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United States Department of the Interior

GEOLOGICAL SURVEY
Water Resources Division
5 Aerial Way
Syosset New York 11791
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November 17, 1986

Mr. Vance Bryant
N.Y. State Dept. of Environmental Conservation
Room 618
50 Wolf Road
Albany, New York 12233-0001

Dear Mr. Bryant:

Enclosed are two publications that report on the downward rate of the wetting fronts. We will be happy to assist you in the future and don't hesitate to call on us again.

For the Subdistrict Chief:

Sincerely,

Henry F. H. Ku jp

Henry F. H. Ku
Hydrologist

HFHK:jp
Encls.

National Water Well Association Proceedings, 1984

Monitoring the Movement and Chemical Quality of Artificial-Recharge Water in the Unsaturated Zone on Long Island, New York

by Brian J. Schneider, James Oliva, Henry F.H. Ku and
Edward T. Oaksford

Abstract

Artificial-recharge experiments with tertiary-treated waste water are being conducted in central Nassau County, Long Island, N.Y.; a heavily populated suburban area whose sole fresh water supply is ground water. These tests will evaluate the feasibility of replenishing the water table aquifer through shallow recharge basins and injection wells. Water in this aquifer has deteriorated in chemical quality and been depleted by sewering.

One aim of this program is to study the role of the unsaturated zone in controlling infiltration rates and altering water quality. A 72-hour recharge test was conducted in the Summer of 1983 at a 5,000 square-foot (ft^2) recharge basin equipped with an observation manhole. Three million gallons (Mgal) were applied to this basin over the three-day period.

Preliminary findings were:

1. Infiltration rates ranged from 1.1 to 1.47 feet per hour (ft/h) during the test. This wide range can be attributed to the effect of a silty layer inhibiting infiltration within the unsaturated zone.
2. This layer was located by horizontal tensiometers measuring unsaturated pressure-head distribution. Average vertical hydraulic conductivity for this layer was 11 ft/d, less than half the average of 24 ft/d for the entire saturated thickness.
3. Average interstitial velocity calculated from soil-moisture logs and water-table response was 6.0 ft/h through the whole unsaturated section.
4. Water-quality analyses showed that concentrations of a majority of inorganic constituents and volatile organic compounds were not influenced by travel through the unsaturated zone.

These findings indicate that the recharge capacity of ponding basins is decreased by zones of lower permeability within the unsaturated zone and reclaimed water remains relatively unchanged chemically after percolation to the water table. Chemical stability of the water is attributed to the unreactive nature of the unsaturated zone materials, the rapid movement of water moving through the unsaturated zone and the effectiveness of treatment that the waste water receives before recharge.

Introduction

Ground water is the sole source of drinking water for central and eastern Long Island. The aquifers have been greatly stressed during the past 40 years through pumpage due to population growth and through reductions in recharge resulting from sewering and loss of undeveloped land for infiltration of precipitation. Waste water was originally discharged to the ground through cesspools and septic tanks and gradually began to contaminate the shallow ground water. To stop this, a centralized sewer system was constructed in much of Nassau County to intercept the waste water and route it to sewage-treatment plants, where it is treated and pumped to the sea. Although this protects the ground water from further sewage contamination, it decreases the island's ground water supply by continually diverting water to the ocean that would otherwise be returned to the water table aquifer.

As a partial solution to this problem, a study was devised to examine the feasibility of artificially recharging the ground water with reclaimed waste water. In 1978, at East Meadow (Figure 1), a system of shallow basins and injection wells was constructed where up to 4 million gallons per day (Mgal/d) of reclaimed waste water can be returned to the water table aquifer. Part of the program was designed to evaluate the influence of the unsaturated zone on infiltration rate and chemical quality of water during artificial recharge. The unsaturated zone is now being studied at basins equipped with instrumented observation manholes extending 16 feet below the basin floor. Results of initial tests indicate high infiltration rates and only limited chemical interaction between reclaimed water and the unsaturated medium.

Study Site

The location of the site, known as the East Meadow Artificial-Recharge Facility, is shown in Figure 1. Reclaimed water is provided by the nearby Cedar Creek Waste Water Reclamation Facility through a 6.25-mi pipeline.

Reclaimed water is generated through a tertiary-treatment process that includes denitrification for nitrogen removal, multi-media filtration, carbon filtration for removal of organic compounds and final chlorination. At the East Meadow Recharge Facility, the reclaimed water is released by gravity into shallow 5,000 square foot (ft^2) ponding basins or is pumped into shallow injection wells (Figure 2). The operating effectiveness of both management schemes is being evaluated by the U.S. Geological Survey in cooperation with Nassau County Department of Public Works.

Purpose and Scope

This article presents the results of a 72-hour ponding test conducted in June 1983 to evaluate the influence of the unsaturated zone on: (1) infiltration rate of reclaimed effluent, and (2) the chemical quality of reclaimed effluent as it percolates to the water table. Results are given in plots of infiltration rate and soil-moisture tension and in four tables of chemical analyses.

Hydrogeology

Long Island's subsurface (Figure 3) consists of a southward-dipping wedge of unconsolidated material overlying

Figure 1: Location of East Meadow Artificial Recharge Facility and Cedar Creek Waste Water Reclamation Facility.

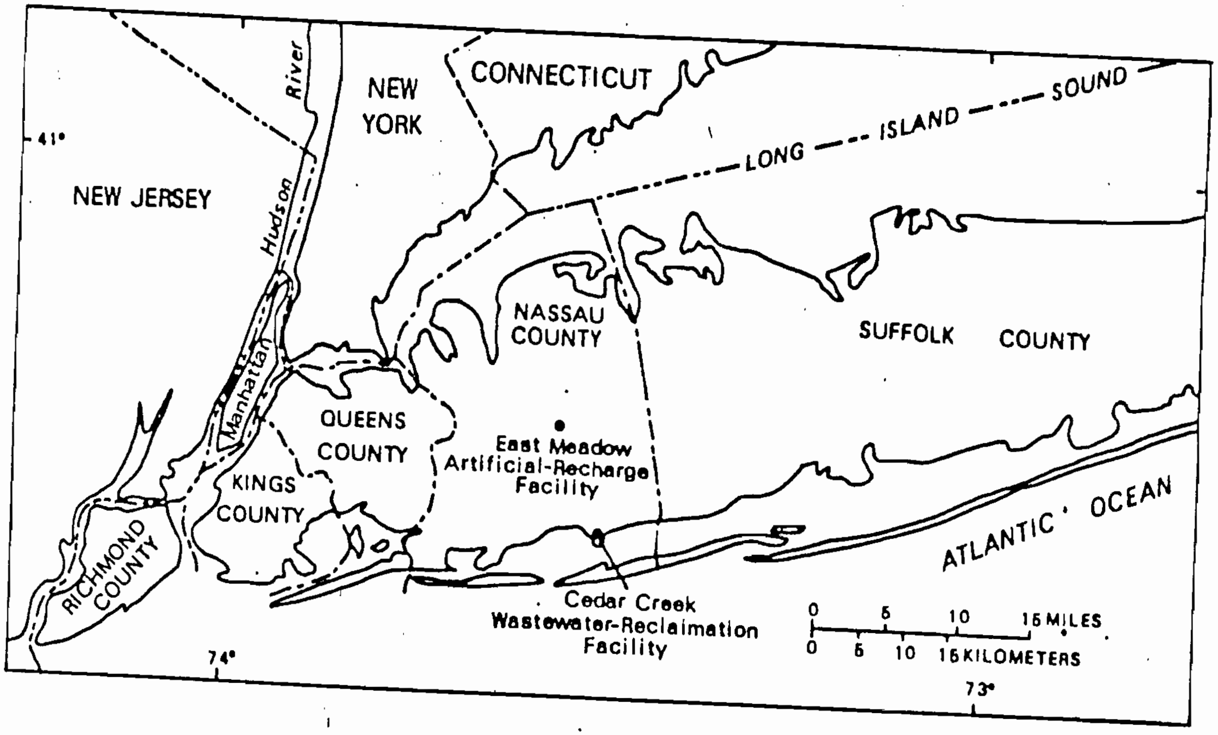
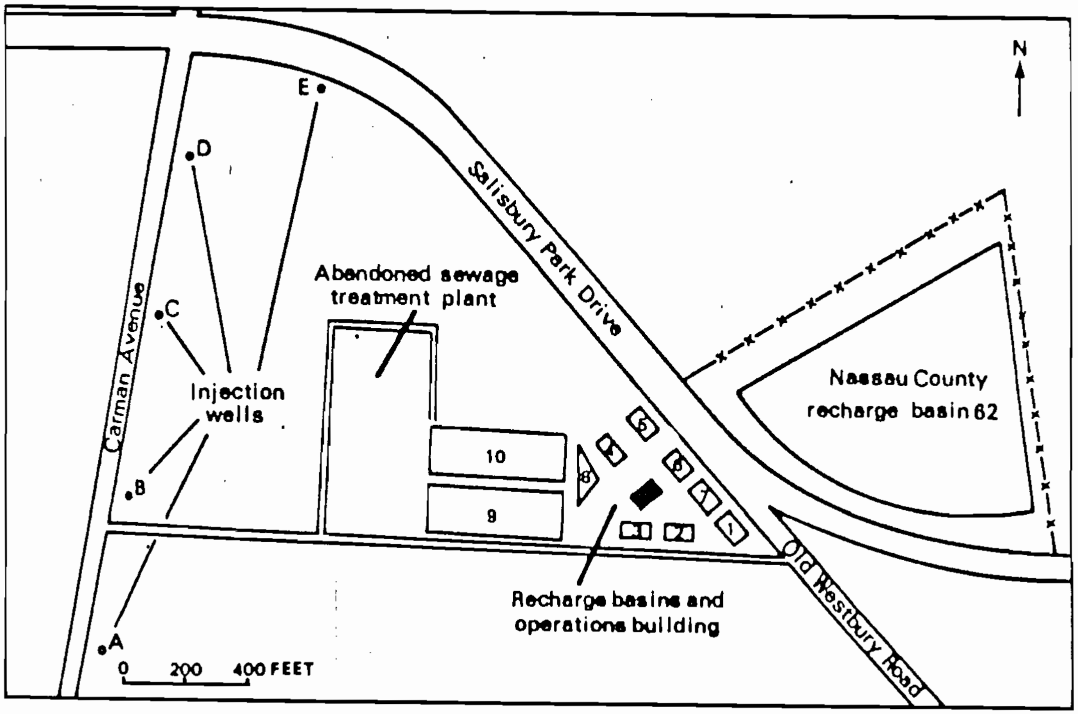
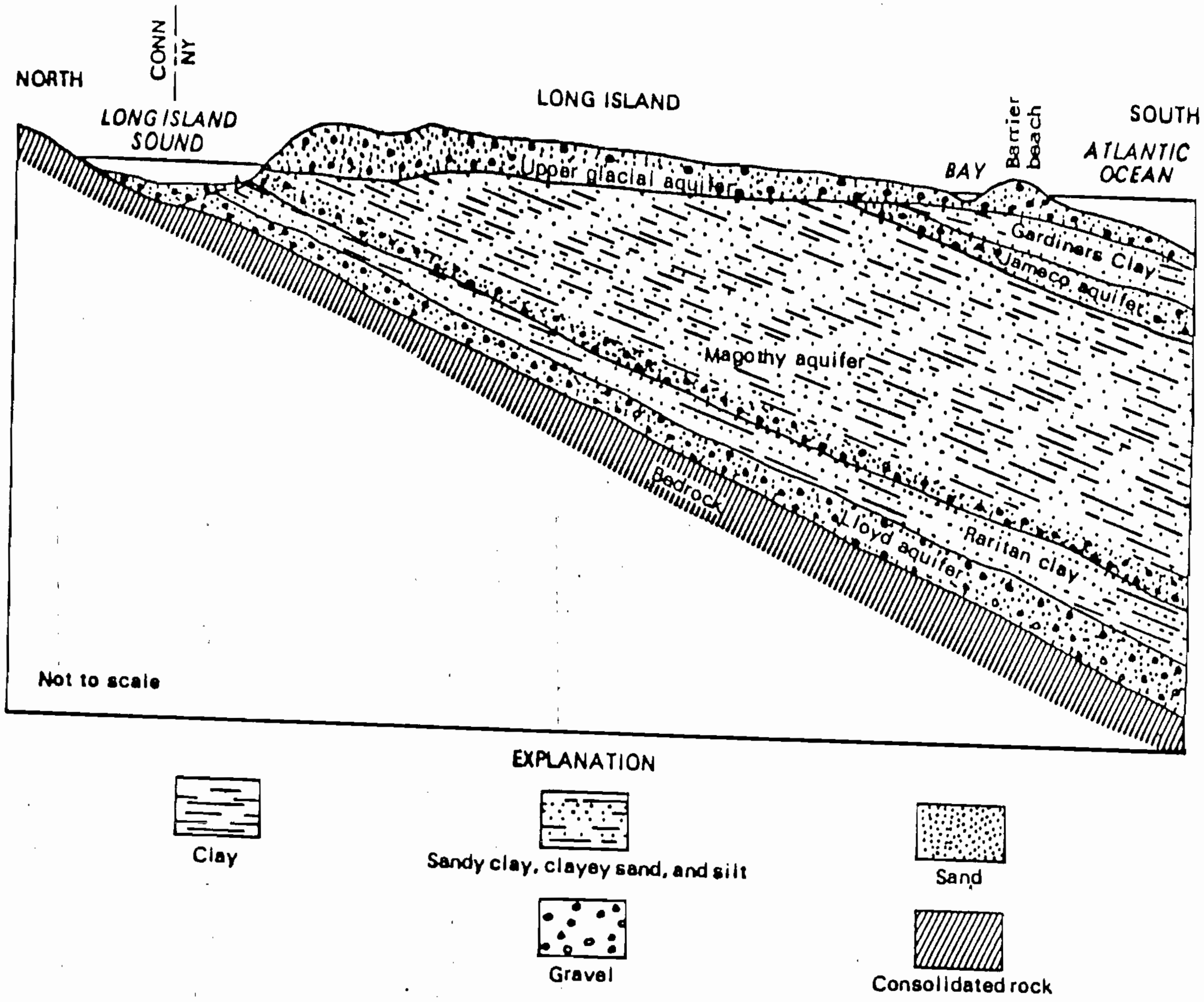


Figure 2: Plan View of Recharge Facility Showing Location of Recharge Basins and Injection Wells.



Base from Beckman
and Avendi, 1973

Figure 3: Generalized Geologic Section Showing Relative Position of Upper Glacial Aquifer. (Modified from Franke and McClymonds, 1972, p. 10F).



crystalline bedrock. The upper glacial aquifer, the uppermost water-bearing unit, is under water table conditions and is the recipient of the reclaimed waste water. The water table is 30 feet below the land surface in the study area. The aquifer consists of unconsolidated sand and gravel of Pleistocene age with moderate to high permeability and hydraulic conductivity. An extensive description of the hydrologic properties beneath the recharge facility is given by Aronson et al. (1983).

Selection of a recharge method depends largely on the type of aquifer material. The high permeability of the surficial deposits on Long Island suggests that ponding of water would be the most efficient method here. Since 1930, more than 3,000 storm water basins have been constructed on Long Island to intercept the large quantities of storm runoff that would otherwise be discharged to coastal waters. These basins absorb storm water rapidly and are usually dry within a few hours after a rainfall (Aronson et al. 1979). It is therefore expected that reclaimed water, which is generally of higher quality than storm runoff, would also be rapidly transmitted to the water table through ponding basins.

Description of Recharge Techniques and Results

Experimental basin 3 (Figure 4) is one of seven recharge basins used for disposal of reclaimed water at the recharge facility. The basin measures 50 x 100 feet (5,000 ft^2) and consists of an earth-floored excavation bounded by a retaining wall 5 feet high and 1 foot thick. Within the basin, near the eastern wall, the observation manhole extends 16 feet below the basin's earth floor. The manhole is constructed of three circular rings of 1-foot-thick reinforced concrete and has an inside diameter of 12 feet.

Rates of Inflow and Infiltration

A total of 3 Mgal was applied to basin 3 during a 72-hour recharge test in June 1983. An inflow rate of 700 gallons per minute (gal/min) was maintained except during a 30-minute shutdown period, in which the inflow rate decreased to 500 gal/min. The water ponded within the first three hours of the test and reached its highest stage of 1.11 feet after 14 hours. This initial ponding is attributed to entrapped air within the basin soil and a gray silt layer of low permeability between 4 and 5 feet below the basin floor. During the 30-minute shutdown period, which began 24 hours into the test, water stage dropped from 0.96 feet to 0.58 feet. When normal inflow resumed, the stage decreased until only 75 percent of the 5,000-ft^2 basin floor was covered with water. This continued decrease in basin stage was a manifestation of increased infiltration rates resulting from the removal of entrapped air probably by dissolution into the relatively oxygen-free effluent.

A plot of infiltration rate and basin water temperature with respect to time is given in Figure 5. Infiltration rate is obtained by adding the inflow rate divided by area of the wetted basin to the change in storage in the basin over time and is expressed as:

Figure 4: Photograph of Recharge Basin 3 with Observation Manhole (Aronson 1983).

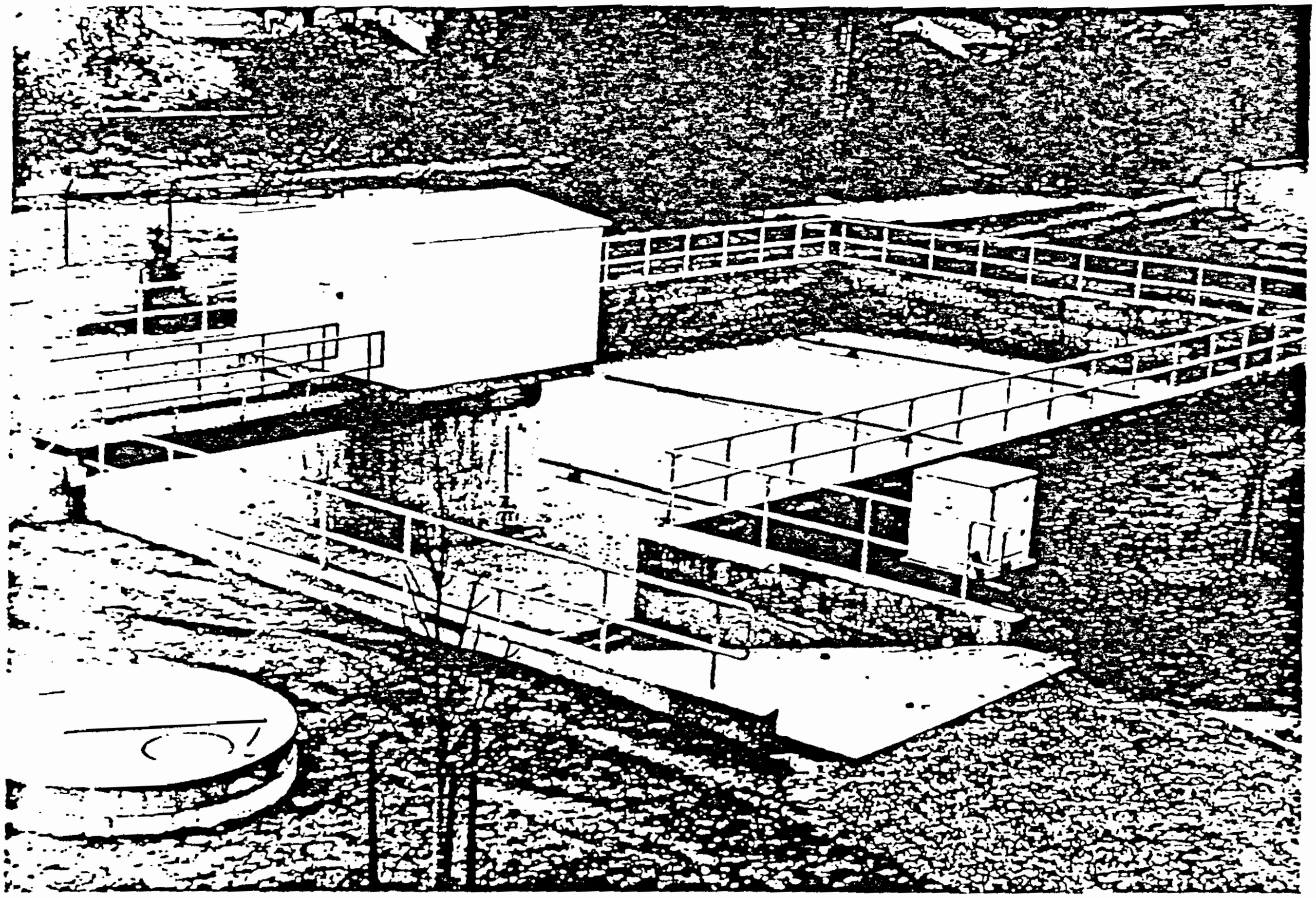
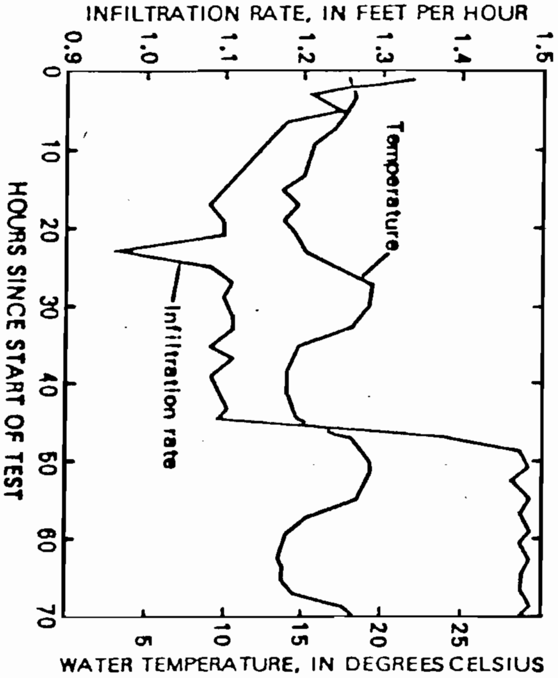


Figure 5: Infiltration Rate and Temperature with Respect to Time During Ponding Test of June 20-23, 1983.



$$IR = \frac{Q}{A} \pm \frac{\Delta s}{t}$$

where:

IR = infiltration rate (ft/h)
Q = inflow rate (ft^3/h)
A = wetted area of basin (ft^2)
Δs = change in storage in basin (ft^3)
t = time (h).

The infiltration rate at this basin remained constant at 1.47 ft/h during the latter part of the test. At the beginning of the test, the infiltration rate exceeded the inflow rate until the water reached the silt layer, at which time ponding began. When the inflow rate decreased to 500 gal/min during the 30-minute shutdown interval, both basin stage and infiltration rate decreased. As the inflow rate was restored, however, the infiltration rate increased and the basin stage declined. By the end of the test, it was evident that an inflow rate of 700 gal/min could be maintained for several days before the basin would be fully ponded.

Effect of Controlling Zone

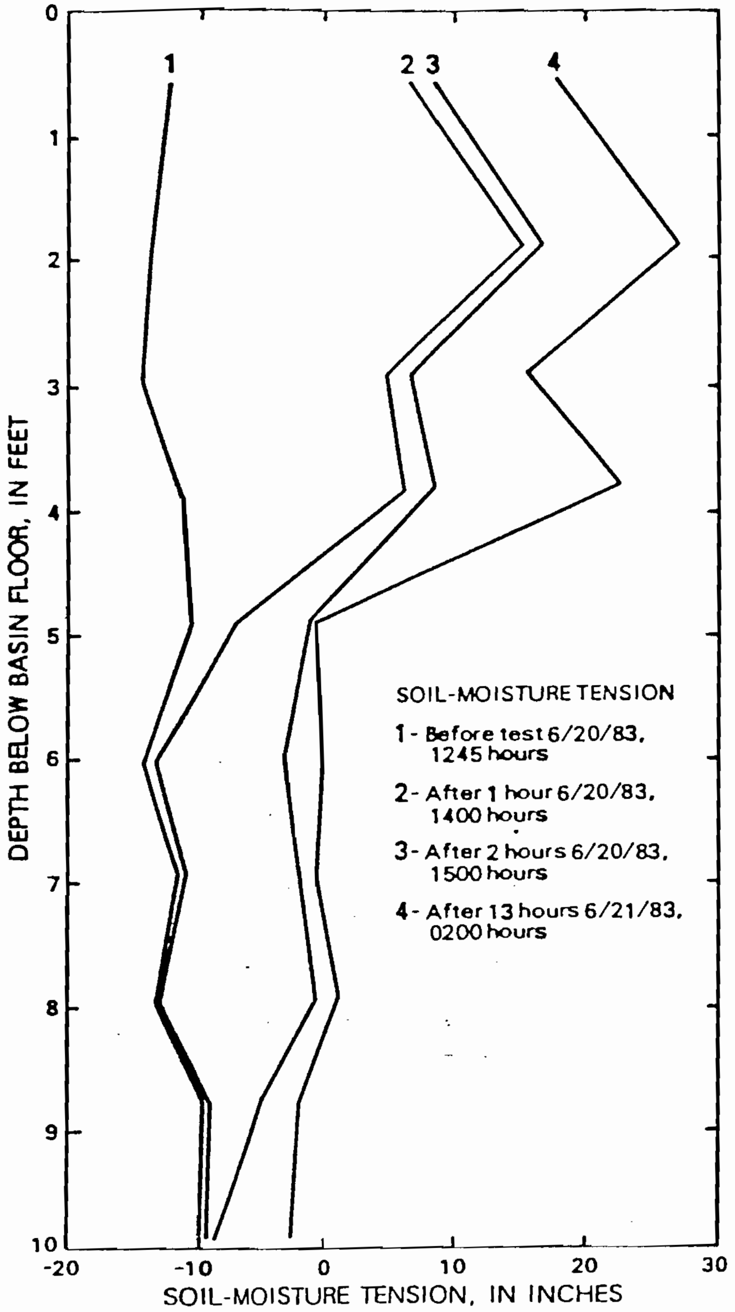
The depth of the subsurface layer limiting the rate of infiltration within the unsaturated zone was located by use of 14 tensiometers installed horizontally at different depths. The pressure-head distribution within the unsaturated zone during background conditions (line 1 in Figure 6) shows a relatively uniform negative pressure head. As the test progressed, the soil tensions increased rapidly (lines 2, 3 and 4). The ponding of water in the basin after several hours indicated a limiting zone (layer of lower permeability) in the upper 4 feet of the unsaturated zone.

The average vertical hydraulic conductivity of the entire "saturated" thickness of the unsaturated zone (0 to 4 feet) was 24.2 ft/d. The value calculated for the zone between the tensiometers at 4 and 5 feet depths was 11 ft/d--less than half the average for the entire "saturated" thickness. For this reason, the layer between the 4 feet and 5 feet depths controls the recharge capacity of the basin. The significance of pressure-head distribution is that it indicates the depth and thickness of the controlling zone.

Movement of Wetting Front

Neutron logs were taken during the test to monitor the movement of water in the unsaturated zone. Soil-moisture logs were obtained from six neutron-access tubes (Figure 7) to show the progression of the wetting front both vertically and horizontally from the point of recharge. A series of neutron logs from one of the neutron access tubes in basin 3 is shown in Figure 8. The deflection to the right at

Figure 6: Pressure-head Distribution Within the Unsaturated Zone, 1,2, and 13 Hours After Start of Pending Test.



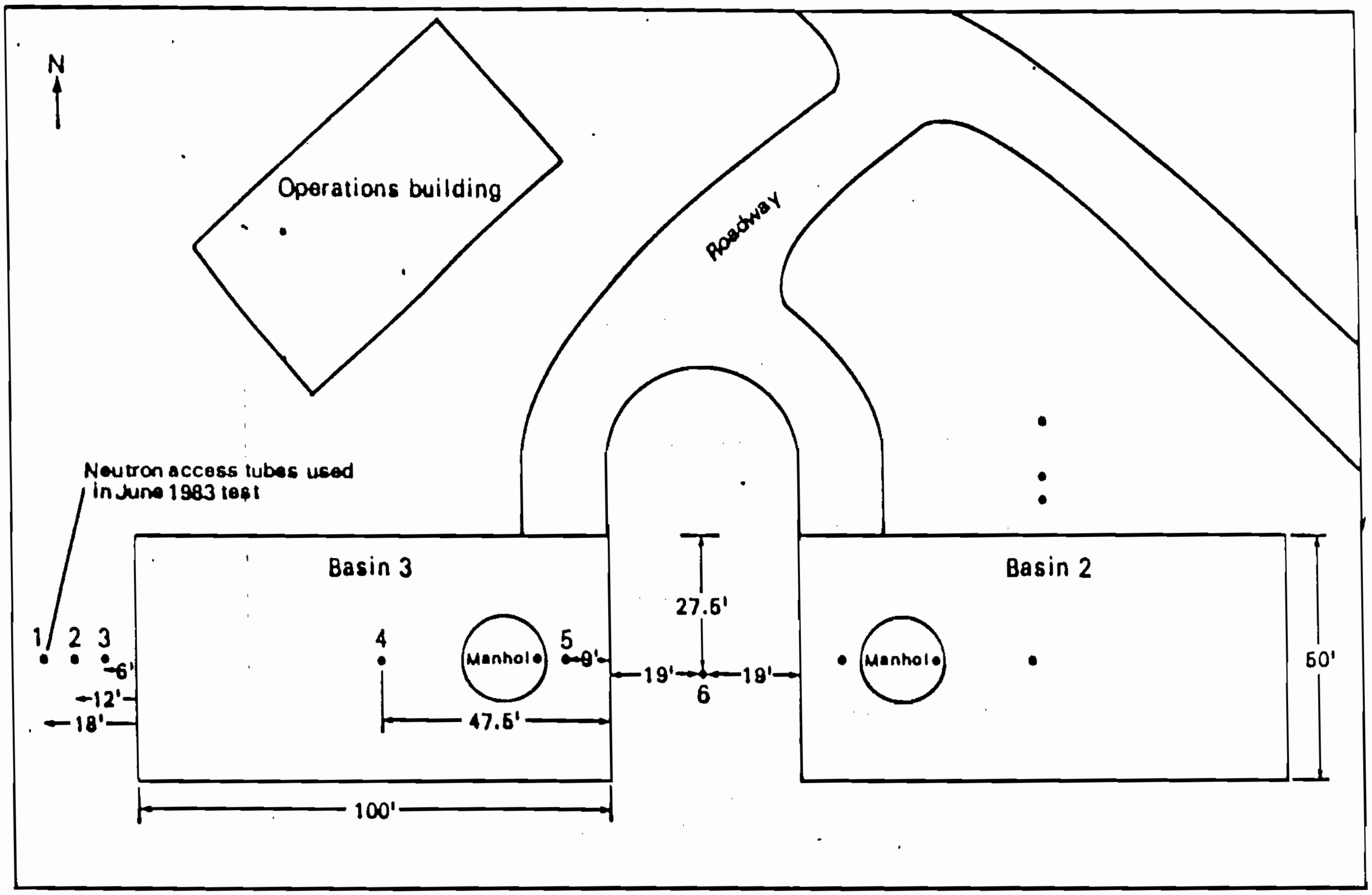
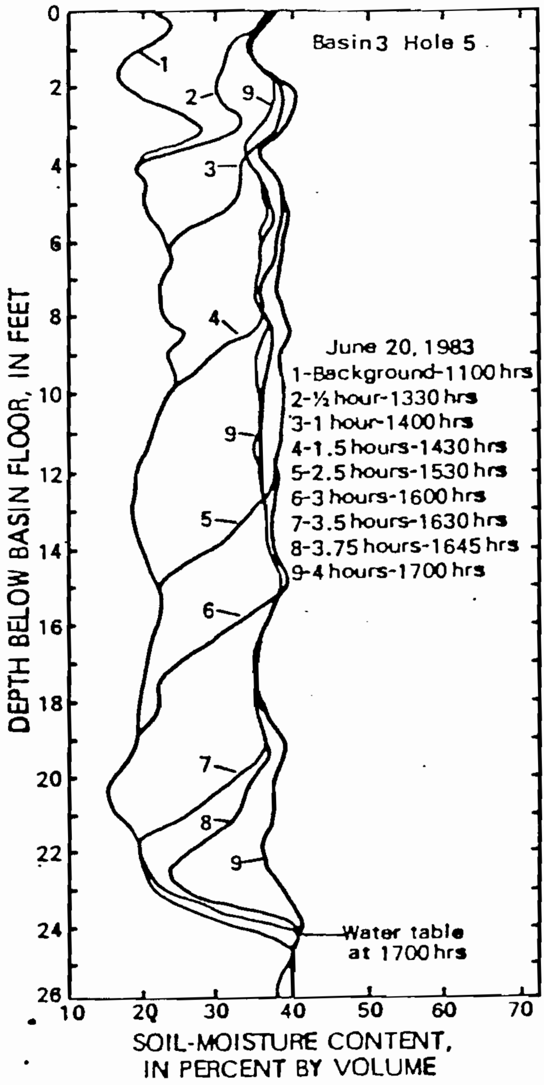


Figure 7: Location of Six Neutron Access Holes Used in June 1983 Ponding Test. (General Location of Basins is Shown in Figure 2).

Figure 8: Neutron Logs From Neutron Access Hole 5 During Recharge Test. (Location is Shown in Figure 7.)



← TEST STARTED AT 1300 HRS (1:00 PM)

24 ft
4 hrs

24 feet marks the position of the water table, which was verified by water level measurements in nearby observation wells. The average vertical interstitial velocity calculated from the advance of the wetting front on the logs averaged 6.0 ft/h. This value was also verified by the water table response at observation wells within the basin. Logs obtained from the access holes 6 feet, 12 feet and 18 feet west of the basin (Figure 7), show negligible lateral movement of water above the water table. The moisture buildup ranged from 0 percent at a distance of 18 feet from the basin to 5 percent, 6 feet away.

Water Quality - Sample Collection

Four gravity lysimeters were installed through the manhole wall at depths of 2.5 feet, 5.2 feet, 8.3 feet and 11 feet below the basin floor to collect water samples from undisturbed soil in the unsaturated zone during infiltration. Water samples were also collected from the ponded basin, the lysimeters and an observation well installed directly beneath the manhole and screened at the water table. Chemical analyses of all samples were obtained to help evaluate the changes that take place in the reclaimed water as it passes through the soil to the water table.

The gravity lysimeters (Figure 9) consist of: (1) a 6-inch-diameter stainless steel tube that extends diagonally upward through the manhole wall into the soil; (2) an extended screened plate assembly within the tube to retain the soil; (3) a purging system that can be used to redevelop the lysimeter should it become clogged; and (4) an airtight end cap that prevents exchange of pressure between the manhole and soil atmosphere. The hydraulic design considerations for the installation of gravity lysimeters used at this facility are discussed in Oaksford (1983).

Lysimeters 1, 3 and 4 (at depths of 2.5 feet, 8.3 feet and 11 feet, respectively), captured sufficient volumes of reclaimed water to permit daily sampling. The fourth lysimeter, whose capture plane is 5.2 feet below the basin floor, did not produce sufficient water for sampling, probably because it tapped the less-conductive silt layer and because the process of installation compacted the material, making it virtually impermeable. This caused diversion of percolating water around and away from the plane of capture of the lysimeter.

A total of 20 samples were taken during the 72-hour test, including four from the basin, four from each working lysimeter and four from an observation well within the basin and screened at the water table. Samples were analyzed for nitrogen, carbon and phosphorus (Table 1), selected inorganic constituents (Table 2), heavy metals (Table 3) and low-molecular weight organic compounds (Table 4).

Soil-water samples taken from the unsaturated zone were timed to accurately reflect water quality of the same volume of water that had entered the system at the basin surface as it progressed through the unsaturated zone. Examining the analyses of samples gathered in this fashion provides the basis for evaluating the degree of chemical alteration imparted to the reclaimed water during passage through the

Figure 9: Cross Section Through Inclined Gravity Lysimeter Used To Sample Soil Water During Recharge Test.

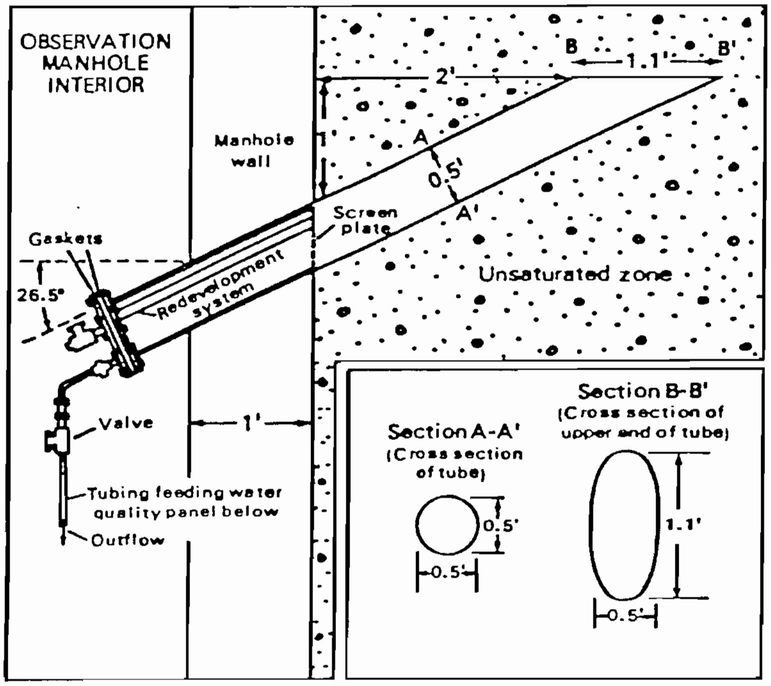


Table 1. Concentrations of nitrogen, carbon and phosphorous species in water from harge basin 3, unsaturated zone and water table beneath basin, June 20-23, 1983.

[All values are in mg/L]

		Source				
			Lysimeters			Observation
Date	Constituent	Basin	1	3	4	Well
6-20-83	Nitrogen, total as N	0.7	0.60	0.9	0.7	1.3
	Nitrogen, total NH_4 + as N	0.03	0.3	0.03	0.02	0.03
	Nitrogen, total $NO_2 + NO_3$ as N	0.39	0.3	0.5	0.5	0.97
	Nitrogen, total organic as N	0.27	0.27	0.37	0.18	0.27
	Carbon, organic total	2.10	3.0	4.6	1.6	2.7
	Phosphorous, total	0.35	0.01	0.01	0.01	0.03
6-21-83	Nitrogen, total as N	1.0	0.8	1.0	0.7	0.7
	Nitrogen, total NH_4 + as N	0.04	0.02	0.03	0.02	0.03
	Nitrogen, total $NO_2 + NO_3$ as N	0.60	0.4	0.5	0.50	0.5
	Nitrogen, total organic as N	0.36	0.38	0.47	0.18	0.17
	Carbon, organic total	2.00	1.90	1.90	1.6	1.9
	Phosphorous, total	0.43	0.06	0.02	0.01	0.02
6-22-83	Nitrogen, total as N	0.70	0.8	0.8	0.90	0.8
	Nitrogen, total NH_4 + as N	0.01	0.01	0.01	0.01	0.01
	Nitrogen, total $NO_2 + NO_3$ as N	0.50	0.50	0.50	0.60	0.60
	Nitrogen, total organic as N	0.30	0.3	0.3	0.30	0.20
	Carbon, organic total	2.10	2.3	2.1	1.9	2.3
	Phosphorous, total	0.36	0.13	0.02	0.02	0.03
6-23-83	Nitrogen, total as N	0.8	0.7	0.7	0.7	0.8
	Nitrogen, total NH_4 + as N	0.03	0.05	0.01	0.02	0.01
	Nitrogen, total $NO_2 + NO_3$ as N	0.5	0.5	0.5	0.5	0.5
	Nitrogen, total organic as N	0.3	0.3	0.3	0.3	0.3
	Carbon, organic total	2.5	2.2	2.3	2.4	2.1
	Phosphorous, total	0.27	0.15	0.06	0.02	0.04

Table 2. Concentrations of selected inorganic cations and anions in water from recharge basin 3, unsaturated zone and water table beneath basin, June 20-23, 1983.

[All values are in mg/L]

		Source				
			Lysimeters			Observation
Date	Constituent	Basin	1	3	4	Well
6-20-83	Calcium	49	30	42	30	32
	Magnesium	6.71	3.4	1.5	1.3	2.6
	Potassium	12	4.0	13	6.8	34
	Sodium	96	38	57	61	45
	Chloride	120	84	110	110	60
	Fluoride	0.3	0.1	--	0.1	0.1
	Sulfate	71	36	58	81	44
6-21-83	Calcium	50	48	49	47	42
	Magnesium	7.7	7.4	7.6	7.4	6.0
	Potassium	12	11	12	12	28
	Sodium	94	95	96	95	92
	Chloride	120	120	120	120	120
	Fluoride	0.2	0.2	0.2	0.2	0.2
	Sulfate	63	63	62	63	65
6-22-83	Calcium	50	50	51	49	47
	Magnesium	7.4	7.3	7.5	7.3	6.9
	Potassium	12	11	12	12	20
	Sodium	92	93	93	90	93
	Chloride	110	110	110	110	110
	Fluoride	0.2	0.2	0.2	0.2	0.3
	Sulfate	71	69	68	68	69
6-23-83	Calcium	52	51	51	51	48
	Magnesium	7.7	7.6	7.8	7.6	7.3
	Potassium	12	12	12	12	17
	Sodium	91	91	93	91	95
	Chloride	120	120	120	120	120
	Fluoride	0.3	0.2	0.2	0.3	0.3
	Sulfate	82	81	82	81	80

Table 3. Concentrations of selected heavy metals in water from recharge basin 3, aturated zone and water table beneath basin, June 20-23, 1983.

[All values are in mg/L]

		Source				
			Lysimeters			Observation
Date	Constituent	Basin	1	3	4	Well
6-20-83	Lead	3	9	10	20	3
	Chromium	10	20	20	20	20
	Iron	40	3,600	140	200	360
	Nickel	11	11	6	7	5
	Manganese	<10	70	30	20	10
	Zinc	270	130	90	80	100
6-21-83	Lead	7	12	19	12	9
	Chromium	10	10	10	10	20
	Iron	60	1,300	150	30	100
	Nickel	9	7	5	4	8
	Manganese	10	20	10	<10	<10
	Zinc	30	50	30	40	40
6-22-83	Lead	3	6	9	5	2
	Chromium	10	10	10	10	10
	Iron	70	590	860	130	60
	Nickel	15	10	8	9	4
	Manganese	<10	10	10	<10	10
	Zinc	30	50	100	30	30
6-23-83	Lead	15	4	4	5	9
	Chromium	10	10	10	<10	10
	Iron	1,500	130	140	90	230
	Nickel	19	11	8	13	11
	Manganese	30	10	10	10	10
	Zinc	170	50	30	30	40

Table 4. Concentrations of selected low-molecular-weight organic compounds in water from recharge basin 3, unsaturated zone and water table beneath basin, June 20-23, 1983.

[All values are in µg ~~mg~~/L]

Date	Constituent	Source				
			Lysimeters			Observation Well
		Basin	1	3	4	
6-20-83	Dichloromethane — METHYLENE CHLORIDE	0.70	0.31	2.31	0.51	0.15
	Trichloromethane — CHLOROFORM	.28	.10	.41	.18	.11
	1,1,1-Trichloroethane	BDL[1]	.03	BDL	BDL	.07
	Bromodichloromethane	.73	BDL	.16	.20	BDL
	Dibromochloromethane	3.51	2.93	5.21	5.71	1.54
	Tribromomethane	41.63	14.52	26.60	28.66	8.62
6-21-83	Dichloromethane	.83	.58	.63	.73	.71
	Trichloromethane	.25	.30	.39	.38	.26
	1,1,1-Trichloroethane	BDL	BDL	.17	BDL	BDL
	Bromodichloromethane	1.25	1.00	1.10	6.82	1.13
	Dibromochloromethane	11.02	3.41	8.67	10.18	10.28
	Tribromomethane	47.36	34.47	34.64	35.02	50.14
6-22-83	Dichloromethane	.72	1.5	.80	1.00	1.1
	Trichloromethane	.73	.60	1.00	.80	.60
	1,1,1-Trichloroethane	BDL	BDL	BDL	.30	BDL
	Bromodichloromethane	1.57	1.20	1.94	2.80	2.6
	Dibromochloromethane	3.26	10.80	3.40	12.00	12.3
	Tribromomethane	26.51	38.20	23.46	32.00	31.2
6-23-83	Dichloromethane	.20	1.5	1.40	2.50	6.0
	Trichloromethane	.30	.60	.60	.60	.5
	1,1,1-Trichloroethane	BDL	BDL	BDL	BDL	BDL
	Bromodichloromethane	.70	1.2	1.40	1.2	.8
	Dibromochloromethane	8.5	10.8	11.0	10.8	8.9
	Tribromomethane	40.0	38.2	36.0	45.0	36.0

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[1] BDL - Below detection limits.

unsaturated zone. The data presented in Tables 1, 2, 3 and 4 are arranged in sample groupings by day. The sample analyses shown on each day follow the chemical history of a given quantity of water moving from the basin to the water table when read from left to right. The first day of recharge, June 20, 1983, marked the first passage of reclaimed water through the system and analyses from samples collected at each sampling point represent the first arrival of reclaimed water and therefore reflect concentrations diluted somewhat by mixing with water retained in the unsaturated zone before recharge.

Results of Chemical Analyses

The results summarized in Tables 1 through 4 indicate the ability of the unsaturated zone to alter the chemical quality of reclaimed water as it percolates through the unsaturated system to the water table. The chemical quality of reclaimed water compared to the overall native ground water quality is not addressed in this paper. It is important to note, however, that several constituents were significantly lower in concentration in reclaimed water than in native ground water; one of these constituents is nitrogen.

The concentration of nitrogen in reclaimed water, although unaffected by travel through the unsaturated zone, was significantly lower than in the upper glacial aquifer. Previous use of cesspools and fertilizers in the area has caused elevated total nitrogen concentrations of 10 to 16 mg/L in most nearby observation wells. Throughout the three-day testing period, nitrogen concentrations in the reclaimed water did not exceed 1 mg/L.

One of the few constituents that was affected during travel through the unsaturated zone was phosphorus. The decrease in concentration of phosphorus (Table 1) on June 20 from 0.35 mg/L to 0.01 mg/L within the unsaturated zone was largely caused by dilution from mixing with native pore water that was retained within the unsaturated zone before recharge. Changes in concentration throughout the profile in the subsequent daily samplings support the conclusion that phosphorus was being absorbed by the soil material. Results from the samples collected on June 22 and 23 (the third and fourth suites) show phosphorus beginning to appear in higher concentrations at the first lysimeter, indicating that the absorptive capacity of the upper 2.5 feet of soil was approaching its limit.

All major inorganic anions and cations except potassium (Table 2) show relatively little change within the unsaturated zone in each day's suite of samples. Although the other major ions showed an initial decrease in concentration as a result of dilution by water retained in the unsaturated zone on the first day, potassium showed a marked increase between lysimeter 4 and the water table during the first two days. This increase may reflect the stripping of potassium from the soil particles between the fourth lysimeter and the water table. This phenomenon greatly subsided after three days of testing, however. Ten background soil-water samples collected from the unsaturated zone before recharge indicate that average concentrations of sodium and potassium are 15 and 5 mg/L, respectively. This ratio (3:1) is much less than the ratio of sodium to potassium in reclaimed water (8:1). The increase in sodium forces potassium to leach from exchange sites within the soil matrix to reach a new equilibrium. The most pronounced change occurred on the first day of testing, when reclaimed water was initially released into the unsaturated zone. As the system began to reach equilibrium over the next two days of testing, less potassium was leaching into percolating water and potassium concentrations in ground water therefore decreased.

Results of heavy-metals analyses are shown in Table 3. Most notable is the initial incease in iron and manganese, which are presumably derived from iron and manganese hydroxide coatings commonly found on the sands and gravels of the upper glacial aquifer. Most of the other metals show either a net decrease or no change with passage through the unsaturated zone.

Concentrations of selected low-molecular-weight organic compounds known to be present in the reclaimed waste water (Table 4) remained essentially unchanged during passage through the unsaturated zone.

Other Observations

Continual application and extended ponding experiments were conducted at several other basins at the site to observe time-dependent characteristics of infiltration rates. Results indicated no significant decrease in infiltration rate with time but suggest a need for shorter application cycles because extended ponding provided ideal conditions for the propagation of several insect populations, which could easily be avoided with a weekly or biweekly drying period.

The chemical observations in the unsaturated zone indicate a lack of significant interaction between percolating reclaimed water and the soil material except for three or four constituents. This is attributed to three major factors: (1) the sands and gravels of these glacial outwash deposits are largely inert; (2) the high infiltration rates allow only a short residence time within the unsaturated zone--4 to 6 hours, and (3) reclaimed water has received extensive treatment and is not materially altered by the additional filtration provided by the soil medium.

Future Studies

Chemical analyses of water in the aquifer are planned for the future, after the reclaimed water has remained in the aquifer several months and moved hundreds of feet laterally. Further testing involving greater hydraulic loadings is also planned, which may help define the maximum infiltration rates that can be achieved. Studies involving recharge periods up to 6 months are already in progress to assess the physical and chemical effects of the unsaturated zone on reclaimed water during long-term recharge operations.

Summary and Conclusions

A 72-hour ponding experiment was conducted in June 1983 at a recharge basin equipped with an observation manhole and instrumentation designed to monitor the physical and chemical changes of reclaimed water as it percolates through the unsaturated zone.

At an inflow rate of 700 gal/min, infiltration rate remained constant at 1.47 ft/h during the latter part of the test. Horizontally installed tensiometers measuring the pressure-head distribution within the unsaturated zone indicated the presence of a silty zone controlling infiltration. Continuous monitoring of pressure-head distribution can help determine when the hydraulic conductivity decreases to a point where recharge capacity is significantly reduced.

The average vertical interstitial velocity (6.0 ft/h) was calculated from: (1) the advance of the wetting front on soil-moisture logs, and (2) timed water-table response at observation wells within the basin. Neutron logging can aid in determining both vertical and horizontal movement from recharge points.

Gravity lysimeters, installed through the manhole wall at varying depths, were used to collect 20 water samples from undisturbed soil during infiltration. Samples were analyzed for nitrogen, carbon and phosphorous species, selected inorganic constituents, heavy metals and low-molecular-weight organic compounds. Relatively few constituents showed a change in concentration after traveling through the unsaturated zone. Fluctuations in potassium, phosphorus, iron and manganese concentrations were the most notable.

The lack of significant interaction between percolating reclaimed water and the soil material can be attributed to: (1) largly inert properties of soil; (2) short residence times because of high infiltration rates; and (3) extensive treatment of reclaimed waste water before recharge.

Figure Captions

Fig. 1. Location of East Meadow Artificial Recharge Facility and Cedar Creek Waste Water Reclamation Facility.

Fig. 2. Plan view of recharge facility showing location of recharge basins and injection wells.

Fig. 3. Generalized geologic section showing relative position of upper glacial aquifer. (Modified from Franke and McClymonds, 1972, p. 10F.)

Fig. 4. Photograph of recharge basin 3 with observation manhole. (Aronson 1983).

Fig. 5. Infiltration rate and temperature with respect to time during ponding test of June 20-23, 1983.

Fig. 6. Pressure-head distribution within the unsaturated zone, 1, 2 and 13 hours after start of pending test.

Fig. 7. Location of six neutron access holes used in June 1983 ponding test. (General location of basins is shown in Figure 2.)

Fig. 8. Neutron logs from neutron access hole 5 during recharge test. (Location is shown in Figure 7.)

Fig. 9. Cross section through inclined gravity lysimeter used to sample soil water during recharge test.

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Biographical Sketches

Brian J. Schneider has been employed as a hydrologist for 3 years with the Water Resources Division of the U. S. Geological Survey. He received his B.S. and M.S. in earth science from Adelphi University in New York. He has experience in various aspects of hydrology and has contributed to studies dealing with artificial ground water recharge and the unsaturated zone.

Henry F.H. Ku has been a hydrologist with the Water Resources Division of the U. S. Geological Survey for 16 years. He received his B.S. and M.S. in geology from the University of Michigan. He has extensive experience in diverse aspects of hydrology and has conducted numerous studies dealing with ground water, surface water and urban hydrology.

Edward T. Oaksford received a B.A. and M.A. in geological science from the State University of New York at Buffalo. He worked with the Corps of Engineers in Buffalo on the Niagara Falls project and has spent the last 9 years on Long Island with the Water Resoures Division of the U. S. Geological Survey studying the ground water system, with particular emphasis on artificial recharge and the movement of water in the unsaturated zone. Oaksford has had extensive experience with monitoring pressure head, moisture content and soil water in coarse unconsolidated sediments during artificial recharge experiments and has published papers dealing with sampling tool design and sampling techniques, notably soil moisture tensiometers and gravity lysimeters.

James A. Oliva received a Bachelor's degree in marine engineering from the State University of New York, Maritime College, Fort Schuyler, N.Y. in 1959 and a Master of Science in civil (Sanitary) engineering from the New York University in 1973. He is a licensed Professional Engineer in the State of New York and holds a Grade IA Sewage Treatment License.

He is the director of the advance waste water treatment facilities at the Bay Park Sewage Treatment Plant and is the Chief Sanitary Engineer at the Cedar Creek Waste Water Reclamation Plant. He has been working in the sanitary engineering field since January 1965 and has worked for the Nassau County Department of Public Works since March 1970.

QUESTION

What volatile organic compounds did you look for? Any significant attenuation?

ANSWER

We have been monitoring low-molecular weight halogenated hydrocarbons in native ground water since the study's inception. Compounds such as trichloromethane (chloroform), tetrachloromethane (Carbon Tet), benzene, 1,1,1-trichloroethane and 14 others must be monitored according to the State Pollutant Discharge Elimination System (SPDES) discharge permit prior to recharge. In our unsaturated zone study, concentrations of these compounds, which were well below the limits set forth on the SPDES permit, remained relatively unchanged after percolation through the vadose zone.

QUESTION

Did you analyze for total nitrogen removal due to movement through the vadose zone? Or was nitrogen already removed in the tertiary treatment?

ANSWER

Nitrogen was already removed in the treatment process through the use of a two-stage biological treatment system consisting of a nitrification-denitrification process to promote biological nitrogen removal in combination with oxidation of remaining carbonaceous material.

Even though this process effectively reduced nitrogen concentrations, we still monitored the nitrogen attenuation through the vadose and found no further removal.

QUESTION

How were neutron access holes installed? What strength is the neutron source? Any estimate of effective porosity for material underlying the recharge basin?

ANSWER

The 11 neutron access tubes, which consist of 2" diameter galvanized steel, were driven to a depth of 45 feet by the cable tool method. In order to assure a plumb access tube, we used a square (flat) cap plug on each tube.

The neutron source used for logging during the study is americium with a strength of 250mc.

Effective porosity value for the upper glacial material beneath the facility has been estimated at 35-40 percent.

QUESTION

Did you test a suction lysimeter and compare the results to those obtained with the gravity lysimeter?

ANSWER

No, we did not test a suction lysimeter for the simple reason that we were reluctant to impress any artificial stimulus to the soil water sample. We went to great lengths to insure that the unsaturated zone remained undisturbed during basin construction and manhole installation. Gravity lysimeters further enhanced our chances of collecting undisturbed soil-water samples.

QUESTION

Could you please comment on the design of the injection wells, i.e., screen locations relative to the water table, slot size design relative to grain size, etc?

ANSWER

The five injection wells which were installed for use in this study are of the same basic design. All five wells consist of 12-inch diameter fiberglass casing and a 30-foot section of stainless-steel wire wrapped screen (type 316). The screen was set 65 to 96 feet below grade, and the static water level is 35 feet below grade. The main difference between the wells is essentially in the type of packing around the well screen. One well consists of a natural pack, where natural aquifer material is packed around the well screen. Three others contain 6-inch thickness of artificial gravel pack in contact with the screen. The fifth well contains this gravel pack but also has its own self-contained redevelopment system that will be used when the well clogs. The operating efficiency of each type of well will be evaluated to determine which type is most effective.

QUESTION

Did you try to model the shape of the mound and, if so, how did the predictions of the model compare to measured values?

ANSWER

A two-dimensional model was created to predict mounding within the recharge area due to injection into wells and application into basins. A comparison of measured values to predicted values has not been made at this time, but is the next logical step in this study. To obtain a copy of the modeling report by Aronson and others, 1982, write to:

Open-File Services Section
Western Distribution Branch
U.S. Geological Survey
Box 25425, Federal Center
Denver, CO 80225

QUESTION

Do you feel that tertiary treatment is necessary prior to recharge or would secondary treatment be adequate?

ANSWER

The question of necessity is a difficult one to address, but in Long Island's situation, I would have to say "yes." Because of the relatively high rates of vertical movement through the unsaturated zone and the unreactive nature of the sands and gravels that make up the upper-glacial aquifer, secondary treatment would not be enough. In other parts of the world where soils have greater attenuation capabilities, then secondary treatment would suffice. But when dealing with an aquifer with sole-source status, there is no room for speculation.

Ponding-Test Procedure For Assessing the Infiltration Capacity of Storm-Water Basins, Nassau County, New York

By ROBERT C. PRILL *and* DAVID A. ARONSON

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 2049

U.S. DEPARTMENT OF THE INTERIOR
March 3, 1849

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1978

discussion of water movement is based on only one of the tests—that of October 15, 1971, at test plot A2.

MOISTURE BUILDUP

Moisture content below the test plots became stabilized after a ponding period of from 1.5 to 2 hours. The moisture pattern below the test plots during this period is characterized by the logs in figure 6, which were collected near the center of plot A2. The moisture pattern that developed as a wetting front (leading edge of the added water) moved vertically through the unsaturated zone is similar to the classic distribution pattern described by Bodman and Coleman (1944) for infiltration in homogenous ma-

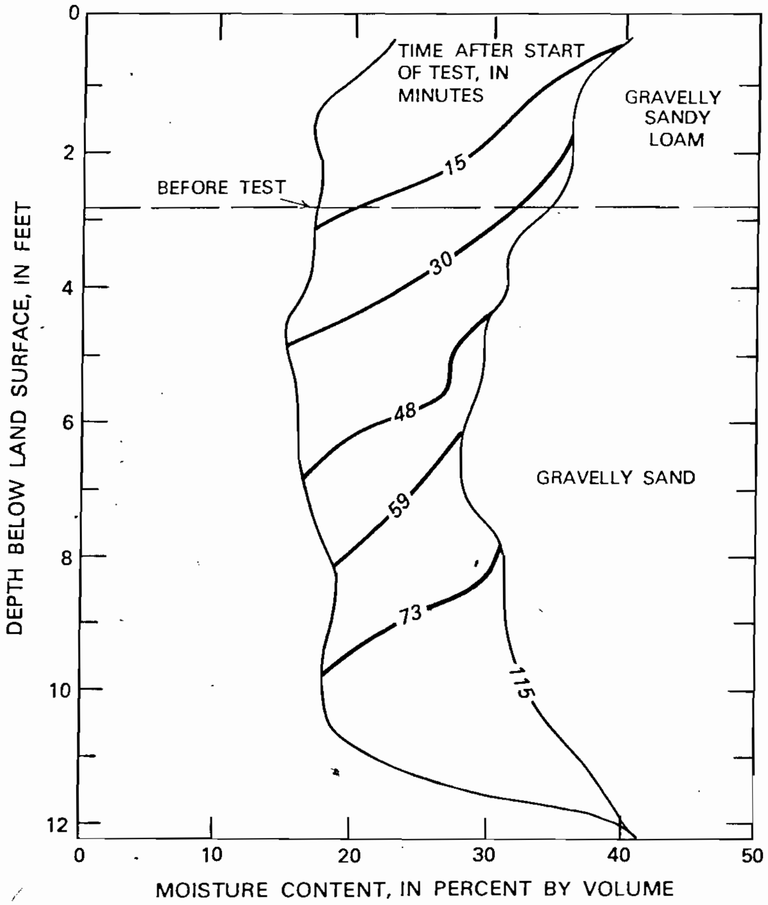

FIGURE 6.—Soil-moisture buildup at neutron access site 1 during test at plot A2, October 15, 1971.

terials. The time required for the wetting front to reach the water table, which was about 12 ft below land surface, was generally between 1 and 1.5 hours. After the arrival of the wetting front, there was a rapid rise in the water table. The total rise was 2 ft, almost all of which occurred within a 30-minute period. Changes in moisture content after this period were negligible, which indicates that flow through the unsaturated zone had virtually reached steady state.

The wetting front moved laterally only a few feet beyond the confines of test plots. Moisture profiles 5 ft from the edge of plots A2 and B were the same during ponding as before ponding. However, there was a noticeable increase in moisture content 1.5 ft from plot A2 and 2.5 ft from plot B during ponding. Moisture profiles 1.5 ft from test plot A2 before and during ponding are shown in figure 7. The profiles show that moisture contents there during ponding were from 2 to 13 percent higher than before ponding. However, moisture contents 2.5 ft from plot B were only from 1 to 5 percent higher than before ponding; thus, the lateral limit of the wetting front was between 2.5 and 5 ft from the test plots.

Beyond the confines of the test plots, where lateral spreading was restricted to distances of less than 5 ft, flow through the wetted materials was in general considerably less than that below the confines of the test plot. Flow is directly dependent on effective hydraulic conductivity, which, in turn, is dependent on moisture content. This sharp decrease in moisture content with distance from the plot can be seen by comparing the percentages of moisture content near the center of plot A2 (fig. 6) and 1.5 ft from the plot's edge (fig. 7) 115 minutes and 200 minutes after the start of ponding, respectively. At the center of the plot, the moisture content of the gravelly sand and the 5- to 9-ft depth interval was about 30 percent, whereas outside the plot it was about 17 percent. Watson (1966) found that the effective hydraulic conductivity of coarse-textured materials is about one order of magnitude higher when moisture content is 30 percent than when it is 17 percent.

Because water moved only a short distance laterally, and because the vertical flow rate associated with the water movement beyond the confines of the test plot was low compared with the vertical flow rate below the basin, it is assumed that most of the infiltrating water moved directly downward and that flow in the unsaturated zone at the North Massapequa basin is essentially vertical.

VOLATILE ORGANIC COMPOUNDS AND INORGANIC CONSTITUENTS IN GROUND WATER IN THE BETHPAGE-HICKSVILLE-LEVITTOWN AREA, LONG ISLAND, NEW YORK

UNITED STATES GEOLOGICAL SURVEY

Water-Resources Investigations Report 90-XXXX

Prepared in cooperation with the

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1990

DEPARTMENT OF THE INTERIOR

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Federal Center, Bldg. 41
Box 25425
Denver, CO 80225

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CONVERSION FACTORS AND ABBREVIATIONS

For the convenience of readers who prefer metric (International System) units rather than the inch-pound units in this report, the following conversion factors may be used:

Multiply inch-pound units	by	To obtain SI (metric units)
	Length	
inch (in)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	0.4047	hectare
square foot (ft^2)	0.09294	square meter (m^2)
square mile (mi^2)	2.59	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
	Flow	
foot per day (ft/d)	0.3048	meter per day (m/d)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)

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."

VOLATILE ORGANIC COMPOUNDS AND INORGANIC CONSTITUENTS IN GROUND WATER IN THE BETHPAGE-HICKSVILLE-LEVITTOWN AREA, LONG ISLAND, NEW YORK

By Steven M. Feldman, Douglas A. Smolensky, and John P. Masterson

ABSTRACT

A plume of contaminated ground water has been delineated within an 11.4-square-mile area in east-central Nassau County, Long Island, where residential neighborhoods surround an area zoned for industrial use. Within the industrial zone are firms that at one time have discharged effluent that contained volatile organic compounds into on-site seepage basins. In this area the upper glacial deposits and the underlying Magothy aquifer lie in direct hydraulic connection; the first continuous formation that impedes downward movement of ground water is the Raritan clay confining unit, which is more than 500 feet below datum.

The chemicals present in ground water and their distribution were determined by analysis of water samples from 57 monitoring wells and 11 industrial wells collected bi-annually in the spring and fall of 1986 and 1987. Trichloroethylene and tetrachloroethylene near the water table were measured at concentrations greater than 1,000 micrograms per liter and were detected more than 5,000 feet downgradient of the industrial zone. Delineation of the occurrence of several other volatile organic compounds indicate that there is more than one contaminant source in the industrial area. The plume of volatile-organic-contaminated ground water is 12,000 feet long, 5,700 feet wide, and more than 500 feet thick.

Fourteen industrial wells pumped contaminated ground water from the Magothy aquifer at an average rate of 8.05 million gallons per day in 1987. The water was primarily used for cooling purposes and the chemically unaltered water was subsequently routed to recharge basins from which it could percolate back down to the water table. Water-table mounding beneath basins and drawdown in the vicinity of pumping wells dramatically increase the vertical component of ground-water flow beneath the industrial zone. This alteration in ground-water-flow paths has resulted in an increased rate of advective movement of contaminated ground water downward toward the screen zones of pumping wells deep in the Magothy aquifer. The concentration of tetrachloroethylene dissipates much more rapidly than trichloroethylene downgradient of the industrial zone, indicating that sorption and (or) biodegradation may be important plume attenuating mechanisms. The major effect of industrial activity on inorganic water quality is due to the mixing of recharged Magothy aquifer water having a lower concentration of ionic species with upper glacial water in the vicinity of the recharge basins.

INTRODUCTION

Background

Alteration of ground-water quality as a result of urbanization is a problem of growing concern. The deterioration of ground-water quality from landfill leachate has been documented on Long Island (Kimmel and Braids, 1980; Wexler, 1988). More recent studies describe contamination of ground water underlying industrial zoned areas by synthetic organic compounds (Fischer and others, 1987; Ali, 1982). This is often the result of past practices of on-site treatment of industrial wastewater and disposal into unlined seepage basins, leaching of sludge drying-bed residue, accidental spills, and leakage from corroding waste drums.

Contamination of ground water is of particular concern on Long Island (fig. 1) because the underlying material is quite permeable and surface pollutants can be transported by precipitation or artificially-recharged water from land surface down to the water table of the ground-water reservoir. As the sole source of public drinking water for the residents of Nassau and Suffolk Counties, proper management of Long Island's ground-water reservoir is of vital importance.

Figure 1 (caption on next page) belongs near here.

Figure 1.--Location of study area.

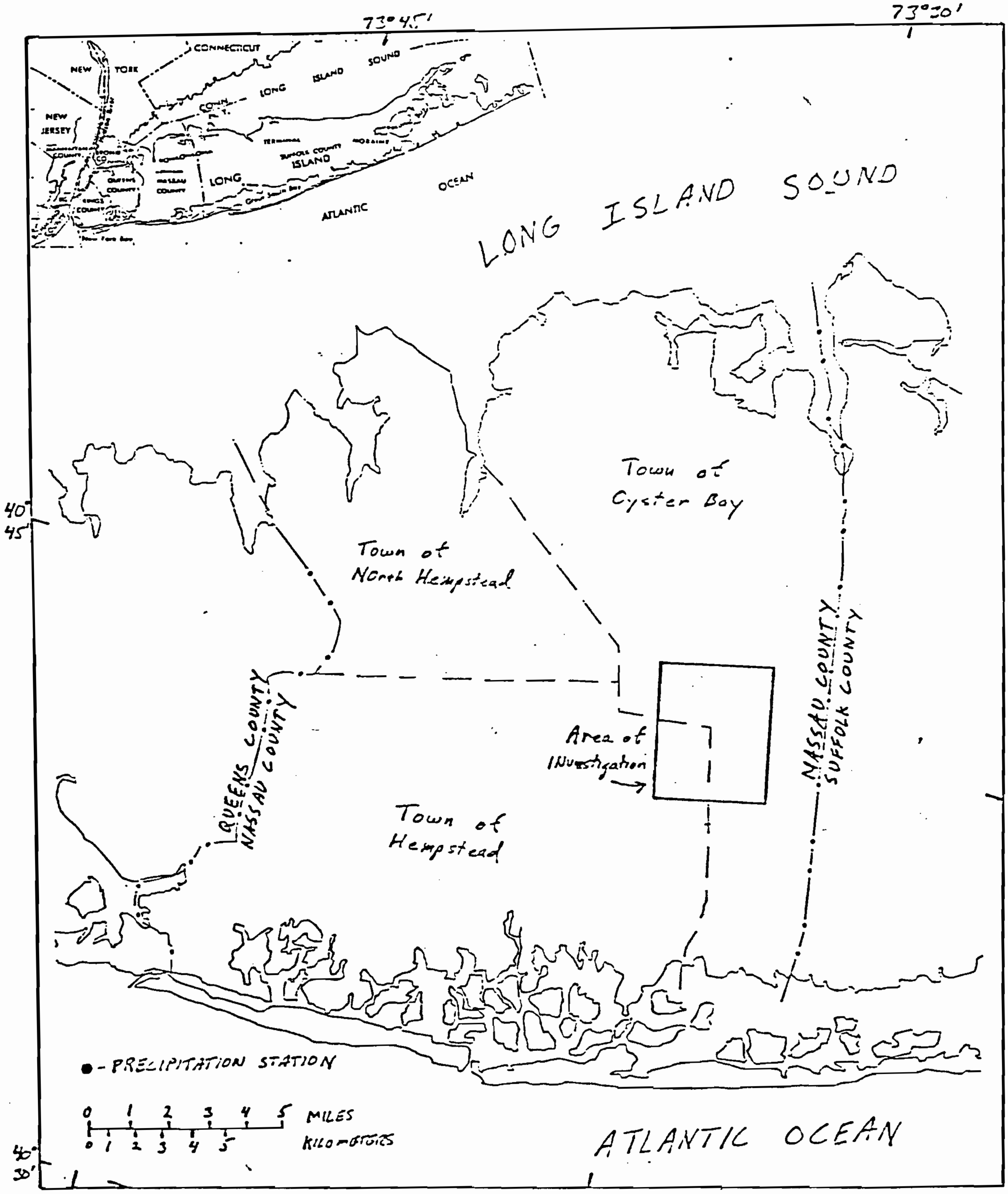

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Fig ①

Contamination of ground water in the residential/industrial setting of the study area poses a particular threat because VOCs (volatile organic compounds) have been detected at depths from which public-supply withdrawals are taken. Years of on-site discharge of effluent containing industrial wastes has led to a situation where VOCs have entered the ground-water system and moved laterally and vertically at accelerated rates due to pumping and recharge stresses within the industrial zone.

Purpose and Scope

This report identifies which VOCs have entered the ground-water system underlying the area of investigation and presents maps which delineate the vertical and horizontal extent of contaminant plumes. It also examines the role that local stresses, such as pumpage and recharge, have in affecting the distribution of contaminants, and discusses, to the extent possible, the various sources of contamination and their eventual fate as they migrate off site.

The report documents the chemical quality of ground water in and around an industrial-zoned area surrounded by residential neighborhoods. Wells were drilled to augment the water-level and water-quality monitoring network. Analyses of samples are presented in the appendix.

Location and Description of Study Area

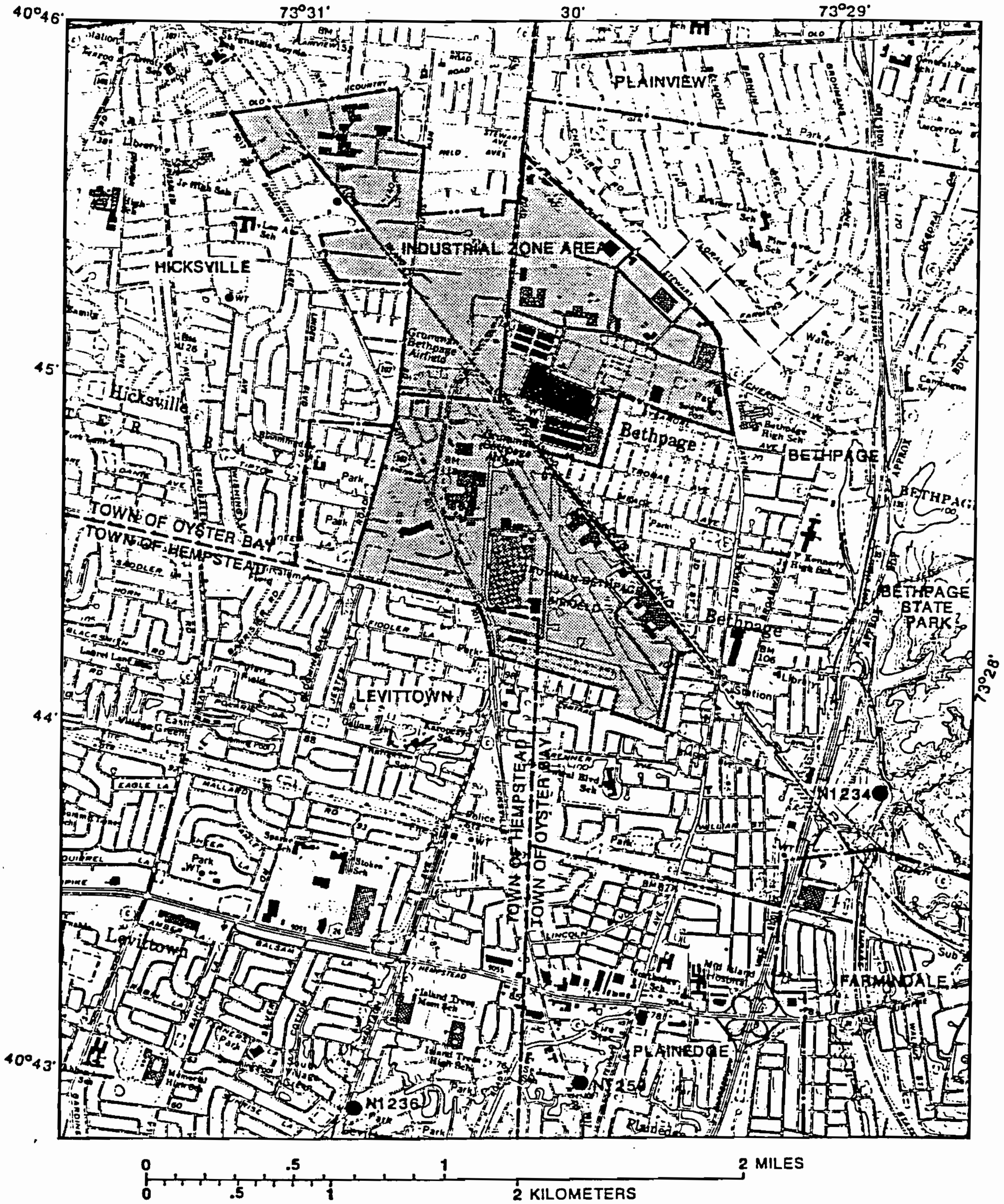
The area of study is an 11.4-mi^2 (square mile) rectangle that is situated in east-central Nassau County. It measures 3.8 mi (miles) from north to south, and 3.0 mi from east to west. This area, which will herein be referred to as the Bethpage-Hicksville-Levittown area, contains several land uses which are typical for Nassau County. Most of the area is comprised of suburban single family housing; commercial enterprises occupy much of the land adjacent to the major roadways, and a large section in the northern part of the area is zoned industrial/commercial (fig. 2).

Figure 2 (caption on next page) belongs near here.

Within the industrial zone are found several commercial establishments with an aerospace corporation and a plastics manufacturer being the major chemical users and waste producers in the area. The aerospace corporation is a major defense contractor that is engaged in the manufacture of aircraft parts and subassemblies. It occupies a site about 458 acres in size and has been in operation since 1937.

Industrial activity at the 14-acre site of the plastics manufacturer began in 1945 with the concentrating and compounding of rubber products, and gradually expanded to include the production of plastics and other synthetic compounds. Through the years it has produced vinyl chloride polymers, polyester, diester, and polyurethane products (Nassau County Department of Health, 1979).

Figure 2.--Map of study area showing Town and Village boundaries and location of industrial-zoned areas.



EXPLANATION

—··— INDUSTRIAL ZONE BOUNDARY

— — — TOWN BOUNDARY

—·— VILLAGE BOUNDARY

● N1236 WATER-TABLE WELL WITH RECORD SINCE 1938 -- Number is identification code

Fig 2:

Acknowledgments

The authors thank John Lovejoy of the Nassau County Department of Health for his assistance during the course of this study.

HYDROGEOLOGIC SETTING

Description of Hydrogeologic Units

Long Island is composed of unconsolidated sediments of Upper Cretaceous and Pleistocene age that overlie crystalline bedrock generally considered to be of Precambrian age. This bedrock peneplain was a depositional surface upon which hundreds of feet of gravel, sand, silt, and clay accumulated (Suter and others, 1949). The hydrogeologic units in the Bethpage-Hicksville-Levittown area (table 1), including information describing their thickness and water-bearing properties are presented by Smolensky and Feldman (in press). A brief description of these units is provided in the following paragraphs.

Table 1 belongs near here.

The bedrock surface beneath the area of investigation slopes southeastward at a rate thought to be about 90 ft/mi (feet per mile). Altitude of the bedrock surface in the Bethpage-Hicksville-Levittown area ranges from about 950 ft below sea level in the northwest to 1,250 ft below sea level in the southeast. A sequence of Cretaceous-age sediments were deposited on this rock floor. The deposits generally display a lack of sorting as shown by the presence of interspersed streaks of sand, silt, and clay.

Table 1

ble 1.—Hydrogeologic units and their water-bearing properties in the Bethpage–Hicksville–Levittown area, Nassau County, N.Y.

[Modified from Smolensky and ~~[illegible]~~ Feldman, in press]

Series	Series	Geologic unit	Hydrogeologic unit	Approximate maximum thickness (ft)	Character of deposits	Water-bearing properties
Quaternary	Holocene	Recent deposits and fill	Recent deposits	10	Sand, gravel, clay, silt, organic mud, loam, and fill.	Constitutes soil zone and fill areas and is hydraulically connected to underlying upper glacial aquifer.
	Pleistocene	Upper Pleistocene deposits	Upper glacial aquifer	~~75~~ 100	Sand, fine to coarse, gravel, glacial outwash deposits, commonly brown or tan but may be yellow or orange. Some thin local lenses of clay or silty zones.	Outwash deposits are moderately to highly permeable. Average horizontal hydraulic conductivity is approximately 270 ft/d; anisotropy is approximately 10:1.
		unconformity				
Cretaceous	Upper Cretaceous	Magothy Formation-Matawan Group, undifferentiated	Magothy aquifer	650	Sand, fine to medium, clayey in part; interbedded with lenses and layers of coarse sand and sandy and solid clay. Gravel is common in basal zone. Sand and gravel are quartzose. Lignite, pyrite, and iron oxide concretions are common. Colors are gray, white, red, brown, and yellow.	Most layers are poorly to moderately permeable; some are highly permeable locally. Water is unconfined in uppermost parts, elsewhere confined. Principal aquifer for public supply. Average horizontal hydraulic conductivity is 50 ft/d; anisotropy is approximately ~~400~~:1. 45
		unconformity				
		Raritan Formation Unnamed clay member	Raritan confining unit	175	Clay, solid and silty; few lenses and layers of sand. Lignite and pyrite are common. Colors are gray, red, and white, commonly variegated.	Low to very low permeability; constitutes confining layer above Lloyd aquifer. Average vertical hydraulic conductivity is approximately 0.001 ft/d.
		Lloyd Sand Member	Lloyd aquifer	300	Sand, fine to coarse, and gravel, commonly with clayey matrix; some lenses and layers of solid and silty clay; locally contains thin lignite layers. Sand and most of gravel are quartzose. Colors are yellow, gray, and white; clay is red locally.	Permeability low to moderate. Water is confined by overlying Raritan clay. Average horizontal hydraulic conductivity is 40 ft/d; anisotropy is approximately 10:1.
		unconformity				
Paleozoic and Precambrian	- - -	Bedrock	Bedrock	- -	Crystalline metamorphic and (or) igneous rocks; muscovite-biotite schist, gneiss, and granite. Contains a soft, clayey weathered zone more than 50 ft thick locally.	Poorly permeable to relatively impermeable; lower boundary of ground-water system. Some hard fresh water is contained in joints and fractures but is impractical to develop at most places.

The oldest of these deposits that unconformably overlie the bedrock surface is the Raritan Formation, which is divided into the lower Lloyd Sand Member (Lloyd aquifer) and an overlying unnamed clay member (Raritan confining unit). The Lloyd aquifer reaches a maximum thickness of approximately 300 ft and is estimated to have an average hydraulic conductivity of 40 ft/d (feet per day) in this part of Nassau County (Smolensky and Feldman, in press). Conformably overlying the Lloyd Sand Member is the unnamed clay member of the Raritan Formation (Raritan confining unit). The unit has a maximum thickness of approximately 175 ft thick and has a vertical hydraulic conductivity estimated to be 0.001 ft/d (Franke and Cohen, 1972).

The youngest Cretaceous deposit forms the Magothy Formation-Matawan Group, undifferentiated (Magothy aquifer) and overlies the Raritan confining unit. Its surface is highly eroded in the Bethpage-Hicksville-Levittown area, with a surface altitude that ranges from about 100 ft above sea level to more than 25 ft below sea level. The Magothy aquifer in the Bethpage-Hicksville-Levittown area reaches a maximum thickness of about 650 ft and is characterized by local clay lenses that cause a high degree of anisotropy. The estimated average hydraulic conductivity is 50 ft/d and anisotropy is approximately 45:1.

Overlying the Magothy aquifer are outwash deposits that are a product of the Pleistocene ice advances. The glacial sediments consist of medium-to-coarse sand and gravel, have an average horizontal hydraulic conductivity of approximately 270 ft/d, and anisotropy is approximately 10:1 (Franke and Cohen, 1972).

Ground-Water Flow System

Regional System

Natural recharge to the ground-water system occurs as precipitation that percolates downward through the zone of aeration to the water table. Under predevelopment conditions approximately 50 percent of the precipitation infiltrates down to the ground-water reservoir; the rest is either lost as evapotranspiration or to sea through overland runoff to streams. In developed areas, much of the overland flow is diverted through a system of storm drains to either recharge basins or stream channels.

The island's ground-water divide, which extends east-west along the north-central part of the island, determines whether water entering the ground-water system flows north or south to eventual areas of discharge (fig. 3). Ground water discharges regionally to regions of salty ground water underlying Long Island Sound to the north and the bays and Atlantic Ocean to the south. Ground water also discharges locally to stream channels that intersect the water table and to nearshore wetlands.

Figure 3 (caption on next page) belongs near here.

The boundaries of the ground-water reservoir are the water table, the freshwater-saltwater interface, and the bedrock surface. The water table is the upper boundary of the fresh ground -water system whose altitude fluctuates with changes in recharge and discharge. The freshwater-saltwater interface forms a lateral boundary where fresh ground water moves parallel to the interface. The bedrock surface forms an impermeable lower boundary to the ground-water reservoir.

Figure 3.--Generalized section through study area showing directions of ground-water flow.

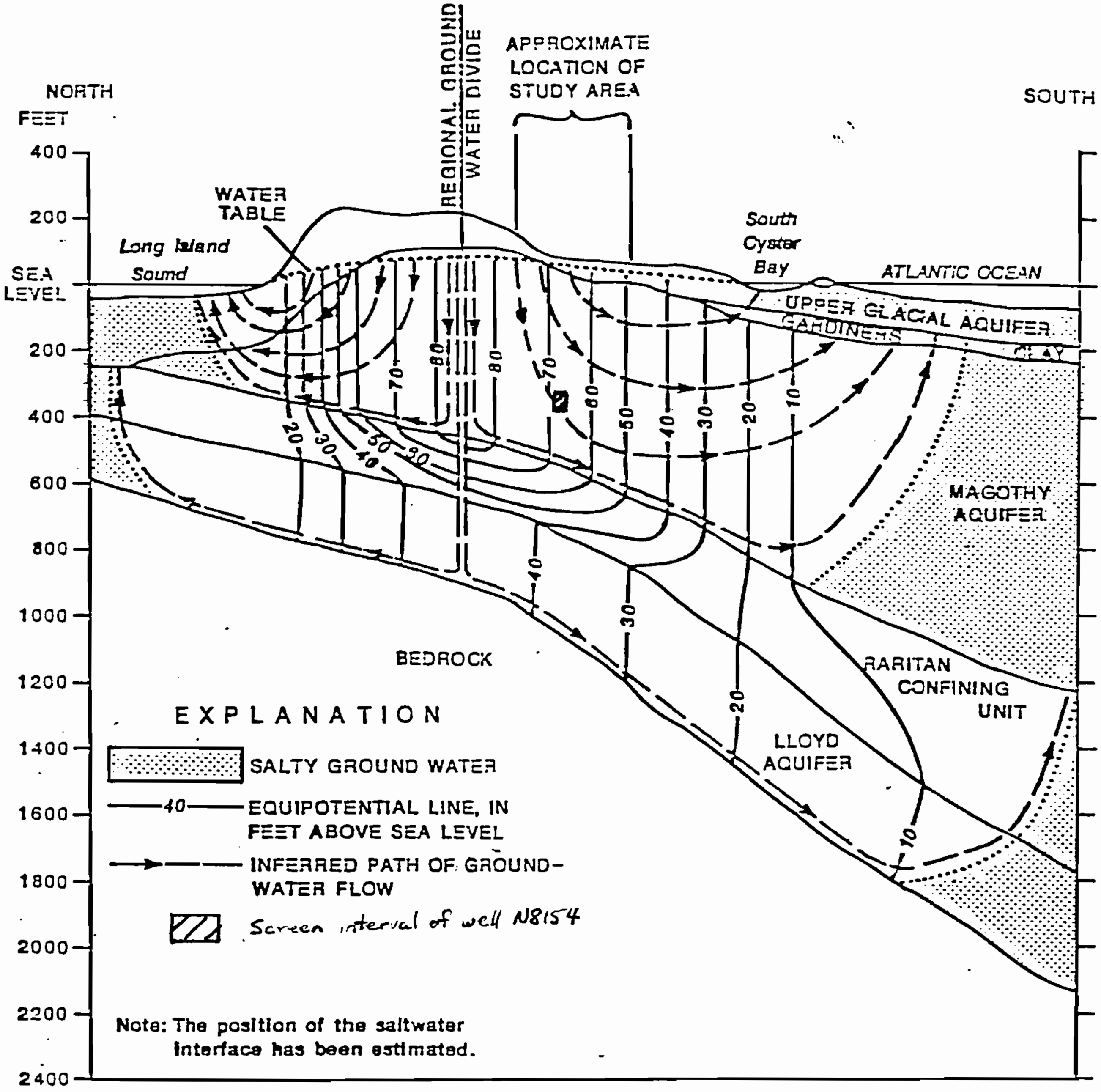

NORTH
FEET
400
200
SEA LEVEL
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
REGIONAL GROUND WATER DIVIDE
APPROXIMATE LOCATION OF STUDY AREA
SOUTH
WATER TABLE
Long Island Sound
South Oyster Bay
ATLANTIC OCEAN
UPPER GLACIAL AQUIFER
GARDINERS CLAY
MAGOTHY AQUIFER
RARITAN CONFINING UNIT
LLOYD AQUIFER
BEDROCK
80
80
70
70
60
50
40
30
20
10
20
30
40
50
30
40
30
20
10
EXPLANATION
SALTY GROUND WATER
40 EQUIPOTENTIAL LINE, IN FEET ABOVE SEA LEVEL
INFERRED PATH OF GROUND-WATER FLOW
Screen interval of well N8154
Note: The position of the saltwater interface has been estimated.

Fig 3

Local System

The Bethpage-Hicksville-Levittown area lies 1.5 mi south of the ground-water divide where regional ground-water flow is to the south. The area of investigation has four arbitrarily fixed lateral boundaries that were selected to define a particular area of interest and do not coincide with natural system boundaries. In order to obtain an estimate of the flow crossing each boundary, a rough water budget of the area of investigation was obtained from an islandwide three-dimensional ground-water flow model (Buxton and Smolensky, in press). Approximately 80 percent of the recharge to the study area originates as precipitation at land surface with the remaining 20 percent entering the area as ground-water underflow from the regional flow system. Ground-water flow following regional gradients recharges and discharges all three aquifers at the north and south faces of the study area, respectively. The ground-water fluxes across the eastern and western boundaries are substantially less than the northern and southern boundaries because the hydraulic gradients are relatively small. A natural vertical head difference of 2 to 4 ft is responsible for a small downward component of flow between the water table and basal Magothy aquifers.

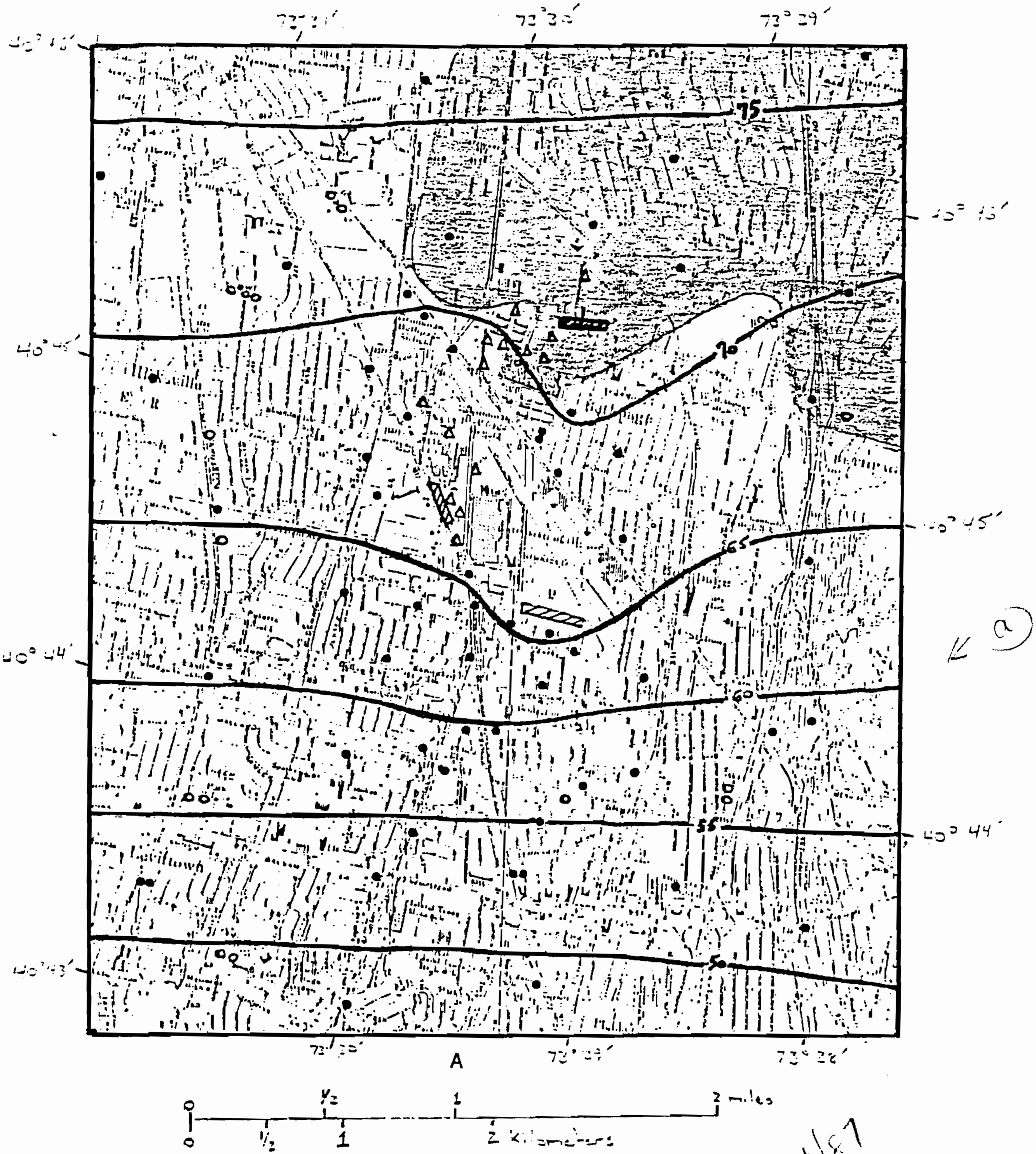
The configuration of the water table during April and August of 1987 is presented in figure 4. In general, the water table is 1.5 to 3 ft lower in August as a result of less recharge from precipitation and increased pumpage at this time of year; this decline is within the range of fluctuation for an average annual cycle. Mean annual precipitation in the area was between 41.5 and 43 in (inches) during 1951-65 (Miller and Frederick, 1969).

Figure 4 (caption on next page) belongs near here.

Depth to the water table in the Bethpage-Hicksville-Levittown area ranges from about 15 to 75 ft. This depth increases from south to north and varies with local differences in land-surface elevation. The saturated thickness of the upper glacial deposits ranges from 0 to about 100 ft thick. The horizontal gradient or slope of the water table is about 0.0015 or 7.8 ft/mi in the vicinity of the industrial zone. Using a gradient of 0.0015, a hydraulic conductivity of 270 ft/d, and a porosity value of 0.3, the average horizontal velocity in the water-table aquifer would be 1.35 ft/d. Vertical gradients within the upper glacial aquifer were negligible in areas unaffected by artificial recharge. Downward movement of water in the upper glacial aquifer occurs when temporary vertical gradients develop in response to precipitation. There are no streams in the Bethpage-Hicksville-Levittown area.

The Magothy aquifer is in direct hydraulic connection with the upper glacial aquifer. In the northeast portion of the study area, the upper glacial deposits are unsaturated and the water table occurs in the Magothy aquifer (fig. 4).

Figure 4.--Water-table altitude in April and August 1987.



↙ (a)

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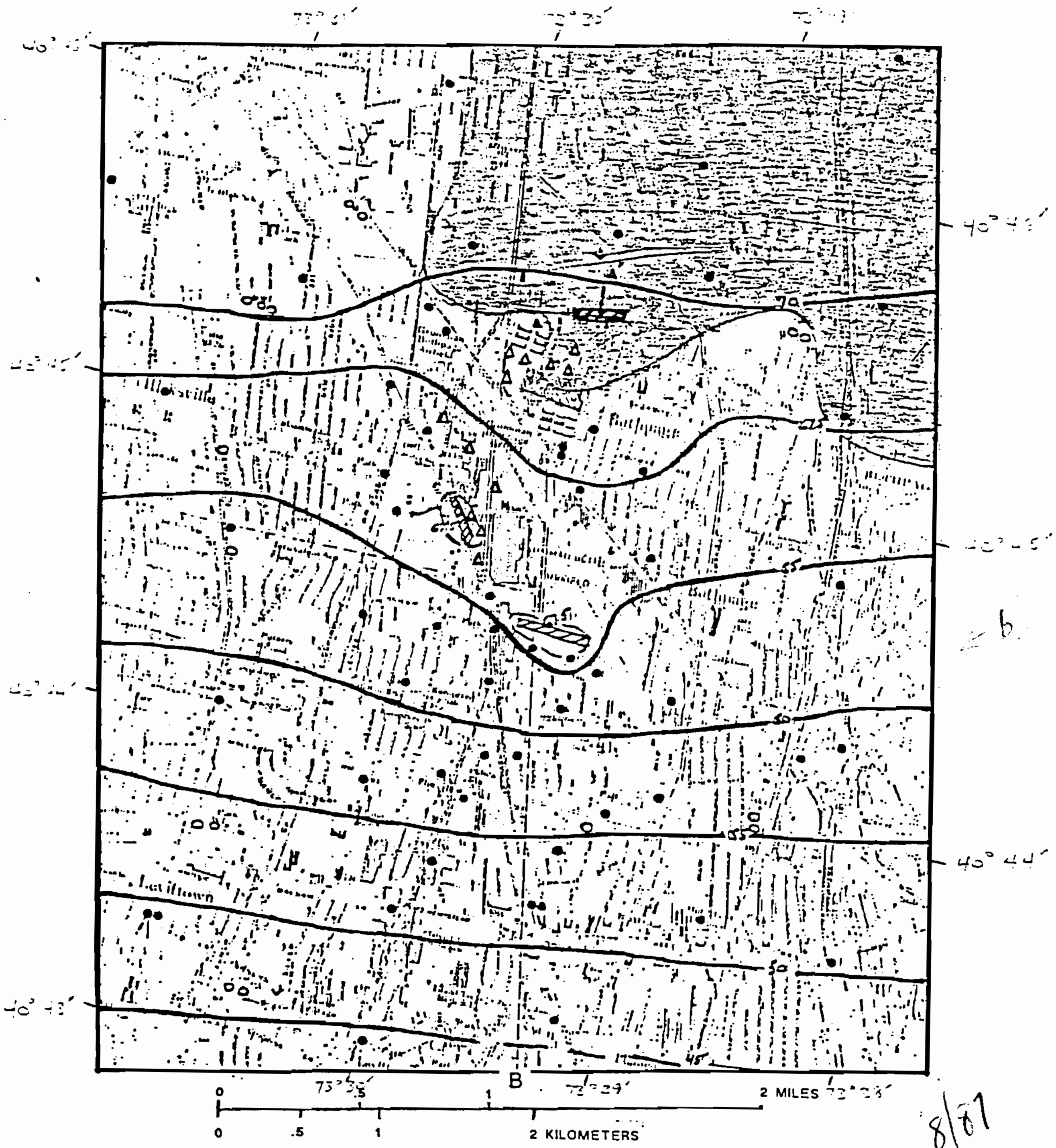
Fig 9



b.

8/87

EXPLANATION

▨ ACTIVE INDUSTRIAL RECHARGE BASIN

▩ AREA WHERE WATER TABLE IS WITHIN THE MAGOTHY AQUIFER

——50—— WATER-TABLE CONTOUR --Shows altitude of water-table.
Contour interval is 5 feet. Dashed where approximately located.
Datum is sea level.

○ PUBLIC SUPPLY WELL

will be changed { ⊙ △ INDUSTRIAL WELL

● OBSERVATION WELL SCREENED AT WATER TABLE

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Figure 4. Water table altitude in the Bethpage-Hicksville-Levittown area during a) April 1987 and b) August 1987.

Water Use and Disposal

Domestic

Public drinking water in the Bethpage-Hicksville-Levittown area is supplied by four water districts whose wells are screened in the Magothy aquifer. In 1985 public-supply wells in the study area pumped an average of 10.2 Mgal/d (million gallons per day) of ground water. Monthly pumpage is normally at its maximum in July, then declines gradually into the winter. Prior to 1980, this water was disposed of in cesspool systems or septic tanks that were installed on-site for each residential home or commercial building. This method of water disposal was in essence a means of recharging water that was pumped from deeper zones of the ground-water system. By returning much of the water that was used for domestic purposes back to the ground-water system, an approximate balance was maintained between well-water withdrawals and recharge to the ground-water system.

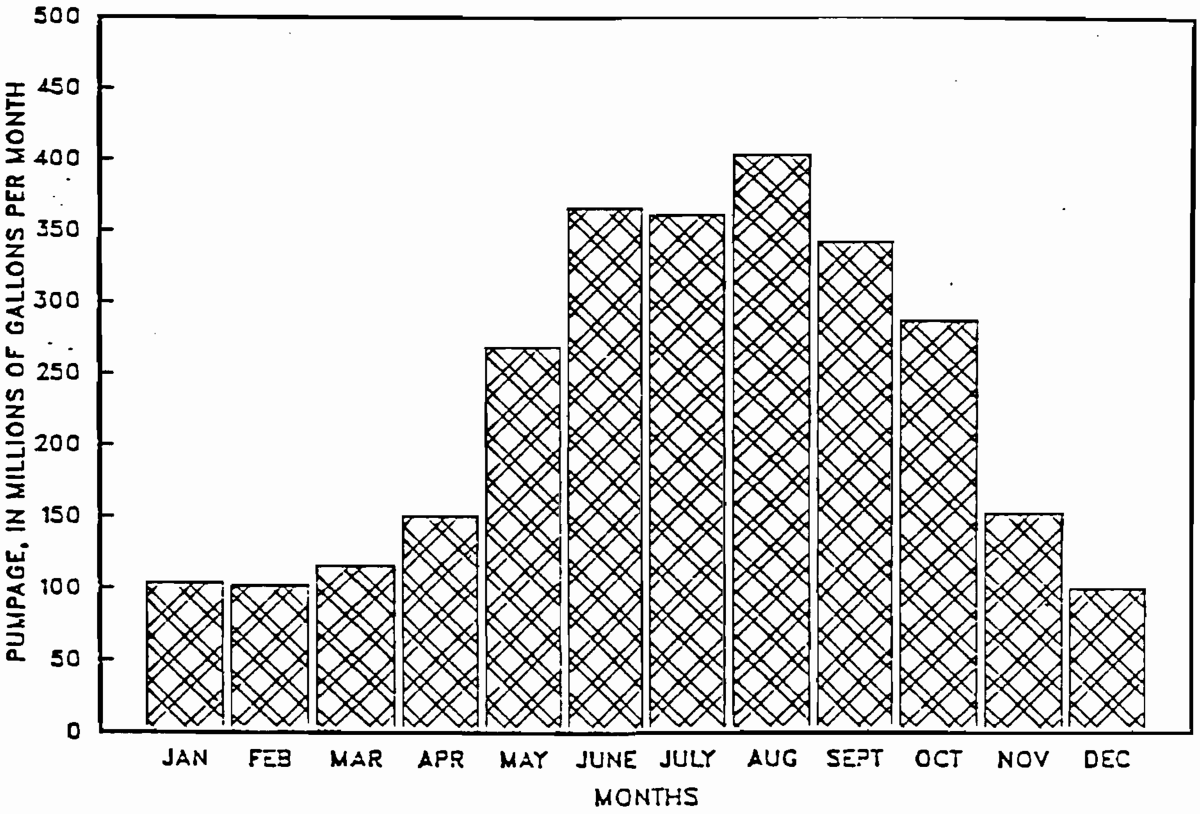
This balance has been disrupted since 1980, when wastewater in the study area began to be diverted through sewer lines to a centralized sewage-treatment plant and eventual discharge at sea. While greatly reducing the pollutant loading to the ground-water system, sewering also decreased from approximately 85 percent to 20 percent the recharge of water to the ground-water system pumped by the water districts (Buxton and Smolensky, in press). This substantial loss of recharge to the ground-water system is partially responsible for the observed decline in water levels during the past several years. Except for an increase in water levels in 1983 and 1984, which coincided with unusually high precipitation, water levels in the Bethpage-Hicksville-Levittown area have been on a declining trend throughout the 1980's (Smolensky and Feldman, in press).

Industrial

Several industrial and commercial establishments have onsite wells that pump water for non-domestic purposes. Most companies use this water for cooling purposes and inject the water back into the aquifer at the same screen zone from which it was removed. This has little effect on the overall water budget or the direction of ground-water flow in the area. The only significant industrial pumping in the study area is at the aerospace manufacturing firm, where 14 wells pumped a total of 8.05 Mgal/d from the Magothy aquifer in 1987. Average monthly pumpage for 1968-85 has been greatest during the summer months (fig. 5). Most of this water is used for air conditioning and equipment cooling; the remainder is used in manufacturing processes and is diverted through sewer lines to an offsite treatment facility. After being used, the cooling water (non-contact water) is returned to unlined surface recharge basins from which the water percolates down to the water table. Three basin groups are used for most of the recharge. Water levels in the area are being affected not only by the regional sewering stress and natural fluctuations, but also by pumping and recharging that cause very localized stresses. Comparison of April water levels with those of August (fig. 4) indicate that water-table altitude beneath the recharge basins are probably about 5 ft to 7 ft higher in August, when demand for cooling water was greatest. Water-table mounding beneath basins and drawdown in the vicinity of pumping wells dramatically increase the vertical potentiometric gradient beneath the industrial zone.

Figure 5 (caption on next page) belongs near here.

Figure 5.--Average monthly pumpage of aerospace facility wells, 1968-85.



Average Monthly
Pumping -
Grumman

1968 - 85

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Fig 5

DATA COLLECTION AND ANALYSIS

Monitoring Wells

Existing wells in the Bethpage-Hicksville-Levittown area at the beginning of the investigation included observation wells of the Nassau County Department of Public Works, public-supply wells of four water districts, and industrial/commercial wells of several owners. An additional 45 observation wells were installed to improve the network of collection points for water-level and water-quality data. Most shallow boreholes were drilled with a U.S. Geological Survey auger rig; auger flights were hosed off before being used at the next wellsite. The black carbon-steel casing was steam cleaned prior to well installation. Five-foot stainless-steel drive-point screens were used. Deep wells were installed by a private contractor with a mud rotary drill rig. Contract specifications assured that no organic compounds would be introduced into the ground-water system or water-quality samples.

Sampling Equipment and Procedures

Observation wells were sampled with a 1.75 in (inch) submersible Fultz[1] pump that uses stainless-steel and teflon for its internal wetted parts. The unit was outfitted with a teflon discharge hose to transmit the pumped water to land surface. The pump provided a flow rate of close to 1 gallon per minute. Three casing volumes of water were evacuated before sampling to ensure that stagnant well water was purged and only aquifer formation water was being pumped.

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

Industrial and public-supply well water was collected at the wellhead from a valve suitable for sampling. A teflon hose with brass fitting was connected to the sampling valve. The teflon tube was lowered to the bottom of the sample bottle so that the flow tube outlet was quickly submerged, thereby eliminating bubbling and minimizing exposure of ground water to air.

The sampling pump was flushed with about 2 gallons of clean water after each well was sampled. The flush water was collected and scanned for volatile organics by gas chromatography with flame ionization detection at the U.S. Geological Survey office in Syosset, N.Y., to verify the cleanliness of the sampling equipment.

Sample bottles were supplied by the Nassau County Department of Health Laboratory. Samples for volatile organic analysis were collected in glass bottles and sealed with teflon septa. The bottles were previously prepared by washing with detergent, then rinsing with clean water, distilled water, and finally baked in an oven to dry.

All samples for inorganic constituent analyses were collected in containers provided by the analyzing laboratory. Samples for dissolved metals were filtered through 0.45-μm membrane filters, and all metals samples were preserved by acidification with nitric acid to keep metals in solution. Both organic and inorganic samples were stored with ice in a cooler during transport from the field to the laboratory.

Water-Quality Analyses

Ground-water samples were analyzed for volatile halogenated and volatile aromatic compounds at the Nassau County Department of Health, Division of Laboratories and Research, Hempstead, N.Y. Samples were collected from 57 observation wells and 11 industrial wells (fig. 6). Volatile organic compounds were scanned by gas chromatography with electron capture detection (for volatile halogenated compounds) and photoionization detection (for volatile aromatics). Vinyl chloride was analyzed with a similar gas chromatograph outfitted with a Hall electrolytic conductivity detector (Lichtman, Nassau County Department of Health, oral commun., 1989). Appendix 1 (at end of report) lists the laboratory analysis of selected organic compounds.

Figure 6 (caption on next page) belongs near here.

Samples were also given a complete inorganic chemical examination, and laboratory analysis of selected metals and non-metals are listed in appendix 2 (at end of report). Analysis procedures are outlined in U.S. Environmental Protection Agency (1979) and American Public Health Association (1985) (N. Rogers, Nassau County Department of Health, oral commun., 1989).

Figure 6.--Location of wells sampled during fall 1987.

will be changed

Figure 6. Location of wells sampled in Fall 1987

Fig 6

Quality Assurance

All samples to be analyzed for VOCs were taken in duplicate, and one sample was scanned by gas chromatograph with flame ionization detection for quality control at the U.S. Geological Survey office in Syosset, N.Y. The Nassau County Department of Health organics lab insures quality assurance by analyzing reference samples to detect errors or malfunctions, and by participating in quarterly proficiency examinations for New York State certification. The inorganics lab, in addition to New York State certification and testing of reference samples, participates in the Standard Reference Water Sample (SRWS) Program, a quality assurance program administered by the U.S. Geological Survey.

A certain amount of error is inherent during the process of ground-water sampling and analysis (Pearsall and Wexler, 1986). The silt content of a few samples may have introduced some additional error. Silty samples may lower the measured concentration of VOCs because of adsorption onto organic solids, which is not deemed to be significant in the few shallow wells that contained silt. For metals analysis the silt was digested with nitric acid, and measured concentrations may be increased.

VOLATILE ORGANIC COMPOUNDS

Occurrence

Fifteen of the 22 organic compounds analyzed for were detected in the Bethpage-Hicksville-Levittown area. Six of these compounds were selected to show the horizontal and vertical extent of the plumes and the distribution of the most widespread contaminants. The compounds selected are: trichloroethylene (TCE), tetrachloroethylene (PCE), 1,1,1-trichloroethane, 1-1-dichloroethane, c&t-1,2-dichloroethylene, and vinyl chloride. TCE and PCE were the two compounds detected most frequently and in the highest concentrations in the Bethpage-Hicksville-Levittown area. In some locations, several compounds seemed to be emanating from a single source. Conversely, some compounds were so pervasive that it was not possible to determine the number and general location of contaminant sources.

Chemical Usage and Waste Disposal

The plastics manufacturer produced several synthetic materials through the years depending on the demand for their products. From 1956 to 1975 a polyvinyl chloride resin facility produced both vinyl chloride homopolymer and vinyl chloride/vinyl acetate copolymer. After centrifuging out the resin the wastewater from the operation was discharged into sand sumps on the plant property. This wastewater contained vinyl chloride, trichloroethylene and vinyl acetate. Wastewater volume from this facility was 2 million gallons per year (J. Harrison, Ruco Polymer Corporation, written commun., 1978).

In 1951 the first of four ester reactors was put on-line and began making phthalate and adipate plasticizers. Over the years operations were expanded to include production of trimellitate plasticizers and various other ester compounds. This esterification process gradually expanded from a production rate of 5 million lbs/yr (pounds per year) to 26 million lbs/yr, generating a wastewater stream of about 4,000 gallons per day. The wastewater contained glycols, alcohols, tetrachloroethylene, methanol, and several organic acids which from 1951 to 1974 were fed directly into a sand sump. Since early 1975 these ester wastes have been incinerated and nothing has been sent to the sand sumps. Additional plant site problems included corroding waste drums that allowed organic contaminants to soak into the ground and periodic release of PCB therminol from a relief pipe that soaked a small area of land (Harrison, 1978).

Chromium was widely used at the aerospace firm for plating and annodizing purposes. In the military aircraft industry, the use of chromium and cadmium to enhance the corrosion resistance of aluminum and other metals became common (Lieber and others, 1964). The aerospace firm began discharging their chromic acid waste directly into seepage basins in 1943. This waste received much attention when in 1947 a downgradient shallow public-supply well contained as much as 1,400 μg/L hexavalent chromium. By 1949 the firm implemented a treatment method for this waste before discharging it into seepage basins (Nassau County Department of Health, 1977). However, organic chemicals were used at several locations with some eventually discharging to seepage basins.

Paint solvents used in the paint booths were carried away by recirculating water curtains to remove paint particulates, and then moved along with other wastewater to a facility where it was chemically treated only for chromium reduction; the chlorinated hydrocarbons that did not volatilize remained in the treated wastewater and were discharged into seepage basins (Grumman, 1978).

Halogenated solvents are also generated from vapor degreasers that use cleaning solvents to remove oil, grease, and dirt from parts. These wastes, along with waste from anodizing and plating tanks and paint shops, are pumped or trucked to an on-site industrial-waste-treatment facility. Spillage from liquid chemical storage tanks was collected in floor drains and discharged into large recharge basins. Sludge drying beds used for chromium hydroxide sludge and phenolic sludge were also located on-site (J. Welsch, Nassau County Department of Health, written commun., 1976).

Since introduction of small quantities of organic contaminants can pollute large areas, trying to determine the location and time frame in which contamination occurred is a very uncertain undertaking. Several smaller companies could be responsible for some of the contaminants detected by the well network, and two other companies are known to have had on-site industrial treatment facilities for removal of chromium (New York State Department of Environmental Conservation, 1985; J. Welsch, Nassau County Department of Health, written commun., 1976). While understanding how chemical use and disposal may cause introduction of contaminants to ground water is a useful undertaking, this study focuses on how stresses to the ground-water system affect chemical distribution, transport, and fate once contaminants have entered the ground-water system.

Past Monitoring of Organic Compounds

Routine monitoring of ground-water quality in east-central Nassau County in the early 1970's revealed that four of 14 Magothy aquifer wells at the aerospace firm approached or exceeded the New York State nitrate limit of 10.0 mg/L, six wells showed high levels of ammonia, and five wells indicated odors of a hydrocarbon nature (Nassau County Department of Health, written commun., 1975). While elevated levels of nitrates are not uncommon in the Magothy aquifer in central Nassau County, ammonia detection and hydrocarbon odors are indicative of direct contamination by sanitary sewage and industrial wastes. At the time, the aerospace corporation was known to be discharging its treated sanitary waste into seepage basins at three locations, and industrial wastes, particularly those being discharged by the plastics manufacturer located adjacent to the aerospace firm's property, were considered responsible for the degradation in quality of the aerospace firm's wells (Nassau County Department of Health, 1977).

In 1974, Nassau County Department of Health requested the U.S. Environmental Protection Agency to perform organic compound sampling and analysis for three of the aerospace firm's wells, but no organic compounds were detected. Sampling was also conducted at two aerospace firm sewage plant recharge basins with positive vinyl chloride results, and at the plastics manufacturer's condenser water and PVC discharge water lagoons. Traces of TCE and PCE and higher concentrations of oxtyl alcohol and vinyl chloride were found at the condenser water lagoon, while larger amounts of vinyl chloride and acetic acid were found at the PVC operation's lagoon. In November of 1975, additional samples were collected and transmitted to the State health department laboratory to confirm prevous analyses and to determine if the contamination problem extended downgradient. Vinyl chloride, dichloroethylene, TCE, and PCE were detected in several of the aerospace firm's wells and in their drinking water distribution system (Nassau County Department of Health, 1979).

Composition of Contaminant Plumes

Interpretation of the bi-annual samples that were collected by the U.S. Geological Survey in the spring and fall of 1986 and 1987 showed that the distribution of contaminants did not change significantly during this time period. There was no indication that the concentration of organic compounds varied seasonally, or that movement of distinct pulses of contaminated ground water were exhibiting a trend toward increasing or decreasing concentrations through time. However, there was enough variation in the magnitude of contaminant concentrations from one sampling period to another that these data presented in areal maps and vertical sections represent an averaged view of the actual distribution of contaminants. More precise information as to the location, concentration, and time of entry of contaminants along with water-quality data collected over a longer period of time would be required to determine whether or not the distribution of compounds was changing with time.

Distribution

Water-quality samples were collected at wells that were screened in the water-table aquifer and both the middle and deep zones of the Magothy aquifer. There are no wells in the Bethpage-Hicksville-Levittown area that penetrate through the Raritan confining unit to the underlying Lloyd aquifer. Due to the low vertical hydraulic conductivity and considerable thickness of this confining unit there was no reason to expect any significant amount of organic contamination in the Lloyd aquifer. This water-quality investigation was, therefore, limited to the water table and Magothy aquifers.

The contaminant plume covers a large area in the water-table aquifer where there are several contaminant sources and the greatest amount of spreading due to localized mounding. Contaminants may enter the ground-water reservoir beneath the industrial zone as a result of (1) chemical usage, (2) waste disposal, or (3) artificial ground-water recharge. The first activity relates to past chemical usage in which inadvertent leaks and spills may have been diverted to seepage basins via storm sewers, or may have soaked the ground in any number of locations and eventually been transported by percolating rainwater down to the water table. Disposal of sanitary and industrial waste effluent into seepage basins prior to hookup with the Nassau County sewage-disposal system presented a means for introduction of volatile organics into the ground-water system. Pumping of contaminated ground water for air conditioner cooling, and subsequent disposal of the water into seepage basins creates secondary sources of contamination to the ground-water system. Industrial wells pump contaminated Magothy aquifer water that is eventually routed to four recharge basins, resulting in efficient percolation of contaminated water down to the water table.

Trichloroethylene

TCE is widely used in industrial processes such as metal degreasing and organic synthesis, and often is a good indicator of ground-water contamination from an industrial source. One area of particularly high TCE concentration was near well N10595 located along the eastern edge of the aerospace firm's property just north of the railroad tracks (fig. 7A). This sampling point is located approximately 2,000 ft downgradient of an area where a sanitary-sewage-treatment plant, seepage basins, chemical usage, and sludge drying beds all existed. As was mentioned earlier in the report, since 1980, only non-contact cooling water is disposed of in seepage basins; all sanitary sewage and process waste is presently being piped offsite to a Nassau County sewage-treatment facility. TCE concentrations were measured at levels exceeding 500 µg/L near well N10595 and over 800 µg/L near well N10599 which is downgradient of an area where a manufacturing facility, industrial treatment plant, and seepage basins are located. Although the water-quality data and knowledge of site history is insufficient to pinpoint precise sources of contamination, clearly the occurrence of VOCs such as TCE in the water-table aquifer resulted from the introduction of contaminants within the industrial zone. Examining the distribution of TCE in the plume downgradient of the industrial zone, well doublet N10816 and N10817 indicates that ground-water flow paths are likely to be moving TCE deeper into the water-table aquifer. The well screened about 90 ft below the water table had a TCE concentration of 56 µg/L whereas the well screened 15 ft below the water table had a concentration of only 3 µg/L.

Figure 7 (caption on next page) belongs near here.

Figure 7.--Areal distribution of trichloroethylene: A. Water-table aquifer. B. Mid-Magothy aquifer. C. Deep Magothy aquifer.

Explanation

—— 10 —— Line of equal TCE concentration -- dashed where approximately located.

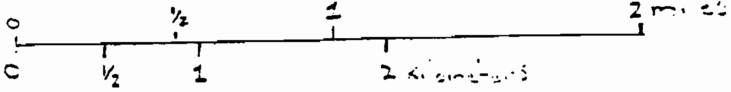
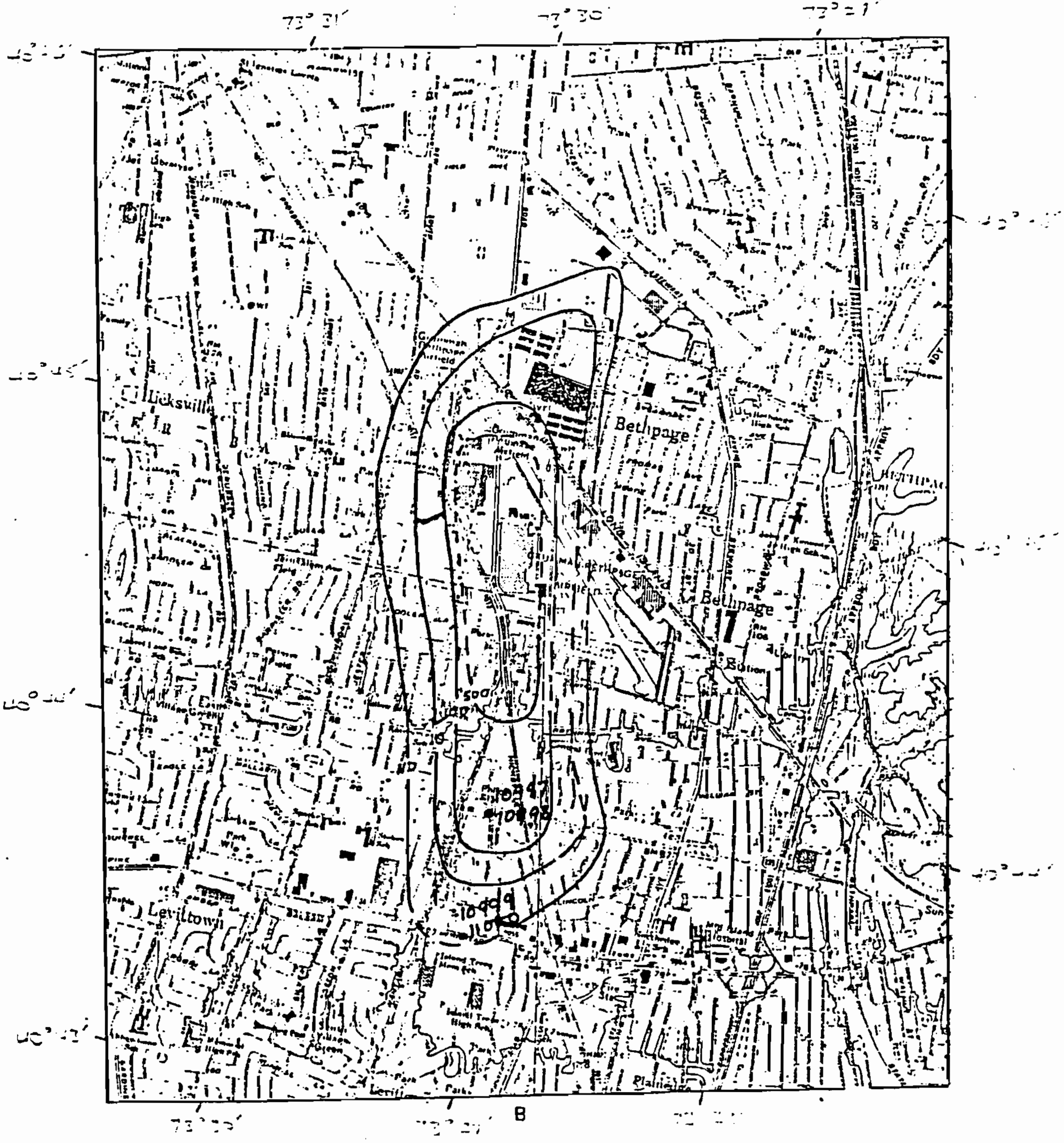


Figure 7 Areal distribution of trichloroethylene in the (a) water table aquifer (0 to 50 feet below the water table surface), (b) mid-Magothy aquifer (75 to 275 feet below water table), and (c) in the deep Magothy aquifer (300 to 450 feet below the water table).

TCE in
Water-table
aquifer



TCE in mid-Magothy aquifer

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C

TCE in
deep-Magothy
aquifer

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TCE was also encountered in the mid-Magothy aquifer (between 75 ft and 275 ft below the water table) and in the deep-Magothy aquifer (between 300 ft and 450 ft below the water table) (fig. 7B, 7C). Industrial wells had TCE concentrations as high as 1,200 µg/L in the mid-Magothy, and as high as 770 µg/L in the deep zone. Observation wells installed downgradient of the industrial zone confirmed that TCE had migrated offsite at depth in the Magothy aquifer. An observation well doublet (N10997, N10998) installed approximately 2,500 ft south of the industrial zone showed that TCE was still persistent in both Magothy zones with concentrations in the range of 200 µg/L. Another well doublet (N10999, N11000) approximately 1,500 ft farther downgradient shows that within the mid-Magothy zone at this location the concentration probably diminishes with depth from approximately 10µg/L to below detection.

Tetrachloroethylene

The area where the highest concentration of PCE was detected coincides with the highest TCE concentration along the eastern edge of the industrial area (fig. 8A). A second distinct area of high PCE concentration occurs to the west, where the level of PCE at well N10598 was over 200 µg/L. During the 2-year sampling program PCE levels in this well were as high as 1,100 µg/L. TCE levels in this area were less than 10 µg/L. The fact that there is no corresponding high level of TCE in this area indicates that the contaminants (TCE and PCE) probably did not originate from a single source.

Figure 8 (caption on next page) belongs near here.

Figure 8.--Areal distribution of tetrachloroethylene: A. Water-table aquifer. B. Mid-Magothy aquifer. C. Deep Magothy aquifer.

Explanation

—— 10 —— Line of equal PCE concentration --- dashed where approximately located.

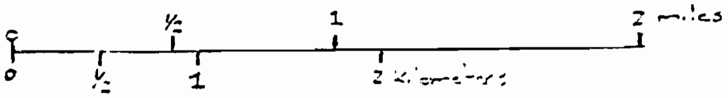
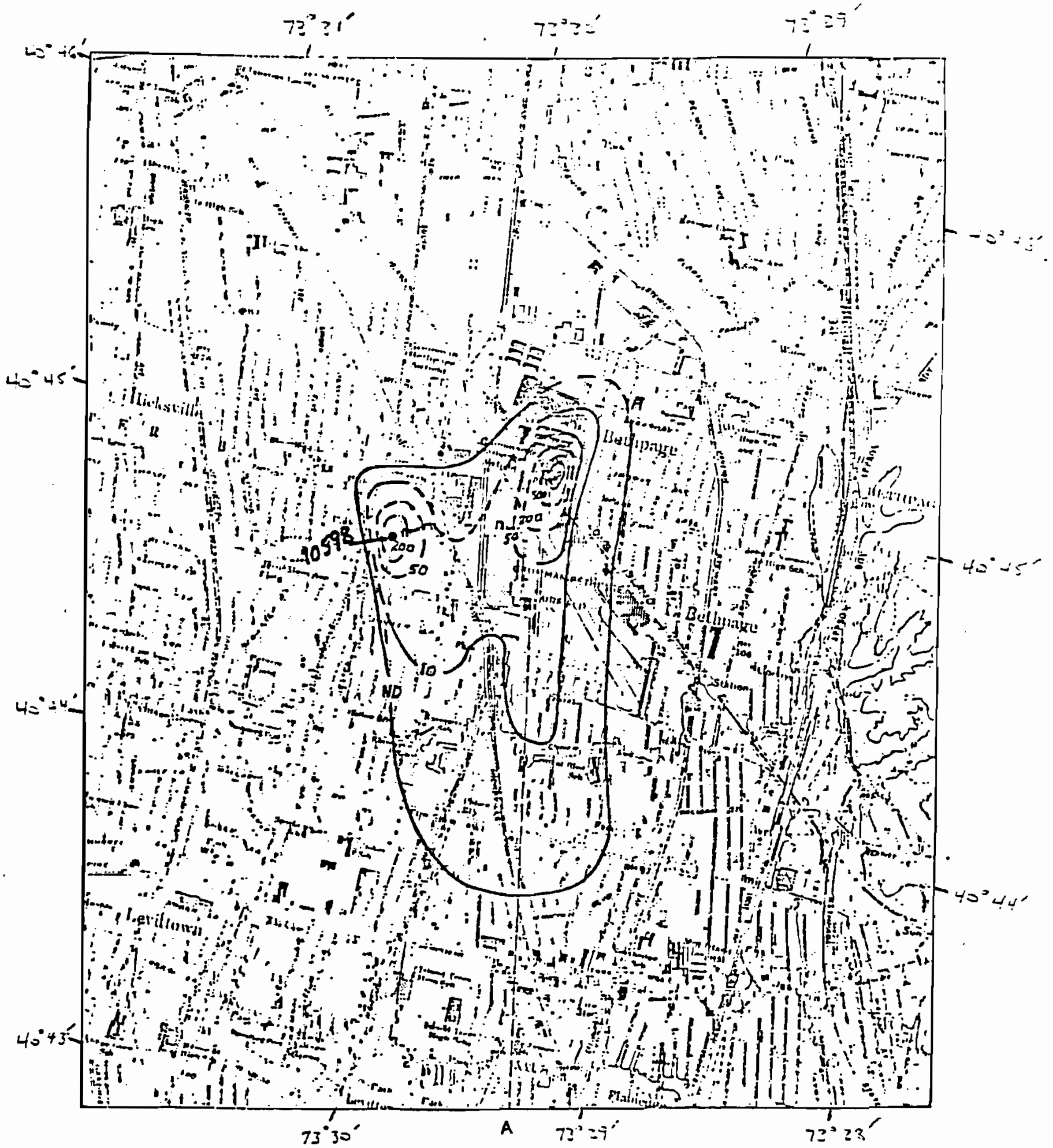


Figure 8. Areal distribution of tetrachloroethylene in the (a) water-table aquifer (0 to 50 feet below the water-table surface), (b) mid-Magothy aquifer (75 to 275 feet below the water table), and (c) in the deep Magothy aquifer (300 to 450 feet below the water table).



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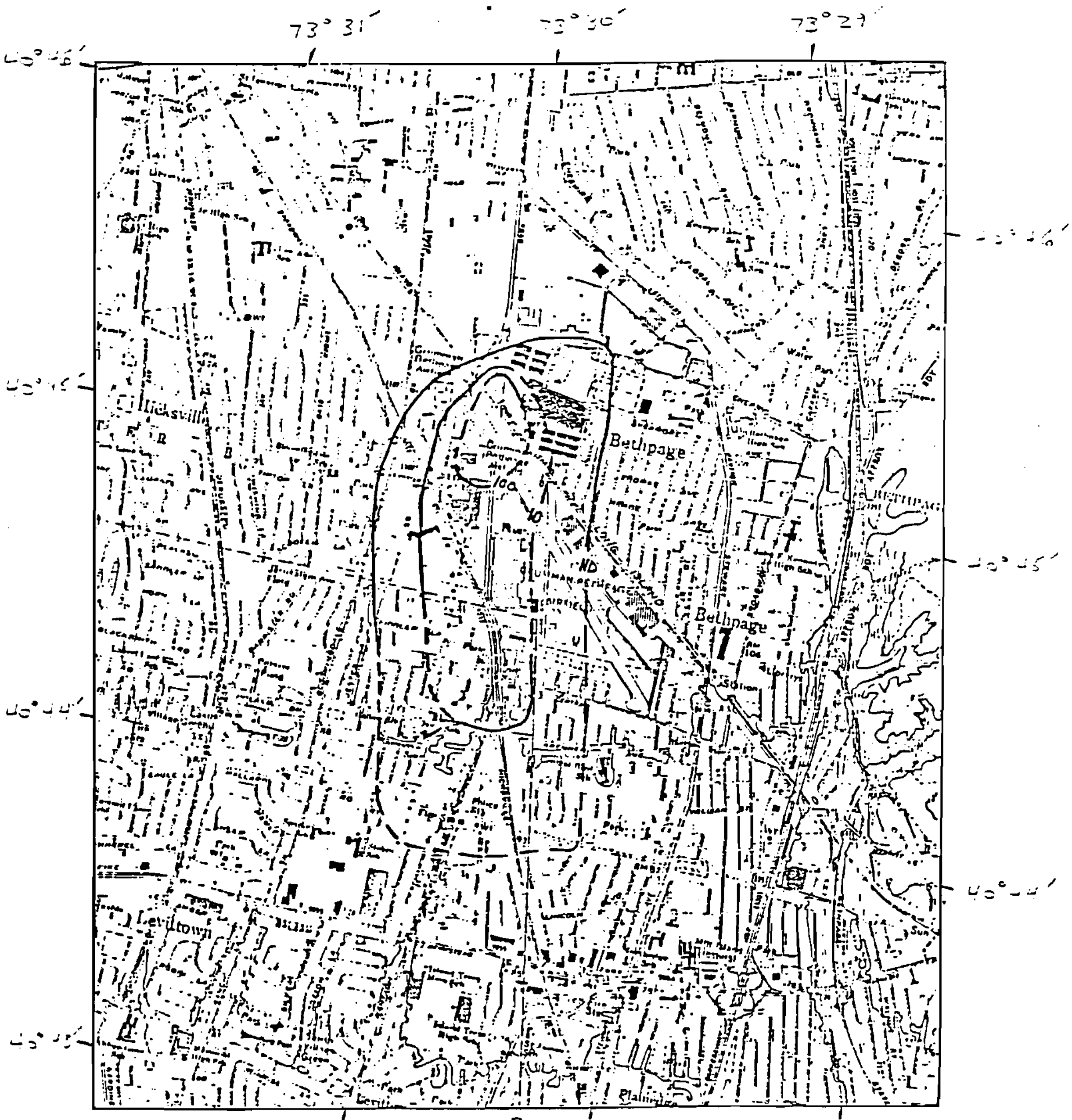
PCE in
Water Table
Aquifer



B

PCE in
mid-Magothy
Aquifer

C

PCE in deep-Magothy aquifer

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Downgradient of the industrial zone the concentration of PCE decreases much more rapidly than does TCE. The occurrence of PCE does not extend as far downgradient of the industrial zone as does the occurrence of TCE, and the highest detected concentration south of the industrial zone was 13 µg/L. In the intermediate and deep zones of the Magothy aquifer the concentration of PCE is significantly lower than observed concentrations at the water table, except for areas near some aerospace firm wells that are upgradient of source areas. In these areas, PCE concentrations in the Magothy aquifer are greater because contaminated ground water is being drawn north of areas of shallow ground-water contamination because drawdowns at pumping wells alter local hydraulic gradients.

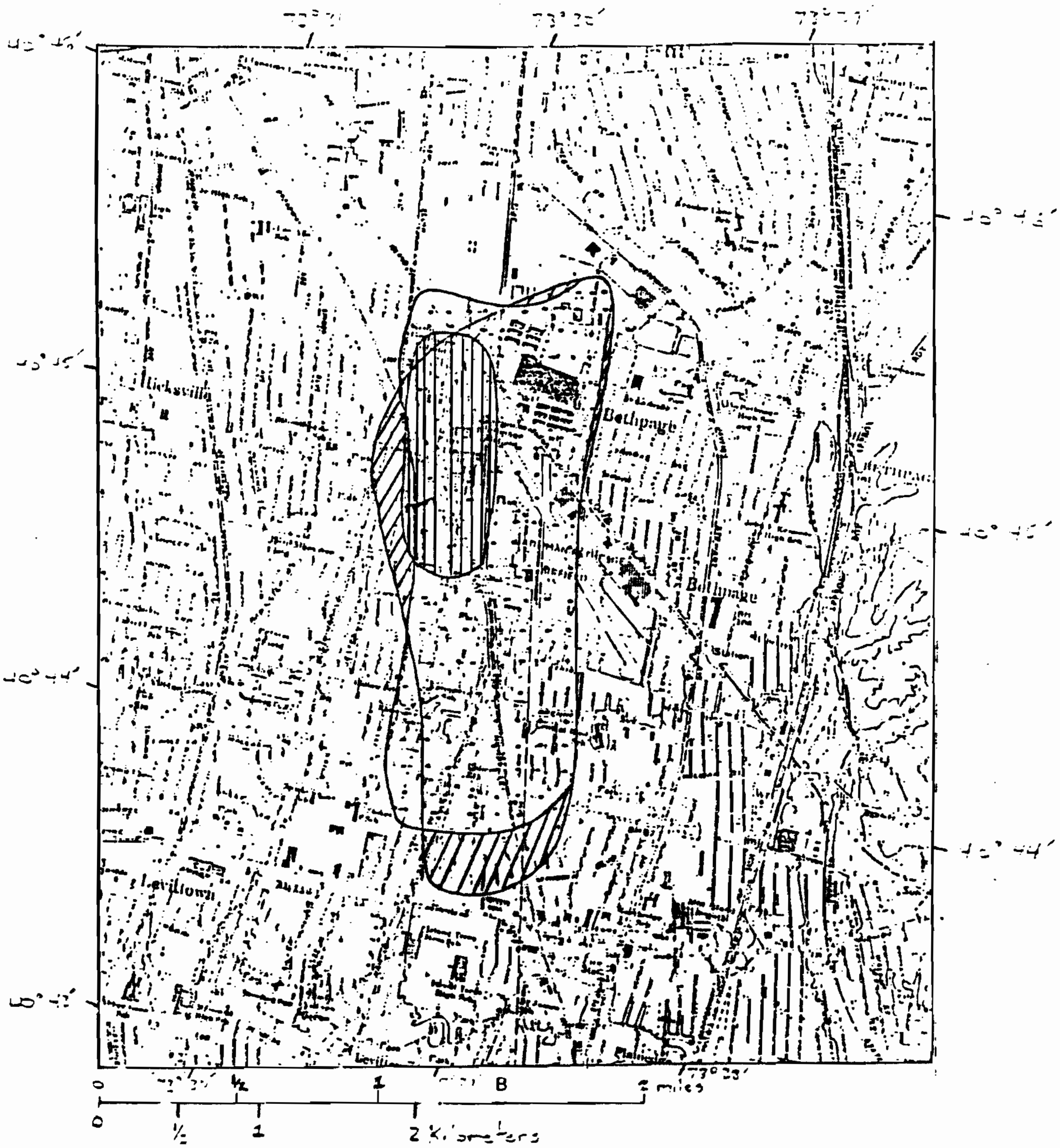
Other Compounds

By examining the areal extent of 1,1,1-trichloroethane, 1,1-dichloroethane, c&t-1,2-dichloroethylene, and vinyl chloride, it became more evident that the volatile organic compound plume underlying the industrial zone is actually a composition of several individual plumes that overlap each other (fig. 9A). The mapping of their occurrence in the water-table aquifer clearly illustrates that several contaminants may be emanating from a single source area, with the possibility of several additional source areas. Except for low levels of 1,1,1-trichloroethane detected in the water-table aquifer downgradient of the industrial zone, there was a greater incidence of downgradient contamination in the intermediate zone of the Magothy aquifer where both 1,1,1-trichloroethane and vinyl chloride were detected. Because the possibility of several sources exists, it is difficult to determine whether or not the various compounds are being transported at different rates or if certain contaminants have additional sources along the downgradient flow path. However, the compounds vinyl chloride and 1,1,1-trichloroethane, which have migrated off-site in the intermediate and deep zones of the Magothy aquifer, are detected at approximately the same distance downgradient of the industrial zone.

Figure 9 (caption on next page) belongs near here.

Figure 9.--Occurrence of four frequently detected contaminants in: A. Water-table aquifer. B. Mid-Magothy aquifer. C. Deep Magothy aquifer.

Fig 9

40°46'
73°30'
Hicksville
Bethpage
Bethpage
Levittown
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B
0
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½
1
2 Kilometers

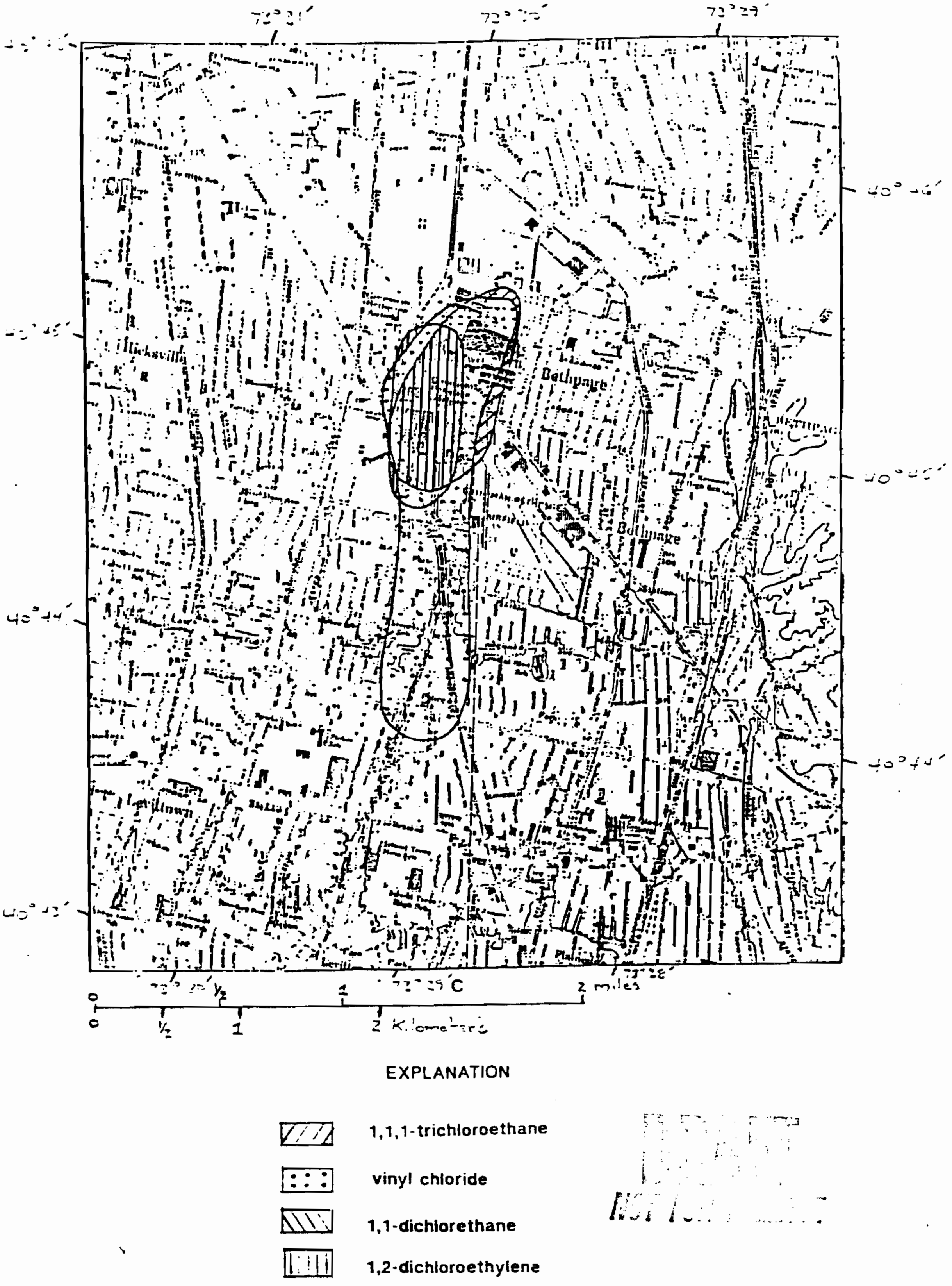


Figure 9. Occurrence of four frequently detected contaminants in the (a) water table aquifer (0 to 50 feet below the water table surface), (b) mid-Magothy aquifer (75 to 275 feet below the water table), and (c) in the deep Magothy aquifer (300 to 450 feet below the water table).

Transport and Fate

Advection

Advection is the process by which solutes are transported by the bulk motion of flowing ground water. Evaluating what the ground-water-flow system would be like under unstressed "predevelopment" conditions and observing that volatile organic contaminants were undetected in Magothy aquifer wells upgradient of the industrial zone indicated that local stresses to the ground-water system must be responsible for the transport of contaminants deep into the Magothy aquifer. Concentrated well withdrawals and subsequent routing of pumped water into recharge basins cause large vertical head gradients. These stresses result in changes in the natural hydraulic gradients which dramatically increase the vertical component of flow beneath the industrial zone. Franke and Cohen (1972) calculated regional rates of ground-water movement on Long Island using the following modified form of the Darcy equation,

$$V_s = \frac{K_s i}{n}$$

where V_s = the velocity along a segment of the flow line s,

K_s = the hydraulic conductivity of the aquifer along the segment of the flow line s,

$i = \frac{\Delta h}{L}$, the hydraulic gradient along the segment of the flow line, and

n = the porosity of the aquifer, assumed to be 30 percent.

Using this methodology, representative values for K_s were calculated using the hydraulic conductivity ellipsoid (Freeze and Cherry, 1979, p. 35-36) along a segment of an estimated predevelopment flow line as depicted in figure 3 from the northern boundary of the study area to the middle of the screen interval for aerospace firm well N8154. The conductivity value K_s can be calculated for any direction of flow in an anisotropic medium assuming that the horizontal and vertical conductivities are known. The values used were $K_x = 50$ ft/d, $K_z = 1.1$ ft/d, $\Delta h = 12$ ft, a horizontal distance of 8,300 ft, and a screen setting, or vertical distance of 400 ft below the water table. The flow line was divided into six segments and the hydraulic conductivity and velocity increments along the entire flow line from the northern boundary to 400 ft below the water table, a distance of 8,300 ft, were calculated. The velocity distribution along the flow line yielded a travel time from the water table to the area of the well screen of 109 years. Although this value is very approximate, it further substantiates the fact that contaminants originated from sources within the industrial zone.

Concentrated pumping by deep industrial wells and the diversion of pumped water to recharge basins act to decrease the length of time required for water to travel deep into the Magothy aquifer for two important reasons. First, the head differential between the water table and deep zone of pumping is increased because of drawdown at the well screen and water-table mounding beneath the basins. Second, the representative flow line is deflected to have a much more pronounced vertical alignment, which effectively reduces the length of the flow path from the water table to the deep zone of the Magothy aquifer.

Hypothetical calculations were made for the travel time from the water table beneath a recharge basin to a pumping well a distance of 1,000 ft away. This scenario occurs at two locations within the industrial zone, and was calculated for well N8154, which is approximately 1,000 ft northeast of a basin group (fig. 10). Assuming water-table mounding of 6 ft beneath the recharge basin and a drawdown of 12 ft at the pumping well, the velocity distribution along segments of a flow line resulting from present day "stressed" conditions was calculated. The approximate time of travel from the recharge basin to being captured by a pumping well was 10.3 years.

Referring back to figure 7A-C, it is evident that ground-water pumping significantly affects the advective transport of contaminants as illustrated by the shape and areal extent of a plume along an imaginary flow path from the water table, through the intermediate zone of the Magothy aquifer, and into the deep zone. Rather than dispersing as the contaminants move away from the source areas, the concentration contours become more constricted as ground-water flow paths converge on the screen zones of individual pumping wells. Advective transport exerts such a predominant role in determining the fate of the contaminants that other transport mechanisms become insignificant. The location of pumping wells seems to influence the distribution of volatile organic contaminants in the Magothy aquifer. Several wells are located in a cluster in the northern section of the aerospace firm with the remainder located in a band along the western rim of the property; there is a notable lack of pumping in the eastern part of the property (fig. 6).

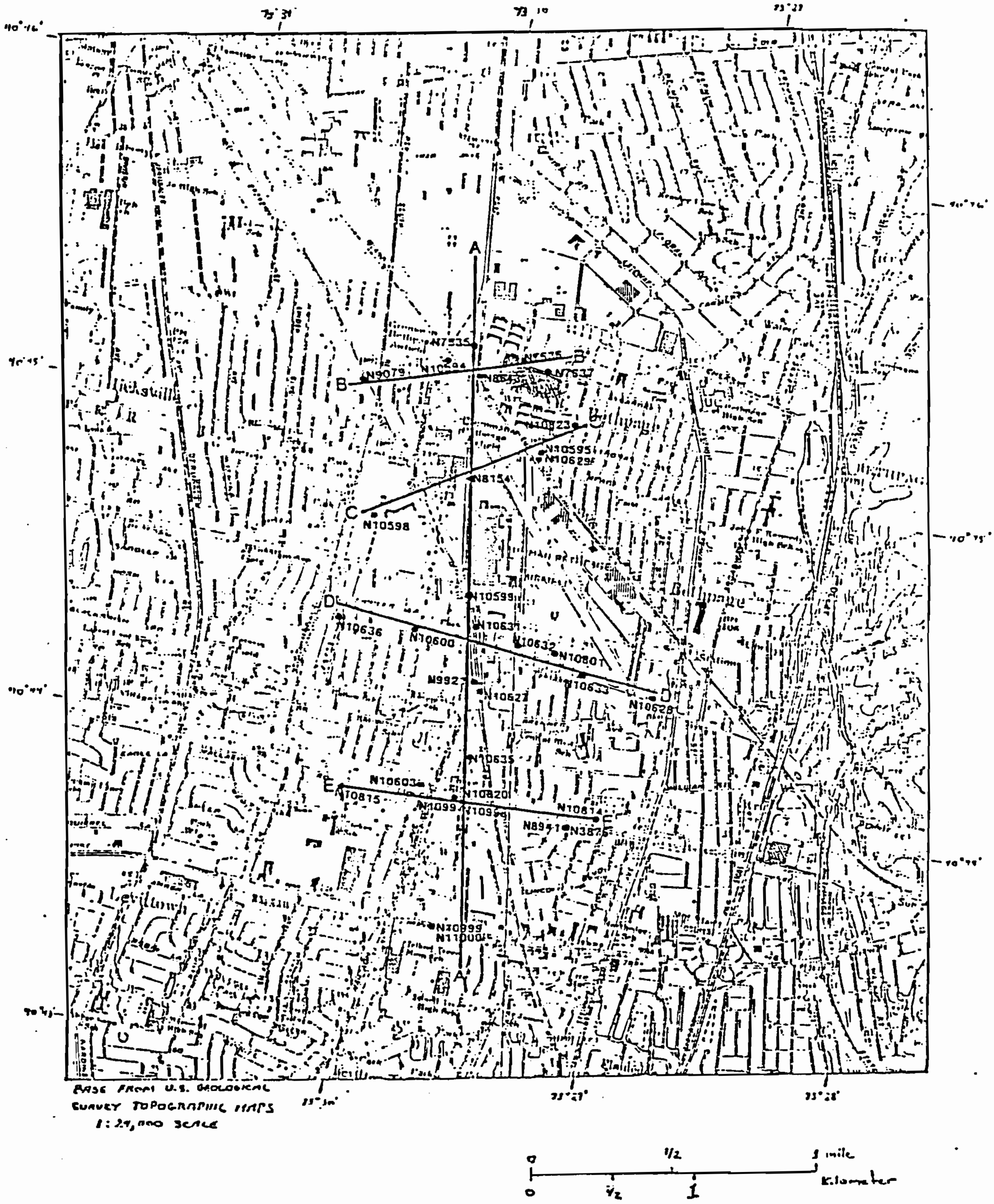
The three zone areal plots were transformed into one north-south and four east-west cross sections to better depict the vertical distribution of contaminants (fig. 10). This process involved contouring chemical concentrations of wells on the cross section and interpolating contours from data not explicitly on the sections. The vertical distribution of TCE shows that the configuration of pumping wells strongly influences the transport of TCE (fig. 11). Section A-A' shows that TCE moves vertically downward from areas of high concentration at the water table to the pumping wells where large drawdowns are occurring. In addition to moving vertically downward, TCE is also being pulled from east to west by the pumping along the western edge of the aerospace firm's property. By observing section B-B', C-C', and D-D' in progression, these drawdown effects are quite evident as the TCE plume moves downgradient. Section E-E' shows that once the plume has migrated beyond the influence of industrial pumpage the plume movement is governed by regional ground-water flow paths and was estimated to be moving at a rate of approximately 100 to 120 ft/yr (feet per year) in the Magothy aquifer. In this area where contaminant distribution is no longer influenced by industrial pumping and recharge, regional gradients have moved the plume deeper than water-table conditions as evidenced by the first 100 ft below the water table where the concentration of TCE increases with depth. The public-supply-well doublet of N3876 and N8941 shown in section E-E' has tested positive for TCE and appears to be drawing the plume toward the screen zones.

Figure 10 (caption on next page) belongs near here.

Figure 11 (caption on next page) belongs near here.

Figure 10.--Location of sections used to show the vertical distribution of trichloroethylene and tetrachloroethylene.

Figure 11.--Hydrochemical sections through the plume showing the vertical distribution of trichloroethylene.



BASE FROM U.S. GEOLOGICAL SURVEY TOPOGRAPHIC MAPS 1:24,000 SCALE

Location of sections used to show the vertical distribution of TCE and PCE.

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Fig 1C

Explanation

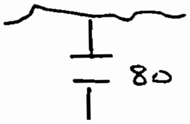
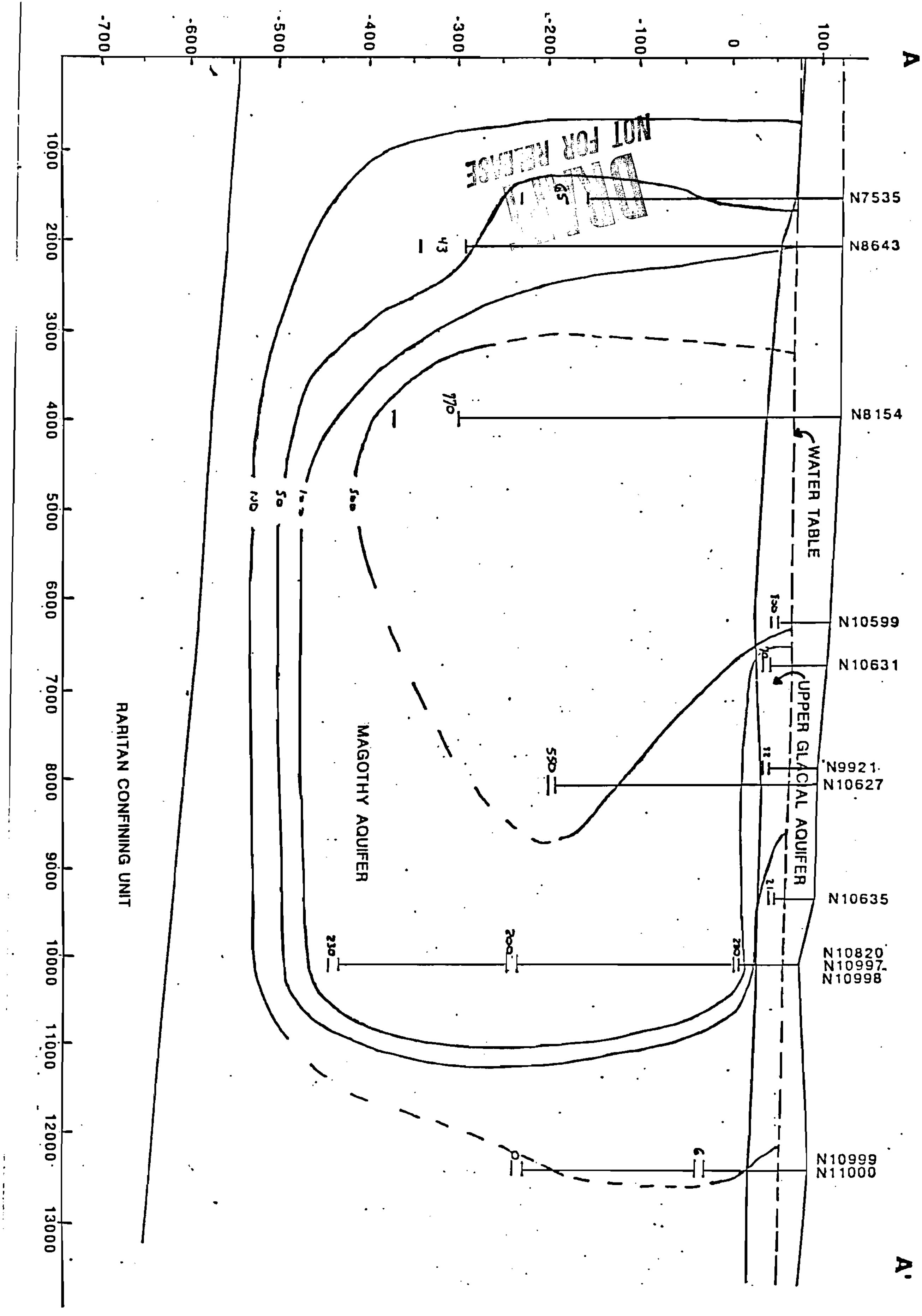
—— 50 ——	Line of equal TCE concentration - - - dashed where approximately located.
 80	Well site showing the screen interval and chemical concentration, µg/l.
- - - - -	Water table
————	Geologic contact

Figure 11. Hydrochemical sections through the plume showing the vertical distribution of TCE.



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A'
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0
-100
-200
-300
-400
-500
-600
-700
1000
2000
3000
4000
5000
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8000
9000
10000
11000
12000
13000
N7535
N8643
N8154
N10599
N10631
N9921
N10627
N10635
N10820
N10997
N10998
N10999
N11000
WATER TABLE
UPPER GLACIAL AQUIFER
MAGOTHY AQUIFER
RARITAN CONFINING UNIT
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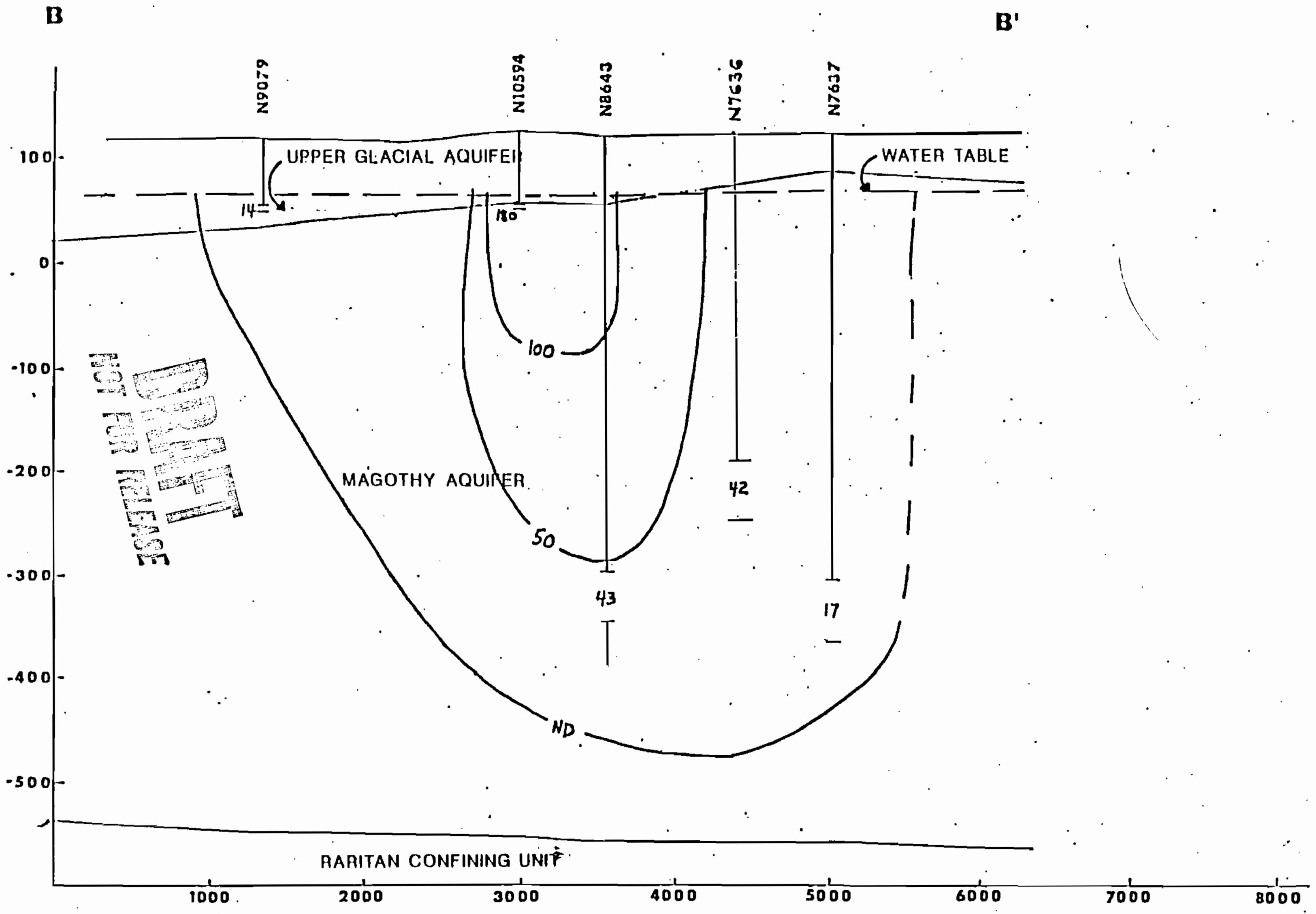
50
10
130
70
11
550
21
230
200
220
6
0



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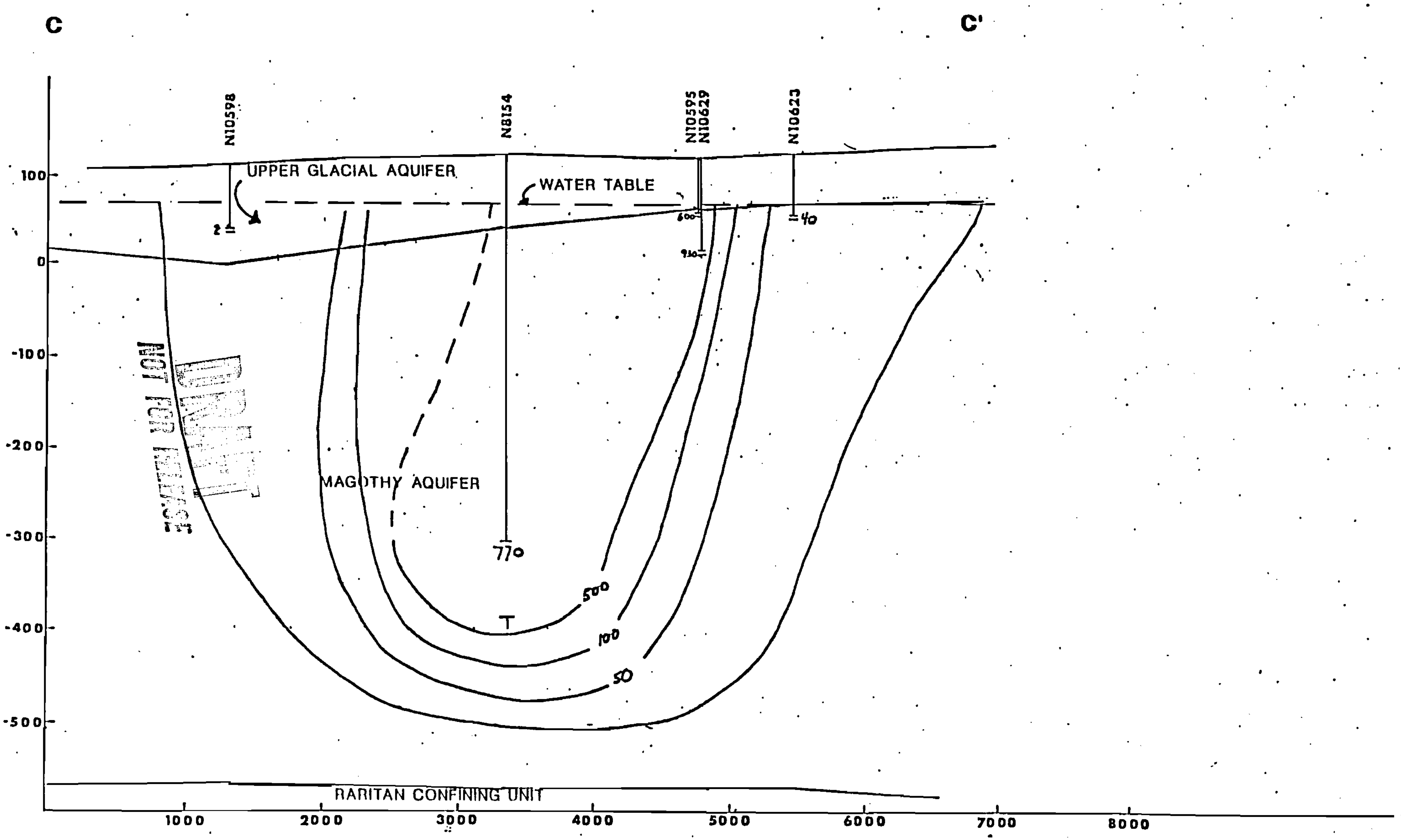

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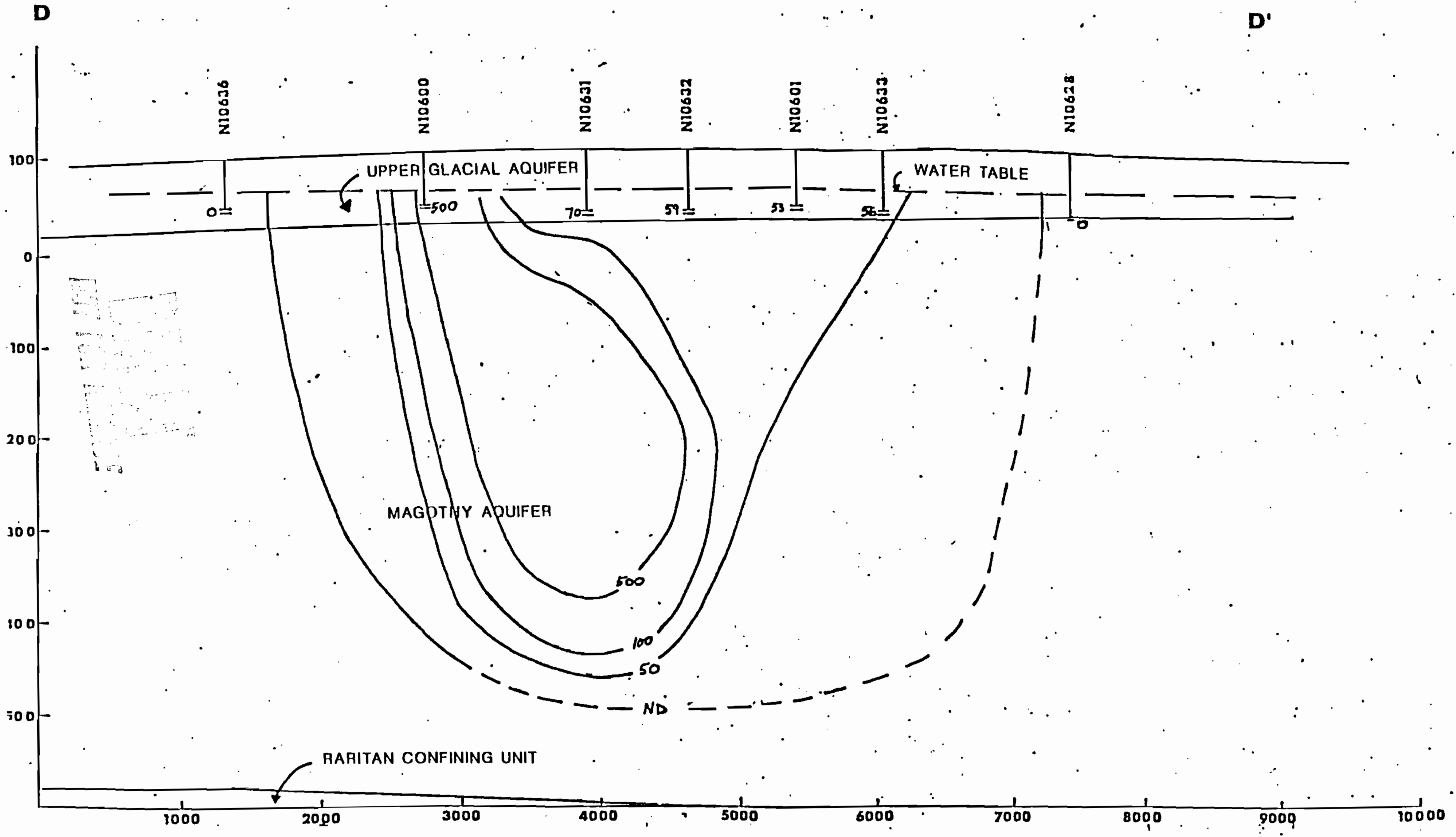
D
D'
N10636
N10600
N10631
N10632
N10601
N10633
N10628
UPPER GLACIAL AQUIFER
WATER TABLE
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500
70
59
53
56
0
MAGOTHY AQUIFER
500
100
50
ND
RARITAN CONFINING UNIT
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100
200
300
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500
1000
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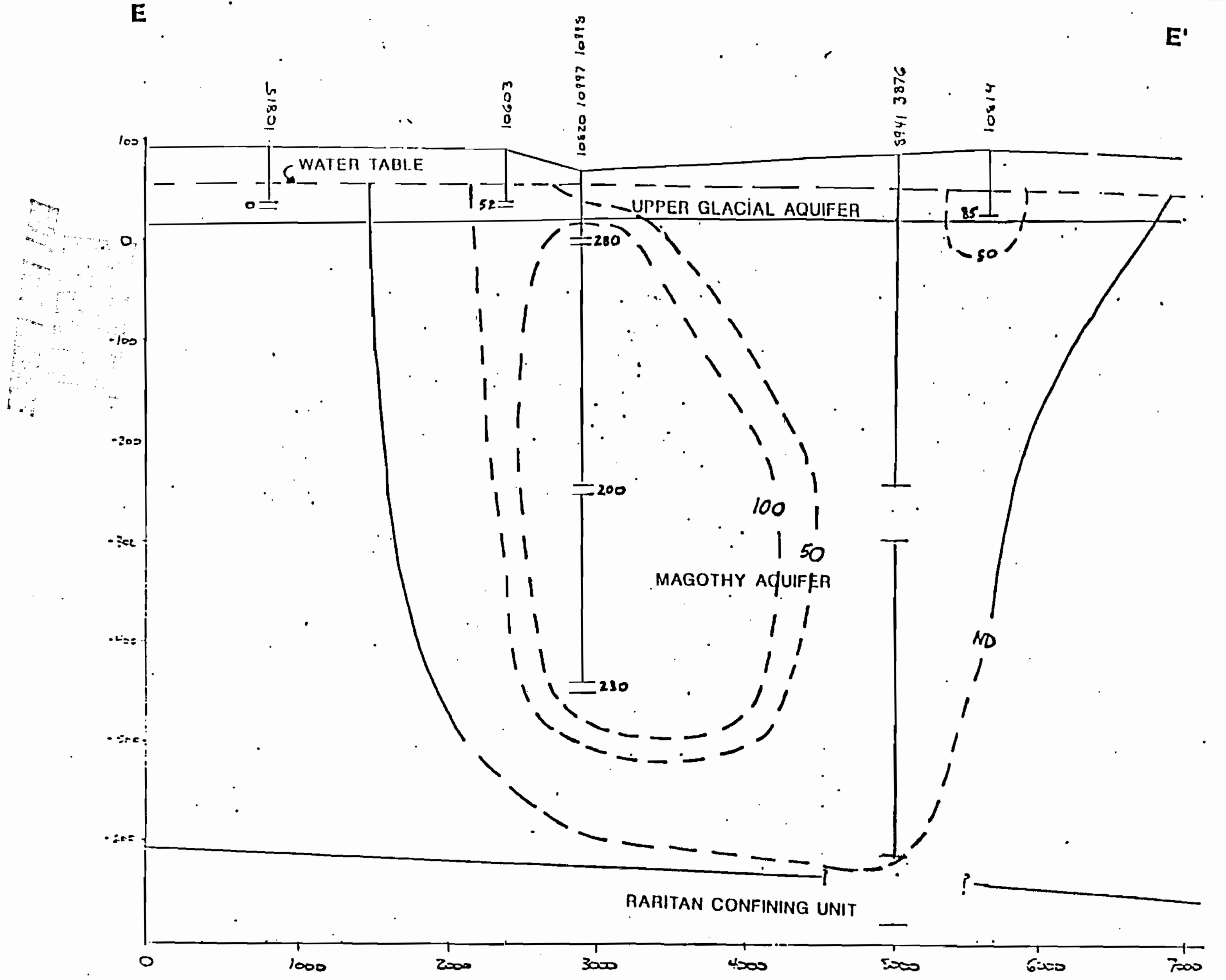
3000
4000
5000
6000
7000
8000
9000
10000


E
E'
10815
10603
10820 10997 10995
5941 3876
10614
WATER TABLE
UPPER GLACIAL AQUIFER
MAGOTHY AQUIFER
RARITAN CONFINING UNIT
0
52
280
200
230
85
50
100
50
ND
?
100
0
-100
-200
-300
-400
-500
-600
0
1000
2000
3000
4000
5000
6000
7000

Vertical sections were also constructed for PCE, which had two areas of very high concentrations at the water table to the east and west of well N8154 (fig. 12, section C-C'). Referring to section A-A', the area of highest concentration is north of well N8154 in the Magothy aquifer where there is a cluster of industrial wells. Section B-B' clearly shows that contaminated ground water is actually being drawn slightly upgradient of what would be the natural southward flow path under unstressed conditions. Shallow wells along section B-B' had only traces of PCE below 5 μg/L, and the plume was undetected upgradient of the section. Also evident is the fact that once the PCE plume migrates downgradient of the industrial zone, it moves deeper than water-table conditions and dissipates much more quickly than levels of TCE.

Figure 12 (caption on next page) belongs near here.

Dispersion

The spreading of dissolved contaminants by mechanical mixing and molecular diffusion as they move with ground water is a process known as dispersion. Dispersion was not expected to be uniform in the Bethpage-Hicksville-Levittown area because of variations in pore geometry, variations in ground-water velocity, and fluctuations in flow directions attributed to ground-water pumping and recharging. In the area affected by industrial pumping, larger head gradients increase ground-water velocity. The increased local flow rate increases the frictional forces within the porous medium and increases the mechanical mixing in the longitudinal direction. Transverse spreading is not a factor in the area of pumping because ground-water flow paths are converging on individual screen zones of the pumping wells.

Figure 12.--Hydrochemical sections through the plume showing the vertical distribution of tetrachloroethylene.

Explanation

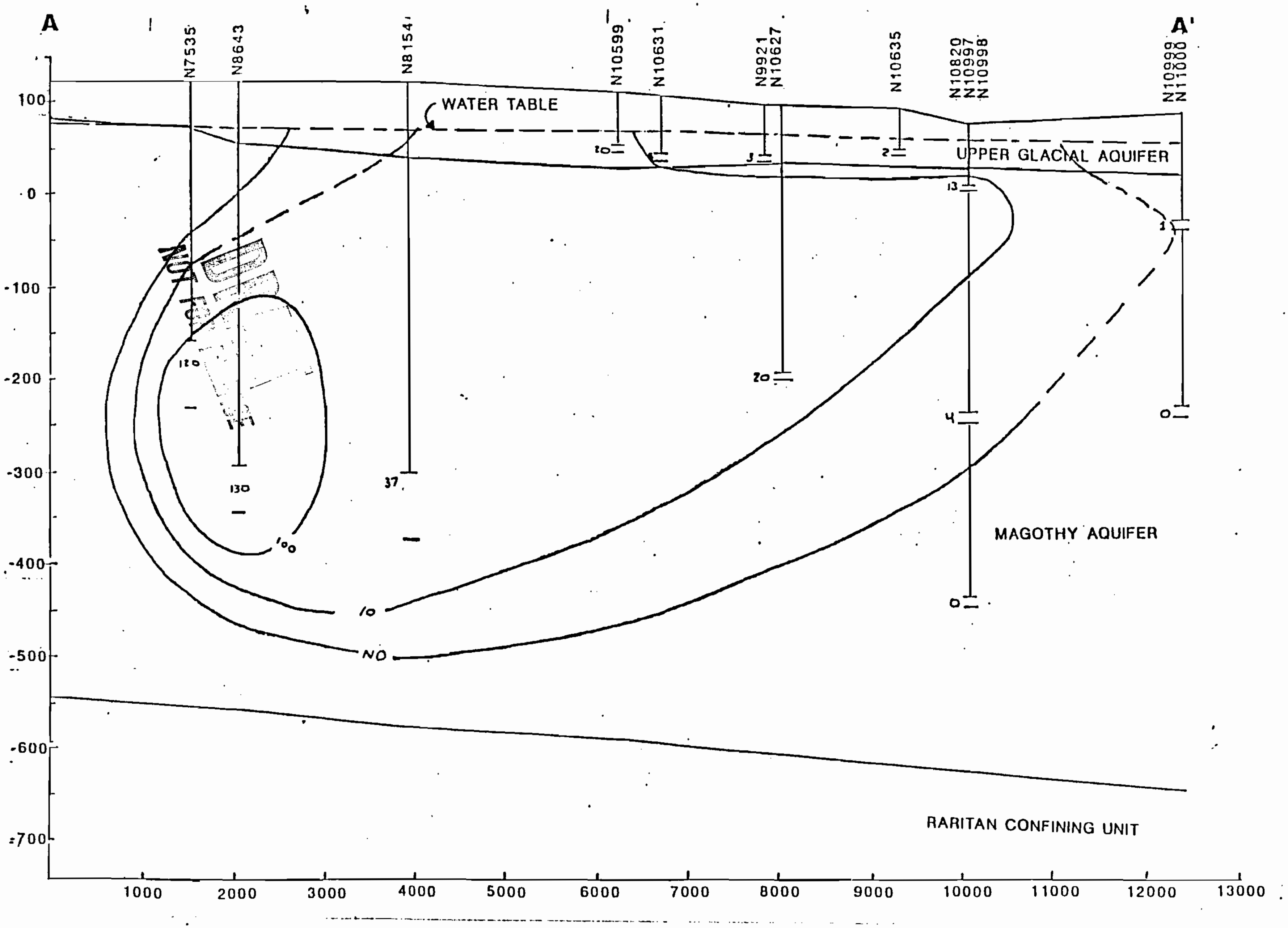
— 50 — Line of equal PCE concentration---dashed where approximately located.

80 Well site showing the screen interval and the chemical concentration

- - - - Water table

——— Geologic contact

Figure 12. Hydrochemical sections through the plume showing the vertical distribution of PCE.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N10631
N9921
N10627
N10635
N10820
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N10998
N10999
N11000
WATER TABLE
UPPER GLACIAL AQUIFER
MAGOTHY AQUIFER
RARITAN CONFINING UNIT
100
0
-100
-200
-300
-400
-500
-600
-700
1000
2000
3000
4000
5000
6000
7000
8000
9000
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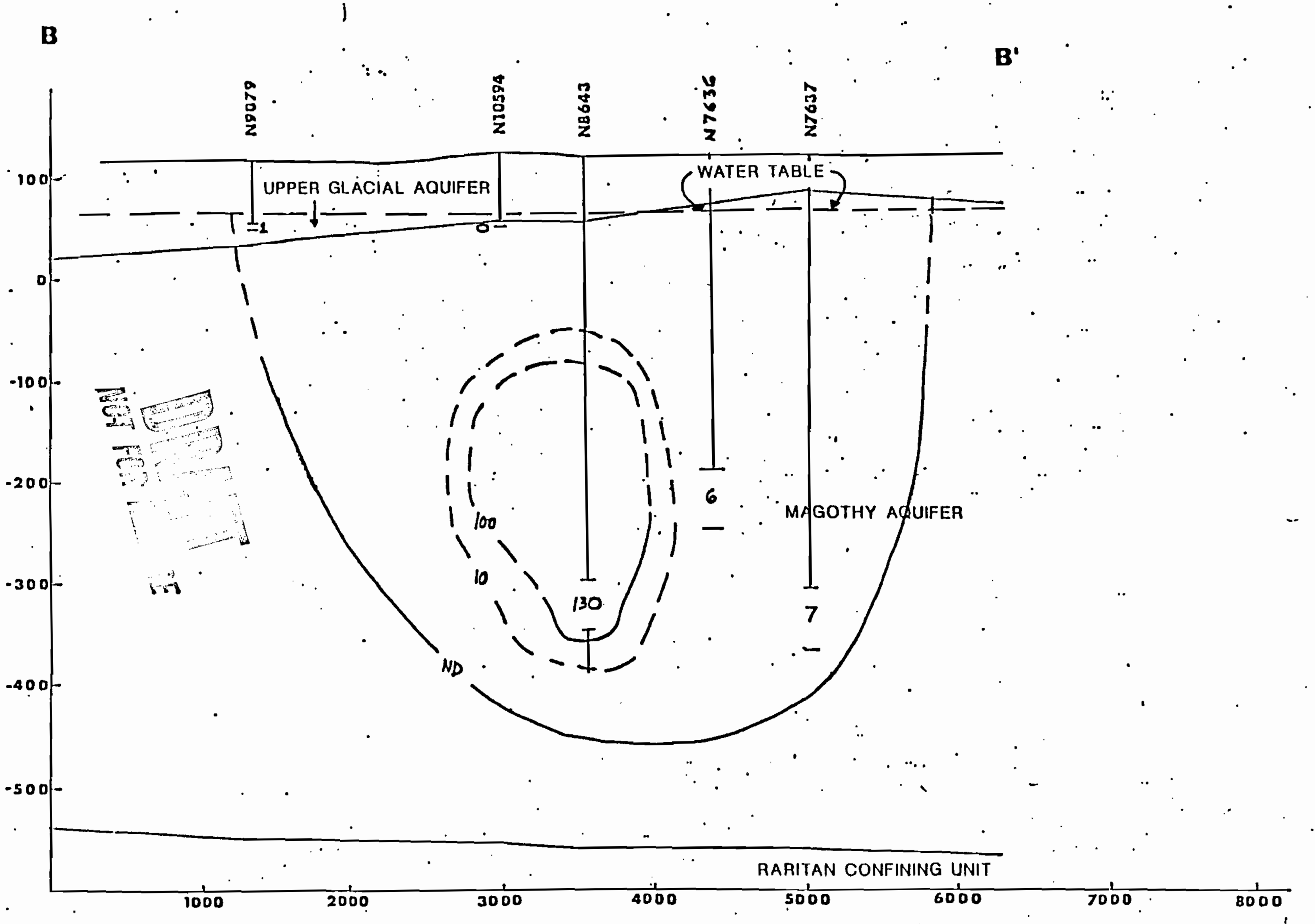
ND



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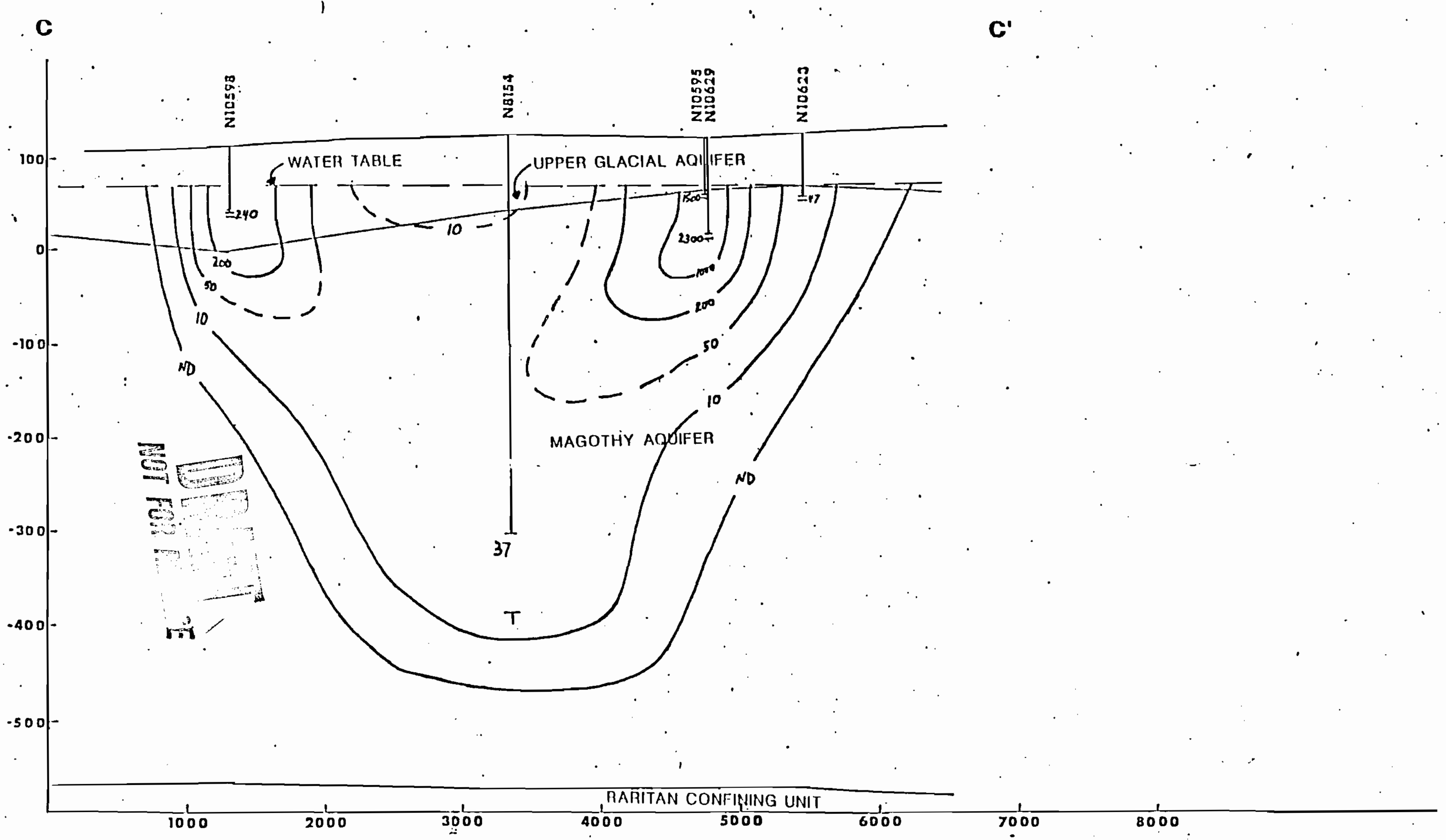
C
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N10623
WATER TABLE
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MAGOTHY AQUIFER
RARITAN CONFINING UNIT
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1500
2300
17
37
T
200
50
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3000
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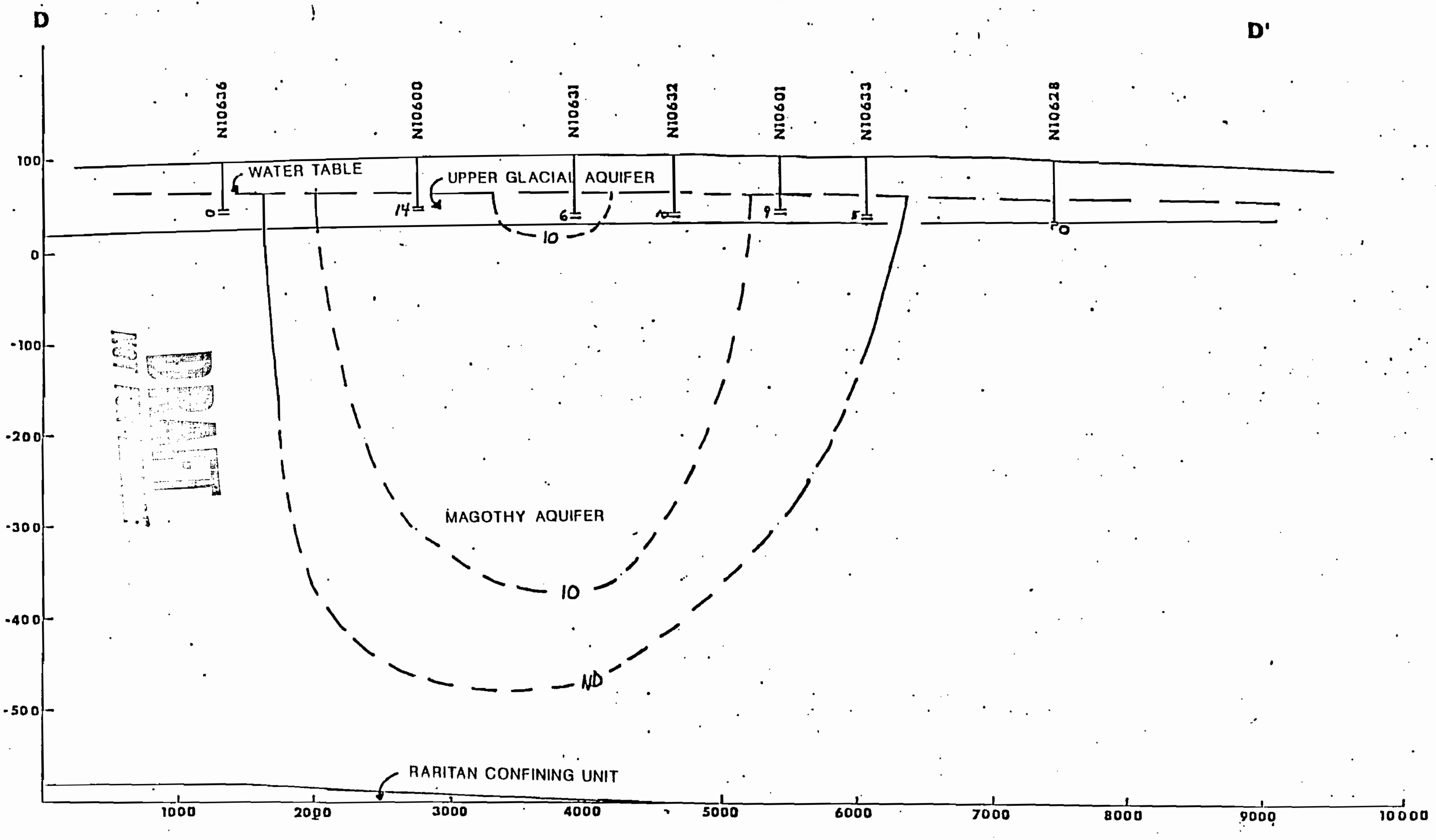
5000
6000
7000
8000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N10631
N10632
N10601
N10633
N10628
WATER TABLE
UPPER GLACIAL AQUIFER
MAGOTHY AQUIFER
RARITAN CONFINING UNIT
0
14
6
10
9
5
0
10
10
ND
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0
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7000
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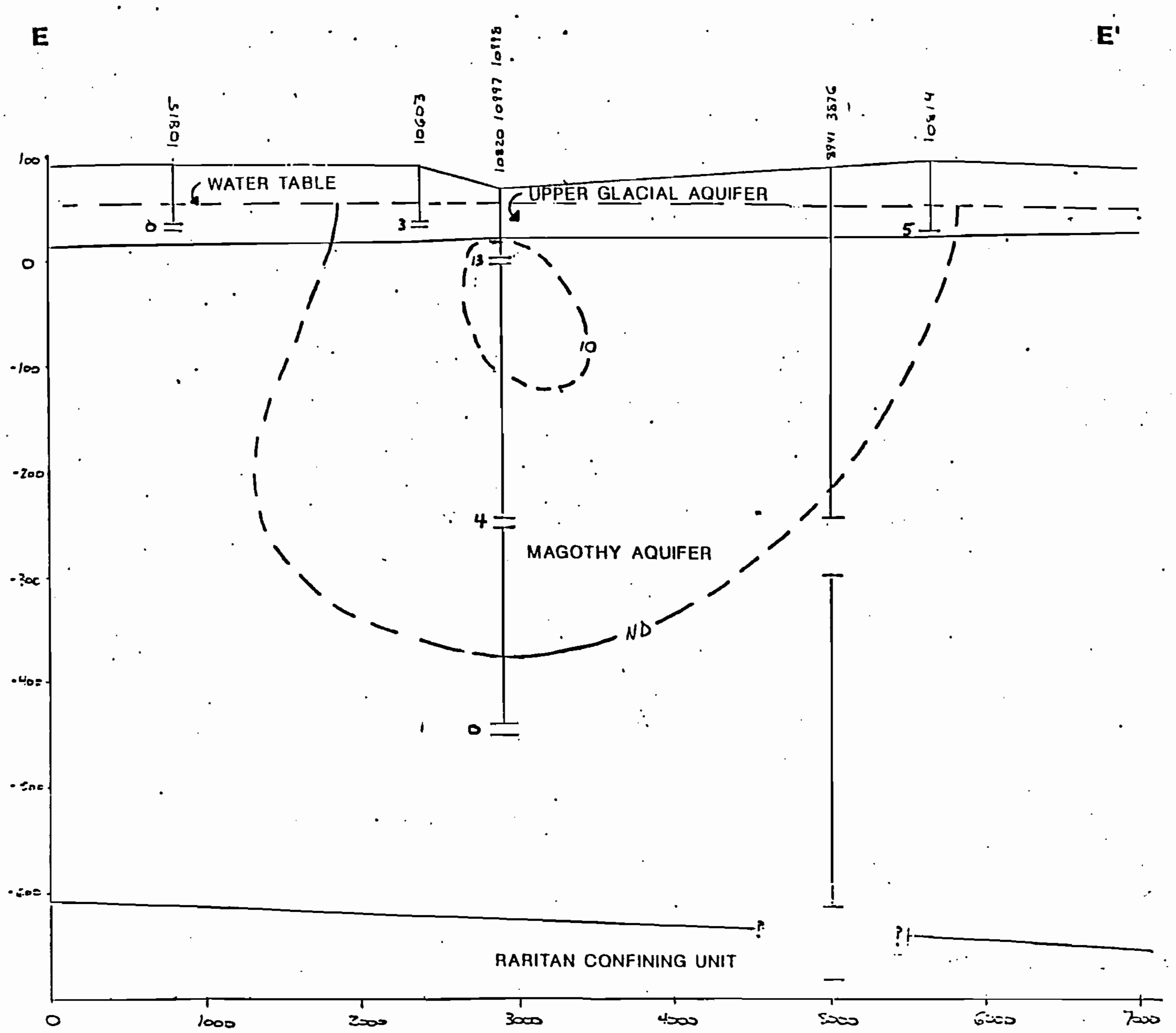
E
E'
10815
10603
10820 10997 10118
3941 3876
10814
WATER TABLE
UPPER GLACIAL AQUIFER
MAGOTHY AQUIFER
RARITAN CONFINING UNIT
6
3
13
10
4
0
5
ND
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100
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-100
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-300
-400
-500
-600
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1000
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5000
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7000

Dispersive spreading occurs beneath the industrial recharge basins where contaminated ground water is returned after use for industrial cooling (table 2). Again, there is a large head difference caused by water-table mounding, but flow paths are emanating from a source rather than converging on a sink.

Table 2 belongs near here.

Once the plume is downgradient of the effects of industrial pumping, contaminant transport is influenced by regional hydraulic gradients. The large variations in contaminant concentration near the sources diminish with distance from the contaminant sources as spreading and dilution lead to more plume uniformity.

Sorption

The two significant factors that can affect the interaction of organic compounds with the aquifer formation are how hydrophobic the compound and the content of organic carbon in the aquifer material. Geologic logs and borehole cuttings from recent drilling activity show that the Magothy aquifer beneath the Bethpage-Hicksville-Levittown area contains several scattered lenses of solid lignite. It was earlier mentioned that the concentration of TCE did not dissipate nearly as rapidly as PCE downgradient of the industrial zone. PCE is structurally similar to TCE except for an additional chlorine atom that makes it less soluble and more hydrophobic than TCE. It is therefore more prone than TCE to be adsorbed by an organic solid such as lignite.

Table 2.--Organic chemical analysis of recharge basin #6 samples in the fall of 1986 and 1987

[Concentrations are in micrograms per liter. NA, not analyzed.]

Constituent	Fall 1986 concentration	Fall 1987 concentration
Trichloroethylene	450	110
Tetrachloroethylene	30	8
1,1,1-Trichloroethane	3	2
C&T 1,2-dichloroethylene	0	0
Vinyl chloride	NA	3
1,1-Dichloroethane	0	0
Benzene	0	0

Biological/Chemical Mechanisms

Assessment of how degradation processes in ground water affect contaminant concentrations and distributions is beyond the scope of this study. In addition to conflicting and inconclusive studies of transformation processes and the factors that influence them, it is impossible to determine rates of transformation due to insufficient knowledge of when, where, and at what concentration the contaminants entered the ground-water system. Pumping and recharging stresses to the ground-water system greatly complicate the tracking of flow direction and the rate of contaminated ground-water movement. Therefore, biodegradation and chemical reactions will be discussed in general terms to review the processes that may be responsible for observations regarding the fate of organic contaminants in ground water underlying the study area.

In recent years many studies have uncovered evidence that biological transformation of organic compounds in ground water can occur through the action of microorganisms attached to solid surfaces within the aquifer. The attached bacteria obtain energy and nutrients from the solute as it passes through the porous medium and may form biofilms as their numbers increase (Mackay and others, 1985).

The two most commonly encountered contaminants in this study, TCE and PCE, were found throughout most of the industrial area. As these contaminants moved downgradient off of the industrial site, TCE concentration in the plume remained as high as several hundred µg/L. PCE concentrations decreased significantly with the highest downgradient concentration being only 13 µg/L. This occurrence is mentioned because of the fact that tetrachloroethylene may undergo sequential reductive dehalogenation to TCE, dichloroethylene, and finally vinyl chloride (U.S. Environmental Protection Agency, 1988). Vinyl chloride has also been detected in areas where it was not used or disposed of, indicating that it may be an intermediate compound formed by biotransformation. Chemical reactions such as hydrolysis and oxidation can affect organic contaminants but most chemical reactions in ground water are believed to be slow compared with transformations mediated by microorganisms (Mackay and others, 1985).

INORGANIC CONSTITUENTS

Ambient Conditions

The native fresh ground water of Long Island generally contains only small amounts of dissolved mineral matter. Prior to development, dissolved-solids content of ground water changed very little as it moved through the ground-water reservoir because the aquifer formation deposits were relatively inert chemically (Franke and McClymonds, 1972). In Nassau County, sewage disposal is cited as the primary source of inorganic constituents such as nitrate, ammonia, calcium, sodium, sulfate, and chloride in the ground-water system. Nitrate-enriched ground water has received much attention in past years because it poses a potential health threat (Ragone and others, 1981). An average nitrate content greater than 1 mg/L (milligram per liter) is considered to be due to human activities (Perlmutter and Koch, 1972).

Upper Glacial Aquifer

The inorganic chemical quality of ground water in the Bethpage-Hicksville-Levittown area has been altered by human activities to the point that ambient water in the upper glacial aquifer differs substantially from native water. Return of wastewater from cesspools and septic tanks prior to sewering, and infiltration of dissolved road salts and lawn fertilizers all contribute to the deterioration of ground-water quality. The high concentrations of dissolved substances from these activities is shown by high specific conductance values, indicating elevated levels of dissolved ionic substances in the ground water. Nitrogen occurs primarily in the form of nitrate in the Bethpage-Hicksville-Levittown area. Nitrogen loading has substantially decreased as cesspools and septic tanks have been phased out of the area. Ammonia in the ground water has undergone oxidation to nitrate, a process which occurs in the presence of dissolved oxygen.

Magothy Aquifer

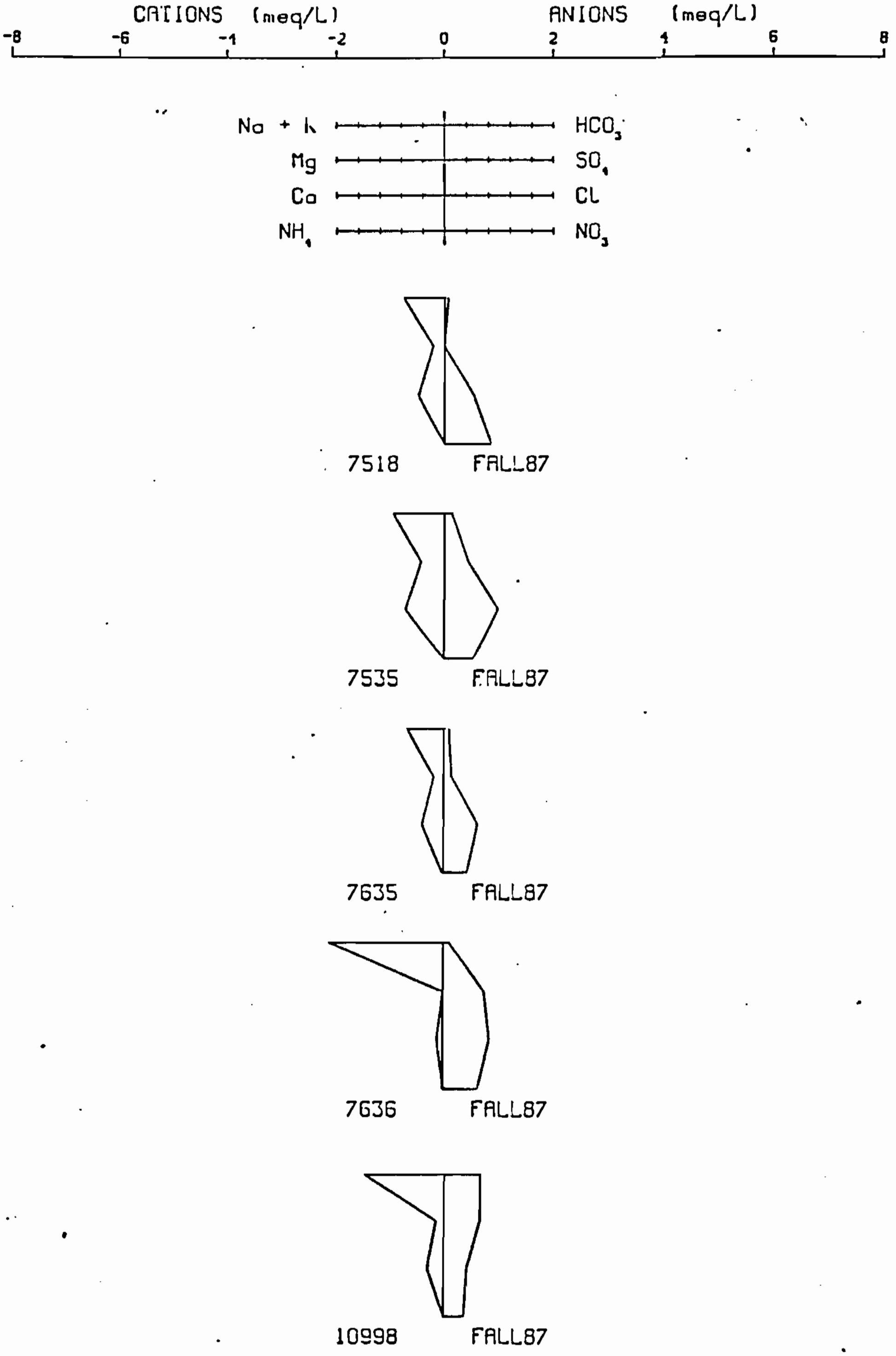
Concentrations of inorganic constituents showed a progressive decrease with increasing depth in the ground-water reservoir (fig. 13). Although closer in chemical composition to native ground water than upper glacial water, Magothy aquifer water at or near the industrial zone nevertheless had elevated nitrate concentrations and levels of total dissolved solids exceeding 50 mg/L. Furthermore, the dominant cations and anions were present in higher concentrations than were found in ground-water samples believed to represent natural chemical quality of Magothy aquifer water (Cohen and others, 1968).

Figure 13 (caption on next page) belongs near here.

Figure 13.--Concentration of chemical constituents of water from selected Magothy aquifer wells showing conditions in: A. Intermediate zone. B. Deep zone.

Concentrations of chemical constituents of water from selected Magothy aquifer wells showing conditions in the a) intermediate zone and b) deep zone.

Fig 13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Mg
SO4
Ca
CL
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NO3
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7535
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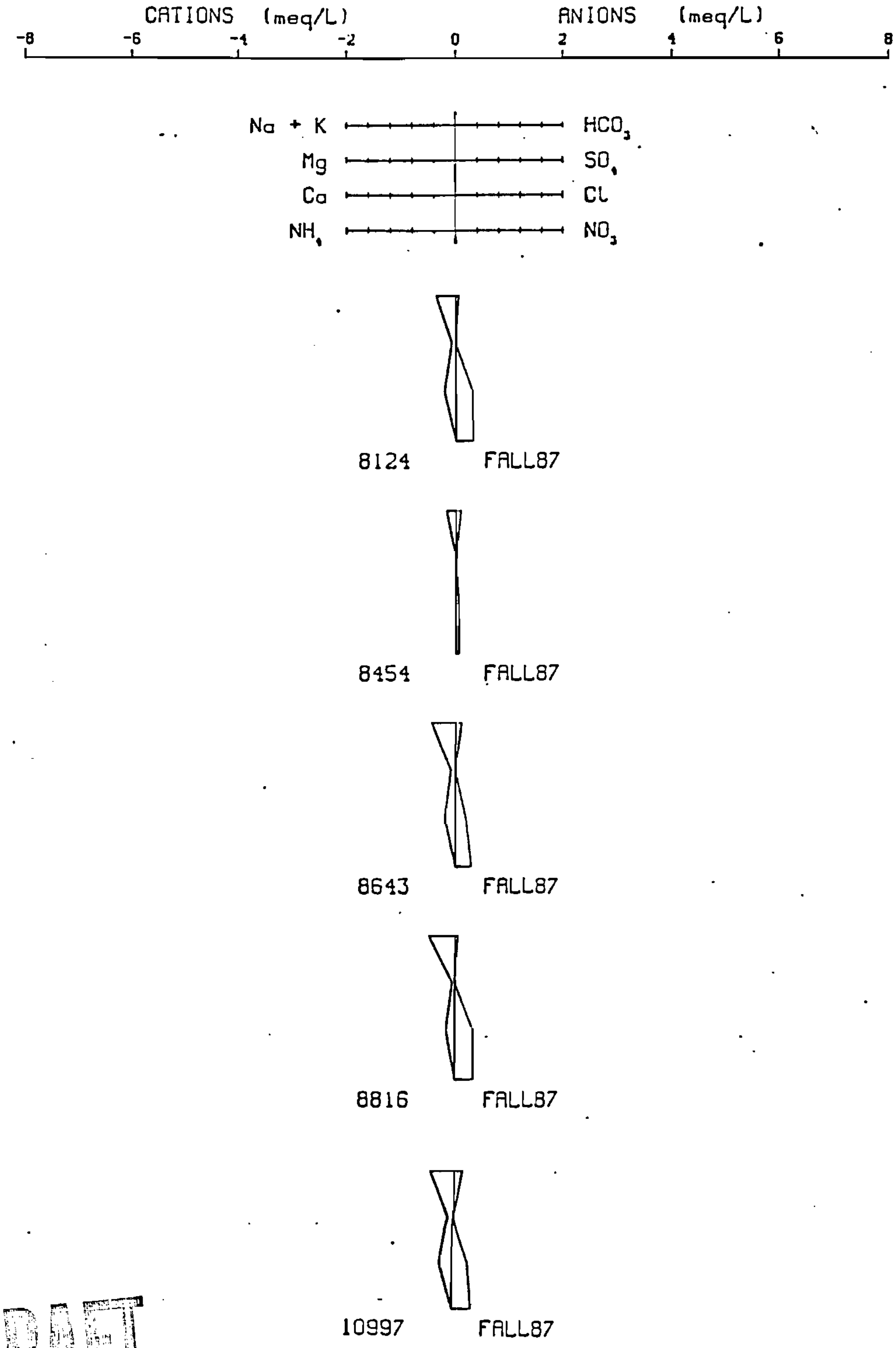
10998
FALL87

A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ANIONS (meq/L)
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6
8
Na + K
Mg
Ca
NH_4
HCO_3
SO_4
CL
NO_3
8124 FALL87
8454 FALL87
8643 FALL87
8816 FALL87
10997 FALL87

B

Effect of Industry on Inorganic Water Quality

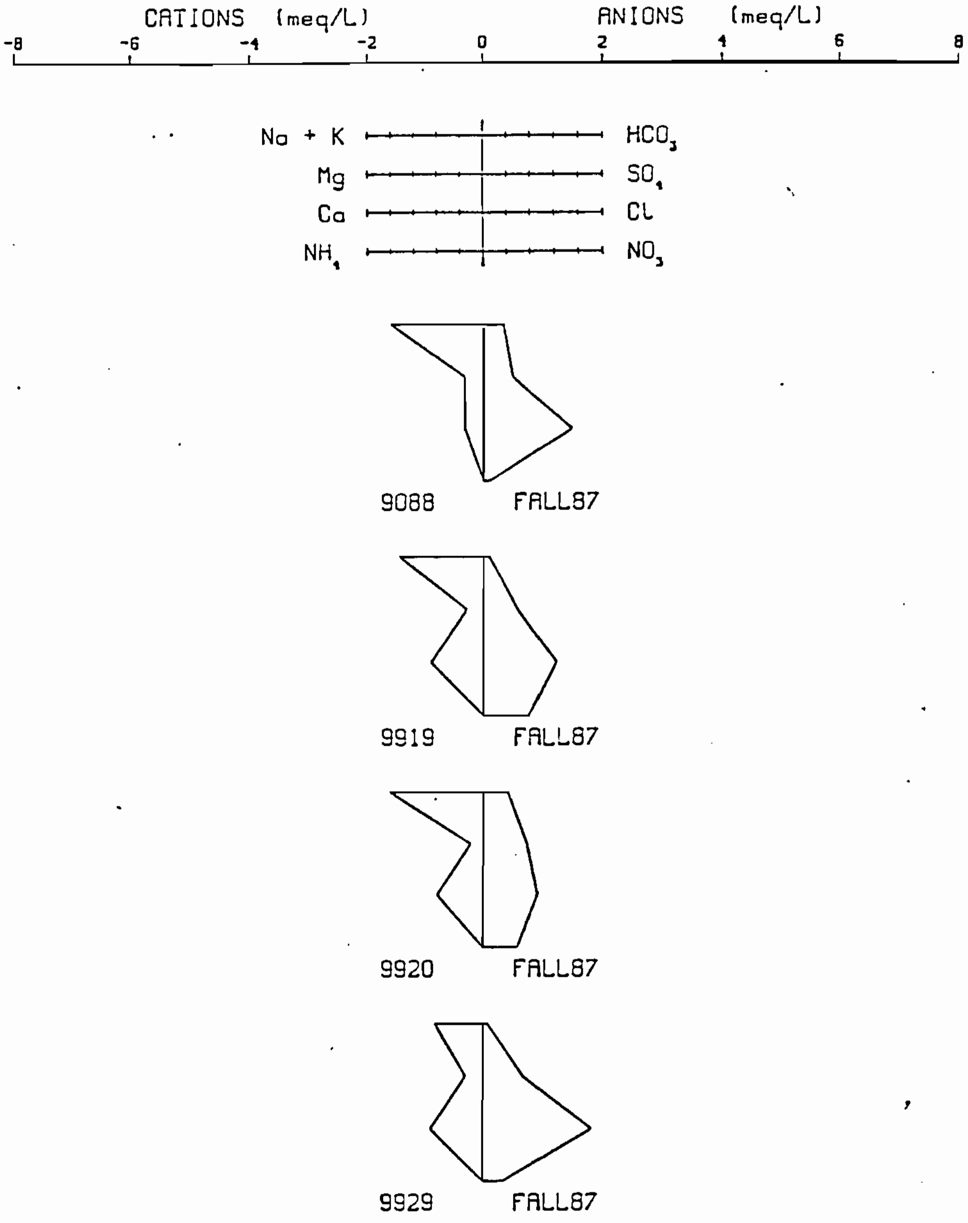
Analyses of inorganic ground-water quality from the water table aquifer and Magothy aquifer show that industrial activities have altered the chemical character of ground water. Water-quality samples from the water-table aquifer can be differentiated by analyzing how human activities alter the major ionic components of ground water (fig. 14). Pumping of Magothy aquifer water and subsequent return to industrial recharge basins alter the inorganic chemical composition of the water-table aquifer in the vicinity of the basins. Recharging of non-contact cooling water mixes with and, to a large extent, displaces ground water for several feet down into the upper glacial aquifer (fig. 14B). Wells screened approximately 20 ft below the water-table surface on the downgradient side of industrial recharge basins show inorganic constituents content more similar to ambient conditions in the Magothy aquifer. Vertical gradients produced by water-table mounding beneath the basins act to push upper glacial water with high inorganics content down below the recharged Magothy aquifer water.

Figure 14 (caption on next page) belongs near here.

Figure 14.--Concentration of chemical constituents of water from selected water-table wells showing: A. Background conditions. B. Mixing and displacement by recharged Magothy aquifer water. C. Contamination from past sewage-disposal operations.

Concentration of chemical constituents of water from selected water table wells showing a) background conditions, ~~b)~~ c) contamination from past sewage disposal operations, ~~and~~ ~~c)~~ b) mixing and displacement by recharged Magothy aquifer water, and

Fig 14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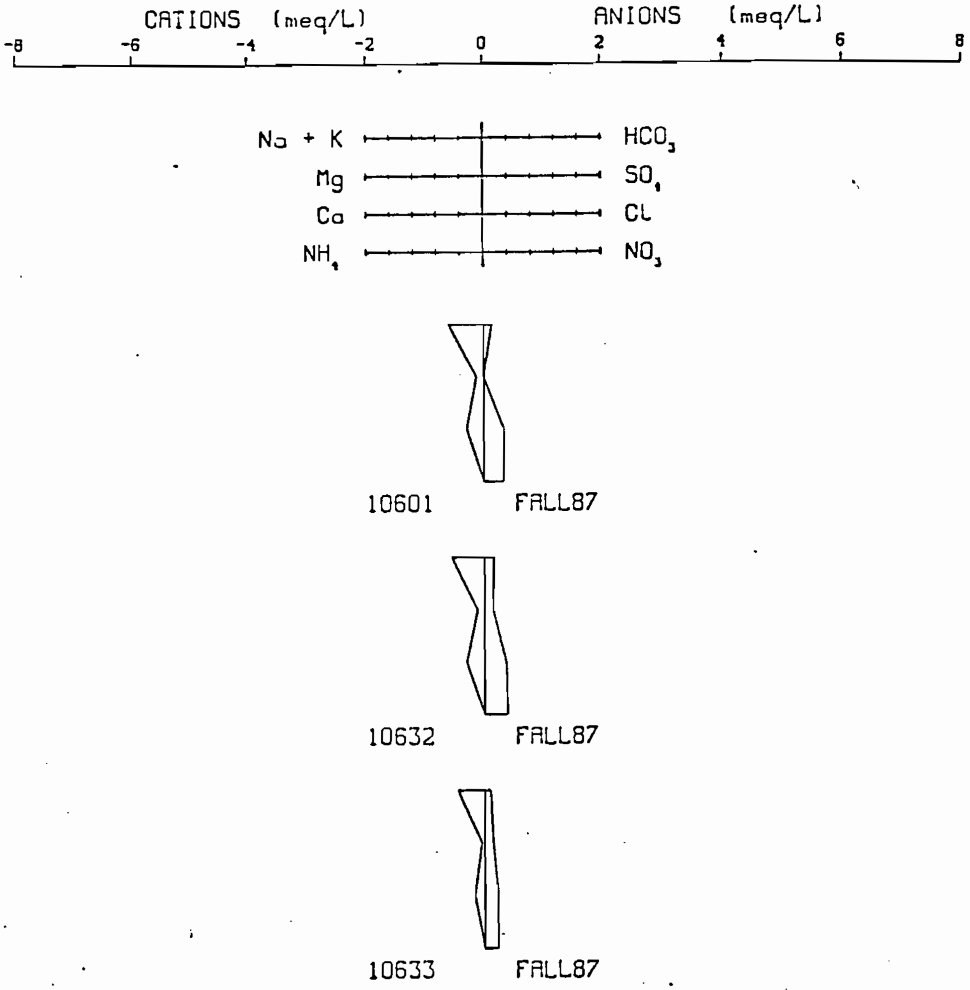
FALL87

A



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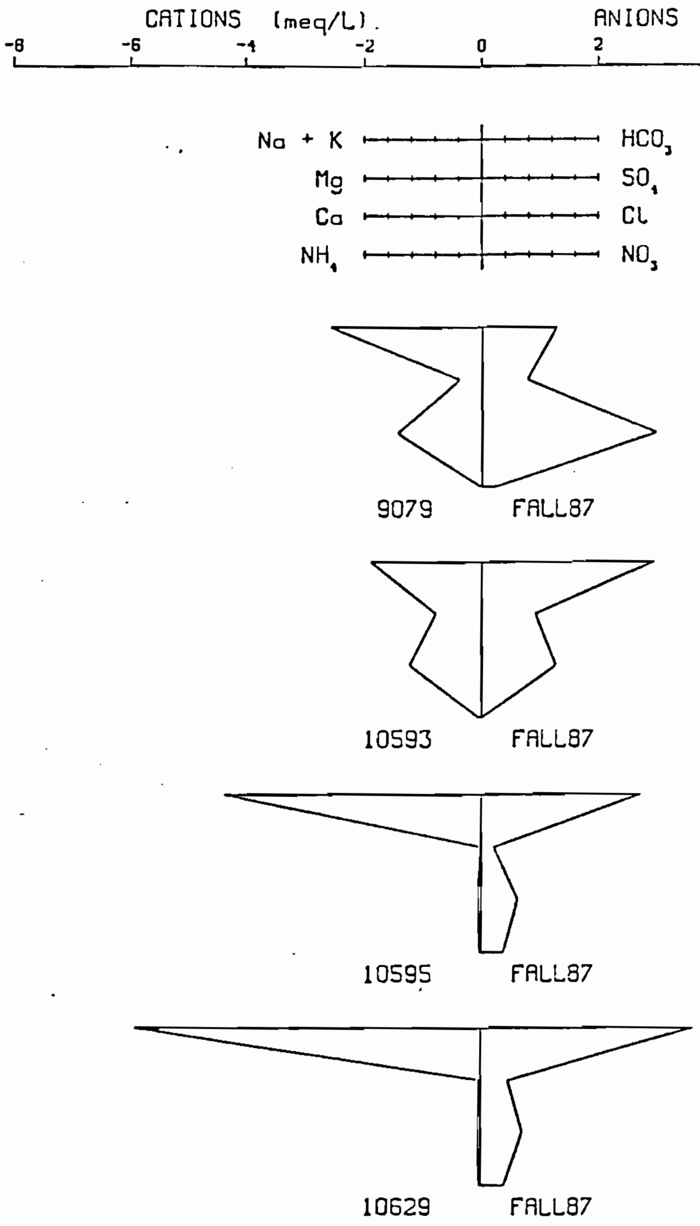
~~C~~
B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HCO$_3$
SO$_4$
Cl
NO$_3$
9079
FALL87
10593
FALL87
10595
FALL87
10629
FALL87

~~B~~
C

Farther downgradient from the basins along the southern border of the industrial zone, a gradual deterioration of water quality occurs, as a smaller percentage of ambient water has been mixed and diluted with ground-water recharge originating from those basins. A well doublet was installed along a flow path about 5,000 ft downgradient of the basins with screens set at depths of 15 ft and 90 ft below the water-table surface. The dissolved-solids content of the deeper well is almost 60 percent higher than that of the shallow well. This is an indication that regional gradients are moving contaminants downward in the water-table aquifer once beyond the influence of industrial pumping and recharging.

Samples from a few wells that were installed near the plastics manufacturer to the west and aerospace firm to the east show contamination typical of treated sewage (fig. 14C). The wells are downgradient of sites where sanitary-sewage disposal operations were located. Treated effluent was disposed of in unlined seepage basins until about 1980. Ground-water samples from wells N10595 and N10629 near the aerospace firm showed especially high levels of total dissolved solids, pH, sodium, and bicarbonate. The high total dissolved solids content and sodium bicarbonate nature of this water distinguishes it from ambient water-table conditions (sodium chloride water). These are the same wells that had the highest concentrations of volatile organic compounds. Despite this correspondence and some insights into ground-water displacement from industrial activities, inorganic constituents were not a good indicator of VOC distribution.

SUMMARY AND CONCLUSIONS

Ground-water contamination has resulted from use and disposal of synthetic organic contaminants in an industrial-zoned area that lies 1.5 mi south of the ground-water divide in east-central Nassau County, Long Island. Bi-annual samples were collected in the spring and fall of 1986 and 1987 and analyzed for volatile organic compounds and inorganic constituents. The VOC plume in the water-table aquifer is approximately 5,700 ft wide and 12,000 ft long. The plume, more than 500 ft thick, has also moved into the underlying Magothy aquifer, from which 14 industrial wells pumped an average of 8.05 Mgal/d in 1987. Most of the water is used for cooling purposes and is then returned to recharge basins. Although the chemical character is unaltered by use for cooling, the wells pump water from an already contaminated Magothy aquifer and subsequently discharge that water into on-site recharge basins. Cones of depression at pumping wells and water-table mounds beneath recharge basins have altered the natural ground-water flow system by dramatically increasing the vertical component of flow beneath the industrial zone.

TCE and PCE were the most frequently detected contaminants, with concentrations that exceed 1,000 µg/L in some locations. Delineation of the occurrence of four other commonly encountered VOCs indicate that there are several contaminant sources in the area. Hydrochemical sections show the occurrence of contaminants at depth, that, under regional ground-water-flow directions would be upgradient of known contamination at the water table. This indicates that advective movement is the predominant mechanism of contaminant transport in the study area, and that in response to the stresses of pumping and recharge, local hydraulic gradients are altered so that flow paths converge on pumping wells. The areal extent of the plume decreases with depth because of the drawdown near pumping wells. The result is that the plume moves vertically downward and east to west as it moves downgradient in the direction of regional flow. Other transport phenomena become insignificant in comparison to the effect of advective movement, although dispersion beneath recharge basins results in spreading of the plume at the water table.

The inorganic chemical quality of ground water in the study area has been altered by human activities to the point that ambient water differs substantially from native ground-water quality. Concentrations of inorganic constituents in ground water in and around the industrial zone show a progressive decrease with depth into the ground-water reservoir. The major effect of industry on inorganic ground-water quality is the mixing of recharged Magothy aquifer water with upper glacial water in the vicinity of the basins. In addition, a few wells downgradient of inactive sewage-treatment operations show elevated levels of dissolved solids, sodium, and bicarbonate.

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Appendix 1. Laboratory organic constituent analysis from the Bethpage-Hicksville-Levittown area, fall 1987

[°, degrees; ', minutes; ", seconds; <, less than; NR, no report due to technical difficulty. All values are in micrograms per liter.]

Well number	Latitude ° ' "	Longitude ° ' "	Date of sample yy mm dd	Methylene chloride[1]	Cis- & Trans-1,2-dichloro-ethylene	1,1-dichloro-ethane	Chloro-form	1,1,1-trichloro-ethane	Carbon tetra-chloride
A. Observation Wells									
N9079	404508	733026	87/11/02	<8	22	<4	<1	<1	<1
N9088	404413	732823	87/10/30	<8	<5	<1	<1	<1	<1
N9411	404409	733051	87/11/04	<8	<5	NR	<1	<1	<1
N9654	404330	732804	87/10/27	<7	<9	<5	<1	5	<1
N9661	404338	732804	87/10/26	<7	<9	<5	<1	<1	<1
N9667	404320	733056	87/11/04	<8	<5	NR	<1	6	<1
N9918	404434	733057	87/11/11	<8	<5	<5	<1	<1	<1
N9919	404535	733146	87/12/14	<10	<8	<5	<1	<2	<1
N9920	404606	733029	87/12/03	<10	<8	<5	<1	1	<1
N9921	404416	732951	87/12/10	<10	<8	<5	<1	<1	<1
N9922	404340	732951	87/10/27	<7	<9	<5	<1	<1	<1
N9929	404339	732840	87/10/26	<7	<9	<5	<1	<1	<1
N9931	404502	732917	87/11/10	<8	<5	<4	NR	1	1
N9932	404602	732920	87/11/03	<8	<5	NR	4	10	<1
N10588	404457	733121	87/11/20	<8	<5	<4	<1	<1	<1
N10589	404524	733051	87/11/20	<8	<5	<4	<1	2	<1
N10590	404546	732937	87/12/07	<10	<8	<5	<1	<1	<1
N10591	404539	732914	87/12/08	<10	<8	<5	<1	4	<1
N10592	404520	732833	87/12/09	<10	<8	<5	<1	<1	<1
N10593	404520	733014	87/12/08	<10	<8	<5	<1	<1	<1
N10594	404514	733007	87/12/08	<10	91	<5	<1	<1	<1
N10595	404502	732939	87/11/19	120	120	52	5	320	<1
N10596	404500	733013	87/11/04	20	<5	83	<1	100	<1
N10597	404451	733022	87/11/05	<8	<5	<4	<1	<1	<1
N10598	404444	733017	87/12/08	30	<8	<5	<1	<1	<1
N10599	404432	732949	87/11/05	<8	6	<4	<1	5	<1
N10600	404424	733001	87/11/03	<8	<5	<4	<1	2	<1
N10601	404425	732927	87/11/02	<8	<5	NR	<1	<1	<1
N10602	404403	732935	87/10/28	<8	<5	<4	<1	<1	<1
N10603	404356	732952	87/10/27	<7	<9	8	1	10	<1

Appendix 1. Laboratory organic constituent analysis from the Bethpage-Hicksville-Levittown area, fall 1987--continued

Well number	Date of sample	Trichloro-ethylene	Tetra-chloro ethylene	Vinyl chloride	Benzene	Toluene	Chloro-benzene	Xylene
N9079	87/11/02	14	1	<1.0	150	4	<3	17
N9088	87/10/30	<1	<1	<1.0	<3	<3	<3	<6
N9411	87/11/04	<1	<1	<1.0	<3	<3	<3	<6
N9654	87/10/27	<1	<1	<1.0	<3	<3	<3	<6
N9661	87/10/26	1	<1	<1.0	<3	<3	<3	<6
N9667	87/11/04	<1	2	<1.0	<3	<3	<3	<6
N9918	87/11/11	<1	<1	<1.0	<3	<3	<3	<6
N9919	87/12/14	<1	79	<1.0	<3	<3	<3	<7
N9920	87/12/03	<1	<1	<1.0	<3	<3	<3	<6
N9921	87/12/10	52	3	<1.0	200	<3	<3	88
N9922	87/10/27	<1	<1	1.0	<3	<3	<3	<6
N9929	87/10/26	<1	<1	1.0	<3	<3	<3	<6
N9931	87/11/10	1	2	<1.0	<3	<3	<3	<6
N9932	87/11/03	<1	6	<1.0	<3	<3	<3	<6
N10588	87/11/20	<1	<1	NR	<3	<3	<3	<6
N10589	87/11/20	<1	1	NR	<3	<3	<3	<6
N10590	87/12/07	<1	<1	<1.0	<3	<3	<3	<6
N10591	87/12/08	<1	<1	<1.0	<3	<3	<3	<6
N10592	87/12/09	<1	<1	<1.0	<3	<3	<3	<6
N10593	87/12/08	3	<1	280.0	<3	<3	<3	<6
N10594	87/12/08	180	<1	1.0	<3	<3	<3	<7
N10595	87/11/19	600	1,500	NR	<3	<3	<3	<6
N10596	87/11/04	<1	4	21.0	<3	<3	<3	<6
N10597	87/11/05	1	30	<1.0	<3	<3	<3	<6
N10598	87/11/05	2	240	35.0	<3	<3	<3	<7
N10599	87/11/05	800	20	2.0	<3	<3	<3	<7
N10600	87/11/03	500	14	<1.0	<3	<3	<3	<6
N10601	87/11/02	53	9	2.0	<3	<3	<3	<6
N10602	87/10/28	28	1	<1.0	<3	<3	<3	<6
N10603	87/10/27	52	3	<1.0	<3	<3	<3	<6

Appendix 1. Laboratory organic constituent analysis from the Bethpage-Hicksville-Levittown area, fall 1987--continued

Well number	Latitude ° ' "	Longitude ° ' "	Date of sample yy mm dd	Methylene chloride[1]	Cis- & Trans- 1,2-dichloro-ethylene	1,1-dichloro-ethane	Chloro-form	1,1,1-trichloro-ethane	Carbon tetra-chloride
N10623	404508	732933	87/11/19	<8	9	4	1	24	<1
N10625	404455	732932	87/11/19	<8	<5	<4	<2	7	<1
N10626	404445	732912	87/11/06	<8	<5	<4	<1	<1	<1
N10627	404415	732943	87/12/17	<10	<8	<5	<1	2	<1
N10628	404419	732900	87/11/03	<8	<5	<5	<4	<1	<1
N10629	404502	732939	87/11/18	52	540	200	4	960	<1
N10630	404451	733022	87/12/17	<10	<8	<5	<1	1	<1
N10631	404427	732947	87/11/05	<8	<5	<4	<1	7	<1
N10632	404425	732936	87/11/02	<8	<5	NR	<1	1	<1
N10633	404422	732919	87/11/03	<8	<5	<4	<1	<1	<1
N10634	404413	732928	87/10/28	<8	<5	<4	<1	2	<1
N10635	404402	732943	87/10/27	<7	<9	<5	<1	<1	<1
N10636	404424	733020	87/11/03	<8	<5	7	<1	3	<1
N10812	404538	733012	87/11/20	<8	<5	<4	<1	<1	<1
N10813	404413	733007	87/10/27	<7	<9	<5	2	2	<1
N10814	404356	732909	87/10/23	<7	<9	<5	<5	4	<1
N10815	404353	733012	87/12/09	<10	<8	<5	<1	1	<1
N10816	404336	732921	87/10/22	<7	<9	18	1	18	<1
N10817	404336	732921	87/10/22	<7	<9	25	<1	22	<1
N10818	404347	732918	87/10/23	<7	<9	<5	<1	2	<1
N10820	404354	732945	87/12/07	<10	<8	8	<1	10	<1
N10821	404401	732857	87/12/09	<10	<8	<5	<1	<1	<1
N10997	404354	732945	87/12/11	<10	<8	<5	<1	<1	<1
N10998	404354	732945	87/12/10	29	10	8	1	15	<1
N10999	404331	732944	87/12/21	<10	<8	<5	<1	<1	<1
N11000	404331	732944	87/12/14	<10	<8	<5	1	2	<1

Appendix 1. Laboratory organic constituent analysis from the Bethpage-Hicksville-Levittown area, fall 1987--continued

Well number	Date of sample	Trichloro-ethylene	Tetra-chloro ethylene	Vinyl chloride	Benzene	Toluene	Chloro-benzene	Xylene
N10623	87/11/19	40	47	3.0	<3	<3	<3	<6
N10625	87/11/19	20	6	<1.0	<3	<3	<3	<6
N10626	87/11/06	<1	<1	<1.0	<3	<3	<3	<6
N10627	87/12/17	550	20	10	<3	<3	<3	<7
N10628	87/11/03	<1	<1	<1.0	<3	<3	<3	<6
N10629	87/11/18	930	2,300	75.0	<3	<3	<3	<6
N10630	87/12/17	1	4	<1.0	<3	<3	<3	<7
N10631	87/11/05	70	6	3.0	<3	<3	<3	<6
N10632	87/11/02	59	10	2.0	<3	<3	<3	<6
N10633	87/11/03	56	5	1.0	<3	<3	<3	<6
N10634	87/10/28	71	10	2.0	<3	<3	<3	<6
N10635	87/10/27	21	2	2.0	<3	<3	<3	<6
N10636	87/11/03	<1	<1	<1.0	<3	<3	<3	<6
N10812	87/11/20	<1	7	<1.0	<3	<3	<3	<6
N10813	87/10/27	7	1	<1.0	<3	<3	<3	<6
N10814	87/10/23	85	5	2.0	<3	<3	<3	<6
N10815	87/12/09	<1	<1	<1.0	<3	<3	<3	<6
N10816	87/10/22	56	2	5.0	<3	<3	<3	<6
N10817	87/10/22	22	<1	<1.0	<3	<3	<3	<6
N10818	87/10/23	36	2	<1.0	<3	<3	<3	<6
N10820	87/12/07	280	13	9.0	<3	<3	<3	<7
N10821	87/12/09	9	<1	1.0	<3	<3	<3	<7
N10997	87/12/11	230	<1	8.0	<3	<3	<3	<7
N10998	87/12/10	200	4	28.0	<3	<3	<3	<7
N10999	87/12/21	<1	<1	<1.0	<3	<3	<3	<7
N11000	87/12/14	6	1	<1.0	<3	<3	<3	<7

Appendix 1. Laboratory organic constituent analysis from the Bethpage-Hicksville-Levittown area, fall 1987--continued

Well number	Latitude ° ' "	Longitude ° ' "	Date of sample yy mm dd	Methylene chloride[1]	Cis- & Trans 1,2-dichloro-ethylene	1,1-dichloro-ethane	Chloro-form	1,1,1-trichloro-ethane	Carbon tetra-chloride
				B. Industrial Wells					
N7518	404535	732938	87/11/10	8	<5	<4	<1	7	<1
N7535	404518	733000	87/11/13	NR	<5	<4	2	88	<1
N7536	404518	732953	87/11/13	26	<5	<4	<1	52	<1
N7635	404459	733004	87/11/10	58	17	<4	<1	20	<1
N7636	404517	732949	87/11/13	<8	<5	<4	<1	5	<1
N7637	404516	732941	87/11/10	<8	<5	<4	<1	2	<1
N8124	404445	732959	87/11/13	44	9	<4	<1	1	<1
N8154	404454	732952	87/11/10	46	10	<4	<1	11	<1
N8454	404524	732952	87/11/10	<8	<5	<4	<1	<1	<1
N8816	404523	732941	87/11/13	<8	<5	<4	<1	4	<1
N8643	404513	732957	87/11/10	<8	10	<4	<1	1	<1

Well number	Date of sample	Trichloro-ethylene	Tetra-chloro ethylene	Vinyl chloride	Benzene	Toluene	Chloro-benzene	Xylene
N7518	87/11/10	8	<1	6.0	<3	<3	<3	<6
N7535	87/11/13	65	120	93.0	<3	<3	<3	<6
N7536	87/11/13	79	5	3.0	<3	<3	<3	<6
N7635	87/11/10	1,200	110	25.0	<3	<3	<3	<6
N7636	87/11/13	42	6	2.0	<3	<3	<3	<6
N7637	87/11/10	17	7	1.0	<3	<3	<3	<6
N8124	87/11/13	170	34	NR	<3	<3	<3	<6
N8154	87/11/10	770	37	39.0	<3	<3	<3	<6
N8454	87/11/10	<1	<1	<1.0	<3	<3	<3	<6
N8816	87/11/13	12	3	1.0	<3	<3	<3	<6
N8643	87/11/10	43	130	27.0	<3	<3	<3	<6

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[1] This value is a sum of the values for the constituents methylene chloride, 1,1-dichloroethylene, and 1,1,2-trichlorotrifluoroethane.

Appendix 2.--Laboratory inorganic constituent analysis from the Bethpage-Hicksville-Levittown area, fall 1987.

[°, degrees; ', minutes; ", seconds; deg C, degrees Celsius; µmhos/cm, micromhos per centimeter; mg/L, milligrams per liter]

Well number	Latitude ° ' "	Longitude ° ' "	Date of sample yy mm dd	Temperature (deg C)	Specific conductance (µmhos/cm)	pH	Alkalinity, total as $CaCO_3$ (mg/L)	Total dissolved solids (mg/L)	Ammonia as N (mg/L)	Nitrit as N (mg/L)
				A. Observation Wells						
N9079	404508	733026	87/11/02	15.1	628	5.7	64	319	0.29	0.272
N9088	404413	732823	87/10/30	13.8	271	5.0	17	154	0.04	0.016
N9411	404409	733051	87/11/04	14.6	462	5.8	52	266	0.00	0.103
N9654	404330	732804	87/10/27	15.1	330	5.5	17	217	0.73	0.010
N9661	404338	732804	87/10/26	12.1	372	6.3	12	163	0.07	0.005
N9667	404320	733056	87/11/04	14.9	269	5.1	16	159	0.03	0.005
N9918	404434	733057	87/11/11	14.9	127	4.5	3	68	0.00	0.002
N9919	404535	733146	87/12/14	14.9	295	5.0	5	193	0.00	0.000
N9920	404606	733029	87/12/03	14.6	311	5.8	21	182	0.06	0.010
N9921	404416	732951	87/12/10	16.1	594	5.7	40	229	0.14	0.372
N9922	404340	732951	87/10/27	14.2	456	4.9	7	254	0.00	0.000
N9929	404339	732840	87/10/26	14.1	341	5.1	4	177	0.00	0.001
N9931	404502	732917	87/11/10	16.9	251	5.3	16	133	0.05	0.001
N9932	404602	732920	87/11/03	14.1	316	5.0	17	202	0.00	0.001
N10588	404457	733121	87/11/20	14.4	76	5.4	5	43	0.00	0.000
N10589	404524	733051	87/11/20	13.0	301	5.4	10	173	0.05	0.010
N10590	404546	732937	87/12/07	12.7	63	6.1	7	31	0.00	0.008
N10591	404539	732914	87/12/08	13.4	234	6.0	8	149	0.00	0.003
N10592	404520	732833	87/12/09	13.2	223	4.8	2	111	0.78	0.000
N10593	404520	733014	87/12/08	15.7	540	6.6	148	307	0.05	0.011
N10594	404514	733007	87/12/08	13.3	363	5.6	13	185	0.42	0.009
N10595	404502	732939	87/11/19	15.9	490	10.3	137	668	0.17	0.015
N10596	404500	733013	87/11/04	18.2	185	5.2	16	99	0.32	0.013
N10597	404451	733022	87/11/05	16.5	236	5.2	13	134	0.02	0.066
N10598	404444	733017	87/12/08	14.8	167	4.7	6	96	0.07	0.003
N10599	404432	732949	87/11/05	16.8	126	6.0	7	73	0.06	0.008
N10600	404424	733001	87/11/03	16.0	179	5.3	10	105	0.00	0.060
N10601	404425	732927	87/11/02	21.4	118	5.6	7	67	0.03	0.005
N10602	404403	732935	87/10/28	15.2	214	5.2	11	133	0.03	0.010
N10603	404356	732952	87/10/27	14.7	295	5.4	15	189	0.00	0.011

Appendix 2.--Laboratory inorganic constituent analysis from the Bethpage-Hicksville-Levittown area, fall 1987--continued.

Well number	Sample date yy mm dd	Nitrate as N (mg/L)	Calcium (Ca) (mg/L)	Magnesium (Mg) (mg/L)	Sodium (Na) (mg/L)	Potassium (K) (mg/L)	Sulfate (SO_4) (mg/L)	Dissolved iron (Fe) (mg/L)	Dissolved manganese (Mn) (mg/L)
N9079	87/11/02	3.0	29.0	4.7	57.0	4.2	37	8.80	18.00
N9088	87/10/30	1.5	6.4	4.0	36.0	2.0	24	6.10	0.15
N9411	87/11/04	7.7	18.0	2.5	68.0	3.2	43	0.00	0.00
N9654	87/10/27	13.0	12.0	1.5	4.0	5.2	29	0.91	1.30
N9661	87/10/26	1.2	3.1	5.0	27.0	2.2	<5	0.44	0.06
N9667	87/11/04	7.7	15.0	2.2	28.0	3.2	24	1.50	0.73
N9918	87/11/11	4.9	7.9	1.8	6.0	2.0	6	0.05	0.07
N9919	87/12/14	11.0	18.0	3.5	31.0	4.6	31	0.25	0.26
N9920	87/12/03	8.3	16.0	2.7	35.0	4.0	36	1.10	1.10
N9921	87/12/10	1.7	25.0	4.8	78.0	4.0	46	10.00	0.31
N9922	87/10/27	6.6	20.0	2.5	62.0	3.8	23	0.37	0.53
N9929	87/10/26	4.7	18.0	3.7	18.0	2.2	33	0.00	0.16
N9931	87/11/10	9.6	14.0	4.4	18.0	4.8	<5	1.50	0.01
N9932	87/11/03	15.0	22.0	6.5	23.0	4.4	30	0.00	0.00
N10588	87/11/20	2.7	1.20	<.1	12.0	1.1	10	0.22	0.00
N10589	87/11/20	8.8	17.0	3.2	25.0	3.9	29	0.76	0.26
N10590	87/12/07	0.6	3.5	0.4	6.0	1.9	<5	1.20	0.16
N10591	87/12/08	9.4	15.0	2.8	20.0	3.9	21	0.20	0.10
N10592	87/12/09	0.9	6.8	2.0	25.0	2.2	15	0.58	0.05
N10593	87/12/08	0.1	25.0	1.9	40.0	6.1	44	41.00	1.90
N10594	87/12/08	2.3	17.0	4.8	34.0	3.3	18	1.60	0.33
N10595	87/11/19	5.3	1.3	0.1	100.0	0.6	10	1.50	0.05
N10596	87/11/04	3.8	11.0	2.6	14.0	1.0	12	2.30	0.38
N10597	87/11/05	7.5	13.0	0.2	22.0	4.1	11	1.60	0.25
N10598	87/11/05	2.9	10.0	4.9	9.0	2.7	26	1.30	0.00
N10599	87/11/05	4.6	7.6	1.2	12.0	2.2	5	0.26	0.00
N10600	87/11/03	6.9	11.0	1.7	14.0	0.2	9	0.81	0.00
N10601	87/11/02	4.6	5.8	1.5	13.0	1.2	<5	0.10	0.00
N10602	87/10/28	5.7	21.0	2.2	14.0	3.4	27	0.62	0.00
N10603	87/10/27	13.0	21.0	4.9	24.0	4.6	31	0.81	0.00

Appendix 2.--Laboratory inorganic constituent analysis from the Bethpage-Hicksville-Levittown area, fall 1987--continued

Well number	Latitude ° ' "	Longitude ° ' "	Date of sample yy mm dd	Temperature (deg C)	Specific conductance (umhos/cm)	pH	Alkalinity, total as $CaCO_3$ (mg/L)	Total dissolved solids (mg/L)	Ammonia as N (mg/L)	Nitrite as N (mg/L)
				A. Observation Wells (continued)						
N10623	404508	732933	87/11/19	14.1	153	6.3	19	782	0.12	0.029
N10625	404455	732932	87/11/19	14.9	270	5.6	8	146	0.00	0.005
N10626	404445	732912	87/11/06	15.0	236	5.4	25	112	0.34	0.040
N10627	404415	732943	87/12/17	16.7	163	-	9	99	0.11	0.024
N10628	404419	732900	87/11/03	12.3	152	5.8	33	83	0.00	0.005
N10629	404502	732939	87/11/18	17.3	645	10.2	181	2,212	0.44	1.52
N10630	404451	733022	87/12/17	14.6	315	-	24	177	6.30	0.010
N10631	404427	732947	87/11/05	16.3	132	6.0	14	75	0.15	0.015
N10632	404425	732936	87/11/02	20.1	121	5.6	8	78	0.00	0.009
N10633	404422	732919	87/11/03	17.3	90	5.5	5	57	0.03	0.021
N10634	404413	732928	87/10/28	16.6	121	5.6	6	77	0.01	0.003
N10635	404402	732943	87/10/27	16.1	353	5.4	27	210	0.02	0.023
N10636	404424	733020	87/11/03	14.1	231	5.8	18	121	0.02	0.012
N10812	404538	733012	87/11/20	13.3	145	5.8	12	89	0.02	0.009
N10813	404413	733007	87/10/27	16.0	204	5.1	10	128	0.03	0.009
N10814	404356	732909	87/10/23	15.7	266	5.3	11	164	0.07	0.042
N10815	404353	733012	87/12/09	13.6	241	5.2	5	185	0.00	0.002
N10816	404336	732921	87/10/22	14.4	317	5.2	10	188	0.13	0.026
N10817	404336	732921	87/10/22	14.2	203	5.1	9	119	0.00	0.004
N10818	404347	732918	87/10/23	14.7	178	6.2	11	101	0.04	0.015
N10820	404354	732945	87/12/07	14.5	321	5.4	12	193	0.89	0.025
N10821	404401	732857	87/12/09	13.9	191	5.1	8	135	0.03	0.003
N10997	404354	732945	87/12/11	12.5	97	6.5	8	63	0.02	0.043
N10998	404354	732945	87/12/10	13.9	247	5.4	33	154	0.00	0.138
N10999	404331	732944	87/12/21	11.9	--	--	7	64	0.00	0.098
N11000	404331	732944	87/12/14	12.9	354	5.5	24	221	0.13	0.510

Appendix 2.--Laboratory inorganic constituent analysis from the Bethpage-Hicksville-Levittown area, fall 1987--continued

Well number	Sample date yy mm dd	Nitrate as N (mg/L)	Calcium (Ca) (mg/L)	Magnesium (Mg) (mg/L)	Sodium (Na) (mg/L)	Potassium (K) (mg/L)	Sulfate (SO_4) (mg/L)	Dissolved iron (Fe) (mg/L)	Dissolved manganese (Mn) (mg/L)
N10623	87/11/19	4.4	7.3	2.3	17.0	1.3	36	0.73	0.06
N10625	87/11/19	4.0	16.0	3.4	20.0	5.4	27	0.71	0.97
N10626	87/11/06	3.6	15.0	3.6	9.0	4.8	15	3.10	0.10
N10627	87/12/17	5.4	5.5	1.1	21.0	1.8	21	-	-
N10628	87/11/03	1.8	1.3	<.1	29.0	0.7	10	0.52	0.00
N10629	87/11/18	5.5	1.3	0.3	135.0	1.2	22	0.66	0.00
N10630	87/12/17	3.4	12.0	4.8	24.0	5.3	43	-	-
N10631	87/11/05	4.6	6.1	1.1	11.0	1.1	5	2.90	0.12
N10632	87/11/02	5.5	6.0	1.4	12.0	1.2	7	0.80	0.06
N10633	87/11/03	3.2	3.4	0.6	9.0	2.5	7	0.07	0.00
N10634	87/10/28	5.4	5.9	1.3	12.0	2.6	7	0.00	0.06
N10635	87/10/27	5.3	16.0	4.0	30.0	5.6	30	5.60	0.35
N10636	87/11/03	2.1	16.0	2.6	18.0	3.0	8	1.40	0.06
N10812	87/11/20	1.2	7.2	3.2	11.0	1.5	28	2.90	0.13
N10813	87/10/27	6.0	16.0	2.1	15.0	4.8	31	0.55	0.17
N10814	87/10/23	15.0	13.0	8.3	12.0	5.2	27	0.15	0.00
N10815	87/12/09	13.0	20.0	2.5	16.0	6.1	35	0.15	1.50
N10816	87/10/22	17.0	20.0	5.3	11.0	7.1	31	0.27	0.00
N10817	87/10/22	5.5	17.0	1.9	6.0	4.7	29	0.21	0.20
N10818	87/10/23	4.0	11.0	3.1	7.0	4.1	25	0.38	0.17
N10820	87/12/07	11.0	16.0	4.4	30.0	5.6	35	1.40	0.00
N10821	87/12/09	7.9	12.0	2.5	16.0	4.9	24	0.46	0.10
N10997	87/12/11	4.9	4.9	1.3	10.0	0.6	<5	2.00	0.00
N10998	87/12/10	5.2	6.2	1.7	34.0	0.9	32	10.00	0.59
N10999	87/12/21	5.3	6.6	1.9	8.0	0.8	<5	-	-
N11000	87/12/14	11.0	21.0	7.4	33.0	3.8	32	4.80	0.23

Appendix 2.--Laboratory inorganic constituent analysis from the Bethpage-Hicksville-Levittown area, fall 1987--continued

Well number	Latitude ° ' "	Longitude ° ' "	Date of sample yy mm dd	Temperature (deg C)	Specific conductance (umhos/cm)	pH	Alkalinity, total as $CaCO_3$ (mg/L)	Total dissolved solids (mg/L)	Ammonia as N (mg/L)	Nitrite as N (mg/L)
				B. Industrial Wells						
N7518	404535	732938	87/11/10	12.1	183	5.2	4	113	0.00	0.004
N7535	404518	733000	87/11/13	13.4	259	5.1	7	147	0.12	0.000
N7536	404518	732953	87/11/13	12.1	168	5.1	5	105	0.00	0.000
N7635	404459	733004	87/11/10	13.4	164	5.2	5	94	0.36	0.003
N7636	404517	732949	87/11/13	15.7	282	5.4	5	166	0.00	0.001
N7637	404516	732941	87/11/10	15.4	141	4.6	3	73	0.00	0.000
N8124	404445	732959	87/11/13	14.1	94	5.1	3	54	0.00	0.000
N8154	404454	732952	87/11/10	14.1	108	5.0	6	61	0.15	0.001
N8454	404524	732952	87/11/10	11.7	36	5.3	5	21	0.00	0.003
N8643	404513	732957	87/11/10	12.1	94	5.5	3	58	0.00	0.000
N8816	404523	732941	87/11/13	13.2	100	5.1	6	53	0.00	0.004

Well number	Sample date yy mm dd	Nitrate as N (mg/L)	Calcium (Ca) (mg/L)	Magnesium (Mg) (mg/L)	Sodium (Na) (mg/L)	Potassium (K) (mg/L)	Sulfate (SO_4) (mg/L)	Dissolved iron (Fe) (mg/L)	Dissolved manganese (Mn) (mg/L)
N7518	87/11/10	12.0	9.7	2.5	17.0	0.8	<5	0.08	0.00
N7535	87/11/13	7.5	15.0	5.2	21.0	1.9	21	0.00	0.00
N7536	87/11/13	9.9	7.0	2.0	18.0	0.8	8	0.00	0.00
N7635	87/11/10	6.0	8.1	2.2	15.0	1.1	7	0.22	0.00
N7636	87/11/13	8.9	2.2	<.1	49.0	0.4	36	0.10	0.00
N7637	87/11/10	4.6	4.4	1.0	18.0	0.7	<5	0.06	0.00
N8124	87/11/13	4.5	4.3	0.9	8.0	0.7	<5	0.00	0.00
N8154	87/11/10	4.7	3.9	1.0	12.0	0.7	<5	0.20	0.00
N8454	87/11/10	0.9	0.9	<.1	4.0	0.2	<5	0.10	0.00
N8643	87/11/10	4.2	3.9	1.0	10.0	0.5	<5	0.00	0.00
N8816	87/11/13	4.8	3.3	0.6	11.0	0.5	<5	0.13	0.00