GROUND-WATER MOVEMENT IN THE UPPER GLACIAL AQUIFER IN THE MANORVILLE AREA, TOWN OF BROOKHAVEN, LONG ISLAND, NEW YORK, IN NOVEMBER 1983

by David A. V. Eckhardt and Eliezer J. Wexler

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(in pocket)

CONVERSION FACTORS AND ABBREVIATIONS

Multiply inch-pound units	by	To obtain metric units
	Length	
inch (in)	25.40	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Flow	
foot per day (ft/d)	0.3048	meter per day (m/d)
	Specific capacity	
gallon per minute per foot [(gal/min)/ft]	0.2070	liter per second per meter [(L/s)/m]
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)

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Abstract

Water levels in 52 wells near the Manorville scavenger-waste-disposal facility in the Town of Brookhaven were measured in November 1983 to determine hydraulic gradients and the velocity of ground-water flow in the upper glacial aquifer. Ground water moves south-southeastward (S22°E) from the ground-water divide, about 6 miles north of the facility, to discharge points near East Moriches and beneath Moriches Bay. The hydraulic gradient beneath the disposal facility is 6.5 feet per mile (0.0012 foot per foot), and the rate of horizontal flow is 0.9 to 1.7 feet per day. Vertical movement of ground water since closure of the disposal facility in 1982 is probably negligible because the vertical gradients are small and the upper glacial aquifer is anisotropic. During operation of the facility, however, ground-water mounding may have developed beneath the unlined settling basins, which could have induced downward movement of water in the upper glacial aquifer.

INTRODUCTION

Ground water is the sole source of water supply for nearly 3.1 million residents of Nassau and Suffolk Counties on Long Island. The Town of Brookhaven, in central Suffolk County (fig. 1), is expected to have continued population growth; thus proper management of the ground-water resource is essential. The aquifer system that supplies water to the Town of Brookhaven consists primarily of Pleistocene sand and gravel, which is called the upper glacial aquifer, and a deeper sequence of Cretaceous sand, silt, and clay deposits that rests on bedrock.

In recent years, leachate from solid- and liquid-waste-disposal sites in the Town of Brookhaven has entered the upper glacial aquifer, but neither the extent of contamination nor the potential for further migration are known. In 1981, the U.S. Geological Survey, in cooperation with the Town of Brookhaven, began a hydrogeologic study to evaluate the movement of ground water at a scavenger-waste-disposal facility near Manorville, in the east-central part of the Town of Brookhaven (fig. 1). The facility received solid waste, liquid sewage, and sludge from 1964 through 1982. As a preliminary step in the study, the Geological Survey installed 19 wells in 1983 to evaluate the rates and direction of ground-water movement within the 35-acre disposal site and surrounding area.

Purpose and Scope

This report describes the observation-well network that was established in the upper glacial aquifer in the Manorville area, lists the water levels measured in November 1983, and describes the rates and direction of ground-water movement in the upper glacial aquifer in the area. It also presents two water-table maps--one of the Manorville area (36 mi^2, pl. 1) and one of the waste-disposal-facility area (4 mi^2, pl. 2).

Acknowledgments

The authors thank Elaine McKibbin, Director of Sanitation, Town of Brookhaven, and Joseph Lapienski, Manorville facility supervisor, for their cooperation and assistance during the study. The authors also thank Paul E. Moore, of McLean and Associates, Brookhaven, N.Y., for his help in coordinating the vertical control surveys.

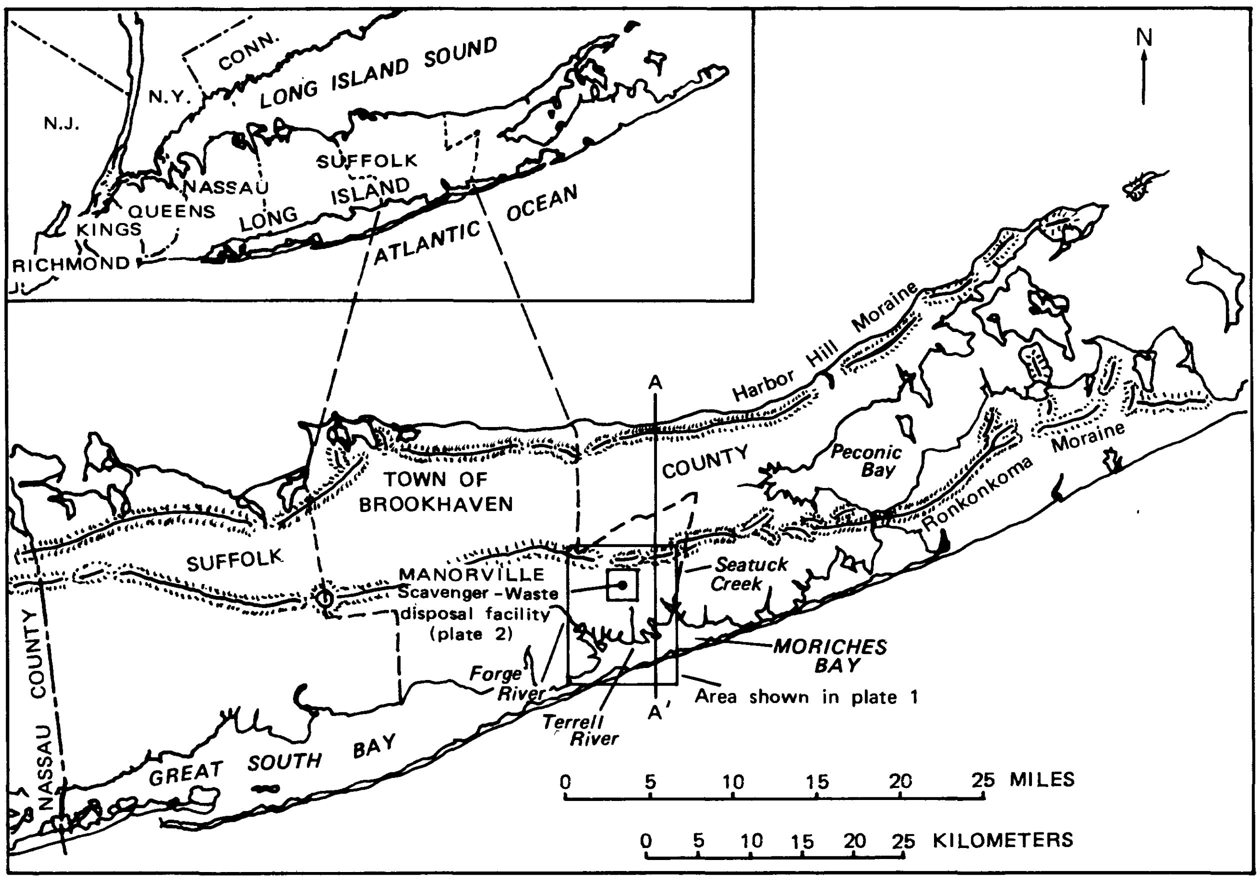

Figure 1.--Location of the Manorville area on Long Island. (Geologic section A-A' is shown in fig. 2.)

METHODS OF INVESTIGATION

A network of observation wells screened in the upper glacial aquifer was established in the Manorville area (pl. 1) and at the disposal facility (pl. 2) to define the ground-water flow patterns. First, an inventory of all wells in the 36-mi^2 Manorville area was made, and 32 wells were selected for the network. An additional 19 wells were then installed in the glacial outwash to supplement the network at the disposal site and surrounding areas. A reference-point altitude for each well was established by vertical control surveys from established benchmarks. The locations, physical characteristics, ownership, and other pertinent information about the wells are given in table 1. The wells range from 2 to 14 inches in diameter and are constructed of steel or polyvinyl chloride (PVC). A 14-inch observation well, owned by the Suffolk County Water Authority (S33920), is screened in the Magothy aquifer at 629 ft below land surface (pl. 2) and provides data for assessing vertical movement of ground water between the two aquifers.

Two or three observation wells were installed adjacent to each other at seven locations. Each well was screened at a different depth in the upper glacial aquifer to provide information about vertical head gradients and associated vertical flow of ground water between the screened intervals at each location. The well clusters can also be used for water-quality monitoring to provide data on the vertical distribution of contaminants.

Water levels in the wells were measured over a 6-hour period on November 23, 1983, and two water-table maps were constructed from the measurements. One is a regional map (pl. 1) that depicts general ground-water flow patterns in the Manorville area; the other (pl. 2) depicts flow patterns at the waste-disposal facility.

DESCRIPTION OF THE MANORVILLE AREA

The Manorville area, in the southeast part of the Town of Brookhaven (fig. 1), is bordered by the Peconic River on the north, Forge River on the west, Seatuck Creek on the east, and the saltwater of Moriches Bay and the Atlantic Ocean on the south (pl. 1). The surrounding region, known locally as the Pine Barrens, contains sandy soil that supports a natural growth of pitch pine and scrub oak. Irrigated cropland in the area supports prosperous vegetable farms and nurseries.

Climate

The climate in the Manorville area is influenced more by the ocean than by the adjacent mainland, and diurnal temperature changes are moderated accordingly. Precipitation, the only source of freshwater in this area, averages about 46 inches per year (Miller and Frederick, 1969) and is distributed fairly evenly throughout the year. Precipitation readily penetrates the sandy soil and glacial outwash, and direct runoff to streams is negligible. Evapotranspiration is about 22 inches, or nearly half the annual precipitation. Rates of evapotranspiration vary during the year and

Table 1.--Data on observation wells in the Manorville area.

[Locations are shown on pl. 1]

Well no.	Latitude/Longitude		Owner[1]	Depth (ft)	Depth to screen Top (ft)	Depth to screen Bottom (ft)	Well diameter (in)
S31460	405004	724659	TOB	100	90	100	4
S31461	404956	724642	TOB	68	62	68	4
S31462	405000	724643	TOB	73	67	73	4
S33919	404908	724730	SCDHS	78	67	78	4
S33920	404908	724730	SCDHS	629	588	629	14
S36150	405117	724903	USGS	45	43	45	2
S36152	405014	724438	USGS	66	62	66	2
S46546	405131	724557	USGS	123	120	123	2
S46913	404920	724846	SCDHS	20	10	15	6
S46914	404917	724845	SCDHS	22	6	11	6
S46966	404952	724705	SCDHS	86	72	82	6
S47755	405136	724645	SCDHS	58	45	55	4
S48946	405121	724906	SCDHS	45	31	41	6
S65604	404928	724835	USGS	56	51	56	2
S67198	404959	724645	SCDHS	97	90	95	4
S73790	405007	724648	USGS	61	58	61	2
S73791	404957	724655	USGS	61	58	61	2
S73792	404959	724651	USGS	61	58	61	2
S73793	405000	724643	USGS	56	53	56	2
S73794	404945	724652	USGS	73	70	73	2
S73795	404946	724644	USGS	47	44	47	2
S73796	404947	724639	USGS	55	52	55	2
S73797	404949	724635	USGS	57	54	57	2
S73798	404953	724623	USGS	66	63	66	2
S73799	404956	724642	USGS	101	98	101	2
S73800	405025	724622	USGS	83	80	83	2
S73801	404929	724622	USGS	50	47	50	2
S73802	404837	724848	USGS	34	30	34	2
S73803	404825	724711	USGS	48	42	45	2
S73804	404835	724629	USGS	22	19	22	2
S73805	404850	724527	USGS	53	50	53	2
S73806	404931	724511	USGS	66	60	63	2
S73807	405102	724506	USGS	100	95	98	2
S73808	405053	724826	USGS	60	54	57	2
S73809	404937	724642	private[2]	50	40	50	6
S73810	404923	724638	private[2]	50	40	50	6
S73811	405014	724657	TOB	85	80	85	4
S73812	405014	724657	TOB	65	60	65	4
S73813	404956	724645	TOB	88	83	88	4
S73814	404956	724645	TOB	68	63	68	4
S73815	404956	724645	TOB	53	48	53	4
S73816	404955	724652	TOB	70	65	70	4
S73817	404955	724652	TOB	90	85	90	4
S73818	404955	724652	TOB	110	105	110	4
S73819	404745	724812	CMFD	42	--	--	6
S73820	404756	724653	CMFD	46	--	--	6
S73821	404755	724544	EMFD	45	--	--	6
S73822	404828	724441	EMFD	45	--	--	6
S73823	405009	724748	private[3]	70	--	--	3
S74293	405017	724950	USGS	71	67	71	2
S74294	405213	724811	USGS	36	32	36	2
S74295	405045	724726	USGS	56	52	56	2

[1] TOB, Town of Brookhaven
SCDHS, Suffolk County Department of Health Services
USGS, U.S. Geological Survey
CMFD, Center Moriches Fire Department
EMFD, East Moriches Fire Department

[2] Unused irrigation well.

[3] Unused domestic well.

are highest during summer (Warren and others, 1968). Precipitation recharges the ground-water system only when evapotranspiration losses are small and after soil-moisture deficiencies have been satisfied. On Long Island, the highest rates of recharge occur during late fall, winter, and early spring.

Hydrogeologic Setting

The hydrogeology of eastern Long Island has been described in detail by several authors, including Krulikas (1986), Koszalka (1984), Jensen and Soren (1974), McClymonds and Franke (1972), Warren and others (1968), and deLaguna (1963). A generalized geologic section of the aquifer system is shown in figure 2.

The Manorville disposal facility is excavated in highly permeable Pleistocene sand and gravel outwash that forms the upper glacial aquifer. The outwash is estimated to be about 160 ft thick at the facility and probably is underlain by the Gardiners Clay of Pleistocene age (fig. 2). Geologic information about clay units in the area is lacking, however.

The Monmouth Group, which consists of Cretaceous greensand and clay known as the Monmouth greensand, underlies the upper glacial aquifer in the southern part of the Manorville area. Its northern limit is uncertain but is assumed to be south of the disposal facility.

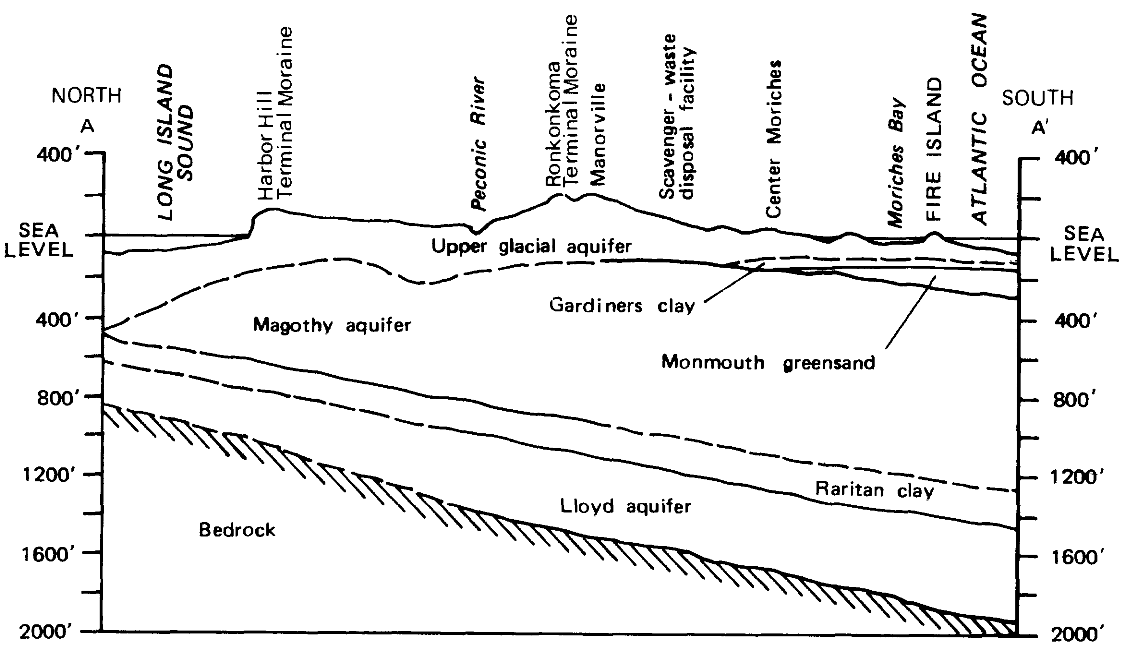

Figure 2.--Generalized hydrogeologic section showing relative positions of the major aquifers. (From Jensen and Soren, 1974.)

The Gardiners Clay and the Monmouth greensand, where present, unconformably overlie the Matawan Group and Magothy Formation, undifferentiated, of Cretaceous age, a thick body of continental deltaic deposits containing gradational sequences of sand, sandy clay, clay, and, in basal sections, some gravel. The Matawan-Magothy sequence may exceed 900 ft in thickness in the Manorville area and forms the Magothy aquifer.

The Raritan Formation of Cretaceous age, which underlies the Magothy Formation, consists of two members--an upper unnamed clay member that forms the Raritan confining unit, and the lower Lloyd Sand Member, which forms the Lloyd aquifer (fig. 2). The Raritan Formation rests on crystalline bedrock. The estimated thickness of the clay and sand member is 200 and 400 ft, respectively. The total thickness of unconsolidated material in the Manorville area, therefore, is more than 1,600 ft.

Hydraulic Characteristics of the Upper Glacial Aquifer

A compilation of pumping yields, drawdowns, and specific capacities (yield per foot of drawdown) reported by well drillers for 14 irrigation and public-supply wells in the Manorville area is given in table 2. Generally, these wells have a high specific capacity, with a median of 19 (gal/min)/ft. The median hydraulic conductivity in the upper glacial aquifer was computed from data in table 2 by a method described by McClymonds and Franke (1972, p. E11) to be 430 ft/d. They indicate, however, that values calculated by this method may be higher than actual values because of vertical flow to partially screened wells. Thus, the value of 430 ft/d may represent an upper limit for horizontal hydraulic conductivity in this area.

An analysis of pumping tests in the upper glacial aquifer in southern Nassau County (Lindner and Reilly, 1983) indicated horizontal hydraulic conductivity of the glacial outwash to range from 140 to 380 ft/d. Mean hydraulic conductivity of the aquifer in the vicinity of the Horseblock Road sanitary landfill in the Town of Brookhaven, 8 mi west of the Manorville area (fig. 1), is estimated to be 220 ft/d (E. J. Wexler, U.S. Geological Survey, written commun., 1984). Because hydraulic conductivity controls the average rate of ground-water movement and associated transport of dissolved contaminants, an accurate estimate is essential for predicting contaminant movement. Although the values above give a probable range of values, additional aquifer testing would permit a more accurate determination of mean hydraulic conductivity.

Estimates of the ratio of horizontal to vertical hydraulic conductivity in the upper glacial aquifer range from 5:1 to 24:1 (Lindner and Reilly, 1983, p. 2). Porosity of the aquifer was assumed to be 30 percent (McClymonds and Franke, 1972).

Hydraulic Characteristics of the Magothy Aquifer

Few data on the hydraulic conductivity of the Magothy aquifer in the Manorville area are available because only one well in the area is screened in the formation. Regional estimates of horizontal hydraulic conductivity range between 13 and 54 ft/d (Warren and others, 1968) and from 40 to 54 ft/d

(McClymonds and Franke, 1972). Anisotropy in the Magothy aquifer (the ratio of horizontal to vertical hydraulic conductivity) was estimated by Getzen (1977) to range from 30:1 to 60:1. Aquifer porosity is assumed to be 25 percent (McClymonds and Franke, 1972).

Table 2.--Specific-capacity data from drillers' reports on wells screened in the upper glacial aquifer in the Manorville area.

[Well locations are shown in pl. 1]

Well no.	Depth (ft)	Screen length (ft)	Screen diameter (in)	Pumping rate (gal/min)	Drawdown (ft)	Specific capacity [(gal/min)/ft]	Specific capacity per ft of screen [(gal/min)/ft^2]
S11260	154	20	12	800	25	32	1.6
S20633	60	20	6	250	9	28	1.4
S21768	133	41	16	2,400	30	80	2.0
S23876	100	15	6	150	12	12.5	0.8
S34156	95	10	6	200	14	14	1.4
S35469	74	15	6	250	14	18	1.2
S46712	100	27	8	150	5	30	1.1
S46913	20	5	6	50	6	8.3	1.7
S46914	22	5	6	50	6	8.3	1.7
S46966	86	10	6	80	4	20	2.0
S47755	58	10	4	20	3	6.7	0.7
S48946	45	10	6	75	6	12.5	1.2
S56038	158	36	12	500	10	50	1.4
S56039	163	40	12	1,404	12	117	[1]2.9

[1] Well has 70-ft gravel pack, which effectively lengthens reported screen length and reduces specific capacity per foot of screen to about 1.7 (gal/min)/ft^2

DESCRIPTION OF THE MANORVILLE WASTE-DISPOSAL FACILITY

The Manorville scavenger-waste-disposal facility is on Paper Mill Road in the southern part of Manorville (pl. 2). The facility covers 35 acres. It is at the head of the Terrell River valley, which contains flowing water intermittently, and lies on the glacial outwash plain immediately south of the Ronkonkoma terminal moraine (fig. 1). The site is bordered on the south and east by tree nurseries and on the north and west by woodland.

The Manorville scavenger-waste-disposal facility received municipal sludge and liquid septic wastes from domestic holding tanks for 9 years and may also have received liquid industrial wastes periodically. The wastes were deposited in a series of unlined settling basins that were excavated in the glacial outwash. The disposal facility had a design capacity of 50,000 gal/d, but incoming sewage and sludge volumes frequently exceeded that amount (Dvirka and Bartilucci, 1981). The scavenger waste typically contained high amounts of suspended solids, both organic and inorganic, as well as high concentrations of total nitrogen, biochemical oxygen demand (BOD), and chemical oxygen demand (COD). Elevated concentrations of heavy metals and volatile organic compounds, particularly toluene, indicated some industrial waste in the scavenger waste (Dvirka and Bartilucci, 1981). The primary forms of waste treatment in the basins were chlorination and aeration of the fluids.

Liquid-waste disposal started in 1964 and continued until August 1982. Municipal solid wastes were also landfilled at the site during 1960-72. The facility was closed in November 1982 when it did not meet New York State environmental criteria for operation. After closure of the site, the basins were allowed to dry. Bottom material is currently (1984) being excavated and removed to a nearby sanitary landfill.

GROUND-WATER MOVEMENT

Observation wells provide a method for measuring water pressure at the point in the aquifer at which the well is screened. The depth to water below a known reference altitude indicates the total hydraulic head at that point, which is expressed in feet above sea level. Because water moves from areas of higher total head to areas of lower total head, directions of ground-water flow may be deduced from simultaneous head measurements over a given area. Estimates of ground-water velocities can be made from the gradients in hydraulic head and the hydraulic conductivity and effective porosity of the aquifer material.

Water-Level Measurements

The U.S. Geological Survey measured water levels in 52 observation wells on November 23, 1983. The water-table altitudes and the single Magothy aquifer potentiometric-surface measurement are given in table 3. The water-table contours within the Manorville area are shown on plate 1, and those at the waste-disposal facility on plate 2. Ground water flows perpendicular to water-table contours; thus, in the Manorville area, the direction of flow is south-southeastward (S22°E) from the ground-water divide near the Ronkonkoma moraine (fig. 1) toward East Moriches and Moriches Bay.

Rate of Flow

Ground-water flow rates were estimated from Darcy's law (Bear, 1979), which directly relates ground-water velocity to the hydraulic gradient between two points in an aquifer. The rate of ground-water flow in the aquifer was calculated by multiplying the hydraulic conductivity by the hydraulic gradient and then dividing by the effective porosity of the material (a measure of interconnected pore space through which water may move).

The hydraulic gradient that drives ground-water flow has two components--a horizontal gradient and a vertical gradient--which allows computation of horizontal and vertical ground-water flow rates. The horizontal (water-table) gradient in the upper glacial aquifer beneath the waste-disposal facility is

Table 3.--Measurement-point altitudes and ground-water levels in the Manorville area, November 1983.

[Well locations are shown on pls. 1 and 2]

Well no.	Well depth (ft)	Measurement-point altitude (ft above sea level)	Depth to water (ft)	Water-level altitude (ft above sea level)
31460	100	89.14	63.25	25.89
31461	68	68.23	43.49	24.74
31462	73	70.45	45.21	25.24
33919	78	65.75	45.49	20.24
33920	629	66.10	46.13	19.97
36150	45	49.75	15.18	34.57
36152	66	64.68	43.68	21.00
46546	123	124.49	94.17	30.32
46913	20	30.62	7.85	22.72
46914	22	32.98	22.60	22.60
46966	86	87.46	62.66	24.80
47755	58	59.74	27.40	32.34
48946	45	44.12	9.84	34.28
65604	56	64.18	40.17	24.01
67198	97	79.35	54.05	25.30
73790	61	75.31	49.02	26.29
73791	61	84.27	59.15	25.12
73792	61	80.30	54.99	25.31
73793	56	68.77	43.59	25.18
73794	73	85.56	61.83	23.73
73795	47	56.75	33.10	23.65
73796	55	67.05	43.45	23.60
73797	57	68.94	45.17	23.77
73798	66	75.31	51.59	23.72
73799	101	69.02	44.28	24.74
73800	83	101.11	74.26	26.85
73801	50	65.24	44.29	20.95
73802	34	30.09	17.17	12.92
73803	48	45.91	32.48	13.43
73804	22	23.35	10.25	13.10
73805	53	46.04	33.25	12.79
73806	66	50.86	35.15	15.71
73807	100	108.75	82.15	26.60
73808	60	61.14	29.60	31.54
73809	50	38.30	16.01	22.29
73810	50	37.84	17.22	20.62
73811	85	83.47	56.10	27.37
73812	65	83.03	55.65	27.38
73813	88	64.13	39.32	24.81
73814	68	64.16	39.36	24.80
73815	53	64.17	39.35	24.82
73816	70	87.06	62.21	24.85
73817	90	87.35	62.50	24.85
73818	110	87.02	62.17	24.85
73819	20	13.12	10.03	3.09
73820	20	12.54	6.66	5.88
73821	20	15.62	11.14	4.48
73822	20	17.18	12.14	5.04
73823	70	88.64	62.02	26.62
74293	71	83.37	53.14	30.23
74294	36	57.58	21.44	36.14
74295	56	68.83	38.95	29.88

6.5 ft/mi or 0.0012 ft/ft. With this gradient, an average hydraulic conductivity of 220 to 430 ft/d, and a porosity of 0.30, the rate of horizontal flow ranges from about 0.9 to 1.7 ft/d. At these flow rates, ground water beneath the facility will move from 6,600 to 12,000 feet south-southeastward in the upper glacial aquifer in 20 years. The flow patterns and gradients at Manorville agree with those reported in a study of the nearby Pine Barrens area of Suffolk County (Krulikas, 1986). The flow patterns and gradients reported for the Manorville area represent measurements on only one date, however, and do not account for possible seasonal variations.

Vertical gradients were measured at the waste-disposal facility to determine rates of vertical movement of water to deeper zones within the upper glacial aquifer. Aquifer heads at five well clusters near the facility differed slightly and indicate downward movement of water, but the differences were extremely small--less than 0.01 ft--which is below the limits of accuracy for vertical-control surveys of measurement-point altitudes and water-level measurements. Because these vertical gradients were small, and also because the vertical hydraulic conductivity of the upper glacial aquifer may only be from 1/5 to 1/24 of the horizontal value, the vertical movement of ground water beneath the disposal facility since its closure in 1982 is probably negligible.

During operation of the disposal facility, mounding of the water table may have occurred as wastewater seeped out of the unlined basins. Although the regional ground-water movement in this area is predominantly horizontal, increased vertical gradients during mounding could have caused downward movement of wastewater within the aquifer. The water-table mounds would have dissipated shortly after waste-disposal operations ceased in 1982, however.

Measurable differences in vertical heads were observed between well S33920, which is screened at an intermediate depth in the Magothy aquifer, and an adjacent well, S33919, screened in the upper glacial aquifer (well locations are shown in pl. 2). The vertical gradient measured at this well cluster in November 1983 was equal to 0.0005 ft/ft and indicates that ground water moves downward from the upper glacial aquifer to the Magothy aquifer at this site. The rate of downward movement can be calculated from estimates of effective porosity, hydraulic conductivity, and the ratio of anisotropy for the Magothy aquifer. The computed rates of vertical movement are extremely low, between 0.16 and 1.3 ft/yr. If the Gardiners Clay overlies the Magothy aquifer beneath the disposal facility, rates of vertical movement would be considerably lower. Additional hydrogeologic data would be required to more fully appraise the potential for downward movement of water from the upper glacial aquifer to the Magothy aquifer.

SUMMARY AND CONCLUSIONS

Water-level measurements were made at 52 observation wells in the 36-mi^2 area near the Manorville scavenger-waste disposal facility in November 1983 to determine the direction and velocity of ground-water flow. Ground water moves south-southeastward (S22°E) from the ground-water divide north of the facility toward East Moriches and Moriches Bay. Horizontal flow at the facility is induced by a 6.5-ft/mi (0.0012) hydraulic gradient on the water table. From an average hydraulic conductivity ranging from 220 to 430 ft/d and an effective porosity of 0.30, the average ground-water flow rate in the upper glacial aquifer beneath the disposal facility may range from 0.9 to 1.7 ft/d. Within this range of flow rates, ground water beneath the facility will move 6,600 ft to 12,000 ft south-southeastward in the upper glacial aquifer in 20 years. The principal direction of ground-water movement in the upper glacial aquifer is horizontally toward discharge points near East Moriches and beneath Moriches Bay.

Vertical gradients at the Manorville disposal facility are small compared to the average horizontal (water-table) gradient of 0.0012 ft/ft. Vertical movement of ground water beneath the disposal facility since its closure in 1982 is probably negligible because of the small vertical gradients and the low vertical hydraulic conductivity of the upper glacial aquifer (1/5 to 1/24 of the horizontal value). Mounding of the water table below the unlined settling basins during operation of the facility, however, may have caused downward movement of wastewater.

The vertical gradient measured at a well cluster 1.1 mi downgradient of the disposal facility was used to compute the rate of downward flow of ground water from the upper glacial aquifer to the Magothy aquifer. The estimated rates of downward flow are low, ranging from 0.16 to 1.3 ft/yr.

REFERENCES CITED

deLaguna, Wallace, 1963, Geology of the Brookhaven National Laboratory and vicinity, Suffolk County, New York: U.S. Geological Survey Bulletin 1156-A, 35 p.

Dvirka, Miro, and Bartilucci, N. J., 1981, Scavenger waste landfill leachate study for Town of Brookhaven: Syosset, N.Y., Dvirka and Bartilucci Consulting Engineers, Inc., 166 p.

Getzen, R. T., 1977, Analog-model analysis of regional three-dimensional flow in the ground-water reservoir of Long Island, New York: U.S. Geological Survey Professional Paper 982, 49 p.

Jensen, H. M., and Soren, Julian, 1974, Hydrogeology of Suffolk County, Long Island, New York: U.S. Geological Survey Hydrologic Investigation Atlas HA-501, 2 sheets.

Koszalka, E. J., 1984, Geohydrology of the northern part of the Town of Brookhaven, Suffolk County, New York: U.S. Geological Survey Water-Resources Investigations Report 83-4042, 37 p.

Krulikas, R. K., 1986, Hydrologic appraisal of the Pine Barrens, Suffolk County, New York: U.S. Geological Survey Water-Resources Investigations Report 84-4271, 53 p.

REFERENCES CITED (Continued)

Lindner, J. B., and Reilly, T. E., 1983, Analysis of three tests of the unconfined aquifer in southern Nassau County, Long Island, New York: U.S. Geological Survey Water-Resources Investigations Report 82-4021, 46 p.

McClymonds, N. E. and Franke, O. L., 1972, Water-transmitting properties of aquifers on Long Island, New York: U.S. Geological Survey Professional Paper 627-E, 24 p.

Miller, J. F., and Frederick, R. H., 1969, The precipitation regime of Long Island, New York: U.S. Geological Survey Professional Paper 627-A, 21 p.

Warren, M. A., deLaguna, Wallace, and Lusczynski, N. J., 1968, Hydrology of the Brookhaven National Laboratory and vicinity, Suffolk County, New York: U.S. Geological Survey Bulletin 1156-C, 127 p.