 73815	404956	724645	Glacial	53	48	53	5	E	Steel	4
S 73816	404955	724652	Glacial	70	65	70	5	C	Steel	4
S 73817	404955	724652	Glacial	90	85	90	5	C	Steel	4
S 73818	404955	724652	Glacial	110	105	110	5	C	Steel	4
S 76402	404946	724644	Glacial	68	64	68	4	H	PVC	2
S 76403	404946	724644	Glacial	88	84	88	4	H	PVC	2
S 76404	404946	724644	Glacial	108	104	108	4	H	PVC	2
S 76405	404946	724644	Glacial	137	133	137	4	H	PVC	2
S 76406	404947	724639	Glacial	78	74	78	4	I	PVC	2
S 76407	404947	724639	Glacial	98	94	98	4	I	PVC	2
S 76408	404947	724639	Glacial	117	113	117	4	I	PVC	2
S 76409	404949	724635	Glacial	99	95	99	4	J	PVC	2
S 76410	404949	724635	Glacial	123	119	123	4	J	PVC	2
S 76411	404947	724639	Glacial	146	142	146	4	I	PVC	2
S 76412	404937	724636	Glacial	78	74	78	4	L	PVC	2
S 76413	404937	724636	Glacial	118	114	118	4	L	PVC	2
S 77637	405014	724657	Magothy	263	258	263	5	A	PVC	4
S 77638	404928	724621	Magothy	240	231	236	5		PVC	4
S 79107	404955	724648	Glacial	64	60	64	4	D	PVC	2
S 79108	404955	724648	Glacial	84	80	84	4	D	PVC	2
S 79109	404955	724648	Glacial	104	100	104	4	D	PVC	2
S 79110	404955	724648	Glacial	121	117	121	4	D	PVC	2
S 79111	404955	724648	Glacial	142	138	142	4	D	PVC	2
S 79112	404945	724652	Glacial	103	98	103	5	G	PVC	2
S 79113	404945	724652	Glacial	123	118	123	5	G	PVC	2
S 79114	404945	724652	Glacial	144	139	144	5	G	PVC	2
S 79115	404936	724640	Glacial	62	58	62	4	K	PVC	2
S 79116	404936	724640	Glacial	82	77	82	5	K	PVC	2
S 79117	404936	724640	Glacial	102	98	102	4	K	PVC	2
S 79118	404936	724640	Glacial	124	120	124	4	K	PVC	2
S 79119	404936	724640	Glacial	142	138	142	4	K	PVC	2
S 79120	404937	724636	Glacial	62	58	62	4	L	PVC	2
S 79121	404937	724636	Glacial	102	98	102	4	L	PVC	2
S 79122	404937	724636	Glacial	142	138	142	4	L	PVC	2
S 79123	404929	724637	Glacial	64	60	64	4	M	PVC	2
S 79124	404929	724637	Glacial	84	80	84	4	M	PVC	2
S 79125	404929	724637	Glacial	105	101	105	4	M	PVC	2
S 79126	404929	724637	Glacial	121	117	121	4	M	PVC	2
S 79127	404929	724637	Glacial	140	136	140	4	M	PVC	2
S 79128	404930	724633	Glacial	66	62	66	4	N	PVC	2
S 79129	404930	724633	Glacial	84	80	84	4	N	PVC	2
S 79130	404930	724633	Glacial	105	101	105	4	N	PVC	2
S 79131	404930	724633	Glacial	125	121	125	4	N	PVC	2
S 79132	404930	724633	Glacial	145	141	145	4	N	PVC	2
S 79231[b]	404946	724644	Magothy	256	243	253	10	H	PVC	2
S 79232	404915	724631	Glacial	65	60	65	5	O	PVC	2
S 79233	404915	724631	Glacial	85	80	85	5	O	PVC	2
S 79234	404915	724631	Glacial	106	101	106	5	O	PVC	2
S 79235	404915	724631	Glacial	125	120	125	5	O	PVC	2
S 79236	404915	724631	Glacial	145	140	145	5	O	PVC	2
S 93799[b]	404946	724644	Glacial	183	175	180	5	H	PVC	2
S 93800[b]	404946	724644	Glacial	159	151	156	5	H	PVC	2

[a] Water-level recorder installed, well not sampled.

[b] Installed in borehole S79231 at cluster H.

Well locations were selected according to the direction of ground-water flow as determined from the November 1983 water-table map (Eckhardt and Wexler, 1986) and an electromagnetic terrain conductivity survey (Mack and Maus, 1987). Wells were installed along flow lines leading downgradient from the disposal facility. A centrally located flow line extending 1 mi downgradient from the site (C-C', fig. 7) was selected for extensive water-quality monitoring. Wells were drilled in clusters at selected locations and screened at differing depths to provide information on vertical variability of water quality in the upper glacial aquifer.

Ground-water samples were collected from monitoring wells in August 1984 and June 1985; results of laboratory and field analyses are given in appendix 1 (at end of report). In August 1984, 29 wells were sampled (appendix 1A), and in June 1985, 63 wells were sampled, including a resampling of 26 of the wells sampled in 1984 (appendix 1B). A minimum of three casing volumes were evacuated from each well by submersible pump to obtain representative ground-water samples. Temperature, pH, specific conductance, and dissolved-oxygen concentration of each sample were recorded at the well site. Samples for dissolved-constituent analysis were filtered in the field through 0.45-μ or 0.65-μ cellulose filters and shipped to the laboratory that had been contracted by the Town of Brookhaven (New York Testing Laboratories[1] of Westbury, N.Y.). The analyses included pH, specific conductance, dissolved solids, total alkalinity, bicarbonate, chloride, sulfate, ammonium, nitrate, nitrite, total Kjeldahl nitrogen, calcium, iron, lead, magnesium, manganese, potassium, selenium, and sodium. Six duplicate samples in 1984 and 12 in 1985 were sent to the U.S. Geological Survey National Water Quality Laboratory in Doraville, Ga. for inorganic analysis for quality-assurance purposes. The U.S. Geological Survey National Water Quality Laboratory and New York Testing Laboratories participate in the Standard Reference Water Sample Program, a quality-assurance program administered by the U.S. Geological Survey.

The 1985 sampling included analyses for priority pollutant[2] organic chemical compounds (appendix 2) by the U.S. Geological Survey National Water Quality Laboratory in Doraville, Ga. Samples from 20 wells along the central flowline (C-C') were tested for volatile organic compounds, and six were tested for acid- and base/neutral-extractable organic compounds and for polychlorinated biphenyls (PCBs). Results for volatile organic compounds and base/neutral-extractable compounds that were found to be above the detection limit in one or more wells are given in appendix 3.

Background Water Quality

Eight wells outside the leachate plume in the study area were sampled to gather information on background levels of chemical constituents. One well in the Magothy aquifer and two wells in the upper glacial aquifer hydraulically upgradient from the site were sampled. A cluster of three wells in the upper

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[1] Use of firm name in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

[2] Priority pollutants are constituents listed in the Environmental Protection Agency list of 129 priority pollutants (Keith and Telliard, 1979, p. 418.)

glacial aquifer, one additional well in the upper glacial aquifer, and one well in the Magothy aquifer east of the plume were also sampled. Water-quality data from 1973-84 from an additional nearby well in the upper glacial aquifer were obtained from the Suffolk County Department of Health Services.

The inorganic chemical quality of water from background wells that tap the upper glacial aquifer near the site is summarized in table 3. This table shows the median, minimum, and maximum concentrations of 16 constituents and specific conductance, and the number of samples analyzed for each.

The sources of chemical constituents in native ground water are discussed by Franke and McClymonds (1972), deLaguna (1964), and Wexler (1988a). Generally, the quality of water from background wells in the study area is similar to that of ground water in relatively undeveloped parts of Long Island. Synthetic organic chemical compounds were not detected at background wells.

Table 3.--Chemical quality of samples from wells that represent background water quality.

[Dashes indicate no data available.]

Constituent	Upper glacial aquifer at Manorville waste-disposal facility				Uncontaminated Long Island ground water[1]
	Median	Minimum	Maximum	Number of samples	
Oxygen, dissolved (mg/L)	11.2	9.7	12.2	15	--
Specific conductance (µS/cm)	46	35	302	17	50
Dissolved solids (mg/L)	23	17	120	8	36
Alkalinity, lab (mg/L as $CaCO_3$)	17.5	10	300	8	9
Sulfate, dissolved (mg/L as SO_4)	[2]4.7	2	18	17	8
Chloride, dissolved (mg/L as Cl)	7	4	70	17	5
Iron, dissolved (µg/L as Fe)	[2]121	<20	830	9	200
Manganese, dissolved (µg/L as Mn)	[2]17	<10	62	9	--
Calcium, dissolved (mg/L as Ca)	1.07	0.25	8.7	10	2
Magnesium, dissolved (mg/L as Mg)	1.3	0.58	3.9	10	1.5
Potassium, dissolved (mg/L as K)	0.5	0.3	2.0	16	0.6
Sodium, dissolved (mg/L as Na)	4.1	3.7	40	16	4
Selenium, dissolved (µg/L as Se)	<1	<1	4	9	--
Ammonia (mg/L as N)	[2]0.026	0.020	1.51	9	--
Nitrate (mg/L as N)	[2]0.041	0.020	4.16	10	0.5
Nitrite (mg/L as N)	<0.010	<0.010	0.030	9	--
Total Kjeldahl nitrogen (mg/L as N)	[2]0.06	0.03	29	9	--

[1] Values from deLaguna, 1964.

[2] Median values calculated by method described by Helsel and Cohn (1988).

DeLaguna (1964) presented chemical data from typical samples of uncontaminated ground water in central Suffolk County. These values, also presented in table 3, are close to the median concentrations of the constituents measured in the background ground water near the disposal facility. The 1984 and 1985 samples of ambient ground water in the study area had a median specific conductance of 46 µS/cm (microsiemens per centimeter at 25° Celsius); only a few exceeded 100 µS/cm. DeLaguna found the typical specific conductance to be 50 µS/cm. Of the 11 constituents compared, only three (sodium, alkalinity, chloride) exceeded the concentrations given by deLaguna. Sodium (4.1 mg/L compared to 4 mg/L) and chloride (7 mg/L compared to 5 mg/L) were only slightly higher, but alkalinity (17.5 mg/L to 9 mg/L) was nearly twice as high.

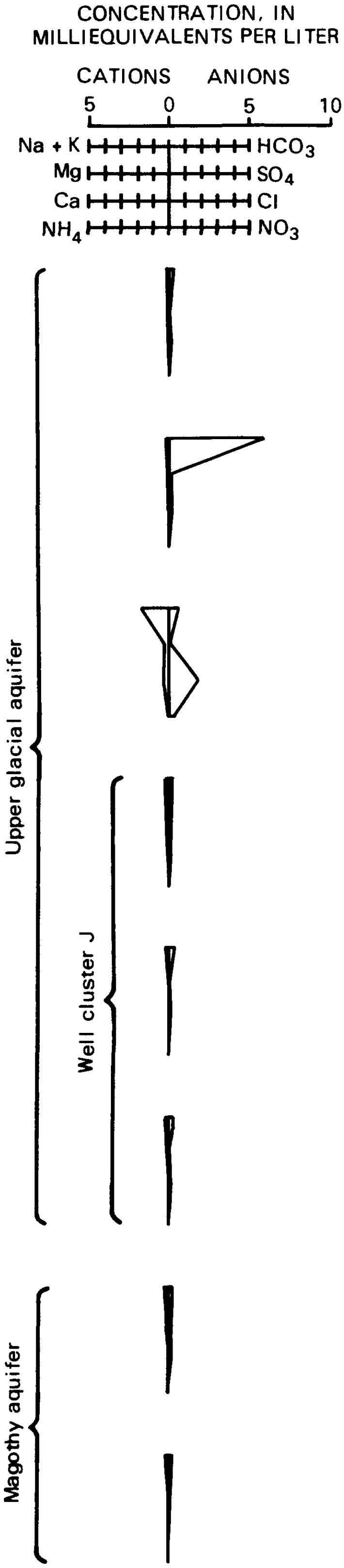
Stiff diagrams, which present concentrations of five major cations and four major anions (Stiff, 1951) of background samples from the study area, are shown in figure 8. Stiff diagrams are used to compare inorganic chemical ratios and patterns among samples and to detect local differences or temporal changes in water quality. The diagrams indicate generally low concentrations of chemical constituents (less than 0.5 meq/L, milliequivalents per liter) in background wells in the study area, although some variation is evident, with a few unusually high values.

The anomalous pattern for well S73801, which is south of Sunrise Highway on Chapman Boulevard, reflects substantially higher levels of sodium, calcium, potassium, and chloride than at other background wells. The well is screened about 6 ft below the water table, and the ion concentrations of this sample probably reflect winter salting of roads, as also found by Wexler (1988a) at the Brookhaven landfill site.

Stiff diagrams (fig. 8) for wells S77637 (263 ft deep) and S77638 (240 ft deep) show that background water quality in the Magothy aquifer is similar to that in the upper glacial aquifer. Concentrations of most constituents at these two wells (appendix 1B, at end of report) are generally close to the median values of constituents in the upper glacial aquifer (table 3), except that sulfate, iron, specific conductance, ammonium, and total Kjeldahl nitrogen values are higher, and nitrate and dissolved oxygen values are lower.

Effects of Waste Disposal on Ground-Water Quality

The concentrations of inorganic and organic chemicals in the liquid scavenger wastes that were discharged to basins at the facility were analyzed in a study by Dvirka and Bartilucci (1981); a partial listing of results is given in table 4. The wastes were characterized by elevated concentrations of total and dissolved solids and the presence of a variety of chemical constituents, including calcium, potassium, sodium, iron, nitrogen, some heavy metals, and some synthetic organic chemical compounds. Dvirka and Bartilucci (1981) noted that industrial wastes, in addition to cesspool and septic tank waste and county sewage sludge, also may have been disposed of at the site at times, as indicated by the presence of heavy metals and certain organic chemical compounds.



Well Number	Date of Sample (mo/d/yr)	Specific Conductance (microsiemens per centimeter at 25° C)	Depth of screen zone below water table of November 1983 (in feet)
73811	06/25/85	57	24-29
73790	06/28/85	53	9-12
73801	06/14/85	294	3-6
73797	08/21/84	52	9-12
76409	08/21/84	36	50-54
76410	08/21/84	47	74-78
77637	06/25/85	72	199-204
77638	06/26/85	79	210-215

Figure 8.--Background concentrations of major ions in ground water in study area. (Well locations are shown in fig. 7.)

Table 4.--Results of chemical analyses of wastewater from a disposal basin

[Modified from Dvirka and Bartilucci, 1981. mg/L, milligrams per liter; µg/L, micrograms per liter; < less than.]

Physical properties and inorganic constituents	Value (in mg/L except as noted)	Organic compounds	Value (in µg/L)
Specific conductance	793 µS/cm	Benzene	2
pH	6.0 units	Bromoform	<1
Total solids[1]	10,568	Carbon tetrachloride	<1
Dissolved solids[1]	1,216	Chlorodibromomethane	<1
Total alkalinity	428	Chloroform	<2
Chloride	72	Bromodichloromethane	<1
Sodium	130	Methylene chloride	11
Sulfate	47	Tetrachloroethylene	80
Total Kjeldahl nitrogen	135	Toluene	300
Calcium	42	Trichloroethylene	14
Iron	49	1,1,-Dichloroethylene	<5
Lead	0.7	1,1-Dichloroethane	.8
Manganese	1.5	1,1,1-Trichloroethane	44
Potassium	27	1,1,2-Trichloroethane	<5
		1,2-Dichloroethane	<5
		1,2-Dichlorobenzene	20
		1,4-Dichlorobenzene	27

[1] Number of samples analyzed for dissolved and total solids was unequal.

Upper Glacial Aquifer

Dissolved-solids concentration.--Dissolved-solids concentration and the related physical property of specific conductance often can be used to delineate zones where ground water has been contaminated by wastes (Kimmel and Braids, 1980; Wexler, 1988a). At the Manorville site, background water quality has generally less than 50 mg/L of dissolved solids, except when it is affected by road salting. Wells downgradient from the facility were considered to be part of a plume of leachate-influenced ground water if their samples contained dissolved-solids concentrations greater than 50 mg/L. The dissolved-solids concentration of ambient ground water near the site is generally less than 50 mg/L, whereas that of the plume is generally greater than 100 mg/L; this makes dissolved-solids concentration a useful indicator for locating the plume at this site. The direct relationship between dissolved solids and specific conductance (Hem, 1985) makes specific conductance a useful field test for dissolved solids because it is easily measured directly at the well site.

The ranges of concentrations of selected constituents at wells showing the effects of leachate and at wells showing no effects can be compared through use of box plots. These diagrams are described by Chambers and others

(1983). Box plots illustrate the distribution of values within a group by showing the samples' median concentration and interquartile range and also indicate the concentration at 1.5 times the interquartile range and the concentrations of outliers. Comparison of the box plots for contaminated samples with those for uncontaminated samples generally reveal a marked difference.

A box plot showing the range of dissolved-solids concentrations in samples from wells screened in the plume and in water outside the plume is shown in figure 9. The median value of dissolved-solids concentrations for background wells is 23 mg/L, which contrasts markedly with the 190-mg/L value for wells affected by the plume; also, the values for background wells are more closely grouped than those for affected wells. The two outliers in the background well box plot are from well S73801, which is affected by winter road salting. The wider range of dissolved-solids concentrations within the plume probably is due to longitudinal dispersion, discussed farther on.

Maps showing concentrations of dissolved solids at three depths in the upper glacial aquifer are shown in figure 10; the concentrations of dissolved solids at wells along longitudinal section C-C' in June 1985 are shown in vertical section in figure 11. The concentrations in figures 10 and 11 indicate that the plume extends to about 4,700 ft south of the facility's southern border.

Figures 10 and 11 show that the plume reaches its greatest length in deeper parts of the aquifer. Dissolved-solids concentrations decrease downgradient from the site through dispersive mixing with unaffected ground water. The increase in dissolved-solids concentration with depth in downgradient well clusters (fig. 11) indicates that the high vertical

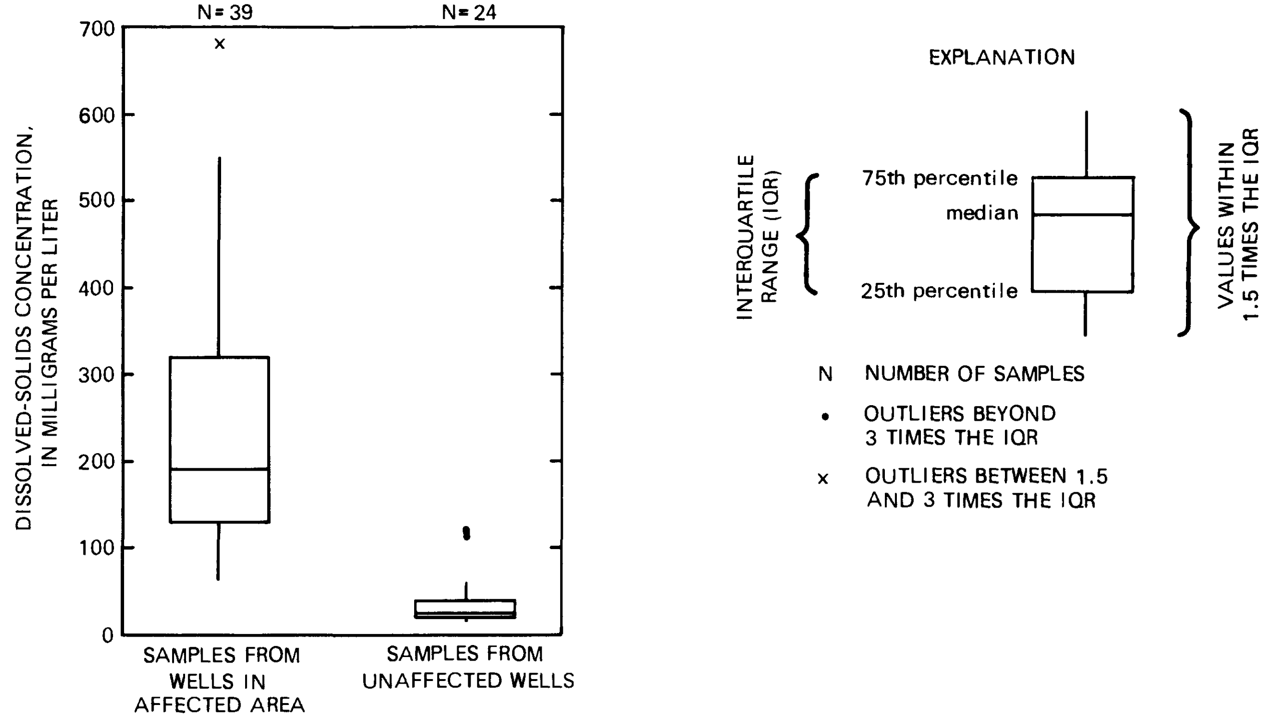


Figure 9.--Range of dissolved-solids concentrations in leachate plume and in unaffected ground water.

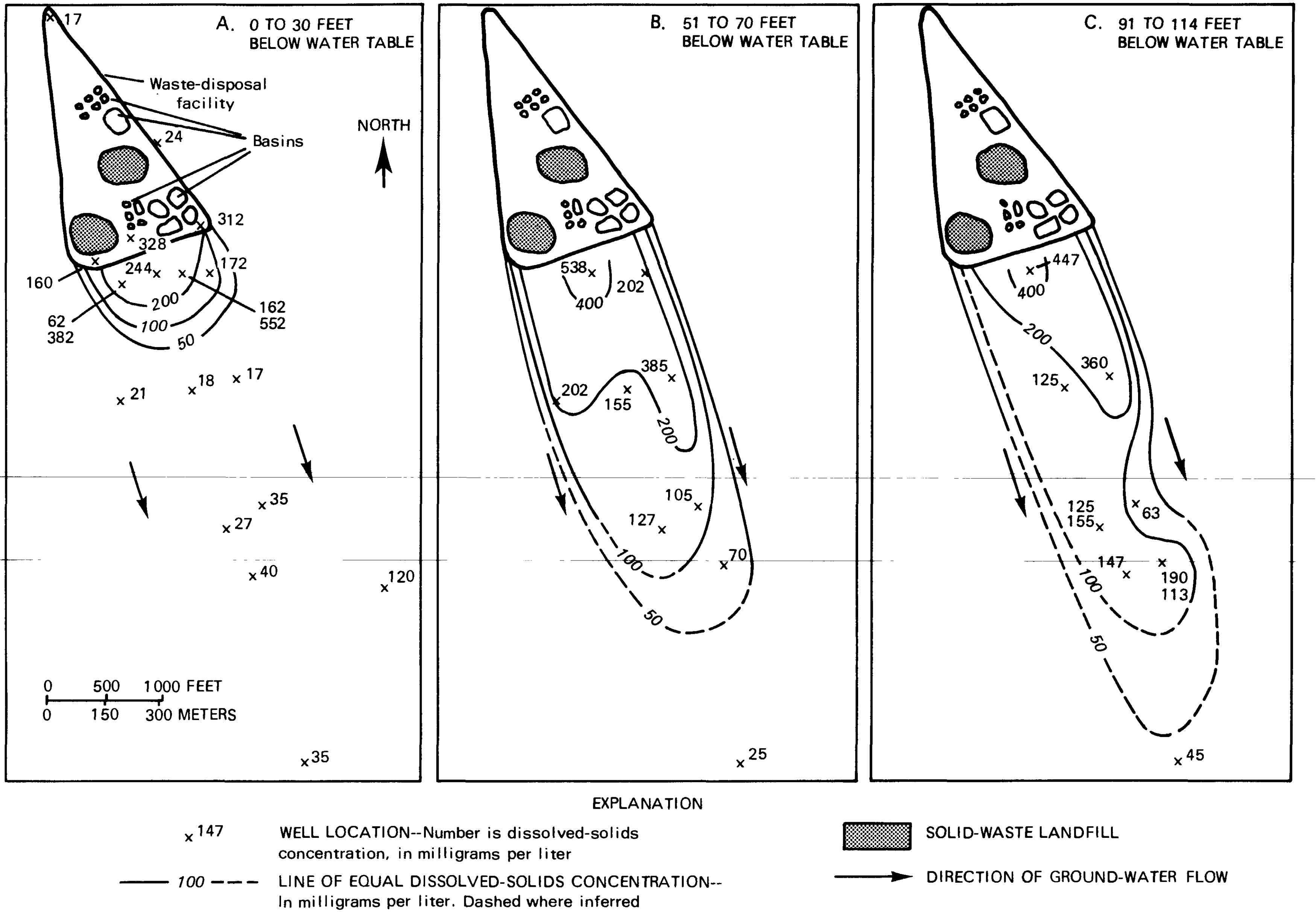


Figure 10.--Dissolved-solids concentrations in June 1985 at wells screened 0 to 30 feet, 51 to 70 feet, and 91 to 114 feet below the water table.

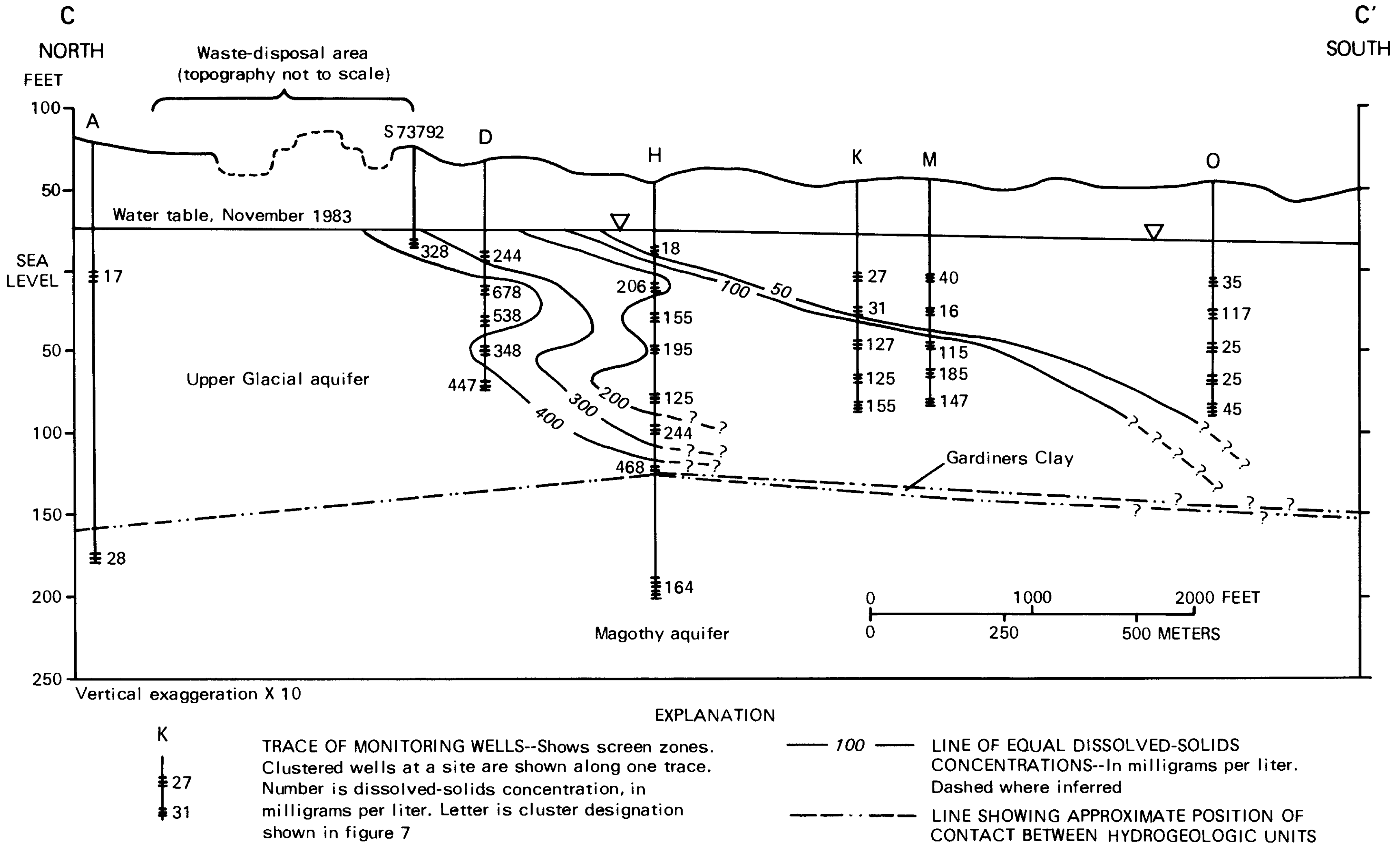


Figure 11.--Dissolved-solids concentrations along longitudinal section C-C′ in June 1985. (Line of section is shown in fig. 7.)

gradients that resulted from water-table mounding beneath the basins caused wastewater to move downward before entering the natural horizontal flow field beyond the site during disposal operations. In addition, fresh recharge from precipitation enters the aquifer at the water table, where it displaces and dilutes the uppermost ground water and thereby forms a layer of uncontaminated water above the contaminated layer. The difference in density between contaminated and uncontaminated water may also play a role in the downward movement of the plume (Kimmel and Braids, 1980).

Figure 12 shows dissolved-solids concentrations along a transverse section through the plume 1,400 to 1,500 ft downgradient from the site's southern border. Well cluster J, about 100 ft east of the bounding eastern flowline of the plume, does not show contamination. The lack of significant lateral spreading of the plume, indicated by the difference of dissolved-solids concentrations between clusters I and J, indicates that the plume's width is similar to that of the facility--about 1,300 ft.

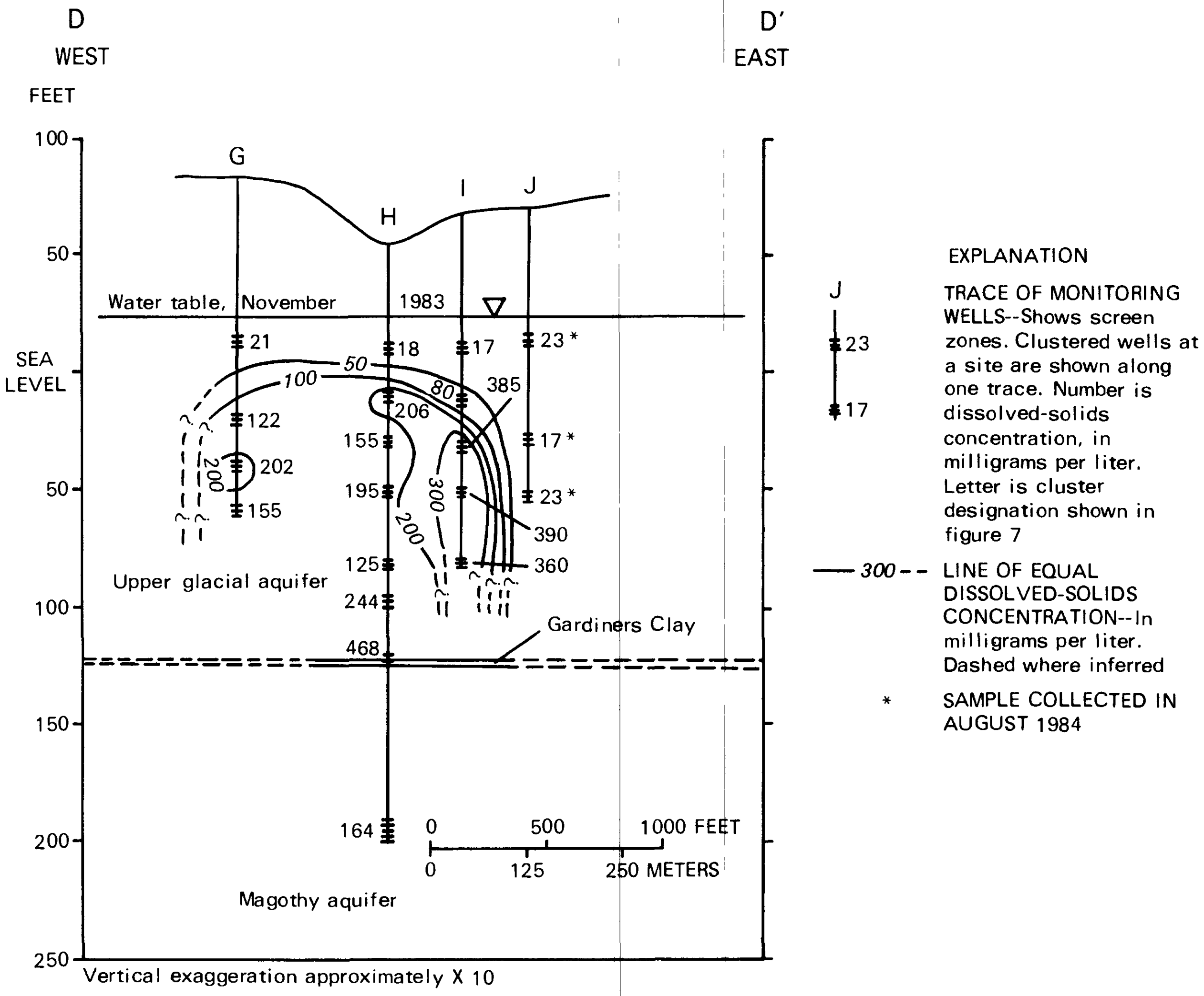


Figure 12.--Dissolved-solids concentrations along transverse section D-D' in June 1985. (Line of section is shown in fig. 7.)

The dissolved-solids concentrations plotted on the maps in figure 10 and in section D-D' in figure 12 indicate that the alignment and configuration of the facility and the position of the various wastes within the site have affected ground water to differing degrees. Wells along the central longitudinal flowline C-C' are downgradient of wastewater basins and solid-waste landfill areas, whereas the western part of the facility consists mostly of a solid-waste landfill. The ground-water plume emanating from the latter area tends to be lower in most constituents than the part emanating from the wastewater basins. Geophysical data from the site (Mack and Maus, 1987) also indicate the plume to be slightly asymmetric with higher terrain conductivity (a measure of ground water's specific conductance) and greater downgradient movement in its eastern part, which is associated with the area containing the basins and solid-waste landfill. The geophysical survey was useful in estimating lateral boundaries of the plume.

Characteristics and extent of contaminated ground water.--In June 1985, the plume extended 4,700 ft downgradient from the disposal facility and was about 1,300 ft wide 1,200 ft south of the site's south border. Chemical analyses of samples from wells that intercept the plume showed concentrations of most inorganic chemical constituents to be above background levels (appendixes 1A and 1B, at end of report). Box plots of major constituents (fig. 13) illustrate the contrast between the plume and background water.

Stiff diagrams of samples from wells along section C-C' (fig. 14) show that bicarbonate, determined from total alkalinity, is the predominant anion in most of the plume. The Stiff diagrams and data from appendix 1 show that sodium, calcium, iron, ammonium, and magnesium are the predominant cations. These diagrams illustrate the contrast between major-ion concentrations in the plume and those in adjacent unaffected ground water. Note that the first well (S73811) is hydraulically upgradient from the site and therefore is representative of background ground-water quality.

The maximum concentrations of most major constituents during the two sampling periods (August 1984 and June 1985) were at wells within 500 ft of the southern border of the facility. In August 1984, the maximum values of specific conductance and nine inorganic constituents (see appendix 1) were in samples from two wells inside the facility (S73792 and S73793). In June 1985, the maximum values of specific conductance and nine inorganic chemical constituents (see appendix 1) were in samples from wells at cluster D, which was installed 400 ft south of the facility during March 1985.

Constituents that were detected in concentrations at or above New York State recommended guidelines for drinking water at several wells were iron, manganese, nitrate, selenium, and some organic chemical compounds. Dissolved-solids concentrations exceeded the guidelines (500 mg/L) in five wells within 500 ft of the south border of the facility.

The synthetic organic chemical compounds that were detected in the ground water (appendix 3) probably originated from the disposal-site wastes. The concentrations and distribution patterns of organic compounds detected along flow line C-C' differ widely. Chlorobenzene, detected in 11 wells, was the most commonly found volatile organic compound. Chlorobenzene was detected above the drinking-water standard in wells as far as 2,760 ft from the site and may indicate contamination from the sewage-disposal basins. With the

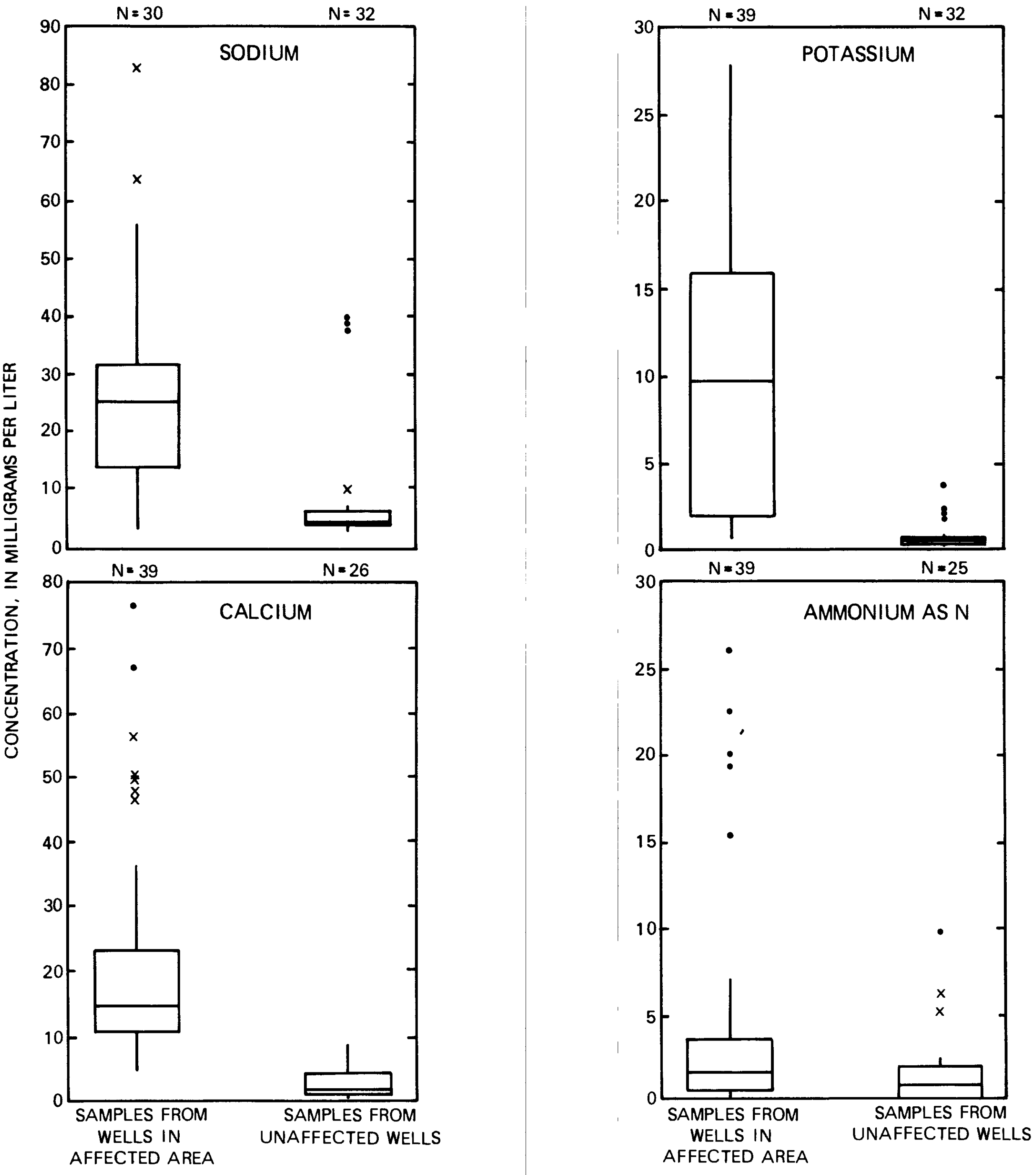


Figure 13.--Range of sodium, potassium, calcium, ammonium, alkalinity, chloride, sulfate, and organic nitrogen concentrations in plume and unaffected ground water.

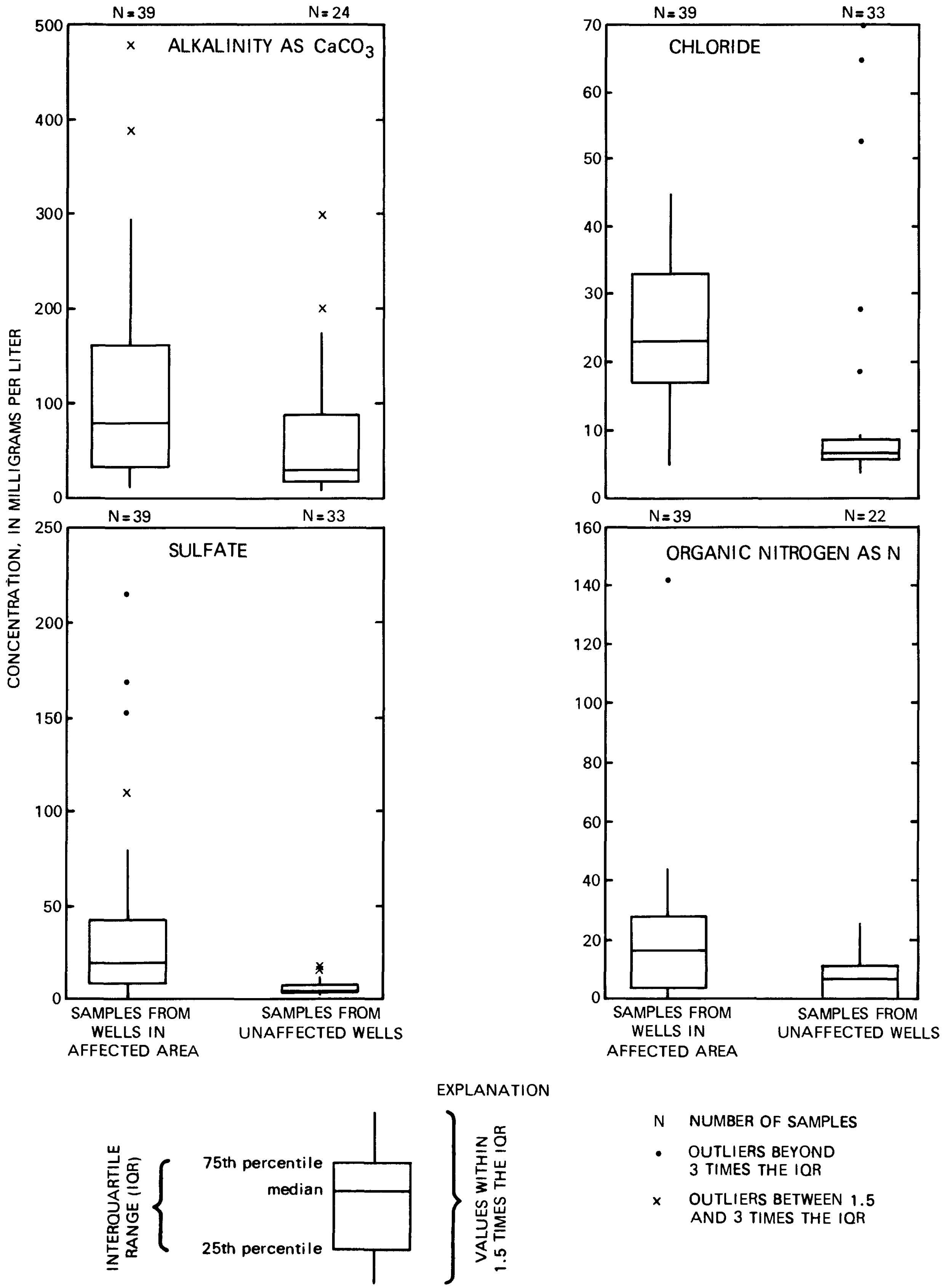


Figure 13 (continued).

exception of 1,2-dichlorobenzene in three wells, 1,3-dichlorobenzene in one well, and 1,4-dichlorobenzene in two wells, acid- and base/neutral-extractable compounds were not detected in the six wells selected for these analyses. Polychlorinated biphenyls were not detected in these six wells.

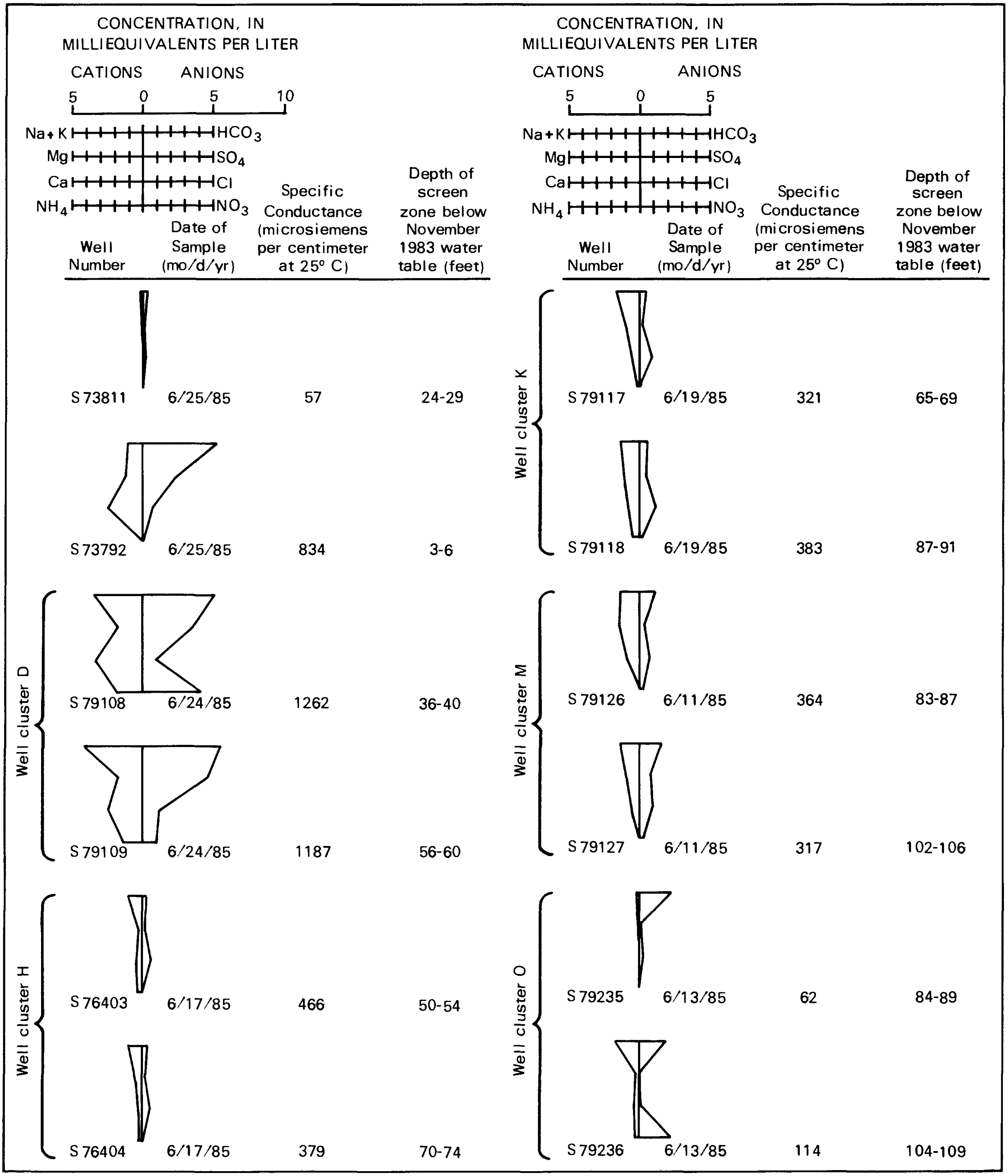
The spatial distribution of inorganic chemical constituents within the plume also changes with distance from the site, as indicated in figures 10, 11, 12, and 14. Dissolved-solids concentrations decrease with distance in a nonuniform manner (fig. 10) and are higher at wells in cluster I than at clusters G and H (fig. 12). The lack of a distinct pattern among the Stiff diagrams of plume-water samples (fig. 14) also indicates a dissimilarity among constituent distributions along the length of the plume. Kimmel and Braids (1980), using Stiff diagrams for analysis of two Long Island landfills, noticed similar nonuniformity in plume-water quality.

The nonuniformity of water quality within the plume results from the processes of advection and hydrodynamic dispersion in a nonuniform medium and reflects differences among waste sources--solid refuse and liquid scavenger wastes, unknown amounts of industrial wastes, the seasonal and inconsistent disposal patterns, and the temporal variation in chemical and physical properties of wastewater released to the basins. Although the glacial-outwash sand is well sorted and clay layers are minor and discontinuous, recent work on Cape Cod, Mass., a hydrologically similar area, indicates that relatively small local geologic differences in a "uniform" well-sorted outwash may significantly affect solute transport (LeBlanc and others, 1987). Other factors that may influence the distribution of chemical constituents within the plume include adsorption processes and oxidation-reduction conditions.

Adsorption processes include ion exchange and adsorption of nonpolar compounds to nonpolar surfaces. Ion exchange involves the attraction of ions to electrically charged surfaces of sediment grains, which influences the mobility of reactive chemical species. This process occurs readily with clay particles, but Freeze and Cherry (1979) point out that it also can occur on quartz grains and on colloidal particles in deposits of sorted sand, such as the upper glacial aquifer in the study area. More clay layers and interstitial clay are present in the Magothy aquifer, however, and adsorption may have a greater influence on ionic movement there.

<u>Oxidation-reduction conditions</u>.--Several chemical constituents of ground water are subject to oxidation and reduction (redox) reactions. Factors that affect redox reactions in the ground-water system include (1) availability of organic material, (2) redox potential, (3) reaction kinetics and the ability of bacteria to mediate the reactions, and (4) availability of oxygen.

Bacterial metabolism (oxidation) of organic matter requires oxidizing agents to act as electron acceptors. The succession of redox reactions that result from the breakdown of organic matter by subsurface bacteria is discussed by Stumm and Morgan (1981). Oxygen is reduced first, which results in anaerobic conditions. This is followed by denitrification, the conversion of nitrate to nitrogen. Increasingly reducing conditions convert ferric iron to ferrous iron, and, under strongly reducing conditions, certain bacteria (if present) reduce sulfate to sulfide. From this sequence, the concentrations of dissolved oxygen, nitrate, nitrite, ammonia, total Kjehdahl nitrogen, iron, and sulfate can be used to indicate the redox potential of the ground-water system.



Well Number	Date of Sample (mo/d/yr)	Specific Conductance (microsiemens per centimeter at 25° C)	Depth of screen zone below November 1983 water table (feet)
S73811	6/25/85	57	24-29
S73792	6/25/85	834	3-6
S79108	6/24/85	1262	36-40
S79109	6/24/85	1187	56-60
S76403	6/17/85	466	50-54
S76404	6/17/85	379	70-74
S79117	6/19/85	321	65-69
S79118	6/19/85	383	87-91
S79126	6/11/85	364	83-87
S79127	6/11/85	317	102-106
S79235	6/13/85	62	84-89
S79236	6/13/85	114	104-109

Figure 14.--Concentrations of major ions in selected wells along longitudinal section C-C'. Well S73811 (upper left) is in unaffected area. (Well locations are shown in fig. 7.)

Chemical constituents involved in redox reactions in the study area. Dissolved oxygen is the first oxidizing agent consumed by bacteria in the subsurface environment. Field measurements of dissolved oxygen in samples from wells that intercept the plume from within the site to at least 3,200 ft downgradient (appendixes 1A, 1B) are below background concentrations (fig. 15). Samples from most wells in areas affected by the waste have concentrations below 2.5 mg/L, whereas those from wells that tap unaffected water in the shallow parts of the upper glacial aquifer have dissolved-oxygen concentrations greater than 9 mg/L.

The ratio of reduced nitrogen compounds, represented by total Kjehdahl nitrogen (organic nitrogen plus ammonia), to oxidized nitrogen compounds (nitrate plus nitrite) shows a decrease from as high as 1,300:1 within 500 ft of the site to mostly less than 10:1 at distances greater than 3,000 ft from the site.

Maps showing the concentrations of dissolved iron at three depth intervals downgradient from the disposal facility are given in figure 16. Iron concentrations are highest (greater than 40,000 µg/L) at well clusters 400 and 450 ft downgradient from the facility but are not detected in samples from well clusters greater than 1,400 ft south of the site.

Elevated iron concentrations in ground water near the site are derived from two major sources--the scavenger waste itself and the dissolution of naturally occurring oxidized iron coatings on sediment grains. Extremely high iron concentrations (49,000 µg/L) were detected in liquid scavenger waste by

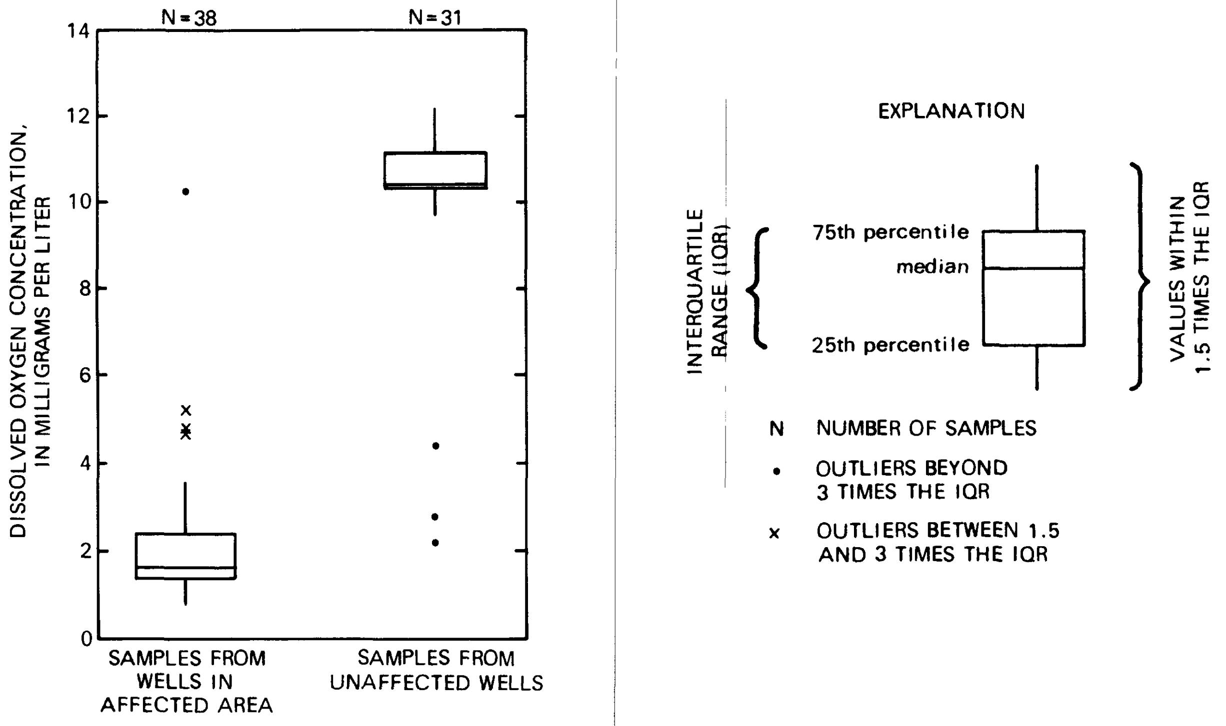


Figure 15.--Range of dissolved-oxygen concentrations in plume and in unaffected ground water.

Dvirka and Bartilucci (1981) (table 4, p. 20). Iron concentrations downgradient from the scavenger-waste basins in the south-central and southeast parts of the site (fig. 16) were nearly 20 times greater than those south of the solid-waste landfill in the western part of the site, presumably because the scavenger waste contains greater quantities of dissolved iron than the solid waste. Below the water table in and near the site, iron in naturally formed iron oxide coatings on sand grains has been reduced to the soluble ferrous form. Evidence for this was observed in geologic samples from monitoring-well borings at the site, which contained sand grains from which the natural iron stains had been removed.

Sulfate concentrations varied along downgradient flowlines and reached maximum levels within 500 ft of the site.

Redox intensity in the study area. The distribution of redox-sensitive chemical constituents in ground water in the study area indicates a decreasing reduction potential with distance from the site. Reducing conditions have developed in and near the site to at least the point of iron reduction. The presence of both ammonia and nitrate in significant amounts indicates a state of nonequilibrium. Sulfate concentration reaches its maximum in this area, but its degree of reduction to sulfide was not determined.

Reducing conditions diminish through most of the area from more than 500 ft to at least 1,500 ft from the site except in the deepest part of the aquifer. Dissolved iron concentrations were still elevated in the deeper wells at cluster H, about 1,400 ft south of the site. Absolute concentrations of nitrogen compounds are lower here than near the site, although the ratio of reduced to oxidized nitrogen remains high, generally between 100:1 and 600:1.

Nitrate concentrations increase downgradient to about 3,000 ft, possibly through the process of nitrification (conversion of ammonia to nitrate), and the ratio of reduced to oxidized nitrogen at this distance is less than 100:1.

From about 3,000 ft to the end of the plume, the ratio of reduced to oxidized nitrogen generally decreases to less than 10:1. Dissolved-oxygen concentrations remain low, although the presence of oxygen at depth may be influenced by several factors besides contamination.

Magothy Aquifer

Three wells screened in the Magothy aquifer were sampled in June 1985 (appendix 1B). Only one (S79231, cluster H) of the three is directly downgradient of the site; the two others yield water of background quality (fig. 8). Well S79231 contained 164 mg/L dissolved solids and elevated concentrations of several other constituents (appendix 1B). This one sample suggests that the upper part of the Magothy aquifer is affected by contaminated ground water emanating from the site; but definition of the plume's extent in the Magothy aquifer was beyond the scope of this study.

Although ground-water movement in the upper glacial aquifer is primarily horizontal (Eckhardt and Wexler, 1986), the site is above a zone in which ground water moves downward to recharge the Magothy aquifer (Krulikas, 1986). During periods of disposal at the site, water-table mounding beneath the

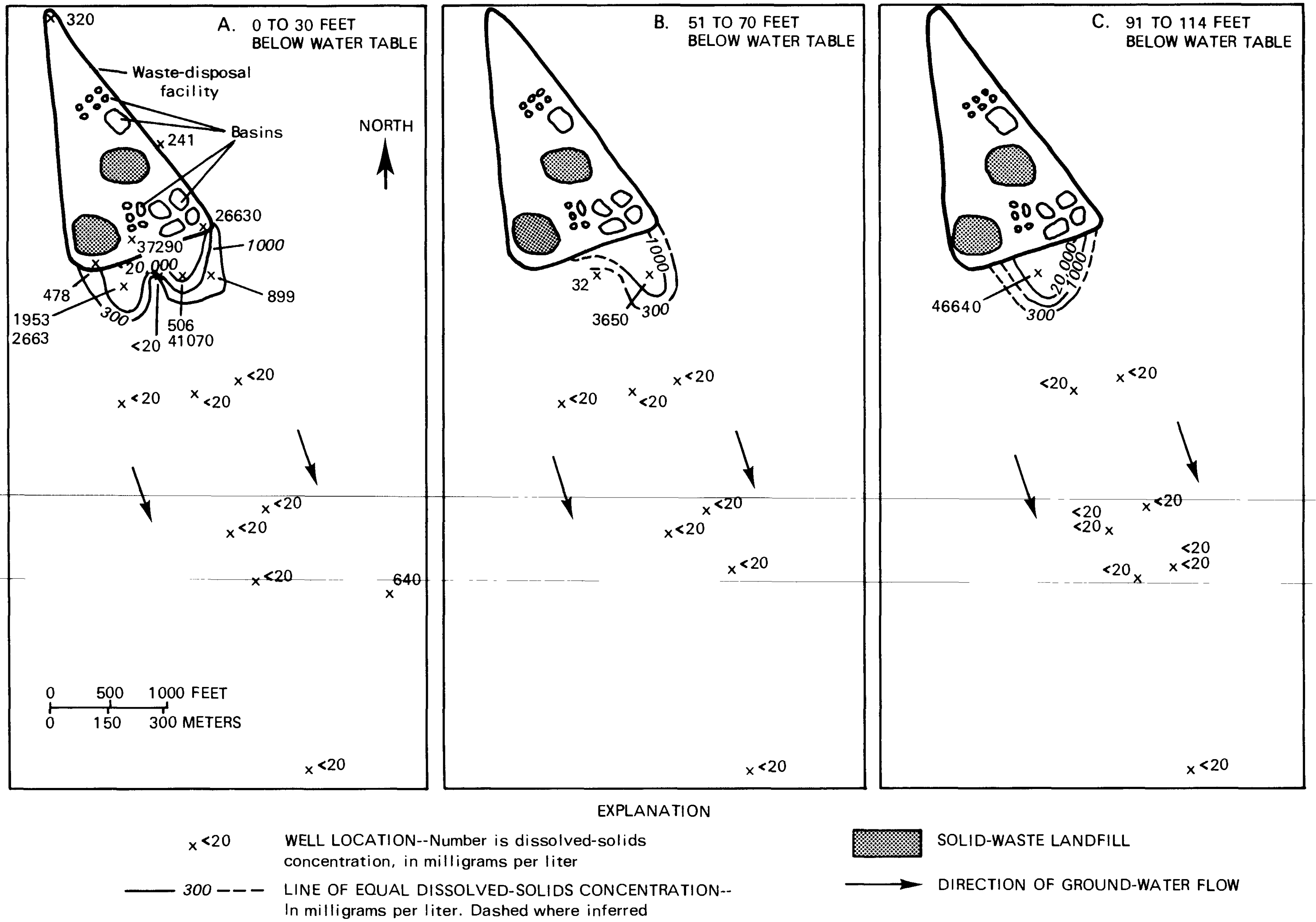


Figure 16.--Dissolved-iron concentrations in June 1985 at wells screened 0 to 30 feet, 51 to 70 feet, and 91 to 114 feet below the water table.

basins increased the vertical gradient, and the absence of effective confining beds in the upper glacial aquifer beneath the site probably allowed contaminated water to move into the upper part of the Magothy aquifer. The spread of contamination within the upper part of the Magothy aquifer may be slowed, however, by (1) the presence of clay beds at depth, (2) the relatively low hydraulic conductivity of the sediments, and (3) the greater potential for chemical adsorption here than in the upper glacial aquifer.

SUMMARY AND CONCLUSIONS

The scavenger-waste-disposal facility at Manorville received solid and liquid wastes from 1960 through 1982, when it ceased operations. The facility exhibits hydrogeologic and geochemical similarities and differences to the previously investigated landfill sites at Babylon and Islip (Kimmel and Braids, 1980), Cape Cod (LeBlanc, 1984), and Brookhaven (Wexler, 1988a). The major hydrogeologic similarity among these sites is that they are established in permeable, well-sorted glacial outwash deposits. This allows elongated plumes to develop in the direction of ground-water flow.

The U.S. Geological Survey drilled three geologic test borings and established an observation well network of 66 wells during 1983-85 to evaluate the effect of the wastes on water quality and hydrogeologic conditions of the upper glacial aquifer in the 0.88-mi^2 study area. Ground-water samples were collected during August 1984 and June 1985.

The water table is in the upper glacial aquifer, which in the study area extends to between 180 and 205 ft below land surface and consists of well-sorted sand and gravel with a few thin, discontinuous clay layers that provide little impediment to downward flow. The upper glacial aquifer in the northern part of the study area is directly underlain by the Magothy aquifer, which contains beds of sand, silty and clayey sand, sandy clay, and clay. In the southern part of the study area, the upper glacial aquifer is underlain by a thin layer of a sandy facies of the Gardiners Clay. The hydraulic conductivity of the Magothy aquifer is locally variable but in general is lower than that of the upper glacial aquifer. The liquid waste-disposal operations caused water-table mounding beneath the site and, thus, increased the vertical ground-water gradient in the upper glacial aquifer from natural conditions.

The ground-water flow conditions at the Manorville facility are different from the other landfills on Long Island in that the Gardiners Clay is absent or not present as a significant restriction to vertical flow to the Magothy aquifer. Also, the facility is in a region with a naturally downward vertical flow component between the two aquifers.

Dissolved-solids concentrations have been used at other Long Island landfills to delineate ground-water plumes and were useful at the Manorville site. Water from wells unaffected by leachate have the same low concentrations of chemical constituents as water in relatively undeveloped parts of Long Island. These contrast sharply with the elevated concentrations in samples of plume water.

The median dissolved-solids concentration in background wells, 23 mg/L, is substantially lower than that in the plume, 190 mg/L. The spatial distribution of dissolved solids indicates that the plume of affected ground water was about 4,700 ft long and 1,300 ft wide in the upper glacial aquifer in June 1985. The depth to the top of the plume increases with distance downgradient from the disposal facility. During disposal operations, mounding of the water table below the infiltration basins increased the vertical gradient and, combined with the lack of significant clay layers, allowed the affected water to move downward before entering the natural, more nearly horizontal flow system. Although the extent of the plume in the Magothy aquifer was not addressed as part of this study, one sample from the Magothy aquifer was found to be affected by the wastes.

The physical processes of hydrodynamic dispersion and advection have produced a trend of decreasing dissolved-solids concentrations with distance from the site. Local variations in water quality with depth and distance along the plume may be attributed to physical and chemical processes that affect solute transport and to differences in the type and location of waste sources within the disposal facility over time.

Natural redox conditions in the upper glacial ground-water system have been altered by the wastes. Reduced (ferrous) iron concentrations exceed background levels to at least 1,400 ft south of the facility, and dissolved-oxygen levels in the plume remain low for at least 3,200 ft downgradient from the site. Similar reducing conditions exist near other landfill sites on Long Island allowing for the presence of elevated dissolved-iron concentrations. However, nitrate and sulfate concentrations are substantially higher at this facility than at the Brookhaven landfill (Wexler, 1988a), indicating a less strongly developed state of reducing conditions here.

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APPENDIXES

Appendix 1.--Inorganic chemical analysis of ground-water samples from disposal facility at Manorville.

[Analyses by New York Testing Laboratories, Westbury N.Y. Well locations shown in fig. 7. Asterisk (*) indicates maximum value of property or constituent during sampling period: Deg C, degrees Celsius; mg/L, milligrams per liter; μg/L, micrograms per liter; μS/cm, microsiemens per centimeter at 25 degrees Celsius.]

Well number	Date of sample (mo/d/yr)	Time of sample	Temperature (Deg C)	pH field value (standard units)	pH lab value (standard units)	Dissolved oxygen (mg/L)	Specific conductance field value (μS/cm)	Specific conductance lab value (μS/cm)	Dissolved solids (mg/L)	Alkalinity (mg/L as $CaCO_3$)	Sulfate (mg/L as SO_4)
A. August 1984											
S 31461	8-22-84	1530	14.3	6.4	6.30	0.1	264	609	288	83	21
S 73791	8-23-84	1000	14.2	6.0	5.16	0.1	736	570	270	273	95
S 73792	8-23-84	1100	14.1	6.4	6.38	0.2	1650*	1260	647*	559*	78
S 73793	8-23-84	1145	12.7	6.5	6.46	0.1	1480	1070	550	412	210*
S 73794	8-23-84	1325	12.8	5.6	6.04	11.1	46	34	16	13	6.0
S 73795	8-24-84	1145	11.5	6.0	6.37	9.5	39	30	14	9.0	7.0
S 73796	8-22-84	0900	11.1	4.9	6.29	10.5	48	520	258	7.0	26
S 73797	8-21-84	1115	11.2	6.4	6.06	10.4	52	49	23	12	8.0
S 73799	8-23-84	0900	12.5	6.1	6.17	0.2	324	688	326	244	81
S 73801	8-23-84	1245	12.8	5.4	5.91	9.7	302	236	112	14	18
S 73811	8-22-84	1000	10.8	6.1	6.02	11.2	47	34	21	10	15
S 73813	8-22-84	1445	13.8	7.1	6.18	0.2	676	109	50	275	10
S 73814	8-22-84	1415	13.8	6.8	6.29	0.1	1410	323	153	488	10
S 73815	8-22-84	1330	13.6	6.7	6.72	0.1	351	327	154	90	4.0
S 73816	8-22-84	1045	12.5	5.8	5.99	0.1	221	150	71	66	21
S 73817	8-22-84	1120	12.5	6.5	6.08	0.1	798	795	409	303	100
S 73818	8-22-84	1155	12.8	6.4	7.00	0.1	845	806	415	313	76
S 76402	8-24-84	1120	11.8	6.6	6.38	0.2	500	382	181	139	15
S 76403	8-24-84	1045	12.2	7.0	6.47	0.1	602	447	104	221	10
S 76404	8-24-84	1010	12.2	6.6	6.63	0.1	548	416	200	202	9.0
S 76405	8-24-84	0930	11.9	6.5	6.56	0.1	689	566	199	254	11
S 76406	8-21-84	1420	11.5	6.8	5.91	0.2	145	142	85	29	3.0
S 76407	8-21-84	1450	11.7	6.6	6.01	0.1	825	768	438	300	13
S 76408	8-21-84	1530	11.9	6.9	6.18	0.1	819	759	391	311	7.0
S 76409	8-21-84	1045	10.7	6.5	6.15	11.5	36	37	17	19	2.0
S 76410	8-21-84	1000	10.7	6.3	6.10	10.4	49	49	23	18	2.0
S 76411	8-21-84	1345	11.7	6.9	6.08	0.1	811	788	373	322	4.0
S 76412	8-23-84	1500	12.2	5.7	6.05	10.9	58	43	20	6.0	5.0
S 76413	8-23-84	1430	11.8	6.3	6.12	0.1	431	325	154	150	11

Appendix 1.--Inorganic chemical analysis of ground-water samples from disposal facility at Manorville--continued.

Well number	Dis-solved sodium (mg/L as Na)	Dis-solved chloride (mg/L as Cl)	Dis-solved calcium (mg/L as Ca)	Dis-solved magne-sium (mg/L as Mg)	Dis-solved potas-sium (mg/L as K)	Total ammonium (mg/L as N)	Total nitrate (mg/L as N)	Total nitrite (mg/L as N)	Total Kjeldahl nitrogen (mg/L as N)	Dis-solved iron (µg/L as Fe)	Dis-solved manga-nese (µg/L as Mn)	Dis-solved lead (µg/L as Pb)	Dis-solved sele-nium (µg/L as Se)
A. August 1984													
S 31461	14	17	6.5	6.1	3.5	3.33	0.160	<0.010	4.0	4400	8100	<25	<1
S 73791	12	8.0	50	17	21	5.54	0.630	0.140*	10	1300	15000	<25	<1
S 73792	79*	100*	33	19	25	103*	0.070	<0.010	100	35000*	560	<25	<1
S 73793	51	42	25	16	38*	96.1	1.70	0.140*	92	2900	2200	<25	<1
S 73794	4.3	4.0	<0.02	1.1	0.46	<0.040	0.080	<0.010	<0.04	110	13	<25	<1
S 73795	3.4	5.0	0.39	1.1	0.31	<0.040	0.070	<0.010	<0.04	44	88	<25	3
S 73796	4.1	8.0	0.55	1.3	0.54	0.140	0.080	<0.010	0.22	61	20	<25	<1
S 73797	4.1	6.0	0.62	1.5	0.47	<0.040	<0.040	<0.010	<0.04	54	<10	<25	1
S 73799	58	87	26	10	19	32.5	0.140	<0.010	44	4500	27000	<25	<1
S 73801	39	70	8.7	2.9	1.7	<0.040	2.03	<0.010	<0.04	830	62	<25	<1
S 73811	3.7	7.0	0.52	1.6	0.44	<0.040	<0.040	<0.010	0.11	120	17	<25	<1
S 73813	18	22	16	10	13	50.3	<0.040	<0.010	55	4900	23000	<25	2
S 73814	31	35	26	13	18	97.6	<0.040	<0.010	100*	32000	2000	<25	<1
S 73815	15	15	26	6.3	3.5	<0.040	1.15	0.020	<0.04	850	11000	<25	<1
S 73816	7.3	11	13	5.0	5.0	1.52	0.050	<0.010	1.6	3000	3300	<25	<1
S 73817	16	21	64*	22	21	15.3	<0.040	<0.010	16	3200	15000	<25	<1
S 73818	16	23	55	21	19	19.2	<0.040	<0.010	22	570	28000*	<25	<1
S 76402	25	29	4.6	3.9	8.7	29.9	3.65	<0.010	28	<20	82	<25	1
S 76403	23	28	11	6.4	11	38.7	0.090	<0.010	40	<20	48	<25	2
S 76404	23	29	13	9.2	13	32.1	0.120	<0.010	33	83	260	<25	3
S 76405	31	34	24	13	14	34.3	4.48*	<0.010	36	<20	3600	<25	2
S 76406	6.6	7.0	3.3	2.3	4.4	1.15	3.70	<0.010	4.0	<20	1800	<25	5*
S 76407	26	8.0	9.6	4.4	20	51.5	1.99	<0.010	54	<20	27000	<25	<1
S 76408	32	37	27	20	13	40.0	<0.040	<0.010	42	<20	3600	<25	1
S 76409	5.0	4.0	0.25	0.58	0.32	<0.040	<0.040	<0.010	<0.04	<20	<10	<25	<1
S 76410	4.3	6.0	0.64	1.3	0.40	<0.040	<0.040	<0.010	<0.04	<20	<10	<25	<1
S 76411	36	43	38	28*	11	37.7	<0.040	<0.010	40	47	1100	<25	1
S 76412	5.8	9.0	0.26	1.0	0.48	<0.040	0.410	<0.010	<0.04	20	<6	<25	<1
S 76413	25	29	12	11	8.4	17.5	0.820	<0.010	17	20	17	<25	<1

Appendix 1.--Inorganic chemical analysis of ground-water samples from disposal facility at Manorville--continued.

Well number	Date of sample (mo/d/yr)	Time of sample	Temperature (Deg C)	pH field value (standard units)	pH lab value (standard units)	Dissolved oxygen (mg/L)	Specific conductance field value (µS/cm)	Specific conductance lab value (µS/cm)	Dissolved solids (mg/L)	Alkalinity (mg/L as $CaCO_3$)	Sulfate (mg/L as SO_4)
B. June 1985											
S 31461	6-28-85	0945	11.2	6.2	6.28	3.6	466	314	172	170	36
S 73790	6-28-85	1045	10.5	5.7	5.59	10.8	53	45	24	300	4.0
S 73791	6-26-85	0950	13.3	5.9	5.83	1.9	385	349	160	136	46
S 73792	6-25-85	1335	13.4	6.4	6.45	1.8	834	699	328	263	110
S 73793	6-25-85	1450	12.5	6.5	6.56	1.7	809	632	312	144	150
S 73794	6-20-85	1430	11.5	6.1	6.06	11.0	56	45	21	85	7.0
S 73795	6-17-85	1400	11.5	6.0	5.78	10.2	54	38	18	24	5.0
S 73796	6-17-85	1450	11.4	5.9	5.75	9.8	45	37	17	13	3.0
S 73799	6-14-85	1400	11.6	6.4	6.64	1.4	505	428	203	38	58
S 73801	6-14-85	1125	12.2	5.4	5.72	10.4	294	245	120	32	4.0
S 73811	6-25-85	1215	10.4	6.4	6.23	10.9	57	39	17	17	5.0
S 73813	6-27-85	1015	12.5	6.9	7.02	5.2	575	534	251	478*	18
S 73814	6-27-85	1045	12.3	6.7	6.69	4.7	1130	986	552	216	38
S 73815	6-27-85	1110	12.2	6.1	6.14	4.8	235	224	162	72	8.0
S 73816	6-27-85	1410	12.5	5.5	5.39	2.8	120	105	62	202	4.0
S 73817	6-27-85	1345	12.7	6.6	6.71	3.3	703	683	382	239	79
S 73818	6-27-85	1320	12.7	6.6	6.69	2.6	494	493	226	265	43
S 76402	6-17-85	1330	11.7	6.4	6.48	1.4	494	433	206	15	12
S 76403	6-17-85	1255	12.0	6.6	6.78	1.5	466	416	155	13	7.0
S 76404	6-17-85	1205	12.2	6.6	6.81	1.2	379	319	195	16	6.0
S 76405	6-17-85	1110	12.1	6.8	6.95	1.5	353	288	125	17	4.0
S 76406	6-20-85	1225	11.6	5.8	5.90	2.6	212	118	80	153	3.0
S 76407	6-20-85	1155	11.5	6.6	6.81	2.0	758	743	385	65	15
S 76408	6-20-85	1115	11.7	6.7	6.92	2.0	718	778	390	73	3.0
S 76411	6-20-85	1025	11.7	6.8	7.03	2.0	741	680	360	143	6.0
S 76412	6-18-85	1315	11.1	5.9	5.87	10.4	69	49	25	39	3.0
S 76413	6-18-85	1200	11.1	6.2	6.72	1.6	423	401	215	26	9.0
S 77637	6-25-85	1200	11.8	6.0	6.12	2.0	72	51	28	17	8.0
S 77638	6-26-85	1440	11.3	5.9	5.79	3.4	79	46	21	13	8.0
S 79107	6-24-85	1350	12.8	5.9	5.94	1.5	569	478	244	97	77
S 79108	6-24-85	1310	13.3	6.3	6.42	1.2	1260*	1110	678*	254	170
S 79109	6-24-85	1220	13.3	6.3	6.42	1.2	1190	1080	538	275	220*
S 79110	6-24-85	1130	12.9	6.7	6.50	1.5	945	740	348	296	53
S 79111	6-24-85	1035	12.7	6.7	6.66	0.9	1120	840	447	388	19
S 79112	6-21-85	1110	11.4	6.35	6.49	1.4	335	369	122	114	31

Appendix 1.--Inorganic chemical analysis of ground-water samples from disposal facility at Manorville--continued.

Well number	Dis-solved sodium (mg/L as Na)	Dis-solved chloride (mg/L as Cl)	Dis-solved calcium (mg/L as Ca)	Dis-solved magne-sium (mg/L as Mg)	Dis-solved potas-sium (mg/L as K)	Total ammonium (mg/L as N)	Total nitrate (mg/L as N)	Total nitrite (mg/L as N)	Total Kjeldahl nitrogen (mg/L as N)	Dis-solved iron (µg/L as Fe)	Dis-solved manga-nese (µg/L as Mn)	Dis-solved lead (µg/L as Pb)	Dis-solved sele-nium (µg/L as Se)
						B. June 1985							
S 31461	25	26	15	4.3	5.7	0.300	0.040	<0.010	31	900	8200	<25	5
S 73790	4.4	6.0	1.2	1.3	0.59	0.220	0.070	<0.010	29	240	<10	<25	3
S 73791	6.9	7.0	48	7.5	12	0.800	11.1	0.330*	21	480	12000	<25	3
S 73792	19	23	50	15	11	1.85	0.060	<0.010	24	37000	750	<25	9
S 73793	20	13	56	19	15	0.700	0.120	<0.010	24	27000	2600	<25	19
S 73794	4.6	7.0	0.71	2.6	0.29	1.96	0.160	0.030	24	<20	<10	<25	<1
S 73795	5.0	5.0	0.78	<0.20	0.29	2.20	0.110	0.030	28	<20	<10	<25	<1
S 73796	4.7	28	0.90	<0.20	0.48	9.87	0.030	0.030	21	<20	<10	<25	<1
S 73799	32	39	18	3.6	1.8	1.76	0.120	0.030	4.8	3700	12000	<25	10
S 73801	40	65*	7.2	3.9	2.0	1.51	4.16	0.030	3.1	640	27	<25	4
S 73811	3.7	7.0	0.91	1.3	0.45	1.09	0.190	<0.010	2.6	320	41	<25	<1
S 73813	14	19	15	5.3	12	2.30	0.080	<0.010	38	1300	900	<25	<1
S 73814	39	45	37	15	19	1.70	0.010	0.040	6.3	41000	2200	<25	<1
S 73815	3.4	5.0	20	4.2	7.3	2.58	12.6	<0.010	3.4	510	5200	<25	<1
S 73816	3.3	6.0	7.5	2.4	3.7	5.38	1.02	<0.010	21	2000	2700	<25	<1
S 73817	13	19	76*	17	22	4.54	0.070	<0.010	21	2700	9800	<25	8
S 73818	11	18	46	11	16	3.00	0.060	<0.010	23	260	16000	<25	1
S 76402	21	22	11	10	9.7	2.35	4.33	0.030	23	<20	160	<25	<1
S 76403	20	21	11	4.7	10	6.08	0.080	<0.010	16	<20	160	<25	<1
S 76404	18	19	7.5	7.3	12	5.77	0.070	<0.010	21	<20	400	<25	<1
S 76405	14	19	8.0	4.4	8.8	3.90	0.090	0.030	30	<20	1700	<25	<1
S 76406	4.6	10	4.9	3.4	2.9	0.420	5.69	0.030	7.0	<20	3200	<25	<1
S 76407	26	43	10	5.5	18	1.09	0.050	<0.010	29	<20	18000*	<25	<1
S 76408	29	40	23	13	18	1.20	0.050	0.030	29	<20	4700	<25	<1
S 76411	31	40	23	15	16	2.55	0.060	<0.010	35	<20	13000	<25	<1
S 76412	6.3	9.0	1.4	<0.20	0.42	0.270	0.200	<0.010	5.4	<20	<10	<25	<1
S 76413	27	25	15	10	5.6	0.350	0.200	<0.010	4.7	<20	<10	<25	<1
S 77637	5.2	8.0	1.6	1.2	0.51	0.920	0.050	<0.010	2.5	290	39	<25	<1
S 77638	5.1	5.0	1.5	0.98	0.54	0.560	0.280	<0.010	25	<20	38	<25	<1
S 79107	35	12	31	9.2	19	15.5	22.1	<0.010	18	<20	3700	<25	2
S 79108	64	30	67	21	28*	26.1*	57.9*	<0.010	170*	<20	4900	<25	13
S 79109	83*	40	50	22*	24	19.4	13.5	<0.010	58	32	9700	<25	13
S 79110	40	17	6.4	13	25	22.6	0.070	<0.010	51	47000*	7700	<25	8
S 79111	56	28	6.4	12	22	20.2	0.050	<0.010	64	47000	15000	<25	2
S 79112	9.9	14	8.7	8.3	11	0.210	0.160	0.030	16	<20	<10	<25	<1

Appendix 1.--Inorganic chemical analysis of ground-water samples from disposal facility at Manorville--continued.

Well number	Date of sample (mo/d/yr)	Time of sample	Temperature (Deg C)	pH field value (standard units)	pH lab value (standard units)	Dissolved oxygen (mg/L)	Specific conductance field value (µS/cm)	Specific conductance lab value (µS/cm)	Dissolved solids (mg/L)	Alkalinity (mg/L as $CaCO_3$)	Sulfate (mg/L as SO_4)
B. June 1985											
S 79113	6-21-85	1025	11.5	6.3	6.38	1.8	426	417	202	125	43
S 79114	6-20-85	1400	11.6	6.3	6.49	2.4	337	403	155	140	38
S 79115	6-19-85	1425	11.1	6.4	5.80	11.0	62	42	27	27	4.0
S 79116	6-19-85	1400	11.2	5.9	5.79	4.4	87	66	31	28	4.0
S 79117	6-19-85	1315	11.1	5.8	6.07	2.5	321	272	127	27	9.0
S 79118	6-19-85	1210	11.1	5.6	5.79	1.2	383	303	125	29	21
S 79119	6-19-85	1050	10.9	6.2	6.29	2.4	531	309	155	26	7.0
S 79120	6-18-85	1340	11.4	5.6	5.92	11.0	86	68	35	20	8.0
S 79121	6-18-85	1240	11.2	5.2	5.48	1.6	283	234	105	22	36
~~S 79122~~	~~6-18-85~~	~~1110~~	~~11.1~~	~~6.1~~	~~6.49~~	~~1.6~~	~~153~~	~~130~~	~~63~~	~~29~~	~~9.0~~
S 79123	6-12-85	1345	11.7	5.6	5.94	10.0	110	86	40	72	1.0
S 79124	6-12-85	1300	11.4	5.9	6.08	11.4	48	39	16	61	4.0
~~S 79125~~	~~6-13-85~~	~~1050~~	~~11.0~~	~~5.6~~	~~5.86~~	~~1.4~~	~~258~~	~~214~~	~~115~~	~~150~~	~~20~~
S 79126	6-11-85	1500	10.8	6.0	6.23	--	364	301	185	56	15
S 79127	6-11-85	1300	11.9	5.6	5.90	1.3	317	247	147	80	39
S 79128	6-12-85	1200	11.7	5.4	5.56	12.3	113	92	40	42	8.0
S 79129	6-12-85	1130	11.6	5.5	5.67	11.0	161	104	70	56	1.0
S 79130	6-12-85	1050	11.3	5.6	5.82	2.2	300	241	128	72	36
S 79131	6-10-85	1515	10.9	--	6.40	0.8	396	333	190	69	19
S 79132	6-10-85	1400	10.9	--	6.47	0.8	254	210	113	77	17
S 79231	6-26-85	1225	11.3	6.1	6.14	1.1	372	284	164	134	4.0
S 79232	6-14-85	1025	10.8	5.6	5.71	10.4	66	64	35	29	12
S 79233	6-13-85	1500	10.9	5.6	5.67	10.2	222	204	117	176	17
S 79234	6-13-85	1420	10.7	5.7	5.83	11.0	52	44	25	93	4.0
S 79235	6-13-85	1325	10.9	6.0	6.17	11.0	62	51	25	116	2.0
S 79236	6-13-85	1220	10.7	5.9	6.05	2.2	114	99	45	98	1.0
S 93799	6-21-85	1245	11.7	6.7	6.77	2.0	911	933	468	372	6.0
S 93800	6-21-85	1350	11.5	6.55	6.66	1.5	529	561	244	210	5.0

Appendix 1.--Inorganic chemical analysis of ground-water samples from disposal facility at Manorville--continued.

Well number	Dis- solved sodium (mg/L as Na)	Dis- solved chloride (mg/L as Cl)	Dis- solved calcium (mg/L as Ca)	Dis- solved magne- sium (mg/L as Mg)	Dis- solved potas- sium (mg/L as K)	Total ammonium (mg/L as N)	Total nitrate (mg/L as N)	Total nitrite (mg/L as N)	Total Kjeldahl nitrogen (mg/L as N)	Dis- solved iron (µg/L as Fe)	Dis- solved manga- nese (µg/L as Mn)	Dis- solved lead (µg/L as Pb)	Dis- solved sele- nium (µg/L as Se)
S 79113	14	19	14	13	10	0.160	1.62	0.030	17	<20	<10	<25	<1
S 79114	13	17	16	17	9.3	0.670	0.620	0.030	3.1	<20	<10	<25	<1
S 79115	4.5	7.0	0.81	2.3	0.27	2.58	0.210	<0.010	2.4	<20	<10	<25	1
S 79116	7.1	7.0	1.7	4.0	0.40	6.46	5.54	<0.010	23	<20	<10	<25	6
S 79117	38	32	11	12	1.5	2.44	0.200	<0.010	14	<20	<10	<25	1
S 79118	30	41	17	14	1.4	7.28	2.96	<0.010	11	<20	<10	<25	1
S 79119	33	43	21	20	5.7	3.40	0.280	<0.010	12	<20	<10	<25	<1
S 79120	5.2	7.0	4.0	<0.20	2.3	0.130	5.02	<0.010	3.0	<20	<10	<25	<1
S 79121	27	27	7.5	11	1.2	0.330	5.27	0.040	2.4	<20	<10	<25	<1
S 79122	9.2	12	8.0	6.2	1.0	0.130	0.120	<0.010	3.3	<20	210	<25	<1
S 79123	5.2	19	5.1	4.8	0.45	<0.040	6.60	<0.010	11	<20	<10	<25	<1
S 79124	4.3	6.0	1.0	2.7	0.23	<0.040	0.120	<0.010	7.7	<20	<10	<25	<1
S 79125	32	38	7.4	10	1.2	0.640	6.07	<0.010	3.1	<20	<10	<25	11
S 79126	32	26	20	18	2.0	0.260	3.35	<0.010	1.6	<20	<10	<25	4
S 79127	32	34	12	11	1.3	1.04	4.31	<0.010	44	<20	<10	<25	9
S 79128	3.9	9.0	3.8	9.3	0.51	<0.040	6.18	<0.010	8.4	<20	<10	<25	<1
S 79129	4.7	12	12	5.8	0.64	1.68	9.68	<0.010	27	<20	<10	<25	<1
S 79130	27	30	12	13	1.2	0.920	3.20	0.040	0.95	<20	<10	<25	<1
S 79131	25	27	23	21	2.8	1.59	0.920	<0.010	2.7	<20	<10	<25	10
S 79132	18	15	12	14	1.0	<0.040	1.28	<0.010	1.7	<20	<10	<25	7
S 79231	22	25	15	9.9	2.8	0.650	0.050	<0.010	18	7200	590	<25	<1
S 79232	7.3	10	2.5	0.67	0.66	2.16	3.36	0.030	4.0	<20	<10	<25	1
S 79233	10	53	4.1	7.6	0.66	1.46	1.93	0.030	12	<20	<10	<25	26*
S 79234	6.5	8.0	1.6	3.4	0.34	1.01	5.70	0.030	15	<20	<10	<25	8
S 79235	6.3	8.0	1.1	2.3	0.28	1.15	0.860	<0.010	9.2	<20	<10	<25	10
S 79236	38	9.0	5.3	2.3	2.2	2.58	33.4	<0.010	3.3	<20	<10	<25	12
S 93799	41	46	34	21	5.3	0.190	0.140	0.030	19	6200	1500	<25	<1
S 93800	19	21	4.5	4.7	14	<0.040	0.140	0.030	20	3200	11000	<25	<1

Appendix 2.--Priority pollutants[1] for which ground-water samples were analyzed.

A. Volatile organic compounds

Benzene
Bromoform
Carbon tetrachloride
Chlorobenzene
Chlorodibromomethane
Chloroethane
2-Chloroethyl vinyl ether
Chloroform
Dichlorobromomethane
Dichlorodifluoromethane
1,1-Dichloroethane
1,2-Dichloroethane
1,1-Dichloroethylene
1,2-*trans*-Dichloroethylene
1,2-Dichloropropane
1,3-Dichloropropene
Ethylbenzene
Methylbromide
Methylene chloride
1,1,2,2-Tetrachloroethane
Tetrachloroethylene
Toluene
1,1,1-Trichloroethane
1,1,2-Trichloroethane
Trichloroethylene
Trichlorofluoromethane
Vinyl chloride

B. Acid-extractable organic compounds

4-Chloro-3-methylphenol
2-Chlorophenol
2,4-Dichlorophenol
2,4-Dimethylphenol
4,6-Dinitro-2-methylphenol
2,4-Dinitrophenol
2-Nitrophenol
4-Nitrophenol
Pentachlorophenol
Phenol
2,4,6-Trichlorophenol

C. Base/neutral-extractable organic compounds

Acenaphthene
Acenaphthylene
Anthracene
Benzidine
Benzo(a)anthracene
Benzo(b)fluoranthene
Benzo(k)fluoranthene
Benzo(g,h,i)perylene
Benzo(a)pyrene
4-Bromophenyl phenyl ether
Butyl benzyl phthalate
bis(2-Chloroethoxy)methane
bis(2-Chloroethyl)ether
bis(2-Chloroisopropyl) ether
2-Chloronaphthalene
4-Chlorophenyl phenyl ether
Chrysene
Dibenz(a,h)anthracene
1,2-Dichlorobenzene
1,3-Dichlorobenzene
1,4-Dichlorobenzene
3,3'-Dichlorobenzidine
Diethyl phthalate
Dimethyl phthalate
Di-*n*-butyl phthalate
2,4-Dinitrotoluene
2,6-Dinitrotoluene
Di-*n*-octyl phthalate
bis(2-Ethylhexyl) phthalate
Fluoranthene
Fluorene
Hexachlorobenzene
Hexachlorobutadiene
Hexachlorocyclopentadiene
Hexachloroethane
Indeno(1,2,3-cd)pyrene
Isophorone
Napthalene
Nitrobenzene
N-Nitrosodimethylamine
N-Nitrosodiphenylamine
N-Nitrosodi-*n*-propylamine
Phenanthrene
Pyrene
2,3,7,8-Tetrachlorodibenzo-*p*-dioxin
1,2,4-Trichlorobenzene

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[1] Priority pollutants are constituents listed in the EPA list of 129 priority pollutants (Keith and Telliard, 1979, p. 418.)

Appendix 9.--Organic chemical analyses of ground-water samples from disposal facility at Manorville, June 1985.

[Analyses by U.S. Geological Survey National Water Quality Laboratory, Doraville, Ga. Concentrations are total values, in micrograms per liter. Well locations are shown in fig 7. --, not not analyzed for; <, less than (below detection limit).]

Well number	Date of sample (mo/d/yr)	Time of sample	Chloro-benzene	Chloro-form	Methyl-ene chlo-ride	Toluene	Tri-chloro-ethyl-ene	1,1-Di-chloro-ethane	1,1,1-Tri-chloro-ethane	1,2-*Trans*-Di-chloro-ethyl-ene	1,2-Di-chloro-benzene	1,3-Di-chloro-benzene	1,4-Di-chloro-benzene
S 73792	6-25-85	1336	45	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<1.0	3.0	9.0
S 73811	6-25-85	1216	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	--	--	--
S 76402	6-17-85	1331	18	<3.0	<3.0	15	<3.0	<3.0	<3.0	<3.0	--	--	--
S 76403	6-17-85	1256	<3.0	<3.0	<3.0	13	<3.0	<3.0	<3.0	<3.0	<1.0	<1.0	<1.0
S 76404	6-17-85	1206	8.1	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	--	--	--
S 76405	6-17-85	1111	5.7	<3.0	<3.0	<3.0	<3.0	5.1	<3.0	<3.0	--	--	--
S 79107	6-24-85	1351	9.8	<3.0	<3.0	<3.0	<3.0	3.9	<3.0	<3.0	--	--	--
S 79108	6-24-85	1311	6.2	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	--	--	--
S 79109	6-24-85	1221	9.1	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	2.0	<1.0	2.0
S 79110	6-24-85	1131	<3.0	19	<3.0	<3.0	<3.0	6.3	<3.0	<3.0	--	--	--
S 79111	6-24-85	1036	21	<3.0	<3.0	<3.0	<3.0	27	<3.0	<3.0	--	--	--
S 79117	6-19-85	1316	70	<3.0	<3.0	<3.0	<3.0	8.8	<3.0	<3.0	--	--	--
S 79118	6-19-85	1211	8.9	<3.0	<3.0	<3.0	4.5	27	<3.0	13	3.0	<1.0	<1.0
S 79119	6-19-85	1051	18	<3.0	<3.0	<3.0	<3.0	25	<3.0	4.7	--	--	--
S 79125	6-13-85	1051	<3.0	<3.0	5.3	<3.0	<3.0	12	<3.0	6.6	--	--	--
S 79126	6-11-85	1501	<3.0	<3.0	13	<3.0	<3.0	19	4.9	11	2.0	<1.0	<1.0
S 79127	6-11-85	1301	<3.0	<3.0	5.0	<3.0	6.9	17	6.7	15	--	--	--
S 79234	6-13-85	1421	<3.0	<3.0	6.3	<3.0	<3.0	<3.0	<3.0	<3.0	--	--	--
S 79235	6-13-85	1326	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<1.0	<1.0	<1.0
S 79236	6-13-85	1221	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	--	--	--