GEOHYDROLOGY OF THE MEADOWBROOK ARTIFICIAL-RECHARGE SITE AT EAST MEADOW, NASSAU COUNTY, NEW YORK

By David A. Aronson, Juli B. Lindner, and Brian G. Katz

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FACTORS FOR CONVERTING INCH-POUND UNITS

TO INTERNATIONAL SYSTEM (SI) UNITS

Multiply Inch-pound units	by	To obtain SI units
	Length	
inch (in)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	0.4047	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume per unit time (includes 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)
gallon per day per square ft [$(gal/d)/ft^2$]	40.74	liter per day per square meter [$(L/d)/m^2$]
cubic foot per second (ft^3/s)	28.32	liter per second (L/s)
	Mass per unit area	
pound per acre (lb/acre)	1.121	kilogram per hectare (kg/ha)

Altitude datum

The term "National Geodetic Vertical Datum of 1929" (abbreviation, NGVD of 1929) replaces the formerly used term "mean sea level" to describe the datum for altitude measurements. The NGVD of 1929 is derived from a general adjustment of the first-order leveling networks of both the United States and Canada.

Geohydrology of the Meadowbrook Artificial-Recharge Site at East Meadow, Nassau County, New York

by

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ABSTRACT

In Nassau and Suffolk Counties, where the quality and quantity of potable ground water have declined as the result of urbanization, the use of reclaimed wastewater (highly treated sewage) to replenish the ground-water reservoir has been demonstrated to be technically feasible.

At the Meadowbrook artificial-recharge project site, a system of 11 recharge basins and 5 shallow injection wells will return 4 million gallons per day of reclaimed wastewater to the ground-water reservoir. The water will be supplied by the nearby Cedar Creek Water-Reclamation facilities.

Aquifer tests analyzed by a two-dimensional Galerkin finite-element flow model indicate that the upper glacial aquifer has a horizontal and vertical hydraulic conductivity of 390 feet per day and 160 feet per day, respectively. Calculated storage coefficient for the upper glacial aquifer is 0.20, and specific storage for the Magothy aquifer is 0.5×10^{-4} per foot.

Results of the two-dimensional flow analysis were incorporated into a finite-difference regional flow model to predict changes in head from artificial recharge in and around the recharge site. A maximum water-table rise of 17 feet is predicted beneath the recharge basins under "worst-case" conditions; buildups will be somewhat higher near the injection wells. The predicted increase in streamflow at East Meadow Brook is 3.0 to 3.5 cubic feet per second, depending on the aquifer-permeability value used in the model.

The upper glacial aquifer in the recharge area contains significant concentrations of nitrate and low-molecular-weight halogenated hydrocarbons, and detectable concentrations of organochlorine insecticides and polychlorinated biphenyls. Concentrations of chloride and nitrate are about 10 times greater in ground water than in precipitation, and concentrations of sulfate are 5 times greater. Sources of contaminants include cesspools and septic tanks, road-deicing salts, fertilizers, and pesticides.

The projected chemical quality of the treated effluent to be used for aquifer recharge will be superior to that of water already present in the upper part of the ground-water reservoir at the recharge site. Therefore, the recharge effort should both increase the quantity and improve the quality of the ground water in the vicinity of the recharge site.

INTRODUCTION

Ground water is the sole source of drinking water for the nearly 2.8 million residents of Nassau and Suffolk Counties, Long Island, N.Y. (fig. 1). In recent years, urbanization has created freshwater demands that may locally deplete the ground-water supply or severely lower the water table.

Urbanization has also increased the amount of wastewater discharged to the ground through septic tanks and cesspools, and this discharge now threatens the quality of the ground-water supply. To prevent wastewater from reaching the ground-water reservoir, several sewer systems have been completed, and additional sewers are now being installed. The water collected by these sewer systems is piped to wastewater-treatment facilities, where it is then treated and discharged to coastal waters. Although removal of wastewater through sewers protects the ground-water reservoir from sewage contamination, it threatens to accelerate the depletion of the island's ground-water supply by continually removing water that would otherwise be returned to the system. The depletion of ground water will result in a lowering of the water table, which will, in turn, diminish streamflow.

As a partial solution to this dilemma, the recycling of treated wastewater has been under intensive study on Long Island and elsewhere for more than a decade. If some of the island's wastewater can be treated to meet drinking-water standards, and if the water can then be returned to the ground-water reservoir in sufficient volume, it will replenish the ground-water supply and improve its chemical quality. Also, by preventing the water table from declining, this replenishment will help to sustain the flow of streams.

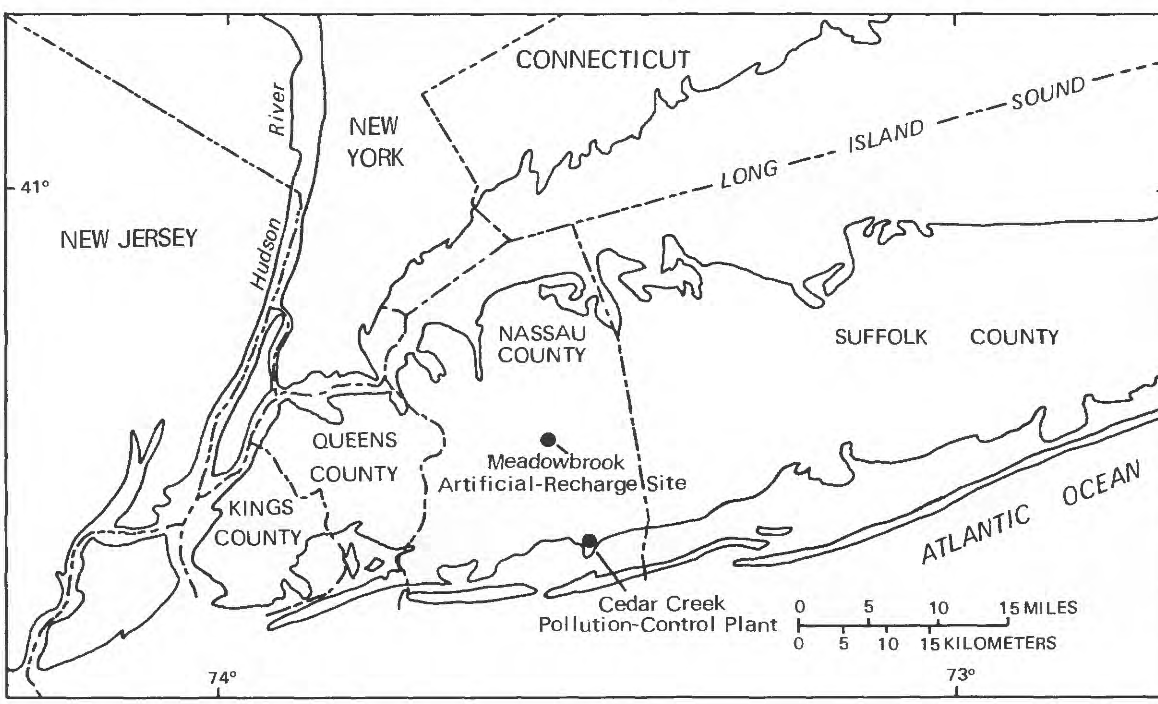


Figure 1.--Location of Meadowbrook artificial-recharge site and Cedar Creek Water-Pollution Control Plant, Nassau County, N.Y.

Purpose and Scope

The Meadowbrook artificial-recharge project, a cooperative effort between the U.S. Geological Survey and the Nassau County Department of Public Works (NCDPW) since 1975, is intended to demonstrate the feasibility of using reclaimed wastewater to replenish and improve the quality of Long Island's ground water.

This report presents the results of geologic, hydrologic, and hydrochemical studies that were done at the Meadowbrook artificial-recharge site to define conditions prevailing before the start of recharge operations.

Previous Work

The earliest report on the regional geology and hydrology of Long Island was prepared by Veatch and others (1906). Fuller (1914) prepared a more detailed geologic report. An extensive compilation of well records and a detailed description of the subsurface geology of Long Island are given in a report by Suter, deLaguna, and Perlmutter (1949). Perlmutter and Geraghty (1963) and Isbister (1966) discussed the geohydrology of southern and northeastern Nassau County, respectively. General discussions of regional hydrologic conditions are given by Cohen, Franke, and Foxworthy (1968), McClymonds and Franke (1972), and Franke and McClymonds (1972).

The general operation of the Cedar Creek Pollution-Control Plant and Advanced Wastewater-Reclamation Facilities, and of the Meadowbrook artificial-recharge site, have been described by Consoer, Townsend, and Associates, (1978). Aronson (1980) described the Meadowbrook artificial-recharge project in nontechnical terms for the general public.

Acknowledgments

The water-treatment and recharge facilities were designed mainly by Consoer, Townsend, and Associates, engineering consultants to the NCDPW. Individuals who have had a major role in the conception, design, and construction of the water-treatment and recharge facilities include Michael R. Pender, Commissioner, Francis J. Flood, Director of Environmental Engineering, and James Oliva, Sanitary Engineer and manager of the Advanced Wastewater-Treatment facilities at Cedar Creek, all with the NCDPW. Particular recognition is given to Philip Cohen and John Vecchioli of the Geological Survey, whose efforts early in the project permitted the detailed scientific studies at the recharge site.

Thanks are also extended to Peter Dolan of the NCDPW and Herbert Heller of Consoer, Townsend, and Associates for their assistance during construction of the recharge facilities. Thanks are also given to Leo Matthews of Hofstra University for heavy-mineral separations and size-distribution analyses of deposits underlying the recharge site, to Les Sirkin of Adelphi University for palynological studies of core samples, and to the many Geological Survey staff members who assisted in the collection and analysis of background data on which the conclusions of this report are based.

Methods of Study

Early work in the project included construction of the Cedar Creek Water-Pollution Control Plant and Advanced Wastewater-Reclamation facilities, (fig. 1), construction of recharge basins, injection wells, and observation wells at Meadowbrook, and instrumentation of the basins and wells for studies of recharge processes. Lithologic core samples collected during drilling of the observation and injection wells, and geophysical logs of the wells, were studied to define the hydrogeologic framework of the recharge site. Aquifer tests were made to determine the hydraulic characteristics of the injection wells and aquifers. These tests were supplemented by mathematical (digital) model studies designed to predict the response of the water table to artificial recharge. Water-quality studies were made to define the background geochemical environment of the aquifer.

PROJECT FACILITIES

Water-Reclamation Facilities

Reclaimed wastewater will be supplied by the Advanced Wastewater-Reclamation Facilities at the Cedar Creek Water-Pollution Control Plant. This plant is a conventional activated-sludge facility designed to treat an average flow of 45 Mgal/d. As much as 5.5 Mgal/d of sewage would be diverted after screening and grit removal to serve as the influent to the reclamation facilities; the remainder would receive secondary treatment and be pumped into the ocean.

The reclamation facilities consist of a 5.5-Mgal/d wastewater-treatment plant designed to produce a potable effluent suitable to return to the ground-water reservoir. Reclamation entails the following processes:

1. Chemically assisted primary sedimentation.--Screened and degritted wastewater from the Cedar Creek plant is mixed with lime to remove a significant part of the phosphorus, micro-organisms, suspended solids, and heavy metals.

2. Activated sludge and nitrification.--The wastewater is then piped to the activated-sludge unit, which contains recycled sludge that is rich in microbes that flourish in the presence of oxygen. This unit is heavily aerated to provide oxygen to the microbes to enable them to convert carbon compounds into water and carbon dioxide and nitrogen compounds into nitrates and water.

3. Denitrification.--The nitrified wastewater is then piped to an anaerobic unit (without dissolved oxygen), where it is treated with methanol (a type of alcohol) and recycled sludge rich in bacteria. The bacteria use the carbon in the methanol to convert nitrate to nitrogen gas, which is released to the atmosphere.

4. Chemically assisted final sedimentation.--The denitrified effluent is then mixed with allum ($AL_2(SO_4)_3 \cdot 14H_2O$) to remove suspended solids, phosphorus, and heavy metals that were not removed previously.

5. Filtration.--The wastewater is then pumped to a dual-media (sand-anthracite) filter to remove residual suspended organic and inorganic solids.

6. Carbon adsorption.--The wastewater then flows through two columns of activated carbon to remove remaining dissolved organic substances.

7. Chlorination.--The wastewater undergoes final chlorination to destroy residual micro-organisms.

The reclaimed water produced by the reclamation facilities will then be analyzed for constituents before it is pumped 6.25 mi north to the Meadowbrook artificial-recharge project site.

Meadowbrook Artificial-Recharge Site

The Meadowbrook artificial-recharge site is in the triangular piece of land owned by Nassau County southeast of the intersection of Carman Avenue and Salisbury Park Drive in the Town of Hempstead (figs. 2 and 3). The site contains 35 acres and includes the Meadowbrook Sewage-Treatment Plant, which

Figure 2.--Aerial photograph of the Meadowbrook artificial-recharge site showing location of injection wells, recharge basins, and the discontinued Meadowbrook sewage-disposal plant. (View is to northwest.)

ceased operation in 1979. A description of the layout and operation of the recharge site is given by Aronson (1980). The recharge facilities incorporate a system of 11 basins, 7 of which have been specially constructed for the infiltration of reclaimed water, and 5 shallow injection wells. (Layout is shown in figs. 2 and 4.) About 2 Mgal/d of reclaimed water will be applied through basins and 2 Mgal/d through injection wells over a 1- to 2-year period.

A ground-water monitoring network of 48 observation wells at 22 sites was established within the 1-mi^2 area encompassing the recharge site. (Locations are shown in fig. 3.) Each well site contains either one, two, or three wells screened at depths of from 45 to 50 ft, 95 to 100 ft, and 195 to 200 ft below land surface (table 1). Hereafter, these wells will be referred to as 50-, 100-, and 200-ft wells.

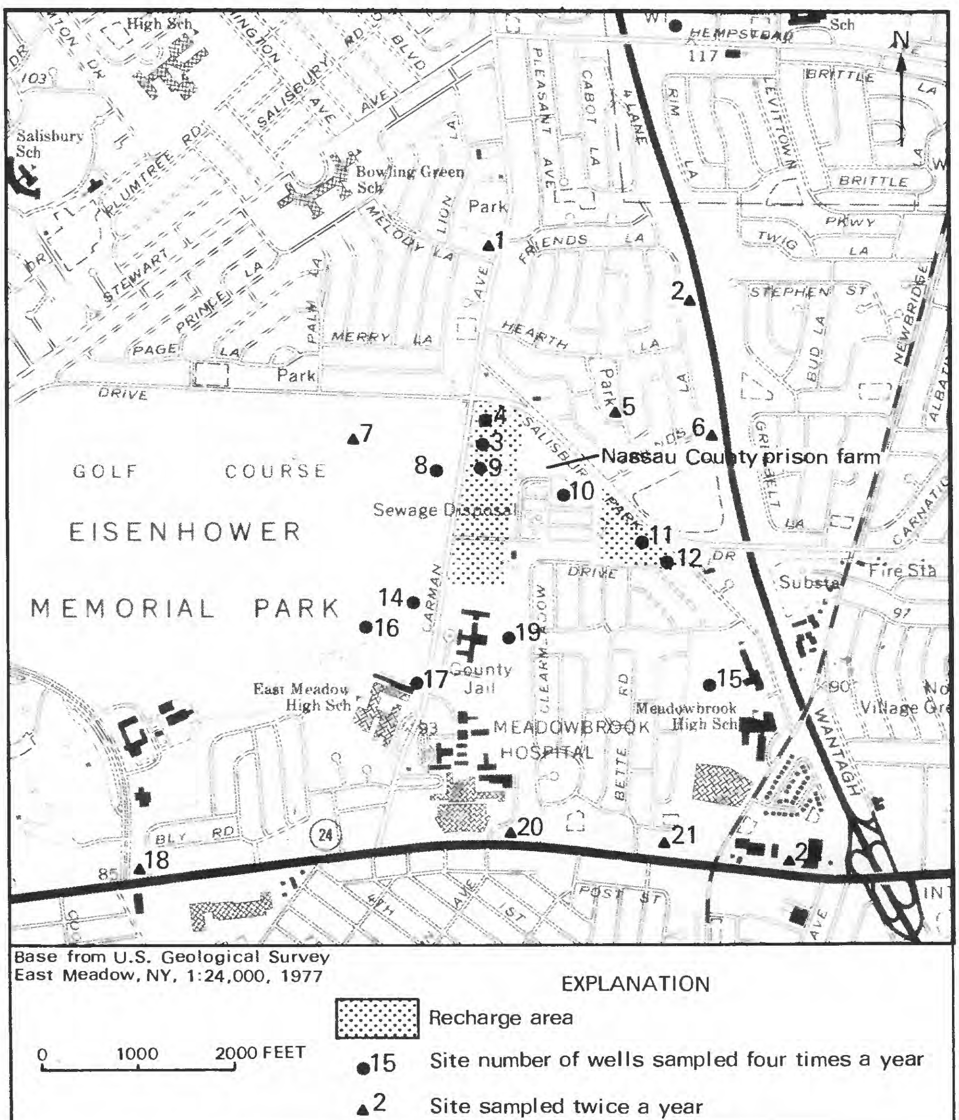


Figure 3.--Locations of recharge basins and observation wells, Meadowbrook artificial-recharge site. (From Katz and Mallard, 1980.)

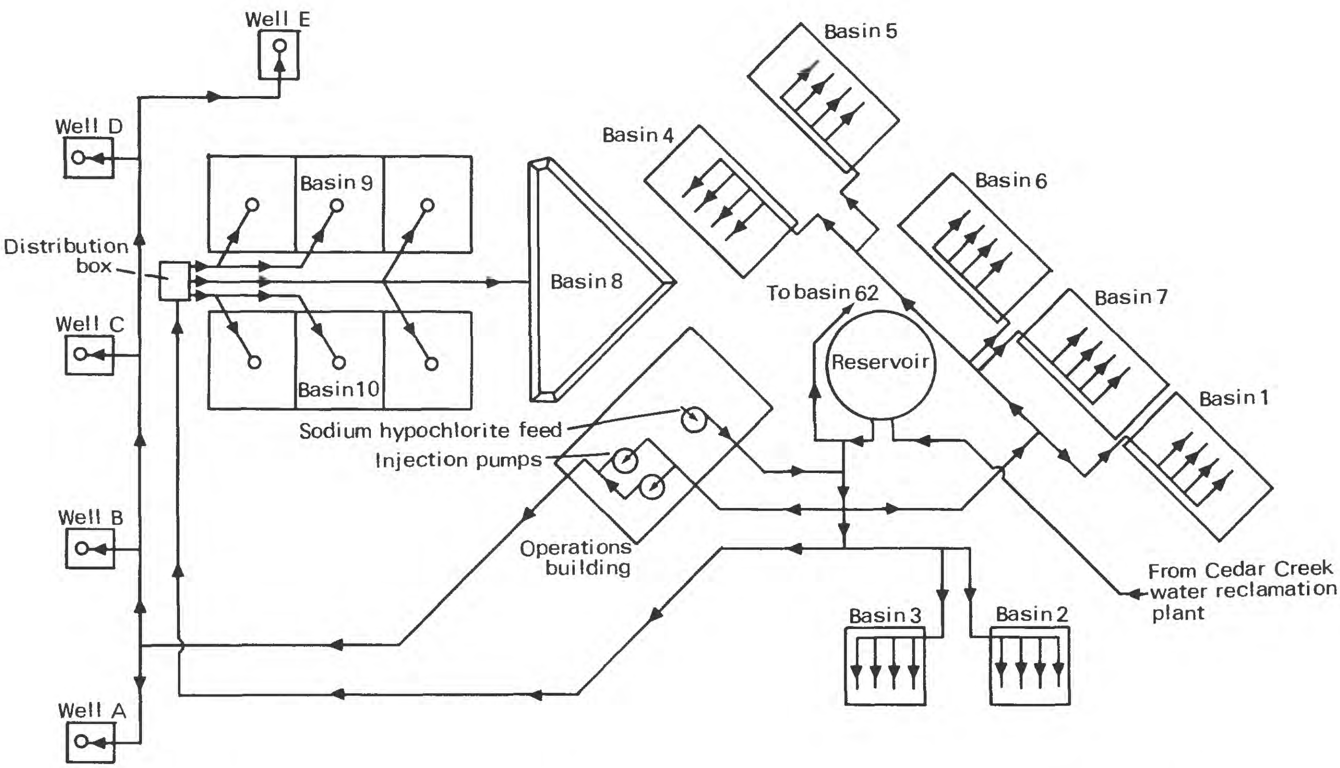


Figure 4.--Schematic diagram of Meadowbrook artificial-recharge site showing relative position of recharge basins, injection wells, and water-transmission mains. (Modified from Consoer, Townsend, and Associates, 1978.)

Recharge Basins

Basins 1-7.--The basins numbered 1 through 7 in figure 2 are shallow recharge basins 5 ft in depth. They will be studied intensively to evaluate (1) management practices that are most effective for optimizing recharge, (2) causes of clogging of the basin floor during ponding of reclaimed wastewater, and (3) the ability of the unsaturated zone (the sand and gravel deposits that lie between the basin floor and the underlying water table) to improve the quality of percolating reclaimed water. A view of basin 3 is shown in figure 5.

Previous studies have shown that infiltration rates at ponding sites tend to decline with time, regardless of the purity of the reclaimed wastewater. Decreases in infiltration rate can be attributed to (1) swelling of soil particles after wetting, (2) clogging of the soil pores with organic slimes or chemical precipitates produced by microbial activity, and (3) particles that are intercepted at the soil surface.

Where the flow of reclaimed water into the soil and to the water table is slowed, soil treatments and other procedures can be applied to increase soil permeability and recharge rates. Some procedures to be used at the Meadowbrook site to maintain high infiltration rates include (1) alternating a period of water ponding with a period of drying out (an application-and-rest cycle); (2) tilling or scarifying (scraping) the basin floor when it becomes

Table 1.--Screened depths and identifying codes of observation and injection wells shown in figure 3.

Code no.	Well no.[1]	Screened depth[2]	Code no.	Well no.[1]	Screened depth[2]
1A	N9234	200 - 205	11B	N9197	90 - 95
1B	N9235	100 - 105	11C	N9198	41 - 46
1C	N9236	45 - 50	12A	N9367	100 - 105
2	N9217	45 - 50	12B	N9368	40 - 45
3A	N9360	200 - 205	14A	N9219	90 - 95
3B	N9361	93 - 98	14B	N9220	40 - 45
3C	N9362	40 - 45	15A	N9247	90 - 95
4A	N9363	100 - 105	15B	N9248	40 - 45
4B	N9364	40 - 45	16A	N9221	90 - 95
5A	N9449	193 - 198	16B	N9222	40 - 45
5B	N9450	99 - 104	17A	N9223	103 - 108
5C	N9451	36 - 41	17B	N9224	40 - 45
6	N9218	39 - 44	18	N9201	40 - 45
7A	N9239	200 - 205	19A	N9365	90 - 95
7B	N9240	100 - 105	19B	N9366	40 - 45
7C	N9241	40 - 45	20	N9225	39 - 44
8A	N9199	100 - 105	21A	N9252	190 - 195
8B	N9200	40 - 45	21B	N9253	90 - 95
9A	N9182	191 - 196	21C	N9254	41 - 46
9B	N9183	101 - 106	22	N9226	40 - 45
9C	N9184	40 - 45	A	N9202D[3]	65 - 95
10A	N9193	190 - 195	B	N9203D	65 - 95
10B	N9194	90 - 95	C	N9204D	65 - 95
10C	N9195	41 - 46	D	N9205D	65 - 95
11A	N9196	201 - 206	E	N9206D	65 - 95

[1] N is for Nassau County.
[2] Depth is in feet below land-surface datum.
[3] D designates injection well.

clogged by detritus or microbial activity, (3) ponding the reclaimed water deeply to increase pressure at the ponding surface, (4) mulching the soil to increase porosity and permeability, (5) covering the floor of the basin with gravel to disperse clogging materials, and (6) planting vegetation on the infiltration area to increase soil porosity and permeability and to provide root channels through which water can percolate.

The management practices to be used at basins 1-7 are summarized in table 2. The practices represent different application-rest cycles as well as several methods for promoting infiltration and dispersal of clogging materials that may accumulate or form at or near the basin floor during ponding. The tentative plan calls for four basins to operate at any given time. Infiltration will proceed until a basin can no longer dispose of 350 gal/min, at which time the basin will be rested or renovated as appropriate and another basin brought into service.

Basins 8-11.--Basin 8 is a deep pit. Studies at this basin will be directed toward evaluating the effectiveness of deep-pit recharge.

Basins 9 and 10 are shallow and were originally used for the infiltration of reclaimed water from the Meadowbrook sewage-treatment plant. These two basins would be used primarily for water in excess of that required for operating basins 1 through 8. As the study proceeds, data from basins 1 through 8 may indicate the desirability of running supplemental studies in these basins.

An 11th basin, Nassau County recharge basin 62, is currently being used for the disposal of storm runoff (fig. 2). This basin would be used primarily for the emergency disposal of reclaimed water. Whenever sufficient water becomes available, studies may be conducted at this basin to evaluate the effectiveness of using storm-runoff basins for supplemental recharge with reclaimed wastewater.

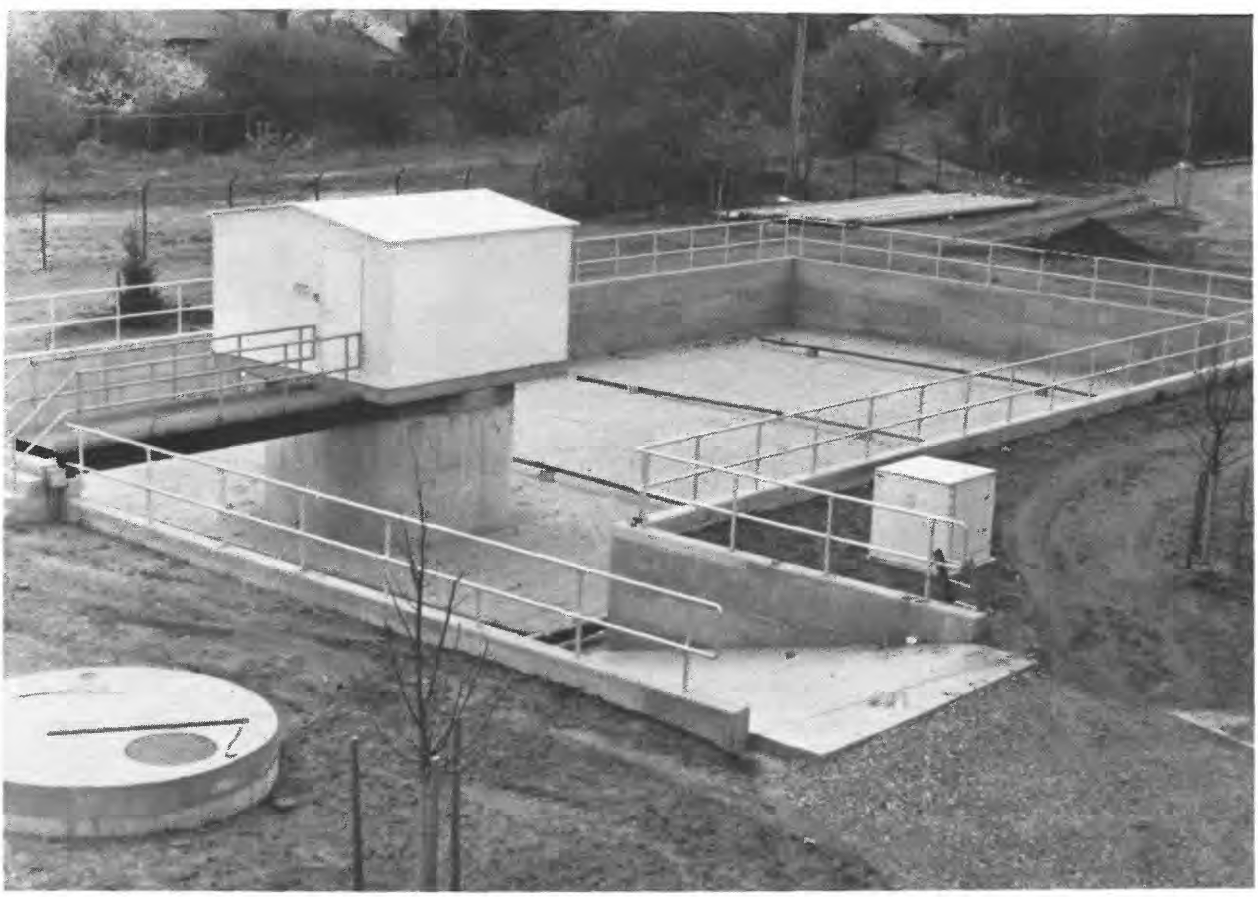


Figure 5.--Recharge basin 3. View is to southwest. [Location is shown in fig. 4.]

Table 2.--Proposed management practices for basins 1-7.

[Locations are shown in figs. 2 and 4]

Basin no.	Application-rest cycle[1]	Treatment
1	Continuous	None
2	2:1	None
3	1:2	None
4	1:1	None
5	1:1	Basin cleaned and cultivated during rest period.
6	1:1	Layer of pea-sized gravel on basin floor.
7	1:1	Seeded to grass (perhaps Reed canary grass).

[1] The numbers to the left and right of the colon represent the relative periods of time that water will be applied (ponded) and not applied (rested) during each application-rest cycle, respectively.

Injection Wells

A major phase of the Meadowbrook artificial-recharge project involves the return of reclaimed water through a system of five shallow injection wells (fig. 6). Four wells (A-D) will be in operation at any given time, with one on standby. Each well will inject 0.5 Mgal/d (350 gal/min) of reclaimed wastewater for a total of 2 Mgal/d. Each well is screened from 65 to 95 ft below land surface. The wells consist of fiberglass-reinforced epoxy casing, 65 ft in length and 1 ft in diameter, above a stainless steel, wire-wrapped screen 30 ft in length and 1 ft in diameter. A stainless-steel sand trap 5 ft in length is attached to the bottom of four of the screens (fig. 7). The fifth well (E) has a 40-ft sand trap. In wells B, C, D, and E, the space between the screen and the surrounding sand and gravel deposits is filled with a "filter pack" of fine gravel. Well A was constructed without a filter pack; that is, the well screen is in direct contact with the sand and gravel deposits, which in effect form a natural gravel pack. This will permit comparison of the operating efficiency of natural-pack wells with artificial-pack wells.

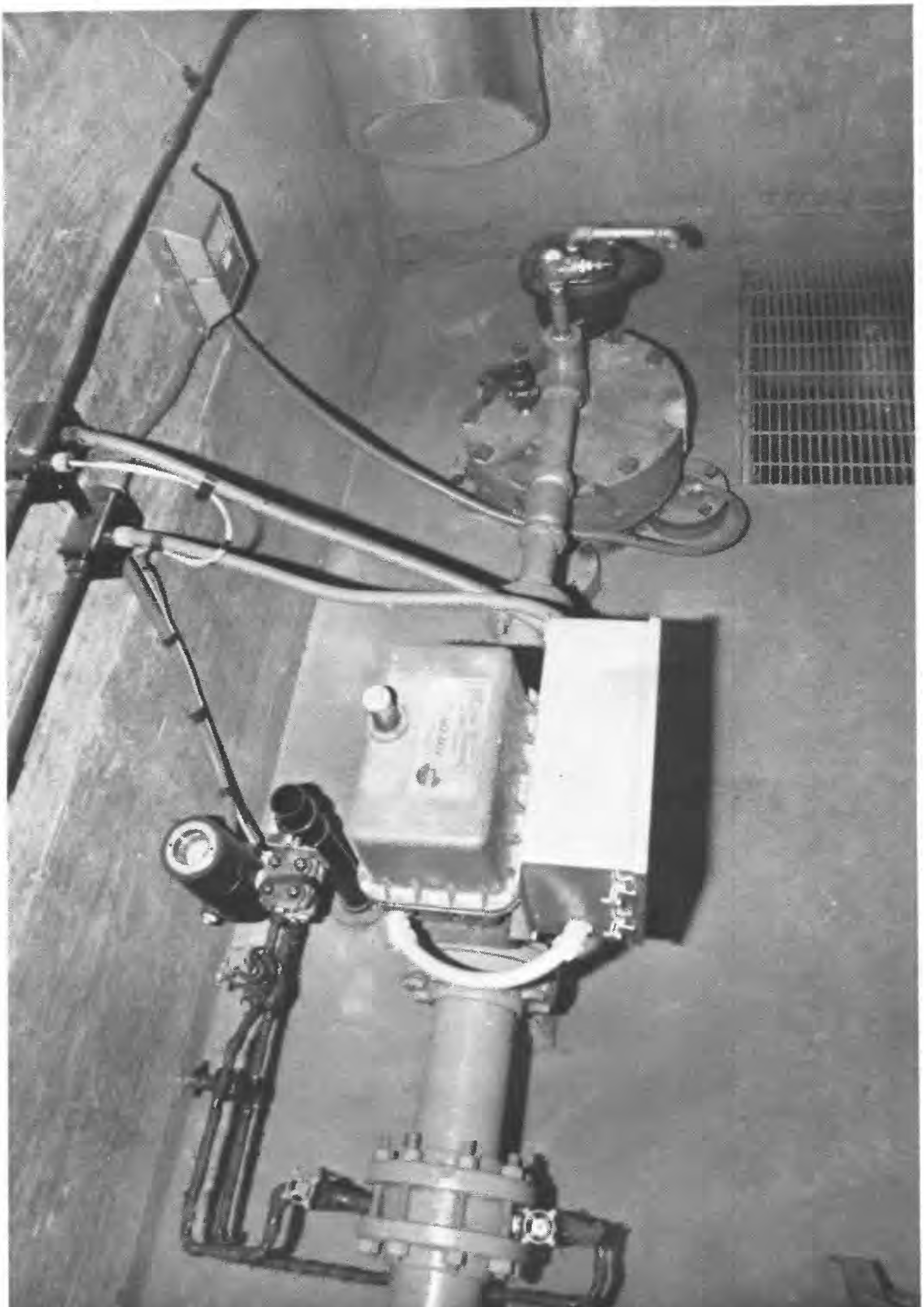


Figure 6.--Interior of vault housing injection well B.

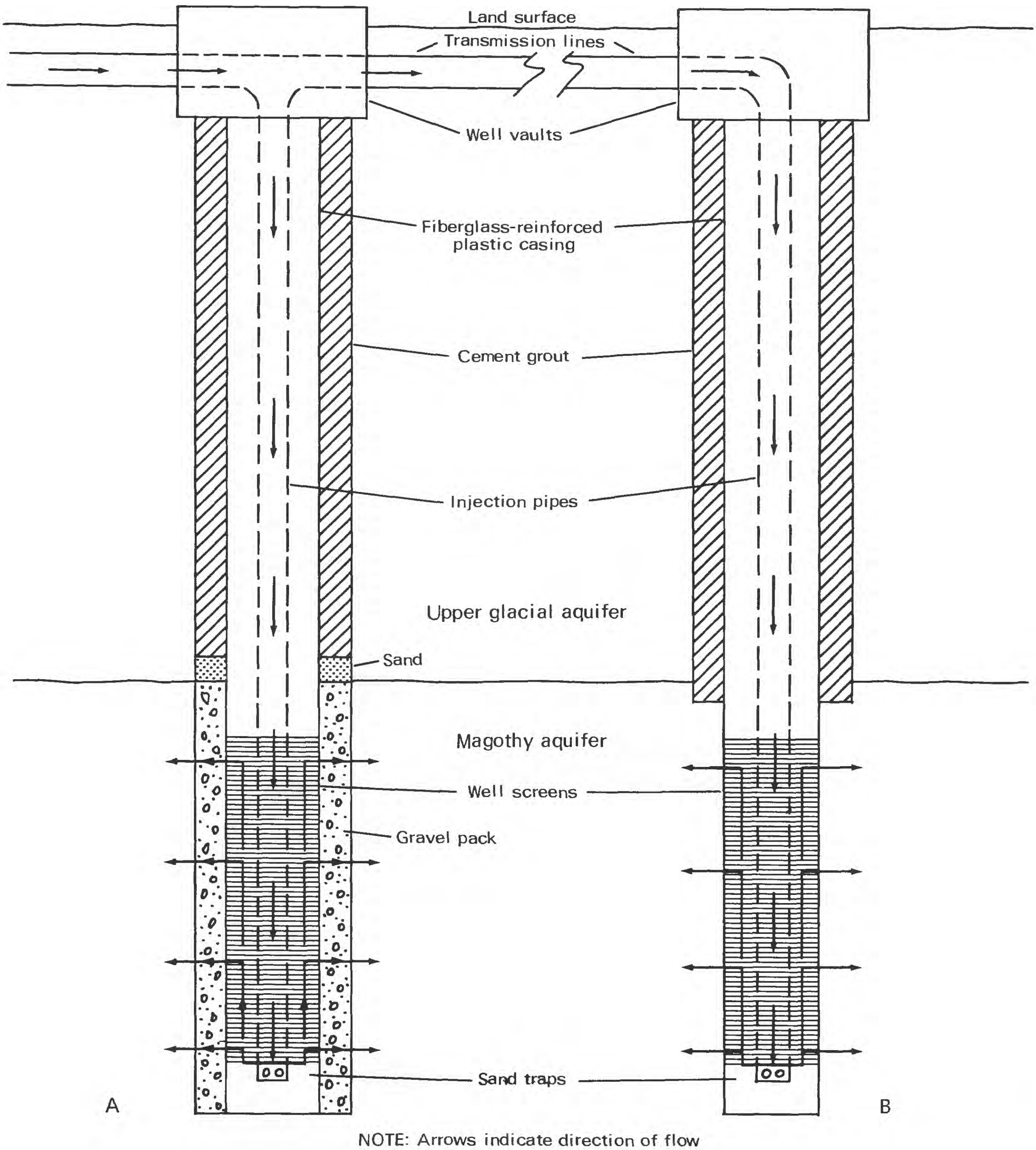


Figure 7.--Generalized cross sections of wells at Meadowbrook artificial-recharge site: A, artificial gravel pack; B, natural gravel pack. (From Aronson, 1980.)

GEOLOGIC ENVIRONMENT

Regional Geology

Long Island lies at the extreme north end of the Atlantic Coastal Plain physiographic province. The island is underlain by unconsolidated deposits of sand, gravel, and clay of Quaternary and Late Cretaceous age, which in turn overlie bedrock of schist, gneiss, and granitic rocks of Precambrian age (fig. 8).

Bedrock crops out in northwestern Queens County and dips generally southeastward to a depth of more than 2,000 feet below NGVD of 1929 (National Geodetic Vertical Datum of 1929) on the south shore of Suffolk County (Suter and others, 1949, pls. 8 and 9).

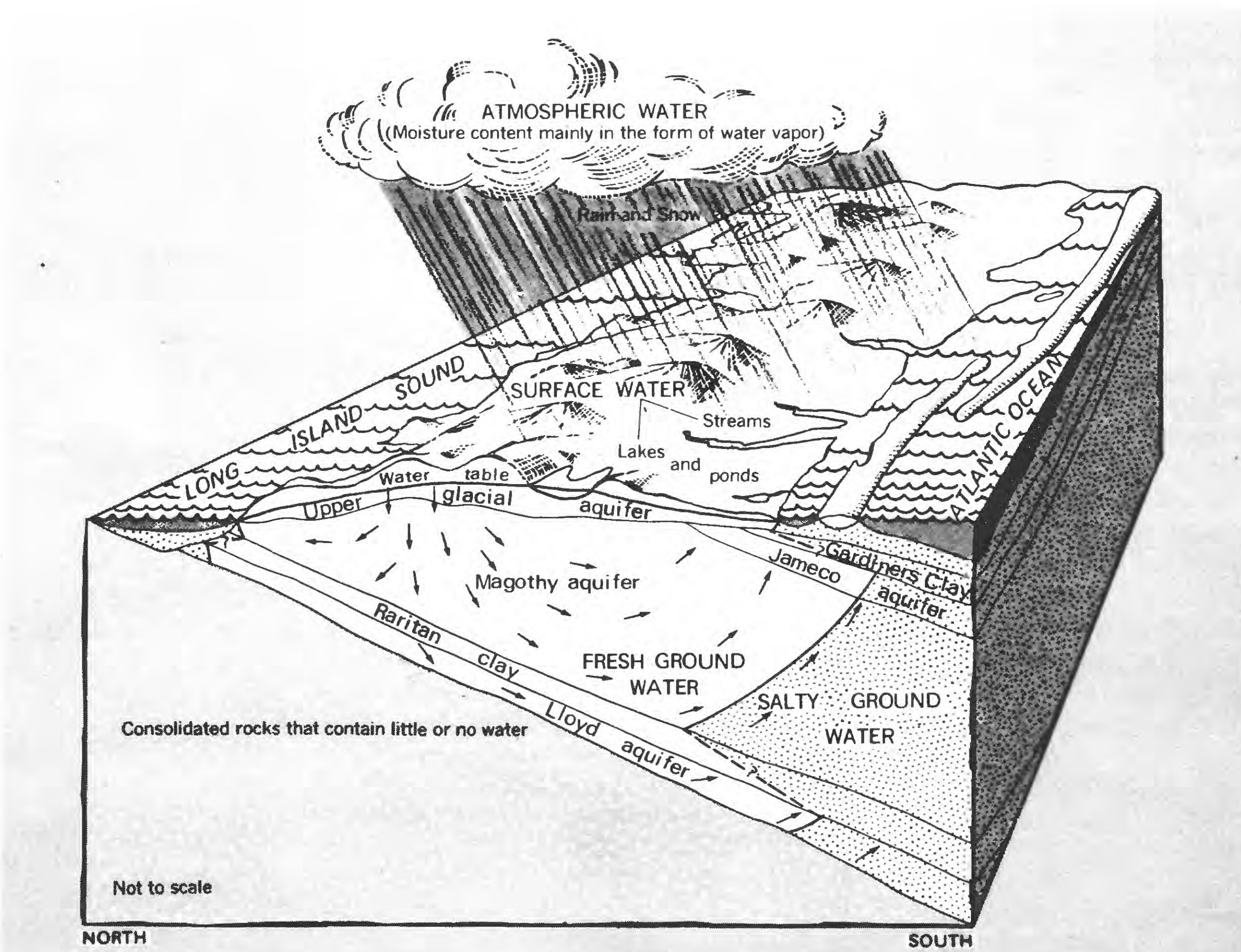


Figure 8.--Generalized cross section of Long Island showing sources and types of water, major hydrogeologic units, and paths of ground-water flow. (Modified from Cohen and others, 1968.)

Directly above the bedrock is the Raritan Formation, which is divided into the lower Lloyd Sand Member and the upper clay member. The Lloyd overlies bedrock everywhere beneath Long Island except where it has been eroded locally in Kings, Queens, and northern Nassau Counties. It ranges in thickness from 0 ft in northwestern Queens County to 300 ft or more in southeastern Suffolk County. The Lloyd consists chiefly of beds of gray and white sand and gravel and commonly some interstitial clay; interbedded in it also are lenses of sandy clay and nearly pure clay. It is the lowermost aquifer on Long Island. The Raritan clay, which is formally referred to as the clay member of the Raritan Formation, ranges in thickness from 30 ft in northern Kings County to about 300 ft along the south shore of Long Island. It consists typically of light- to dark-gray laminated silty clay or nearly pure clay beds. Beds of red, white, yellow, and mottled clay are less common. Sand layers occur locally, as do layers of lignite and pyrite interbedded with carbonaceous clay. The Raritan clay acts as a confining unit separating the Lloyd aquifer from the aquifers above.

The Magothy Formation-Matawan Group, undifferentiated, overlies the Raritan clay. Hydrologically this unit is known as the Magothy aquifer; it is the principal aquifer on Long Island. The Magothy aquifer consists of as much as 1,000 ft or more of mostly fine- to medium-gray quartzose sand interbedded with gray clay and silt. Subordinate gravelly beds are common near the base of the unit. The upper surface of the Magothy aquifer is an erosional surface everywhere on Long Island except in south-central Suffolk County, where it is overlain by the Monmouth Group, undifferentiated. There the Monmouth consists of as much as 200 feet of dark-gray and black silty and sandy micaceous clay and greenish-gray glauconitic sandy clay (Perlmutter and Todd, 1965).

In the study area, the Upper Cretaceous beds are overlain unconformably by Pleistocene deposits, till, lacustrine silt and clay, and outwash sand and gravel. These deposits are generally less than 100 ft thick but are much thicker where they fill buried valleys or form morainal deposits. In recent reports, these deposits are referred to as the upper glacial aquifer (Cohen and others, 1968).

Holocene deposits of swamp bogs, stream alluvium deposits, lagoonal sediments, and beach and dune sand occur along the margins of Long Island in beds generally less than 20 feet thick.

Stratigraphic Section at the Artificial-Recharge Site

The deepest observation wells at the artificial-recharge site do not exceed 205 ft in depth; thus the stratigraphic section below this depth is not known with certainty. An approximation of the strata underlying the site can be derived from lithologic logs from deep wells bordering the area (fig. 9). Lithologic logs of two 550-ft wells 4,900 ft north and 6,200 ft south of the center of the site (figs. 10 and 11) suggest that the Magothy aquifer in the area consists of an unbroken, relatively uniform sequence of interbedded fine to medium, light-gray sand containing variable amounts of silt and clay, with discontinuous lenses of dark gray clay containing varying amounts of silt and sand. Clay lenses rarely exceed 5 ft in thickness, and no sand-clay sequence has identifiable lateral persistence in the area.

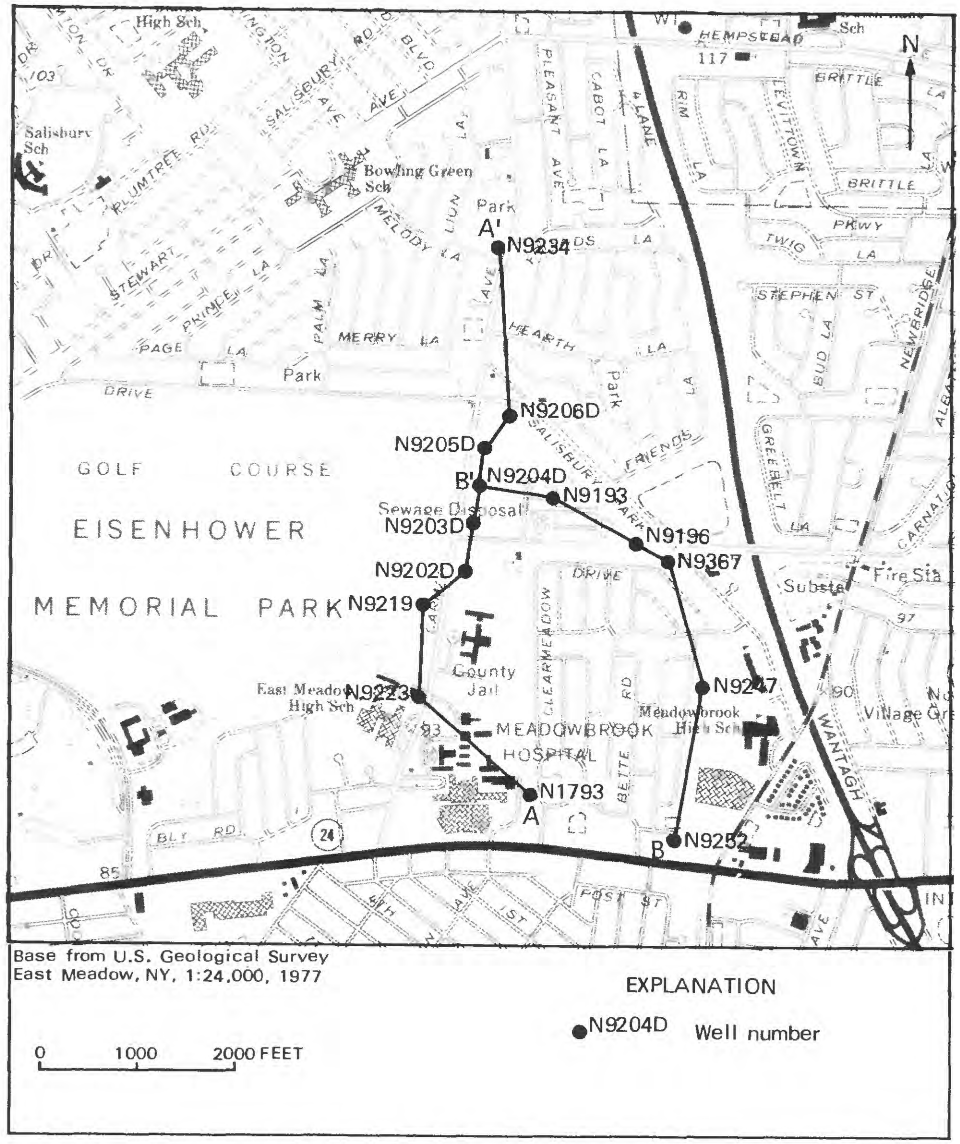
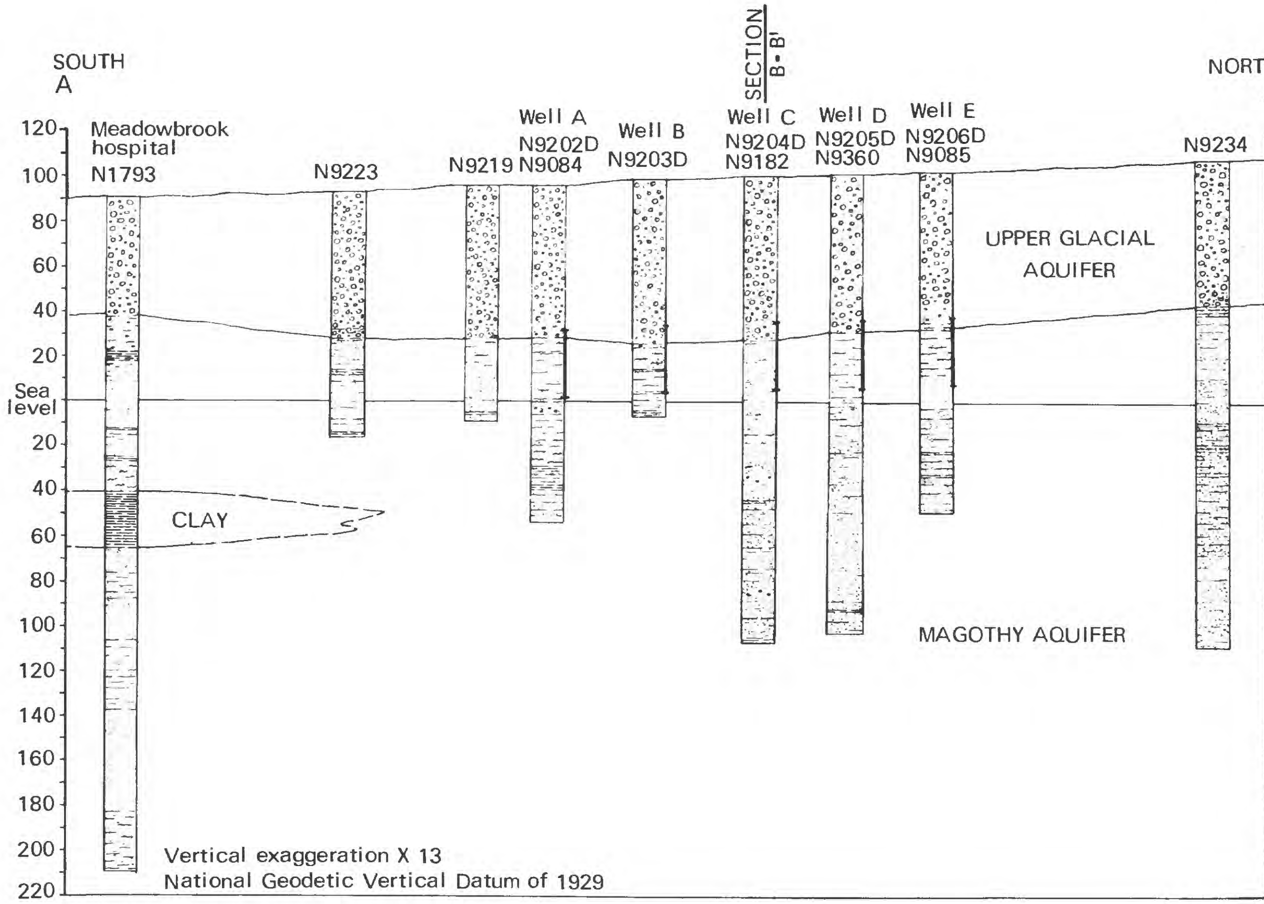


Figure 9.--Location of hydrogeologic sections A-A' and B-B' in vicinity of Meadowbrook artificial-recharge site.

Aquifer Characteristics

In the Meadowbrook area, the depth of the Pleistocene-Cretaceous contact varies areally, as shown in the hydrogeologic sections along lines of injection and observation wells (fig. 10). In this area the Pleistocene-Cretaceous contact is not clearly defined megascopically; however, upper glacial and Magothy deposits can be distinguished on the basis of compositional and textural characteristics:

(1) The Magothy sands tend to have a somewhat higher degree of sorting (lower sorting index) and a considerably smaller mean diameter than upper glacial sands. A size-distribution analysis of 20 core



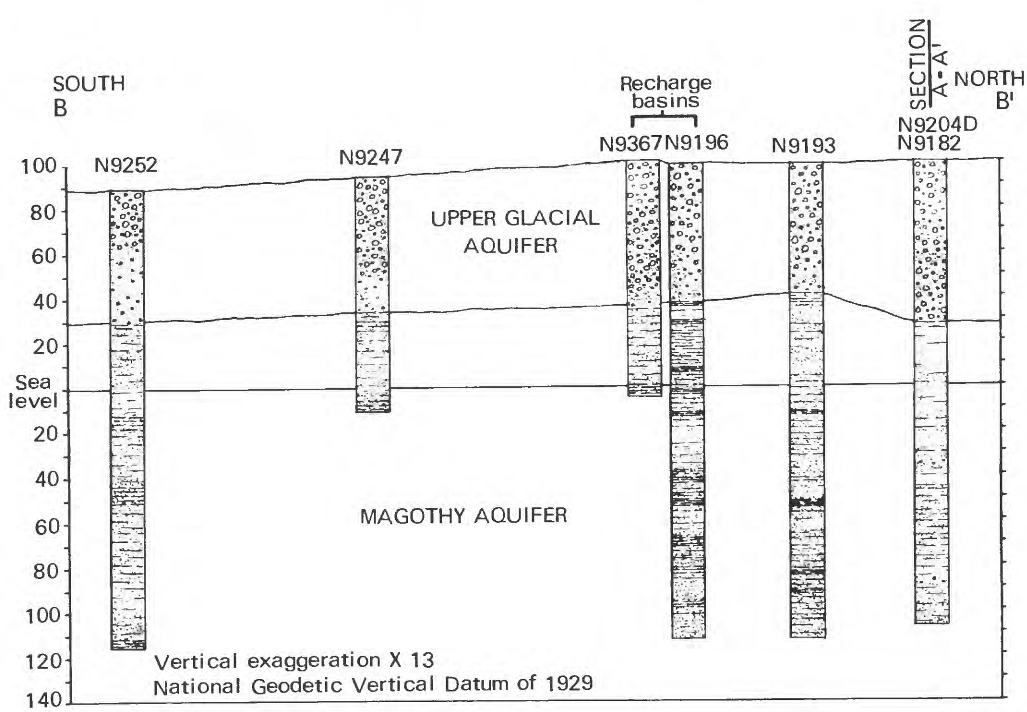


Figure 10.--Hydrogeologic sections A-A' and B-B'. (Locations are shown in fig. 9.)

samples of upper glacial deposits and 80 core samples of Magothy deposits obtained from 14 observation and injection wells showed the following relationships:

	Upper Glacial Aquifer	Magothy aquifer
Median grain diameter	2.71 mm	1.38 mm
Sorting coefficient (Trask, 1932)	2.00 mm	2.38 mm
Skewness	.90	1.09
Kurtosis	.23	.25

(2) The upper glacial deposits contain a different suite of trace heavy minerals than the Magothy deposits. Typical minerals found by preliminary petrographic analysis of heavy mineral grains, after separation and grouping by heavy liquid (bromoform) fractionation and isomagnetic separation, are summarized in table 3. Sampled upper glacial deposits contain 1.51 percent heavy minerals by weight, and Magothy deposits 1.45 percent heavy minerals by weight. Table 3 indicates that the upper glacial and Magothy aquifers in the study area contain distinctive suites of heavy minerals. Andalusite, for

Table 3.--Average percentage of minerals in heavy-mineral fractions of upper glacial and Magothy deposits, in alphabetic order.

	Upper glacial aquifer (percent)	Magothy aquifer (percent)
Andalusite	0	2.00
Biotite	0.66	.77
Chlorite (may include green biotite)	1.00	4.08
Clinozoisite	3.43	0
Collophane	.55	0
Corundum	.22	0
Epidote	.22	.08
Garnet	8.42	4.31
Hornblende	10.96	0
Kyanite	15.73	7.39
Muscovite	3.54	3.31
Olivine	.11	.08
Opaques	32.89	56.97
Rutile	2.66	1.00
Sillimanite	4.43	.54
Spinel	.22	.08
Staurolite	4.98	7.47
Topaz	0	.46
Tourmaline	5.09	10.00
Tremolite	1.66	.08
Zircon	3.10	.69
Unknowns	.11	.66
Totals:	99.98	99.97

example, is present in Magothy deposits but absent from upper glacial deposits, whereas hornblende and clinozoisite are common accessory minerals in upper glacial deposits but are apparently absent from Magothy deposits. Other minerals such as collophane, corundum, and topaz may also serve as useful index minerals (table 3).

HYDROLOGIC ENVIRONMENT

General Features

The ground water on Long Island originates as precipitation that falls on the island. Of the approximately 40 inches that falls yearly, nearly half is returned to the atmosphere by evapotranspiration, a very small amount enters streams as direct runoff, and the remainder percolates downward through the unconsolidated deposits to the water table and enters the ground-water reservoir (Cohen and others, 1968).

The general direction of ground-water movement on Long Island is seaward, from recharge areas near the center of the island to discharge areas at and beyond the shores. (See fig. 8.) Ground water that is not diverted by pumping discharges both by seepage into streams and by direct subsurface outflow into salty ground water, which in turn is hydraulically connected with tidewater.

The horizontal components of ground-water flow in the unconfined upper glacial aquifer throughout Nassau County and at the Meadowbrook artificial-recharge site are depicted in figures 11 and 12, respectively. Near the ground-water divide, ground-water movement is generally downward from the upper glacial aquifer into the underlying deposits, then becomes progressively more horizontal with distance from the divide. Near the shores, the direction of ground-water flow may have an upward component.

The horizontal movement of ground water parallel to bedding planes on Long Island is more rapid than vertical (downward) movement because the many scattered layers of silt and clay retard the downward flow, and also because the largest dimensions of unevenly shaped particles such as clay tend to be oriented horizontally. Approximate rates of ground-water movement can be computed from hydraulic gradients and estimated coefficients of aquifer permeability and porosity. (See section "Digital-Model Studies.") Rates of horizontal movement in the upper glacial and Magothy aquifers in the Meadowbrook area are estimated to average 2.5 ft/d and 0.5 ft/d, respectively.

Long-Term Regional Water-Table Fluctuations

Under natural (undisturbed) conditions, the water table of Long Island fluctuates over a range of several feet in a seasonal pattern; the lowest levels are in late autumn, the highest levels in early spring. This pattern reflects the large loss of water through evapotranspiration during the growing season and the absence of such losses between growing seasons. In undeveloped areas the hydrologic system is in equilibrium, with inflow balancing outflow. In developed areas, however, where large amounts of water are continually

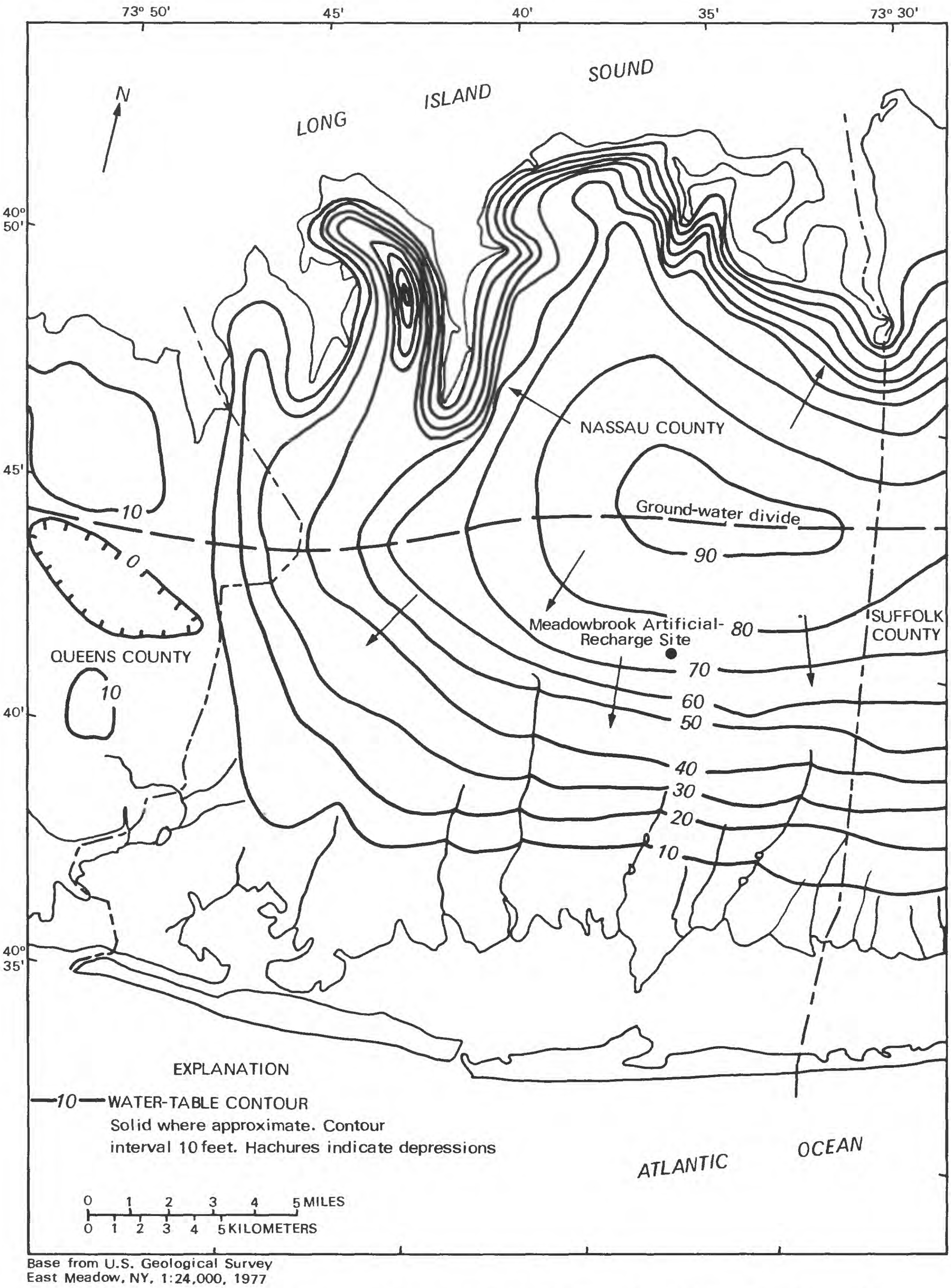


Figure 11.--Nassau County water-table contours in 1980. Horizontal component of ground-water flow is perpendicular to contours. (Modified from Donaldson and Koszalka, 1983.)

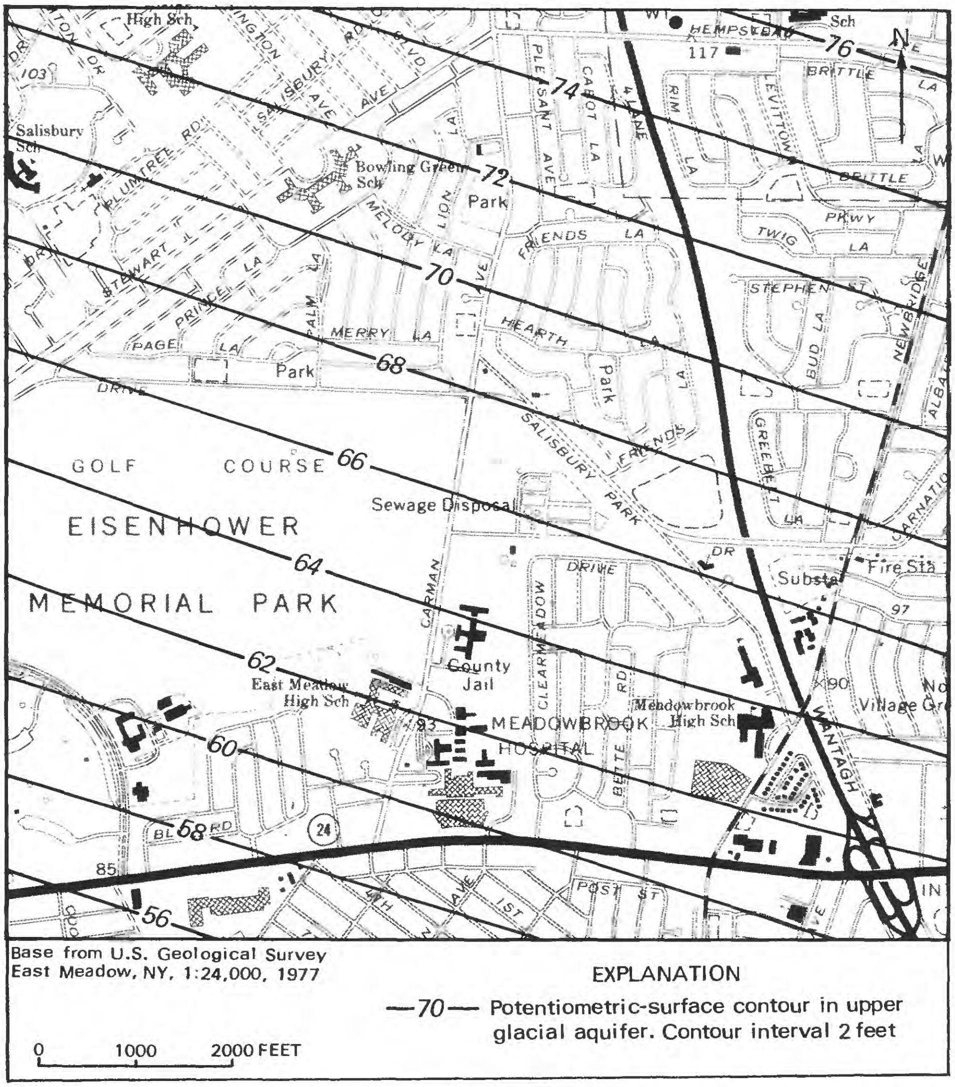


Figure 12.--Potentiometric surface of the water table at the Meadowbrook artificial-recharge site during October 14-16, 1980.

pumped out of the ground-water system, the water table declines until it reaches equilibrium at a lower level, which results in a loss of ground water from storage, decreased subsurface outflows, and a reduction or cessation of streamflow.

Hydrologic conditions in the vicinity of the Meadowbrook project site have been changing slowly as a result of long-term trends in ground-water recharge and public-water supply pumpage. In 1930, the altitude of the water table in the area was about 68 ft above NGVD of 1929 and remained nearly constant for more than two decades. In 1954, a large sanitary-sewer network in southwestern Nassau County caused a net reduction in recharge to the ground-water reservoir and a local decline in water levels (Franke, 1968). From 1962-66, water levels continued to drop at an increased rate over almost all of Nassau and neighboring counties as a result of a regional drought (Cohen and others, 1968). During 1951-70, the maximum water-table decline in Nassau County was more than 20 ft, but at Meadowbrook was less than 5 ft.

During 1970-79, ground-water levels rose throughout most of Nassau County, primarily as a result of increased precipitation after the 1962-66 drought. At Meadowbrook, ground-water levels remained relatively constant from 1970-74 (Koszalka, 1975) but by 1979 had risen about 8 feet to an altitude of 73 ft above NGVD of 1929 because of continued above-normal precipitation (Donaldson and Koszalka, 1983). Since 1979, continued sewer construction in central and southern Nassau County and a reduction in precipitation over much of the northeastern United States have resulted in a gradual but continued lowering of water levels throughout the island. At the study site, average water-level declines from May 1980 to August 1981 have ranged from 0.20 ft per month at well 20 to 0.45 ft per month at wells 2, 6, 11, and 12. (See fig. 13.) The average water-table decline at all wells in the area from May 1980 to August 1981 has been 0.42 ft per month.

Short-Term Water-Table Fluctuations

The Meadowbrook artificial-recharge project site lies in an area of intensive ground-water development. Accordingly, local water-level fluctuations caused by variations in pumping from nearby wells are a prominent characteristic. The number of pumping wells in the area, and the lack of detailed pumpage records for many of them, precluded an analytical evaluation.

Water-level records collected at observation wells in the area since May 1980 indicate that short-term water-level fluctuations are of two principal types--those caused by pumping and those caused by storms. Fluctuations due to pumping are generally less than $\pm$ 0.3 ft and rarely exceed $\pm$ 0.5 ft. Such fluctuations are diurnal and have distinct maxima and minima during each 24-hour period (fig. 13). The largest water-table fluctuations caused by pumping tend to occur in wells within and near the Eisenhower Park golf course and the Nassau County prison farm (fig. 3), probably as the result of proximity to water-supply wells for irrigation at these sites. Near these

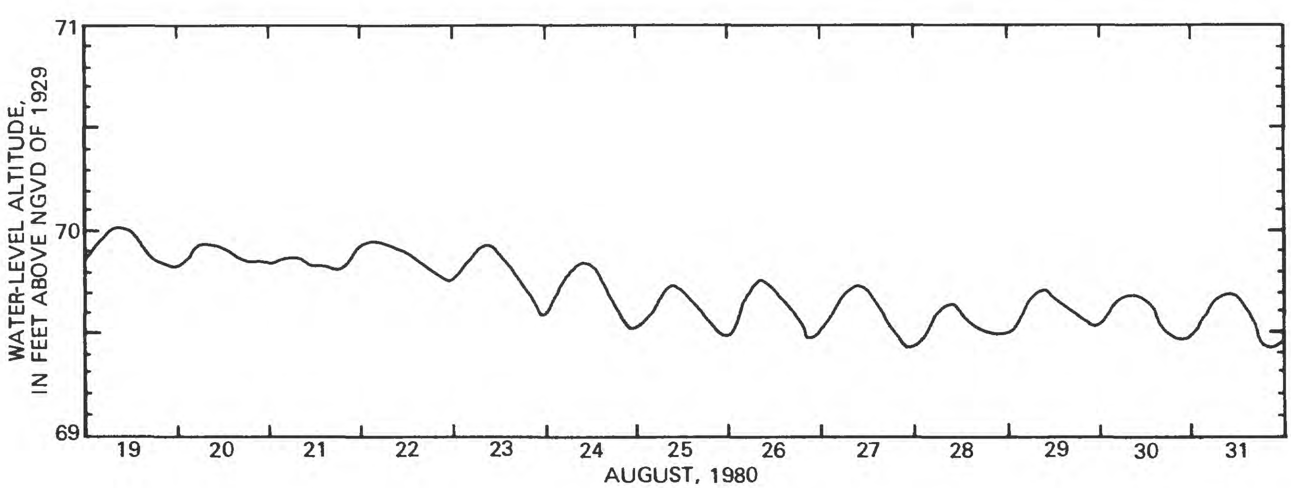


Figure 13.--Diurnal water-table fluctuations at well 11C. (Location is shown in fig. 3.)

locations, pumping-induced fluctuations are greater in observation wells screened at the 100-and 200-ft depths than in water-table wells because the deeper well screens are stratigraphically closer to the water-supply well screens. Conversely, water-table wells exhibit larger fluctuations from storms than do the deeper observation wells. The water-table rise resulting from storms within the study area rarely exceeds 1 ft.

Short-term water-table fluctuations caused by pumping or storms are expected to have minimal effect on the interpretation of recharge effects on the water-table configuration. Inasmuch as recharge experiments are expected to last for several months, water-level fluctuations of a day or less will be superimposed on long-term water-level rises caused by artificial recharge. A correction equal and opposite to the short-term fluctuation can then be applied to water-level measurements at each observation well.

DIGITAL MODEL STUDIES

Four pumping tests were conducted at the Meadowbrook site to study the hydrologic characteristics of the area. Because of the nonhomogeneity of the strata and the many factors affecting water levels in the area, no analytical or curve-matching solution technique was employed to analyze these tests; rather, the site was simulated on a two-dimensional Galerkin finite-element radial flow model (Reilly, 1983).

The values of hydraulic conductivity and storage coefficient obtained by this technique were then applied to a three-dimensional finite-difference model that simulates the hydrologic response to recharge operations throughout the region. The three-dimensional model is uncalibrated and therefore is described here only to make a preliminary appraisal of the effects of recharge on the ground-water system.

Published Aquifer Coefficients

Numerous estimates of hydraulic conductivity in the Meadowbrook region have been published. For the upper glacial aquifer, values of 170 ft/d (Perlmutter and Geraghty, 1963), 250 ft/d (McClymonds and Franke, 1972), and 270 ft/d (Franke and Cohen, 1972) have been reported; and for the Magothy, the same authors report 130 ft/d, 56 ft/d, and 50 ft/d, respectively. Franke and Cohen (1972), the only ones to estimate vertical hydraulic conductivity, report 27 ft/d for the upper glacial aquifer and 1.4 ft/d for the Magothy. Recent analysis of a 2-day pumping test in the upper glacial aquifer at Seaford, 7 mi southeast of the study area, has yielded an estimate of 300 ft/d in the horizontal direction and 125 ft/d in the vertical direction (Lindner and Reilly, 1983).

The regional storage coefficient of the upper glacial aquifer has been estimated to be 0.18 (Getzen, 1977), 0.24 (Perlmutter and Geraghty, 1963), and 0.15 locally (Lindner and Reilly, 1983). Lohman (1979) reports the storage coefficient of an unconfined aquifer (such as the upper glacial) to be generally in the range 0.1 to 0.3.

Pumping Tests

An aquifer test was made at each injection well (A, B, C, and D) from May 4 to June 12, 1978. (Locations are shown in fig. 3.) During each test, the respective well was pumped at 750 gal/min for 12 hours. Drawdowns were measured in the pumping well, in an observation well screened in the annular space of the pumping well, and in several nearby observation wells screened at various depths in the upper glacial and Magothy aquifers. Water-table recovery data were collected from these wells for an equal period. Average thicknesses of the upper glacial and Magothy aquifers in the study area are 70 ft and 610 ft, respectively. Average depths to water table from land surface range from 32 ft in the southern part to 38 ft in the northern part of the area.

From the estimates of hydraulic conductivity and storage coefficient obtained from the literature, the authors attempted to simulate the pumping tests through a radially symmetric transient-flow finite-element model (Reilly, 1983). The model simulates a vertical cross section of aquifer that is assumed to be radially symmetric around the well. The diagram in figure 14 shows the section of aquifer simulated by this model. The model is capable of analyzing the hydraulic response to recharge given any sort of radially symmetric aquifer material with any number of differing layers and any depth of well screen. Hydraulic conductivity can vary laterally and vertically throughout the model, although it is constant within a single element.

The area modeled is 20,000 ft in radius and extends from the water table to the base of the Magothy aquifer. A 515-node, 942-element grid was constructed to represent this site (fig. 15). Although it is doubtful that

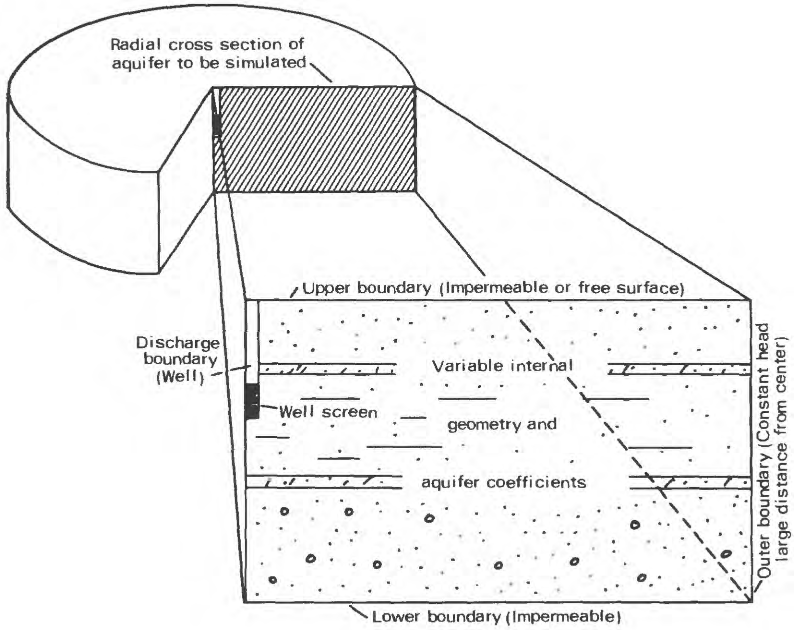


Figure 14.--Two-dimensional section of aquifer as simulated by radial model. (From Reilly, 1983, fig. 1.)

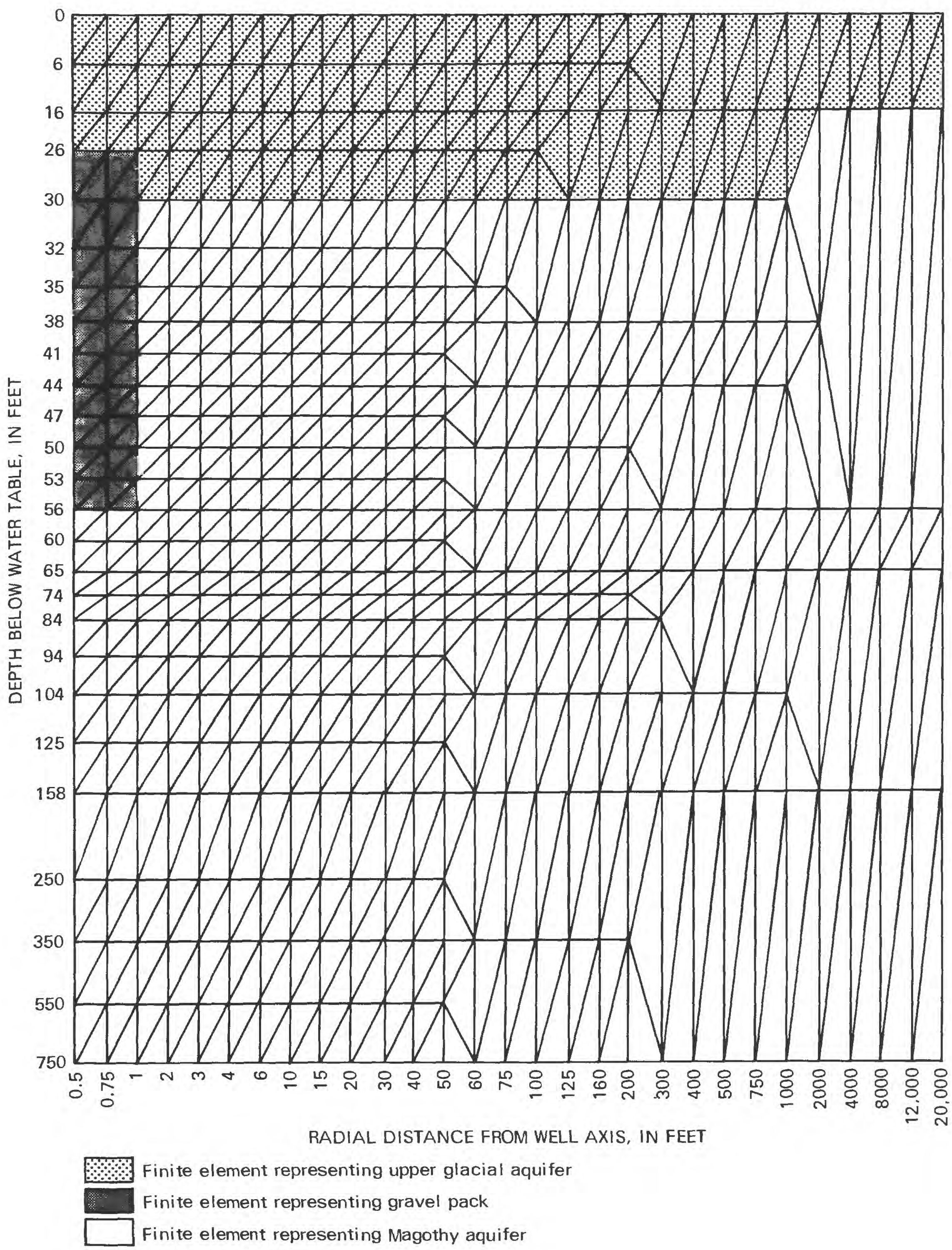


Figure 15.--Finite-element model grid used to simulate a pumping-test site.

the aquifers are actually uniform over this entire area, the model represented homogeneous, horizontal layers of uniform thickness. This simplification was necessary because detailed geologic data were insufficient but was also dictated by the radial symmetry imposed by the model.

A gravel pack having a radius of 1 ft, a horizontal hydraulic conductivity of 100,000 ft/d (fig. 7), and a vertical hydraulic conductivity of 10,000 ft/d was simulated around the well screen. Horizontal and vertical conductivity of the upper glacial and Magothy aquifers were first estimated from regional data from McClymonds and Franke (1972) and then adjusted until a match was obtained. Final estimates for the hydraulic conductivity of the upper glacial aquifer were 390 ft/d in the horizontal direction and 160 ft/d in the vertical direction; those for the Magothy aquifer were 66 ft/d and 6 ft/d, respectively. (Because the model was insensitive to the anisotropy of the Magothy aquifer, the vertical hydraulic conductivity may have a large error associated with it.) Calculated storage coefficient for the upper glacial aquifer was 0.20, and specific storage for the Magothy aquifer was 0.5×10^{-4} per ft.

Regional Finite-Difference Model

When the Meadowbrook site is fully operational, reclaimed water will be injected at 350 gal/min through each of four wells screened at the bottom of the upper glacial aquifer and the top of the Magothy aquifer, and will be applied at a rate of 100 (gal/d)/ft^2 through the four shallow basins. The authors attempted to evaluate the regional effects of this recharge scheme by modeling the area with the values of aquifer characteristics established by the aquifer tests. The model simulated ground-water flow in three dimensions (Trescott, 1975). The model uses the finite-difference method to generate a set of simultaneous algebraic equations that are then solved by the strongly implicit procedure (SIP).

The study area and the surrounding region were represented by a six-layer model (three layers represent the saturated part of the upper glacial aquifer, and three represent the Magothy) having a 40- x 40-node grid. Spacing of the nodes represented as little as 40 ft at the injection site and increased to nearly 5 mi at the model boundary. Figure 16 shows the study area that is represented by a fine-grid spacing (which is also the area represented in figs. 14 and 15) and the area represented by the entire model.

The boundary conditions used in the model are as follows:

(1) Lateral boundaries:

(a) North and south shores are represented as constant-head boundaries.

(b) Eastern and western boundaries also are represented as constant-head boundaries but are assumed to have little impact. (The observed effects of simulated recharge did not extend to these boundaries.)

(2) Bottom boundary:

The Raritan confining unit is assumed to be impermeable and is represented as a no-flow boundary.

(3) Top boundary:

The water table is represented as a free surface, and the transmissivity of the top layer changes with water-table altitude.

(4) Streams:

The major stream in the study area (East Meadow Brook, figs. 11 and 16) is represented as a series of constant-head nodes and completely penetrating the top 13-ft layer of the upper glacial aquifer. The model blocks containing stream nodes represent a larger area and greater channel depth than the actual stream, and the assumption of constant head gives the simulated stream, in effect, a limitless capacity to carry water away from the site. To compensate for this discrepancy, horizontal and vertical permeabilities in the blocks containing stream nodes were adjusted to represent the actual area of the stream bed.

The fact that the stream is modeled as a series of constant-head nodes also means that the geographic location of the start of flow in the model remains constant over time. The real situation may be different, however, because a ground-water mound will develop as recharge continues, and the

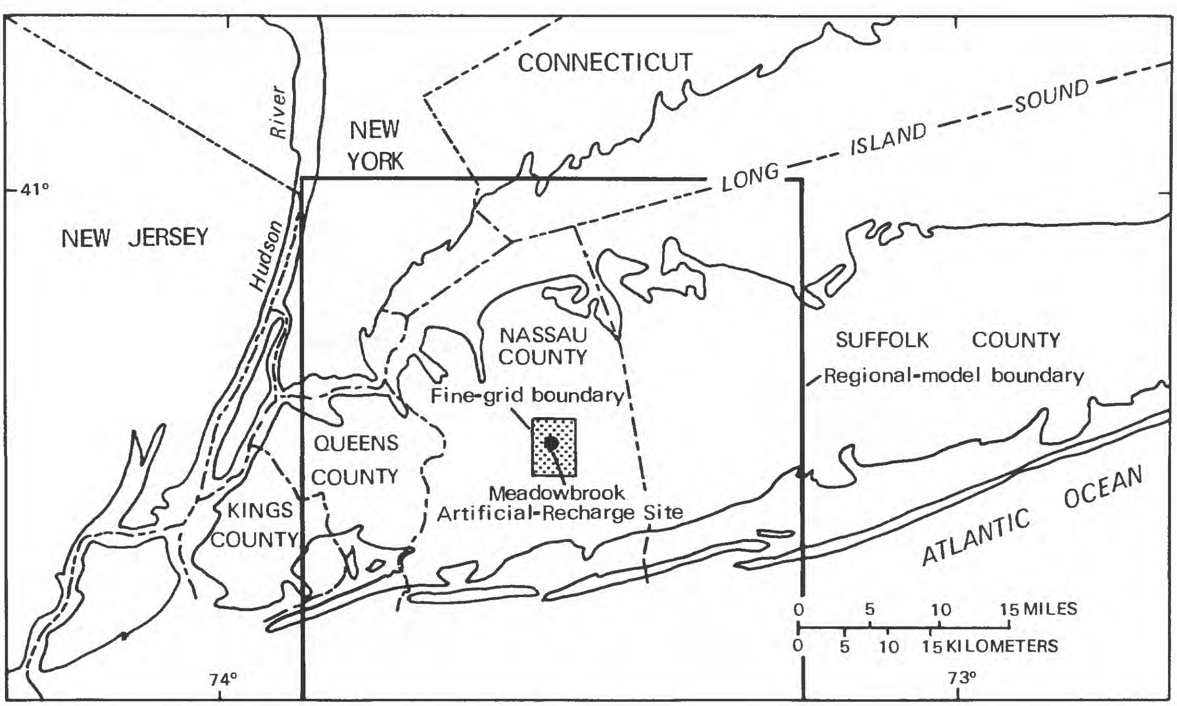


Figure 16.--Boundaries of study area and surrounding region as defined in model.

stream channel will increase in length. Thus, the model compensates by increasing the amount of flow in the stream, not by lengthening the stream channel. The effect of this inaccuracy on head buildups at the site is probably minor, however, and would tend to make predictions of the magnitude of water-table buildup slightly greater than the true case.

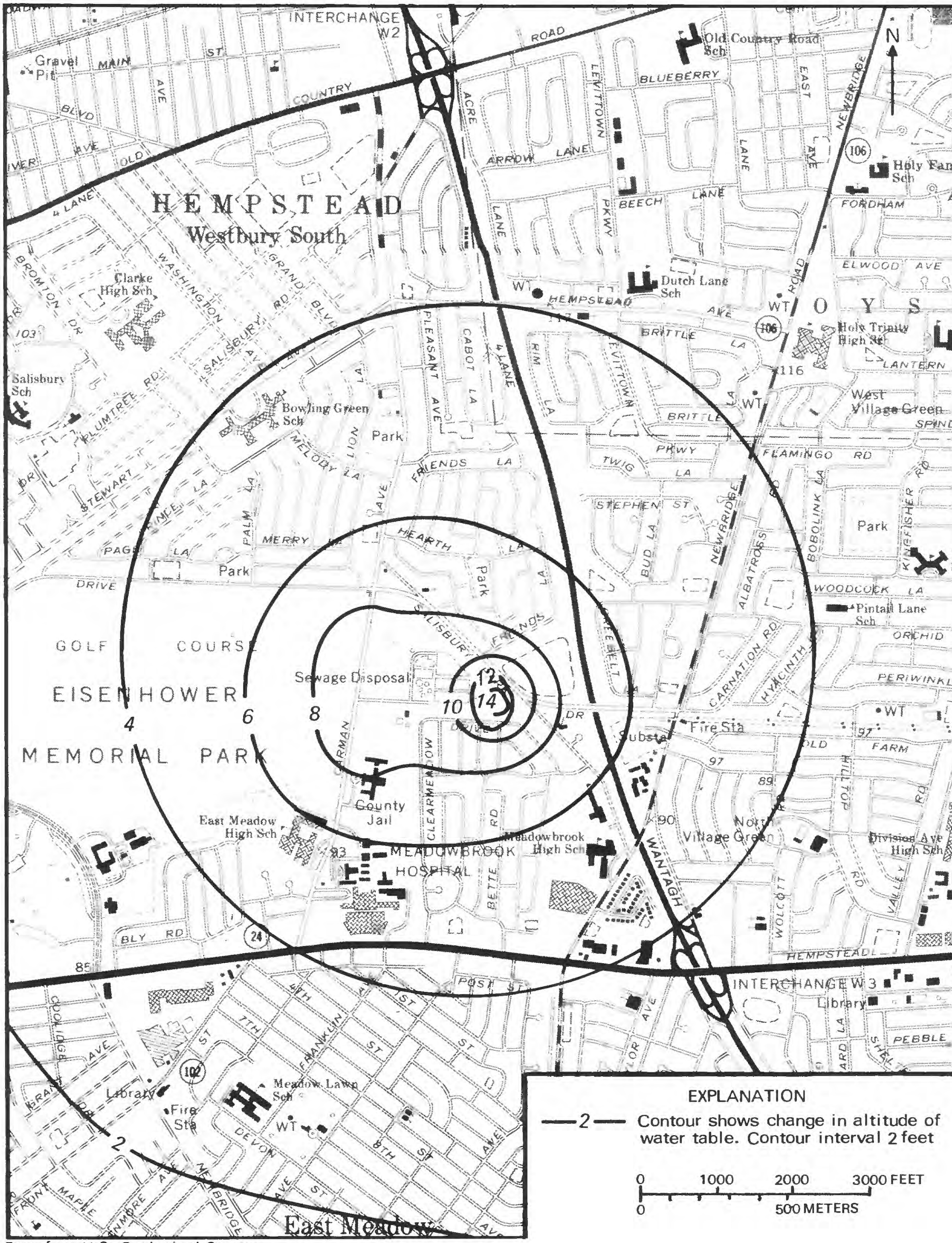
The K (hydraulic conductivity) values obtained from the pumping-test analyses were significantly higher than those reported by McClymonds and Franke (1972) for the region as a whole. The areal extent of the high-K area is unknown; therefore, two simulations were made. In the first, the assumption was made that the areas of high K are localized in the immediate vicinity of the injection wells, and that the published (lower) values for regional K apply everywhere else. This corresponds to a sort of "worst-case" condition, which would result in maximum head buildup. In the second simulation, the alternate assumption was that the area of high K is widespread throughout the study area. In this case, model results would represent "best-case" conditions. The true situation probably lies somewhere between these two interpretations. For both cases, the model was run with all four wells and four basins operating simultaneously because this configuration resulted in maximum stress to the system.

Table 4 gives predicted head buildups at injection wells, basins, and observation wells after 10 days, 1 month, 6 months, and 1.3 years of constant recharge, and also after the system has come to equilibrium for the lower K; table 5 gives the corresponding results for the higher K.

Figures 17A and 17B are computer-generated contour maps of predicted change in regional water table due to recharge under equilibrium (steady-state) conditions for the "worst" and "best" cases (localized vs. extensive high-K area), respectively, under maximum stress. Maximum head buildup under the first condition (fig. 17A) is 17 ft at basin 2 (table 4); the maximum head buildup under the latter is only 11 ft (fig. 17B). The predicted increase in streamflow at East Meadow Brook under low-K conditions is 3 ft^3/s (1.94 Mgal/d) and under higher K conditions is 3.5 ft^3/s (2.26 Mgal/d). (East Meadow Brook, shown in figs. 11 and 16, is not included in figs. 17 or 18. The stream is approximately 3 mi to the west-southwest, and the necessarily large scale used to construct figs. 17 and 18 prohibited inclusion of East Meadow Brook.)

Figure 18 is similar to figure 17 except that it shows changes in potentiometric surface in the upper Magothy aquifer, the zone in which the four injection wells are screened. In the lower-permeability case, with all four injection wells and four basins operating, the maximum increase in potential is 16 ft (well B); in the higher permeability case, the maximum increase is only 8 ft.

By the nature of the finite-difference technique, the head value predicted by the model for an injection-well node is the average value over the entire model block, rather than just at the well. It is this head value that is contoured in figures 17 and 18. Thus, the predicted head buildup at a well node is somewhat less than the true value. In the case of the basins, this situation does not lead to serious inaccuracy because the area of the basins is comparable to that represented by the model blocks.



Base from U.S. Geological Survey
East Meadow, NY, 1:24,000, 1977

Figure 17A.--Predicted change in water-table altitude with steady-state recharge under low-permeability conditions.

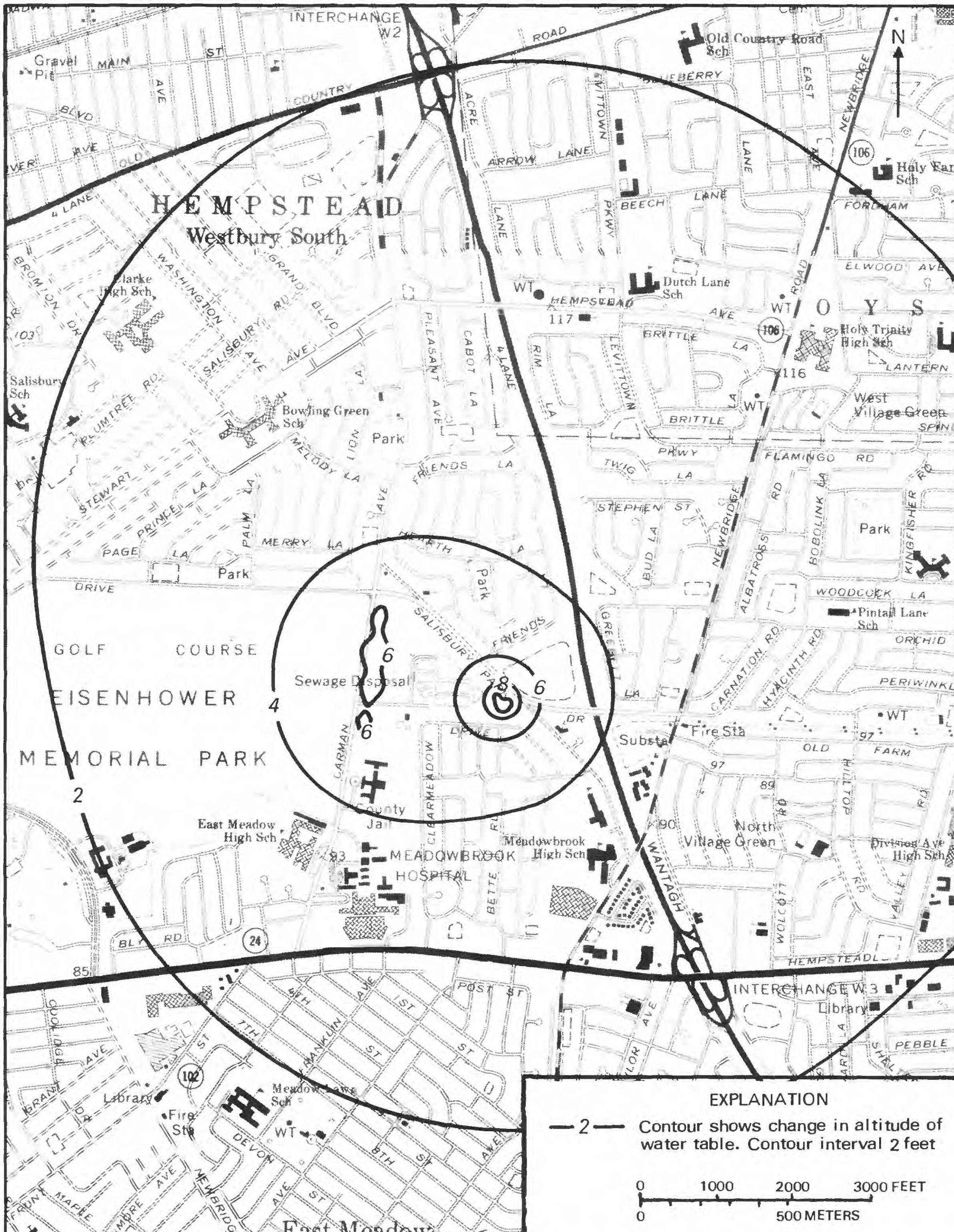


Figure 17B.--Predicted change in water-table altitude with steady-state recharge under high-permeability conditions.

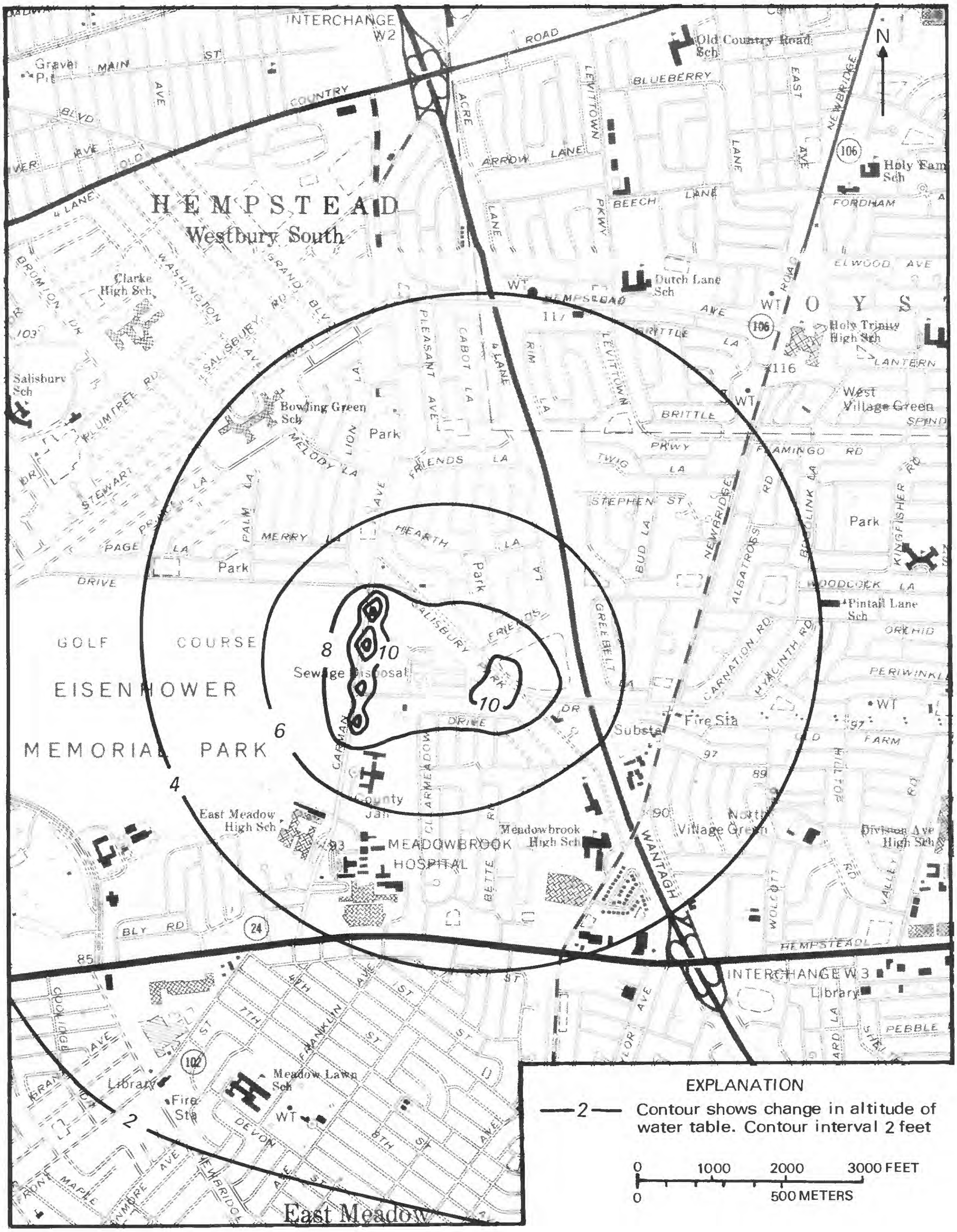


Figure 18A.--Predicted change in potentiometric surface of Magothy aquifer with steady-state recharge under low-permeability conditions.

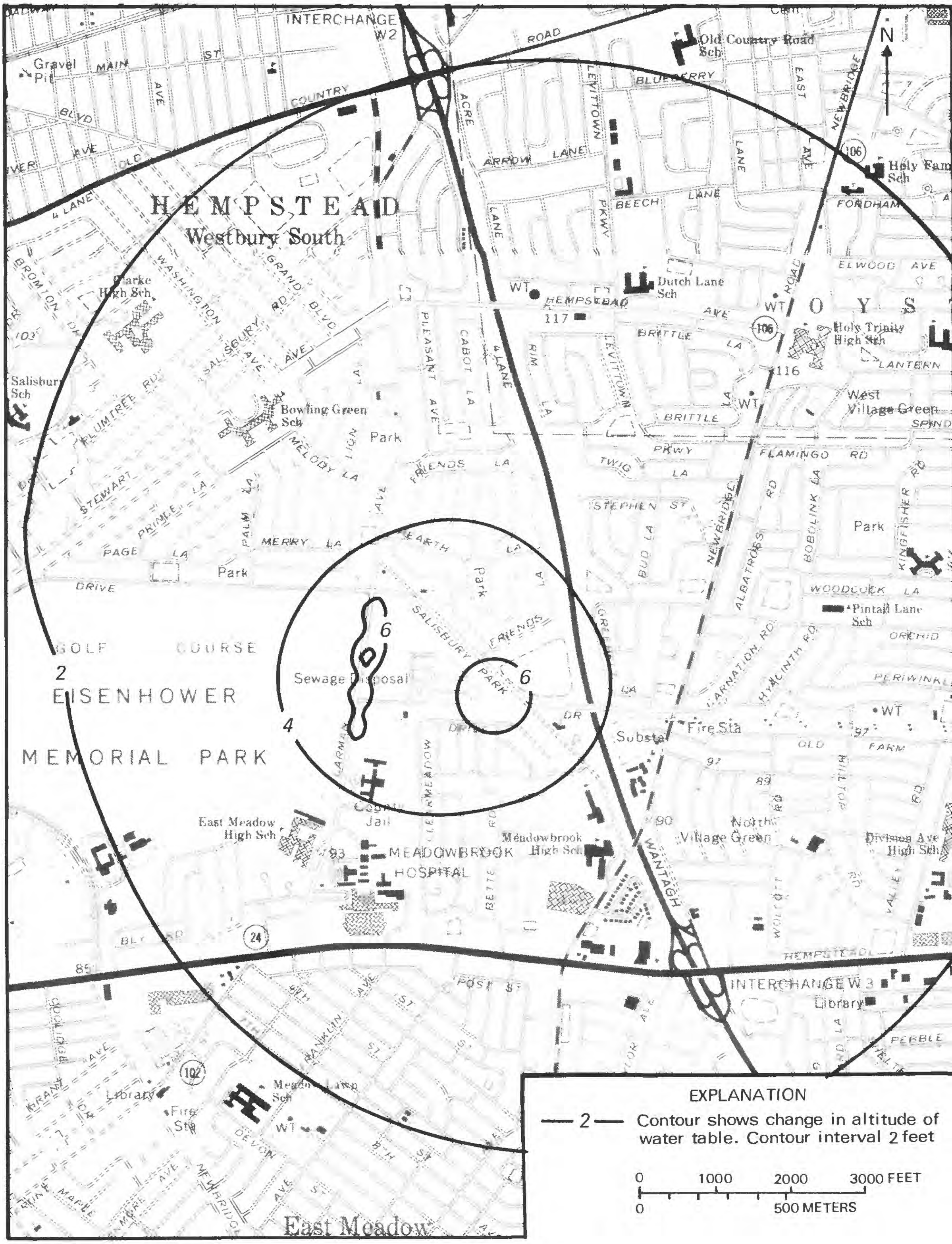


Figure 18B.--Predicted change in potentiometric surface of Magothy aquifer with steady-state recharge under high-permeability conditions.

Table 4.--Predicted head buildups at selected basins, observation wells, and injection wells after recharge for various periods of time under "lower permeability" conditions.

[Values are in feet]

	Head buildups, in feet, after indicated time periods				
	10 days	1 month	6 months	1.3 years	Steady-state (equilibrium)
Injection wells					
A	8.27	9.93	12.45	13.33	14.75
B	9.52	11.33	13.89	14.76	16.14
C[1]	5.62	7.46	10.01	10.86	12.12
D[1]	5.23	6.87	9.37	10.22	11.47
Basins					
6	10.61	12.51	14.73	15.47	16.69
7	10.57	12.47	14.70	15.45	16.68
1	9.75	11.64	13.89	14.65	15.90
2	11.34	13.17	15.34	16.07	17.26
Observation wells					
1A	0.25	0.78	2.55	3.41	4.97
1B	.14	.67	2.64	3.54	5.14
1C	.12	.65	2.65	3.56	5.16
2C	.23	1.07	3.33	4.27	5.90
5A	.95	2.11	4.29	5.16	6.67
5B	1.25	2.96	5.57	6.48	8.00
5C	1.24	3.06	5.76	6.68	8.20
6C	.64	1.95	4.42	5.35	6.93
7A	.72	1.62	3.62	4.44	5.81
7B	.72	1.91	4.25	5.12	6.51
7C	.68	1.93	4.33	5.21	6.60
8B	3.26	4.97	7.49	8.36	9.74
8C	2.41	4.23	6.82	7.69	9.07
9A	1.61	2.81	5.00	5.08	7.25
9B	9.52	11.33	13.89	14.76	16.14
9C	3.20	5.12	7.73	8.59	9.96

[1] Head at this well is an average of heads calculated for a combination of nodes in model layers 3 and 4, inasmuch as the well screen is located within two aquifers.

Table 4 (continued).--Predicted head buildups at selected basins, observation wells, and injection wells after recharge for various periods of time under "lower permeability" conditions.

[Values are in feet]

	Head buildups, in feet, after indicated time periods				
	10 days	1 month	6 months	1.3 years	Steady-state (equilibrium)
Observation wells					
10A	1.32	2.65	4.90	5.75	7.19
10B	1.98	4.10	6.81	7.70	9.12
10C	2.02	4.29	7.10	7.99	9.42
11A	1.28	2.54	4.74	5.60	7.06
11B	3.64	5.62	8.15	9.01	10.42
11C	6.91	9.06	11.54	12.35	13.67
12B	3.49	5.35	7.82	8.68	10.11
12C	5.85	7.89	10.35	11.18	12.54
13A	1.01	2.12	4.24	5.10	6.60
13B	2.23	3.96	6.44	7.33	8.81
13C	2.45	4.34	6.89	7.78	9.25
14B	1.60	3.02	5.45	6.31	7.64
14C	1.51	3.02	5.51	6.38	7.71
15B	.28	1.12	3.31	4.20	5.68
15C	.25	1.11	3.35	4.25	5.73
16B	.43	1.92	4.23	5.09	6.41
16C	.73	1.94	4.32	5.18	6.51
17B	.31	1.12	3.26	4.11	5.42
17C	.28	1.11	3.30	4.16	5.47
18C	.01	.12	1.12	1.74	2.70
19B	.62	1.83	4.25	5.13	6.49
19C	.59	1.85	4.34	5.22	6.59
20C	.11	.63	2.60	3.45	4.80
21A	.16	.58	2.18	2.99	4.38
21B	.08	.47	2.23	3.09	4.51
21C	.07	.45	2.23	3.10	4.52
22C	.03	.26	1.72	2.56	4.04
Other					
Storm-water basin 62	3.49	5.50	8.05	8.93	10.37
Meadowbrook Hospital	.11	.63	2.59	3.44	4.75

Table 5.--Predicted head buildups at selected basins, observation wells, and injection wells after recharge for various periods of time under "higher permeability" conditions.

[Values are in feet]

	Head buildups, in feet, after indicated time periods				
	10 days	1 month	6 months	1.3 years	Steady-state (equilibrium)
Injection wells					
A	4.04	5.11	6.60	7.10	7.77
B	4.76	5.89	7.38	7.88	8.53
C1/	3.38	4.50	5.99	6.47	7.10
D1/	3.10	4.15	5.62	6.10	6.70
Basins					
6	7.12	8.27	9.64	10.11	10.73
7	7.19	8.33	9.70	10.17	10.80
1	6.60	7.73	9.11	9.59	10.22
2	7.61	8.74	10.08	10.54	11.15
Observation wells					
1A	.23	.75	2.05	2.58	3.33
1B	.19	.71	2.05	2.59	3.34
1C	.18	.71	2.05	2.59	3.34
2C	.31	.99	2.43	2.99	3.77
5A	.98	1.93	3.40	3.94	4.66
5B	1.06	2.16	3.70	4.24	4.97
5C	1.07	2.18	3.74	4.28	5.01
6C	.62	1.51	3.00	3.56	4.32
7A	.67	1.44	2.80	3.28	3.91
7B	.65	1.50	2.92	3.41	4.04
7C	.64	1.51	2.94	3.43	4.06
8B	1.95	3.03	4.53	5.02	5.67
8C	1.88	2.99	4.49	4.99	5.63
9A	1.63	2.61	4.06	4.56	5.22
9B	4.76	5.89	7.38	7.88	8.53
9C	2.70	3.85	5.35	5.84	6.49

1/Head at this well is an average of heads calculated for a combination of nodes in model layers 3 and 4, inasmuch as the well screen is located within two aquifers.

Table 5 (continued).--Predicted head buildups at selected basins, observation wells, and injection wells after recharge for various periods of time under "higher permeability" conditions.

[Values are in feet]

	Head buildups, in feet, after indicated time periods				
	10 days	1 month	6 months	1.3 years	Steady-state (equilibrium)
Observation wells					
10A	1.35	2.42	3.91	4.43	5.10
10B	1.59	2.85	4.42	4.93	5.61
10C	1.61	2.91	4.49	5.01	5.68
11A	1.52	2.54	4.00	4.52	5.22
11B	3.15	4.34	5.83	6.34	7.02
11C	4.85	6.08	7.55	8.04	8.70
12B	2.93	4.06	5.54	6.05	6.74
12C	4.10	5.27	6.74	7.24	7.91
13A	1.18	2.09	3.53	4.06	4.78
13B	1.73	2.81	4.30	4.84	5.55
13C	1.81	2.92	4.43	4.96	5.68
14B	1.18	2.14	3.59	4.07	4.67
14C	1.20	2.18	3.64	4.12	4.72
15B	.33	.81	2.41	2.93	3.62
15C	.32	1.01	2.41	2.93	3.63
16B	.67	1.50	2.91	3.38	3.97
16C	.67	1.51	2.93	3.40	3.99
17B	.34	1.01	2.36	2.82	3.39
17C	.33	1.01	2.36	2.83	3.40
18C	.03	.19	.95	1.26	1.63
19B	.60	1.48	2.93	3.42	4.04
19C	.59	1.48	2.94	3.43	4.05
20C	.17	.69	1.98	2.46	3.05
21A	.16	.59	1.78	2.27	2.92
21B	.13	.55	1.78	2.28	2.93
21C	.12	.54	1.78	2.28	2.93
22C	.06	.36	1.47	1.97	2.66
Other					
Storm-water basin 62	2.49	3.66	5.16	5.69	6.39
Meadowbrook Hospital	.17	.69	1.97	2.43	3.01

HYDROCHEMICAL ENVIRONMENT

The background microbiologic setting and the organic and inorganic chemistry of ground water beneath the Meadowbrook artificial-recharge project site was described by Katz and Mallard (1980). Their study showed that the upper glacial aquifer contains significantly high concentrations of nitrate and low-molecular-weight halogenated hydrocarbons relative to background levels as well as detectable concentrations of organochlorine insecticides and polychlorinated biphenyls (Katz and Mallard, 1980, p. 12-15). The chemical conditions of water in the upper glacial aquifer, however, should be improved by aquifer replenishment with a treated effluent that is projected to be superior in quality to shallow ground water already present at the recharge site.

As of 1980, no fecal contamination was evident in either the upper glacial or Magothy aquifers in the study area. In the few samples containing fecal indicator bacteria, the numbers were low (Katz and Mallard, 1980, p. 16).

Since publication of the findings of Katz and Mallard (1980), additional inorganic water-quality data have been collected. The following section discusses the major inorganic constituents of ground water beneath the study area.

Analytical Methods

Inorganic substances in samples of ground water were analyzed at the U.S. Geological Survey Central Laboratory in Doraville, Ga., by methods developed by Skougstad and others (1979).

Water-quality data from the observation-well network could be grouped either by depth of the well screen or by location within the recharge area. In this report, the data are grouped by screen depth to allow comparison among 50-, 100-, and 200-ft depths. (See table 1.)

Alteration of Ground-Water Quality by Nonpoint Sources

Population growth and urbanization on Long Island have caused a steady increase in the demand for fresh ground water and have diminished its chemical quality through the discharge of wastes and other contaminants to the ground-water reservoir.

Natural recharge water (precipitation), which initially contains only material dissolved from the atmosphere, becomes concentrated by evapotranspiration and may be further modified on land surface and in the soils by dissolution of minerals or by discharges from nonpoint sources. Nonpoint sources such as wastewater from cesspools and septic tanks, salts for road deicing, and fertilizers for lawns and agriculture, have contributed to the deterioration of water quality of the upper glacial aquifer and the upper parts of the Magothy aquifer in Nassau County. For this reason, the concentrations of pollution-indicator ions such as chloride, nitrate, and sulfate in ground water are greater than in the precipitation.

The concentrations of selected ions in precipitation at Eisenhower Park in East Meadow (fig. 3) are presented in table 6; the values have been corrected for evaporation for October 1978 through September 1979. Table 6 also gives the average concentrations of chloride, nitrate, and sulfate in water from wells screened at depths of 50, 100, and 200 ft below land surface. Concentrations of chloride and nitrate in water from the 50- and 100-ft wells are about 10 times greater than in precipitation; sulfate concentrations at the 50- and 100-ft wells are about five times greater than in precipitation. The presence of chloride, nitrate, and sulfate from nonpoint sources in ground water beneath the study area is discussed in more detail in the following sections.

Concentrations of ammonium and hydrogen are lower in ground water than in precipitation (table 6). Discharges from nonpoint sources may account in part for the lower concentrations of hydrogen in ground water; however, interactions in the soil zone such as through ion-exchange reactions may also be responsible. Oxidation-reduction, cation-exchange reactions, and

Table 6.--Average concentrations of chloride, nitrate, sulfate, ammonium, and hydrogen ions in atmospheric precipitation and in water from wells in study area

[Values are in milligrams per liter. Precipitation analyses of 12 monthly composite samples by U.S. Geological Survey (1980)]

Ions	Precipitation[1]	Well water[2]		
		50-ft depth	100-ft depth	200-ft depth
Chloride (Cl^-)	3.8	40	37	22
Nitrate-N (NO_3^-)	0.96	11	8.9	9.2
Sulfate (SO_4^{--})	7.5	36	32	17
Ammonium-N (NH_4^+)	0.66	0.18	0.12	0.01
Median value	---	0.02	0.0	0.01
Hydrogen (H^+)	30×10^{-6}	4.8×10^{-6}	2.8×10^{-6}	8.7×10^{-6}

[1] Adjusted for losses by evapotranspiration, as determined by Cohen (1968).

[2] Wells are grouped according to depth of well screen below land surface. Average water-table depth below land surface ranges from 32 ft in the southern part of the study area to 38 ft in the northern part.

microbiological nitrification/denitrification processes in the unsaturated and saturated zones may account for the lower concentrations of ammonium in ground water than in precipitation. Sulam and Ku (1979) reported that ammonium concentrations decreased with movement through the unsaturated zone under parts of Nassau County.

Chloride

Concentrations of chloride beneath the study area are significantly higher than the background concentration of 5 to 10 mg/L reported by DeLuca and others (1965) and Pluhowski and Kantrowitz (1964). Chlorides in ground water result from agricultural and lawn fertilizers, effluent from septic-tank and cesspool systems, storm-water runoff, and road-deicing salts.

Fertilizers applied to residential and farmed areas within and upgradient from the study area may contribute significant amounts of chloride to ground water (Saffigna and Keeny, 1977). Hoffman and Spiegel (1958) found that chloride concentrations of 40 to 65 mg/L were common in ground water in eastern Suffolk County in areas where fertilizers were used extensively.

Septic-tank and cesspool systems may also be important sources of chloride in ground water beneath the study area. Chloride concentrations in ground water near these sources range from 50 to about 120 mg/L (Nassau-Suffolk Research Task Group, 1969).

Chloride concentration in storm runoff has ranged from 4 to 310 mg/L at various intervals during storms (V. I. Minei, Suffolk County Department of Environmental Control, written commun., 1976). Consequently, chloride concentration in ground water may increase significantly after storms, especially near recharge basins, which are the major route by which storm runoff infiltrates to the aquifer (Seaburn and Aronson, 1974). Seaburn and Aronson (1974, p. 50-51) report that chloride concentrations in inflow to storm-water basins ranged from 0 to 20 mg/L during selected storms.

Chloride from the solution of calcium and sodium chloride salts applied to highways in winter, and occasionally for dust control in specific areas such as racetracks in summer (Hoffman and Spiegel, 1958, DeLuca and others, 1965), may also be a major source of chloride in ground water. Hoffman and Spiegel (1958) estimate that in the immediate vicinity of treated highways, water infiltrating to the aquifer could have chloride concentrations as high as several hundred mg/L.

In the study area, which is predominantly residential and unsewered, mean concentrations of chloride decrease with depth. However, no significant difference (at the 0.05 probability level) was noted between mean chloride concentrations in water from the 50-ft depth and that from the 100-ft depth (table 7).

Nitrate and Ammonium

Elevated concentrations of nitrate in ground water in Nassau County may arise from effluent from cesspools and septic tanks, fertilizers, and stormwater runoff.

Table 7.--Mean, median, and range of chloride, nitrate-N, ammonium-N, and sulfate ions in water from wells in study area.

Ions	Depth of well screen below land surface (feet)	Concentration, in milligrams per liter			Number of analyses
		Mean	Median	Range	
Cl^-	50	40	33	2.8 - 220	50
	100	37	34	7.3 - 69	46
	200	22	21	7.0 - 46	20
NO_3^- as N	50	11	11	0.93 - 26	45
	100	8.9	8.7	0.26 - 20	34
	200	9.2	7.9	0.07 - 25	17
NH_4^+ as N	50	0.18	0.02	0.0 - 1.9	50
	100	0.12	0.0	0.0 - 2.0	41
	200	0.01	0.01	0.0 - 0.03	20
SO_4^{--}	50	36	38	6.4 - 52	56
	100	32	30	2.6 - 56	46
	200	17	16	0.0 - 44	20

In 1982, approximately 850,000 people resided in unsewered areas of Nassau County. During the past 10 years, approximately 60 Mgal/d of domestic waste was discharged through 150,000 cesspools and septic tanks into the shallow zone of the ground-water reservoir (Nassau-Suffolk Regional Planning Board, 1978). The effluent from septic tanks and cesspools can contain variable amounts of dissolved nitrogen in several forms. Average ammonia concentrations (as NH_4) in this type of effluent have been reported to range from 52 to 115 mg/L (Nassau-Suffolk Research Task Group, 1969). If all this ammonia were oxidized to nitrate, the average nitrate equivalent concentration (as N) in the effluent would range from 40 to 90 mg/L.

Before the 1950's, agriculture was one of the major industries in Nassau County. Although the county's farming area decreased rapidly with the steady development of suburban communities since the 1930's, the amount of land that was still being used for farming in 1950 was estimated to be 4,900 acres (Bond, 1953). Neither historical nor current data regarding the rate of fertilizer application for this farmland are available; however, the amount of fertilizers applied for production of potatoes and other vegetables was probably significant. Recent nitrogen-isotope studies have shown that agricultural sources have contributed nitrate to ground water (Kreitler and others, 1978), although the amounts cannot be determined directly.

The contribution of nitrogen from lawn fertilizers has been documented. From a field survey made by the Cooperative Extension Service of Cornell University, the average annual application rate in Nassau County was

102 lb/acre (S. R. Pacenka, Cornell Univ., written commun., 1978); about 60 percent of the nitrogen from this source eventually reaches the aquifers (K. S. Porter, Suffolk County Cooperative Extension Service, oral commun., 1977).

In a study of the influence of recharge basins on the hydrology of Long Island, Seaburn and Aronson (1974) reported that inflow to storm-water recharge basins ranged in nitrate (as N) concentration from 0.02 to 2.5 mg/L during selected storms. In a similar study, runoff collected over a 2-hour period during a storm was found to contain nitrate (as N) concentrations ranging from 1.2 to 8.3 mg/L (Vito Minei, Suffolk County Department of Environmental Control, written commun., 1976).

In ground water beneath the study area, nitrate-N concentrations range from 0.07 to 26 mg/L (table 7). Water from more than half (55 percent) of all wells screened at 50 ft below land surface contained nitrate (as N) concentrations that exceeded the drinking-water limit of 10 mg/L (U.S. Environmental Protection Agency, 1976). Water from approximately one-third of all wells sampled at the 100- and 200-ft depth contained nitrate concentrations exceeding this limit. Ammonium-N concentrations decrease with depth (table 7), which would be expected because water from the deeper (100- and 200-ft) wells is being withdrawn from the deeper regional flow system, in which water contains lower concentrations of dissolved ions. Chemical reactions such as ion-exchange, sorption, and oxidation-reduction may also account for this decrease in ammonium concentrations with depth.

Sulfate

Sulfate concentrations above a background level of about 5 mg/L (Pluhowski and Kantrowitz, 1964) probably result from precipitation, storm runoff, and effluent from septic-tank and cesspool systems.

Because of Long Island's proximity to sea water and to the heavily industrialized New York and New Jersey metropolitan area, the concentration of sulfate in precipitation is high and varies widely with time. Sulfate concentrations in precipitation that has entered the ground can be as high as 17 to 18 mg/L after evaporation--twice as high as that in precipitation above land surface (Pearson and Fisher, 1971).

Another source of sulfate in ground water is storm runoff. Seaburn and Aronson (1974) report that sulfate in composite samples of runoff from selected storms ranged from 3 to 30 mg/L; the high concentrations in runoff may partly account for the elevated sulfate concentrations in ground water.

A major source of sulfate in unsewered areas is effluent from cesspool and septic-tank systems. This source is also highly variable; sulfate concentration in sewage has been reported to range from 2 to 180 mg/L (Nassau-Suffolk Research Task Group, 1969).

During the study, sulfate concentrations in ground water at Meadowbrook ranged from 0 to 56 mg/L (table 7); a substantial decrease occurs with depth. This decrease can probably be attributed to the lower concentrations of sulfate in the regional flow system tapped by the deeper wells.

SUMMARY

The Meadowbrook artificial-recharge project is intended to demonstrate the feasibility of replenishing the ground-water reservoir with reclaimed wastewater. A system of 11 spreading basins and 5 shallow injection wells will return 4 Mgal/d of reclaimed wastewater to the upper glacial and Magothy aquifers. The water will be supplied by the Cedar Creek Water-Reclamation facilities, 7.5 miles south of the injection site.

The spreading basins are excavated in the upper glacial aquifer, and the injection wells are screened above and below contact between the Magothy and upper glacial aquifers. The upper glacial sediments at the project site are lithologically and mineralogically distinct from Magothy sediments. Andalusite and hornblende seem to be reliable index minerals for identifying Magothy and upper glacial materials, respectively.

Aquifer tests analyzed by a two-dimensional Galerkin finite-element flow model indicate that the upper glacial aquifer has a permeability of 390 ft/d in the horizontal direction and 160 ft/d in the vertical direction. Calculated storage coefficient of the upper glacial aquifer is 0.20; specific storage for the Magothy is 0.5×10^{-4} per ft.

Results of the two-dimensional flow analysis were incorporated in a finite-difference regional flow model to predict changes in head within and around the site resulting from artificial recharge. A maximum water-table rise of 11 to 17 ft is predicted beneath the spreading basins, depending on aquifer permeability. Somewhat higher buildups would occur locally near the injection wells. The predicted increase in streamflow at East Meadow Brook is not expected to exceed 3.5 ft^3/s.

The upper glacial aquifer in the area contains significant concentrations of nitrate and low-molecular weight halogenated hydrocarbons and detectable concentrations of organochlorine insecticides and polychlorinated biphenyls. Concentrations of chloride and nitrate are about 10 times greater in water from the 50- and 100-ft depth than in precipitation; sulfate concentrations in water from the 50- and 100-ft depth are about five times greater than in precipitation. The principal nonpoint sources of chloride, nitrate, and sulfate in ground water beneath the study area include cesspools and septic tanks, road-deicing salts, and fertilizers.

The projected chemical quality of the treated effluent to be used for aquifer recharge will be superior to that of water already present in the upper part of the ground-water reservoir at the recharge site. Therefore, the recharge effort should both increase the quantity and improve the quality of the ground water in the vicinity of recharge.

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