RELATION BETWEEN LAND USE AND GROUND-WATER QUALITY IN THE UPPER GLACIAL AQUIFER IN NASSAU AND SUFFOLK COUNTIES, LONG ISLAND, NEW YORK

by David A. V. Eckhardt, William J. Flipse, Jr., and Edward T. Oaksford

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CONVERSION FACTORS AND ABBREVIATIONS

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

Multiply inch-pound unit	by	To obtain metric unit
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	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)
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)

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Abstract

The chemical quality of ground water in the upper glacial (water-table) aquifer in Nassau and Suffolk Counties was examined in relation to 10 types of land use to evaluate the effect of human activities on ground water. The upper glacial aquifer, which consists of unconsolidated Pleistocene deposits composed primarily of sand and gravel, overlies thick Cretaceous deposits that form the bulk of the island's aquifer system. The aquifers are the sole source of drinking water for more than 2.6 million people in the two-county area. Contamination has restricted the use of the upper glacial aquifer for public-water supply in developed areas; thus, its use is restricted except in rural areas of Suffolk County.

The water-quality data were selected from nearly 14,000 chemical analyses of samples from 903 wells in the two-county area that were made by Federal, State, and county agencies during 1978-84. Land-use categories were those used in a 1981 survey by the Long Island Regional Planning Board; they are industrial, commercial, transportation, agricultural, institutional, recreational, undeveloped areas, and four different densities of residential areas. Parametric and nonparametric statistical procedures were used to evaluate the relation between ground-water quality and the predominant land use within a 1/2-mile radius of sampled wells.

The highest median chloride and total dissolved-solids concentrations were found in wells in high-density residential areas (more than 5 dwellings per acre), and the highest median nitrate, sulfate, and calcium concentrations were found in wells in agricultural and high-density residential areas. Relatively low median concentrations of inorganic chemical constituents were found in wells in undeveloped and low-density residential areas (1 or fewer units per acre); volatile organic compounds were rarely detected in these same areas. The highest concentrations and most frequent detection of volatile organic compounds were generally in wells in industrial and commercial areas, but these compounds were also detected frequently in wells in high-density residential, institutional, and transportation areas.

The most commonly detected volatile organic compounds were 1,1,1-trichloroethane (24 percent of wells), tetrachloroethylene (20 percent), trichloroethylene, (18 percent), chloroform (9 percent), and 1,2-dichloroethylene (5 percent). The spatial distributions of trichloroethylene and 1,1,1-trichloroethane in the upper glacial aquifer are directly correlated with population density in the two-county area.

Carbofuran, a carbamate insecticide, was detected in 42 percent of wells in agricultural areas, and heptachlor epoxide, a chlorinated-hydrocarbon insecticide, was detected in 20 percent of wells in high-density residential areas.

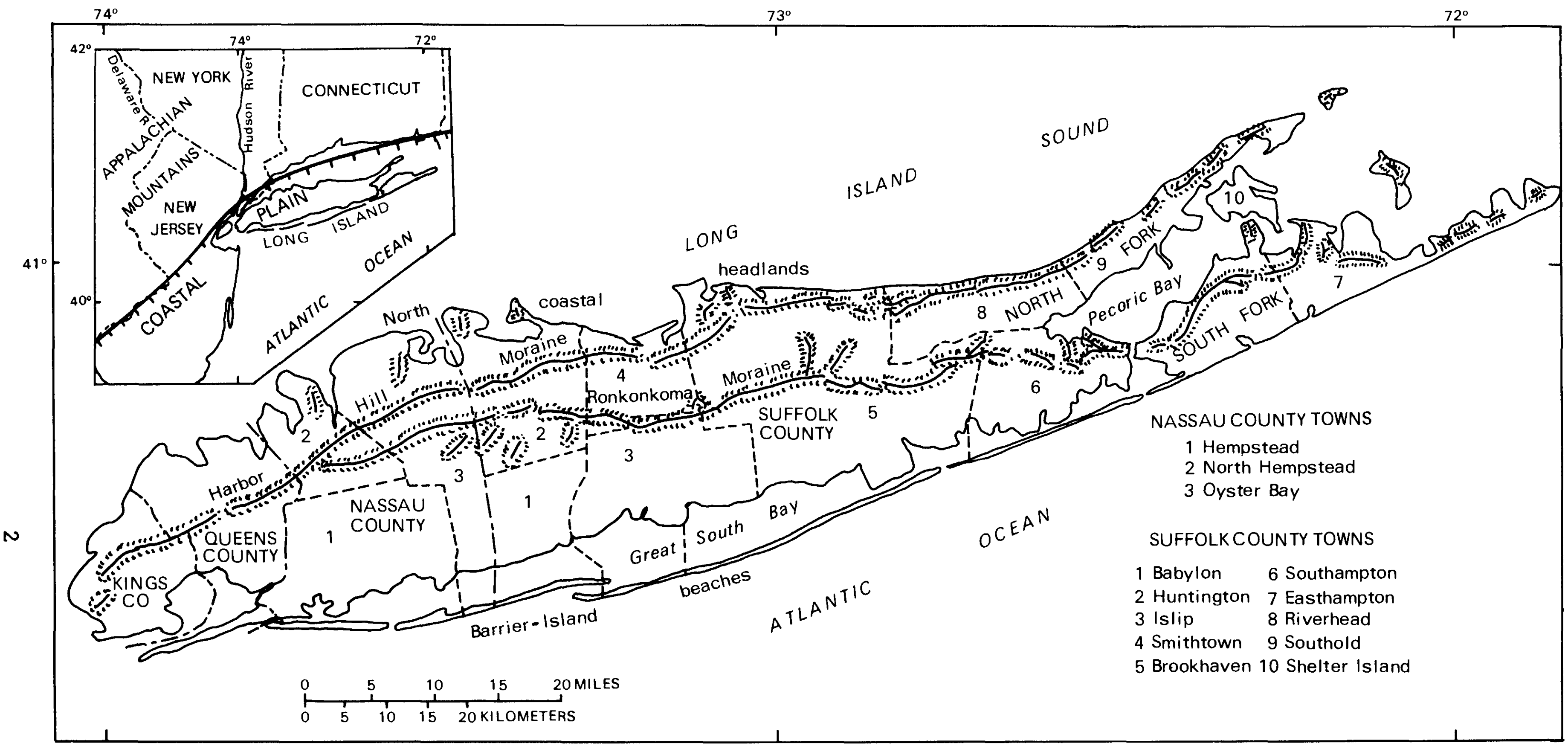


Figure 1.--Major physiographic features and Town boundaries of Long Island. Inset map shows location of Long Island in northern part of the Atlantic Coastal Plain.

Median concentrations of total dissolved solids and detection frequencies of tetrachloroethylene, trichloroethylene, and 1,1,1-trichloroethane were higher in sewered areas than in unsewered areas. This indicates that the effects of sewering in the highly developed areas of Nassau and Suffolk Counties may be obscured by other factors, such as (1) concentration of commerce and industry in sewered areas, which are sources of leaks and spills of these contaminants, and (2) potential leakage from sewers. Also, some contaminants that were present in areas before sewer installation may persist within the aquifer system.

INTRODUCTION

In 1984, the U.S. Geological Survey began preliminary regional assessments of ground-water contamination by human activities in 14 areas of the United States (Ragone, 1984). The objective was to assess the current quality of the Nation's ground water and the nature and extent of contamination in terms of local hydrogeologic conditions and land use to provide a basis for appraising ground-water quality in other areas of the country (Helsel and Ragone, 1984). The upper glacial aquifer in Nassau and Suffolk Counties on Long Island, N.Y. (fig. 1), was selected because it represents a combination of land-use categories--highly-developed suburban land, agricultural land, and relatively pristine land--in the Atlantic Coastal Plain.

About 2.6 million people in Nassau and Suffolk Counties on Long Island depend on ground water for public supply. Because of this dependency, the U.S. Environmental Protection Agency (USEPA) has designated the Long Island aquifer system as a sole source of potable water pursuant to section 1424(e) of the Safe Drinking Water Act (Public Law 93-523). The aquifer system is composed of unconsolidated Pleistocene and Cretaceous deposits of gravel, sand, silt, and clay and is bounded by crystalline bedrock on the bottom and by saltwater on the sides. The aquifer system provides sufficient freshwater for the current demand, but contamination from a variety of sources has begun to restrict its use in several areas. The effects of land development and land use on ground-water quality have therefore become a public concern.

The distribution of population and its growth pattern on Long Island has created a complex assemblage of land uses ranging from urban in boroughs of New York City in the west to virtually pristine pine-barren forests in the east. Residential housing for more than 5 million people, commercial services, industry, agriculture, and open recreational land create an aggregation of potential effects on ground-water quality that have changed with time as development progresses eastward on Long Island. An understanding of the effect of human activities on the quality of water in the aquifer system is essential to the development of water-management plans by local agencies.

The highly permeable sand and gravel deposits that form the water-table aquifer are exposed at land surface and thus provide a direct pathway for contaminant entry to the aquifer system. The shallow aquifer system on Long Island has already been affected by man's activities (Katz and Lindner, 1978; Katz and others, 1980; Ragone and others, 1981). Contamination by nitrates and detergents (Flynn and others, 1958; Perlmutter and Koch, 1964 and 1971; Perlmutter and Guerrera, 1970; Smith and Myott, 1975) was detected in the

1940's. More recently, synthetic organic compounds were discovered in ground water in Nassau and Suffolk Counties. The most commonly detected organic contaminants have been tetrachloroethylene, trichloroethylene, 1,1,1-trichloroethane, chloroform, and trichlorofluoroethane, which are used primarily as industrial and commercial solvents (Myott, 1980; Suffolk County Department of Health Services, 1984a). Aldicarb, a pesticide that was used from about 1970 until 1981 for controlling potato beetles and golden nematodes, has also been detected in more than 2,000 wells, primarily in agricultural regions of Suffolk County (Baier and Robbins, 1982a,b; Trautmann and others, 1983; and Soren and Stelz, 1985). The detection of these and other contaminants in ground water has prompted an increase in monitoring of ground-water quality on Long Island, and Federal, State, county, and municipal agencies maintain extensive records of organic and inorganic chemical analyses of ground-water samples. Thus, Nassau and Suffolk Counties were chosen as a representative area where human effects on ground-water quality could be statistically evaluated.

Purpose and Scope

This study was designed to statistically evaluate and compare chemical data from ground-water samples representing 10 categories of land use on Long Island. The samples were collected from the upper glacial aquifer in Nassau and Suffolk Counties during 1978-84. The study included only Nassau and Suffolk Counties (fig. 1) because the aquifer system is their sole source of water supply and because extensive data describing land use and ground-water quality are available. (Kings and Queens Counties form a part of New York City and have far less ground-water data because most of their water is from surface-water reservoirs on the mainland north and west of the city.) The upper glacial (water-table) aquifer was selected for this study because it has been directly affected by contamination from land surface.

This report describes ground-water quality in relation to land use and population distribution through statistical procedures. Emphasis is on contamination by organic compounds, but contamination by several inorganic constituents, such as nitrate, sulfate, potassium, calcium, chloride, and total dissolved solids, is also addressed. The report is preliminary because methods for studies of this type are still in the developmental stage; these methods will continue to be refined for use in subsequent studies to evaluate the effects of land use on water quality in areas that recharge deeper parts of the Long Island aquifer system.

Acknowledgments

Many officials from State, county, and local agencies on Long Island provided published material and analytical data. Philip Barbato of the New York State Department of Environmental Conservation provided data and maps showing locations of contaminated public-supply wells, leaks and spills of toxic substances, and sewage and industrial-wastewater discharges. Dennis Moran, Steven Cary, and Ronald Greene of the Suffolk County Department of Health Services provided analytical data on private and public-supply wells, which included data collected under Suffolk County's pesticide monitoring program. Michael Alarcon of the Nassau County Health Department, Bureau of Public Water Supply, provided lists of contaminated public-supply wells and analytical data on organic compounds in samples collected during local studies

in Nassau County. James Mulligan and Richard Liebe of the Nassau County Department of Public Works, Water Supply Unit, provided analytical data on organic compounds in samples collected from the county's observation-well network. Arthur Kunz and Edith Tannenbaum of the Long Island Regional Planning Board, and Peter French of Resources Planning Associates, Inc., provided land-use data and help in data interpretation. Carole Swick and Roy Fedelem of the Long Island Regional Planning Board provided population-density statistics. Funding was provided by the U.S. Geological Survey's Toxic Waste--Ground-Water Contamination Program.

METHODS

The approach used in this study is based on the premise that land use may affect water quality in shallow underlying aquifer systems and that the types and amounts of chemicals that are introduced at the surface and may reach ground water are related to land use (Helsel and Ragone, 1984). Testing the relation between land use and ground-water quality requires (1) accurate characterization of land use, hydrogeologic conditions, and ground-water quality (through representative sampling) and (2) valid statistical analyses.

Water-Quality Data

The data used in this study include all water-quality data from the Geological Survey's WATSTORE system for wells in the two-county area and data from several county agencies. Analytical data from 13,894 samples collected from 903 wells during 1978-84 were used. (Well distribution is shown in fig. 2.) The Suffolk County Department of Health Services provided data on samples from an additional 127 wells having analyses for aldicarb pesticide and 478 wells having volatile organic compound analyses. The Nassau County Health Department contributed results of organic chemical analyses of routine samples collected from 58 wells during 1978-81. The Nassau County Department of

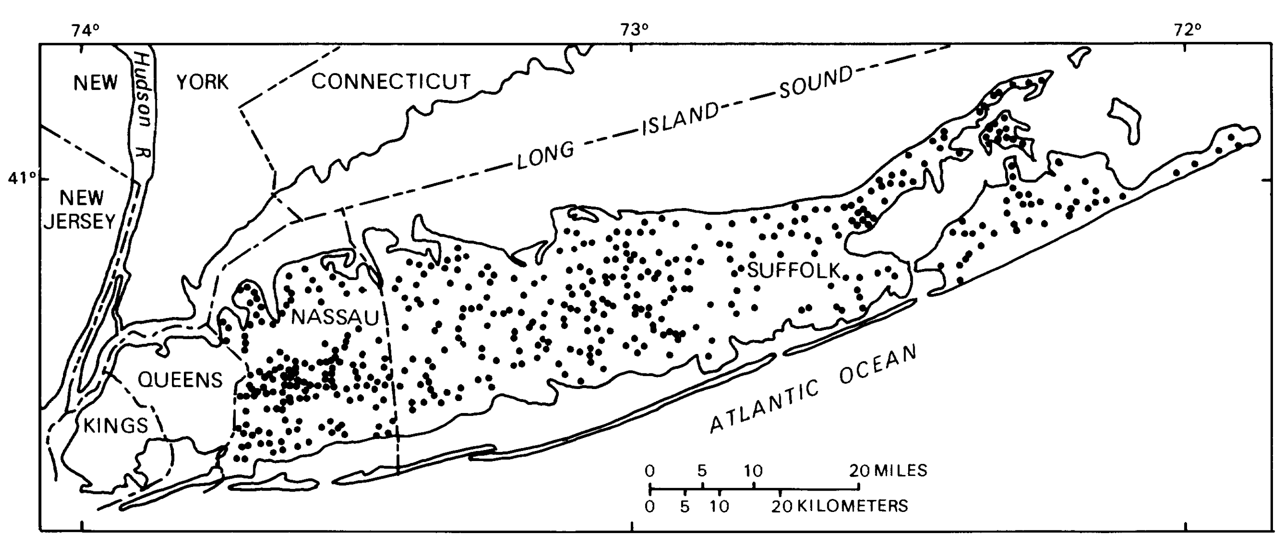


Figure 2.--Locations of wells having 1978-84 water-quality data.

Public Works contributed results of analyses of 85 samples that were routinely collected from monitoring wells during 1983-85. Organic chemical analyses of samples collected by the Geological Survey from 84 wells in central Nassau County were also used. Only one analysis, the most recent determination for each constitutent of interest, was used for each well in the statistical analyses; this enabled statistical determination of current water quality amid the changing land-use conditions by equally weighting data from each well.

Water-quality data from several types of wells were used in this study, including monitoring and production wells. Screen and casing material included stainless steel, polyvinyl chloride (PVC), and fiberglass. Median depth of screen penetration below the water table was 31 ft; the 25th and 75th percentile depths, which indicate the range for half the screen-penetration depths about the median, were 17 and 86 ft, respectively. Sampling procedures are generally not documented because the data were collected by several agencies over a period of 7 years; however, agencies that contributed data follow recommended procedures for sample collection. Most of the analyses were conducted by the U.S. Geological Survey or by laboratories operated by Nassau and Suffolk Counties, which participate in the U.S. Geological Survey's standard-reference-sample program.

Land-Use Data

A 1981 land-use survey by the Long Island Regional Planning Board (1982a) differentiated 12 types of land use:

- Undeveloped
- Institutional
- Agricultural
- Recreation
- Commercial
- Marine commercial
- Transportation, communication, and utilities
- Industrial
- Low-density residential (fewer than 2 dwellings per acre)
- Medium-density residential (2 to 4 dwellings per acre)
- Intermediate-density residential (5 to 10 dwellings per acre)
- High-density residential (11 or more dwellings per acre)

The land-use data contained in that report were given as percentages of total area and as total area for cells on a map containing a 762-cell grid overlay in which each cell represented 1,440 acres (2.25 mi^2). A summary of land use based on results of the 1981 survey and earlier surveys is given further on in the section "Land Use in Nassau and Suffolk Counties" (p. 11).

The land use occupying the greatest percentage of land area in the 1/2-mi radius around each well was identified from the 1981 map. The reason for using a 1/2-mi radius of influence around each well is that ground water in the upper glacial aquifer moves about 1/2 mi in 7 years at an average horizontal flow rate of 1 ft/d, and the water-quality data used in the statistical analyses were selected from 1978-84, a 7-year period that overlaps the 1981 land-use data that were used. This approach is assumed to reflect the predominant source of potential contamination near each well.

Statistical Procedures

Three types of statistical procedures were used to hypothesize relationships between land use and ground-water quality. They were: (1) parametric procedures that quantify means, medians, and variances within discrete land-use categories of water-quality data; (2) nonparametric procedures that compare ranks of concentrations (from lowest to highest) in each land-use category, and (3) contingency-table analyses that compare detection frequencies of values within each land-use category. Helsel and Ragone (1984) show that all three types of procedures have certain advantages and disadvantages that are dependent on the types of data that are analyzed.

The statistical procedures used quantify the probabilities that significant differences exist among groups of water-quality data in differing land-use categories. The significance level, alpha, describes the probability of falsely detecting differences among chemical data from different land-use categories and was chosen to be 0.05 (95-percent confidence level) for all significance tests herein.

LONG ISLAND GROUND-WATER SYSTEM

Considerable information on the water resources of Long Island is available as a result of more than 45 years of study by the U.S. Geological Survey in cooperation with State and local agencies. Descriptions of the hydrogeologic framework and ground-water movement in the aquifer system are given in several reports, including Cohen and others, (1968); Cohen and others (1969); Jensen and Soren (1971, 1974); Franke and Cohen (1972); McClymonds and Franke (1972); and Franke and Getzen (1976).

Hydrogeologic Framework

Long Island is underlain by a mass of unconsolidated deposits that unconformably overlie gently southward sloping, relatively impermeable crystalline bedrock. The deposits are about 2,000 ft thick in south-central Suffolk County. The ground-water system consists of a vertical sequence of aquifers and confining units of Pleistocene and Cretaceous gravel, sand, silt, and clay, and mixtures thereof (fig. 3). The Lloyd aquifer, Raritan confining unit, and Magothy aquifer, all of Cretaceous age, are the oldest deposits and form the bulk of the aquifer system. The Monmouth greensand--a shallow marine deposit of Cretaceous age--overlies the Magothy aquifer along the southern part of Long Island, primarily in Suffolk County. (The Monmouth greensand is not shown in fig. 3 because that geologic section is in Nassau County.) The Gardiners Clay--an interglacial marine clay of limited extent--overlies the Cretaceous deposits in the southern part of the island where it and the Monmouth greensand hydraulically separate the Magothy aquifer from the overlying upper glacial aquifer. The upper glacial (water-table) aquifer at the top of the sequence is composed of Pleistocene moraine and outwash deposits typical of glacial deposits in the Northeast. The system also contains less extensive hydrogeologic units such as the Jameco aquifer in the southwestern part of Long Island and the Port Washington aquifer in the northern part of Nassau County (neither of which appears in fig. 3).

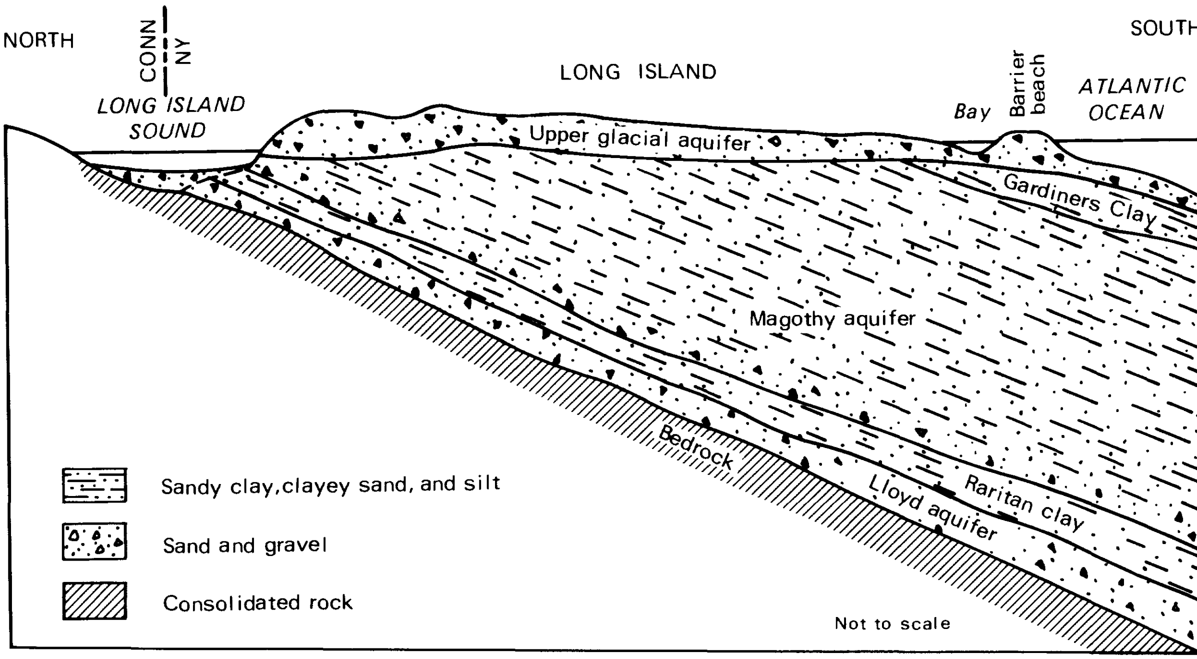


Figure 3.--Generalized geologic section of the Long Island aquifer system in Nassau County. (Modified from Franke and McClymonds, 1972, p. F10.)

The upper glacial aquifer is nearly continuous across Long Island except in small areas in northeastern Nassau County and northwestern Suffolk County, where the Pleistocene deposits are unsaturated and the water table is in the underlying Magothy aquifer. The upper glacial aquifer covers about 92 percent of the Nassau-Suffolk County area. In general, the aquifer is thickest near the north shore of the island and in eastern Suffolk County. Hydraulic conductivity is greatest (270 ft/d and higher) in most of the southern part of the island, where the outwash deposits are coarse sand and gravel. Hydraulic conductivity is about 130 ft/d and lower in north-central areas, where the deposits contain more silt and clay than elsewhere (McClymonds and Franke, 1972). Several Pleistocene clay units in the upper glacial aquifer have been identified and mapped in parts of Long Island; these include the "Smithtown clay" (Krulikas and Koszalka, 1983), the "Manorville clay" (deLaguna, 1963), and the "20-foot clay" (Doriski and Wilde-Katz, 1983). The clay units retard the vertical movement of water in the upper glacial aquifer and thus separate deeper zones of the aquifer from the water table in areas where they occur.

Ground-Water Movement

Fresh ground water originates as precipitation, which, on Long Island, averages about 44 inches annually. About half the precipitation percolates through the sandy soils at land surface and recharges the ground-water system; the remainder runs off or evaporates. Under predevelopment conditions, about 43 percent of the recharge entering the system flowed laterally through the upper glacial aquifer and discharged to streams; the rest percolated downward and laterally through deeper parts of the aquifer system and then eventually discharged to tidewater (H. T. Buxton, U.S. Geological Survey, written commun., 1985). Areas in which ground-water movement is primarily downward from the upper glacial aquifer into deeper formations are designated as recharge areas; those where ground water from the deeper formations moves upward into the upper glacial aquifer or discharges into saltwater bodies are designated as discharge areas. The delineation of these zones is important because toxic chemicals entering the aquifer system in recharge zones may eventually contaminate parts of deeper aquifers that are sources for public-water supply.

Ground-water movement is three dimensional but may be visualized as having horizontal and vertical components of flow. The horizontal components of ground-water movement in the upper glacial aquifer can be deduced from water-table-contour maps, such as that by Donaldson and Koszalka (1983). In general, water north of the regional ground-water divide, which trends east-west along the island, moves northward toward Long Island Sound, and water south of the divide moves southward toward the Atlantic Ocean (fig. 4). The rate of horizontal flow in the upper glacial aquifer is controlled by the hydraulic gradient of the water table and by the water-transmitting characteristics of the aquifer material. Horizontal velocity in the upper glacial aquifer generally ranges from 1 to 2 ft/d; vertical flow is much slower, especially where confining layers restrict the upward or downward movement of water. Residence times of water in the shallow flow systems in the upper glacial aquifer generally are less than 30 years (Franke and Cohen, 1972).

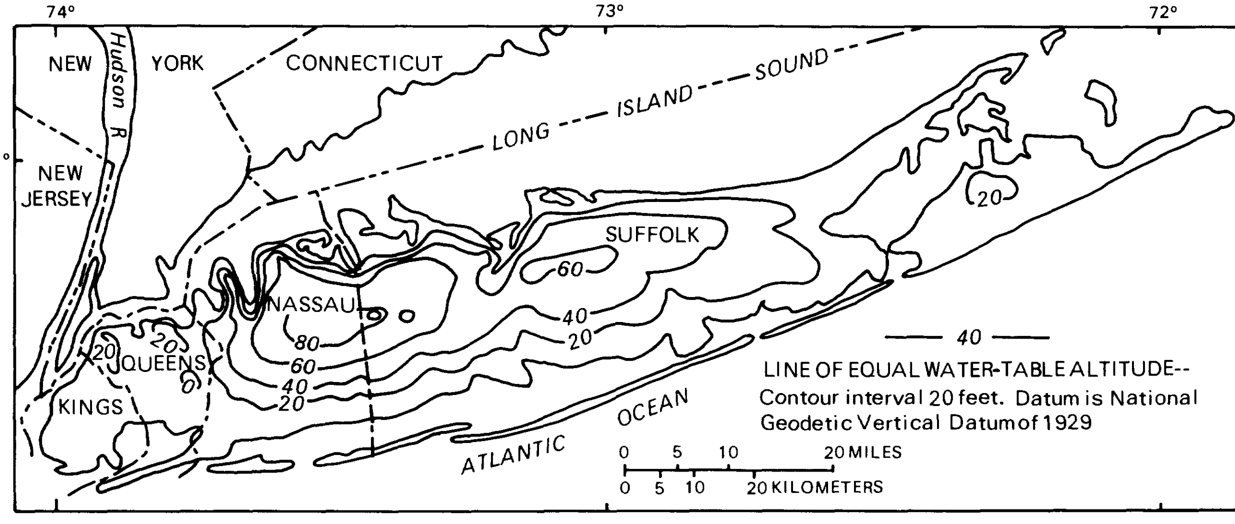


Figure 4.--Water-table altitude in Nassau and Suffolk Counties in 1984. (Modified from Doriski, 1987.)

Influence of Man on the Hydrologic System

Ground-water development on Long Island has passed through three major stages (Cohen and others, 1969; Reilly and others, 1983). In the early years of development, before 1900, domestic and public-supply wells tapped the upper glacial aquifer, and the water was returned to the hydrologic system through open-bottom cesspools. In the second stage, from 1900 to the early 1950's, when the island's population was expanding rapidly, contamination of the upper glacial aquifer by drainage from cesspools eventually forced abandonment of many wells, and new wells were drilled deeper to tap the Magothy aquifer. Still, water was returned to the system through cesspools, and the net loss of ground water from the system remained negligible. In the third (present) stage of development, since the 1950's, large-scale sewer systems have been installed to replace cesspools and divert the wastewater to treatment plants and from there to the sea. This has improved the quality of water within the upper glacial aquifer but also causes a net loss of water from the system, which has resulted in lowering of the water table, the shortening of streams in sewered areas, and some intrusion of saltwater in southwestern Nassau County. The hydrologic effects of sewering are discussed in more detail by Ku and Simmons (1981, 1983), Reilly and others (1983), Buxton and Reilly (1985), and Reilly and Buxton (1985).

The increase in ground-water pumpage during the latter two stages of ground-water development (1940-80) is shown in figure 5. Gross pumpage, which includes all public-supply and principal industrial and commercial pumpage, increased from 30 Mgal/d in Suffolk County in 1940 to 201 Mgal/d in 1980 and from 75 Mgal/d in Nassau County in 1940 to 210 Mgal/d in 1980. Pumpage from domestic wells is not included in the gross value because it is not metered; residential pumpage in Nassau County is probably negligible, but that in Suffolk County is estimated to have been 16.5 Mgal/d in 1980 (Suffolk County Department of Health Services, 1984b), primarily from the upper glacial aquifer.

In Nassau County, water pumped for public supply is obtained from four aquifers. The greatest pumpage is from the Magothy aquifer (91 percent); the remainder is from the Lloyd aquifer (5 percent), the Jameco aquifer (3 percent), and the upper glacial aquifer (1 percent) (Holzmacher, McLendon, and Murrell, 1980a,b). In Suffolk County, most of the public-supply water is

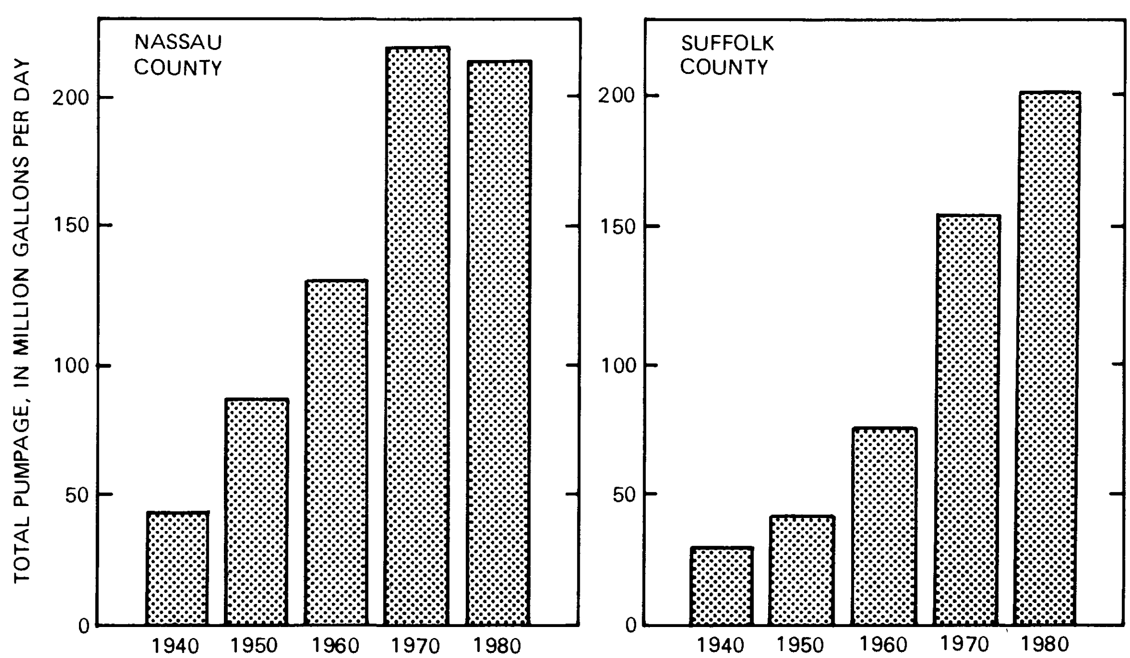


Figure 5.--Total pumpage of ground water from all aquifers in Nassau and Suffolk Counties, 1940-80. (Data from Holzmacher, McLendon, and Murrell, 1980a,b, and Suffolk County Department of Health Services, 1984b.)

pumped from the upper glacial aquifer (58.1 percent), and the remainder is from the Magothy (41.5 percent) and Lloyd (0.4 percent) aquifers (Suffolk County Department of Health Services, 1984b). The greater pumpage from the upper glacial aquifer in Suffolk County reflects the better ground-water quality there than further west; in Nassau County, contamination of the upper glacial aquifer has forced most wells to be abandoned or deepened into the Magothy aquifer.

Increased withdrawal of water from the Magothy aquifer in recharge areas can increase the downward velocity of water in areas above the pumping centers because heavy pumping increases the vertical hydraulic gradients. Thus, contaminants in the shallow aquifer system near pumping centers can be moved deeper into the system and at rates greater than the natural flow patterns would indicate. The presence of trichloroethylene in the basal section of the Magothy aquifer in central Nassau County has been attributed in part to cooling-water and public-supply pumping in that area (Eckhardt and Pearsall, 1985). Reilly (1978) and Phillips and Gelhar (1978) have shown that aquifer characteristics, screen locations and depths, pumping rates, and regional hydraulic gradients all affect the downward movement of contaminants.

Man has also influenced the hydrologic system by installing more than 3,000 recharge basins in the surficial deposits of Long Island, primarily in eastern Nassau and western Suffolk Counties. The basins receive storm runoff from roads and other impervious surfaces and thereby reduce local flooding and increase recharge to the underlying aquifers. Studies of the chemical quality of urban runoff (Koppelman, 1982) have questioned whether urban stormwater alters the quality of ground water beneath recharge basins. In a recent study of the chemical quality of storm runoff and ground water beneath five basins, Ku and Simmons (1987) found that most of the trace elements and all bacteria in stormwater entering the basins were removed in the unsaturated zone, but chloride (from deicing salts in winter) had entered the aquifer system in elevated concentrations.

LAND USE IN NASSAU AND SUFFOLK COUNTIES

Land use on Long Island has been described extensively by the Nassau County Planning Commission (1959), the Suffolk County Department of Planning (1962), the Nassau-Suffolk Planning Board (1968), the Long Island Regional Planning Board (1977, 1982a,b), and Koppelman (1978a,b). As part of the 1981 land-use survey by the Long Island Regional Planning Board (1982a), a color land-use map of the Nassau-Suffolk County region was divided into a grid of square cells, each representing 1,440 acres. The map was then videodigitized by cell to determine what percentage of the two-county area was represented by each land-use category. The distribution of major land uses, based on the predominant use within each grid cell, is shown in plate 1A.

According to the 1981 land-use survey, residential land accounted for 32 percent of the two-county area, which represents all densities of residential land use given by Long Island Regional Planning Board (1982a). The remaining land is undeveloped (27 percent); recreational (16 percent); agricultural (8 percent); transportation, communications, and utilities (7 percent);

institutional (5 percent); commercial (3 percent); and industrial (2 percent). Marine commercial land-use areas were negligible. The land-use percentages for each county are plotted in figure 6.

The population of Nassau and Suffolk Counties in the late 1700's was about 27,000 (Long Island Regional Planning Board, 1982b). Nassau County's population increased steadily to about 1.4 million in 1970 and then dropped by 1980 to 1.3 million, the same as in 1960. The downward trend in population since 1970 is due to migration to the more rural Suffolk County. Suffolk County's population grew at a slower rate than Nassau County's until 1950, then quadrupled during 1950-70. Unlike Nassau County, Suffolk County continued to grow through the 1970's, although at a significantly reduced rate, and had about 1.3 million people in 1980.

Population density, shown on plate 1B, was derived from a population survey compiled in 1980 by the Long Island Regional Planning Board (Carole Swick, Long Island Regional Planning Board, written commun., 1985); each cell on the plate is assigned an area-weighted average. On a regional scale, the major concentration is in Nassau County, especially the southwestern part. The south shore is generally more populated than elsewhere, although some areas in the central and northern parts of the county are becoming densely populated. The most densely populated areas in Suffolk County are in the western Towns of Huntington, Islip, and Babylon (fig. 1); the eastern half of the county has a relatively uniform density of one to two people per acre. The south shore in Suffolk County generally has a greater population density than the north shore, as in Nassau County.

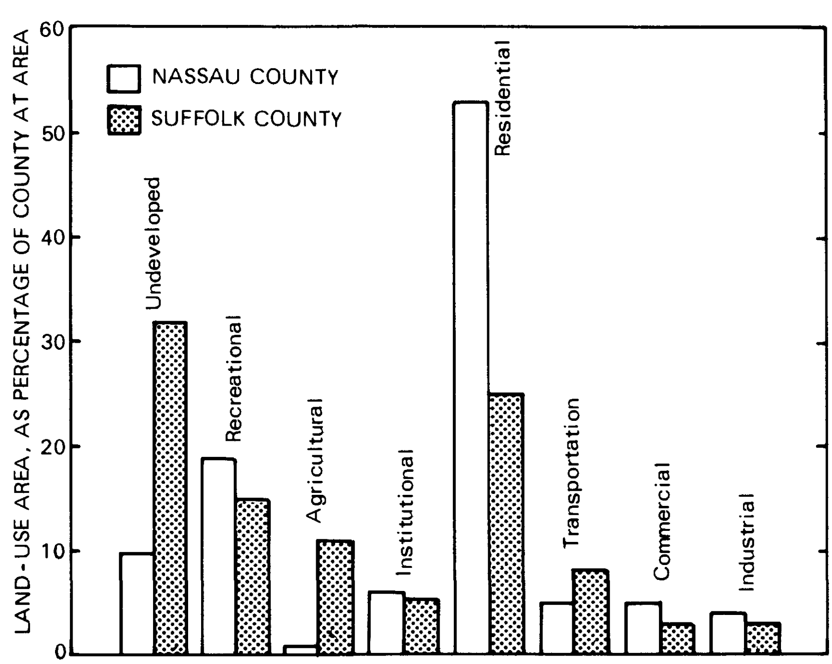


Figure 6.--Land use in Nassau and Suffolk Counties in 1981. (Data from Long Island Regional Planning Board, 1982a.)

RELATION BETWEEN LAND USE AND GROUND-WATER QUALITY

Statistical procedures were applied to water-quality and land-use data to analyze sources of variability in the data and identify relationships between ground-water quality and land use. Water-quality data were divided into 10 categories, each representing the major land use (by area) within a 1/2-mi radius of each well. Water-quality data for the "intermediate-density residential" category were sparse and did not differ significantly from data in the "high-density residential" category, and data for the two categories were combined; no data for the "marine commercial" category were available. The statistical analysis was applied to selected inorganic chemical constituents, volatile organic compounds, and pesticides; the distribution and occurrence of selected inorganic chemical constituents and volatile organic compounds in sewered and unsewered areas for the 10 land-use categories were also evaluated.

Inorganic Chemical Constituents

Median concentrations and interquartile ranges for selected inorganic constituents and properties for 10 land-use groupings are given in table 1. Results of Kruskal-Wallis statistical tests (Kruskal and Wallis, 1952; Conover, 1980) indicate that some of the 10 land-use categories listed show significant differences in concentrations of all eight constituents except alkalinity; no differences were seen in alkalinity concentrations among the land-use categories. Tukey's honest significant difference test was done on ranks of data (Stoline, 1981) for each chemical constituent except alkalinity. Letter designations for the multiple-comparison Tukey's tests indicate which land-use categories do not differ statistically for the given water-quality constituent (table 1); for example, median nitrate concentrations in the undeveloped, recreational, and transportation categories are not significantly different and are designated by the letter C. The results generally show that the highest concentrations of inorganic chemical constituents are in the agricultural, commercial, and high-density residential categories, whereas the lowest concentrations are in the undeveloped, recreational, and low- and medium-density residential categories.

The highest median concentrations of nitrate (6 mg/L as N), sulfate (40 mg/L), and calcium (19 mg/L) were found in wells in the agricultural category, presumably as a result of fertilizers. The highest median specific conductance (296 μS/cm at 25° C), total dissolved solids (202 mg/L), and chloride concentrations (31 mg/L) were found in wells in the high-density residential category. In contrast, the lowest median nitrate (0.7 mg/L as N), sulfate (10 mg/L), potassium (1.0 mg/L), and calcium (5.8 mg/L) concentrations were found in wells in the undeveloped category; the lowest median specific conductance (106 μS/cm) and the second-lowest median total dissolved solids concentration (82 mg/L) were also in the undeveloped category. Median chloride concentrations, which are directly correlated to specific conductance and total dissolved-solids concentrations, were lowest in the low-density and medium-density residential, recreational, and undeveloped categories.

Box plots showing nitrate concentrations for each of the land-use categories are shown in figure 7. The highest medians and greatest variability in nitrate data, indicated by boxes showing the interquartile

Table 1.--Median concentration and interquartile range (IQR) of the eight selected inorganic ground-water constituents in the upper glacial aquifer in 10 land-use categories in Nassau and Suffolk County 1978-84.[1]

Constituent,[2] property, and statistic	Land-use category: Undeveloped	Recreational[3]	Agricultural	Institutional	Low-density residential[4]	Medium-density residential[4]	High-density residential[4]	Transportation[5]	Commercial	Industrial	All land uses combined
Nitrate, as N											
median	0.7	1.9	6.0	2.4	2.8	2.9	4.6	2.0	3.3	2.3	2.4
IQR[6]	1.9	3.1	7.5	4.5	3.8	4.4	7.0	3.7	5.8	4.7	4.8
number of wells	79	77	58	64	29	133	71	46	27	26	610
Tukey's test[7]	C	BC	A	AB	AB	AB	AB	BC	AB	AB	
Chloride											
median	15	13	20	20	12	16	31	23	25	22	18
IQR	17	17	14	31	9.8	13	28	72	23	31	23
number of wells	80	96	60	71	34	134	78	57	33	32	675
Tukey's test	BCD	CD	ABC	ABC	D	BCD	A	AB	AB	AB	
Sulfate											
median	10	14	40	19	13	12	37	16	30	26	16
IQR	8	26	55	44	16	17	36	31	23	24	29
number of wells	81	98	60	72	38	134	86	52	34	33	688
Tukey's test	C	BC	A	AB	BC	BC	A	AB	AB	BC	
Potassium											
median	1.0	1.2	3.0	3.8	1.3	1.6	4.3	2.6	1.9	3.2	1.9
IQR	0.7	1.3	3.5	5.0	0.9	2.1	3.8	7.8	2.3	6.6	3.3
number of wells	45	50	42	25	9	36	39	35	18	10	309
Tukey's test	C	BC	AB	AB	BC	ABC	A	AB	ABC	A	
Calcium											
median	5.8	8.9	19	8.7	8.8	9.3	16	7.8	14	13	9.5
IQR	6.3	8.4	25	14	9.1	7.1	9.0	9.6	14	8.4	11
number of wells	72	61	53	40	19	97	42	35	19	23	461
Tukey's test	D	ABCD	A	ABCD	BCD	ABCD	AB	CD	ABC	AB	

Constituent,[2] property, and statistic	Land-use category										
	Undevel-oped	Recrea-tional[3]	Agricul-tural	Institu-tional	Low-density resi-dential[4]	Medium-density resi-dential[4]	High-density resi-dential[4]	Transpor-tation[5]	Com-mercial	Indus-trial	All land uses combined
Alkalinity, as $CaCO_3$											
median	12	12	13	18	17	15	15	18	31	16	15
IQR	7	15	4	43	26	11	13	94	38	14	19
number of wells	16	29	9	34	13	54	48	24	16	8	251
Tukey's test[8]	--	--	--	--	--	--	--	--	--	--	
Specific conductance, in KS/cm											
median	106	140	220	165	137	155	296	181	202	220	165
IQR	80	128	204	217	177	118	208	269	172	178	166
number of wells	82	90	59	67	32	130	83	53	34	30	660
Tukey's test	C	BC	AB	B	BC	BC	A	B	AB	AB	
Total dissolved solids											
median	82	105	128	170	112	78	202	152	142	110	111
IQR	33	80	141	156	109	65	100	430	174	97	118
number of wells	42	55	14	52	30	81	49	32	17	19	391
Tukey's test	D	BCD	ABC	AB	ABCD	CD	A	AB	ABC	BCD	

1 Analytical data from the most recent sampling date at each well were used to compile the summary statistics.
2 All concentrations in milligrams per liter (mg/L), except where noted. Median and IQR values computed by methods of Gilliom and Helsel (1986).
3 Includes parkways.
4 Low-density residential areas contain fewer than 2 dwelling units per acre; medium-density areas have 2 to 4 dwellings per acre; high-density areas have more than 4 dwellings per acre.
5 Includes utilities and communication facilities.
6 Interquartile range (IQR) is the 75th percentile minus the 25th percentile, which defines the range of 50 percent of the data around the median.
7 Medians with same letter for Tukey's test are not significantly different; for example, median nitrate concentrations in undeveloped areas are not significantly different from those in recreational and transporation categories. Alpha = 0.05.
8 No significant difference among land-use categories.

ranges, are in agricultural and high-density residential areas, whereas the lowest medians and least variability are in undeveloped, transportation, and recreational areas.

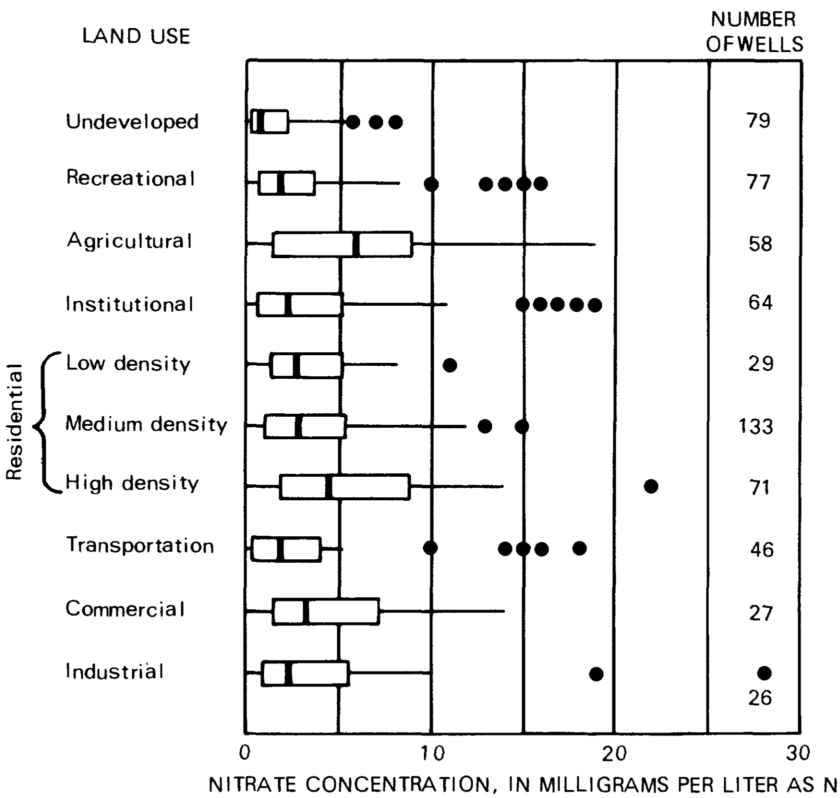


Figure 7.

Nitrate concentrations in ground water from 10 land-use categories. Boxes show the interquartile range (IQR), which is the middle 50 percent of data (25th to 75th percentile). Bar in the box is the median (50th percentile). Horizontal lines to left and right of box extend to extreme values not designated as outliers (values within 1.5 IQR); individual outliers beyond the horizontal lines are shown as ●. (Kleiner and Graedel, 1980).

Volatile Organic Compounds

Ground water in the upper glacial aquifer has been contaminated by volatile organic compounds from a variety of sources, including industrial discharges, landfills, municipal-wastewater discharges, leaks and spills, and possibly domestic cesspool effluent. The percentages of wells in the upper glacial aquifer having concentrations of selected volatile organic compounds and pesticides that exceeded detection limits within each of the 10 land-use categories are given in table 2. The most commonly detected volatile organic compounds in the upper glacial aquifer are 1,1,1-trichloroethane (24 percent of wells), tetrachloroethylene (20 percent), trichloroethylene (18 percent), chloroform (9 percent), and 1,2-dichloroethylene (5 percent). These compounds were also detected in earlier studies of organic contamination in Nassau County (Myott, 1980) and Suffolk County (Suffolk County Department of Health Services, 1984a). The compounds are low-molecular-weight chlorinated hydrocarbons used primarily as industrial and commercial solvents. Chloroform is a trihalomethane that results from chlorination of water containing an organic substrate. 1,2-Dichloroethylene may be a biodegradation product of tetrachloroethylene and trichloroethylene (Parsons and others, 1984; Kleopfer and others, 1985) but may also be a manufacturing by-product associated with trichloroethylene and tetrachloroethylene. The considerable mobility of these compounds

Table 2.--Percentage of upper glacial aquifer wells in Nassau and Suffolk Counties that had samples of selected volatile organic compounds and pesticides with concentrations above detection limits, by land-use category, 1978-84.

[Number in parentheses is total number of wells contributing water-quality data within each land-use category; dashes indicate data unavailable]

Constituent	Detection limit (µg/L)	Land-use category: Undeveloped	Recreational[1]	Agricultural	Institutional	Low-density residential[2]	Medium-density residential[2]	High-density residential[2]	Transportation[3]	Commercial	Industrial	All land uses combined
Volatile Organic Compounds												
Tetrachloroethylene	1-5	0	12	2	21	8	21	33	15	42	51	20
		(76)	(64)	(55)	(47)	(26)	(129)	(92)	(59)	(48)	(45)	(641)
Trichloroethylene	1-5	0	11	4	17	8	13	37	14	41	44	18
		(76)	(64)	(55)	(47)	(26)	(129)	(93)	(59)	(49)	(45)	(643)
1,1,1-Trichloroethane	1-5	0	19	0	38	12	29	42	17	29	47	24
		(76)	(64)	(55)	(47)	(26)	(129)	(92)	(59)	(49)	(45)	(642)
1,2-Dichloroethylene	1-5	0	0	0	2	0	4	12	2	11	12	5
		(68)	(59)	(40)	(46)	(24)	(115)	(83)	(50)	(45)	(43)	(573)
Carbon tetrachloride	1-5	0	0	0	0	4	1	00	12	2	1	
		(76)	(64)	(55)	(44)	(25)	(129)	(76)	(59)	(49)	(44)	(621)
Chloroform	1-5	7	8	4	2	8	4	22	14	14	9	9
		(76)	(64)	(55)	(44)	(25)	(129)	(77)	(59)	(49)	(44)	(622)
Chlorobenzene	1-5	0	0	0	0	0	0	0	5	0	0	<1
		(74)	(55)	(54)	(45)	(24)	(113)	(87)	(59)	(48)	(44)	(603)
Benzene	1-5	0	0	0	0	0	2	2	9	2	2	2
		(74)	(57)	(54)	(42)	(21)	(123)	(70)	(58)	(49)	(44)	(592)
Toluene	1-5	0	0	0	0	0	2	1	9	2	2	2
		(74)	(57)	(54)	(42)	(21)	(123)	(70)	(58)	(49)	(44)	(592)
Pesticides												
Aldicarb	2	0	0	0	0	0	0	0	0	0	--	0
		(36)	(16)	(43)	(5)	(2)	(10)	(3)	(8)	(4)	(0)	(127)
Carbofuran	2	0	6	42	0	0	0	0	0	0	--	15
		(36)	(16)	(43)	(5)	(2)	(10)	(3)	(7)	(4)	(0)	(126)
DDT	0.01	--	0	--	22	--	--	0	0	0	0	5
		(0)	(3)	(0)	(9)	(0)	(0)	(14)	(12)	(3)	(1)	(42)
Heptachlor epoxide	0.01	0	33	0	0	0	0	20	7	25	0	11
		(4)	(3)	(1)	(9)	(1)	(3)	(15)	(14)	(4)	(1)	(55)
Chlordane	0.1	0	0	0	11	0	0	7	0	25	0	5
		(4)	(3)	(1)	(9)	(1)	(3)	(15)	(15)	(4)	(1)	(56)

1 Includes parkways.
2 Low-density residential areas contain fewer than 2 dwelling units per acre; medium-density areas have 2 to 4 dwellings per acre; high-density areas have more than 4 dwellings per acre.
3 Includes utilities and communication facilities.

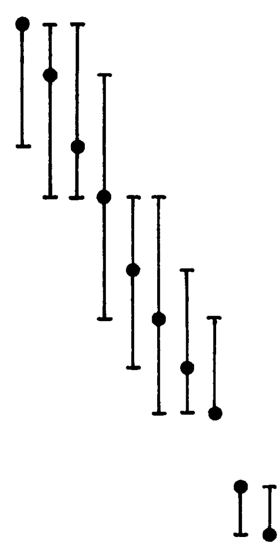
in some ground-water systems, described by Roberts and others (1982), is responsible in part for the migration of these compounds to deeper parts of the Long Island aquifer system (Myott, 1980; Eckhardt and Pearsall, 1985).

Trichloroethylene, 1,1,1-trichloroethane, and tetrachloroethylene were detected most frequently (generally in more than 20 percent of wells) in medium-density, and high-density residential, commercial, and industrial land-use areas. The same compounds were also frequently detected in institutional areas, recreational areas (which include vehicular parkways that traverse Long Island), and in transportation areas. The compounds were not detected in undeveloped areas and were detected infrequently in agricultural and low-density residential areas (table 2). The results of a contingency-table statistical analysis (Bhattacharyya and Johnson, 1977; Conover, 1980) of detection frequencies for 1,1,1-trichloroethane in wells within the 10 land-use categories (table 3) are representative of the occurrence of these compounds in the upper glacial aquifer in the two-county area.

Table 3.--Percentage of 1,1,1-trichloroethane detected in wells in each of 10 land-use categories and results of contingency-table statistical analysis showing which percentages are not significantly different.[1]

[Dot represents land-use category listed in left column; vertical line indicates categories in which percent detection did not differ significantly from that in category represented by dot.]

Land use	Number of wells	Percent detected	Land-use category comparisons[2]
Industrial	45	47	
High-density residential[3]	92	42	
Institutional	47	38	
Medium-density residential[3]	129	29	
Commercial	49	29	
Recreational[4]	64	19	
Transportation[5]	59	17	
Low-density residential[3]	26	12	
Agriculture	55	0	
Undeveloped	76	0	
Total	642	24	



[1] Detection limits for 1,1,1-trichloroethane varied between 1 and 5 µg/L.
[2] Vertical bars bracket those categories for which no significant difference exists
[3] Low-density residential areas contain less than 2 dwelling units per acre; medium-density areas have 2-4 dwellings per acre; high-density areas have more than 4 dwellings per acre.
[4] Includes parkways.
[5] Includes utilities and communication facilities.

Chloroform was the only volatile organic compound detected in water from all 10 land-use categories, most frequently in high-density residential areas (22 percent of wells). Carbon tetrachloride was detected infrequently except in commercial areas, where it was detected in about 12 percent of wells. Benzene and toluene, which are aromatic compounds, were detected infrequently except in areas of transportation, communications, and utility facilities, where they were detected in about 9 percent of wells.

The source of volatile organic compounds in the higher density residential areas on Long Island is difficult to appraise for several reasons. Many residences on Long Island have (or have had) cesspool systems for disposal of septic waste, and many household goods contain the detected compounds (Mackay and others, 1979). However, the proximity of residential areas to commercial and industrial sources of these compounds and rapidly changing land-use patterns may create zones of contaminated ground water that are not related to the predominant land use at certain well locations or at certain times. Industrial and commercial sources of volatile organic compounds that occupy only a small area but are within a 1/2-mi radius of certain wells may be a significant source of contamination at the wells, but the method used in this study fails to account for such sources. The presence of volatile organic compounds in ground water beneath residential areas is discussed in more detail in the section "Comparison of sewered and unsewered areas," p. 22.

The spatial distribution of trichloroethylene (TCE) and 1,1,1-trichloroethane (TCA) (fig. 8) can be rank-correlated with population density, illustrated in plate 1B. The rank correlations were made by determining the percentage of wells in each of the grid cells (pl. 1B) that have detected amounts of the specified organic compound and relating the percentages to the population density of those cells, which ranges from 1 to more than 11 people per acre (Carole Swick, Long Island Regional Planning Board, written commun., 1984). The relation between the detection percentages for the compounds and population density (fig. 9) is quantified by monotonic regression (Conover, 1980), for which the coefficients of determination (R^2) were 0.94 for trichloroethylene and 0.91 for 1,1,1-trichloroethane. The relationship is expressed only for areas having fewer than 11 people per acre because the data for areas of highest population density were sparse. Both organic compounds are detected more frequently as population density increases, notably in central Nassau County and west-central Suffolk County, where population density commonly exceeds 5 people per acre. In these areas, land use is best described by a composite term that includes a mixture of medium- to high-density residential, commercial, industrial, institutional, and transportation land uses, which have a combined effect on ground-water quality that can be quantitatively related to population density.

Pesticides

Aldicarb and carbofuran are carbamate insecticides and nematocides that are the most commonly detected pesticides in ground water on Long Island (Suffolk County Department of Health Services, 1984a). These compounds are used primarily for control of the Colorado potato beetle and the golden nematode in crops. An extensive monitoring program conducted by Suffolk County (Baier and Moran, 1971; Baier and Robbins, 1982a and 1982b; Suffolk

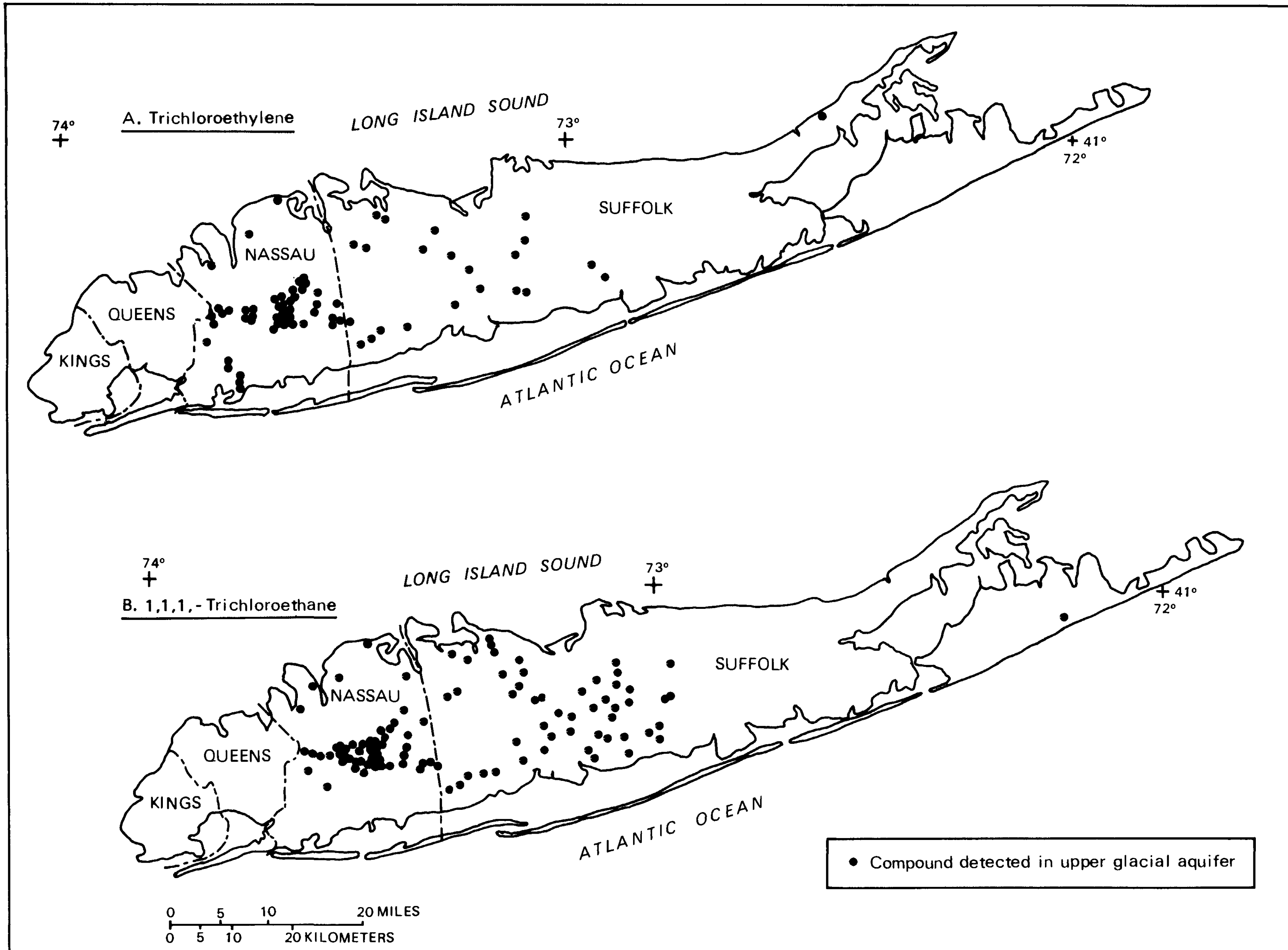


Figure 8.--Distribution of wells in the upper glacial aquifer at which trichloroethylene and 1,1,1-trichloroethane were detected.

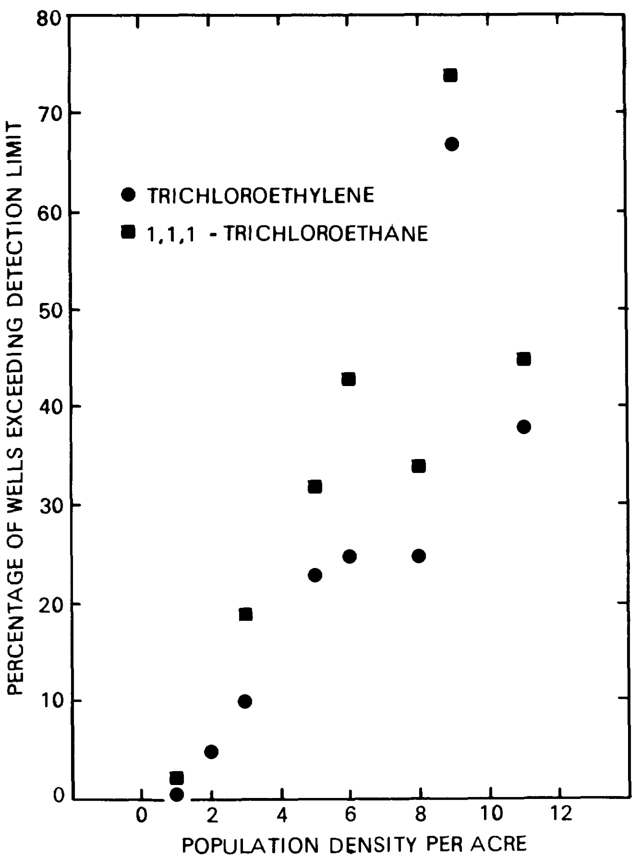


Figure 9. Percentage of wells in the upper glacial aquifer having detected amounts of trichloroethylene and 1,1,1-trichloroethane, plotted in relation to population density. Population-density ranges are shown in plate 1B.

County Department of Health Services, 1984a) showed that of 13,575 wells examined, 3,925 (28.9 percent) exceeded New York State guidelines of 7 µg/L for aldicarb. Of the contaminated wells, 52 percent contained aldicarb concentrations between 8 and 30 µg/L, 32 percent between 31 and 75 µg/L, and 16 percent more than 75 µg/L (Zaki and others, 1982). The well-sampling program was conducted primarily in agricultural areas of eastern Long Island, but precise locations and land-use determinations for the data were unavailable for use in this report. Most of these wells tap the upper glacial aquifer, but a breakdown by aquifer is not available. The data in table 2 are from a limited number of monitoring wells for which locations are known in Suffolk County, whereas data from Baier and Robbins (1982a,b) and Zaki and others (1982) are from a private-well sampling program that was specifically designed to identify contaminated domestic wells in susceptible agricultural areas. The data from known locations (table 2), show aldicarb detection in none of the 10 land-use areas. Carbofuran, however, was detected in 42 percent of wells in agricultural areas and in one other well. A more representative sampling for carbamate insecticides would be needed to evaluate the extent of contamination in other land-use areas.

Soren and Stelz (1985) showed aldicarb to be present to a depth of up to 40 ft below the water table throughout a 900-acre area on the north fork of eastern Long Island (fig. 1). Although clayey and silty deposits in the shallow parts of the upper glacial aquifer seem to have slowed the deeper movement of aldicarb in the aquifer system, high-capacity irrigation wells locally have caused deeper penetration of aldicarb.

Water-quality data compiled in this study show infrequent detection of chlorinated hydrocarbon insecticides, such as DDT, heptachlor epoxide, and chlordane (table 2). Heptachlor epoxide was detected in three wells in high-density residential areas but also in one well each in recreation, commercial, transportation, communication, and utility areas. Detection of 10 additional pesticides in samples collected by local agencies in Suffolk County wells was reported by the Suffolk County Department of Health Services (1984a); these were carbaryl (Sevin[1]), dacthal, dibrom, dinoseb, methomyl (Lannate), oxamyl (Vydate), paraquat, picloram, 1,2-dichloropropane, and chlorothalonil. No information on the relative frequency of detection of these compounds was given, nor are precise locations or land-use classifications for most of the wells available.

Comparison of Sewered and Unsewered Areas

The installation of regional sewer systems began in Nassau County in the late 1940's, when contamination of shallow ground water by cesspool effluent became evident in developed areas. Sewers are still being installed; about 90 percent of Nassau County and 8 percent of Suffolk County is currently sewered (pl. 1C). The remaining area uses cesspools and septic tanks. Several studies of nitrate contamination (Ku and Sulam, 1976; Katz and others, 1980) have concluded that ground-water quality in sewered areas has improved. The higher population density and other sources of ground-water contamination in sewered areas complicate direct comparisons of ground-water quality between sewered and unsewered areas, however.

This study evaluated the effects of sewers on water quality by statistically comparing data from each of 10 land-use categories in sewered areas with those in unsewered areas. A general-linear-models procedure (SAS Institute, Inc., 1979) equivalent to a two-way analysis-of-variance (ANOVA) procedure was used to statistically evaluate differences in ranked concentrations (Conover, 1980) for the effects of land use, sewering, and their interaction. The analysis was done for the contaminants discussed in preceding sections, including inorganic constituents (nitrate, chloride, and total dissolved solids) and selected volatile organic compounds.

Inorganic Chemical Constituents

Median concentrations of nitrate, chloride, and total dissolved solids in samples from 675 wells in 10 land-use categories in sewered and unsewered areas are presented in table 4. Results of the statistical analysis indicate that total-dissolved-solids concentrations are significantly higher in sewered areas than in unsewered areas, whereas nitrate and chloride show no significant difference when the data from all categories are combined. However, all three constituents show a statistical difference between sewered and unsewered areas in some categories (table 4). This is attributed to the combined effects of land use and sewering, as indicated by water-quality differences between sewered and unsewered areas among land-use categories.

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

Table 4.--Median concentration and interquartile range (IQR) of nitrate, chloride, and total dissolved solids in sewered and unsewered areas in 10 land-use categories

[All concentrations in mg/L; dashes indicate no data available]

Constituent, area, statistic[1]	Land-use category: Undevel- oped	Recrea- tional[2]	Agricul- tural	Institu- tional	Low- density resi- dential[3]	Medium- density resi- dential[3]	High- density resi- dential[3]	Transpor- tation[4]	Com- mercial	Indus- trial	All land uses combined
NITRATE (as N)											
Sewered area											
Median	1.0	2.3	0.9	3.3	1.6	3.9	5.2	4.0	4.3	3.7	3.2
IQR	1.8	3.1	3.0	5.4	1.2	3.6	7.1	2.8	5.7	6.1	5.2
number of wells	18	33	7	40	7	37	50	17	21	13	243
Unsewered area											
Median	0.8	1.7	7.0	.9	3.5	2.6	4.2	1.3	1.1	2.2	2.1
IQR	1.7	2.4	7.2	2.8	4.2	3.5	6.2	2.2	3.3	1.9	4.0
number of wells	61	44	51	24	22	96	21	29	6	13	367
CHLORIDE											
Sewered area											
Median	10	16	9	36	6	18	33	66	24	23	23
IQR	11	19	11	32	2.6	12	29	89	27	29	31.5
number of wells	18	38	7	44	7	42	57	28	26	17	284
Unsewered area											
Median	17	11	20	11	14	15	18	12	30	19	15
IQR	22	13	13	9.5	7.0	14	21	13	18	26	16
number of wells	62	58	53	27	27	92	21	29	7	15	391
TOTAL DISSOLVED SOLIDS											
Sewered area											
Median	66	126	49	198	38	108	203	498	142	148	160
IQR	10	74	28	130	42	94	89	142	162	94	158
number of wells	14	28	3	40	6	25	41	18	15	13	203
Unsewered area											
Median	92	80	154	62	128	76	110	75	128	70	90
IQR	37	34	147	54	92	53	190	60	--	60	58
number of wells	28	27	11	12	24	56	8	14	2	6	188

1 Median and IQR values computed by methods of Gilliom and Helsel (1986).
2 Includes parkways.
3 Low-density residential areas contain fewer than 2 dwelling units per acre; medium-density areas have 2 to 4 dwellings per acre; high-density areas have more than 4 dwellings per acre.
4 Includes utilities and communication facilities.

For example, median nitrate concentrations were significantly higher in unsewered agricultural land (7.0 mg/L) than in sewered agricultural land (0.9 mg/L), but nitrate concentrations in the other categories did not show a significant statistical difference (fig. 10). Conversely, median chloride concentrations were significantly higher in sewered transportation areas (66 mg/L) than in similar unsewered areas (12 mg/L).

Median nitrate concentrations were higher in sewered medium-density and high-density residential areas than in similar unsewered residential areas, but the difference is not statistically significant. This conclusion is consistent with those of Ragone and others (1981) and Katz and others (1980) in their studies of nitrate in ground water in sewered and unsewered areas of Nassau County, in which they did not distinguish among land uses. The effects of sewering in highly developed areas may be obscured by other effects on

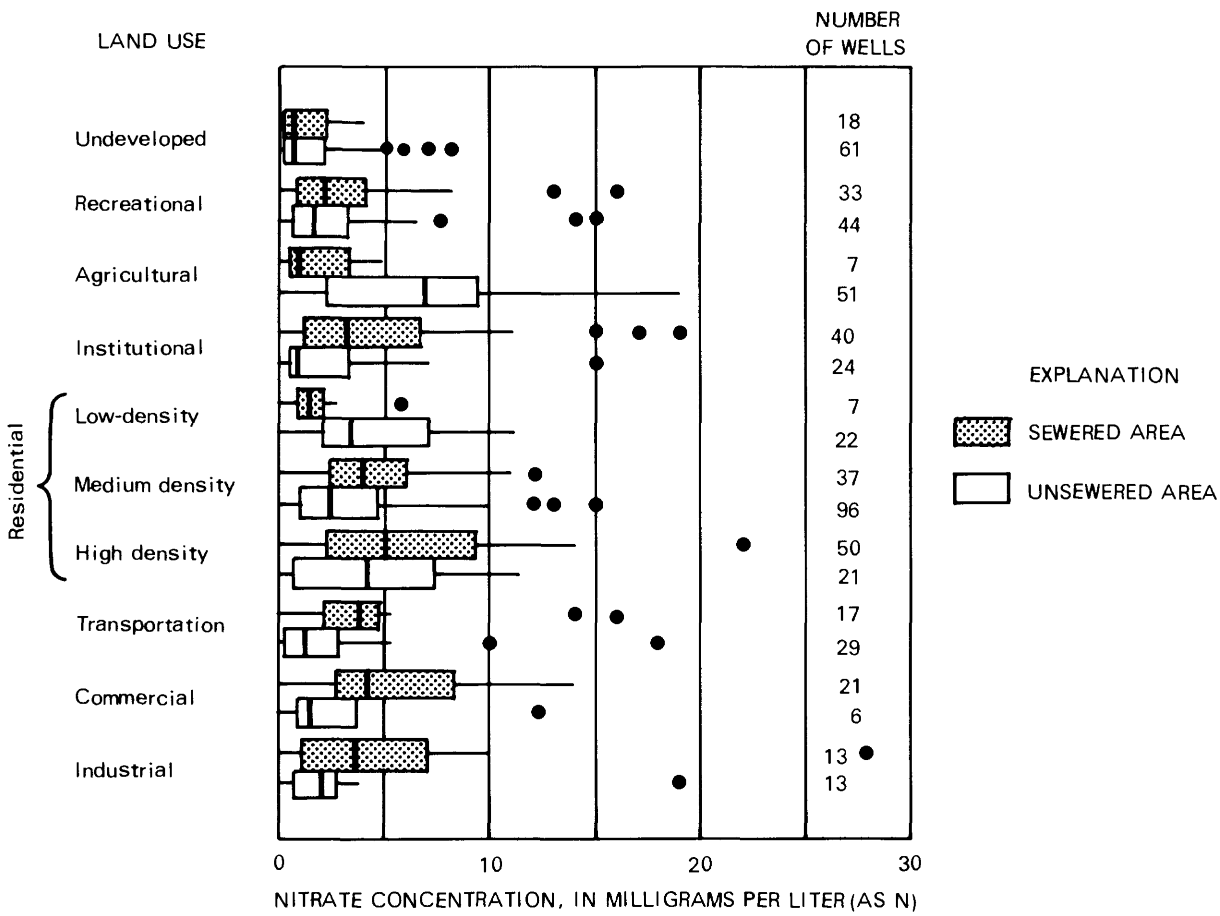

Figure 10.--Nitrate concentrations in ground water from 10 land-use categories in sewered and unsewered areas. Boxes show the interquartile range (IQR), which is the middle 50 percent of data (25th to 75th percentile). Bar in the box is the median (50th percentile). Horizontal lines to left and right of box extend to extreme values not designated as outliers (values within 1.5 IQR); individual outliers beyond the horizontal lines are shown as •. (Kleiner and Graedel, 1980).

ground-water quality, such as applications of road salt and lawn fertilizer or discharges of commercial and industrial contaminants. Flipse and others (1984) reported nitrogen loads of 1,050 lb/yr from lawn and garden fertilizers in a sewered housing development of 180 acres in Suffolk County; their statistical analysis indicated significantly higher nitrate concentrations in shallow ground water in this area after development than before development. Porter (1980) indicated that nitrogen from fertilizers and other sources masks the decreases resulting from replacement of cesspools with sewers and thus obscures any improvement in ground-water quality in sewered areas. The potential for exfiltration from leaky sewerlines compounds the problem. Also, inorganic constituents from cesspools that were present before the installation of sewers may persist in high concentrations within the aquifer system.

Katz and others (1980) and Ragone and others (1981) concluded that the lack of a significant difference between nitrate concentrations in sewered areas and those in unsewered areas may be due in part to sampling bias, to the long residence time of contaminated ground water in the aquifer system relative to sewering in some areas, and to nitrate sources that are unaffected by sewering. These factors introduce considerable variability into water-quality data and were not incorporated in the conceptual approach of this study. A refinement of the approach to incorporate such sources of variation in the statistical analysis of the effects of sewering could include terms describing screen depths below the water table, local direction and rate of ground-water movement, length of time since sewers were installed, land uses prior to sewering, and sources that bypass sewers during entry to the ground-water system.

Volatile Organic Compounds

The numbers of upper glacial aquifer wells that had concentrations of volatile organic compounds exceeding detection limits are given by land-use category for sewered and unsewered areas in table 5; the data represent 643 wells in Nassau and Suffolk Counties. The compounds were more commonly detected in sewered areas (20 percent of wells) than in unsewered areas (4 percent of wells) when data from all land-use categories were combined. Moreover, volatile compounds were most commonly detected in samples from sewered areas in high-density residential areas (26 percent of wells), commercial areas (23 percent), and industrial areas (29 percent). As with the inorganic constituents, this indicates that the effects of sewering in the highly developed areas of Nassau and Suffolk Counties may be obscured by other factors such as discharges of contaminants by leaks or spills and the persistence of contaminants that were present before sewer installation. The effect of population density on the occurrence and distribution of volatile organic compounds in ground water, discussed in previous sections, also obscures the effect of sewers, even though sewers probably diminish the concentrations of volatile organic compounds in the densely populated areas.

The most commonly detected volatile organic compounds among the combined land-use categories in sewered areas were tetrachloroethylene (37 percent of all wells), trichloroethylene (TCE) (33 percent), and 1,1,1-trichloroethane (TCA) (35 percent). In unsewered areas, these three compounds were detected

Table 5.--Percentage of upper glacial aquifer wells in Nassau and Suffolk Counties having samples of volatile organic compounds with concentrations exceeding detection limits, by sewered and unsewered area, 1978-84.[1]

[Number in parentheses is total number of wells contributing water-quality data within each land use-category]

Constituent and area	Land-use category										
	Undevel-oped	Recrea-tional[2]	Agricul-tural	Institu-tional	Low-density resi-dential[3]	Medium-density resi-dential[3]	High-density resi-dential[3]	Transpor-tation[4]	Com-mercial	Indus-trial	All land uses combined
Tetrachloroethylene											
Sewered areas	0	23	0	36	20	35	46	17	49	67	37
	(17)	(26)	(7)	(25)	(5)	(43)	(65)	(29)	(41)	(33)	(291)
Unsewered areas	0	5	2	5	5	14	0	14	0	8	6
	(59)	(38)	(48)	(22)	(21)	(86)	(17)	(29)	(7)	(12)	(339)
Trichloroethylene											
Sewered areas	0	12	0	32	0	28	43	24	48	52	33
	(17)	(26)	(7)	(25)	(5)	(43)	(76)	(29)	(42)	(33)	(303)
Unsewered areas	0	11	4	0	10	6	6	3	0	25	5
	(59)	(38)	(48)	(22)	(21)	(86)	(17)	(30)	(7)	(12)	(340)
1,1,1-Trichloroethane											
Sewered areas	1	19	0	56	0	37	45	17	31	58	35
	(17)	(26)	(7)	(25)	(5)	(43)	(75)	(29)	(42)	(33)	(302)
Unsewered areas	0	18	0	18	14	24	29	17	14	17	14
	(59)	(38)	(48)	(22)	(21)	(86)	(17)	(30)	(7)	(12)	(340)
1,2-Dichloroethylene											
Sewered areas	0	0	0	4	0	11	14	4	12	16	9
	(12)	(23)	(6)	(24)	(5)	(37)	(70)	(28)	(40)	(32)	(277)
Unsewered areas	0	0	0	0	0	1	0	0	0	0	<1
	(56)	(36)	(34)	(22)	(19)	(78)	(13)	(22)	(5)	(11)	(296)
Chloroform											
Sewered areas	0	19	0	5	0	9	28	24	17	9	15
	(17)	(26)	(7)	(22)	(5)	(43)	(61)	(29)	(42)	(32)	(284)
Unsewered areas	8	0	4	0	10	1	0	3	0	8	4
	(59)	(38)	(48)	(22)	(20)	(86)	(16)	(30)	(7)	(12)	(338)

Constituent and area	Land-use category										
	Undeveloped	Recreational[2]	Agricultural	Institutional	Low-density residential[3]	Medium-density residential[3]	High-density residential[3]	Transportation[4]	Commercial	Industrial	All land uses combined
Chlorobenzene											
Sewered area	0	0	0	0	0	0	0	10	0	0	1
	(17)	(21)	(7)	(23)	(4)	(33)	(72)	(29)	(41)	(33)	(280)
Unsewered area	0	0	0	0	0	0	0	0	0	0	0
	(57)	(34)	(47)	(22)	(20)	(80)	(15)	(30)	(7)	(11)	(323)
Benzene											
Sewered areas	0	0	0	0	0	5	2	14	2	0	3
	(17)	(22)	(7)	(20)	(4)	(40)	(56)	(28)	(42)	(32)	(268)
Unsewered areas	0	0	0	0	0	0	0	3	0	8	1
	(57)	(35)	(47)	(22)	(17)	(83)	(14)	(30)	(7)	(12)	(324)
All constituents combined											
Sewered areas	1	11	0	20	3	19	26	16	23	29	20
Unsewered areas	1	5	2	3	6	7	6	6	2	10	4

1 Detection limit for listed compounds varies from 1 to 5 Kg/L.
2 Includes parkways.
3 Low-density residential areas contain fewer than 2 dwelling units per acre; medium-density areas have 2 to 4 dwellings per acre; high-density areas have more than 4 dwellings per acre.
4 Includes utilities and communication facilities.

in 6 percent, 5 percent, and 14 percent of all wells, respectively. Percentages of trichloroethylene in 10 land-use categories in sewered and unsewered areas are shown in figure 11.

TCA, which was used as a cesspool degreaser (Mackay and others, 1979), was the most commonly detected volatile organic compound in unsewered areas; it was banned for cesspool degreasing on Long Island in 1980. TCA was detected in 37 percent of wells from sewered medium-density residential areas and in 45 percent of wells from sewered high-density residential areas; in unsewered areas, TCA was detected in 24 percent and 29 percent of these areas, respectively. Chlorobenzene, another compound that was used as a cesspool degreaser before 1980, was detected in 1 percent of wells in sewered areas but was not detected in unsewered areas.

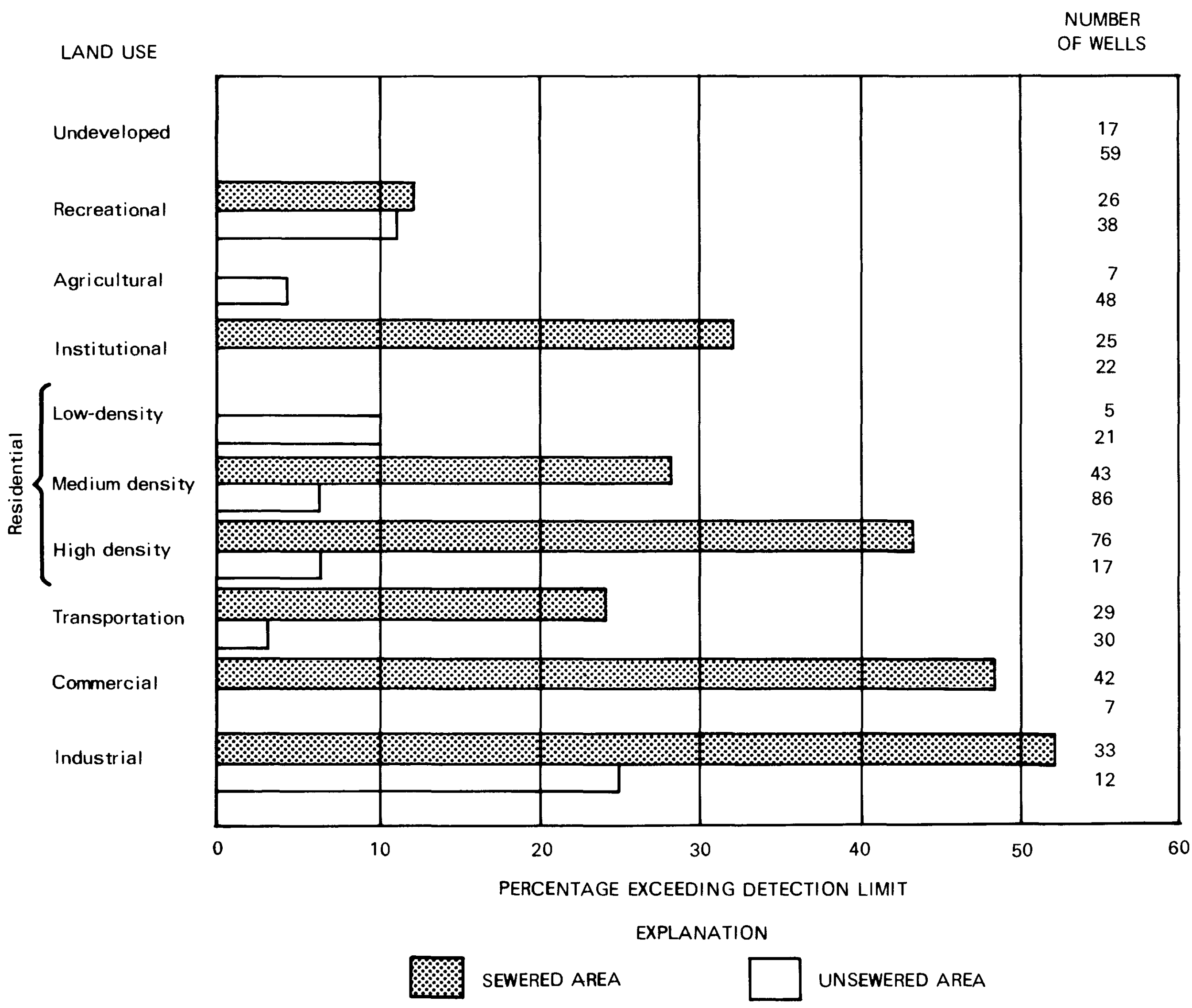

Figure 11.--Percentage of wells in sewered and unsewered areas in which trichloroethylene was detected, by land-use category.

SUMMARY AND CONCLUSIONS

Results of this study indicate that contamination from human activities has affected water quality in the upper glacial (water-table) aquifer in Nassau and Suffolk Counties of Long Island. Statistical comparisons of water quality in 10 land-use categories indicate a correlation between land use and contaminants in the aquifer. Results indicate the following significant relationships between land use and ground-water quality:

(1) Ground water from undeveloped areas had the lowest median concentrations of all major inorganic chemical constituents studied except chloride and total dissolved solids. Water from wells in this category had infrequent detection of volatile organic compounds and no pesticides.

(2) Ground water from agricultural areas had the highest median concentrations of nitrate (6.0 mg/L), sulfate (40 mg/L), and calcium (19 mg/L), presumably as a result of fertilizers. Agricultural areas also had the most frequent detection of the pesticide carbofuran (42 percent of wells). The recognized aldicarb problem on Long Island is not evident from results in this study because private well locations used to define the problem were unavailable for use in this study.

(3) In institutional areas, 1,1,1-trichloroethane was detected in 38 percent of ground-water samples, tetrachloroethylene in 21 percent, and trichloroethylene in 17 percent, but the median concentrations of inorganic chemical constituents generally were low.

(4) Ground water from high-density residential areas had the highest median specific conductance (296 $\mu S/cm$) and the highest median concentrations of chloride (31 mg/L), potassium (4.3 mg/L), and total dissolved solids (202 mg/L); ground water in this category also had the second-highest median concentration of nitrate (4.6 mg/L) and frequency of detection for 1,1,1-trichloroethane (42 percent), trichloroethylene (37 percent), tetrachloroethylene (33 percent), chloroform (22 percent), and 1,2-dichloroethylene (12 percent). Ground water from low-density residential areas had near-average concentrations of inorganic chemical constituents and a relatively low percentage of wells with volatile organic compound and pesticide detection.

(5) Volatile organic compounds were detected most frequently in ground water from industrial and commercial areas. Tetrachloroethylene, trichloroethylene (TCE), and 1,1,1-trichloroethane (TCA) were each detected in at least 40 percent of the samples, except for TCA in commercial areas, which was detected in 29 percent of the samples.

(6) Data for all land-use categories combined indicated significantly higher total dissolved-solids concentrations in sewered areas than in unsewered areas, but neither median nitrate or chloride concentrations differed significantly between sewered and unsewered areas. Nitrate and chloride concentrations in certain individual land-use categories indicated a difference, however. Median nitrate concentrations were significantly higher in unsewered agricultural areas (7.0 mg/L as N) than in sewered agricultural areas (0.9 mg/L as N), and median chloride concentrations were significantly higher in sewered transportation areas (66 mg/L) than

in unsewered transportation areas (12 mg/L). Nitrate concentrations in sewered residential areas were not significantly different from those in unsewered residential areas. With all land-use categories combined, volatile organic compounds were detected more frequently in sewered areas (20 percent of samples) than in unsewered areas (4 percent of samples). Tetrachloroethylene, trichloroethylene, and 1,1,1-trichloroethane were detected more frequently in sewered medium- and high-density residential, institutional, transportational, commercial, and industrial areas than in similar unsewered areas.

The spatial distribution of trichloroethylene (TCE) and 1,1,1-trichloroethane (TCA), in Nassau and Suffolk Counties is directly related to population density. The compounds are detected most frequently in central and south-central Nassau County and west-central Suffolk County, where population density commonly exceeds 5 people per acre. In these areas, land use is best described by a composite term that includes a heterogeneous mixture of medium- to high-density residential, commercial, industrial, institutional, and transportation uses, which create a combined effect on ground-water quality that can be quantitatively related to population density.

REFERENCES CITED

Baier, Joseph, and Moran, Dennis, 1971, Status report on aldicarb contamination of groundwater as of September 1981: Suffolk County Department of Health Services, 45 p.

Baier, Joseph, and Robbins, S. F., 1982a, Report on the occurrence and movement of agricultural chemicals in groundwater, south fork of Suffolk County: Suffolk County Department of Health Services, 68 p.

_____ 1982b, Report on the occurrence and movement of agricultural chemicals in groundwater, north fork of Suffolk County: Suffolk County Department of Health Services, 71 p.

Bhattacharyya, G. K., and Johnson, R. A., 1977, Statistical methods and concepts: New York, John Wiley, 516 p.

Buxton, H. T., and Reilly, T. E., 1985, Effects of sanitary sewers on ground-water levels and streams in Nassau and Suffolk Counties, New York; part 2--model development and application of southwest Suffolk County model: U.S. Geological Survey Water Resources Investigations Report 83-4209, 39 p.

Cohen, Philip, Franke, O. L., and Foxworthy, B. L., 1968, An atlas of Long Island's water resources: New York State Water Resources Commission Bulletin 62, 117 p.

Cohen, Philip, Franke, O. L., and McClymonds, N. E., 1969, Hydrologic effects of the 1962-66 drought on Long Island, New York: U.S. Geological Survey Water-Supply Paper 1879-F, 18 p.

Conover, W. J., 1980, Practical nonparametric statistics, 2nd edition: New York, John Wiley, 493 p.

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

Donaldson, C. D., and Koszalka, E. J., 1983, Potentiometric surface of the Magothy aquifer, Long Island, New York, in March 1979: U.S. Geological Survey Open-File Report 82-160, 2 sheets.

Doriski, T. P., 1987, Potentiometric-surface altitudes of major aquifers on Long Island, New York, in 1984: U.S. Geological Survey Water-Resources Investigations Report, 6 sheets.

Doriski, T. P., and Wilde-Katz, Franceska, 1983, Geology of the "20-foot" clay and Gardiners clay in southern Nassau and southwestern Suffolk Counties, Long Island, New York: U.S. Geological Survey Water-Resources Investigations Report 82-4056, 17 p.

Eckhardt, D. A. V., and Pearsall, K. A., 1985, Trichloroethylene in ground water at Roosevelt Field, Nassau County, Long Island, New York: in Geological Society of America, Proceedings of Northeastern Section, v. 17, no. 1, p. 17.

Flipse, W. J., Jr., Katz, B. G., Lindner, J. B., and Markel, Richard, 1984, Sources of nitrate in ground water in a sewered housing development, central Long Island, New York: Ground Water, v. 22, no. 4, p. 418-426.

Flynn, J. M., Andreoli, Aldo, and Guerrera, A. A., 1958, Study of synthetic detergents in ground water: American Water Works Association Journal, v. 50, no. 12, p. 1551-1562.

Franke, O. L., and Cohen, Philip, 1972, Regional rates of ground-water movement on Long Island, New York, in U.S. Geological Survey Research, 1972: U.S. Geological Survey Professional Paper 800-C, p. C271-277.

Franke, O. L., and Getzen, R. T., 1976, Evaluation of hydrologic properties of the Long Island ground-water reservoir using cross-sectional analog models: U.S. Geological Survey Open-File Report 75-679, 80 p.

Gilliom, R. J., and Helsel, D. R., 1986, Estimation of distributional parameters for censored trace-level water-quality data, 1, Estimation techniques: Water Resources Research, v. 22, no. 2, p. 135-146.

Helsel, D. R., and Ragone, S. E., 1984, Evaluation of regional ground water quality in relation to land use--U.S. Geological Survey toxic waste ground-water contamination program: U.S. Geological Survey Water Resources Investigations Report 84-4217, 33 p.

Holzmacher, R. G., McLendon, S. C., and Murrell, N. E., 1980a, Master water plan, Nassau County, State of New York, volume I: New York, Holzmacher, McLendon, Murrell, P.C., 430 p.

Holzmacher, R. G., McLendon, S. C., and Murrell, N. E., 1980b, Master water plan, Nassau County, State of New York, volume II--appendices: New York, Holzmacher, McLendon, Murrell, P.C., 210 p.

Jensen, H. M., and Soren, Julian, 1971, Hydrogeologic data from selected wells and test holes in Suffolk County, Long Island, New York: Suffolk County Department of Environmental Control, Long Island Water Resources Bulletin 3, 35 p.

_____ 1974, Hydrogeology of Suffolk County, Long Island, New York: U.S. Geological Survey Hydrologic Investigation Atlas HA-501, 2 sheets.

Katz, B. G., and Lindner, J. B., 1978, Nitrogen concentration in Nassau County ground water from early 1950's through 1976 [abstract]: Adelphi University, American Chemical Society Conference, Drinking Water--Is it safe? [1-page handout].

Katz, B. G., Lindner, J. B., and Ragone, S. E., 1980, A comparison of nitrogen in shallow ground water from sewered and unsewered areas, Nassau County, New York, from 1952 through 1976: Ground Water, v. 18, no. 6, p. 607-616.

Kleiner, B., and Graedel, T. E., 1980, Exploratory data analysis in the geophysical sciences: Reviews of geophysics and space physics, v. 18, no. 3, p. 699-717.

Kleopfer, R. D., Easley, D. M., Haas, B. B., and Diehl, T. G., 1985, Anaerobic degradation of trichloroethylene in soil: Environmental Science and Technology, v. 19, no. 3, p. 277-280.

Koppelman, L. E., 1978a, Long Island comprehensive waste treatment management plan: Long Island Regional Planning Board, v. I, 247 p.

_____ 1978b, Long Island comprehensive waste treatment management plan: Long Island Regional Planning Board, v. II, 363 p.

_____ 1982, The Long Island segment of the nationwide runoff program: Long Island Regional Planning Board, 133 p.

Krulikas, R. K., and Koszalka, E. J., 1983, Geologic reconnaissance of an extensive clay unit in north-central Suffolk County, Long Island, New York: U.S. Geological Survey Water-Resources Investigations 82-4075, 9 p.

Kruskal, W. H., and Wallis, W. A., 1952, Use of ranks in one-criterion variance analysis: Journal of the American Statistical Association, v. 47, p. 583-621.

REFERENCES CITED (Continued)

Ku, H. F. H., and Simmons, D. L., 1981, Base flow of streams in Nassau County Sewer Districts 2 and 3, Long Island, New York, 1978-79: U.S. Geological Survey Water-Resources Investigations/Open-File Report 81-420, 32 p.

_____ 1983, Water levels in Nassau County Sewer Districts 2 and 3, Long Island, New York, 1978-79: U.S. Geological Survey Water-Resources Investigations 82-4017, 34 p.

_____ 1987, Effect of urban stormwater runoff beneath recharge basins on Long Island, New York: U.S. Geological Survey Water-Resources Investigations Report 85-4088, 67 p.

Ku, H. F. H., and Sulam, D. J., 1976, Distribution and trend of nitrate, chloride, and total solids in water in the Magothy aquifer in southeast Nassau County, New York, from the 1950's through 1973: U.S. Geological Survey Water-Resources Investigations 76-44, 47 p.

Long Island Regional Planning Board, 1977, Land and water capability, natural resource inventory, existing land use 1977 and land use plan 1995: Hauppauge, N.Y., 42 p.

Long Island Regional Planning Board, 1982a, Quantification and analysis of land use for Nassau and Suffolk Counties, 1981: Hauppauge, N.Y., 47 p.

_____ 1982b, Historical population of Long Island communities 1790-1980: Hauppauge, N.Y., 77 p.

Mackay, S. L., Fleisher, M. B., Casumano, R. D., 1979, Report on consumer products containing or suspected of containing harmful organic chemicals and having the potential of contaminating the ground water of Nassau County, New York: Mineola, N.Y., Nassau County Department of Health, 58 p.

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

Myott, D. H., 1980, Groundwater quality assessment, Nassau County, New York: Nassau County Department of Health, 39 p.

Nassau County Planning Commission, 1959, A compilation of land uses 1956: Nassau County Planning Commission, 23 p.

Nassau-Suffolk Planning Board, 1968, Existing land use 1966: Nassau-Suffolk Planning Board, 30 p.

Parsons, Frances, Wood, P. R., and DeMarco, J. J., 1984, Transformations of tetrachloroethylene and trichloroethylene in microcosms and ground water: Journal of the American Water Works Association, v. 76, p. 56-59.

REFERENCES CITED (Continued)

Perlmutter, N. M., and Guerrera, A. A., 1970, Detergents and associated contaminants in ground water at three public-supply well fields in southwestern Suffolk County, Long Island, New York: U.S. Geological Survey Water-Supply Paper 2001-B, 22 p.

Perlmutter, N. M., and Koch, Ellis, 1964, Contamination of ground water by detergents in a suburban environment--South Farmingdale area, Long Island, New York, in Geological Survey Research 1964: U.S. Geological Survey Professional Paper 501-C, p. C170-C175.

_____ 1971, Preliminary findings on the detergent and phosphate contents of water of southern Nassau County, New York, in Geological Survey Research 1971, U.S. Geological Survey Professional Paper 750-D, p. D171-D177.

Philips, K. J., and Gelhar, L. W., 1978, Contaminant transport to deep wells: American Society of Civil Engineers, Journal of the Hydraulics Division, Proceedings, v. 104, no. HY6, p. 807-819.

Porter, K. S., 1980, An evaluation of sources of nitrogen as causes of ground-water contamination in Nassau County, Long Island: Ground Water, v. 18, no. 6, p. 617-625.

Ragone, S. E., 1984, U.S. Geological Survey toxic waste--ground-water contamination program, fiscal year 1983: U.S. Geological Survey Open-File Report 84-474, 56 p.

Ragone, S. E., Katz, B. G., Kimmel, G. E., and Lindner, J. B., 1981, Nitrogen in ground water and surface water from sewered and unsewered areas, Nassau County, Long Island, New York: U.S. Geological Survey Water-Resources Investigations 80-21, 64 p.

Reilly, T. E., 1978, Convective contaminant transport to pumping well: American Society of Civil Engineers, Journal of the Hydraulics Division, Proceedings, v. 104, no. HY12, p. 1565-1575.

Reilly, T. E., Buxton, H. T., Franke, O. L., and Wait, R. L., 1983, Effects of sanitary sewers on ground-water levels and streams in Nassau and Suffolk Counties, New York, part 1--geohydrology, modeling strategy, and regional evaluation: U.S. Geological Survey Water-Resources Investigations 82-4045, 45 p.

Reilly, T. E., and Buxton, H. T., 1985, Effects of sanitary sewering on ground-water levels and streams, Long Island, New York, part 3, development and application of southern Nassau County model: U.S. Geological Survey Water Resources Investigations 83-4210, 41 p.

Roberts, P. V., Reinhard, Martin, and Valocchi, A. J., 1982, Movement of organic contaminants in ground water--implications for water supply: Journal of the American Water Works Association, v. 74, p. 408-413.

SAS Institute, Inc., 1979, Statistical analysis system users guide: Raleigh, N.C., SAS Institute, Inc., 494 p.

REFERENCES CITED (Continued)

Smith, S. O., and Myott, D. H., 1975, Effect of cesspool discharge on ground-water quality on Long Island, New York: Journal American Water Works Association, v. 67, no. 8, p. 456-458.

Soren, Julian, and Stelz, W. G., 1985, Aldicarb-pesticide contamination of ground water in eastern Suffolk County, Long Island, New York: U.S. Geological Survey Water Resources Investigations 84-4251, 34 p.

Stoline, M. R., 1981, The status of multiple comparisons--simultaneous inference of all pairwise comparisons in one-way ANOVA designs: American Statistician, v. 35, p. 134-141.

Suffolk County Department of Health Services, 1984a, Report on water supply priorities: Hauppauge, N.Y., 26 p.

__________ 1984b, Suffolk County comprehensive water resources management plan: Hauppauge, N.Y., chap. 3, p. 1-28.

Suffolk County Department of Planning, 1962, Existing land use 1962: Hauppauge, N.Y., 42 p.

Trautmann, N. M., Porter, K. S., and Hughes, H. B. F., 1983, Southold demonstration site--New York State fertilizer and pesticide demonstration project: Ithaca, N.Y., Cornell University, Center for Environmental Research, 54 p.

Zaki, M. H., Moran, Dennis, and Harris, David, 1982, Pesticides in ground water--the aldicarb story in Suffolk County, New York: American Journal of Public Health, v. 72, no. 12, p. 1391-1395.