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Ground-water Quality in the Bethpage-Hicksville-Levittown Area, Long Island, New York, with Emphasis on Volatile Organic Compounds

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GROUND-WATER QUALITY IN THE BETHPAGE-HICKSVILLE-LEVITTOWN AREA, LONG ISLAND, NEW YORK, WITH EMPHASIS ON VOLATILE ORGANIC COMPOUNDS

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

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS

Multiply	by	To obtain
	Length	
inch (in)	2.54	centimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Mass	
pound (lb)	0.454	kilogram
	Area	
acre	0.4047	hectare
square foot (ft^2)	0.09294	square meter
square mile (mi^2)	2.59	square kilometer
	Volume	
gallon (gal)	3.785	liter
	Flow	
foot per day (ft/d)	0.3048	meter per day
million gallons per day (Mgal/d)	0.04381	cubic meter per second
gallons per minute (gal/min)	0.06308	liter per second

Equivalent concentration terms

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

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

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Abstract

A plume of contaminated ground water has been delineated within an 11.4-square-mile area in east-central Nassau County, where residential neighborhoods surround an area zoned for industrial use. The industrial zone contains several firms that, in the past, have discharged effluent containing volatile organic compounds into the upper glacial aquifer through onsite recharge basins. The upper glacial aquifer is in direct hydraulic connection with the underlying Magothy aquifer; the first continuous formation that impedes downward movement of ground water is the Raritan confining unit, which is more than 500 feet below sea level.

The chemicals in ground water and their distribution were identified through analysis of water samples collected from 56 monitoring wells and 11 industrial wells in the spring and fall of 1986 and 1987. Trichloroethylene and tetrachloroethylene were found near the water table at concentrations greater than 1,000 micrograms per liter and were detected more than 5,000 feet downgradient of the industrial zone. The distribution of several other volatile organic compounds indicates more than one contaminant source in the industrial area. The plume of contaminated ground water in 1987 was 12,000 feet long, 5,700 feet wide, and more than 500 feet thick.

In 1987, water was pumped from 14 industrial wells, completed in the Magothy aquifer, at an average rate of 8.05 million gallons per day, mainly for cooling purposes. The water was returned chemically unaltered to recharge basins from which it could percolate to the water table. Water-table mounding beneath basins and drawdowns near the pumped wells greatly increase the vertical component of ground-water flow beneath the industrial zone, which has increased the rate of advective movement of contaminated ground water downward toward the screened zones of pumped wells, which are 370 to 560 feet deep in the Magothy aquifer. The concentration of tetrachloroethylene decreases much more rapidly than that of trichloroethylene downgradient of the industrial zone, which indicates that sorption and (or) biodegradation may be occurring. The major effect of industrial activity on inorganic constituents is to decrease the concentration of constituents near the water table in the vicinity of the recharge basins by the addition of water from the Magothy aquifer, where the concentration of inorganic constituents is lower.

INTRODUCTION

Alteration of ground-water quality as a result of urbanization is a problem of growing concern on Long Island, N.Y. The adverse effects of landfill leachate on ground-water quality on Long Island have been documented by Kimmel and Braids (1980) and by Wexler (1988), and contamination of ground water beneath industrial/commercial zoned areas by synthetic organic compounds has been described by Eckhardt and Pearsall (1989), Fischer and others (1987), and Ali (1982). Ground-water contamination beneath industrial sites commonly is the result of past onsite treatment and disposal of industrial wastewater into unlined recharge basins, leaching of sludge drying-bed residue, accidental spills, and leakage from corroding waste-storage drums.

Contamination of ground water is of particular concern on Long Island because the soil is permeable and thus enables surface contaminants to be transported by infiltrating precipitation or through artificial recharge to the water table. Because ground water is the sole source of public drinking water for the residents of Nassau and Suffolk Counties (fig. 1), the protection of Long Island's ground-water reservoir from contamination is of vital importance.

The presence of volatile organic compounds (VOCs) in ground water was first discovered in Nassau County in October 1975, when the New York State Department of Health detected vinyl chloride, trichloroethylene (TCE), and tetrachloroethylene (PCE) in two industrial-supply wells in the Bethpage-Hicksville-Levittown area (Myott, 1980). In an effort to identify the sources and abate the contamination, the Nassau County Department of Health conducted a countywide survey of industrial and commercial establishments to inventory the types and quantities of chemicals used and their method of disposal (Mackay and others, 1979).

Contamination of ground water in the residential/industrial setting of the Bethpage-Hicksville-Levittown area, in east-central Nassau County (fig. 1), poses a particular threat because VOCs have been detected at depths from which public water supplies are pumped. Years of onsite discharge of effluent containing industrial wastes introduced VOCs into the ground-water system, and pumping and recharge within the industrial zone have caused the VOCs to migrate laterally and vertically at accelerated rates.

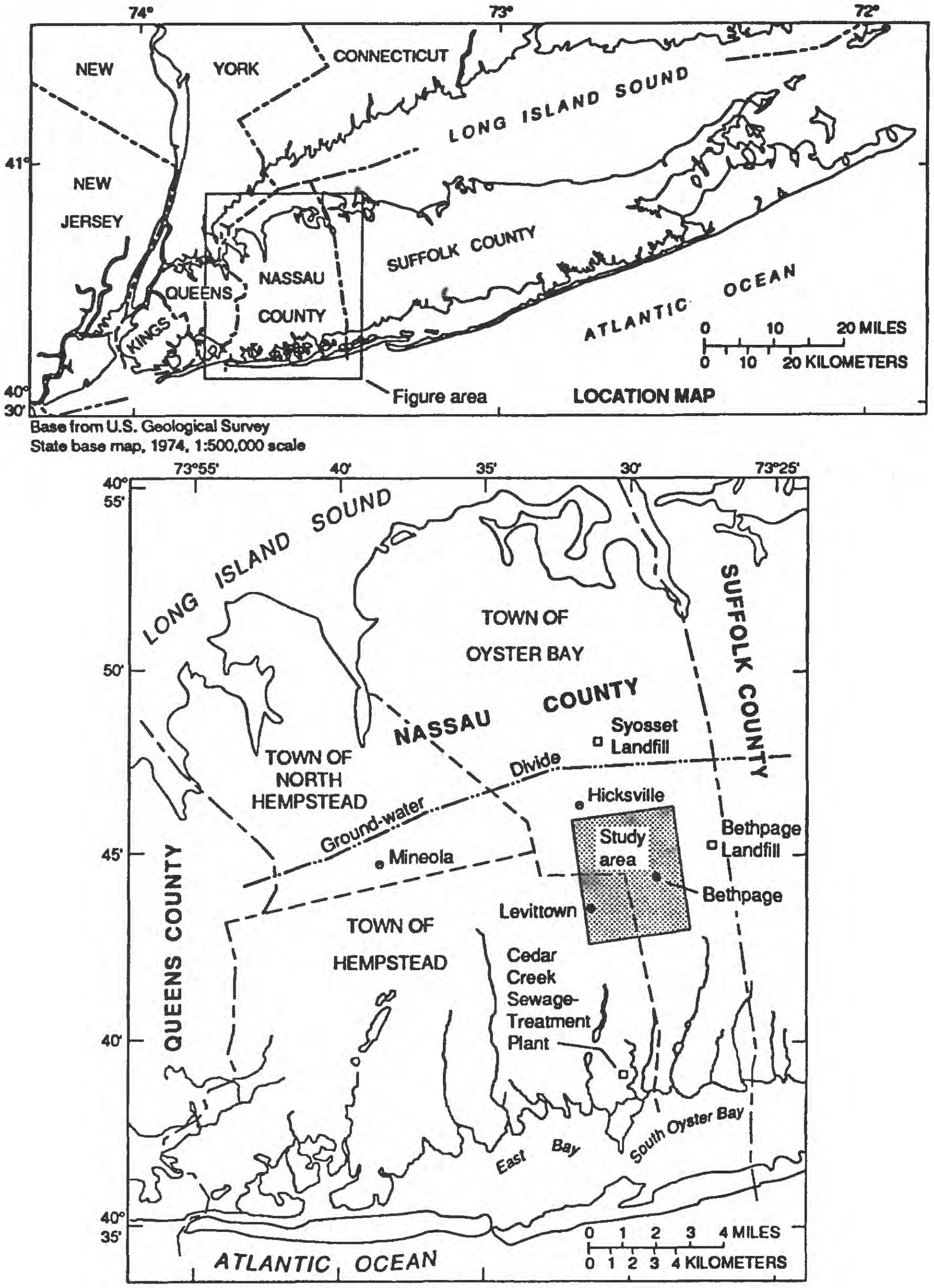
In 1986, the U.S. Geological Survey, in cooperation with the Nassau County Department of Health, began collecting water-quality data from observation, public-supply, and industrial-supply wells in the Bethpage-Hicksville-Levittown area. The primary focus of this investigation was to evaluate how hydrologic stresses affect the distribution, transport, and fate of chemical contaminants after they have entered the ground-water system.

Purpose and Scope

This report documents the chemical quality of ground water in and around the industrial area, identifies which VOCs have entered the ground-water system beneath the area of investigation, and includes maps that delineate the vertical and horizontal extent of the contaminant plumes. It also examines the effect of local stresses, such as pumping and recharge, on the distribution of contaminants and describes the various sources of contamination and the fate of the contaminants as they migrate offsite. Analyses of ground-water samples are presented in the appendixes.

Location and Description of Study Area

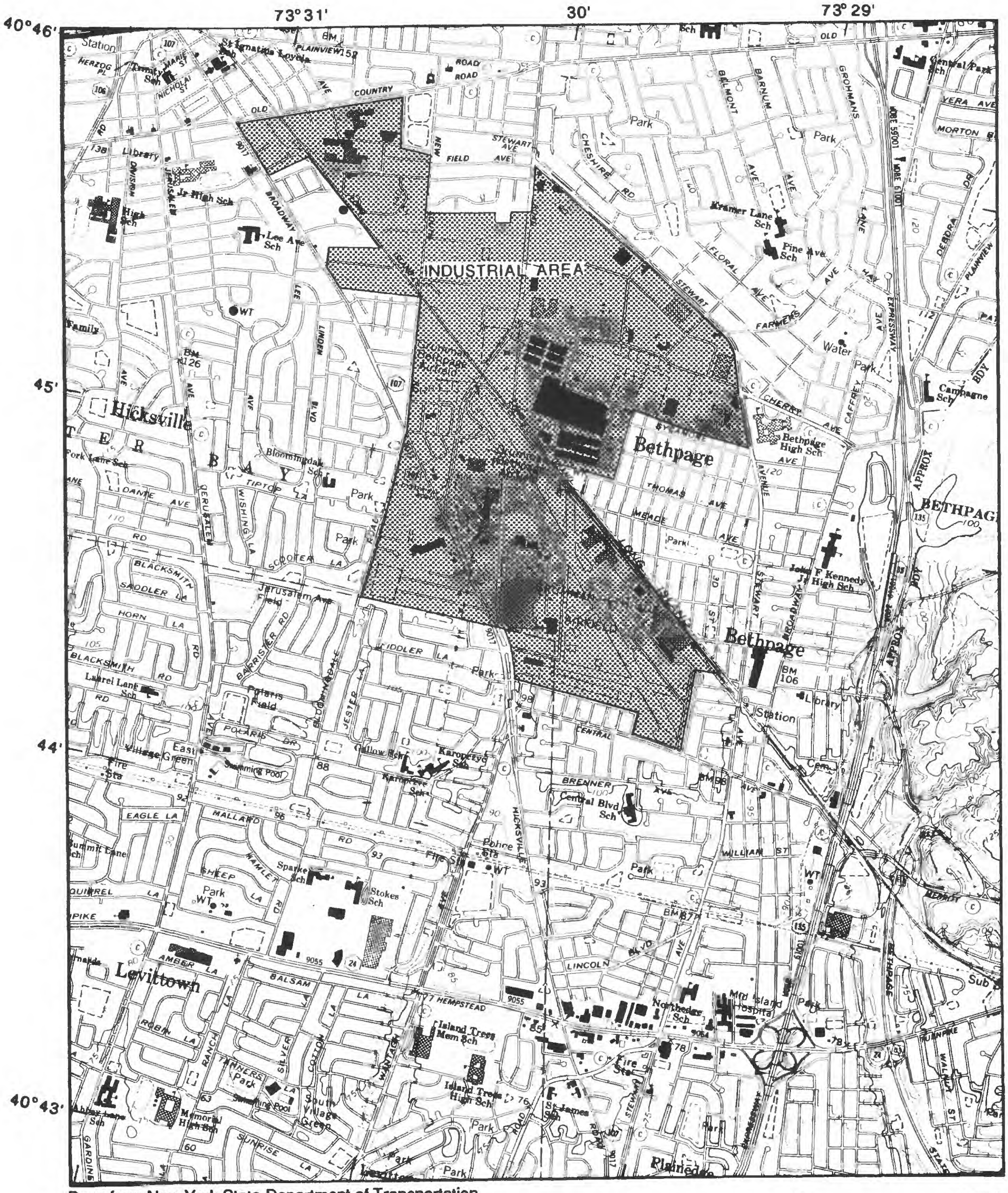
The area of study (fig. 1) is an 11.4-mi^2 rectangle in east-central Nassau County that is hereafter referred to as the Bethpage-Hicksville-Levittown area. The area contains several land uses that are typical of Nassau County. Most of it consists of suburban single-family housing, and much of the land along the major roads is used for commercial enterprises. A large section in the northern part of the area is zoned industrial/commercial (fig. 2).



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

Base from U.S. Geological Survey, 1:250,000 series, New York, 1957

Figure 1.--Location of study area, Nassau County, N.Y.



Base from New York State Department of Transportation
Amityville, Freeport, Hicksville and Huntington, 1981, 1:24,000

Figure 2.--Location of industrial zone (shaded) within the study area. (General location is shown in fig. 1.)

The industrial zone contains several commercial establishments; the major chemical users and waste producers in the area are an aerospace corporation and a plastics manufacturer. The aerospace corporation occupies a site of about 0.72 mi^2 (458 acres) and has been in operation since 1937; the plastics manufacturer occupies 0.02 mi^2 (14 acres) and began industrial activity in 1945 with the concentration 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).

Acknowledgments

The authors thank John Lovejoy of the Nassau County Department of Health (NCDH) for his assistance in providing data. James Adamski and Andrew Lichtman, NCDH, Division of Laboratories and Research, coordinated the analytical laboratory services.

HYDROGEOLOGIC SETTING

Long Island is composed of unconsolidated sediments of Late Cretaceous and Pleistocene age that overlie crystalline bedrock of Precambrian age. This bedrock peneplain was a depositional surface upon which hundreds of feet of gravel, sand, silt, and clay were deposited (Suter and others, 1949).

Hydrogeologic Units

The hydrogeologic units in the Bethpage-Hicksville-Levittown area are described in table 1; detailed information on their thickness and water-bearing properties is given by Smolensky and Feldman (1990).

The bedrock surface beneath the area of investigation slopes southeastward at a rate of about 90 ft/mi. The bedrock-surface altitude in the area ranges from about 950 ft below sea level in the northwest to 1,250 ft below sea level in the southeast. The overlying sequence of Cretaceous-age sediments generally display a lack of sorting, as evidenced by interspersed streaks of sand, silt, and clay.

The oldest deposit that overlies the bedrock surface is the Raritan Formation, which is divided into the lower Lloyd Sand Member (Lloyd aquifer) and a conformably 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 horizontal hydraulic conductivity of 40 ft/d in this part of Nassau County (Smolensky and Feldman, 1990). Overlying the Lloyd Sand Member is the unnamed clay member of the Raritan Formation (Raritan confining unit), which has a maximum thickness of about 175 ft and an estimated vertical hydraulic conductivity of 0.001 ft/d (Franke and Cohen, 1972).

The youngest Cretaceous deposit is the undivided Magothy Formation and Matawan Group (Magothy aquifer), which unconformably overlies the Raritan

Table 1.--Hydrogeologic units and their water-bearing properties in the Bethpage-Hicksville-Levittown area.

[Modified from Smolensky and Feldman (1990, table 1); ft/d = feet per day]

	Series	Geologic unit	Hydrogeologic unit	Approximate maximum thickness (feet)	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	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 and Matawan Group, undivided	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 45:1.

		unconformity					
Cretaceous		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 unit 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 confining unit. Average horizontal hydraulic conduc-tivity 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.

confining unit. Its surface is highly eroded and, in the study area, ranges from about 100 ft above sea level to more than 25 ft below sea level. The Magothy aquifer in this 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 horizontal hydraulic conductivity is 50 ft/d, and horizontal-to-vertical anisotropy is about 45:1.

Overlying the Magothy aquifer are outwash deposits left by the Pleistocene glaciers. The glacial sediments consist of medium-to-coarse sand and gravel and have an average horizontal hydraulic conductivity of about 270 ft/d and a horizontal-to-vertical anisotropy of about 10:1 (Franke and Cohen, 1972).

Ground-Water Flow System

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

Regional System

Long Island's ground-water divide extends east-west along the north-central part of the island (fig. 1). Water entering the ground-water system north of the divide flows northward to regions of salty ground water underlying Long Island Sound, and water entering south of the divide flows to the south-shore bays and the Atlantic Ocean (fig. 3). Ground water also discharges locally to stream channels that intersect the water table and to nearshore wetlands.

The boundaries of the ground-water reservoir are the water table, the freshwater-saltwater interface, and the bedrock surface (fig. 3). The water table is the upper boundary of the fresh ground-water system, and its altitude fluctuates with changes in recharge and discharge. The freshwater-saltwater interface forms a lateral boundary to which fresh ground water moves parallel. The bedrock surface forms an impermeable lower boundary to the ground-water reservoir.

Local System

The northern edge of Bethpage-Hicksville-Levittown area lies 1.5 mi south of the ground-water divide (fig. 1), and the direction of regional ground-water flow is southward. The area of investigation has four lateral boundaries that were selected to define the area of interest; they do not coincide with natural hydrologic boundaries. An estimate of the rate of flow across each boundary was obtained from a water budget of the study area produced by an islandwide three-dimensional ground-water flow model (H. T. Buxton and D. A. Smolensky, U.S. Geological Survey, written commun., 1989). Approximately 80 percent of the recharge to the study area originates as precipitation at land surface, and the remaining 20 percent enters the area as underflow from the regional flow system. Ground-water inflow to all three aquifers occurs at the north face of the study area and discharges at the south face. Ground-water fluxes across the eastern and western boundaries are substantially less than at the northern and southern boundaries because the hydraulic gradients are relatively small. A natural vertical head difference of 2 to 4 ft between the water table and the basal part of the Magothy aquifer causes a downward component of flow.

The configuration of the water table during April and August 1987 is depicted in figures 4A and 4B, respectively. In general, the water table was 1.5 to 3 ft lower in August than in April as a result of the decreased recharge from precipitation and increased pumpage for cooling; this decline is within the range of fluctuation for an average annual cycle for Long Island.

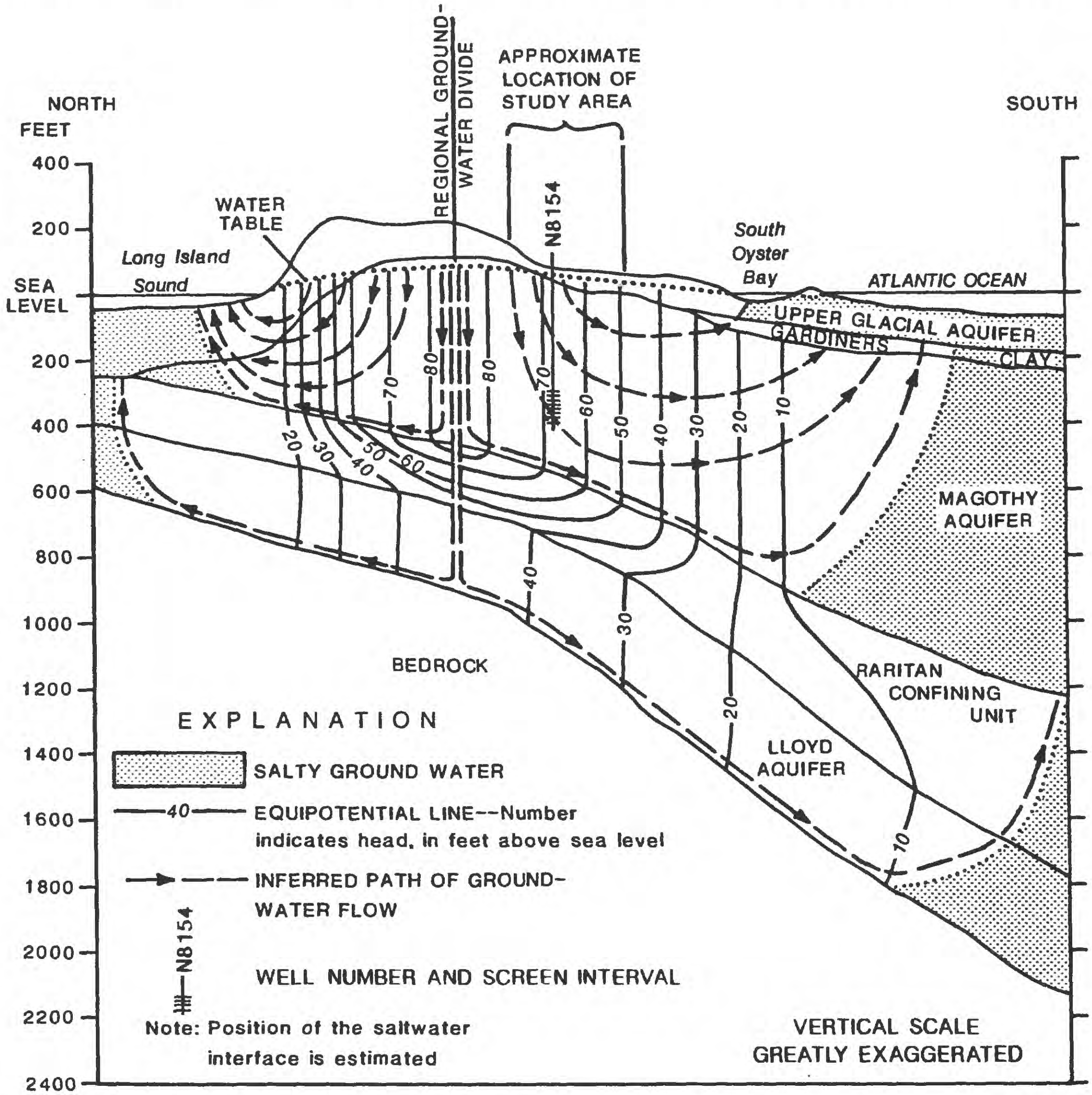
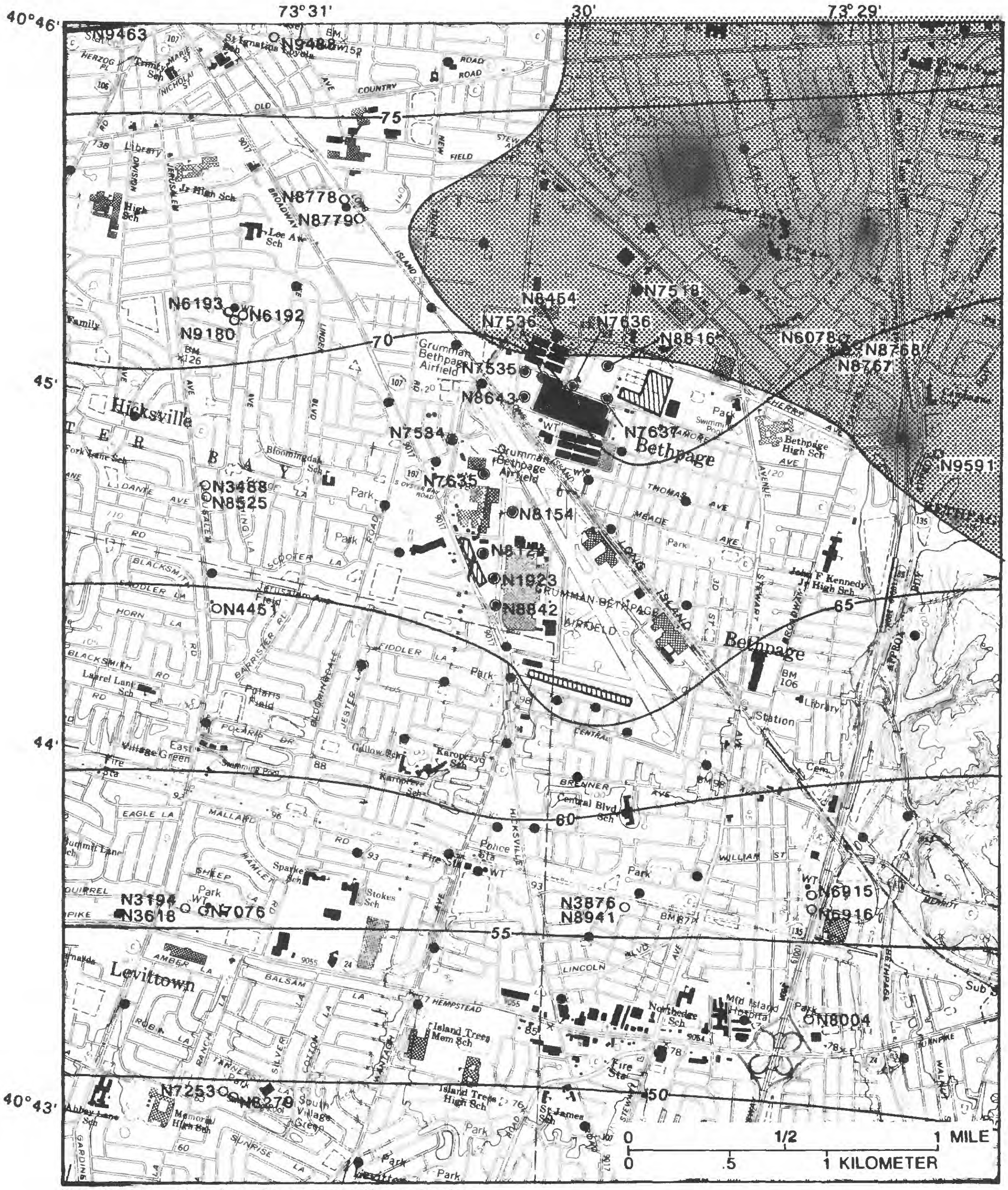


Figure 3.--Generalized hydrogeologic section through study area showing directions of ground-water flow. (Modified from Franke and Cohen, 1972, p. 273.)



Base from New York State Department of Transportation
Amityville, Freeport, Hicksville and Huntington, 1981, 1:24,000

EXPLANATION

▥ ACTIVE INDUSTRIAL RECHARGE BASIN

▨ AREA WHERE WATER TABLE IS WITHIN THE MAGOTHY AQUIFER

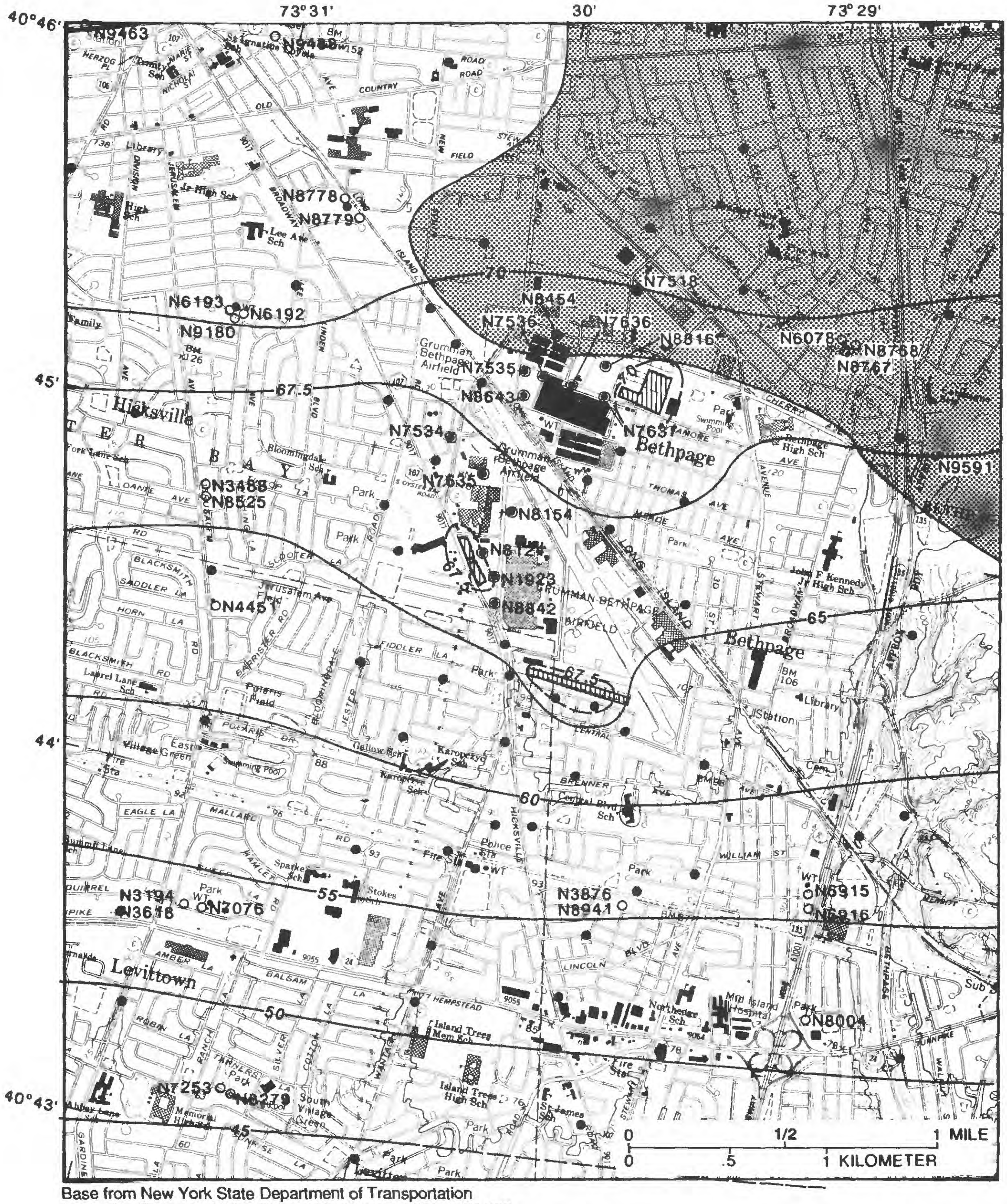
—50— WATER-TABLE CONTOUR -- Shows altitude of water table. Contour interval is 5 feet. Dashed where approximately located. Datum is sea level

○N8004 PUBLIC SUPPLY WELL

◉N8842 INDUSTRIAL WELL

● OBSERVATION WELL SCREENED AT WATER TABLE

Figure 4A.--Water-table altitude in the study area in April 1987.



Base from New York State Department of Transportation
Amityville, Freeport, Hicksville and Huntington, 1981, 1:24,000

EXPLANATION

▥ ACTIVE INDUSTRIAL RECHARGE BASIN

▨ AREA WHERE WATER TABLE IS WITHIN THE MAGOTHY AQUIFER

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

○N8004 PUBLIC SUPPLY WELL

◉N8842 INDUSTRIAL WELL

● OBSERVATION WELL SCREENED AT WATER TABLE

Figure 4B.--Water-table altitude in the study area in August 1987.

Mean annual precipitation in the area during 1951-65 ranged from 41.5 to 43 in. (Miller and Frederick, 1969). Although slightly higher than in the study area, the best long-term precipitation records that include recent data are from the Mineola station (1939-86), approximately 7 mi to the west, where average annual precipitation for the period was 44.58 in. (Smolensky and Feldman, 1990).

Depth to the water table in the Bethpage-Hicksville-Levittown area ranges from about 15 ft to 75 ft. This depth increases northward and varies with land-surface elevation. The saturated thickness of the upper glacial deposits ranges from 0 to about 100 ft. The horizontal gradient or slope of the water table in the vicinity of the industrial zone is about 0.0015, or 7.8 ft/mi. A gradient of 0.0015, horizontal hydraulic conductivity of 270 ft/d, and porosity of 0.30, give an average horizontal velocity in the water-table aquifer of 1.4 ft/d. Vertical gradients within the upper glacial aquifer are negligible in areas unaffected by artificial recharge. Downward movement of water in the upper glacial aquifer occurs when vertical gradients develop in response to precipitation. The study area contains no streams.

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

Water Use

Public drinking water in the Bethpage-Hicksville-Levittown area is supplied by four water districts whose wells are screened in the Magothy aquifer (locations are shown in fig. 4). In 1985, public-supply wells in the study area pumped an average of 10.2 Mgal/d. Monthly pumpage is normally at its maximum in July, then declines gradually into the winter.

Domestic Use

Before 1980, all water pumped by residential and commercial buildings was disposed of through onsite cesspools or septic tanks. This method of disposal returned to the aquifer system water that had been pumped from deeper zones and thereby maintained a balance between withdrawals and recharge to the ground-water system.

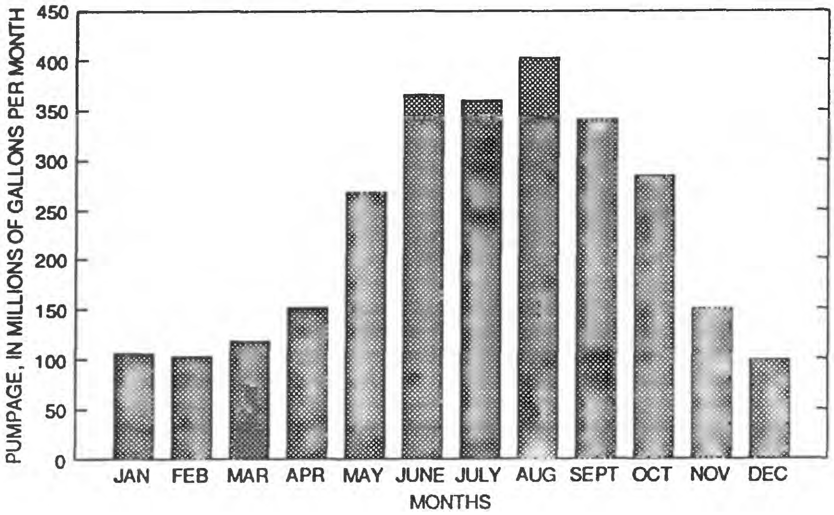
Since 1980, wastewater in the study area has been diverted through sewers to the Cedar Creek sewage-treatment plant (fig. 1) and discharged from there to the sea. While greatly reducing the loading of contaminants to the ground-water system, sewering also decreased the amount of water that was returned to the system from 85 percent before 1980 to 20 percent thereafter (H. T. Buxton and D. A. Smolensky, U.S. Geological Survey, written commun., 1989). This substantial loss of recharge coincides with a general decline in water levels observed during the 1980's (Smolensky and Feldman, 1990).

Industrial Use

Several industrial and commercial establishments use ground water for cooling. The cooling water typically is injected back into the aquifer at the same depth zone from which it was pumped. This pumping and injection has little effect on the overall water budget or the direction of ground-water flow in the area. The only major industrial pumping in the study area that is not injected back into the same aquifer zone 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 was greatest during the summer (fig. 5). Most of this water is used for air conditioning and equipment cooling; the remainder is used in manufacturing and is diverted offsite through sewers to the Cedar Creek treatment facility. The cooling (noncontact) water remains onsite and is returned to unlined recharge basins (fig. 4) from which the water percolates to the water table. (Three groups of basins are used for most of the recharge.) Thus, water levels in this localized area are affected not only by the loss of recharge through sewering and by natural fluctuations in precipitation, but also by the local effects of pumping and recharge. Comparison of April water levels with those of August during 1986-88 (fig. 4) indicates that the water table beneath the recharge basins is 5 ft to 7 ft higher in August, when the demand for cooling water is greatest, than in April. Water-table mounding beneath basins and drawdown in the vicinity of pumping wells also increase the vertical gradient beneath the industrial zone substantially.

Figure 5.

Average monthly pumpage of aerospace facility wells, 1968-85. (Data from New York State Department of Environmental Conservation.)



DATA COLLECTION AND ANALYSIS

Ground-water samples were collected from the upper glacial aquifer and Magothy aquifer in 1986 and 1987 and analyzed for VOCs and inorganic constituents. Samples were collected from 56 monitoring wells and 11 industrial wells (locations are shown in fig. 6).

Base from New York State Department of Transportation
Amityville, Freeport, Hicksville and Huntington, 1981, 1:24,000

EXPLANATION

● N9654 OBSERVATION WELL

◉ N8124 INDUSTRIAL WELL

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

Monitoring Wells

The well network 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 increase the number of collection points for water-level and water-quality data. Most shallow wells were drilled with a U.S. Geological Survey auger rig and cased with black carbon-steel casing. The auger flights were hosed off between well sites, and the casing was steam cleaned before installation. Five-foot stainless-steel drive-point screens were used. Deep wells were installed by a private contractor with a mud-rotary drill rig. Procedures were followed to minimize the likelihood that organic compounds would be introduced into the ground-water system during drilling and installation of the deep wells.

Sampling Equipment and Procedures

Observation wells were sampled with a 1.75-in submersible pump that uses stainless-steel and Teflon[1] 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 about 1 gal/min. Three casing volumes of water were evacuated before sampling to ensure that stagnant well water was purged and only formation water was being pumped.

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

Samples from industrial and public-supply wells were collected at the wellhead from a valve. 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.

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.

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.

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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.

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, in Hempstead, N.Y. VOCs 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 (Andrew Lichtman, Nassau County Department of Health, oral commun., 1989). Appendix 1 (at end of report) lists the laboratory analyses of selected organic compounds.

Samples were also analyzed for selected metals and nonmetals; results are listed in appendix 2 (at end of report). Analytical procedures are outlined in U.S. Environmental Protection Agency (USEPA) (1979) and American Public Health Association (1985).

Quality Assurance

All samples to be analyzed for VOCs were collected in duplicate; 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 quality-assurance program of the Nassau County Department of Health's organic-chemistry laboratory includes analyzing reference samples to detect errors or malfunctions, and participating in quarterly proficiency examinations for New York State certification. The inorganic-chemistry laboratory, in addition to certifying and testing reference samples for New York State, participates in the Standard Reference Water Sample 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). For example, sediment in a sample may introduce error and may lower the measured concentration of VOCs by adsorption onto the organic solids, but this is not deemed to be significant in samples from the few shallow wells that contained sediment.

GROUND-WATER QUALITY

Inorganic Constituents

The fresh ground water of Long Island in areas unaffected by human activities generally contains only small amounts of dissolved solids. Before development, the dissolved-solids concentration of ground water changed very little as it moved through the ground-water system because the aquifer formation deposits are relatively unreactive chemically (Franke and McClymonds, 1972). In Nassau County, the primary source of inorganic constituents such as nitrate, ammonia, calcium, sodium, sulfate, and chloride in the ground-water system is sewage disposal. 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 concentration greater than 1 mg/L is considered to result from human activities (Perlmutter and Koch, 1972).

Upper Glacial Aquifer

The inorganic-chemical quality of ground water in the study area has been altered by human activities. Wastewater from cesspools and septic tanks before 1980, when sewers were installed, and infiltration of dissolved road salts and lawn fertilizers, all contribute to the deterioration of ground-water quality. Elevated concentrations of dissolved substances from these activities is shown by elevated specific conductance values. Nitrogen loading has decreased substantially as use of cesspools and septic tanks have been phased out of the area, and nitrogen now is present primarily in the form of nitrate because the ammonia has undergone nitrification to nitrate, a process that occurs in the presence of dissolved oxygen.

Magothy Aquifer

Concentrations of inorganic constituents decrease with increasing depth in the Magothy aquifer (fig. 7). Although water from the Magothy aquifer at or near the industrial zone is closer in chemical composition to native ground water than is water from the upper glacial aquifer, it nevertheless has elevated concentrations of nitrate, and total dissolved solids concentrations exceed 50 mg/L. Furthermore, the dominant cations and anions in samples from the industrial zone were present in higher concentrations than in ground-water samples representing natural chemical quality of water from the Magothy aquifer (Cohen and others, 1968).

Effect of Industrial Activities on Concentrations of Inorganic Constituents

Analyses of inorganic quality of water from the water-table and Magothy aquifers show that industrial activities have altered the chemical character of both. Samples from the water-table aquifer can be grouped according to whether they have been affected by sewage disposal, by pumping and recharge, or neither (fig. 8). Concentrations of inorganic constituents at wells N10601, N10632, and N10633, screened approximately 20 ft below the water table on the downgradient side of industrial recharge basins, are similar to those in the Magothy aquifer due to dilution and displacement. Vertical gradients induced by water-table mounding beneath the basins act to displace upper glacial aquifer water, which contains high concentrations of inorganic constituents, downward beneath the returned water from the Magothy aquifer.

Ground-water quality downgradient from the recharge basins, along the southern border of the industrial zone, deteriorates with distance from the basins as the ambient water becomes mixed less and less with the cleaner recharge water from those basins. A well pair (N10816, N10817) (fig. 6) was installed along a flow path about 5,000 ft downgradient from the basins with screens set at depths of 15 ft and 90 ft below the water table. The dissolved-solids concentration at the deeper well is almost 60 percent higher than that at the shallow well, which is an indication that recharge from precipitation and regional gradients are moving contaminants downward within the water-table aquifer once they escape the influence of industrial pumping and recharge.

Base from New York State Department of Transportation
Amityville, Freeport, Hicksville and Huntington, 1981, 1:24,000

Figure 7.--Concentrations of inorganic constituents of water from selected Magothy aquifer wells screened in the intermediate zone and deep zone.

Base from New York State Department of Transportation
Amityville, Freeport, Hicksville and Huntington, 1981, 1:24,000

Figure 8.--Concentrations of inorganic constituents of water from selected water-table wells representing background conditions, mixing and displacement by returned Magothy water, and contamination from past sewage-disposal operations.

Samples from a few wells that were installed near the plastics manufacturer to the west (N10593, N9079) and the aerospace firm to the east (N10595, N10629) show contamination typical of treated sewage (fig. 8). The wells are downgradient from the former sewage-disposal operations, where treated effluent was discharged to unlined seepage basins from 1946 until about 1980, when sewer hookups piped the sewage offsite to a centralized treatment facility. Ground-water samples from wells N10595 and N10629, near the aerospace firm, show expecially high levels of total dissolved solids, pH, sodium, and bicarbonate. The high total dissolved solids concentration and sodium bicarbonate nature of this water distinguish it from ambient water (sodium chloride water). These are the same wells that had the highest concentrations of volatile organic compounds. Despite this correlation and delineation of the ground water displaced by industrial discharges, inorganic constituents were not a reliable indicator of VOC distribution.

Volatile Organic Compounds

Fifteen of the 22 organic compounds analyzed for were detected in the study 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 were: trichloroethylene (TCE), tetrachloroethylene (PCE), 1,1,1-trichloroethane, 1-1-dichloroethane, *cis*-and *trans*-1,2-dichloroethylene, and vinyl chloride. TCE and PCE were the two compounds detected most frequently and in the highest concentrations.

Types of Chemicals and Their Disposal

Beginning in 1946, the plastics manufacturer produced several synthetic materials. During 1956-75, a polyvinyl chloride resin operation produced vinyl chloride homopolymer and vinyl chloride/vinyl acetate copolymer. The waste was first centrifuged to remove the resin, then discharged into sand sumps on the plant property. This wastewater contained vinyl chloride, TCE, and vinyl acetate. The wastewater volume from this facility was 2 Mgal/yr (J. B. Harrison, Ruco Polymer Corporation, written commun., 1978).

In 1951, the first of four ester reactors was put into operation and began making phthalate and adipate plasticizers. Operations were expanded over the years to include production of trimellitate plasticizers and various other ester compounds. This esterification process gradually expanded from a production rate of 5 million lb/yr to 26 million lb/yr and generated a wastewater stream of about 4,000 gal/d. The wastewater contained glycols, alcohols, PCE, methanol, and several organic acids that, during 1951-74, were fed directly into a sand sump. The sand sumps were scraped once a year, and the scrapings were sent to the Syosset landfill (1946-68) and Bethpage landfill (1968-78) (fig. 1). Other solid and liquid wastes were regularly removed to offsite waste facilities. Since early 1975, the ester wastes have been incinerated, and nothing has been sent to the sand sumps. Sources of spillage and leakage included truck loading and unloading operations and corroding waste drums that allowed organic contaminants to soak into the ground (J. B. Harrison, Ruco Polymer Corporation, written commun., 1978).

Chromium was widely used at the aerospace firm for plating and anodizing purposes. The military aircraft industry uses chromium to enhance the corrosion resistance of aluminum and other metals (Lieber and others, 1964). The aerospace firm began discharging their chromic acid waste directly into recharge basins in 1943. This waste received much attention when, in 1947, water from a downgradient shallow public-supply well contained as much as 1,400 μg/L hexavalent chromium. By 1949, the firm implemented a treatment method to reduce the hexavalent chromium waste to trivalent chromium before discharging it into recharge basins (Nassau County Department of Health, 1977). Hexavalent chromium is a toxic and relatively mobile ion, whereas trivalent chromium is relatively insoluble (U.S. Environmental Protection Agency, 1989). The chromium concentration was below the detection limit in all but nine water-quality samples in the fall of 1987; the highest concentration was 30 μg/L.

Organic chemicals such as 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 reduction of hexavalent chromium. Solvents also were generated from vapor degreasers that use cleaning solvents to remove oil, grease, and dirt from parts. Spillage from liquid chemical storage tanks was collected in floor drains and discharged into large recharge basins (J. F. Welsch, Nassau County Department of Health, written commun., 1976). The chlorinated hydrocarbons that did not volatilize remained in the treated wastewater and were discharged into recharge basins (Grumman Aerospace Corp., 1978).

The location and time period in which contamination occurred are difficult to determine. Several small companies could be responsible for some of the contaminants detected by the well network, and two other companies are known to have had onsite industrial treatment facilities for removal of chromium (New York State Department of Environmental Conservation, 1985; J. F. Welsch, Nassau County Department of Health, written commun., 1976).

Previous Ground-Water-Quality Monitoring

Routine monitoring of ground-water quality in east-central Nassau County by the Nassau County Department of Health and USEPA in the early 1970's revealed that nitrate concentrations approached or exceeded the New York State limit of 10.0 mg/L as N in 4 of 14 Magothy aquifer wells at the aerospace firm; concentrations of ammonia exceeded 0.01 mg/L at 6 wells; and odors of a hydrocarbon nature were present in water at 5 wells (Nassau County Department of Health, written commun., 1975). Although elevated concentrations of nitrates are not uncommon in the Magothy aquifer in central Nassau County, ammonia detection and hydrocarbon odors are indicative of direct contamination by sewage and industrial wastes. At the time, the aerospace corporation was known to be discharging its treated sewage into recharge basins at three locations, and industrial wastes, particularly those being discharged by the plastics manufacturer next to the aerospace firm's property, were considered the cause of contamination in the aerospace firm's wells (Nassau County Department of Health, 1977).

In 1974, the Nassau County Department of Health requested the USEPA to sample and analyze water from three of the aerospace firm's wells for organic compounds, but none were detected. Water samples from two of the firm's sewage-plant recharge basins contained vinyl chloride, and the plastics manufacturer's condenser-water lagoons contained traces of TCE and PCE and elevated concentrations of octyl alcohol and vinyl chloride. The polyvinyl chloride operation's discharge lagoon contained elevated concentrations of vinyl chloride and acetic acid also. Additional samples were collected in November 1975 and sent to the New York State Department of Health laboratory to confirm previous analyses and to determine whether the contamination extended downgradient. Vinyl chloride, dichloroethylene, TCE, and PCE were detected in several of the aerospace firm's wells (Nassau County Department of Health, 1979).

Delineation of the Contaminant Plume

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 period. The concentrations of organic compounds did not vary seasonally, nor did the movement of contaminated ground water cause an increasing or decreasing trend in concentrations during the period. The concentrations differed somewhat from one sampling to another, however; thus, the data plotted in the maps and vertical sections herein represent an average of the actual distribution of contaminants. To determine whether the distribution of compounds is changing with time would require detailed information as to the location, concentration, and time of entry of contaminants, as well as collection of water-quality data for several more years.

Ground-water samples were collected at wells screened in the water-table aquifer and both the middle and deep zones of the Magothy aquifer. The water-quality investigation was limited to the water-table and Magothy aquifers because no wells in the Bethpage-Hicksville-Levittown area penetrate the Raritan confining unit to the underlying Lloyd aquifer, and the low vertical hydraulic conductivity and considerable thickness of the confining unit are assumed to prevent significant organic contamination of the Lloyd aquifer.

The contaminant plume occupies a large area in the water-table aquifer and underlies several contaminant sources. 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. Contaminants could have entered the ground-water system through (1) leaks and spills, (2) waste disposal, or (3) artificial ground-water recharge. Leaks and spills could have been diverted to recharge basins through storm sewers or could have soaked into the ground at any of several locations and eventually been transported by percolating rainwater to the water table. The second cause--waste disposal (septic and industrial) into recharge basins before hookup with the Nassau County sewage-disposal system--allowed VOCs and inorganic constituents to enter the ground-water system. The third cause--pumping of contaminated ground water for air cooling and subsequent disposal of the water into recharge basins--results in the infiltration of contaminated water to the water-table aquifer.

Trichloroethylene.--Trichloroethylene (TCE) is widely used in industrial processes such as metal degreasing and synthesis of organic compounds, and often is a good indicator of ground-water contamination from an industrial source. The areal distribution of TCE in the three depth zones is shown in figure 9A, 9B, and 9C; the vertical distribution is shown in hydrologic sections in figure 10A (p. 28-29). One area of particularly high TCE concentration was near well N10595, at the eastern edge of the aerospace firm's property just north of the railroad tracks (fig. 9A, p. 25). This sampling point is approximately 2,000 ft downgradient of an area that encompassed a sanitary-sewage-treatment plant, recharge basins, and sludge-drying beds. As mentioned earlier, only noncontact cooling water has been discharged to the recharge basins since 1980.

TCE concentrations exceeded 500 µg/L near well N10595 and 800 µg/L near well N10599; both wells are downgradient from an area containing a manufacturing facility, industrial waste-treatment plant, and recharge basins. Although the water-quality data and information on site history are insufficient to locate the sources of contamination precisely, the presence of VOCs such as TCE in the water-table aquifer is clearly attributable to the introduction of contaminants within the industrial zone. The distribution of TCE in the plume downgradient from the industrial zone is no longer influenced by industrial pumping and recharge. Recharge from precipitation and slightly downward regional gradients have decreased the TCE concentrations in the upper zone of the water-table aquifer. The result is a deepening of the plume, as evidenced by the first 100 ft below the water table, in which the concentration of TCE increases with depth. Water from well N10816, screened about 90 ft below the water table, had a TCE concentration of 56 µg/L, whereas water from well N10817, screened 15 ft below the water table, had a concentration of only 3 µg/L.

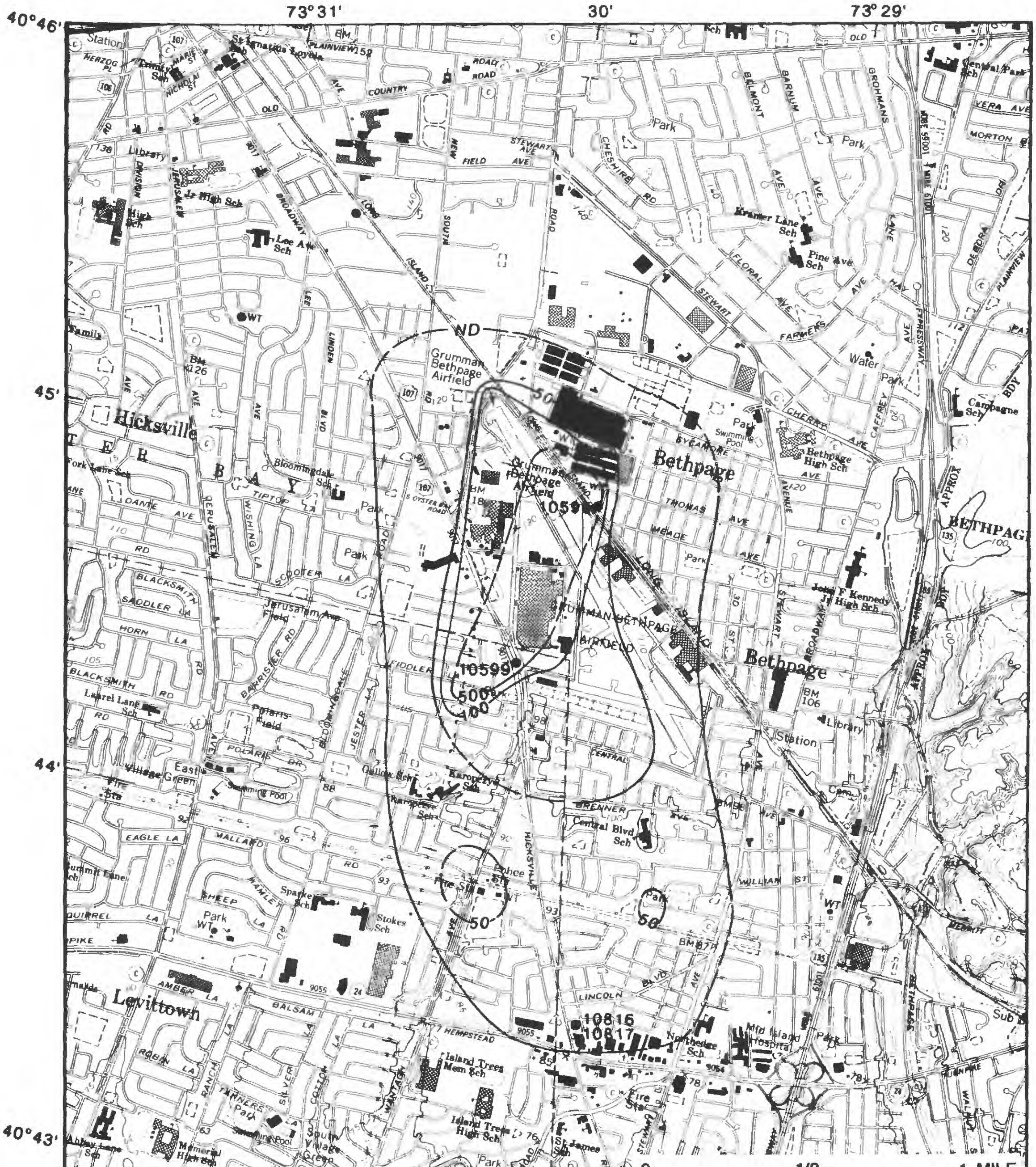
TCE also was present in the middle part of the Magothy aquifer (from 75 ft to 275 ft below the water table) and in the deep part (from 275 ft to 450 ft below the water table) (figs. 9B, 9C). Water from industrial wells had TCE concentrations as high as 1,200 µg/L in the middle Magothy zone and as high as 770 µg/L in the deep Magothy zone. Analyses of water samples from monitoring wells installed downgradient from the industrial zone confirmed that TCE had migrated offsite at depth in the Magothy aquifer. Analyses of water from an observation well pair (N10997, N10998), approximately 2,500 ft south of the industrial zone (figs. 9B, 9C), showed that TCE was still persistent in both Magothy zones in concentrations of about 200 µg/L. Analyses of water from another well pair (N10999, N11000), approximately 1,500 ft farther downgradient, shows that the concentration of TCE at this location within the middle Magothy zone probably diminishes with depth from about 10µg/L to below the detection limit.

One north-south and four east-west cross sections (fig. 10A) depict the vertical distribution of contaminants (locations are shown in fig. 10B). The vertical distribution of TCE (fig. 10A) further illustrates that the location of pumped wells strongly influences its distribution. TCE moves downward from areas of high concentration at the water table toward the pumped wells at the northern and western parts of the aerospace firm property. Downgradient from the industrial zone, the pair of public-supply wells N3876 and N8941, section E-E', has tested positive for TCE and appears to be drawing the plume toward the screened zones. The three zone plots of TCE were combined into one three-dimensional diagram (fig. 11, p. 31) to depict how industrial-supply wells cause downward migration of contaminants. The concentrated pumping by industrial-supply wells in the center of the study area causes a funnel-shaped plume by creating large drawdowns at depth. Despite the containment effect that the pumping has on advective transport, the TCE plume has continued to move downgradient at depth beyond the influence of industrial pumping.

Tetrachloroethylene.--The areal distribution of tetrachloroethylene (PCE) in the three depth zones is shown in figures 12A, B, C (p. 32-34), and the vertical distribution is shown in figure 13 (p. 35-36). The area of highest PCE concentration coincides with the area of highest TCE concentration along the eastern edge of the industrial area (fig. 12A). A second area of high PCE concentration is to the west, where the concentration at well N10598 exceeded 200 µg/L. PCE concentrations in water from this well were as high as 1,100 µg/L during the 2-year sampling program, but TCE concentrations in this area were less than 10 µg/L. The lack of a corresponding high concentration of TCE in this area suggests that the two contaminants (TCE and PCE) in this part of the plume probably did not originate from the same source. The PCE concentration in the middle and deep zones of the Magothy aquifer is lower than in the water-table aquifer, except in the area near some aerospace-firm wells that are upgradient from source areas.

Section A-A' (fig. 13A) shows that the area of highest concentration is north of well N8154 in the Magothy aquifer, near a cluster of industrial wells. Section B-B' shows that contaminated ground water is being drawn slightly upgradient from what would be the natural southward flow path under unstressed conditions. Water from shallow wells along section B-B' had only traces of PCE (less than 5 µg/L), and the plume was undetected upgradient from the section. Also evident in section A-A' is that once the plume migrates downgradient from the industrial zone (south of well N10599), the PCE concentration increases slightly with depth. The concentration of PCE downgradient from the industrial zone decreases much more rapidly than that of TCE, and PCE does not extend as far downgradient as does TCE. The highest detected PCE concentration south of the industrial zone was 13 µg/L.

Other compounds.--Examination of the distribution of 1,1,1-trichloroethane, 1,1-dichloroethane, *cis-* and *trans-*1,2-dichloroethylene, and vinyl chloride indicates that the plume of volatile organic compounds underlying the industrial zone is a composite of several individual plumes (fig. 14A, p. 37). The map of their distribution in the water-table aquifer suggests that several contaminants possibly are emanating from a single source area, but several additional sources are present. Except for low levels of 1,1,1-trichloroethane downgradient from the industrial zone in the water-table aquifer, contamination in the middle zone of the Magothy aquifer was greater than in the overlying water-table aquifer; here both 1,1,1-trichloroethane and vinyl chloride were detected. Because more than one source is likely, determination of whether the various compounds are being transported at differing rates and whether they have additional sources along the flow path is difficult. The compounds vinyl chloride and 1,1,1-trichloroethane, which have migrated offsite in the intermediate and deep zones of the Magothy aquifer, were both detected at approximately the same distance downgradient from the industrial zone.



Base from New York State Department of Transportation
Amityville, Freeport, Hicksville and Huntington, 1981, 1:24,000

EXPLANATION

——50—— LINE OF EQUAL TRICHLOROETHYLENE CONCENTRATION, IN MICROGRAMS PER LITER -- Contour interval variable. Dashed where approximately located. Letters ND indicate not detected

●10817 WELL LOCATION -- Number is well-identification number

Figure 9A.--Areal distribution of trichloroethylene in water-table aquifer (less than 75 feet below water table), fall 1987.

Base from New York State Department of Transportation
Amityville, Freeport, Hicksville and Huntington, 1981, 1:24,000

EXPLANATION

——10—— LINE OF EQUAL TRICHLOROETHYLENE CONCENTRATION, IN MICROGRAMS PER LITER -- Contour interval variable. Dashed where approximately located. Letters ND indicate not detected

●11000 WELL LOCATION -- Number is well-identification number

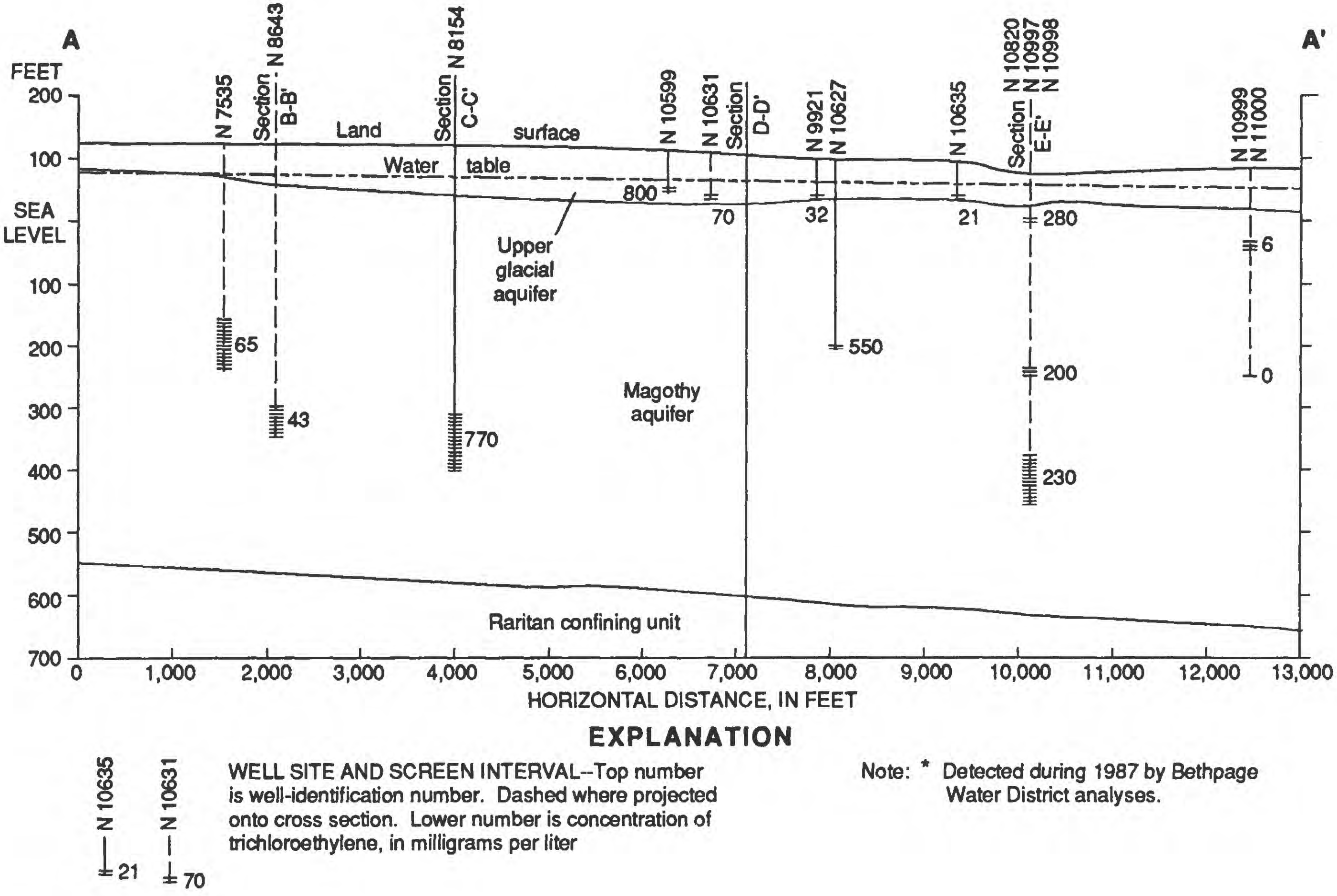
Figure 9B.--Areal distribution of trichloroethylene in middle zone of the Magothy aquifer (75 to 275 feet below water table), fall 1987.

Base from New York State Department of Transportation
Amityville, Freeport, Hicksville and Huntington, 1981, 1:24,000

EXPLANATION

——10—— LINE OF EQUAL TRICHLOROETHYLENE CONCENTRATION, IN MICROGRAMS PER LITER -- Contour interval variable. Dashed where approximately located. Letters ND indicate not detected

Figure 9C.--Areal distribution of trichloroethylene in deep zone of the Magothy aquifer (275 to 450 feet below water table), fall 1987.



EXPLANATION

WELL SITE AND SCREEN INTERVAL--Top number is well-identification number. Dashed where projected onto cross section. Lower number is concentration of trichloroethylene, in milligrams per liter

Note: * Detected during 1987 by Bethpage Water District analyses.

Figure 10A.--Hydrochemical sections A-A' through the plume showing the vertical the vertical distribution of trichloroethylene, fall 1987. (Location is shown in fig. 10B.)

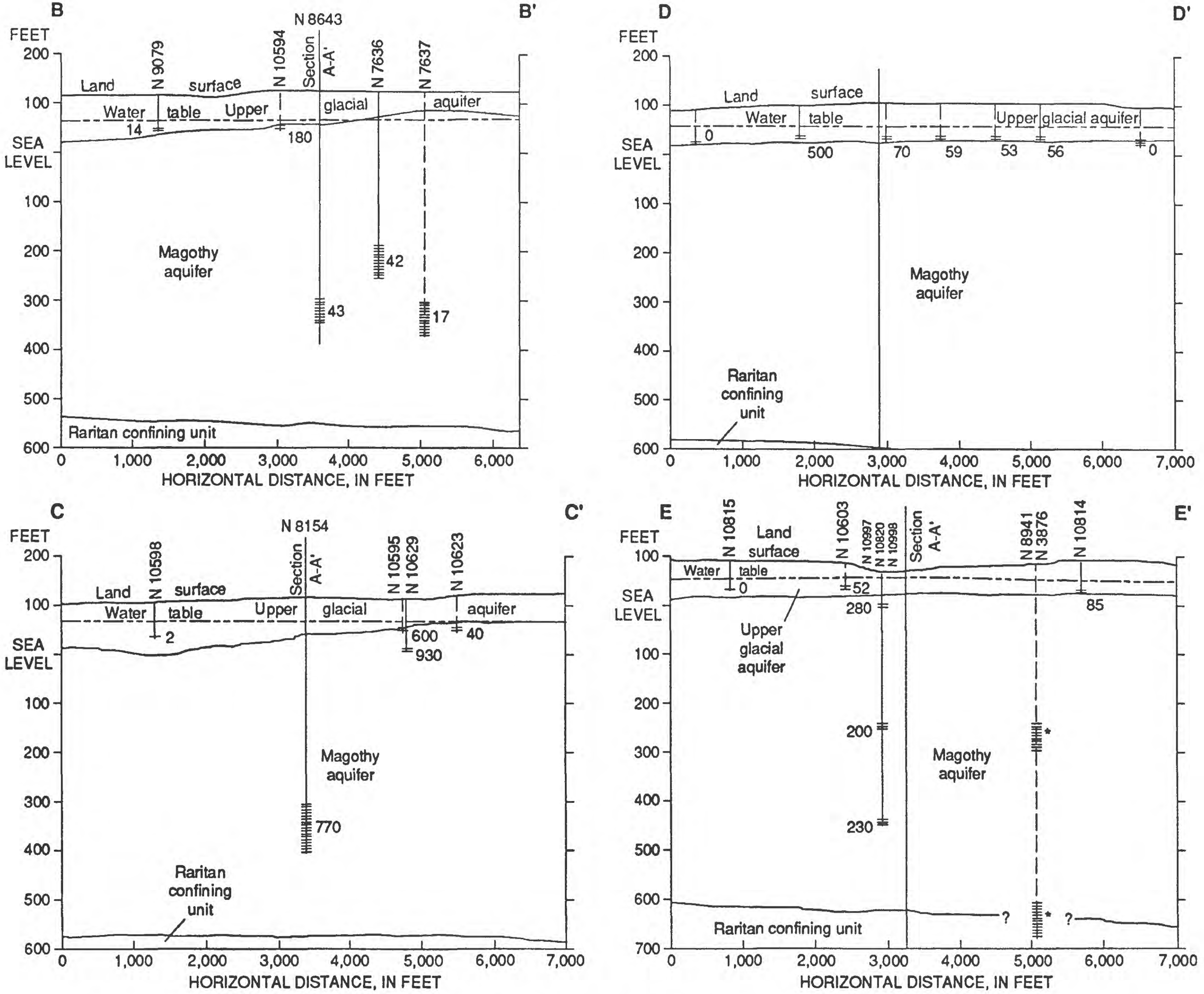
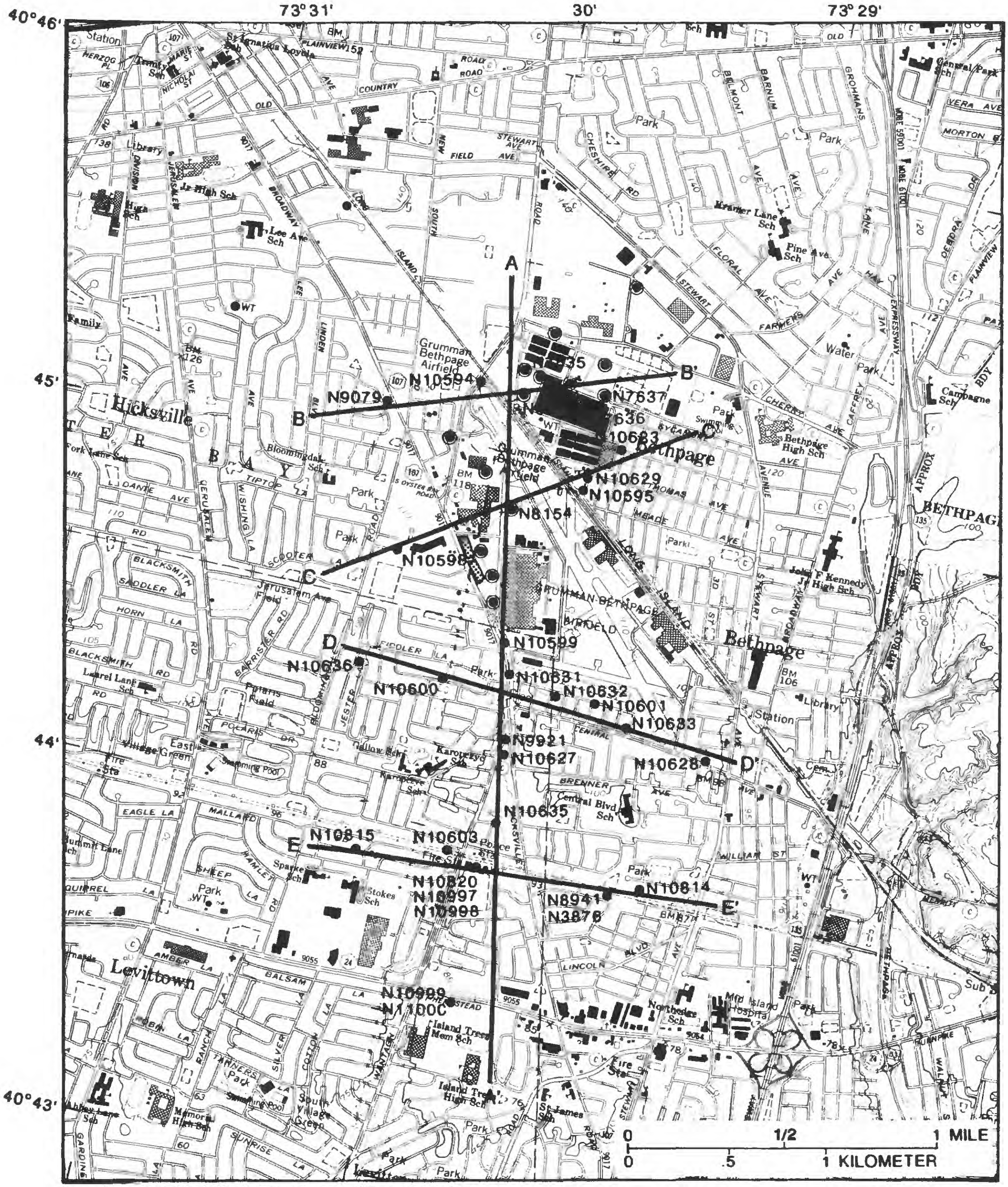


Figure 10A.--Hydrochemical sections B-B' through E-E' through the plume, showing the vertical distribution of trichloroethylene, fall 1987. (Locations are shown in fig. 10B.)



Base from New York State Department of Transportation
Amityville, Freeport, Hicksville and Huntington, 1981, 1:24,000

EXPLANATION

▨ RECHARGE BASIN #6

A——A' TRACE OF HYDROCHEMICAL SECTION

●N11000 LOCATION OF WELL USED IN SECTION AND WELL IDENTIFICATION NUMBER

◉ INDUSTRIAL WELL

Figure 10B.--Location of vertical sections A-A' through E-E'. (Sections are given in figs. 10A and 13.)

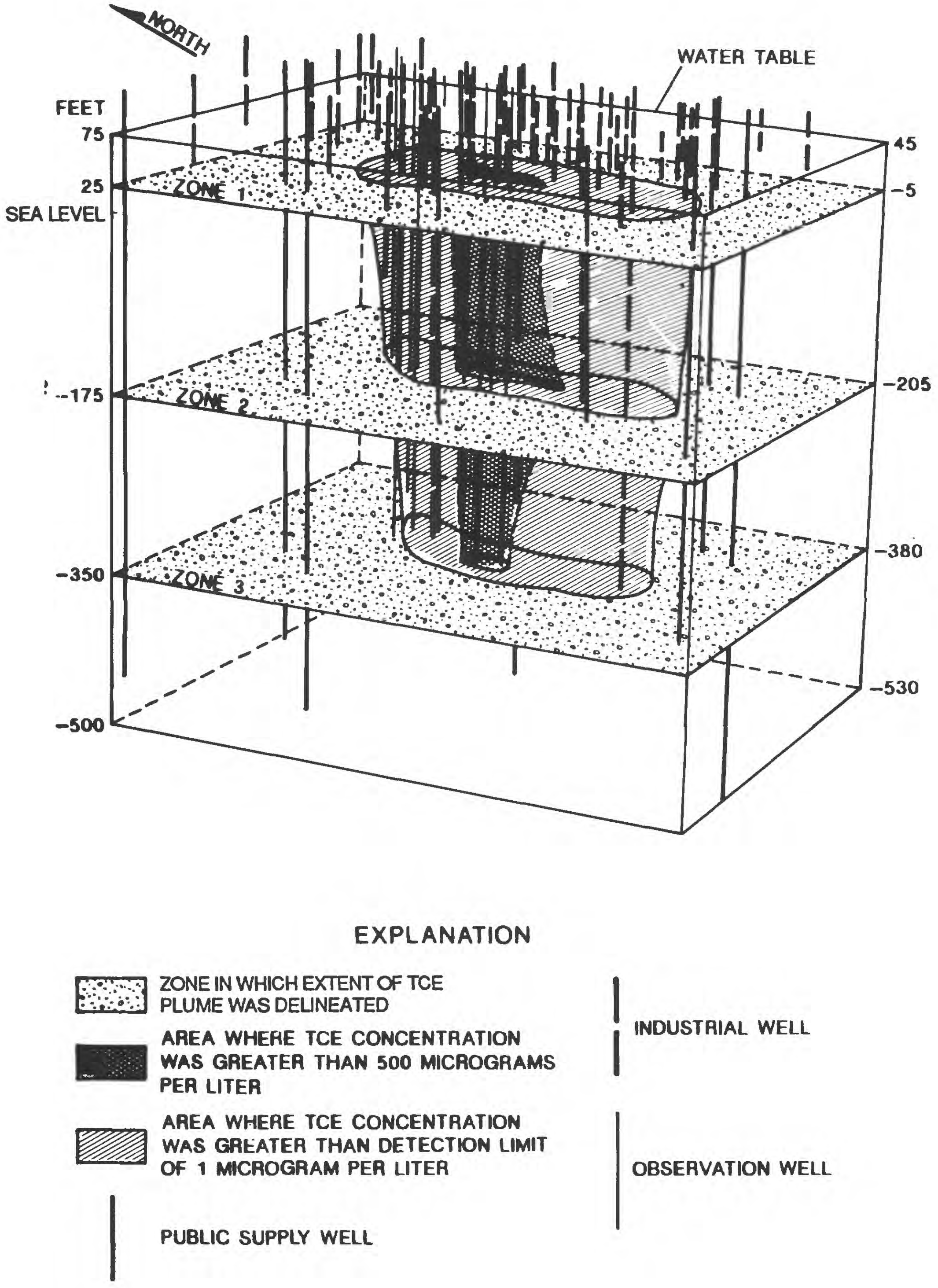


Figure 11.--Schematic diagram showing three-dimensional extent of trichloroethylene within the three depth zones.

Base from New York State Department of Transportation
Amityville, Freeport, Hicksville and Huntington, 1981, 1:24,000

EXPLANATION

——10—— LINE OF EQUAL TETRACHLOROETHYLENE CONCENTRATION, IN MICROGRAMS PER LITER -- Dashed where approximately located. Letters ND indicate not detected

Figure 12A.--Areal distribution of tetrachloroethylene in the water-table aquifer (less than 75 feet below water table), fall 1987.

Base from New York State Department of Transportation
Amityville, Freeport, Hicksville and Huntington, 1981, 1:24,000

EXPLANATION

——10—— LINE OF EQUAL TETRACHLOROETHYLENE CONCENTRATION, IN MICROGRAMS PER LITER -- Dashed where approximately located. Letters ND indicate not detected

Figure 12B.--Areal distribution of tetrachloroethylene in the middle zone of the Magothy aquifer (75 to 275 feet below water table), fall 1987.

Base from New York State Department of Transportation
Amityville, Freeport, Hicksville and Huntington, 1981, 1:24,000

EXPLANATION

——10—— LINE OF EQUAL TETRACHLOROETHYLENE CONCENTRATION, IN MICROGRAMS PER LITER -- Dashed where approximately located. Letters ND indicate not detected

Figure 12C.--Areal distribution of tetrachloroethylene in the deep zone of the Magothy aquifer (275 to 450 feet below water table), fall 1987.

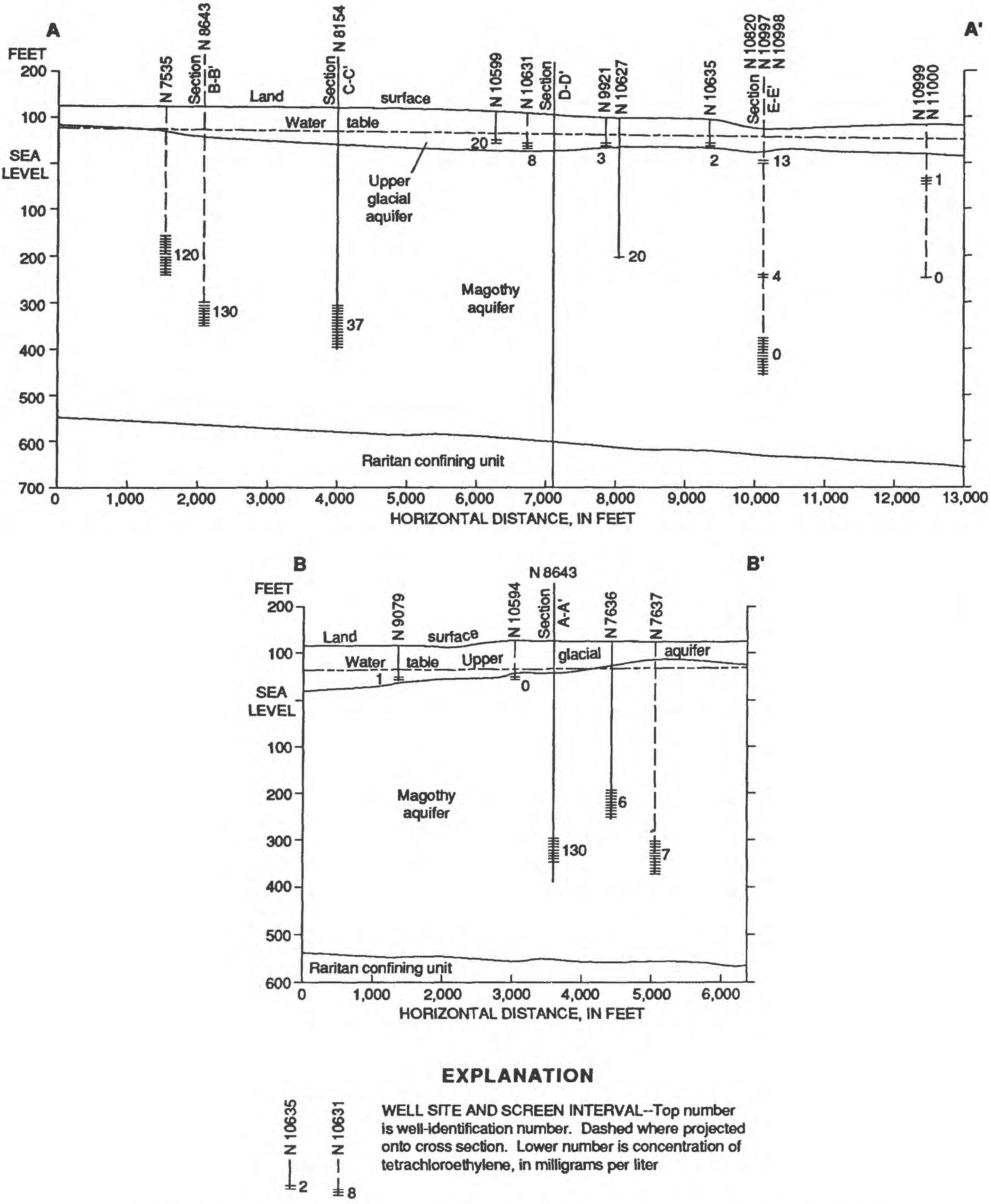
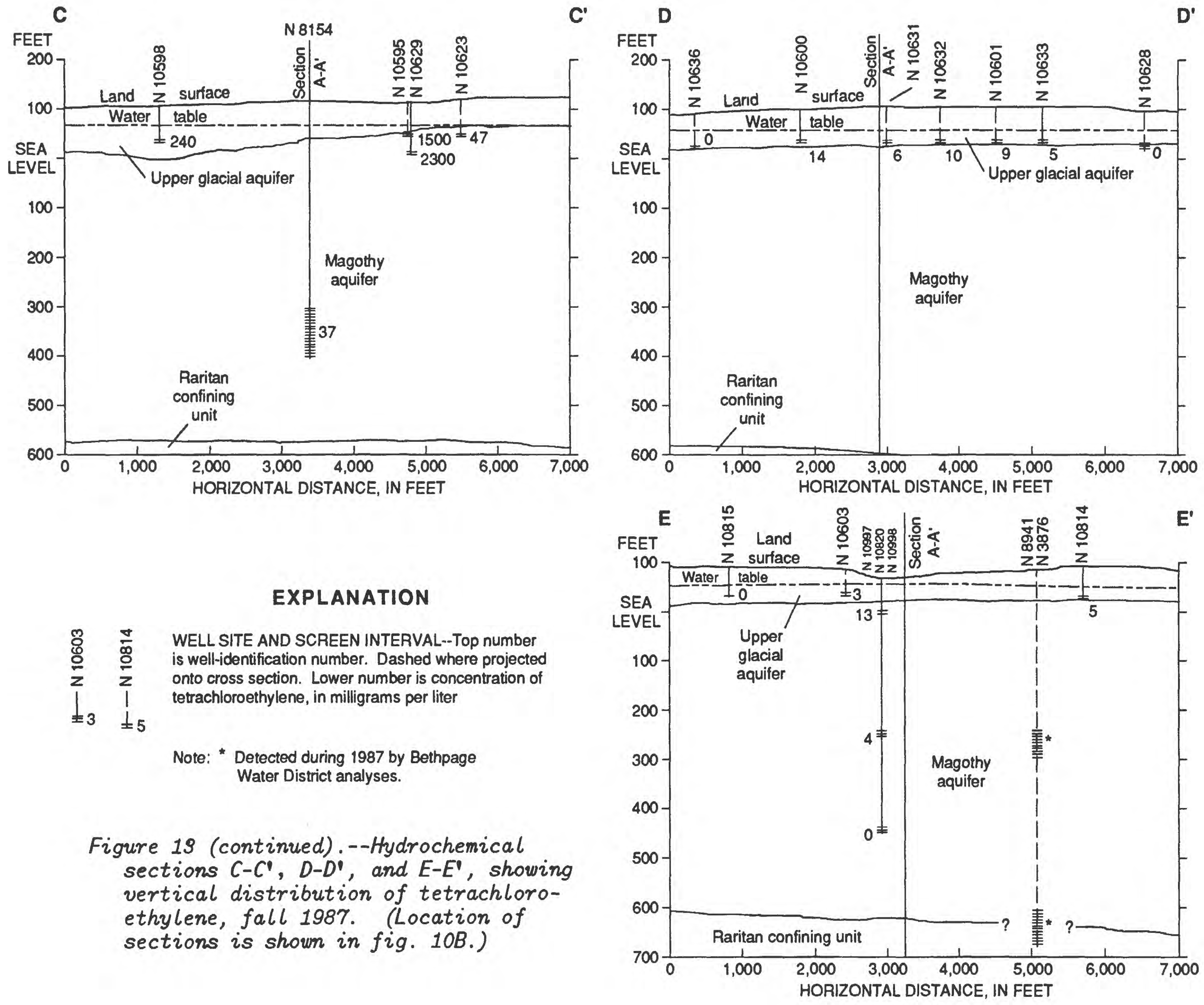


Figure 13.--Hydrochemical sections A-A' and B-B' showing vertical distribution of tetrachloroethylene, fall 1987. (Location of sections is shown in fig. 10B.)



EXPLANATION

WELL SITE AND SCREEN INTERVAL--Top number is well-identification number. Dashed where projected onto cross section. Lower number is concentration of tetrachloroethylene, in milligrams per liter

Note: * Detected during 1987 by Bethpage Water District analyses.

Figure 13 (continued).--Hydrochemical sections C-C', D-D', and E-E', showing vertical distribution of tetrachloroethylene, fall 1987. (Location of sections is shown in fig. 10B.)

Base from New York State Department of Transportation
Amityville, Freeport, Hicksville and Huntington, 1981, 1:24,000

EXPLANATION

- ░ 1
- ▥ 2
- ▒ 1, 2
- ▨ 1, 2, 3
- ▤ 1, 2, 3, 4
- ┅ 3
- ▦ 1, 2, 4
- ☰ 1, 3, 4

DETECTED COMPOUNDS
1: 1, 1, 1 - TRICHLOROETHANE
2: VINYL CHLORIDE
3: 1,2 - DICHLOROETHYLENE
4: 1, 1 - DICHLOROETHANE

Figure 14A.--Distribution of four frequently detected contaminants the water-table aquifer (less than 75 feet below water table), fall 1987.

Base from New York State Department of Transportation
Amityville, Freeport, Hicksville and Huntington, 1981, 1:24,000

EXPLANATION

▒ 1
▥ 2
░ 1, 2
▧ 1, 2, 3

DETECTED COMPOUNDS
1: 1, 1, 1 - TRICHLOROETHANE
2: VINYL CHLORIDE
3: 1,2 - DICHLOROETHYLENE
4: 1, 1 - DICHLOROETHANE

Figure 14B.--Distribution of four frequently detected contaminants in the middle zone of the Magothy aquifer (75 to 275 feet below water table), fall 1987.

Base from New York State Department of Transportation
Amityville, Freeport, Hicksville and Huntington, 1981, 1:24,000

EXPLANATION

▥ 2
▒ 1, 2
▧ 1, 2, 3

DETECTED COMPOUNDS
1: 1, 1, 1 - TRICHLOROETHANE
2: VINYL CHLORIDE
3: 1,2 - DICHLOROETHYLENE
4: 1, 1 - DICHLOROETHANE

Figure 14C.--Distribution of four frequently detected contaminants in the deep zone of the Magothy aquifer (275 to 450 feet below water table), fall 1987.

Transport Processes

The distribution of VOCs is affected by a variety of processes that control the movement of contaminants in ground water. Regional gradients and local anomalies in hydraulic gradients induced by pumping and recharge are the factors that govern the advective movement of VOCs in the study area. Dispersion spreads contaminants within the system, while biological and chemical processes retard the movement of organic compounds in ground water. Density-induced downward flow was not found to be occurring, inasmuch as only small amounts of pure product are likely to have entered the ground-water system. Most known releases of VOCs were introduced as diluted effluent to recharge basins. TCE and PCE, therefore, would not occur as high-density, low-viscosity solvents in the nonaequeous phase. This eliminates the possibility that the density of these solvents could have provided a downward driving force through the Magothy aquifer to the top of the Raritan confining unit. The transport processes deemed significant in the study area--advection, dispersion, sorption, and microbial and chemical mechanisms--are described below.

Advection.--Advection is the process by which solutes are transported by the bulk motion of flowing ground water. A projection of ground-water-flow patterns under nonpumping conditions, together with the absence of VOCs in Magothy aquifer wells upgradient of the industrial zone, indicate that local stresses to the ground-water system are the reason for the transport of contaminants deep into the Magothy aquifer. Concentrated withdrawals and subsequent routing of pumped water into recharge basins cause large vertical head differences that alter the natural hydraulic gradients and greatly increase the vertical component of flow beneath the industrial zone. Franke and Cohen (1972) calculated regional rates of ground-water movement on Long Island through the following modified form of the Darcy equation:

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

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

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

Representative values for K_s were calculated from the hydraulic-conductivity ellipsoid (Freeze and Cherry, 1979, p. 35-36) along a segment of an estimated predevelopment flow line, depicted in figure 3, from the northern boundary of the study area to the middle of the screened interval for aerospace firm well N8154. The hydraulic conductivity along the flow line, K_s, can be calculated for any direction of flow in an anisotropic medium if the horizontal and vertical hydraulic conductivities are known. The values used were K_x = 50 ft/d, K_z = 1.1 ft/d, Δh = 12 ft, horizontal distance = 8,300 ft, and screen setting (vertical distance below the water table) = 400 ft. 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 predevelopment flow line yielded a traveltime of 110 years from the water table to the well screen. Although this value is only an approximation, it supports the evidence that contaminants originated from sources within the industrial zone.

Concentrated pumping by deep industrial wells and the diversion of pumped water to recharge basins decrease the length of time required for water to travel deep into the Magothy aquifer by two processes: First, the difference in head between the water table and deep zone of pumping is increased by the pumping and by the water-table mounding beneath the basins; and second, the flow line is deflected into a pronounced vertical alignment, which effectively decreases the length of the flow path from the water table to the deep zone of the Magothy aquifer.

Hypothetical calculations of the traveltime from the water table beneath a recharge basin to a pumped well 1,000 ft away were made. The pumped well is well N8154, approximately 1,000 ft northeast of a recharge basin (fig. 10). An assumed water-table mounding of 6 ft beneath the recharge basin and a drawdown of 12 ft at the pumped well gave a velocity distribution along segments of a flow line under present-day pumping conditions that yielded an approximate 10-year traveltime from the recharge basin to the pumped well.

Figures 9, 10, 12, and 13 show that ground-water pumping significantly affects the advective transport of contaminants, as illustrated by the shape and extent of a plume along an imaginary flow path from the water table, through the middle 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 screened zones of individual pumped wells. Advective transport is the predominant factor in determining the path of the contaminants, and all transport mechanisms are insignificant by comparison. The location of pumped wells seems to influence the distribution of volatile organic contaminants in the Magothy aquifer. Several wells are in a cluster in the northern part of the aerospace firm, and the remainder lie in a band along the western rim of the property. No pumping is done in the eastern part of the property (fig. 4). The rate of plume migration beyond the influence of industrial pumping is governed primarily by regional ground-water flow paths and is estimated to be 100 to 120 ft/yr in the Magothy aquifer.

Dispersion.--Dispersion is the spreading of dissolved contaminants in ground water by mechanical mixing and molecular diffusion as the contaminants move with the ground water. Dispersion was not expected to be uniform in the Bethpage-Hicksville-Levittown area because local variations in pore geometry alter the ground-water velocity, and local pumping and recharging alter the directions of flow. Head gradients in the area affected by industrial pumping are larger than elsewhere and thereby increase the downward flow velocity; this, in turn, increases the frictional forces within the porous medium and increases the mechanical mixing along the migration path of the plume. Lateral spreading (perpendicular to the migration path) does not occur in the area of pumping because ground-water flow paths converge toward the screened zones of the pumped wells.

Dispersion does occur beneath the industrial recharge basins, where contaminated ground water is returned after use for industrial cooling (table 2). Localized water-table mounding also increases the downward hydraulic gradient, but here the flow paths are emanating from a source rather than converging on a sink.

Where the plume is downgradient from the effects of industrial pumping, contaminant transport is influenced by regional hydraulic gradients. The large local differences in contaminant concentrations near the sources diminish with distance from the sources as a result of dispersion and dilution.

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

[Analyses by Nassau County Department of Health. NA, not analyzed; <, less than. Location is shown in fig. 11.]

Constituent	Concentration, in micrograms per liter Fall 1986	 Fall 1987
Trichloroethylene	450	110
Tetrachloroethylene	30	8
1,1,1-Trichloroethane	3	2
Cis- and *trans* 1,2-dichloroethylene	<5	<5
Vinyl chloride	NA	3
1,1-Dichloroethane	<5	<5
Benzene	<3	<3

Sorption.--Two factors that can significantly affect the interaction of organic compounds with the aquifer material are the degree to which the compounds are immiscible in water, and the amount of organic carbon in the aquifer material. Geologic logs of wells indicate that the Magothy aquifer beneath the Bethpage-Hicksville-Levittown area contains several scattered lenses of lignite. As mentioned earlier, the concentration of TCE does not dissipate nearly as rapidly as that of PCE downgradient from the industrial zone. PCE is structurally similar to TCE except for an additional chlorine atom, which makes it less soluble than TCE and, therefore, more prone to adsorption by organic material such as lignite.

Microbial and chemical mechanisms.--Assessment of microbial and chemical degradation processes in ground water was beyond the scope of this study. Other studies of transformation processes and the factors that influence the processes have produced conflicting and inconclusive results, and data on when, where, and at what concentration the contaminants entered the ground-water system are lacking. In addition, pumping and recharging in the area greatly complicate the direction and rate of ground-water flow; thus, biodegradation and chemical reactions in ground water underlying the study area are discussed only in general terms.

Recent studies indicate that the action of microorganisms attached to solid surfaces within the aquifer can cause the biological transformation of organic compounds in ground water (Mackay and others, 1985; U.S. Environmental

Protection Agency, 1989). The bacteria obtain energy and nutrients from the solute as it passes through the porous medium and can form films on the sediment as their numbers increase.

In this study, the two most common ground-water contaminants (TCE and PCE) were found beneath most of the industrial area. Even where these contaminants had moved downgradient from the industrial site, TCE concentrations remained as high as several hundred micrograms per liter, whereas PCE concentrations decreased significantly. The highest downgradient PCE concentration of only 13 µg/L is possibly the result of the sequential reductive dehalogenation of PCE to TCE, to dichloroethylene, and finally to vinyl chloride (U.S. Environ-mental Protection Agency, 1989). Vinyl chloride has also been detected beneath areas where it was not used or disposed of, which suggests that it may be an intermediate compound formed by biotransformation. Chemical reactions such as hydrolysis and oxidation can affect organic contaminants, but these reactions in ground water are probably slow compared with transformations mediated by microorganisms (Mackay and others, 1985).

SUMMARY AND CONCLUSIONS

Ground-water contamination has resulted from the use and disposal of synthetic organic contaminants in a 11.4-mi^2 industrially zoned area 1.5 mi south of the ground-water divide in east-central Nassau County. Ground-water samples were collected in the spring and fall of 1986 and 1987 and analyzed for volatile organic compounds (VOCs) and inorganic constituents in an attempt to delineate the extent of contamination and the hydrologic factors that affect the transport of VOCs. The VOC plume in the water-table aquifer is approximately 5,700 ft wide, 12,000 ft long, and more than 500 ft thick. The plume has 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 water is chemically unaltered by use for cooling, it is pumped from an already contaminated Magothy aquifer and subsequently discharged to the water table through onsite recharge basins. Cones of depression at pumped wells, and water-table mounds beneath the basins, have increased the vertical component of flow beneath the industrial zone and thereby altered the natural ground-water flow system.

The concentrations of inorganic constituents in ground water in the study area have been altered by human activities to the extent that the water now differs substantially from its native quality. The major effect of industry on inorganic quality of ground water is the mixing of water pumped from the Magothy aquifer with water in the upper glacial aquifer in the vicinity of the recharge basins. In addition, water samples from a few wells downgradient from inactive sewage-treatment plants contain elevated concentrations of dissolved solids, sodium, and bicarbonate. In general, concentrations of the major inorganic constituents in ground water in the vicinity of the industrial zone decrease with depth.

Concentrations of TCE and PCE, the most frequently detected contaminants, exceeded 1,000 µg/L in some locations. Concentrations of TCE in the water-table aquifer were greatest in one source area in the northeast section of the industrial zone. The area of highest PCE concentration coincides with the major TCE source area, but a second area of high PCE concentration also lies to the west. Both contaminants have been transported deep into the underlying Magothy aquifer beneath the industrial zone through the alteration of hydraulic gradients induced by pumping and recharge. Concentrations of PCE, however, decrease much more rapidly than TCE downgradient of the industrial zone, and PCE does not extend as far downgradient as does TCE. Delineation of the extent of four other commonly encountered VOCs indicates that the area contains more than one contaminant source.

The detection of contaminants at depth along regional flow lines that originated upgradient of known contamination at the water table indicates that local hydraulic gradients have been induced by pumping and recharge, and that advective movement is the predominant mechanism of contaminant transport in the area. The size of the plume decreases with depth through the convergence of flow paths near pumped wells. The result is that the plume moves downward as well as westward as it migrates along regional flow paths. Other transport mechanisms are insignificant in relation to advective movement, although dispersion directly beneath recharge basins results in spreading of the plume at the water table.

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APPENDIXES

1. Organic constituent analyses from the Bethpage-Hicksville-Levittown area, fall 1987.

2. Inorganic constituent analyses from the Bethpage-Hicksville-Levittown area, fall 1987.

Appendix 1. Organic constituent analyses from the Bethpage-Hicksville-Levittown area, fall 1987

[Analyses by Nassau County Department of Health. °, degrees; ', minutes; ", seconds; yr, year; mo, month; d, day <, less than; NR, not reported. All values are in micrograms per liter.]

Well number	Latitude ° ' "	Longitude ° ' "	Date of sample yr mo d	Methylene chloride[1]	Cis- & trans-1,2-dichloro-ethylene	1,1-dichloro-ethane	Chloro-form	1,1,1-trichloro-ethane	Carbon tetra-chloride	Trichloro-ethylene	Tetra-chloro ethylene	Vinyl chloride	Benzene	Toluene	Chloro-benzene	Xylene
A. Observation wells																
N9079	404508	733026	87/11/02	<8	22	<4	<1	<1	<1	14	1	<1.0	150	4	<3	17
N9088	404413	732823	87/10/30	<8	<5	<1	<1	<1	<1	<1	<1	<1.0	<3	<3	<3	<6
N9411	404409	733051	87/11/04	<8	<5	NR	<1	<1	<1	<1	<1	<1.0	<3	<3	<3	<6
N9654	404330	732804	87/10/27	<7	<9	<5	<1	5	<1	<1	<1	<1.0	<3	<3	<3	<6
N9661	404338	732804	87/10/26	<7	<9	<5	<1	<1	<1	1	<1	<1.0	<3	<3	<3	<6
N9667	404320	733056	87/11/04	<8	<5	NR	<1	6	<1	<1	2	<1.0	<3	<3	<3	<6
N9918	404434	733057	87/11/11	<8	<5	<5	<1	<1	<1	<1	<1	<1.0	<3	<3	<3	<6
N9919	404535	733146	87/12/14	<10	<8	<5	<1	<2	<1	<1	79	<1.0	<3	<3	<3	<7
N9920	404606	733029	87/12/03	<10	<8	<5	<1	1	<1	<1	<1	<1.0	<3	<3	<3	<6
N9921	404416	732951	87/12/10	<10	<8	<5	<1	<1	<1	52	3	<1.0	200	<3	<3	88
N9922	404340	732951	87/10/27	<7	<9	<5	<1	<1	<1	<1	<1	1.0	<3	<3	<3	<6
N9929	404339	732840	87/10/26	<7	<9	<5	<1	<1	<1	<1	<1	1.0	<3	<3	<3	<6
N9931	404502	732917	87/11/10	<8	<5	<4	NR	1	1	1	2	<1.0	<3	<3	<3	<6
N9932	404602	732920	87/11/03	<8	<5	NR	4	10	<1	<1	6	<1.0	<3	<3	<3	<6
N10588	404457	733121	87/11/20	<8	<5	<4	<1	<1	<1	<1	<1	NR	<3	<3	<3	<6
N10589	404524	733051	87/11/20	<8	<5	<4	<1	2	<1	<1	1	NR	<3	<3	<3	<6
N10590	404546	732937	87/12/07	<10	<8	<5	<1	<1	<1	<1	<1	<1.0	<3	<3	<3	<6
N10591	404539	732914	87/12/08	<10	<8	<5	<1	4	<1	<1	<1	<1.0	<3	<3	<3	<6
N10592	404520	732833	87/12/09	<10	<8	<5	<1	<1	<1	<1	<1	<1.0	<3	<3	<3	<6
N10593	404520	733014	87/12/08	<10	<8	<5	<1	<1	<1	3	<1	280.0	<3	<3	<3	<6
N10594	404514	733007	87/12/08	<10	91	<5	<1	<1	<1	180	<1	1.0	<3	<3	<3	<7
N10595	404502	732939	87/11/19	120	120	52	5	320	<1	600	1,500	NR	<3	<3	<3	<6
N10596	404500	733013	87/11/04	20	<5	83	<1	100	<1	<1	4	21.0	<3	<3	<3	<6
N10597	404451	733022	87/11/05	<8	<5	<4	<1	<1	<1	1	30	<1.0	<3	<3	<3	<6
N10598	404444	733017	87/12/08	30	<8	<5	<1	<1	<1	2	240	35.0	<3	<3	<3	<7
N10599	404432	732949	87/11/05	<8	6	<4	<1	5	<1	800	20	2.0	<3	<3	<3	<7
N10600	404424	733001	87/11/03	<8	<5	<4	<1	2	<1	500	14	<1.0	<3	<3	<3	<6
N10601	404425	732927	87/11/02	<8	<5	NR	<1	<1	<1	53	9	2.0	<3	<3	<3	<6
N10602	404403	732935	87/10/28	<8	<5	<4	<1	<1	<1	28	1	<1.0	<3	<3	<3	<6
N10603	404356	732952	87/10/27	<7	<9	8	1	10	<1	52	3	<1.0	<3	<3	<3	<6
N10623	404508	732933	87/11/19	<8	9	4	1	24	<1	40	47	3.0	<3	<3	<3	<6
N10625	404455	732932	87/11/19	<8	<5	<4	<2	7	<1	20	6	<1.0	<3	<3	<3	<6
N10626	404445	732912	87/11/06	<8	<5	<4	<1	<1	<1	<1	<1	<1.0	<3	<3	<3	<6
N10627	404415	732943	87/12/17	<10	<8	<5	<1	2	<1	550	20	10	<3	<3	<3	<7
N10628	404419	732900	87/11/03	<8	<5	<5	<4	<1	<1	<1	<1	<1.0	<3	<3	<3	<6

Appendix 1. *Organic constituent analyses from the Bethpage-Hicksville-Levittown area, fall 1987--continued*

Well number	Latitude ° ' "	Longitude ° ' "	Date of sample yr mo d	Methylene chloride[1]	Cis- & trans-1,2-dichloro-ethylene	1,1-dichloro-ethane	Chloro-form	1,1,1-trichloro-ethane	Carbon tetra-chloride	Trichloro-ethylene	Tetra-chloro ethylene	Vinyl chloride	Benzene	Toluene	Chloro-benzene	Xylene
							A. Observation wells									
N10629	404502	732939	87/11/18	52	540	200	4	960	<1	930	2,300	75.0	<3	<3	<3	<6
N10630	404451	733022	87/12/17	<10	<8	<5	<1	1	<1	1	4	<1.0	<3	<3	<3	<7
N10631	404427	732947	87/11/05	<8	<5	<4	<1	7	<1	70	6	3.0	<3	<3	<3	<6
N10632	404425	732936	87/11/02	<8	<5	NR	<1	1	<1	59	10	2.0	<3	<3	<3	<6
N10633	404422	732919	87/11/03	<8	<5	<4	<1	<1	<1	56	5	1.0	<3	<3	<3	<6
N10634	404413	732928	87/10/28	<8	<5	<4	<1	2	<1	71	10	2.0	<3	<3	<3	<6
N10635	404402	732943	87/10/27	<7	<9	<5	<1	<1	<1	21	2	2.0	<3	<3	<3	<6
N10636	404424	733020	87/11/03	<8	<5	7	<1	3	<1	<1	<1	<1.0	<3	<3	<3	<6
N10812	404538	733012	87/11/20	<8	<5	<4	<1	<1	<1	<1	7	<1.0	<3	<3	<3	<6
N10813	404413	733007	87/10/27	<7	<9	<5	2	2	<1	7	1	<1.0	<3	<3	<3	<6
N10814	404356	732909	87/10/23	<7	<9	<5	<5	4	<1	85	5	2.0	<3	<3	<3	<6
N10815	404353	733012	87/12/09	<10	<8	<5	<1	1	<1	<1	<1	<1.0	<3	<3	<3	<6
N10816	404336	732921	87/10/22	<7	<9	18	1	18	<1	56	2	5.0	<3	<3	<3	<6
N10817	404336	732921	87/10/22	<7	<9	25	<1	22	<1	22	<1	<1.0	<3	<3	<3	<6
N10818	404347	732918	87/10/23	<7	<9	<5	<1	2	<1	36	2	<1.0	<3	<3	<3	<6
N10820	404354	732945	87/12/07	<10	<8	8	<1	10	<1	280	13	9.0	<3	<3	<3	<7
N10821	404401	732857	87/12/09	<10	<8	<5	<1	<1	<1	9	<1	1.0	<3	<3	<3	<7
N10997	404354	732945	87/12/11	<10	<8	<5	<1	<1	<1	230	<1	8.0	<3	<3	<3	<7
N10998	404354	732945	87/12/10	29	10	8	1	15	<1	200	4	28.0	<3	<3	<3	<7
N10999	404331	732944	87/12/21	<10	<8	<5	<1	<1	<1	<1	<1	<1.0	<3	<3	<3	<7
N11000	404331	732944	87/12/14	<10	<8	<5	1	2	<1	6	1	<1.0	<3	<3	<3	<7
							B. Industrial wells									
N7518	404535	732938	87/11/10	8	<5	<4	<1	7	<1	8	<1	6.0	<3	<3	<3	<6
N7535	404518	733000	87/11/13	NR	<5	<4	2	88	<1	65	120	93.0	<3	<3	<3	<6
N7536	404518	732953	87/11/13	26	<5	<4	<1	52	<1	79	5	3.0	<3	<3	<3	<6
N7635	404459	733004	87/11/10	58	17	<4	<1	20	<1	1,200	110	25.0	<3	<3	<3	<6
N7636	404517	732949	87/11/13	<8	<5	<4	<1	5	<1	42	6	2.0	<3	<3	<3	<6
N7637	404516	732941	87/11/10	<8	<5	<4	<1	2	<1	17	7	1.0	<3	<3	<3	<6
N8124	404445	732959	87/11/13	44	9	<4	<1	1	<1	170	34	NR	<3	<3	<3	<6
N8154	404454	732952	87/11/10	46	10	<4	<1	11	<1	770	37	39.0	<3	<3	<3	<6
N8454	404524	732952	87/11/10	<8	<5	<4	<1	<1	<1	<1	<1	<1.0	<3	<3	<3	<6
N8816	404523	732941	87/11/13	<8	<5	<4	<1	4	<1	12	3	1.0	<3	<3	<3	<6
N8643	404513	732957	87/11/10	<8	10	<4	<1	1	<1	43	130	27.0	<3	<3	<3	<6

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[1] Sum of values for methylene chloride, 1,1-dichloroethylene, and 1,1,2-trichlorotrifluoroethane.

Appendix 2.--Inorganic constituent analyses from the Bethpage-Hicksville-Levittown area, fall 1987

[Analyses by Nassau County Department of Health. °, degrees; ', minutes; ", seconds; yr, year; mo, month; d, day; deg C, degrees Celsius; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter]

Well number	Latitude ° ' "	Longitude ° ' "	Date of sample yr mo d	Temperature (deg C)	Specific conductance (µS/cm)	pH	Alkalinity, total as $CaCO_3$ (mg/L)	Total dissolved solids (mg/L)	Ammonia as N (mg/L)
A. Observation Wells									
N9079	404508	733026	87/11/02	15.1	628	5.7	64	319	0.29
N9088	404413	732823	87/10/30	13.8	271	5.0	17	154	0.04
N9411	404409	733051	87/11/04	14.6	462	5.8	52	266	<0.01
N9654	404330	732804	87/10/27	15.1	330	5.5	17	217	0.73
N9661	404338	732804	87/10/26	12.1	372	6.3	12	163	0.07
N9667	404320	733056	87/11/04	14.9	269	5.1	16	159	0.03
N9918	404434	733057	87/11/11	14.9	127	4.5	3	68	<0.01
N9919	404535	733146	87/12/14	14.9	295	5.0	5	193	<0.01
N9920	404606	733029	87/12/03	14.6	311	5.8	21	182	0.06
N9921	404416	732951	87/12/10	16.1	594	5.7	40	229	0.14
N9922	404340	732951	87/10/27	14.2	456	4.9	7	254	<0.01
N9929	404339	732840	87/10/26	14.1	341	5.1	4	177	<0.01
N9931	404502	732917	87/11/10	16.9	251	5.3	16	133	0.05
N9932	404602	732920	87/11/03	14.1	316	5.0	17	202	<0.01
N10588	404457	733121	87/11/20	14.4	76	5.4	5	43	<0.01
N10589	404524	733051	87/11/20	13.0	301	5.4	10	173	0.05
N10590	404546	732937	87/12/07	12.7	63	6.1	7	31	<0.01
N10591	404539	732914	87/12/08	13.4	234	6.0	8	149	<0.01
N10592	404520	732833	87/12/09	13.2	223	4.8	2	111	0.78
N10593	404520	733014	87/12/08	15.7	540	6.6	148	307	0.05
N10594	404514	733007	87/12/08	13.3	363	5.6	13	185	0.42
N10595	404502	732939	87/11/19	15.9	490	10.3	137	668	0.17
N10596	404500	733013	87/11/04	18.2	185	5.2	16	99	0.32
N10597	404451	733022	87/11/05	16.5	236	5.2	13	134	0.02
N10598	404444	733017	87/12/08	14.8	167	4.7	6	96	0.07
N10599	404432	732949	87/11/05	16.8	126	6.0	7	73	0.06
N10600	404424	733001	87/11/03	16.0	179	5.3	10	105	<0.01
N10601	404425	732927	87/11/02	21.4	118	5.6	7	67	0.03
N10602	404403	732935	87/10/28	15.2	214	5.2	11	133	0.03
N10603	404356	732952	87/10/27	14.7	295	5.4	15	189	<0.01
N10623	404508	732933	87/11/19	14.1	153	6.3	19	782	0.12
N10625	404455	732932	87/11/19	14.9	270	5.6	8	146	<0.01
N10626	404445	732912	87/11/06	15.0	236	5.4	25	112	0.34
N10627	404415	732943	87/12/17	16.7	163	-	9	99	0.11
N10628	404419	732900	87/11/03	12.3	152	5.8	33	83	<0.01
N10629	404502	732939	87/11/18	17.3	645	10.2	181	2,212	0.44
N10630	404451	733022	87/12/17	14.6	315	-	24	177	6.30
N10631	404427	732947	87/11/05	16.3	132	6.0	14	75	0.15
N10632	404425	732936	87/11/02	20.1	121	5.6	8	78	<0.01
N10633	404422	732919	87/11/03	17.3	90	5.5	5	57	0.03
N10634	404413	732928	87/10/28	16.6	121	5.6	6	77	0.01
N10635	404402	732943	87/10/27	16.1	353	5.4	27	210	0.02
N10636	404424	733020	87/11/03	14.1	231	5.8	18	121	0.02
N10812	404538	733012	87/11/20	13.3	145	5.8	12	89	0.02
N10813	404413	733007	87/10/27	16.0	204	5.1	10	128	0.03
N10814	404356	732909	87/10/23	15.7	266	5.3	11	164	0.07
N10815	404353	733012	87/12/09	13.6	241	5.2	5	185	<0.01
N10816	404336	732921	87/10/22	14.4	317	5.2	10	188	0.13
N10817	404336	732921	87/10/22	14.2	203	5.1	9	119	<0.01
N10818	404347	732918	87/10/23	14.7	178	6.2	11	101	0.04
N10820	404354	732945	87/12/07	14.5	321	5.4	12	193	0.89
N10821	404401	732857	87/12/09	13.9	191	5.1	8	135	0.03
N10997	404354	732945	87/12/11	12.5	97	6.5	8	63	0.02
N10998	404354	732945	87/12/10	13.9	247	5.4	33	154	<0.01
N10999	404331	732944	87/12/21	11.9	--	--	7	64	<0.01
N11000	404331	732944	87/12/14	12.9	354	5.5	24	221	0.13
B. Industrial wells									
N7518	404535	732938	87/11/10	12.1	183	5.2	4	113	<0.01
N7535	404518	733000	87/11/13	13.4	259	5.1	7	147	0.12
N7536	404518	732953	87/11/13	12.1	168	5.1	5	105	<0.01
N7635	404459	733004	87/11/10	13.4	164	5.2	5	94	0.36
N7636	404517	732949	87/11/13	15.7	282	5.4	5	166	<0.01
N7637	404516	732941	87/11/10	15.4	141	4.6	3	73	<0.01
N8124	404445	732959	87/11/13	14.1	94	5.1	3	54	<0.01
N8154	404454	732952	87/11/10	14.1	108	5.0	6	61	0.15
N8454	404524	732952	87/11/10	11.7	36	5.3	5	21	<0.01
N8643	404513	732957	87/11/10	12.1	94	5.5	3	58	<0.01
N8816	404523	732941	87/11/13	13.2	100	5.1	6	53	<0.01

Appendix 2.--Inorganic constituent analyses from the Bethpage-Hicksville-Levittown area, fall 1987--continued.

Well number	Sample date yr mo d	Nitrite as N (mg/L)	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)
					A. Observation Wells					
N9079	87/11/02	0.272	3.0	29.0	4.7	57	4.2	37	8.80	18.00
N9088	87/10/30	0.016	1.5	6.4	4.0	36	2.0	24	6.10	0.15
N9411	87/11/04	0.103	7.7	18.0	2.5	68	3.2	43	<0.05	<0.05
N9654	87/10/27	0.010	13.0	12.0	1.5	4	5.2	29	0.91	1.30
N9661	87/10/26	0.005	1.2	3.1	5.0	27	2.2	<5	0.44	0.06
N9667	87/11/04	0.005	7.7	15.0	2.2	28	3.2	24	1.50	0.73
N9918	87/11/11	0.002	4.9	7.9	1.8	6	2.0	6	0.05	0.07
N9919	87/12/14	<0.001	11.0	18.0	3.5	31	4.6	31	0.25	0.26
N9920	87/12/03	0.010	8.3	16.0	2.7	35	4.0	36	1.10	1.10
N9921	87/12/10	0.372	1.7	25.0	4.8	78	4.0	46	10.00	0.31
N9922	87/10/27	<0.001	6.6	20.0	2.5	62	3.8	23	0.37	0.53
N9929	87/10/26	<0.001	4.7	18.0	3.7	18	2.2	33	<0.05	0.16
N9931	87/11/10	<0.001	9.6	14.0	4.4	18	4.8	<5	1.50	0.01
N9932	87/11/03	<0.001	15.0	22.0	6.5	23	4.4	30	<0.05	<0.05
N10588	87/11/20	<0.001	2.7	1.20	<.1	12	1.1	10	0.22	<0.05
N10589	87/11/20	0.010	8.8	17.0	3.2	25	3.9	29	0.76	0.26
N10590	87/12/07	0.008	0.6	3.5	0.4	6	1.9	<5	1.20	0.16
N10591	87/12/08	0.003	9.4	15.0	2.8	20	3.9	21	0.20	0.10
N10592	87/12/09	<0.001	0.9	6.8	2.0	25	2.2	15	0.58	0.05
N10593	87/12/08	0.011	0.1	25.0	1.9	40	6.1	44	41.00	1.90
N10594	87/12/08	0.009	2.3	17.0	4.8	34	3.3	18	1.60	0.33
N10595	87/11/19	0.015	5.3	1.3	0.1	100	0.6	10	1.50	0.05
N10596	87/11/04	0.013	3.8	11.0	2.6	14	1.0	12	2.30	0.38
N10597	87/11/05	0.066	7.5	13.0	0.2	22	4.1	11	1.60	0.25
N10598	87/11/05	0.003	2.9	10.0	4.9	9	2.7	26	1.30	<0.05
N10599	87/11/05	0.008	4.6	7.6	1.2	12	2.2	5	0.26	<0.05
N10600	87/11/03	0.060	6.9	11.0	1.7	14	0.2	9	0.81	<0.05
N10601	87/11/02	0.005	4.6	5.8	1.5	13	1.2	<5	0.10	<0.05
N10602	87/10/28	0.010	5.7	21.0	2.2	14	3.4	27	0.62	<0.05
N10603	87/10/27	0.011	13.0	21.0	4.9	24	4.6	31	0.81	<0.05
N10623	87/11/19	0.029	4.4	7.3	2.3	17	1.3	36	0.73	0.06
N10625	87/11/19	0.005	4.0	16.0	3.4	20	5.4	27	0.71	0.97
N10626	87/11/06	0.040	3.6	15.0	3.6	9	4.8	15	3.10	0.10
N10627	87/12/17	0.024	5.4	5.5	1.1	21	1.8	21	-	-
N10628	87/11/03	0.005	1.8	1.3	<.1	29	0.7	10	0.52	<0.05
N10629	87/11/18	1.52	5.5	1.3	0.3	135	1.2	22	0.66	<0.05
N10630	87/12/17	0.010	3.4	12.0	4.8	24	5.3	43	-	-
N10631	87/11/05	0.015	4.6	6.1	1.1	11	1.1	5	2.90	0.12
N10632	87/11/02	0.009	5.5	6.0	1.4	12	1.2	7	0.80	0.06
N10633	87/11/03	0.021	3.2	3.4	0.6	9	2.5	7	0.07	<0.05
N10634	87/10/28	0.003	5.4	5.9	1.3	12	2.6	7	<0.05	0.06
N10635	87/10/27	0.023	5.3	16.0	4.0	30	5.6	30	5.60	0.35
N10636	87/11/03	0.012	2.1	16.0	2.6	18	3.0	8	1.40	0.06
N10812	87/11/20	0.009	1.2	7.2	3.2	11	1.5	28	2.90	0.13
N10813	87/10/27	0.009	6.0	16.0	2.1	15	4.8	31	0.55	0.17
N10814	87/10/23	0.042	15.0	13.0	8.3	12	5.2	27	0.15	<0.05
N10815	87/12/09	0.002	13.0	20.0	2.5	16	6.1	35	0.15	1.50
N10816	87/10/22	0.026	17.0	20.0	5.3	11	7.1	31	0.27	<0.05
N10817	87/10/22	0.004	5.5	17.0	1.9	6	4.7	29	0.21	0.20
N10818	87/10/23	0.015	4.0	11.0	3.1	7	4.1	25	0.38	0.17
N10820	87/12/07	0.025	11.0	16.0	4.4	30	5.6	35	1.40	<0.05
N10821	87/12/09	0.003	7.9	12.0	2.5	16	4.9	24	0.46	0.10
N10997	87/12/11	0.043	4.9	4.9	1.3	10	0.6	<5	2.00	<0.05
N10998	87/12/10	0.138	5.2	6.2	1.7	34	0.9	32	10.00	0.59
N10999	87/12/21	0.098	5.3	6.6	1.9	8	0.8	<5	-	-
N11000	87/12/14	0.510	11.0	21.0	7.4	33	3.8	32	4.80	0.23
				B. Industrial wells						
N7518	87/11/10	0.004	12.0	9.7	2.5	17	0.8	<5	0.08	<0.05
N7535	87/11/13	<0.001	7.5	15.0	5.2	21	1.9	21	<0.05	<0.05
N7536	87/11/13	<0.001	9.9	7.0	2.0	18	0.8	8	<0.05	<0.05
N7635	87/11/10	0.003	6.0	8.1	2.2	15	1.1	7	0.22	<0.05
N7636	87/11/13	<0.001	8.9	2.2	<.1	49	0.4	36	0.10	<0.05
N7637	87/11/10	<0.001	4.6	4.4	1.0	18	0.7	<5	0.06	<0.05
N8124	87/11/13	<0.001	4.5	4.3	0.9	8	0.7	<5	<0.05	<0.05
N8154	87/11/10	0.001	4.7	3.9	1.0	12	0.7	<5	0.20	<0.05
N8454	87/11/10	0.003	0.9	0.9	<.1	4	0.2	<5	0.10	<0.05
N8643	87/11/10	<0.001	4.2	3.9	1.0	10	0.5	<5	0.00	<0.05
N8816	87/11/13	0.004	4.8	3.3	0.6	11	0.5	<5	0.13	<0.05