LOCAL POINT SOURCES THAT AFFECT GROUND-WATER QUALITY IN THE EAST MEADOW AREA, LONG ISLAND, NEW YORK

By Paul M. Heisig

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 92-4038

Prepared in cooperation with the
NASSAU COUNTY DEPARTMENT OF PUBLIC WORKS

Syosset, New York
1994

DEPARTMENT OF THE INTERIOR

BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY

ROBERT M. HIRSCH, Acting Director

UNITED STATES GOVERNMENT PRINTING OFFICE: 1993

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	*By*	*to obtain*
	Length	
inch (in.)	2.54	centimeter
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	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
million gallons (Mgal)		cubic meters
	Flow	
foot per second (ft/s)	0.3048	meter per second
foot per day (ft/d)	0.3048	meter per day
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
gallon per minute (gal/min)	0.06308	liter per second
gallon per day (gal/d)	0.003785	cubic meter per day
million gallons per day (Mgal/d)	0.04381	cubic meter per second

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 the United States and Canada, formerly called Sea level datum of 1929.

ABBREVIATIONS

< less than
> greater than

LOCAL POINT SOURCES THAT AFFECT GROUND-WATER QUALITY IN THE EAST MEADOW AREA, LONG ISLAND, NEW YORK

By Paul M. Heisig

ABSTRACT

The extent and chemical characteristics of ground water affected by three local point sources—a stormwater basin, uncovered road-salt-storage piles, and an abandoned sewage-treatment plant—were delineated during a 3-year study of the chemical characteristics and migration of a body of reclaimed wastewater that was applied to the water-table aquifer during recharge experiments from October 1982 through January 1984 in East Meadow. The timing, magnitude, and chemical quality of recharge from these point sources is highly variable, and all sources have the potential to skew determinations of the quality of ambient ground-water and of the reclaimed-wastewater plume if they are not taken into account.

Ground water affected by recharge from the stormwater basin is characterized by low concentrations of nitrate + nitrite (less than 5 mg/L [milligrams per liter] as N) and sulfate (less than 40 mg/L) and is almost entirely within the upper glacial aquifer. The plume derived from road-salt piles is narrow, has high concentrations of chloride (greater than 50 mg/L) and sodium (greater than 75 mg/L), and also is limited to the upper glacial aquifer. The sodium, in high concentrations, could react with aquifer material and exchange for sorbed cations such as calcium, potassium, and magnesium. Water affected by secondary-treated sewage from the abandoned treatment plant extends 152 feet below land surface into the upper part of the Magothy aquifer and longitudinally beyond the southern edge of the study area, 7,750 feet south of the recharge site. Ground water affected by secondary-treated sewage within the study area typically contains elevated concentrations of reactive chemical constituents, such as potassium and ammonium, and low concentrations of dissolved oxygen. Conservative or minimally reactive constituents such as chloride and sodium have been transported out of the study area in the upper glacial aquifer and the intermediate (transitional) zone but remain in the less permeable upper part of the Magothy aquifer.

Identification of the three point sources and delineation of their areas of influence improved definition of ambient ground-water quality and delineation of the reclaimed-wastewater plume.

INTRODUCTION

Rapid population growth and development on Long Island since World War II have been accompanied by an increase in the amount of dissolved solids reaching the aquifer system from land surface. Sources of dissolved solids include sewage from domestic cesspools and sewage-treatment facilities, storm runoff from paved surfaces, lawn and agricultural fertilizers, landfill leachate, industrial wastes, and road-deicing salts. The degradation of shallow-ground-water quality in western and central Long Island from point and nonpoint (diffuse) sources has rendered much of the upper glacial aquifer unfit for public supply. The susceptibility of production wells in the underlying Magothy aquifer to contamination by drawdown of shallow ground water (Eckhardt and Pearsall, 1989) has raised concern and created a need for information on factors that affect shallow ground-water quality.

An important step in the protection of ground-water quality in Nassau and western Suffolk counties (fig. 1) has been the installation of sanitary-sewer systems, which prevent most septic effluent from reaching the water table by diverting it to treatment plants that treat and discharge it to the bays and ocean. The use of sanitary sewers also has decreased recharge to the aquifer system, however, by preventing the return of the wastewater to the ground. This, in turn, has caused a lowering of ground-water levels and decreases in streamflow (Reilly and Buxton, 1985). One potential means of replenishing the ground-water system is artificial recharge with reclaimed wastewater. This procedure was tested at East Meadow in Nassau County (fig. 1) from October 1982 through January 1984 to ascertain the maximum rates of recharge that could be sustained and the amount of ground-water mounding that would result. Results are summarized in Schneider and others (1987).

In 1985, the U.S. Geological Survey (USGS), in cooperation with the Nassau County Department of Public Works, began a follow-up study of water quality in the shallow aquifer system at the same site (fig. 2) to determine the fate of the nearly 720 Mgal of reclaimed water that had been applied to the ground-water system through recharge basins during the 1982-84 study. Analysis of water samples from wells throughout the surrounding 1.5-mi^2 area enabled delineation of the recharge plume (Heisig and Prince, 1993) and identification of three other local point sources that have affected shallow ground-water quality in the area: (1) storm runoff from Nassau County stormwater basin 62, (2) leachate from two salt-storage piles, and (3) secondary-treated sewage that was discharged to recharge basins at the Meadowbrook sewage-treatment plant before it was abandoned in 1979. (Locations are shown in fig. 7, p. 12.) The effects of point sources on water quality range from beneficial to detrimental, depending on the source and site conditions. Delineation of the areas of influence from these sources was essential for delineation of the recharge plume. In this report, "shallow" ground water refers to water extending from the water table to 90 ft below it.

Purpose and Scope

This report (1) briefly summarizes the history of ground-water development on Long Island and the hydrogeology, ambient water quality, and suburban development in the East Meadow area; and (2) discusses the effect of the three local point sources on ground-water quality in the study area. Stiff and trilinear diagrams based on chemical analyses of water samples from point sources and observation wells illustrate chemical differences among the three point sources, ambient ground-water, and reclaimed water used in the 1982-84 artificial-recharge experiments, and several maps delineate the extent of selected constituents.

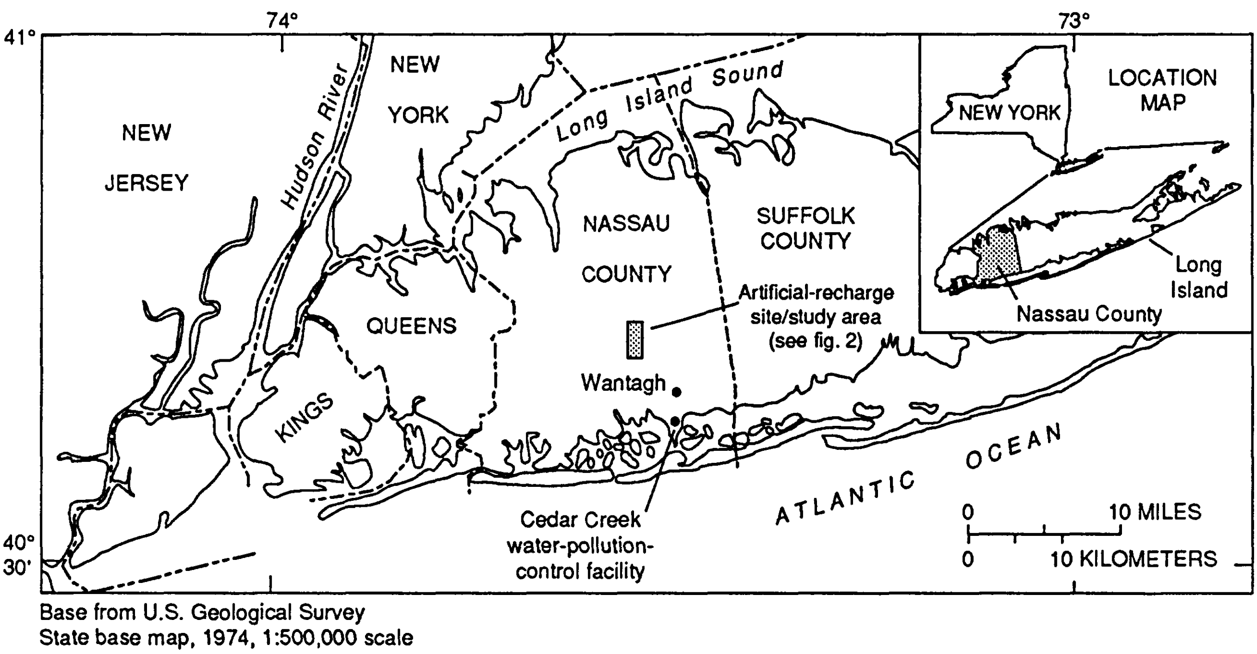
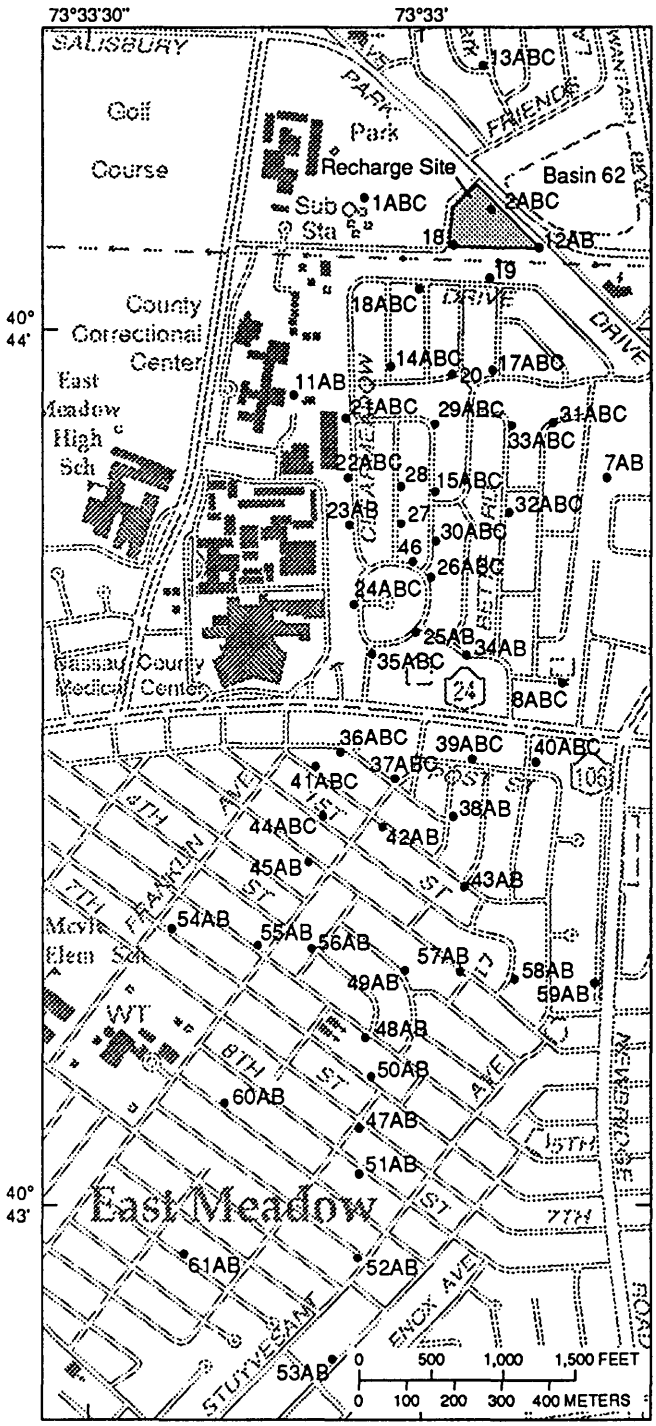


Figure 1.—Location of artificial-recharge site and related features, Nassau County, N.Y.



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EXPLANATION

•45AB WELL SITE AND NUMBER--Number identifies a well site; letters denote individual wells at each site; for example, site 45 contains wells 45A and 45B. By convention, the "A" well is the deepest well at each site.

Figure 2.—Locations of observation wells in the study area. (From Heisig and Prince, 1993, fig. 2. Location is shown in fig. 1.)

Previous Investigations

Aronson and others (1983) made the first geohydrologic assessments at the East Meadow site, and Katz and Mallard (1980) made the first water-quality assessment. Schneider and Oaksford (1986) and Schneider and others (1987) reported details of the artificial-recharge operations; Prince and Schneider (1989) conducted pumping tests near the site; and Heisig and Prince (1993) provide a more recent evaluation of geohydrology and water quality at the site. Ku and Simmons (1986) investigated the chemical quality of storm runoff in and beneath five recharge basins in Nassau and Suffolk Counties as part of the USGS Nationwide Urban Runoff Program. LeBlanc (1984) reported on the effects of infiltration of secondary-treated sewage on ground water at Cape Cod, Mass. Thurman (1987) presented a conceptual model for sewage contamination, and Ceazan and others (1987) documented the importance of cation exchange in the distribution of ammonium and potassium at the Cape Cod site.

Acknowledgments

The author thanks James F. Mulligan, Peter Witkowski, and Ralph Denton of the Nassau County Department of Public Works for providing field crews to assist in well drilling, development, and sampling and also thanks Harold Morgan of the East Meadow Water District, Edward Donahue of the Town of Hempstead Highway Department, and Thomas Palumbo of the Nassau County Department of Public Works for information and access to records and for assistance during well-drilling operations.

Methods of Investigation

The original observation-well network within the study area contained 22 wells and was designed to monitor the local hydraulic and chemical effects of the 1982-84 artificial-recharge operations. A total of 102 new observation wells were installed in three drilling periods during 1985-87; their locations were selected on the basis of water-quality data from previous sampling. The deepest well is screened about 164 ft below the water table, and the shallowest is at the water table, but most are screened within 90 ft of the water table. Well locations are shown in figure 2. Water samples were collected in November-December 1985, March-April 1986, August 1986, and March-April 1987. All water-quality data presented herein are from March-April 1987 unless otherwise specified.

Water samples were obtained by submersible pump in accordance with standard USGS sampling procedures and analyzed for major inorganic constituents by the USGS laboratory in Arvada, Colo. (Fishman and Friedman, 1989). About 10 percent of the samples collected in the study were sent to the Nassau County laboratory at the Cedar Creek water-pollution-control plant (fig. 1) and analyzed for the same constituents. Both laboratories participate in the standard reference water-sample program administered by the USGS.

HYDROGEOLOGY AND DEVELOPMENT OF GROUND-WATER RESOURCES OF LONG ISLAND

The hydrogeology of Long Island is discussed in detail in Suter, DeLaguna, and Perlmutter (1949), Cohen and others (1968), McClymonds and Franke (1972), and Franke and Cohen (1972), and the historic development of the ground-water resources of Long Island is discussed in Cohen and others (1968). Both topics are summarized below.

Hydrogeology

Long Island is underlain by a sequence of unconsolidated deposits of sand, gravel, and clay of Quaternary and Late Cretaceous age that unconformably overlie schist, gneiss, and granitic bedrock of Precambrian age (fig. 3). Overlying the bedrock is the Raritan Formation of Late Cretaceous age, which consists of the Lloyd Sand Member (Lloyd aquifer) and the overlying clay member (Raritan clay), which is an effective confining unit.

Overlying the Raritan Formation is the Magothy Formation and Matawan Group, undifferentiated (Magothy aquifer), also of Late Cretaceous age (fig. 3). These deposits, which are as much as 1,000 ft thick, consist of clayey and silty fine-to-medium quartzose sand, some gravel, and clay layers. The upper surface of the Magothy aquifer is an erosional surface in Nassau County and is in hydraulic contact with the overlying Pleistocene deposits.

Pleistocene sediments are described as lower and upper deposits by Suter and others (1949). The lower Pleistocene deposits are pre-Wisconsin in age and consist of two principal units: the Jameco Gravel and the Gardiners Clay. The Jameco Gravel (Jameco aquifer) is an outwash deposit that reaches a maximum thickness of about 150 ft; it directly overlies the Magothy aquifer in much of Brooklyn and Queens and in the southwestern corner of Nassau County. It is among the oldest Pleistocene deposits on Long Island. The Gardiners Clay, which overlies and locally confines the Jameco or Magothy aquifers, is present along much of the south shore of Long Island. This unit is of marine origin and represents interglacial conditions of high sea level. The upper Pleistocene deposits, which are predominantly outwash sand and gravel and terminal-moraine sediments, cover most of Long Island. Outwash covers most of the southern half of the island, except the shore area and parts of the northern half; morainal sediments cover much of the northern half and the eastern forks (fig. 1 inset), where they reach a maximum thickness of about 300 ft. The saturated part of the upper Pleistocene deposits, referred to as the upper glacial aquifer, is unconfined and covers much of Long Island.

Holocene, or recent, swamp, alluvium, lagoonal, beach, and dune deposits overlie the Pleistocene deposits along the margins of Long Island and are generally less than 20 ft thick.

Development of Ground-Water Resources

Cohen and others (1968) described three stages of ground-water development on Long Island. The earliest stage, before 1900, was characterized by extraction of water from the upper glacial aquifer through domestic and, later, public-supply wells, and the return of wastewater to the aquifer system through cesspools. The introduction of wastewater to the shallow ground-water system had little effect on water quality because the population was the small and scattered. The second stage of development, from 1900 to the early 1950's, was characterized by rapid population growth with corresponding increases in ground-water pumpage and entry of cesspool leachate to the ground-water system. The increased loading of cesspool wastes to the upper glacial aquifer forced the abandonment of many shallow wells and the installation of deeper wells that could extract uncontaminated water from the Magothy aquifer. The most important effect on the ground-water system during this stage was the increase in the volume of ground-water flow into the Magothy aquifer from the overlying upper glacial aquifer as a result of gradients induced by deep pumping.

The third stage extends from the early 1950's to the present. During this period the population has continued to expand, and pumpage from the Magothy aquifer has increased. The movement of contaminated water from the upper glacial aquifer into the upper part of the Magothy has continued where pumping stresses are great and where geologic conditions are favorable. New public-supply wells in these areas are installed at greater depths as a result. The most important effect on the ground-water system during this stage has been the installation of sanitary sewers over much of Nassau County and southwestern Suffolk County to prevent sewage from reaching the water table from cesspools. These sewers route the sewage to treatment plants that treat and discharge it to the ocean and bays. The resulting loss of wastewater recharge to the ground-water system has decreased the dissolved-solids loading to the upper glacial aquifer by diverting wastewater to treatment plants but also has resulted in a lowering of the water table and a corresponding decrease in streamflow (Reilly and others, 1983).

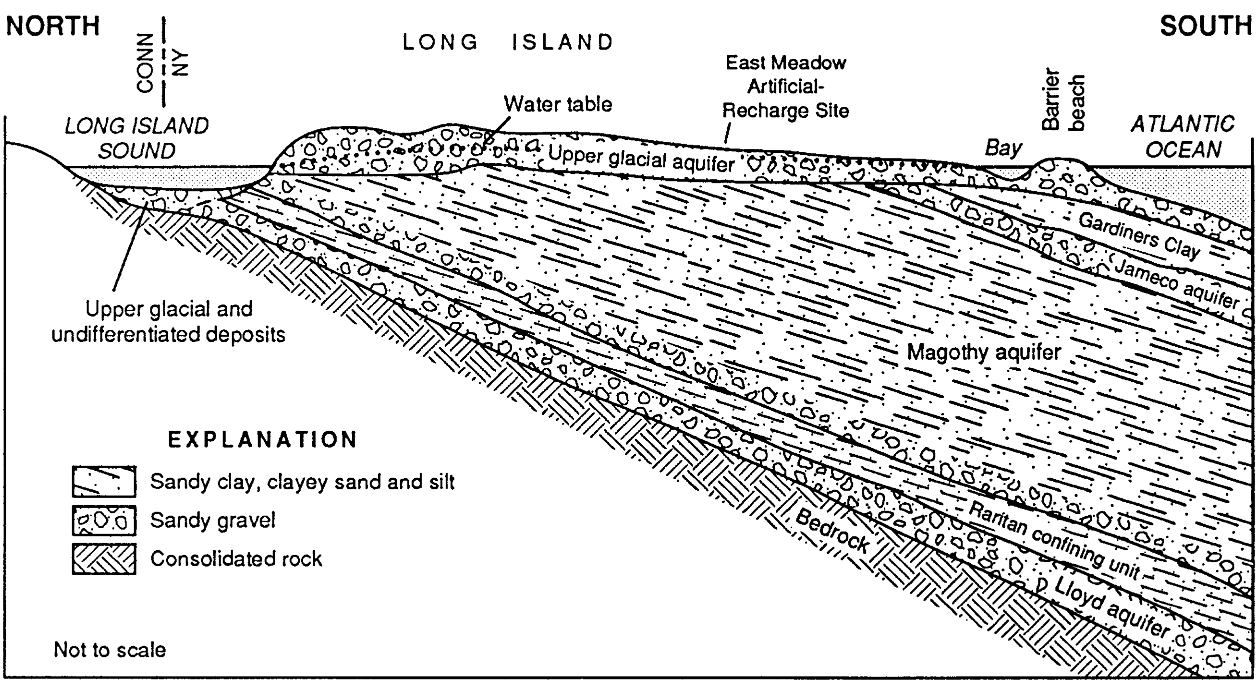


Figure 3.—Generalized north-south geologic section of Long Island showing position of major aquifers. (Modified from Franke and McClymonds, 1972, fig. 3.)

HYDROGEOLOGY, AMBIENT GROUND-WATER QUALITY, AND SUBURBAN DEVELOPMENT IN THE EAST MEADOW AREA

The hydrogeology and chemical quality of ambient ground water in the study area are discussed briefly below and in detail in Heisig and Prince (1993); suburban development in East Meadow is described below in terms of population growth, land use, sewage disposal, and ground-water resources.

Hydrogeology

The deposits of primary interest within the study area are the Pleistocene and uppermost Cretaceous deposits. The Pleistocene deposits consist of fairly homogeneous, medium-to-very-coarse, brownish-orange (iron oxyhydroxide coated) sand and gravel containing interbedded lenses of fine-to-medium silty sand and thin beds of sandy clay. The thickness of the unsaturated zone ranges from about 40 ft at the northern edge of the study area to 24 ft at the southern edge. The saturated part of this unit forms the upper glacial aquifer (unconfined), which ranges between 13 and 36 ft in thickness (Heisig and Prince, 1993). Prince and Schneider (1989) estimated a horizontal hydraulic conductivity of 380 ft/d and a ratio of horizontal to vertical hydraulic conductivity of 2.5 for this aquifer from the results of an aquifer test within the study area. Estimates of local ground-water velocity range from 2.0 to 3.5 ft/d (Prince and Schneider, 1989; Heisig and Prince, 1993).

The Cretaceous deposits directly below the upper glacial aquifer are part of the Magothy aquifer. The uppermost 30 to 60 ft of the 500-ft thickness of the Magothy aquifer constitutes the lower part of the zone of interest in this study and is characterized by gray to white fine sand with higher percentages of silt and clay than those in the upper glacial deposits; this sand is interbedded with discontinuous silt-and-clay lenses. Natural-gamma logs (Heisig and Prince, 1993) indicate local variation in clay-silt content within this zone. Horizontal hydraulic conductivity of the upper part of the Magothy aquifer in the study area has been estimated to be 100 ft/d, with a ratio of horizontal to vertical hydraulic conductivity of 5 (Prince and Schneider, 1989). Heisig and Prince (1993) estimated the velocity of water in the upper Magothy aquifer to be 0.8 ft/d from the movement of reclaimed water after the 1982-84 recharge tests. The Magothy aquifer is unconfined to semiconfined, depending on silt-clay content.

For convenience, the upper glacial aquifer and the Magothy aquifer material within the upper 90 ft of saturated thickness are referenced herein as "zones" or "aquifer zones" because the boundaries discussed here are different from aquifer boundaries described in the literature and because the Magothy zone represents only a small fraction of the Magothy aquifer thickness. The boundary between the upper glacial and Magothy zones is transitional rather than abrupt and was determined by Heisig and Prince (1993) from water-quality, natural gamma-log, and geologic data to range from 24 to 47 ft thick. This intermediate or transition zone has hydraulic characteristics of both aquifer zones. For example, the local variability of clay and silt content in the intermediate zone corresponds to the Magothy zone (Heisig and Prince, 1993), and the persistence of chloride (derived from the artificial-recharge experiments) in the intermediate and Magothy zones and the absence of chloride in the upper glacial zone below the recharge site in 1987, suggest that permeabilities in the intermediate and Magothy zones are similar. In contrast, the maximum downgradient extent of chloride in the intermediate zone matches that in the upper glacial zone rather than that in the Magothy zone. Thus, the ground-water velocity attributed to the intermediate zone (3.4 ft/d, Heisig and Prince, 1993) is similar to that of the upper glacial zone, although water in areas of low permeability will have much lower velocity. A detailed discussion of hydrogeology within the study area is given in Heisig and Prince (1993). The part of the ground-water system that was of interest in this study was the top 90 ft of the zone of saturation, which includes all of the upper glacial aquifer and the intermediate (transition) zone, and the uppermost part of the Magothy aquifer.

Ground-water flow in the three depth zones in the study area is predominantly southward and horizontal. The horizontal gradient is about

0.0019 (Heisig and Prince, 1993). Water-table altitudes in May 1987, during a period of below-normal precipitation and water levels (Ronald Busciolano, U.S. Geological Survey, oral commun., 1990), are depicted in figure 4.

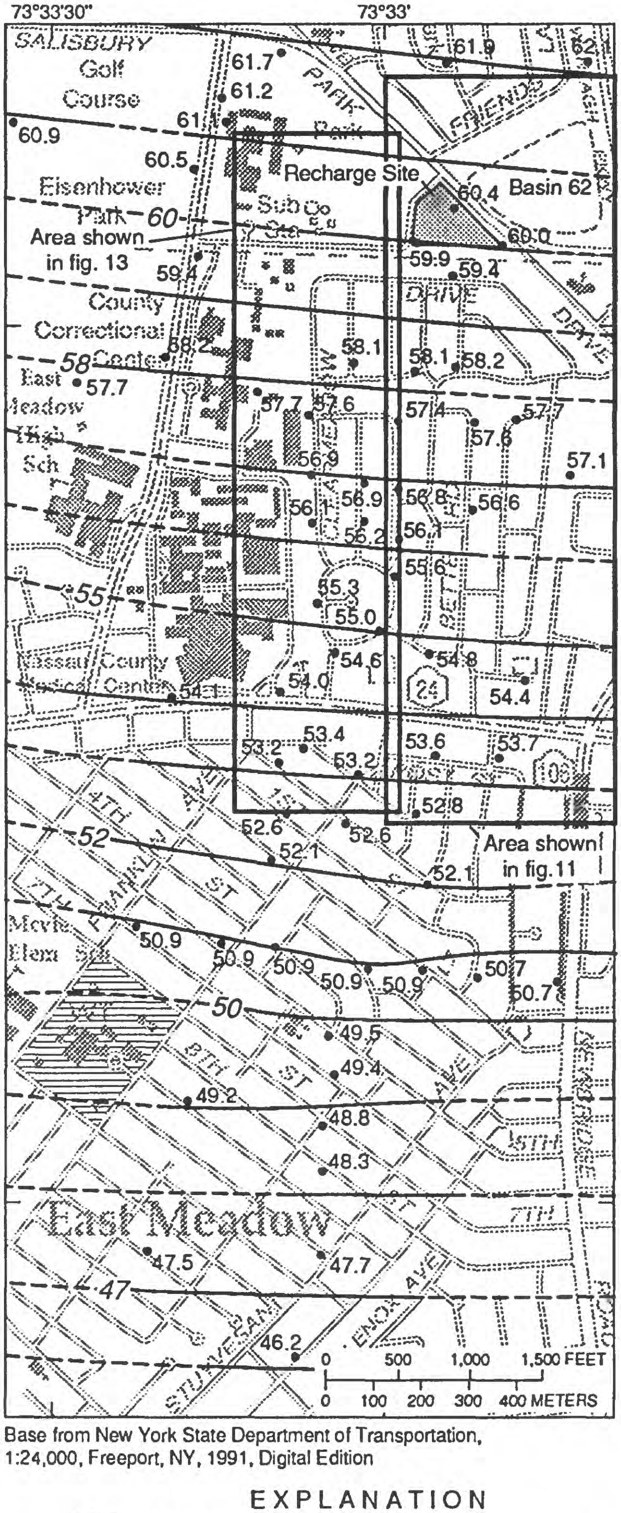
Ground-water flow may depart locally from the generalized patterns described above as a result of local differences in the permeability of the aquifer material and in withdrawals from wells, but the lack of data precludes any assessment of their effects.

Chemical Quality of Ambient Ground Water

Heisig and Prince (1993) reported the chemical characteristics of ambient water from 21 observation wells within the study area (table 1). The wells were chosen on the basis of location, depth, availability of recent (post-1978) water-quality data, and, if downgradient of a point source, from data gathered before that source affected ground-water chemistry. All wells were within or just north of the study area (fig. 5). Several samples from two observation wells along Wantagh Parkway were deleted from the data set because they were collected during periods of contamination by road salt.

All wells are screened within the top 90 ft of the zone of saturation; most are screened within two depth intervals: 50 to 65 ft and 0 to 10 ft below the water table. The number of samples collected from each well ranged from 3 to 19. Median values of each constituent analyzed were determined for each well to provide equal weight to each well.

Median values and distributions of selected water-quality characteristics are related to well-screen depth (Heisig and Prince, appendix I, 1993). These changes with depth provide an indication of the differences and similarities between ambient water and point-source-affected water that are not reflected by overall median-value data. The most pronounced example is boron concentration, which apparently increases with depth. A thorough examination of these variations and causal relation



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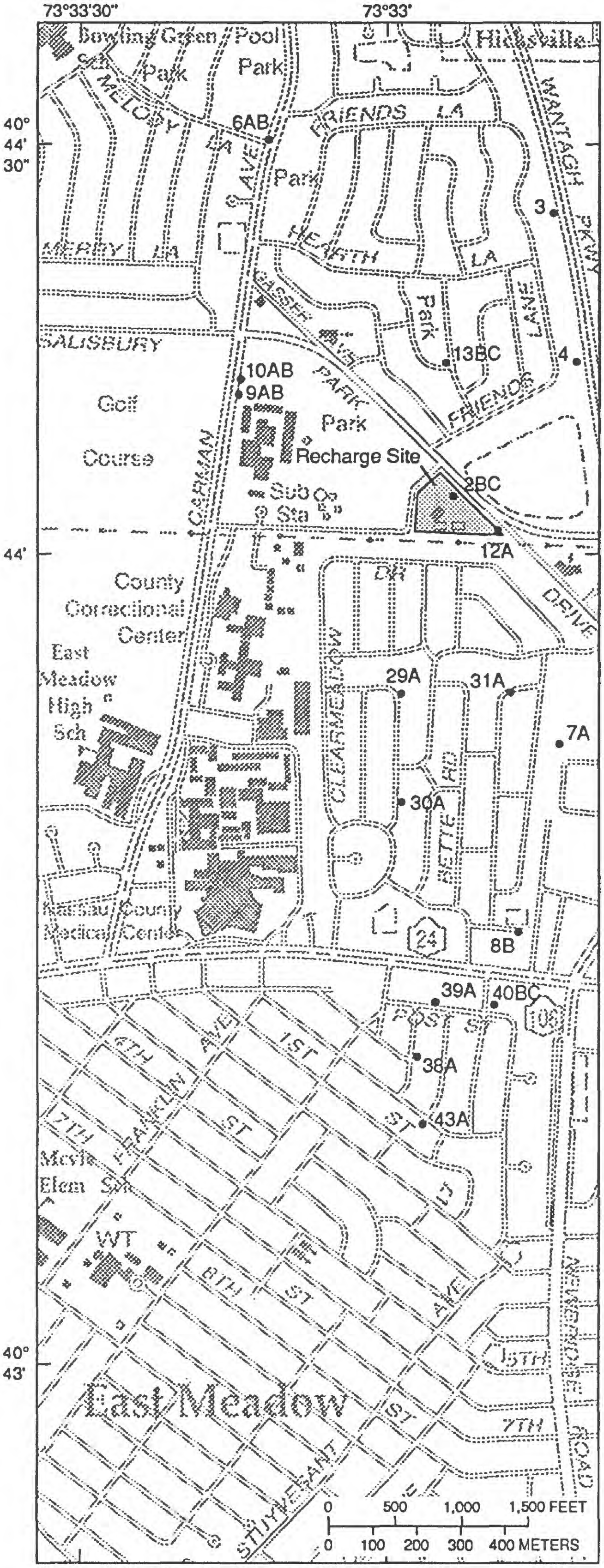
EXPLANATION

•57.7 OBSERVATION WELL--Number is water-table altitude, in feet above sea level

—— 50 — — WATER-TABLE CONTOUR--Shows water-table altitude. Dashed where approximately located. Contour interval 1 foot. Datum is sea level.

PROSPECT AVENUE WELL FIELD

Figure 4.—Water-table altitude in July 1987. (Modified from Heisig and Prince, 1993, fig. 9. Location is shown in fig. 1.)



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was beyond the scope of this study, but changes in median values and distributions of chemical constituents and properties with depth can probably be attributed to ground-water chemistry, aquifer composition, age of the ground water, and human-derived causes.

The overall median, 10th percentile of medians, 90th percentile of medians, and the minimum and maximum medians were calculated from medians at individual observation wells (table 1). The overall median provides a robust measure of the central tendency of each physical property or constituent, and the 10th and 90th percentiles and minimum and maximum medians provide estimates of the range in concentration or value of each constituent. The overall medians in table 1 appear to represent the probable background or general ambient water quality in the study area, although the ranges provided by 10th and 90th percentiles of medians probably include some nonambient water. In this highly developed area, several of the wells chosen as representative of ambient conditions probably are affected in some aspect by unidentified sources upgradient of the study area. Other wells are most certainly affected by contaminants from transient sources or conditions such as cesspools, lawn fertilizers, road salt, or unidentified disposal practices. The high permeability of the Pleistocene sediments makes the shallow ground-water system particularly vulnerable to contamination.

Heisig and Prince (1993) used the averages of the overall median and the 90th percentile of medians and the overall median and the 10th percentile of medians as a conservative estimate of the range of ambient physical properties and constituent concentrations in the study area. The same values are used to differentiate ambient water from water affected by local point sources in this report.

Figure 5.—Locations of observation wells used to define ambient-water quality. (From Heisig and Prince, 1993, fig. 10.)

EXPLANATION

• 9AB WELL SITE AND NUMBER--Number identifies a well site; letters denote individual wells at each site; for example, site 9 contains wells 9A and 9B. By convention, the "A" well is the deepest well at each site

Nitrate + nitrite (N) concentrations (expressed as nitrogen) in ambient ground water suggest that nitrate concentration commonly exceeds New York State drinking-water standards. Because nitrite is an unstable nitrogen species, most nitrogen occurs as nitrate in the analyses. Of the 21 median $NO_3 + NO_2$ as N values, 48 percent exceeded the State 10 mg/L standard. High nitrate concentrations are attributed to many years of cesspool use in this part of Long Island (Perlmutter and Koch, 1972).

Suburban Development

The study area at East Meadow has undergone extensive development since the late 1940's. The increase in population, along with changes in land use, sewage-disposal practices, and water-resources development, have affected both the chemical quality and the flow patterns of ground water, as summarized in the following paragraphs.

Population Growth

East Meadow, like many other villages in Nassau County, underwent rapid growth and development after World War II. Census data show a 15-fold increase in the population of East Meadow (3,145 to 46,036) during 1940-60 (Long Island Regional Planning Board, 1982), but, since 1960, the population has either remained stable or declined slightly. Virtually all of the land was developed in some way by 1960; thus, population growth can occur only where land is redeveloped for residential use.

Land Use

The study area contains five general land-use classes: residential, institutional, commercial, recreational, and utilities (fig. 6). More than half (60 percent) of the land is occupied by medium-density (5 to 10 dwelling units per acre) single-family residences. Institutional uses account for about 17 percent of the land and

Table 1.—Summary of median values for inorganic chemical analyses of ambient water from wells in East Meadow, 1978-87.

[Data from Heisig and Prince, 1993.Analyses by U.S. Geological Survey, Arvada, Colo. Concentrations in milligrams per liter unless specified otherwise. °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 °C; µg/L, micrograms per liter; <, less than]

Physical property or constituent	Number of observation-well medians	Statistics from the population of observation-well medians				
		Minimum median	10th percentile of medians	Overall median of medians	90th percentile of medians	Maximum median
Residue dissolved solids at 180 °C	17	136	140	179	242	275
Specific conductance (field) (µS/cm)	21	230	248	310	379	410
pH (field, stamdard units)	21	4.6	4.8	5.2	5.8	6.0
Alkalinity (as $CaCO_3$)	18	3	3	6	12	27
Chloride	21	19	21	30	35	42
Sulfate	21	14	17	37	42	57
Nitrate and nitrite (as N)	21	5.5	7.7	9.9	19	24
Ammonium (as N)	18	< 0.01	< 0.01	0.02	0.06	0.35
Sodium	21	18	20	26	31	40
Calcium	21	11	14	19	27	31
Magnesium	21	2.3	2.3	3.3	5.6	10
Potassium	21	1.5	2.0	4.8	7.2	7.4
Boron (µg/L) [1]	9	60	60	90	140	170
Silica	21	4.9	5.9	12	15	16
Dissolved oxygen	20	2.0	2.0	4.0	8.0	13

[1] Values based on data from shallow and intermediate-depth wells sampled during this study; no historical data on boron available

include a hospital, jail, schools, and churches. Commercial corridors lie primarily along routes 24 and 106 (fig. 6) and constitute about 6 percent of the study area, and parks and parkways (recreational areas) represent 10 percent. Utilities, which support all of the land uses mentioned, encompass public-supply well fields, sewage-treatment plants, stormwater basins, road-salt storage facilities, and powerline right-of-ways, and account for the remaining 7 percent of the study area.

Sewage Disposal

Cesspools and infiltration beds were the primary means of sewage disposal in the study area before sanitary sewers became operational in 1979-80. Domestic sewage was routed to individual cesspools, and during the 1940's, scavenger wastes (predominantly raw domestic sewage that has been pumped from cesspools) were applied to land surface at the site that later became the Meadowbrook sewage-treatment plant (A.J. Farina, Superintendent of sewage treatment plants, Nassau County, oral commun., 1988), but no record of these activities is available. For 28 years, institutional sewage from the hospital and the county jail underwent secondary treatment at the Meadowbrook plant before disposal through infiltration beds.

Disposal of domestic waste through cesspools, given the high density of housing in the area (fig. 6), represented a significant nonpoint source of shallow ground-water contamination by cesspool leachate. Perlmutter and Koch (1972) attributed nitrate contamination in the upper glacial aquifer in the southern half of Nassau County to domestic sewage leachate and fertilizer leachate.

The application of scavenger waste to the land surface throughout the 1940's would have resulted in the downward movement of salts, dissolved and suspended organic matter, and various nitrogen species. Suspended organic matter would probably be retained in the unsaturated zone until broken down by bacteria in the presence of oxygen. If the load of organic matter were large enough, bacterial decomposition could produce at least temporary anoxic conditions in either the unsaturated zone or the saturated

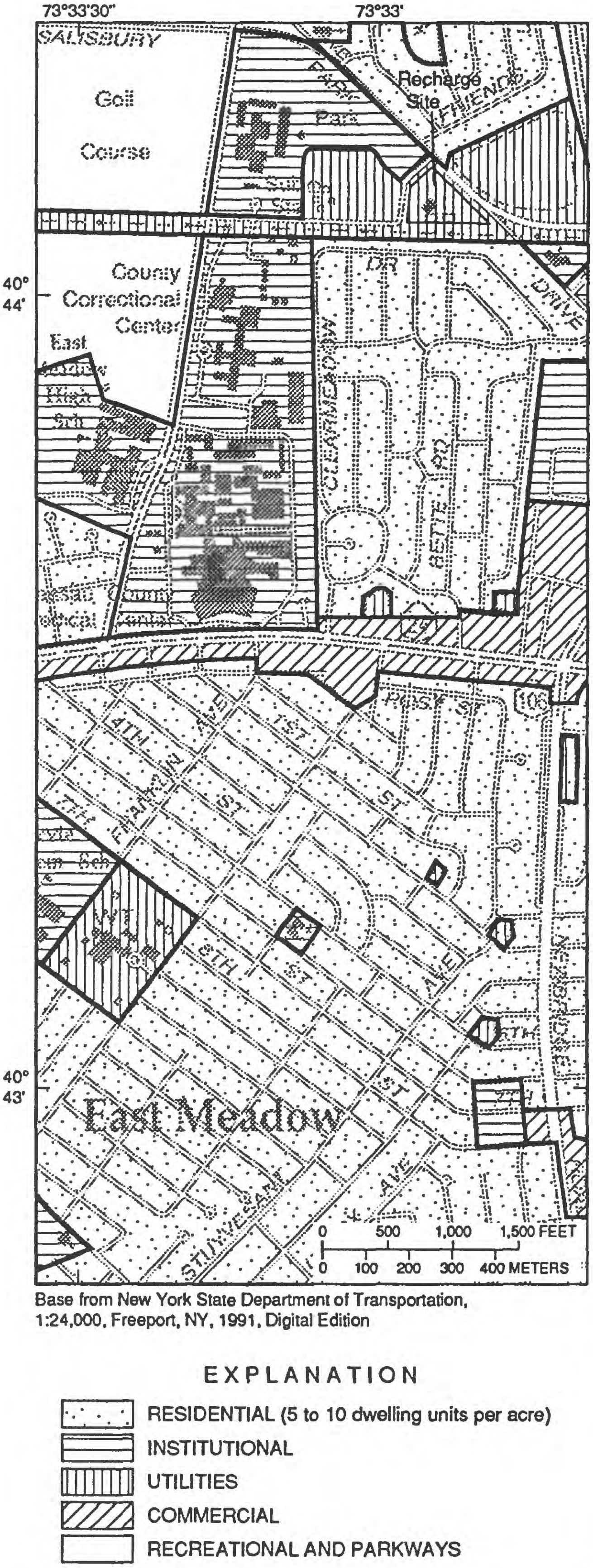


Figure 6.—Land use in the study area.

zone. Decomposition of particulate organic matter within the unsaturated zone could continue to be a source of nitrogen and a sink for oxygen from natural recharge after the cessation of scavenger-waste disposal in the late 1940's. The effects of scavenger-waste disposal on local ground-water quality during and after the period of operation is unknown, however.

Surface application of secondary-treated sewage at the same site continued from 1951 until 1979, when the Meadowbrook sewage-treatment plant served the county jail and the hospital. Plant operation and the effects of effluent disposal are discussed in a later section.

In 1979, both the hospital and county jail were connected to the sanitary-sewer system that carries sewage to the Cedar Creek Sewage Treatment Plant in Wantagh (fig. 1) and, in 1980, the East Meadow community was connected to the sewer system. Although the diversion of domestic sewage to the treatment plant decreases the amount of dissolved solids reaching the upper glacial aquifer, wastes in abandoned cesspools that were not pumped probably continue to leach downward to the water table and affect water quality (Perlmutter and Koch, 1972). Leaks in sanitary sewer lines could also affect ground-water quality (Kimmel, 1972).

Development of Ground-Water Resources

Rapid population growth and development during the early 1950's necessitated the development of ground-water resources in the East Meadow area. A public supply-well field was established by the town on Prospect Avenue in 1951 (fig. 4). Three wells pumped an average of 1.3 Mgal/d in 1952, the first full year of operation. By 1955, pumpage had nearly doubled. In 1988, the well field had 10 active wells, and the average daily pumpage had risen to 5.2 Mgal/d (Harold Morgan, East Meadow Water District, oral commun., 1989). Between 1955 and 1988, several wells were deepened because the water quality had deteriorated. Water from the shallow production wells that remain is blended with water from deeper wells to decrease the high (greater than 10 mg/L) nitrate concentrations. The degradation of water quality at shallow production wells in the Magothy aquifer suggests that shallow ground water affected by cesspool use has been drawn downward by the intensive pumping at the well field.

LOCAL POINT SOURCES THAT AFFECT GROUND-WATER QUALITY IN THE EAST MEADOW AREA

Ground-water quality in the study area has long been subject to a variety of point sources that originate within the study area. A point source is a discrete, definable source of solutes (generally derived from human activity) that alter the chemical composition of ground water as they enter the aquifer system. The point of introduction can be anywhere between land surface and the lower boundary of the aquifer system, and the discharge can be direct, such as injection or surface application of treated wastewater, or it can require interaction with rain or snowmelt to generate leachate, such as road salt, and can have a detrimental, neutral, or beneficial effect on ground-water quality.

Introduction of leachate or solution from a point source can be passive or active. If the point source is passive, the solution or leachate reaches the water table in volumes comparable to the recharge from local precipitation, in volume per area, and has little effect on ground-water flow. A zone of influence, or plume, with a width similar to that of the source will develop as the solution or leachate is transported down-gradient by local flow. If the point source is active, infiltration from the point source greatly exceeds the rate of recharge from precipitation and can alter local ground-water-flow paths by causing mounding, which results in a zone of influence or plume that is wider than the point source. In either case, plumes generated from point sources will widen downgradient through hydrodyamic dispersion.

Investigation of the plume derived from artificial recharge with reclaimed water in the study area (Heisig and Prince, 1993), herein referred to as the recharge plume, led to the identification of three additional point sources and their plumes or zones of influence: (1) Nassau County stormwater-basin 62, (2) road-deicing salt-storage piles, and (3) the nowabandoned Meadowbrook sewage-treatment plant. (Locations are shown in fig. 7.) The artificial-recharge site and the Meadowbrook sewage-treatment plant are considered active sources, the road-salt-storage piles are considered passive, and stormwater basin 62 is considered a combination of the two, depending on the magnitude of rainfall or snowmelt. Each of these sources affects the chemical quality of ground water differently and can complicate determinations of ambient ground-water quality if they are not taken into account.

The chemical differences among ambient ground water, reclaimed water, and ground water affected by any of the three point sources can be illustrated with Stiff and trilinear diagrams. Both types of diagrams were used in this study because each accentuates a different aspect of water composition. Stiff diagrams allow direct comparison of concentrations of given constituents within a single sample or among a number of samples, and trilinear diagrams depict the percentage of cations and anions in a given sample. Trilinear diagrams group within a specific area samples whose anion and cation proportions are similar, even if their concentrations differ widely. Trilinear diagrams also can indicate water-quality evolution over time at a given sampling point. Although the grouping of cations (Na, Ca, Mg, K) and anions (Cl, HCO_3, and SO_4) on the diamond-plot part of the trilinear diagram can mask some differences in the concentrations of individual constituents, such differences can usually be detected in the corresponding Stiff diagrams or the individual triangular anion and cation plots. As a result, samples affected by local point sources can generally be identified through use of these diagrams along with spatial and historical information.

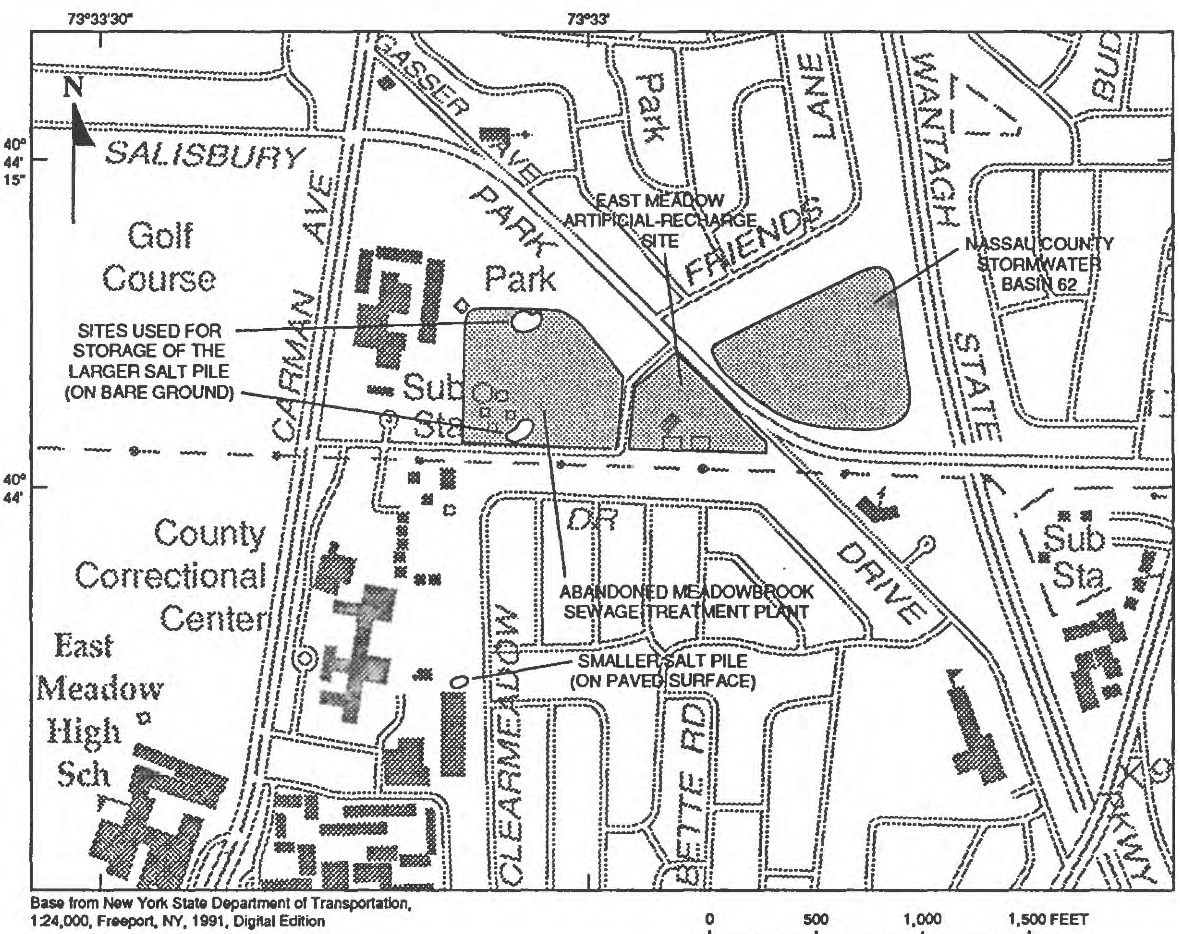


Figure 7.—Locations of point sources in relation to the artificial-recharge site at East Meadow. (Modified from Heisig and Prince, 1993, fig. 13.)

The trilinear and Stiff diagrams in figure 8 depict the chemistry most representative of ambient ground water, reclaimed water used in the artificial-recharge experiments, and water from the three local point sources. Ambient-ground-water data are the overall median values in table 1. Chemical analyses of reclaimed water and water associated with with the other point sources are listed in table 2. Reclaimed-water data are median values from eight composite samples of ponded water in the recharge basins (Heisig and Prince, 1993) during the 1982-84 recharge tests described in Schneider and others (1987). Stormwater data are overall medians of median data reported by Ku and Simmons (1986) for surface water entering five recharge basins in Nassau and Suffolk counties. Bicarbonate concentration in storm runoff was not measured by Ku and Simmons (1986) but was estimated from an alkalinity concentration (10 mg/L as Ca CO_3) in water collected from well 12B (fig. 2) in March 1987, on the assumption that all alkalinity was in the form of bicarbonate under pH conditions near the recharge basin.

The presence of dissolved organic material in storm runoff (Ku and Simmons, 1986), which could contribute to alkalinity, make this a maximum estimate for bicarbonate. Road-salt data are from a salt sample that was collected at the town salt-storage site and dissolved in distilled water (specific conductance of 934 μS/cm). The most reliable estimate of effluent chemistry from the Meadowbrook sewage-plant is based on a ground-water sample collected from observation well 1C (fig. 2), screened 3 ft below the water table and adjacent to the most frequently used infiltration beds in 1977, when the plant was processing 0.6 Mgal/d.

Comparison of data points in figure 8 suggests considerable differences among waters from the different sources. As water from each source moves through the ground-water system,

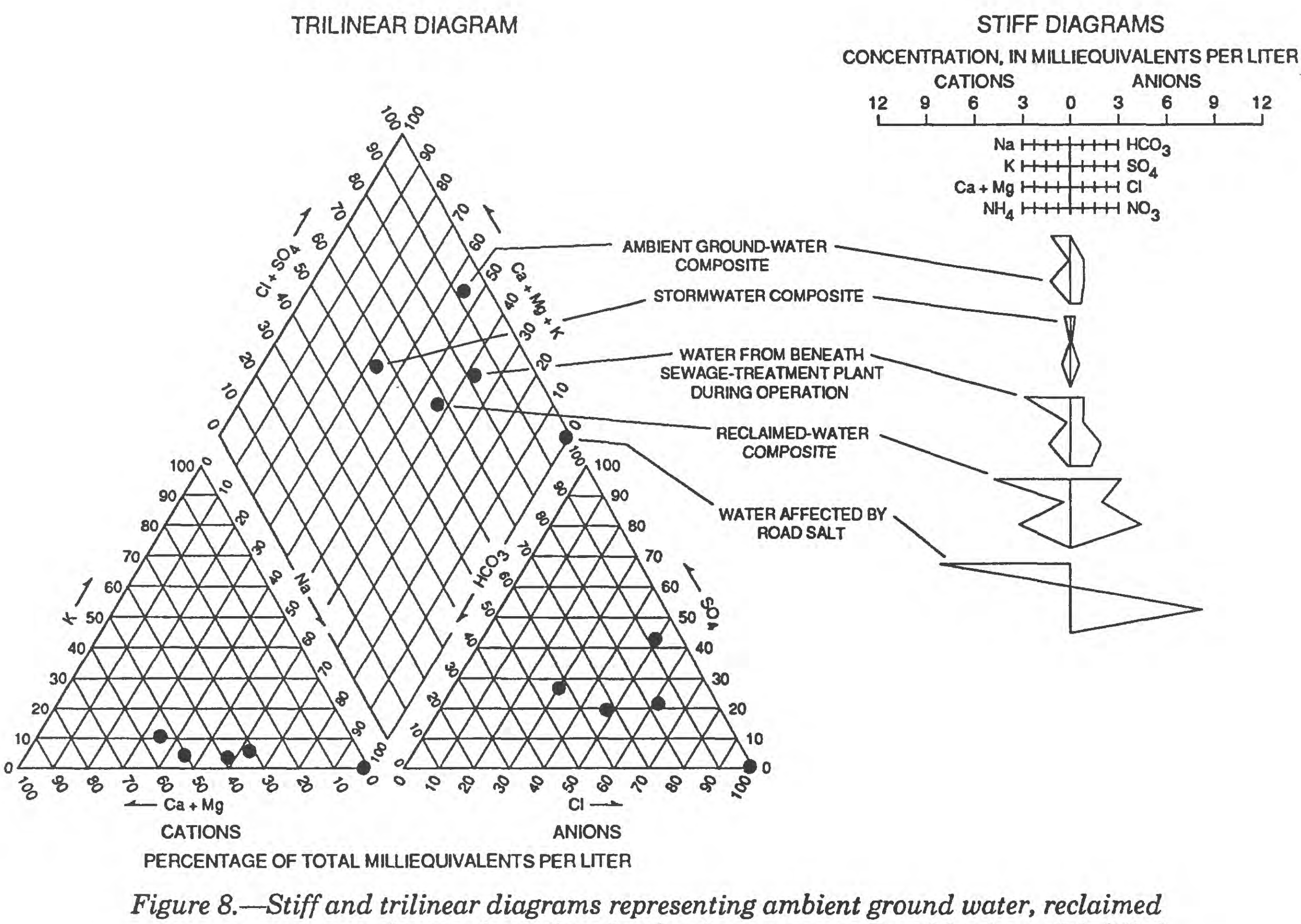


Figure 8.—Stiff and trilinear diagrams representing ambient ground water, reclaimed water, and water from three local point sources at East Meadow. (Modified from Heisig and Prince, 1993, fig. 14. [Analyses listed in tables 1 and 2.]

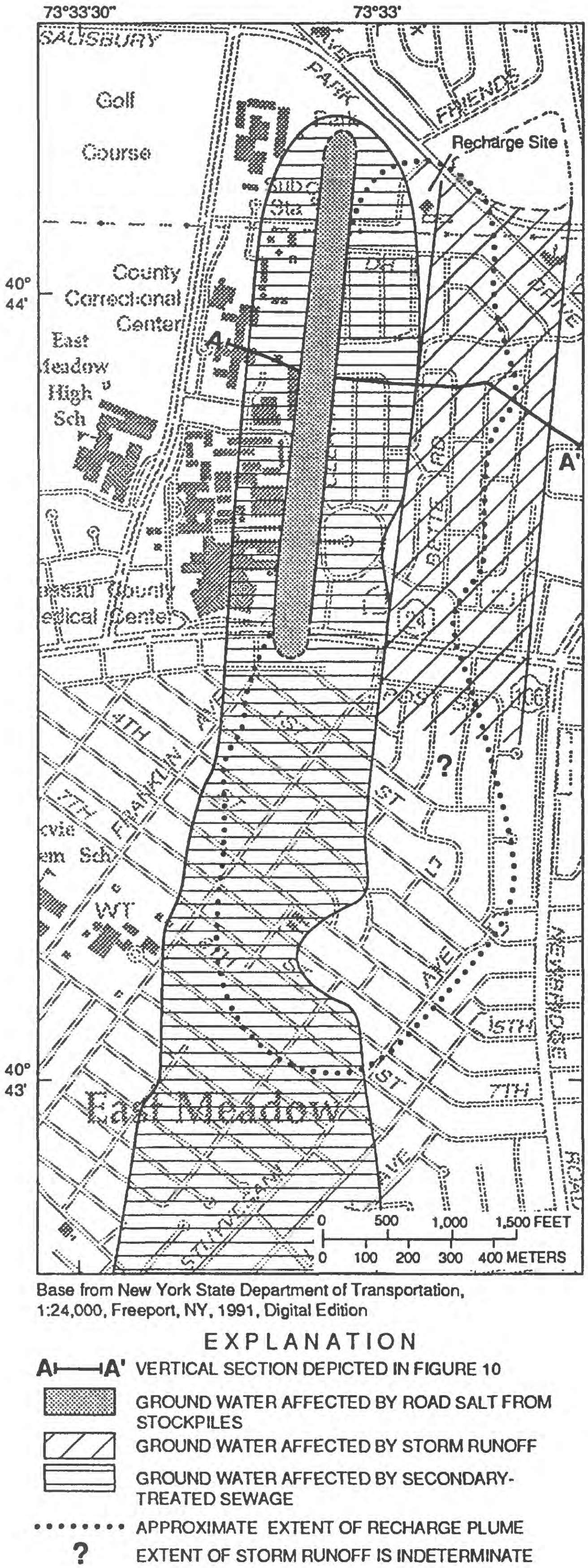


Figure 9.—Horizontal extent of zones of influence from storm runoff, road-salt leachate, secondary-treated sewage, and reclaimed water. (Modified from Heisig and Prince, 1993, fig. 15.)

hydrodynamic dispersion (mixing) and chemical reaction(s) alter its concentration and composition and thereby make identification of the source difficult. Supplemental data, such as source histories, aquifer geometry, interaction processes between water and aquifer material, and sample location, together with chemical data, facilitate identification of the source(s) that affect a water sample.

The horizontal distribution of ground water affected by the three point sources is depicted in relation to the recharge plume in figure 9. Each area represents the maximum known extent of influence of each source within the depth and horizontal limits of the observation-well network. The vertical distributions are shown in figure 10A. The differences in the location, size, and shape of each zone of influence, discussed in the following sections, are related to source location, volume of source water reaching the water table, and the hydraulic properties of the aquifers.

Stiff diagrams that correspond to each observation well in the vertical section (fig. 10B) illustrate some of the chemical variation used to identify zones of influence in figure 10A. Criteria for identification, other than Stiff diagram shape, of point-source-affected ground waters are discussed in the following sections. Comparison of diagrams that depict chemical composition of ambient water with water affected by point sources indicates that the concentrations and proportions of major ions in ground water change significantly after the infiltration of solutes from point sources and the mixing of these solutes with ground water. An example of this is the difference between calcium concentration of the dissolved road-salt sample (fig. 8) and that of ground water affected by road-salt leachate from well 21A (fig. 10B). An explanation for this change is discussed in the section on salt storage piles (p. 17-19).

Stormwater Basins

Precipitation that falls on paved areas served by storm sewers is routed to local stormwater

Table 2.—Chemical data representative of waters derived from several local point sources.

[All concentrations in milligrams per liter unless specified. <, less than; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; C, carbon; N, nitrogen, $CaCO_3$, calcium carbonate.]

	Type of source water			
Physical property or constituent	Reclaimed wastewater [1]	Road-salt leachate [2]	Stormwater runoff [3]	Secondary-treated sewage [4]
Specific conductance (µS/cm)	810	934	60	550
pH (Standard units)	6.5	5.2	6.9	5.7
Alkalinity (as $CaCO_3$)	151	2	—	36
Chloride	120	290	4.1	67
Sulfate	74	< 5.0	5.4	34
Nitrate + nitrite (as N)	0.57	< 0.01	0.42	19.06
Sodium	95	180	3.5	64
Calcium	52	0.22	3.7	22
Magnesium	8.3	< 0.01	0.8	3.6
Potassium	12	0.20	1.6	9.2
Dissolved oxygen	7	—	—	1.6
Organic carbon, dissolved (as C)	—	—	6.3	—
Total organic carbon (as C)	—	—	—	10

[1] Median concentrations of eight composite recharge basin samples. (From table 3, Heisig and Prince, 1993.)

[2] Analysis of a salt-and-sand sample from the town salt-storage site, dissolved in and diluted with distilled water to a specific conductance of 934 µS/cm, May 29, 1987.

[3] Overall median values of storm water runoff from median values of runoff entering five storm water basins in Nassau and Suffolk Counties. (Data from Ku and Simmons, 1986.)

[4] Ground water affected by secondary-treated sewage at well 1C, November 14, 1977. Well location shown in figure 2.

basins from which it percolates downward to the water table and mixes with ground water. (Storm sewers drain only storm runoff and are separate from sanitary sewers). Basins increase recharge to the ground-water system and prevent local flooding during storms. Stormwater basins were first used in Nassau County in 1935, and today (1990) the county has nearly 1,000 basins, which range in size from less than 1 acre to 30 acres (Nassau-Suffolk Regional Planning Board, 1977). Although storm runoff that is directed to recharge basins generally is considered a non-point (diffuse) source with respect to its effect on the ground-water quality of Long Island, it acts as a point source at the scale of this study.

The study area contains 14 stormwater basins, and their drainage areas range from 9.5 to 420 acres (Seaburn and Aronson, 1973). Each basin affects shallow ground-water quality in proportion to the size of its drainage area and the types of roads that are drained. For example, major roads such as parkways generally receive more frequent applications of road salt than those in a residential area.

Storm runoff directed to Nassau County stormwater-recharge basin 62 affects ground-water quality over a larger area than runoff to other basins in the study area because it drains a far greater area. The basin, completed in 1952, was originally designed to serve a section of Wantagh Parkway (fig. 7) (Seaburn and Aronson, 1973). The estimated drainage area served by basin 62 has increased to 420 acres with continued development in the East Meadow area.

The magnitude of annual recharge through this basin can be estimated from the work of Ku and Simmons (1986), who estimate that, in a medium-density residential area similar to the study area, at least 14 percent of the total precipitation enters stormwater basins. The volume of precipitation on the drainage area of basin 62 was calculated as the average annual precipitation for 1984 and 1985 at the rain gage at Eisenhower Park, 1/4 mi west of the study area. The volume of recharge, in cubic feet, was calculated from the drainage area and precipitation data, then multiplied by 0.14 (14 percent) and converted to gallons to obtain a recharge rate of about 71 Mgal/yr or 196,000 gal/d. Stormwater recharge is sporadic and occurs only during storms and snowmelt periods; thus, a single large storm could cause more than 1 Mgal to enter basin 62.

Ku and Simmons (1986) examined chemical quality of storm runoff at five stormwater basins on Long Island and their median basin-water concentrations were used in this study to calculate overall median concentrations of selected inorganic constituents (table 3). Comparison of

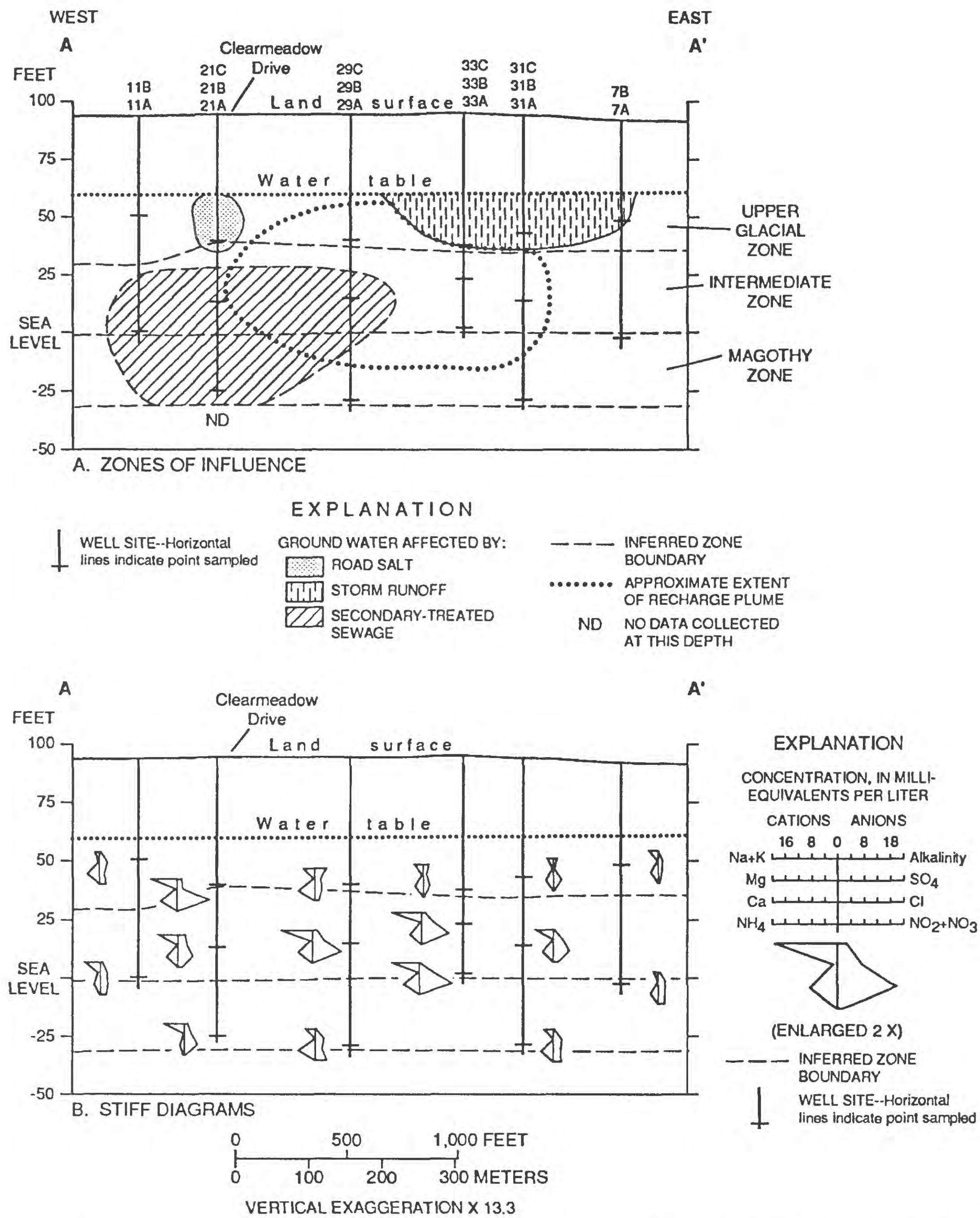


Figure 10.—Vertical section A-A' (Location of section is shown in fig. 9.): A. Zones affected by stormwater runoff, road-salt leachate, secondary-treated sewage, and reclaimed water. B.Stiff diagrams of water samples from observation wells.

these values with median ambient ground-water data (table 1) suggests that (1) storm runoff has lower concentrations of most constituents than the ambient ground water and thus typically acts as a dilutent of dissolved solids in ground water at shallow depths, and (2) the low nitrate concentrations in storm runoff decrease the nitrate concentrations in ground water downgradient of basin 62.

Delineation of the stormwater plume within the shallow ground-water system downgradient of basin 62 is facilitated by characteristically low concentrations of minimally reactive constituents, such as nitrate + nitrite (as N) and sulfate, concentrations of which are not subject to large seasonal fluctuations. These constituents have low concentrations downgradient of basins 62 and 164 (a small basin downgradient of basin 62, fig. 11). The plume of stormwater from basin 62 is predominantly within the upper glacial zone and extends from the water table to a maximum of about 30 ft below the water table (figs. 9, 10A). It is most readily detected near basin 62 because the screened zones of these observation wells are within this depth range and because mixing and effects from other sources are minimal. Delineation of the stormwater plume at downgradient locations is made difficult by the sporadic nature of storms, hydrodynamic dispersion within the aquifer, the presence of recharge-plume water farther downgradient, and limited observation-well coverage. During the infiltration of reclaimed water at the recharge site adjacent to basin 62, stormwater from basin 62 presumably acted as an intermittent dilutent.

Chloride and sodium are relatively conservative constituents whose concentrations in storm runoff or snowmelt fluctuate seasonally in response to the winter application of road-deicing salts (primarily sodium chloride in this area). Periods of thaw or rain after a snowstorm can cause very high concentrations ("spikes") of chloride and sodium in stormwater that flows to recharge basins. For example, the single highest chloride concentration reported by Ku and Simmons (1986) was 1,100 mg/L, whereas the overall median chloride concentration calculated from the five median basin concentrations from the same study was 4.1 mg/L (table 3). The presence of road salt in storm runoff that has infiltrated to the upper glacial aquifer is probably best indicated by high chloride:sulfate ratios because chloride concentrations increase seasonally, whereas sulfate concentrations do not. Stormwater that is not affected by road salt has lower sodium and chloride concentrations than ambient ground water.

Road-Salt Storage Piles

The application of deicing salts and salt-and-sand mixtures to roads is a common practice on Long Island during the winter. Sixty-seven salt and salt-and-sand piles in Nassau County are managed by the State, county, towns, and villages, in addition to an unknown number of privately maintained supplies (Long Island Regional Planning Board, 1984). Many of these piles are not protected from the weather and thus produce briney runoff that can leach downward to the water table.

In the study area, a hospital and the town maintain supplies of road salt for local use (fig. 7). The hospital supply is stored within a maintenance building year-round, but some of that supply has been observed outdoors, during winter, uncovered on a paved surface that apparently drains into a storm sewer. This pile does not appear to be a significant source of leachate to the local ground water, but no downgradient wells are available to confirm this.

The town salt supply is larger and is on the site of the abandoned Meadowbrook sewage-treatment plant almost directly upgradient of the medical center supply. In the past, salt has been stored at the site seasonally, from mid-November or December through April or May and rests uncovered on bare, permeable soil. A salt-and-sand mixture was first stored at this site during the 1984-85 winter. Salt was stored at the northern end of the site during the winters of 1984-85, 1985-86, and 1987-88 and about 500 ft downgradient (south) of that area during the 1986-87 winter (fig. 7) (Edward Donohue, Town of Hempstead, oral commun., 1988). A sample of the salt-and-sand mixture was collected and dissolved in distilled water; chemical analysis revealed that the salt was relatively pure sodium chloride (table 2).

The downward transport of salt at the town site occurs mainly during the nongrowing season (September through April), although some transport may occur during the growing season. Steinhuis and others (1983) reported that nearly all recharge occurs during the nongrowing season, when uptake of water through evapotranspiration is minimal. The presence of salt residue at the site prevents growth of vegetation

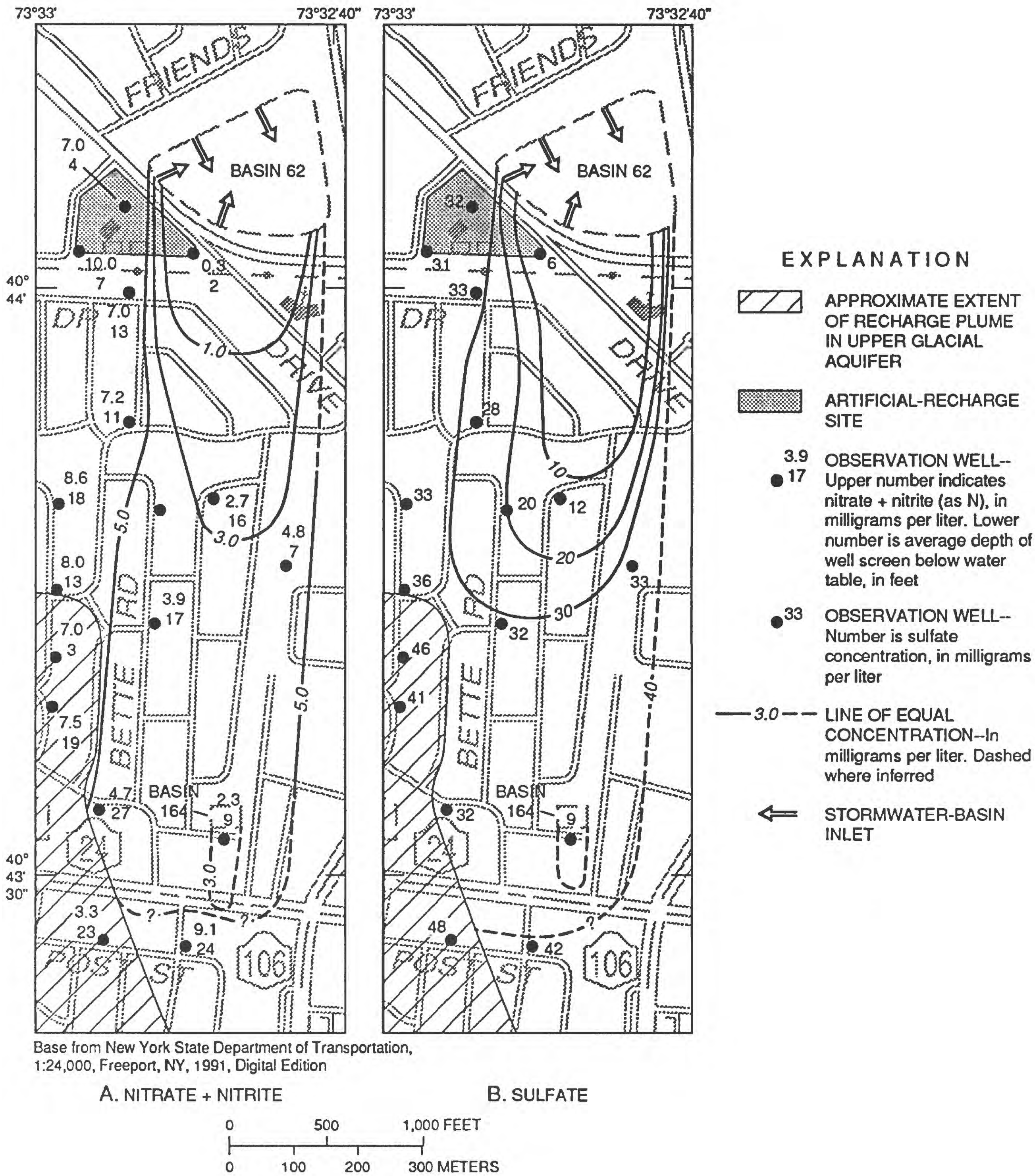


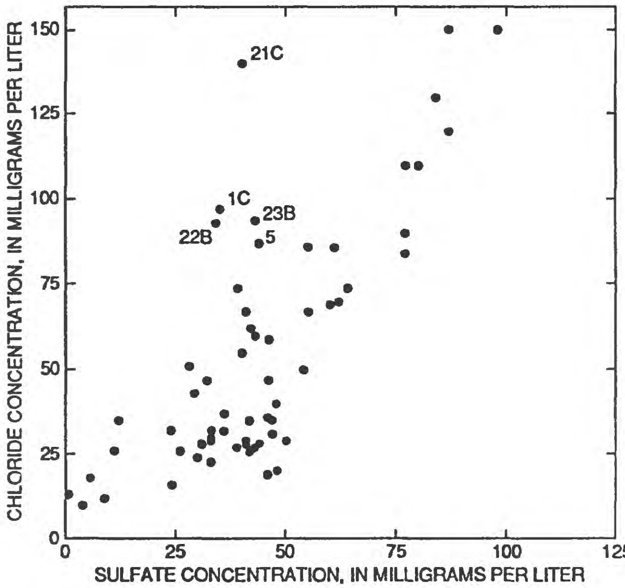
Figure 11.—Distribution of ground water affected by storm runoff from recharge basins 62 and 164 in the upper glacial zone. (Location of area is shown in fig. 4.)
A. Nitrate + nitrite concentration and average depth of well screen below water table.
B. Sulfate concentration.

during the growing season, however, and thereby could allow salt remaining in the unsaturated zone to leach downward to the water table after storms of high intensity and (or) long duration.

A scatter plot of chloride in relation to sulfate in all March-April 1987 ground-water samples from East Meadow (fig. 12) resulted in the identification of five anomalies, which are attributed to the presence of road-salt leachate within the upper glacial zone. These five samples appear on the scatter plot as outliers, characterized by elevated chloride concentrations without a proportional increase in sulfate, above the main trend of the data. The position of the outliers reflects the composition of road salt (table 2). Similar discrepancies were also observed in Stiff and trilinear anion diagrams (figs. 8, 10). The five samples were from wells directly downgradient of the salt piles and screened in the upper glacial zone. Maps of the zone of influence with high chloride-to-sulfate ratios (> 1.70) and high chloride concentrations (> 50 mg/L) clearly distinguish the salt-affected water from the surrounding water (fig. 13). The highest recorded chloride and sodium concentrations from the salt-affected water were 190 and 110 mg/L, respectively. These concentrations are below the New York State drinking-water standard of 250 mg/L for chloride but above the New York State Health Department guideline of 20 mg/L for sodium.

In March-April 1987, the road-salt plume was limited to the upper glacial zone but was detected at least as far south as Route 24, about 3,000 ft downgradient, to a depth between 5 and 10 ft below the water table; it also was identified at a depth of 15 to 20 ft below the water table about 2,000 ft downgradient of the salt piles (fig. 13). Salt leachate can be derived locally from other sources, such as the hospital's salt supply or road salting along Route 24. The narrowness of the plume reflects the small source area and the comparatively small volume of leachate reaching the water table (figs. 11, 13) in rela-tion to stormwater from basin 62. The chloride and sodium concentrations in water affected by road salt varies both laterally and vertically, consistent with the intermittent nature of natural recharge to the ground-water system.

Water affected by road salt appears to react with the upper glacial material as it moves downgradient from the storage site(s) because the percentages of calcium, magnesium, and potassium increase with respect to sodium, apparently in response to cation-exchange processes. As a result, a sample of ground water containing road-salt leachate will not plot in the same location on the trilinear diagram as a simple mixture of ambient ground water and pure road-salt leachate.



EXPLANATION

• SINGLE GROUND-WATER SAMPLE COLLECTED FROM AN OBSERVATION WELL IN MARCH-APRIL 1987--Labeled points denote observation wells where ground water has been affected by road-salt leachate. (Well locations are shown in fig. 2)

Figure 12.—Chloride concentration as a function of sulfate concentration in ground-water samples collected in the study area during March-April 1987.

Meadowbrook Sewage-Treatment Plant

The Meadowbrook sewage-treatment plant served a medical center and the county jail for 29 years. Although the sewage-treatment facility no longer exists, chemical analyses of ground water samples from the study area indicate the presence of constituents and chemical properties associated with treated sewage.

Plant Operation

The Meadowbrook sewage-treatment plant operated during 1951-79, after which all flow was diverted to the Cedar Creek water-pollution-control plant in Wantagh (fig. 1). Treatment of

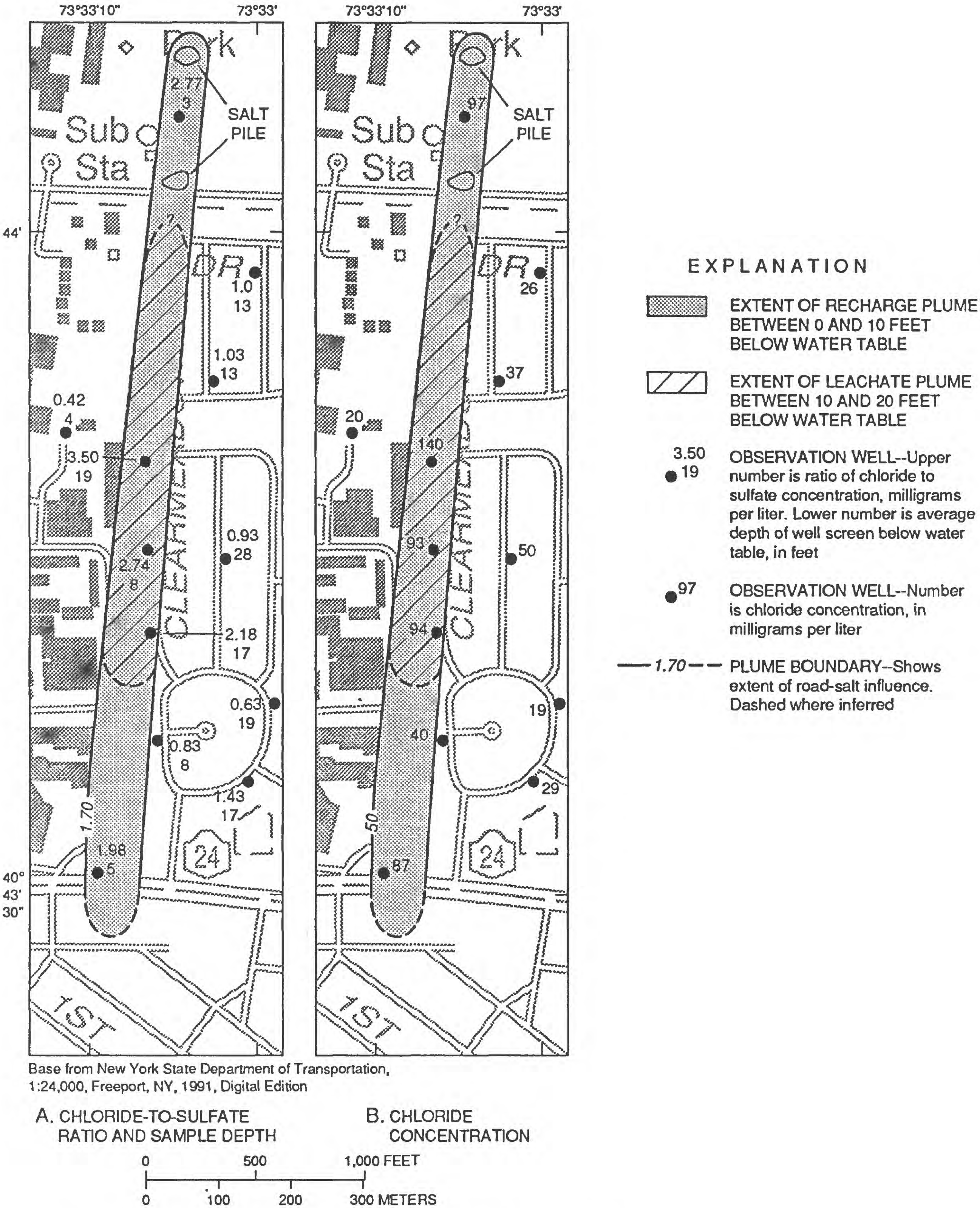


Figure 13.—Extent of road-salt-leachate in the upper glacial zone:
A. Chloride-to-sulfate ratio and average well-screen depth below water table.
B. Chloride concentration.

sewage at the Meadowbrook facility consisted of primary sedimentation, secondary treatment with trickling filters, and return to the ground-water system through sand filtration beds (recharge basins).

Secondary treatment of sewage at the Meadowbrook facility decreased the amount of biologically degradable organic matter and altered the nitrogen speciation. Treatment involved spray application of primary-treated sewage onto a bed of crushed rock or other porous medium that served as a substrate for bacteria. Secondary treatment with single-stage trickling filters is about 77 percent effective in the removal of organic matter, expressed as biochemical oxygen demand (BOD) (Clark and others, 1971). Decomposition of the remaining nitrogen-rich organic material (ammonification) would increase the amount of ammonium (Freeze and Cherry, 1979), which is then subject to oxidation by nitrifying bacteria (nitrification). The net result of secondary treatment on nitrogen speciation is a shift from predominantly reduced forms (organic nitrogen and ammonium) to more oxidized forms (nitrate with minor nitrite).

During its last 5 years of operation, the plant treated and discharged between 0.6 and 1.0 Mgal/d (Thomas Palumbo, Sewage Treatment Plant Supervisor, Nassau County Department of Public Works, written commun., 1988). Of the nine basins used for recharge , the two basins directly north of the plant received the greatest amount of effluent (A.J. Farina, Superintendent of Sewage Treatment Plants, Nassau County Department of Public Works, oral commun., 1988). These basins were used continuously for periods of 2 to 3 weeks until decreased infiltration rates necessitated scarification (break-up of the basin floor). A basin undergoing scarification was generally taken out of service for a few days.

Quality of Secondary-Treated Sewage

Little information on the chemical quality of effluent from the Meadowbrook facility, other than chloride and BOD concentrations, is available from Nassau County Department of Public Works. In 1964, chloride concentrations in effluent ranged from 20 to 90 mg/L with a median of 40 mg/L, and BOD values ranged between 9 and 144 mg/L with a median of 40 mg/L. During the plant's last 5 years of operation (1975-79), chloride concentrations ranged from 20 to 160 mg/L with a median of 65 mg/L, and 5-day BOD values ranged from 5 to 48 mg/L with a median of 20 mg/L. Nitrogen concentrations in secondary-treated sewage from the Meadow-brook facility were not measured during the period of operation, but LeBlanc (1984) reported ranges of 0.72 to 6.9 mg/L for ammonium as N and 8.2 to 16 mg/L for nitrate as N at a similar sewage-treatment facility on Cape Cod, Mass. An estimate of secondary-treated sewage quality is provided by a water sample collected from well 1C (table 4).

Effects of Infiltration on Treated-Sewage Composition

Percolation of secondary-treated sewage through the unsaturated zone to the water table can affect nitrogen speciation and decrease dissolved oxygen concentrations. At the start of recharge, the unsaturated zone is not in chemical equilibrium with recharge water. Conditions would most likely be oxic, and the proportions of adsorbed cations would reflect the chemistry of natural recharge. Initially, adsorption of ammonium at cation-exchange sites in the unsaturated zone would prevent it from reaching the water table. After several days of continuous recharge, however, ammonium would reach the water table after satisfying exchange equilibria, and the filled interstices would prevent oxygen from entering the unsaturated zone (Bouwer, 1974). Thus, oxygen in the effluent could become depleted by bacterial decomposition of organic matter and by nitrification (Clark and others, 1971). Oxygen depletion, in turn, would allow additional ammonium to reach the water table.

When recharge ceases and a basin is allowed to dry for 2 to 3 weeks, oxygen can reenter the pore spaces in the unsaturated zone as they drain. If nitrifying bacteria are present in sufficient numbers, much of the adsorbed ammonium can undergo nitrification to nitrite and then to nitrate, which is easily transported with subsequent recharge (Bouwer, 1974). The oxidation of ammonium will create a need for reequilibration (ammonium adsorption) at cation-exchange sites in the unsaturated zone. If the basin is allowed to dry for only a few days, however, much less ammonium will undergo nitrification. This appears to have been the mode of operation at the two most frequently used basins at the Meadowbrook facility. Thus, infiltration of secondary-treated sewage through the unsaturated zone continues to shift nitrogen speciation to the oxidized species, although the magnitude of the shift is largely determined by recharge practices. In addition, dissolved oxygen concentrations are likely to decrease during infiltration.

Infiltration of secondary-treated sewage through the unsaturated zone can change the concentrations of other constituents as well, such as phosphorus and, to a lesser extent, the major cations, through sorption and cation-exchange processes. The extent of change depends on factors such as the duration of infiltration and drying periods and changes in effluent composition.

Delineation of Ground Water Affected by Treated Sewage

The delineation of ground water affected by secondary-treated sewage in the study area was based on chemical and hydrogeologic data. The sewage-affected water extends to a depth of at least 152 ft below the water table at the treatment-plant site and extends downgradient beyond the study area boundary (figs. 9, 10A). A comparison of ambient-water quality (table 1) with the best estimate of secondary-treated-sewage quality (table 4) suggests that the zone of influence can be delineated from several chemical properties. Water of ambient quality is not prevalent throughout the study area, however, because (1) it is locally affected by the sources named earlier, and (2) the distribution of constituents derived from recharge at the sewage-treatment plant reflect 8 years of transport and mixing since the cessation of plant operations. The following paragraphs describe the extent of sewage-affected water in the three depth zones described earlier.

Upper Glacial Zone

The upper glacial zone, which is characterized by high permeability and high ground-water velocities, shows the least evidence of the effects of infiltration of secondary-treated sewage within the study area. The most conservative (chloride) and least reactive (sodium, sulfate) constituents, except boron and nitrate + nitrite, have been transported downgradient beyond the limits of the study area. In March 1987, elevated boron concentrations were detected in ground water at two wells near the southern boundary of the study area, downgradient of the recharge plume. Elevated concentrations of nitrate + nitrite in the same area could represent either ambient or secondary-treated water. Boron and nitrate + nitrite were interpreted to be more reactive (less mobile) than chloride, sodium, and sulfate during an investigation of the recharge plume in the same study area (Heisig and Prince, 1993).

Potassium provides an indication of the effect of secondary-treated sewage in the upper glacial zone because it is reactive and subject to retardation through cation-exchange processes, as discussed by Heisig and Prince (1993) and thus has low mobility. Heisig and Prince (1993) report that potassium has traveled only 30 percent as far as chloride (a conservative constituent) in the recharge plume in the study area.

The distribution of elevated potassium in the study area is delineated in figure 14A. The 6-mg/L contour represents the average of the overall median and 90th-percentile median of ambient water (from table 1). This measure was selected as a conservative estimate for the upper limit of ambient-water constituents in this highly developed study area (Heisig and Prince, 1993) to decrease the effects of the inherent "noise" from unidentified influences within and upgradient of the study area. The area of slightly elevated potassium concentrations south of Route 24 (fig. 14A) is probably a remnant of secondary-treated sewage. Potassium concentrations approaching 6 mg/L immediately north and south of this area could also be related to secondary-treated sewage; dispersion in addition to cation exchange might explain why this area of elevated potassium is not observed farther downgradient.

The two bodies of elevated potassium north of Route 24 in figure 14A represent the effects of road-salt leachate, discussed earlier, and reclaimed water, discussed in Heisig and Prince (1993). The downgradient extent of potassium associated with secondary-treated sewage, with respect to the two bodies mentioned above, is consistent with a residence time for potassium in the shallow ground-water system that is longer than that for the less reactive ions.

Two unique indicators of the distribution of secondary-treated sewage in the study area are elevated concentrations of ammonium and low concentrations of dissolved oxygen. They are not particularly useful as indicators in the upper glacial zone, however, because natural recharge, which tends to be oxygenated, promotes nitrification of ammonium to nitrite in the presence of nitrifying bacteria. Katz and Mallard (1980) reported the presence of nitrifying bacteria in ground water from the same study area.

Intermediate Zone

The intermediate zone, or transition between the upper glacial and Magothy zones, contains more evidence of secondary-treated sewage than the upper glacial zone because the intermediate zone does not receive oxygenated natural recharge directly and because its permeability tends to be lower than that of the upper glacial zone.

The high organic carbon component, presence of reduced nitrogen species, and low dissolved oxygen concentrations in secondary-treated sewage before recharge make ammonium and dissolved oxygen useful indicators of ground water affected by treated sewage in the intermediate zone. Ammonium concentrations in such ground water are, in general, slightly elevated, > 0.04 mg/L (fig. 14B), and dissolved oxygen concentrations are low, < 1.0 mg/L (fig. 14C). The low dissolved oxygen concentrations are attributed to consumption of oxygen during oxidation of organic matter in the effluent. The persistence of these conditions 8 years after the cessation of recharge with secondary-treated sewage indicates that ammonium and organic matter are reactive and, thus, move more slowly than regional ground-water flow.

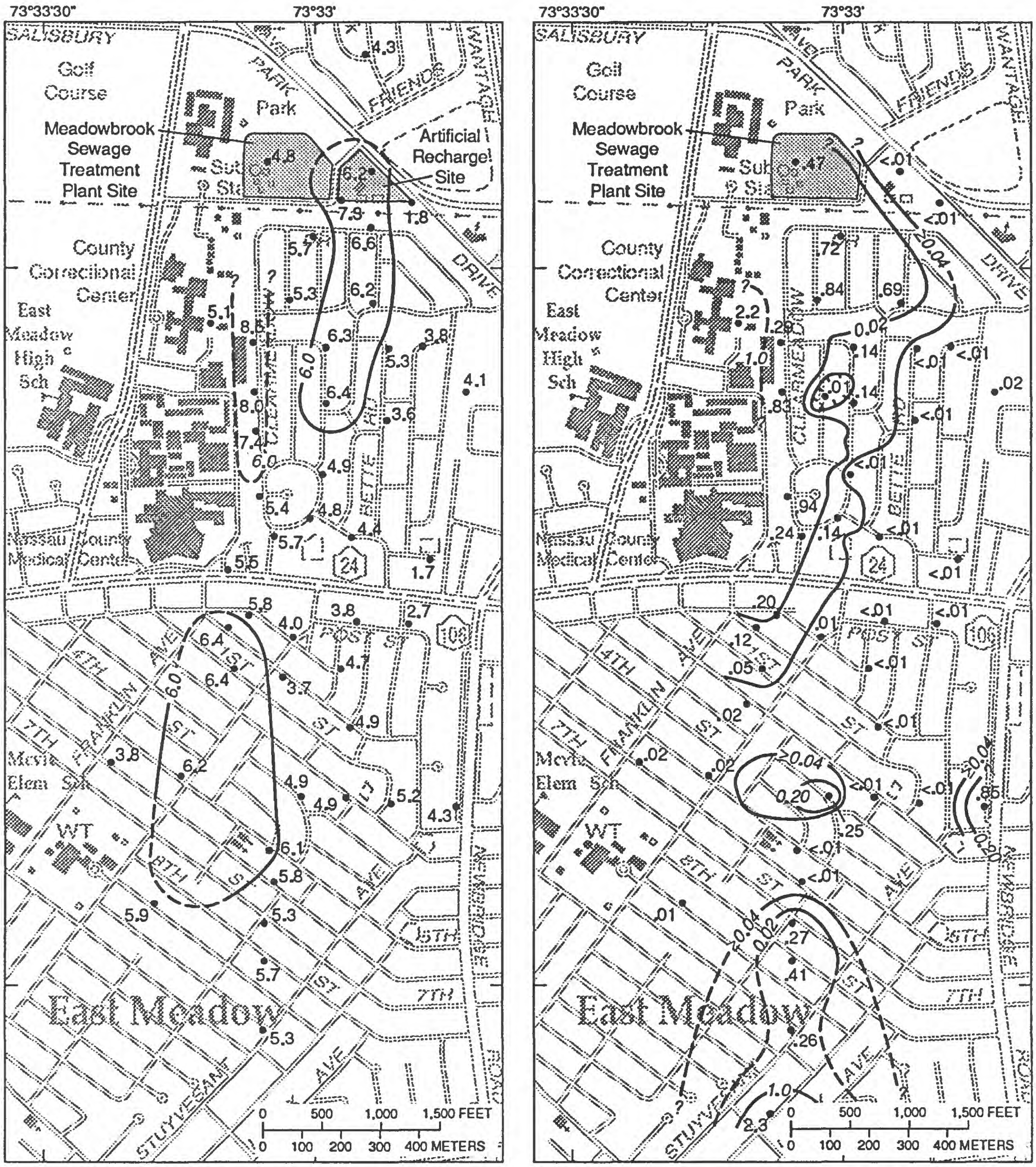
The distribution of ammonium, shown in figure 14B, is not continuous and is characterized by two primary areas of elevated concentration. One area extends about 3,800 ft downgradient from the treatment-plant site, and the other extends from about 6,050 ft downgradient of the site to an unknown distance down-gradient. The area of elevated concentration near the sewage-treatment plant site roughly corresponds to an area of higher clay content and lower permeability than the surrounding material, as indicated by natural-gamma logs. Cation-exchange processes in this area would be expected to slow the transport of ammonium and other cations at the start of sewage-treatment and disposal operations and to release the same species from exchange sites as ambient ground water reentered the system after the cessation of operations. Another source of ammonium is the decomposition of nitrogen-rich organic material (ammonification) (Freeze and Cherry, 1979). The low dissolved oxygen concentrations in this area suggest that organic matter is decomposing.

The area of elevated ammonium concentrations at the downgradient boundary of the study area includes the highest ammonium concentration (2.3 mg/L). This plume concentration lags about 1,000 ft behind those of minimally reactive constituents, discussed later, and probably represents the tail end of the ammonium plume, which has been transported through permeable sediments in the intermediate zone.

Other chemical constituents of secondary-treated sewage persist in the intermediate zone to varying degrees. At several wells they seem to have partly mixed with the same constituents in the recharge plume during and after transport through areas of low permeability. Reactive constituents, such as calcium and potassium, remain at elevated concentrations from near the southern boundary of the study area to about 1,000 ft north of Route 24, where they become indistinguishable from those associated with the recharge plume. Little evidence of conservative or minimally reactive constituents, such as chloride and sodium, remains within the intermediate zone; presumably they have been transported downgradient out of the study area or are masked by the recharge plume. Elevated concentrations of minimally reactive constituents, such as sulfate, boron, and nitrate + nitrite, which are interpreted to be derived from secondary-treated sewage, remain at the southern boundary of the study area, downgradient of the toe of the recharge plume.

Magothy Zone

Water of a chemical quality most similar to that of secondary-treated sewage is found in the Magothy zone, the least permeable and deepest of the three depth zones studied. The low ground-water velocities in this zone (0.6 to 0.8 ft/d) (Prince and Schneider, 1989; Heisig and Prince, 1993) have limited the transport of the trailing edge of conservative and minimally reactive constituents derived from secondary-treated sewage to no more than 1,800 ft from the secondary-treatment site since it closed in 1979. Distinction between water affected by secondary-treated sewage and water affected by the recharge plume is simplified by the small extent of the recharge plume at this depth (Heisig and Prince, 1993).



Base from New York State Department of Transportation, 1:24,000, Freeport, NY, 1991, Digital Edition

A. POTASSIUM IN UPPER GLACIAL ZONE

Base from New York State Department of Transportation, 1:24,000, Freeport, NY, 1991, Digital Edition

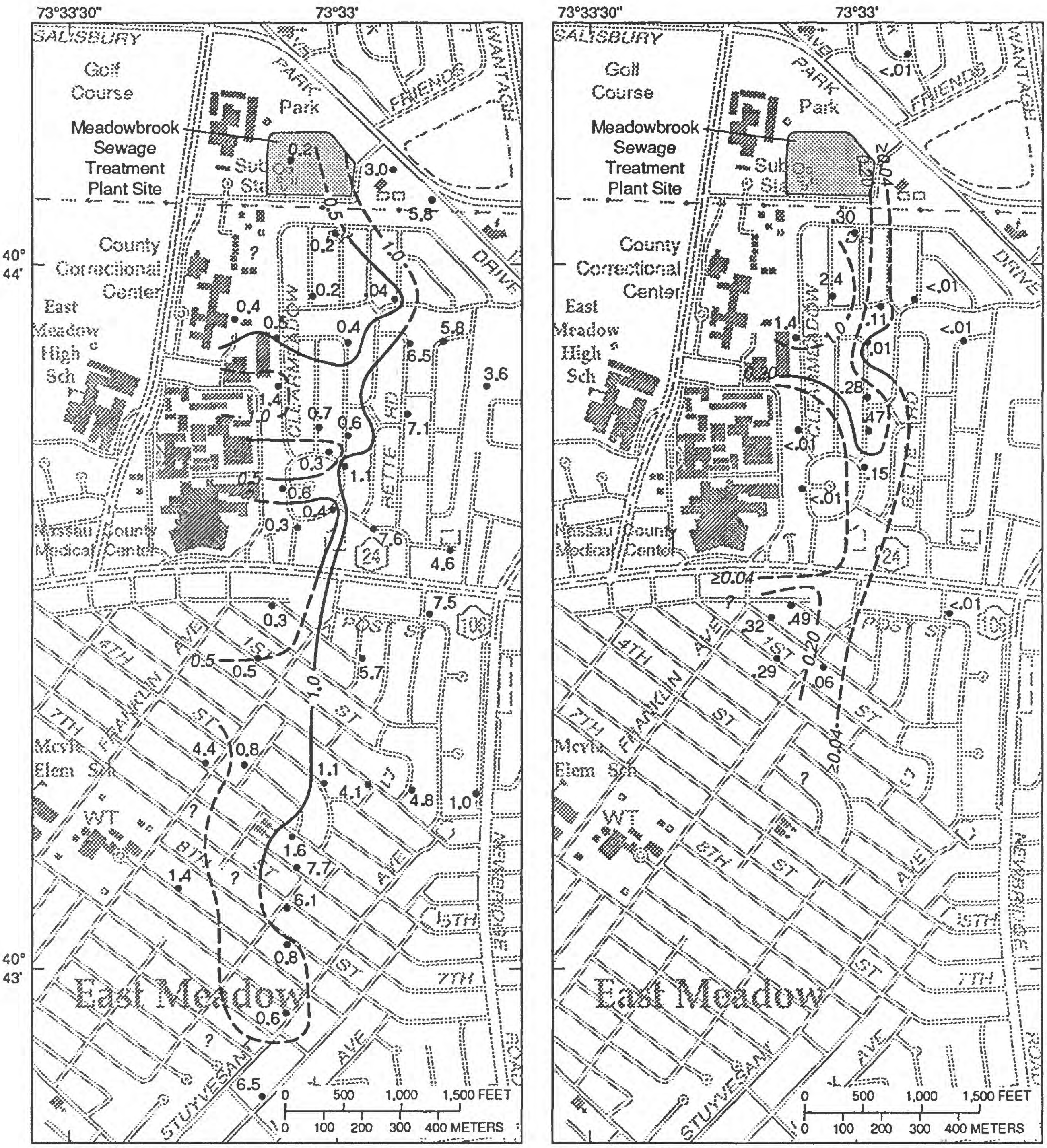
B. AMMONIUM IN INTERMEDIATE ZONE

EXPLANATION

•.26 OBSERVATION WELL--Number is concentration, in milligrams per liter

0.20 — — — LINE OF EQUAL CONCENTRATION--In milligrams per liter. Dashed where approximately located. Hachures indicate depression

Figure 14.—Horizontal distribution of constituents: A. Potassium in the upper glacial zone. (From Heisig and Prince, 1993, fig. 18.) B. Ammonium (as N) in the intermediate zone.



Base from New York State Department of Transportation, 1:24,000, Freeport, NY, 1991, Digital Edition

C. DISSOLVED OXYGEN IN INTERMEDIATE ZONE

Base from New York State Department of Transportation, 1:24,000, Freeport, NY, 1991, Digital Edition

D. AMMONIUM (AS N) IN MAGOTHY ZONE

EXPLANATION

•1.6 OBSERVATION WELL--Number is concentration, in milligrams per liter

——0.20 — — — LINE OF EQUAL CONCENTRATION--In milligrams per liter. Dashed where approximately located

Figure 14.—Horizontal distribution of constituents (continued): C. Dissolved oxygen in the intermediate zone. D. Ammonium (as N) in the Magothy zone.

The area affected by secondary-treated sewage in the Magothy zone is directly downgradient of the secondary-treatment site and extends an unknown distance beyond the observation-well network. A less permeable zone, indicated by gamma logs, lies 1,500 to 3,500 ft downgradient of the secondary-treatment site and extends about 300 ft east from the north-south-trending section of Clearmeadow Drive (fig. 14D) (Heisig and Prince, 1993). Water-quality data indicate that secondary-treated sewage has been partly deflected around this area.

Ammonium provides the best delineation of water affected by secondary-treated sewage in the Magothy zone (fig. 14D). The lack of ammonium in the area of low permeability supports the gamma-log data. The distribution of elevated ammonium concentrations is similar to that of low dissolved oxygen concentrations in most respects, except that dissolved oxygen concentrations, in general, tend to decrease with time and with depth within the ground-water system, which results in low concentrations at some locations elsewhere in the study area.

Other constituents, such as sodium, sulfate, boron, chloride, and alkalinity, tend to follow the same general distribution pattern as ammonium. Of these, only the trailing edges of the elevated chloride and sulfate distributions show evidence of transport away from the sewage-treatment site.

Concentrations of reactive cations, including potassium and calcium, are elevated only near the sewage-treatment site. Elsewhere they are below the medians for ambient ground water, particularly in the less permeable area. These low concentrations could indicate increased adsorption and exchange processes in the presence of finer grained material, but this has not been confirmed.

SUMMARY

Investigations of the hydrochemical effects of artificial recharge in East Meadow identified three local point sources that affect ground-water quality—stormwater basins, road-salt-storage piles, and the Meadowbrook sewage-treatment plant, which ceased operations in 1979. The amount and timing of infiltration, and the chemical quality of water or leachate from these sources, is variable. Land use in the study area since the early 1950's has been predominantly medium-density residential. Before 1979-80, when sanitary sewers became operational, sewage was disposed of in cesspools and by surface application on infiltration beds. Ground-water development in East Meadow consists of a well field with 10 active production wells that pump about 5 Mgal/d.

Stormwater from recharge basins contains lower concentrations of most inorganic constituents than ambient ground water in the study area, except in winter, when chloride and sodium concentrations increase through the dissolution of road-deicing salt runoff. Water that is affected by stormwater from the largest basin (basin 62) extends at least 3,000 ft downgradient before it mixes with the recharge plume derived from artificial-recharge experiments and can no longer be delineated. The depth of influence extends to 30 ft below the water table. Diversion of storm runoff to recharge basins with smaller drainage areas results in proportionately smaller areas of influence.

Sodium chloride is used as a road-deicing salt in the study area. The town and a hospital maintain road-salt storage piles; the hospital supply is generally stored indoors on a paved surface, whereas the town supply rests uncovered on bare soil. Road-salt leachate has infiltrated to the water table beneath the town storage site. The zone of water affected by road-salt leachate extends downgradient about 3,000 ft from the storage site and has a maximum depth of about 20 ft below the water table. The narrow width of the road-salt plume corresponds to the size of the storage piles and the volume of recharge reaching the water table. As the leachate is transported downgradient from the source, cation-exchange reactions with the aquifer material probably alter the leachate composition.

The third source of influence, the Meadowbrook sewage-treatment plant, ceased operations in 1979. Water-quality data from wells sampled 8 years later indicate that some secondary-treated sewage remains in the lower part of the shallow aquifer system. The only constituent of secondary-treated sewage remaining in the permeable upper glacial aquifer zone is potassium, a reactive constituent that has a high affinity for adsorption to aquifer materials. All other constituents appear to have been transported out of the study area. The underlying intermediate (transition) zone and Magothy (deep) zone show increasing amounts of secondary-treated sewage with depth, primarily because the permeability and ground-water velocity decrease with depth. The best indicators of secondary-treated sewage in the intermediate zone are low dissolved oxygen and elevated ammonium concentrations, which extend from the site of recharge to an unknown distance downgradient of the study area. Minimally reactive constituents, such as boron and nitrate + nitrite, were detected in elevated concentrations only at the downgradient boundary of the study area. The Magothy zone contains the least altered secondary-treated sewage of the three zones because it has the lowest permeability. The zone of influence extends an unknown distance downgradient of the observation-well network.

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*U.S. GOVERNMENT PRINTING OFFICE:1994-511-162