ANALYSIS OF THREE TESTS OF THE UNCONFINED AQUIFER IN SOUTHERN NASSAU COUNTY, LONG ISLAND, NEW YORK

by Juli B. Lindner and Thomas E. Reilly

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CONVERSION FACTORS AND ABBREVIATIONS

The following factors may be used to convert inch-pound units of measurement in this report to International System of units (SI).

Multiply inch-pound units	By	To obtain SI units
feet per day (ft/d)	3.528×10^{-6}	meter per second (m/s)
foot (ft)	0.3048	meter (m)
foot squared per day (ft^2/d)	1.075×10^{-6}	meter squared per second (m^2/s)
feet per mile (ft/mi)	0.1894	meters per kilometer (m/km)
inch (in)	2.54	centimeter (cm)
gallons per minute (gal/min)	6.309×10^{-5}	cubic meter per second (m^3/s)
cubic feet per day (ft^3/d)	3.277×10^{-7}	cubic meter per second (m^3/s)

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ABSTRACT

Drawdown and recovery data from three 2-day aquifer tests of the unconfined (water-table) aquifer in southern Nassau County, Long Island, during the autumn of 1979 were analyzed. Several simple analytical solutions, a type-curve-matching procedure, and a Galerkin finite-element radial-flow model were used to determine hydraulic conductivity, ratio of horizontal to vertical hydraulic conductivity, and specific yield. Results of the curve-matching procedure covered a broad range of values that could be narrowed through consideration of data from other sources such as published reports, drillers' logs, or values determined by other analytical solutions. Analysis by the radial flow model was preferred because it allows for vertical variability in aquifer properties and solves the system for all observation points simultaneously, whereas the other techniques treat the aquifer as homogeneous and must treat each observation well separately. All methods produced fairly consistent results. The ranges of aquifer parameters at the three sites were:

- horizontal hydraulic conductivity, 140 to 380 feet per day;
- transmissivity, 11,200 to 17,100 feet squared per day;
- ratio of horizontal to vertical hydraulic conductivity, 2.4:1 to 7:1, and
- specific yield, 0.13 to 0.23.

INTRODUCTION

State and Federal officials and citizens have been concerned over the hydrologic effects of expanded sewering on Long Island, particularly the lowering of ground-water levels. In response, the U.S. Environmental Protection Agency (EPA) funded a major study, known as the "Streamflow Augmentation" study, which was conducted by many local government agencies and private organizations to investigate whether this problem and its effects will need to be mitigated and, if so, what steps might be taken.

As a part of this effort, several Federal, State, and local agencies have undertaken scientific and engineering studies, among which have been (1) an inventory and analysis of geologic, hydrologic, and water-quality data; (2) assessments of the ecology and the esthetic and recreational value of affected streams; (3) water quality and ecologic studies in Great South Bay, which is fed by the island's streams; and (4) modeling studies of the effects of sewering and other stresses on the ground-water system, the quantity and quality of streamflow, and the mixing of fresh and saline water in Great South Bay.

As part of this larger EPA study, the U.S. Geological Survey analyzed drawdown and recovery data from three 2-day aquifer tests of the upper glacial (water-table) aquifer in southern Nassau County. The tests were made at Seaford, Lynbrook, and East Rockaway by Nassau County Department of Public Works, R. E. Wright Associates, and Lawler, Matusky and Skelly, consultants, in the autumn of 1979. Site locations are shown in figure 1.

Purpose and Scope

The purpose of this study was to obtain estimates of aquifer properties. In addition, it provided an opportunity to evaluate the effectiveness of Stallman type curves in relatively ideal field conditions, and compare the results from the Stallman method with results obtained by a finite-element model.

The drawdown data from each test site were first analyzed by simple analytical techniques based on the Theim and Theis equations (Bentall, 1963; Cooper and Jacob, 1946) and a matching of type curves developed by R. W. Stallman (Lohman, 1972). The resulting estimates of transmissivity, specific yield, and ratio of horizontal to vertical hydraulic conductivity (K_r/K_z) provided the initial input values to a two-dimensional finite-element radial flow model (Reilly, 1982), which were then refined. The estimated values of these characteristics produced by the different methods of analysis were compared, and the probable values were determined.

GEOHYDROLOGY OF TEST SITES

Regional Geohydrology

Detailed information on the geology of the area is given in Doriski and Wilde-Katz (1983), McClymonds and Franke (1972), Franke and Cohen (1972), and Perlmutter and Geraghty (1963). A generalized north-south cross section through Long Island is given in figure 2.

The upper glacial aquifer is composed mostly of sand and gravel of Pleistocene age. This aquifer contains the water table, the surface of which slopes southward at 7 ft/mi. Previous estimates of average horizontal hydraulic conductivity range from 200 to 300 ft/d, and saturated thickness ranges from 50 to 100 ft. Ratio of horizontal to vertical hydraulic conductivity (K_r/K_z) has been estimated to range from 5 to 24.

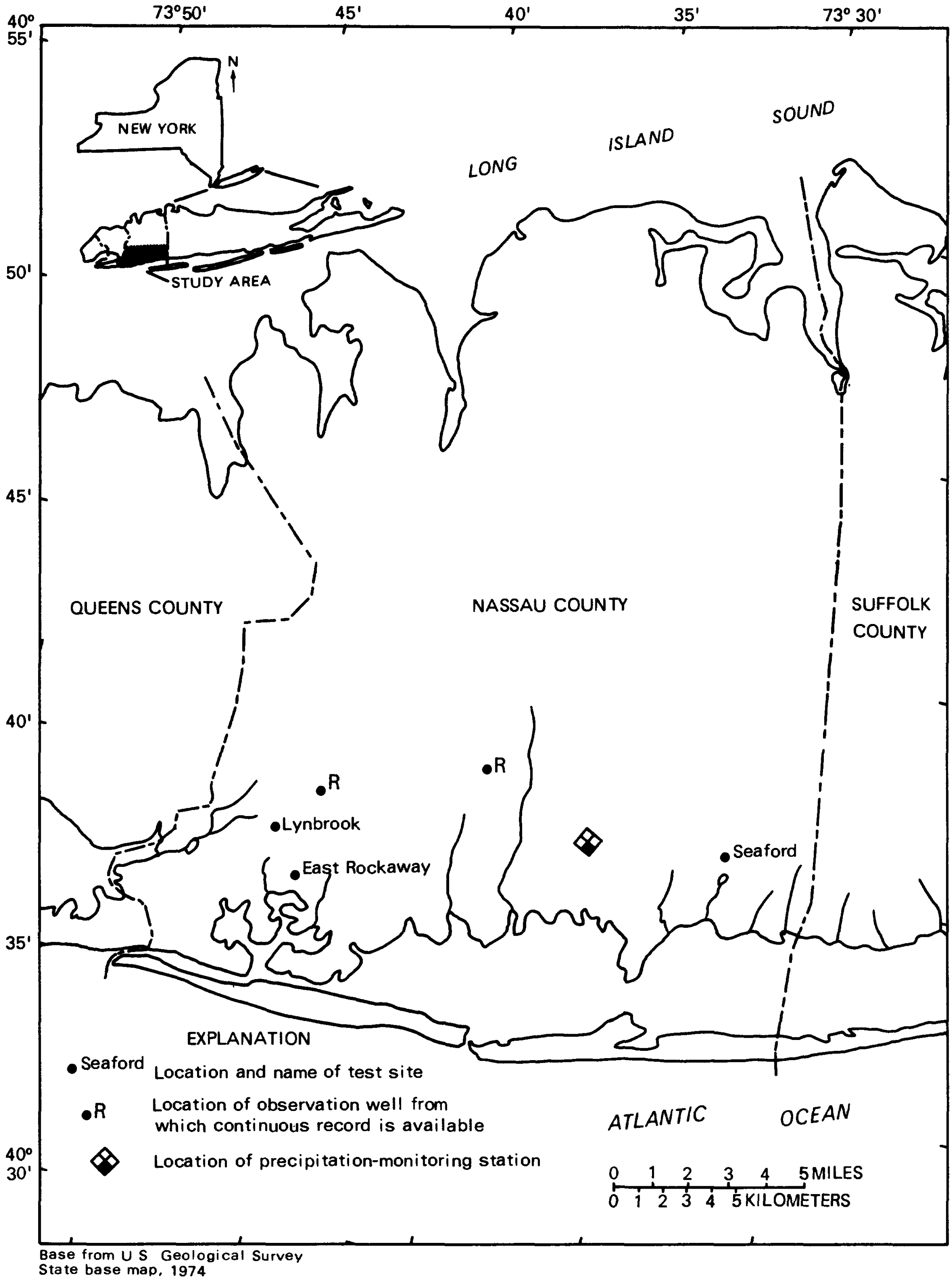


Figure 1.--Location of test sites in southern Nassau County.

The Magothy aquifer, of Cretaceous age, which underlies the upper glacial aquifer, consists of sand, silt, clay, and mixtures thereof. The saturated thickness of the Magothy in southern Nassau County ranges from less than 500 ft in the west to nearly 800 ft in the east. Estimated average horizontal hydraulic conductivity is 50 ft/d (McClymonds and Franke, 1972), and the ratio K_r/K_z ranges from 30 to 100.

In parts of the area studied, the upper glacial and Magothy aquifers are separated by the Gardiners Clay, a confining unit of marine origin that, in the study area, reaches a maximum thickness of 65 ft. Beneath the Magothy is the Raritan clay, a confining unit that ranges from 100 to 300 ft thick. Beneath the Raritan clay is the Lloyd aquifer of Cretaceous age, which ranges from 200 to 500 ft thick and is underlain by Precambrian bedrock. The vertical hydraulic conductivity of both clays is estimated to be 0.001 ft/d.

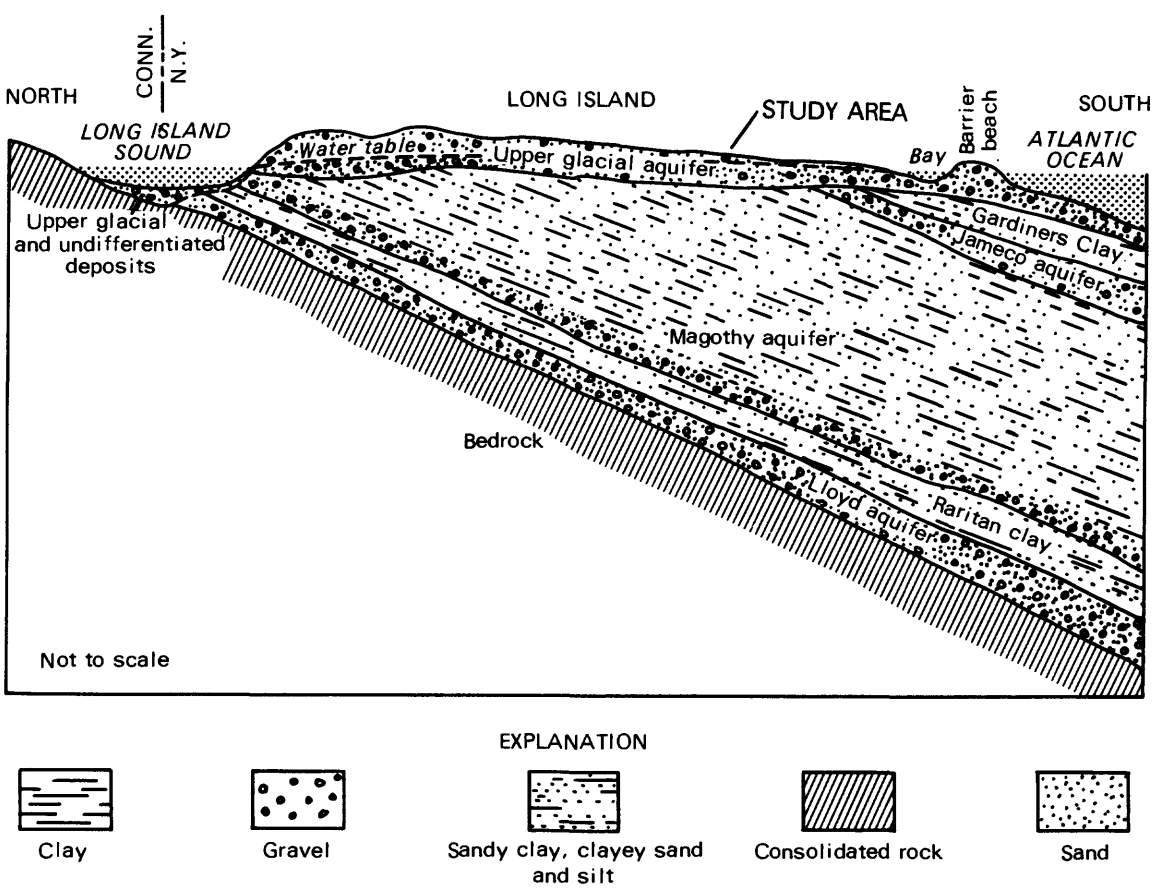


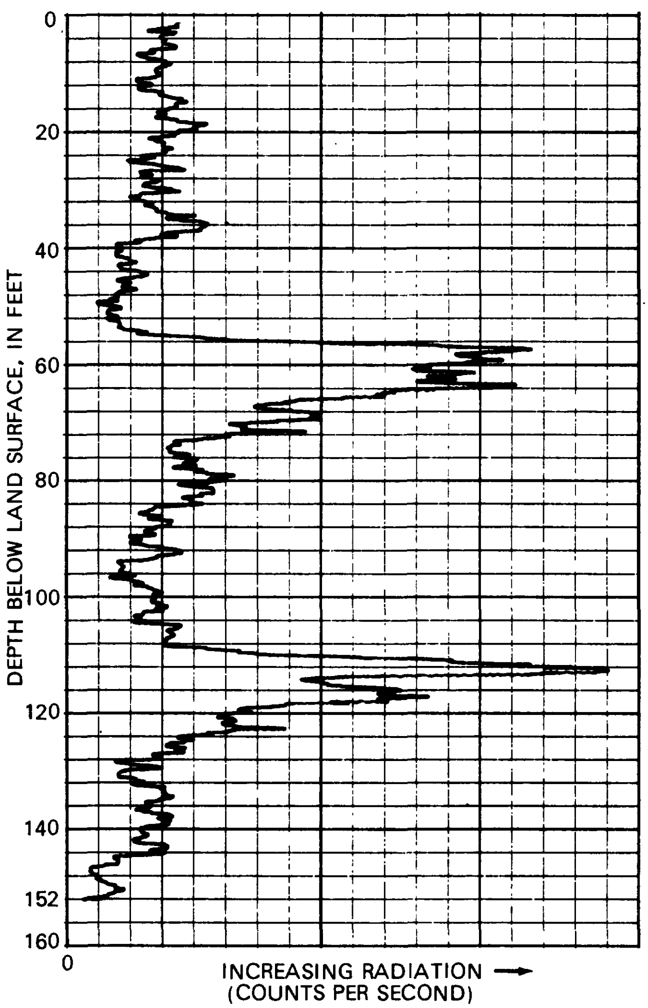
Figure 2.--Generalized geologic section of Long Island showing relative positions of major aquifers. [Modified from McClymonds and Franke, 1972.]

Local Geohydrology

Seaford Site

The Seaford site is geologically fairly uniform. Depth to water ranges from 10 to 14 ft, varying with topography. The upper glacial aquifer consists of 54 to 58 ft of fairly homogeneous coarse to very coarse sand and gravel, the lower 44 ft of which is saturated. Throughout the site, this aquifer is underlain by about 20 ft of Gardiners clay, below which lies the clayey and silty sand of the Magothy aquifer. Figure 3A presents the geologist's log of an observation well at this site and the corresponding gamma-ray log. A deflection to the right in this log indicates clay. The clay from 57 to 75 ft below land surface is probably the Gardiners Clay confining unit; the clay indicated at a depth of 110 to 120 ft may represent a clay lens within the Magothy aquifer.

GAMMA-RAY LOG



GEOLOGIST'S LOG

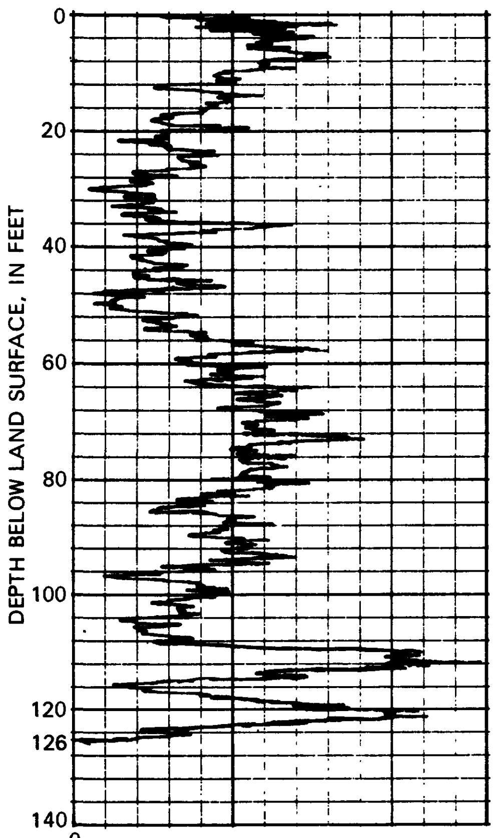
Depth below land surface (feet)	Description
0 - 37	Sand, brownish-orange to brownish-gray, medium to very coarse, angular to subangular; gravel, granular to pebble size. Contains quartz and feldspar with some iron staining.
37 - 57	Sand, orange-tan to yellow-white, fine to very coarse, angular to subrounded. Contains quartz and feldspar with muscovite mica, some iron staining.
57 - 75	Clay, dark-gray, with gravel, granular, consisting of quartz and feldspar; sand, white, coarse to very fine, includes muscovite mica.
75 - 100	Sand, white-gray, very fine to medium. Contains lignite and muscovite mica.
100 - 125	Clay and sandy clay, gray, coarse grained to silt. Contains grains of lignite and muscovite mica.
125 - 155	Sand, gray-white, very fine to medium, subangular to subrounded. Contains some clay, gray-white, muscovite mica, and lignite.

Figure 3A.--Geologist's and gamma-ray logs of observation wells at Seaford site.

Lynbrook Site

The Lynbrook site is somewhat less homogeneous than the Seaford site. The upper glacial layer is 95 ft thick (the lower 87 ft is saturated) and contains sand or sand and gravel and interspersed clay stringers. The amount of clay increases with depth. The log of a deep observation well drilled on the site indicated no specific clay unit, but the log of a pumping well only 50 ft away revealed large amounts of dense black clay from 97 to 100 ft below land surface. Depth to water was 7.5 to 8 ft. The geologist's log and gamma-ray log from the deep observation well (fig. 3B) indicate no clay at the 97-to 100-ft depth.

GAMMA-RAY LOG



GEOLOGIST'S LOG

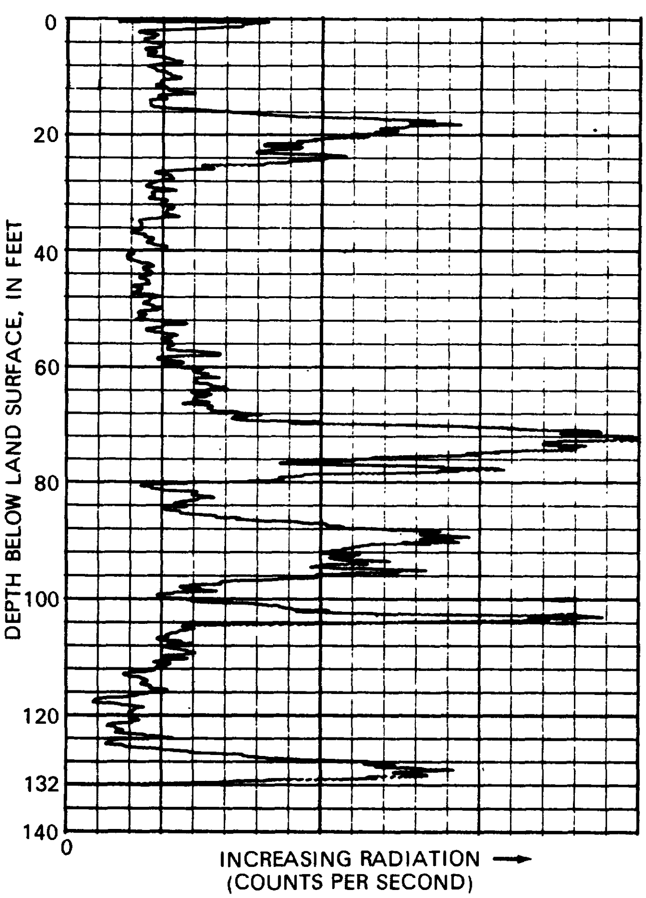
Depth below land surface (feet)	Description
5 - 20	Sand, orange, medium, angular to subrounded. Contains quartz, feldspar, and rock fragments.
20 - 30	Sand, brown, medium to fine, subangular to subrounded. Contains quartz, feldspar, and rock fragments.
30 - 50	Sand, brown to tan, very coarse to fine, subangular to subrounded. Contains quartz and feldspar.
50 - 60	Sand, grayish-tan, coarse to fine, subangular to subrounded. Contains quartz, feldspar, and rock fragments.
60 - 75	Sand, greenish-tan, coarse to medium, subangular to subrounded. Contains gravel and an occasional clay stringer, quartz, feldspar, muscovite and red oxide mineral.
75 - 100	Sand, gray to reddish-brown, coarse to fine, subangular to subrounded. Contains red oxide stained quartz, feldspar, red oxide mineral, rock fragments, micaceous minerals and lignite.
100 - 138	Sand, coarse to fine, gray to tannish-gray, subangular to subrounded. Contains quartz, lignite, muscovite, and some clay lumps.

Figure 3B.--Geologist's and gamma-ray logs of observation wells at Lynbrook site.

East Rockaway Site

The East Rockaway site is geologically more complex than the two other sites. The upper glacial deposits are 67 ft thick and are underlain by a layer of clay 18 ft thick that is in turn underlain by Magothy deposits beginning 85 ft below land surface. Depth to water at the site was 22 ft; thus, the saturated thickness of the aquifer was about 45 ft. The uppermost 8 ft of saturated thickness is silty sand, and beneath this is 32 ft of clean sand underlain by 5 ft of sand mixed with clay. Below the unconfined aquifer is the Gardiners Clay. This sequence is depicted in figure 3C.

GAMMA-RAY LOG



GEOLOGIST'S LOG

Depth below land surface (feet)	Description
0 - 18	Sand, light brown, medium, subrounded to subangular. Contains quartz.
18 - 30	Sand, silty, light gray to orange-brown, medium to coarse, subrounded to subangular. Contains quartz and mica.
30 - 60	Sand, light tan to brown, medium to very coarse, angular to subrounded. Contains quartz, mica, some iron staining.
60 - 70	Sand, tan to orange-brown, fine to very coarse, subangular to subrounded. Contains some lumps of clay.
70 - 80	Clay, silty, black. Contains some orange-stained sand, some gravel.
80 - 110	Sand, light gray to dark gray, fine to very coarse, angular to subrounded. Contains some clay, quartz, lignite, mica.

Figure 3C.--Geologist's and gamma-ray logs of observation wells at East Rockaway site.

DESCRIPTION OF WELLS AND AQUIFER-TEST DATA

The general well configuration was the same at each site. Observation wells were positioned around the pumping well to fit the assumptions in Stallman's method of pumping test-analysis (Lohman, 1972), which are explained in the section "Stallman type-curve method." The areal and vertical design of the sites is depicted in figure 4; distance of observation wells from the pumping well and depth of well screens at the three sites are given in table 1. Each pumping well was 8 in. in diameter and was screened in the bottom third of the saturated thickness of the upper glacial aquifer. Each site contained two triads of 2-in observation wells having 2-ft screens; one set was about 50 ft and the other about 100 ft from the pumping well and colinear with it. Each triad contained a well screened at the top of the aquifer, another in the middle, and another at the bottom. In addition, two single wells were screened in the middle of the aquifer, about 50 ft from the pumping well in other radial directions, to provide information on radial symmetry of flow. An additional observation well was screened in the Magothy aquifer, and another was placed within the annular space of the pumping well and screened at the bottom of the aquifer. Other observation wells screened in the upper glacial aquifer in the area were used to monitor ambient conditions to evaluate the effects of regional trends on the test data.

At each site, the 8-in. well was pumped for 48 hours. Drawdowns in the eight observation wells and the Magothy well were continuously monitored by analog water-level recorders. An air line was used in the pumping well and chalked tape in the annular-space wells. Water-level measurements were taken for the 2 days of the test, and recovery data were collected for 2 days thereafter. In addition, the Magothy well was monitored for 1 day before the start of pumping and for 3 days after the pump was turned off; in no case did water levels in a Magothy well show changes that could be correlated with pumping.

No precipitation occurred at the Lynbrook site for a week before or during the test, but, at the Seaford site, 0.25 in. of rain fell the day before the test, and 0.38 in. fell on the second day of the test. At the East Rockaway site, 0.50 in. fell during the last part of the recovery period (National Oceanic and Atmospheric Administration, 1979). However, records of water levels in two continuously monitored wells screened in the upper glacial aquifer in the study area indicated no change greater than 0.15 ft during the 4 days of any test. (Location of sites and precipitation station is given in fig. 1). None of the solution techniques had provisions to account for recharge from precipitation.

The pumping rate was 400 gal/min at the Lynbrook site, 500 gal/min at the East Rockaway site, and 542 gal/min at the Seaford site. The rate varied during the test by no more than 1 percent at the Lynbrook and Seaford sites and by 3 percent at the East Rockaway site, as measured by a manometer.

Table 1. Data on observation-well locations and position of well screens.

Site	Well	Distance from pumping well (feet)	Depth of screen below water table (feet)	Z (percentage of saturated thickness beneath well screen)[a]
Seaford	A1	49	40-42	0.02
	A2	49	17-19	.57
	A3	49	6-8	.83
	B1	97	38-40	.07
	B2	97	18-20	.55
	B3	97	10-12	.74
	C	61	18-20	.55
	D	52	20-22	.50
	Pumping well	--	24-39	[b]0.43 - 0.07
Lynbrook	A1	51	85-87	0.01
	A2	52	45-47	.53
	A3	52	22-24	.74
	B1	99	85-87	.01
	B2	99	45-47	.53
	B3	99	22-24	.74
	C	50	45-47	.53
	D	50	45-47	.53
	Pumping well	--	57-87	[b]0.34 - 0
East Rockaway	A1	51	41-43	0.07
	A2	49	14-16	.67
	A3	48	0-2	.98
	B1	100	41-43	.07
	B2	99	14-16	.67
	B3	97	0-2	.98
	C	46	14-16	.67
	D	60	14-16	.67
	Pumping well	--	30-45	[b]0.33 - 0

[a] $$Z = \frac{\text{distance from base of aquifer to middle of well screen}}{\text{saturated thickness of aquifer}}$$

Thus, Z = 0 for a well screened at the base of the aquifer, and Z = 1 for a well screened at the water table.

[b] For pumping well, Z of top and bottom of screen is given.

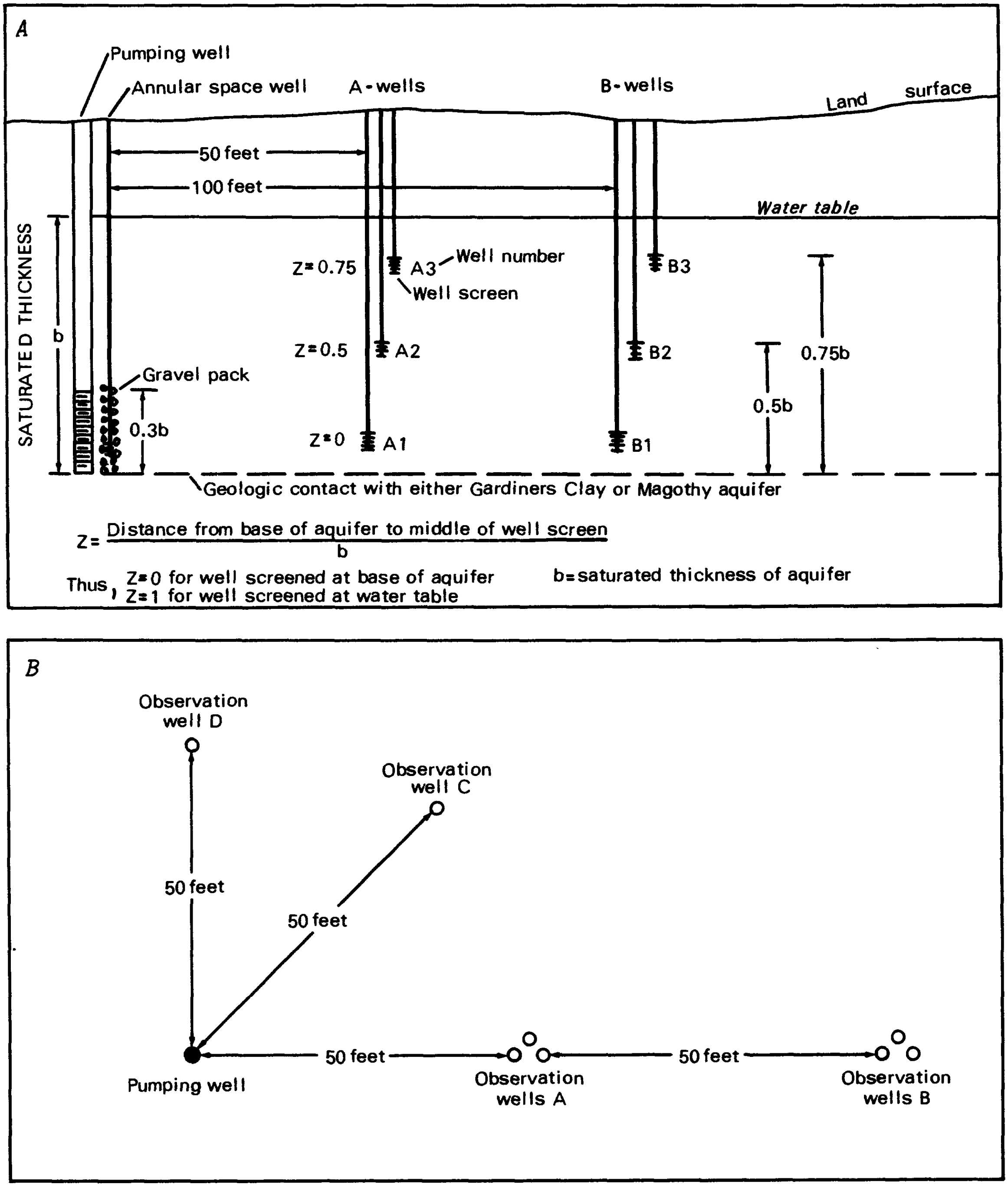


Figure 4.--Typical test-site design: A, vertical section; B, plan view.

ANALYSIS OF AQUIFER TESTS

Three methods were used to evaluate the drawdown and recovery data at each site. The simplest method was the application of two analytical solutions: a formulation equivalent to the Thiem equation based on the Dupuit assumption for unconfined flow (Bentall, 1963), and a modified form of the Theis solution based on the work of Cooper and Jacob (1946). The second method was a curve-fitting procedure that employed type curves developed by R. W. Stallman (Lohman, 1972). The final method was to use these estimated values of hydraulic properties to attempt to reproduce the measured drawdowns with a two-dimensional finite-element model. The numerical model can accommodate variable site geology and also incorporate data from all observation wells simultaneously, rather than determining values on a well-by-well basis, as the other solution techniques do.

Simple Analytical Solutions

The analytical solutions used in analyzing the aquifer tests are based on assumptions that are not entirely correct for the aquifer tests presented. However, these simple methods of analysis are used primarily to generate initial estimates.

Approximation of Hydraulic Conductivity

To obtain a rough estimate of the value of the horizontal hydraulic conductivity (K), the following equation (from Bentall, 1963) was used:

$$K = \frac{2.3Q \log_{10} (r_A/r_B)}{\pi \, (h_A^2 - h_B^2)} \qquad (1)$$

where:

K = hydraulic conductivity
Q = pumping rate
r = distance of well A or B from pumping well, and
h = head in well A or B above impermeable base of aquifer.

This analytical solution is rigorously applicable only in cases of steady-state radial flow in a homogeneous, isotropic aquifer with a fully penetrating well, satisfying the Dupuit assumption (Lohman, 1972, p. 11) that head is constant along any vertical line through the water body (no vertical hydraulic gradient). It was estimated, based on the shape of the drawdown curves, that within the 100-ft radius defined by the farther set of observation wells, all release of water from storage had ceased by the end of the pumping period. This approximately fulfilled the steady-state requirement. The partially penetrating well and inhomogeneous and anisotropic aquifer conditions at the sites will affect the accuracy of the estimate, but the formula is being used only to generate initial estimates, and these estimates are evaluated later in the report.

Figure 5 presents a vertical section of each site with the drawdown at each of the six observation wells after 2 days of pumping to evaluate how closely the Dupuit assumption has been met. Although the head distribution in the vertical direction was essentially constant at all three sites before the start of the tests, the pumping has created some vertical hydraulic gradients.

As can be seen from figure 5A, there was almost no vertical head gradient at the Seaford site at the end of the pumping phase of the test. An approximate horizontal conductivity for the Seaford site was calculated from well data in table 7 (at end of report) for drawdown in wells A3 and B3 after 2 days of pumping and a saturated thickness of 44 ft:

$$h_A = 44.00 - 2.94 = 41.06$$

$$h_B = 44.00 - 2.06 = 41.94$$

Therefore,

$$K = \frac{2.3\ (104{,}342\ ft^3/d)\ [\log_{10}\ (100\ ft/50\ ft)]}{\pi\ (41.94^2 - 41.06^2\ ft^2)}$$

or a hydraulic conductivity of 315 ft/d.

The Lynbrook site had relatively large vertical hydraulic gradients at the end of the pumping period. (See fig. 5B.) Also, drawdown differed among wells A2, C, and D, all of which were 50 ft from the pumping well and screened in the middle of the aquifer; this indicates that the aquifer at this site lacks radial symmetry or homogeneity. The average head (with top of the clay unit as datum) in the three A wells was 84.7 ft and in the three B wells, 85.3 ft. Equation 1 gave an approximate hydraulic conductivity of 166 ft/d for this site.

The calculated value of K at the East Rockaway site was somewhat less reliable. As indicated in figure 5C, some vertical gradients were present at the end of the pumping period and, by the end of the test, water levels were still decreasing. Drawdown data indicate that the aquifer material at this site is not homogeneous. In the first 45 minutes of the test, drawdowns at well B3, 100 ft from the pumping well, were greater than at well A3, only 50 ft from the pumping well. Therefore, equation 1 can provide at best only a rough approximation of average horizontal hydraulic conductivity. Within this context, head values from the two A wells and three B wells at the site were averaged and yielded $h_A = 42.4$ ft and $h_B = 43.2$ ft. From equation 1, with a pumping rate of 500 gal/min, the hydraulic conductivity at this site is calculated to be 310 ft/d.

Approximation of Specific Yield

The Dupuit assumption of no vertical gradient also provides a method for estimating storage coefficient based on the Theis equation and the work of Cooper and Jacob (1946). Drawdown is plotted against distance from the pumping well on semilog paper, with drawdown on the arithmetic scale and

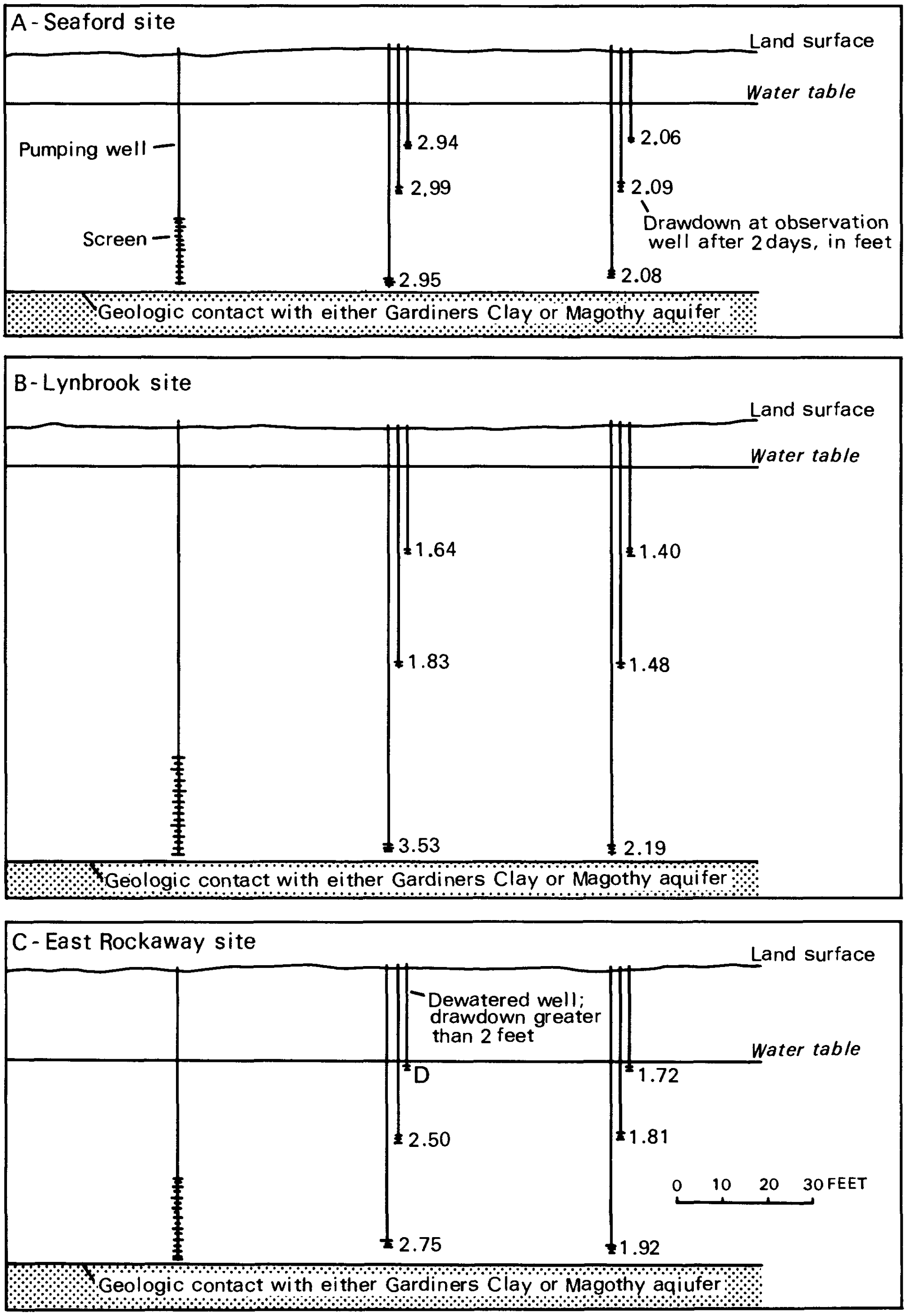


Figure 5.--Vertical sections of aquifer-test sites showing drawdown at each observation well after 2 days of pumping.

distance on the logarithmic scale. A line drawn through these points can be extended to indicate the radial distance to the point of zero drawdown (extent of the cone of depression), where the plotted line crosses the axis. The specific yield (S_y) can then be calculated from:

$$S_y = 2.25T \frac{t}{r_o^2}$$

where:

T = aquifer transmissivity (where $T = Kb$, K = hydraulic conductivity, and b = saturated thickness of aquifer material)
t = time since pumping began
r_o = distance to point of zero drawdown

At the Seaford site, the calculated value of S_y (specific yield) was 0.24. Applying the same average head values for the Lynbrook and East Rockaway sites as were obtained in the previous section and applying the graph technique just described gave an r_o (distance to edge of cone of depression) of 600 ft for the Lynbrook site and 570 ft for the East Rockaway site and S_y values of 0.16 and 0.21, respectively. A summary of the information obtained by the two simple analytical solution techniques is given in table 2.

Table 2.--Summary of data obtained from simple analytical solutions.

Site	Average head at A wells (feet above base of aquifer)	Average head at B wells (feet above base of aquifer)	Pumping rate (ft^3/d)
Seaford	41.06	41.94	104,342
Lynbrook	84.7	85.3	77,005
East Rockaway	42.4	43.2	96,257
	Graphically estimated distance to point of zero drawdown (ft)	Calculated hydraulic conductivity (ft/d)	Calculated specific yield (dimensionless)
Seaford	550	315	0.24
Lynbrook	600	166	.16
East Rockaway	570	310	.21

Stallman Type-Curve Method

Assumptions

The second method of analysis was a curve-matching procedure that uses dimensionless time-drawdown curves developed by R. W. Stallman (Lohman, 1972). Stallman used an electric-analog model to simulate a radial section of an unconfined aquifer. In Stallman's method, the pumping well is screened in the bottom 30 percent of the saturated thickness of the aquifer, and dimensionless curves are generated for observation wells screened at heights above the bottom of the aquifer representing 0, 50, 75, 90, and 100 percent of the saturated-thickness of the aquifer. His method assumes a homogeneous, anisotropic, unconfined aquifer with no leakage from the underlying confining bed. The theory considers vertical movement of water from the water table to the well screen but does not account for certain other details of the physical flow system. For example, very early in the pumping tests, before the changes in head reach the free surface, the aquifer still responds as though it were confined and releases water from storage in response to compression of the aquifer material and expansion of the remaining water. Later, when the influence of the pumping reaches the free surface, a volume of aquifer becomes dewatered. At this time, the yield from storage is controlled by an unconfined storage coefficient. Stallman's model does not account for the artesian aquifer response at the beginning of the tests; thus, unconfined water release from storage is the only type considered.

Procedure

Uncertainties in even the most accurate data available from these tests, combined with similarities in shape of the family of curves and the resulting subjectivity of the fit, allowed the graphs of measured drawdown to be matched with the type curves in several positions rather than at a single location. Because the values obtained for transmissivity and specific yield are extremely sensitive to the choice of a match position in these curves, several positions were chosen for each drawdown curve whenever possible to provide a range that brackets the true values of the aquifer parameters. Results are summarized in tables 3-5.

Values of specific yield resulting from the various match points differed by more than an order of magnitude at one site. It seemed appropriate to exclude all values that appeared physically unreasonable. Previous studies have indicated specific yield (S_y) values of 0.18 (Getzen, 1977) and 0.24 (Perlmutter and Geraghty, 1963, p. A36) for the upper glacial aquifer in southern Nassau County. Lohman (1972) states that specific yield in unconfined aquifers such as the upper glacial on Long Island generally ranges from 0.1 to 0.3. This additional knowledge of the magnitude of S_y facilitated estimation of a reasonable value. Only match points that yielded storage coefficient values between 0.1 and 0.3 were selected, and their associated transmissivity and anisotropy values averaged. (Specific yield was used as the key factor in this selection process rather than transmissivity because few if any T values could be rejected as improbable. An estimate of regional transmissivity in southern Nassau County by McClymonds and Franke (1972) is 12,000 to 15,000 ft^2/d; most values were somewhere in or near this range.)

Table 3.--Summary of results from Stallman type-curve solution for the Seaford site.

Well No.	Transmissivity (ft^2/d)	Average horizontal hydraulic conductivity (ft/d)	Specific yield (dimensionless)	Ratio of horizontal to vertical hydraulic conductivity (K_r/K_z) (dimensionless)
A1	16,500	376	0.21	2.6
A2	14,400	328	.22	2
	15,900	362	.05	12
A3	18,200	414	.05	13
	12,800	292	.19	3
	15,200	345	.01	60
B1	15,800	359	.18	2.3
B2	13,400	304	.20	2.3
B3	16,600	378	.06	42
	10,500	239	.27	2
C	14,500	329	.07	4
D	14,000	319	.12	2.7
	11,100	252	.22	2.7
Range of values	10,500 - 18,200	239 - 414	0.01 - .27	2 - 60
Range of selected values[a]	10,500 - 16,500	239 - 376	0.18 - .27	2 - 3
Average[a]	13,600	308	0.20	2.5

[a]Only match points that yielded values of specific yield in the range 0.1 to 0.3 were used in computing the average. (See section "Discussion of method and results.")

Table 4.--Summary of results from Stallman type-curve solution for the Lynbrook site.

Well No.	Transmissivity (ft^2/d)	Average horizontal hydraulic conductivity (ft/d)	Specific yield (dimensionless)	Ratio of horizontal to vertical hydraulic conductivity (K_r/K_z) (dimensionless)
A	16,400	205	0.01	70
	17,900	224	.05	17
	13,800	172	.10	17
B3	20,800	260	.06	14
	14,300	179	.23	3
B1	21,400	268	.02	14
	17,900	224	.07	14
	19,200	240	.04	14
C	19,200	240	.01	100
	19,200	240	.04	17
	15,700	196	.15	4
D	11,000	138	[a].43	2
	16,000	200	.07	17
	12,200	152	.25	4
Range of values	11,000 - 21,400	138 - 268	0.10 - .43	2 - 100
Range of selected values[b]	12,200 - 15,700	152 - 196	0.10 - .25	3 - 17
Average[b]	14,000	175	0.18	7

[a]This value is included for comparison only. It may be physically unreasonable. (See page 20.)

[b]Only match points that yielded values of specific yield in the range 0.1 to 0.3 were used in computing the average values. (See discussion in section "Discussion of method and results".)

Table 5.--Summary of results from Stallman type-curve solution for the East Rockaway site.

Well No.	Transmissivity (ft^2/d)	Average horizontal hydraulic conductivity (ft/d)	Specific yield (dimensionless)	Ratio of horizontal to vertical hydraulic conductivity (K_r/K_z) (dimensionless)
A1	18,800	419	0.16	8
A2	20,500	455	.03	9
	15,500	345	.11	9
A3	18,500	411	.13	1.6
	17,200	382	.07	7
B1	25,300	563	.05	7
	31,000	690	.06	32
	19,300	429	.17	8
B2	18,500	411	.05	36
	8,730	194	.09	164
B3	31,000	690	.007	30
	21,900	486	.03	30
C	5,350	119	[a].54	30
	9,630	214	[a].95	8
	15,200	339	.10	7
D	14,800	329	.11	61
	16,600	368	.09	12
Range of values	5,350 - 31,000	119 - 690	0.007 - .95	1.6 - 164
Range of selected values[b]	14,800 - 19,300	329 - 429	0.10 - .17	1.6 - 61
Average[b]	17,100	380	0.13	16

[a]This value is included for comparison purposes only. It may be physically unreasonable. (See page 20.)

[b]Only match points that yielded values of specific yield in the range 0.1 to 0.3 were used in computing the average values. (See discussion in section "Discussion of method and results".)

Results of Analysis

Seaford Site

After the test results from all three sites were examined, the Stallman method was judged most applicable to the Seaford site because the nearly perfect radial symmetry and homogeneity of the aquifer corresponded with Stallman's assumptions. The almost textbook-perfect nature of this aquifer test was apparent, especially in the relatively narrow range of transmissivity values resulting from the curve-matching procedure. The records from all eight wells were acceptable and were used in the analysis. Because Stallman's model does not consider decreases in saturated thickness of the aquifer during pumping, the fact that drawdown in the pumping well equaled nearly 50 percent of the total saturated thickness is a possible source of error. This does not mean that the saturated thickness in the aquifer actually decreased that much, however, because the pumping well was only partially penetrating and screened at the bottom of the aquifer. Declines at the free surface would, therefore, be less. Also, well losses and loss of potential due to friction across the well screen and inside the casing would make the drawdown in the well greater than in the surrounding aquifer. (In fact, other information suggests that the actual decrease in saturated thickness may be closer to 10 percent; see section "Comparison of Results from Different Methods of Analysis.")

Drawdowns in the three "A" wells (50 ft from pumping well) were less than 10 percent of total saturated thickness. Choosing match points that yielded the most plausible storage coefficient and averaging them, as discussed in the preceding section, gave a transmissivity of 13,600 ft^2/d (average horizontal hydraulic conductivity = 308 ft/d), a K_r/K_z ratio of 2.5, and a specific yield of 0.20. (See table 3 for a summary of results.) The measured drawdown and recovery data for this test are presented in table 7 (at end of report).

Lynbrook Site

Wells A2, A3, and B2 were eliminated from the Lynbrook site analysis during the drawdown phase of the test because the recorder charts developed a tendency to slip, and serious discrepancies between recorded and measured drawdowns (as much as 0.1 ft over a 24-hour period) were noted. The fact that Stallman's model does not consider change in saturated thickness was not judged significant at this site because drawdown even in the pumping well was less than 20 percent of the total saturated thickness of the aquifer, and drawdown at the "A" wells, 50 ft distant, was less than 5 percent.

Hydraulic conductivity values that resulted from this analysis ranged from 138 ft/d to 268 ft/d (transmissivity from 11,000 to 21,400 ft^2/d). Results of this analysis are given in table 4. Selecting match points with values of specific yield between 0.1 and 0.3 and averaging the values yielded an S_y value of 0.18, an average hydraulic conductivity of 175 ft^2/d (transmissivity of 14,000 ft^2/d), and a ratio of K_r/K_z of 7 (vertical hydraulic conductivity of 25 ft/d).

East Rockaway Site

Records from all eight wells at the East Rockaway site were acceptable and were used in the Stallman analysis. Initially, the range of calculated transmissivities was 5,350 to 31,000 ft^2/d (hydraulic conductivity of 119 to 690 ft/d), and the range of specific yields was 0.007 to 0.95. Note that the lower of these values is more representative of artesian conditions than unconfined ones, and the higher end of the range is physically impossible. These numbers are included to show the range of values resulting from the Stallman analysis.

As at the Seaford site, drawdown in the pumping well was nearly 50 percent of the total saturated thickness of the aquifer; again, however, partial penetration of pumping well and well losses made drawdown in the well greater than in the surrounding aquifer. Choosing only the six analyses that had plausible values of specific yield and averaging them gave a transmissivity of 17,100 ft^2/d (average horizontal hydraulic conductivity of 380 ft/d), a specific yield of 0.13, and a K_r/K_z ratio of 16. (See table 5.)

Finite-Element Model Solution

Assumptions

From the estimated values of hydraulic conductivity and specific yield obtained through analytical and curve-matching solutions, the authors attempted to reproduce the pumping-test drawdowns with a transient-state Galerkin finite-element flow model developed by Reilly (1983). The model simulates a vertical section of aquifer that is assumed to be radially symmetric around the axis of the well and is capable of analyzing the hydraulic response to pumping in any sort of radially symmetric medium, regardless of inhomogeneity or location of well screen. Horizontal and vertical hydraulic conductivity can vary within the model, although they are constant within a single element (triangle within the grid). Unlike the type-curve solution, this model can represent artesian (confined) response at the beginning of the test, where the amount of water released from storage is controlled by the specific storage (S_s). Later, when pumping begins to drain the aquifer, the amount of water released is determined by specific yield (S_y), the unconfined storage coefficent. A sketch of the conceptual model is given in figure 6; the grid representing an aquifer section is depicted in figure 7. Some of the assumptions and restrictions inherent in this model are:

(1) Specific yield and specific storage are constant over the entire grid;
(2) no seepage face exists in the well;
(3) the saturated thickness of the aquifer is constant; and
(4) the aquifer is of finite extent (a constant-potential boundary was defined 20,000 ft from the well).

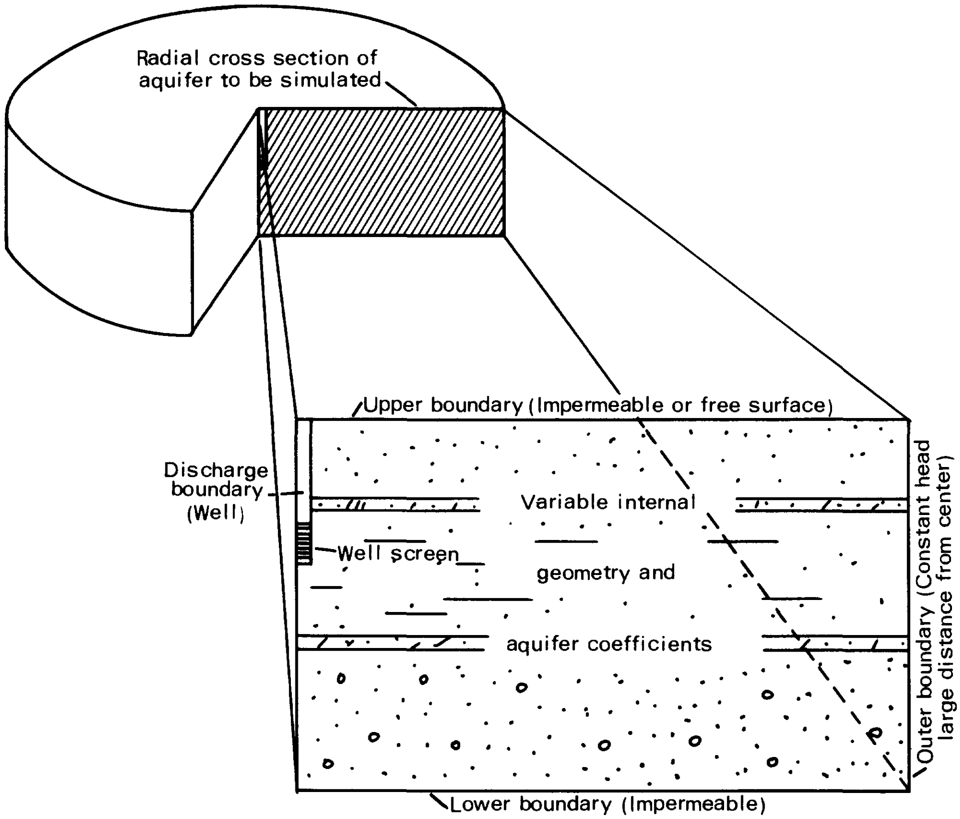


Figure 6.--Conceptual model showing two-dimensional section of aquifer simulated in finite-element model. (Modified from Reilly, 1983.)

Procedure

Each of the three tests was simulated on a variation of the same 515-node, 942-element grid (fig. 7). The area simulated is 20,000 ft in radius and extends from the water table to the base of the Magothy aquifer. Figure 7 depicts the grid as it was used to simulate the East Rockaway site. The thickness of the units and the location of geologic contacts were different for each site. Certain simplifying assumptions were made about the geology of each site; for example, the aquifers and confining units were represented as horizontal homogeneous layers of uniform thickness, with the clay layers present over the entire region, even though it is doubtful that this is strictly true, especially for the Gardiners Clay at the Lynbrook site. This simplification was made partly because detailed geologic data were lacking, but also because of the radial symmetry assumed by the various solution techniques.

Figure 8 depicts the geologic section of each site, as represented in the model, and gives the hydraulic conductivity and specific-yield values used in the initial simulation. Estimates of these values for the upper glacial aquifer were obtained from the type curves and simple analytical solutions;

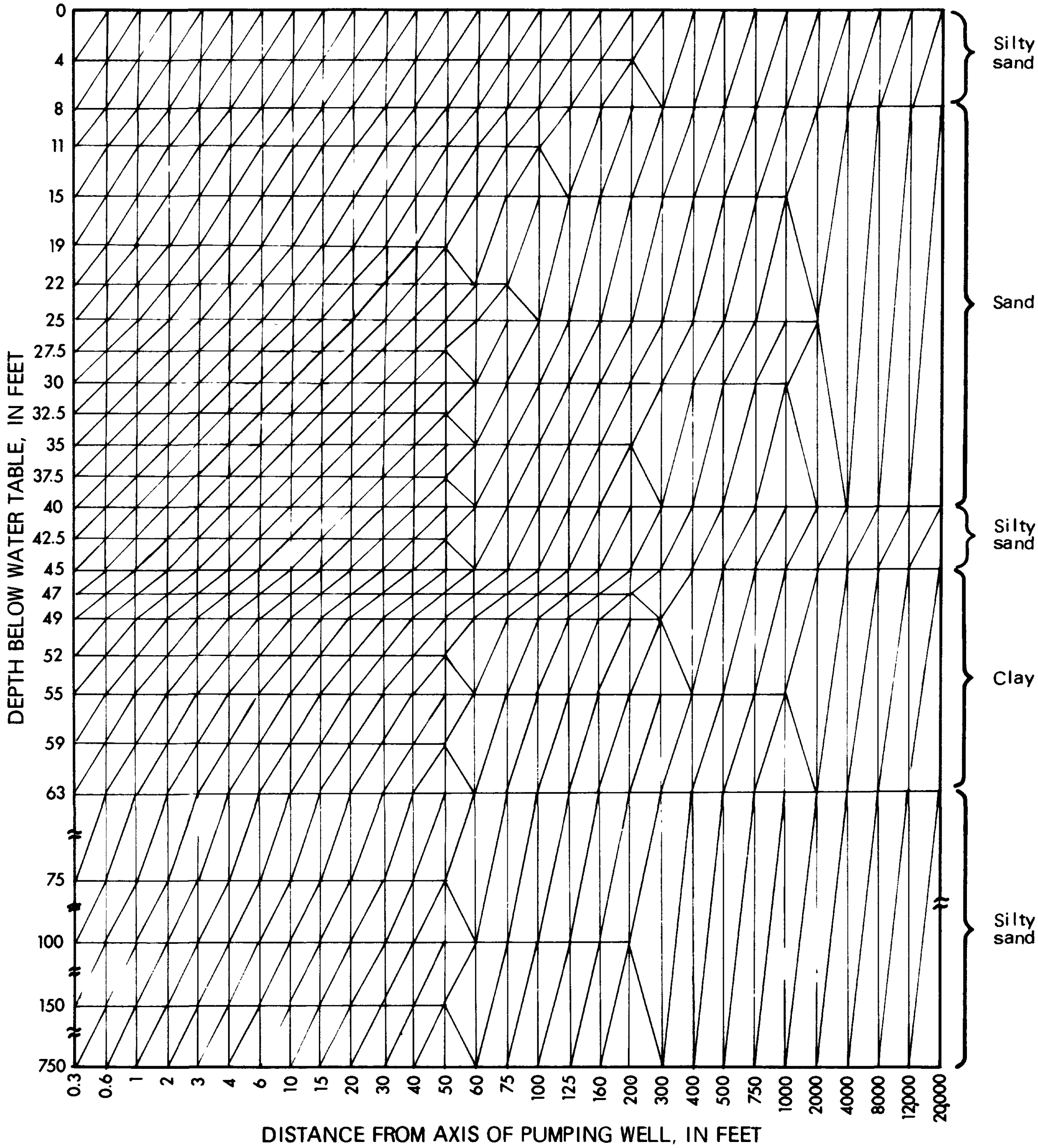
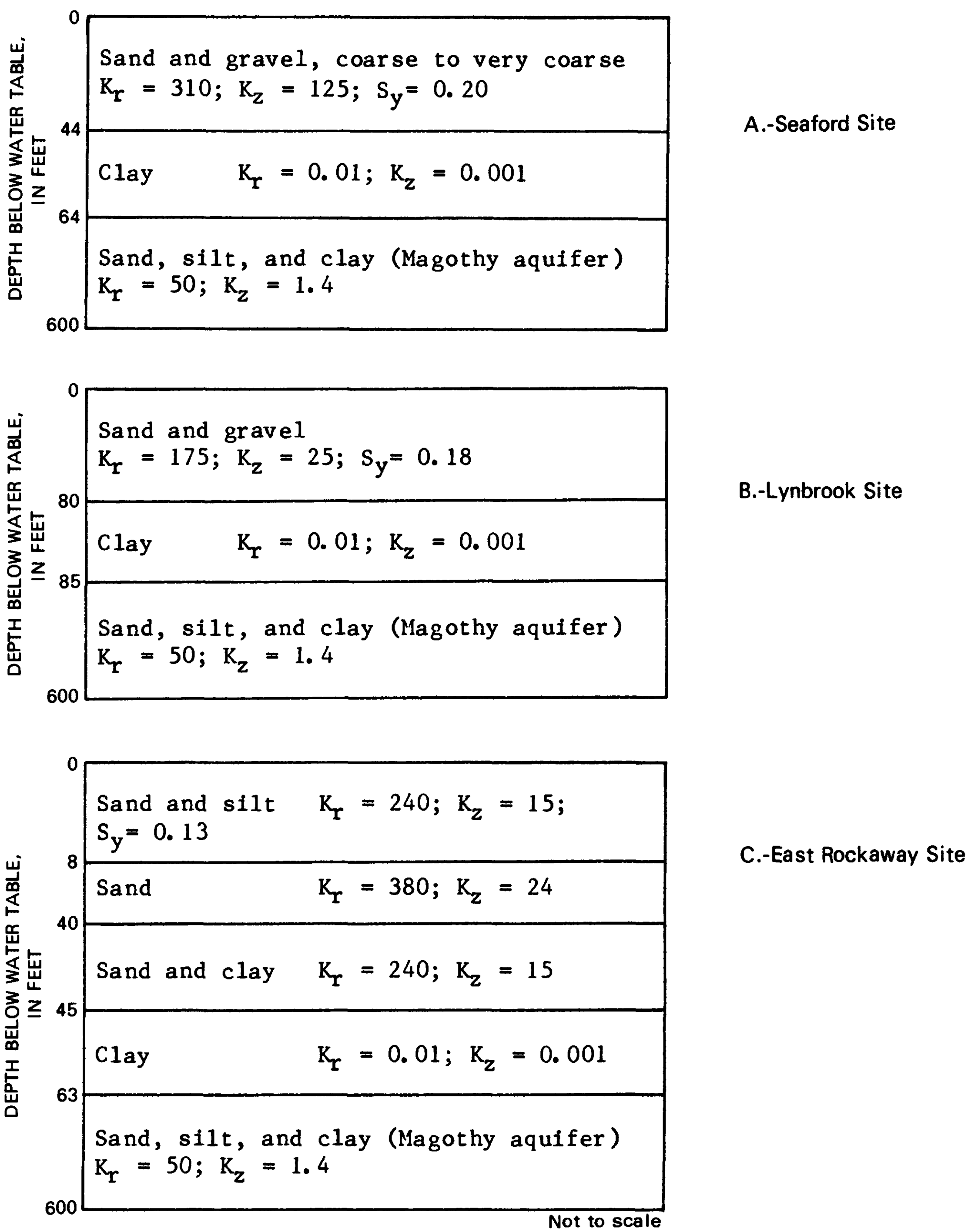


Figure 7.--Model grid representing aquifer section shown in figure 6 as used for the East Rockaway site.



K_r = horizontal hydraulic conductivity, in feet per day;
K_z = vertical hydraulic conductivity, in feet per day;
S_y = specific yield (dimensionless)

Figure 8.--Simplified geologic sections of aquifer-test sites showing radial and vertical hydraulic-conductivity values used in first model run.

estimates for radial and vertical hydraulic conductivity of the Gardiners Clay and Magothy aquifer were obtained from Franke and Cohen (1972). The model was extremely insensitive to changing values of the hydraulic characteristics of underlying units because there was virtually no drawdown beneath the clay unit. A series of simulations was made in which conductivity values of the Magothy were varied by an order of magnitude; these changes had no significant effect on drawdown. Therefore, conductivities in the lower layers were kept at their initial values. As in the field test, the simulated observation well tapping the Magothy at each site showed no water-level fluctuations in response to pumping.

The estimates of transmissivity and specific yield from the Stallman analysis and simple analytical solutions were the basis for the first model run. After the results were examined, these values were varied on a trial-and-error basis in subsequent runs until an acceptable match with field data was obtained. "Acceptable," as defined, meant that the shape of the modeled drawdown curve was similar to that of the field data, and that the two curves would differ by no more than 10 percent after 2 hours of pumping. Efforts continued until this criterion was fulfilled for all wells simultaneously. In addition, even though a formal sensitivity analysis was not made, several simulations were run in which one value was changed while the others were held constant, and the effect on the system was noted. If the model was particularly sensitive to one factor, for example, transmissivity, it was possible to determine the value of that factor fairly accurately, but if a large change in the value had only a small effect on modeled drawdowns, it was difficult or impossible to determine an accurate value. At the Seaford site, it was found that increasing hydraulic conductivity by 10 percent decreased drawdowns at the A-wells (50 ft from pumping well) by a maximum of 14 percent, but increasing storage by 33 percent decreased drawdowns at these wells by a maximum of only 8 percent. Thus, the conductivity of this aquifer was determined more accurately than the specific yield. Published values in the literature and the fairly large number of sensitivity runs that were made strongly suggest that the values of aquifer properties obtained in this study are reasonably close to the true values. This trial-and-error method lies somewhere between the analytical curve-matching and the formal statistical parameter-estimation techniques in terms of accuracy and reliability and is also intermediate in terms of complexity and time required for the analysis. No error bounds are given on these results because no statistical parameter-estimation technique was used; however, the sensitivity runs indicated that the estimate of transmissivity at the Seaford and Lynbrook sites is probably within $\pm$ 10 percent and that of specific yield $\pm$ 20 percent. The East Rockaway site was too complex geologically to evaluate the accuracy of the final results.

Results of Analysis

Seaford Site

Final values of aquifer properties from the modeled solution for the Seaford site were almost identical to the estimates obtained from the type-curve solution. A possible reason for this close agreement is that the geology of this site conforms closely to Stallman's requirements. Horizontal hydraulic conductivity was found to be 300 ft/d, giving a transmissivity of

13,200 ft^2/d, and vertical hydraulic conductivity was 123 ft/d. This latter figure indicates a lesser degree of anisotropy than indicated in the literature, where values of K_r/K_z range from 10 to 24 (Franke and Cohen, 1972; Getzen, 1977; Franke and Getzen, 1975). However, Getzen (1977) refers to three tests in the upper glacial aquifer that indicated a value of the ratio K_r/K_z in the range of 1.8 to 2.8, which conforms to values obtained in this study. Because the present model is relatively sensitive to the value of K_r/K_z, its value of 2.4 seems highly plausible. Specific yield at this site was found to be 0.15, and specific storage, 0.5×10^{-4}. A comparison of modeled and actual measured drawdowns and recoveries is given in figure 9. The apparent divergence of the simulated and field-data curves at the beginning of the test and at the end of the recovery period is due in part to the small magnitude of the drawdowns (a few tenths of a foot) and the scale at which these results are graphed. At small drawdowns, errors in measurement can be a large percentage of the actual drawdown, although the magnitude of the error of measurement is small.

Lynbrook Site

The final aquifer coefficients for the Lynbrook site were:

horizontal hydraulic conductivity, 140 ft/d;
transmissivity, 11,200 ft^2/d;
vertical hydraulic conductivity, 20 ft/d ($K_r/K_z = 7$);
specific yield, 0.23
specific storage 0.25×10^{-4}.

A comparison of simulated drawdowns and recovery plotted with the field measurements for the aquifer test are given in figure 10.

East Rockaway Site

The East Rockaway site had the most complex geology and was the most difficult to simulate, especially because the assumed geology and horizontal and vertical conductivity of the various layers had a profound impact on simulated drawdowns. A horizontal conductivity of 380 ft/d (from the Stallman analysis) was tentatively assigned to the sand layer, 240 ft/d to the silty sand that makes up the top 8 ft of saturated thickness, and 150 ft/d to the sand and clay layer from 40 to 45 ft below the water table. (The values for horizontal hydraulic conductivity of silty sand and sand and clay were chosen from McClymonds and Franke (1972, p. E14) based on analyses of similar material elsewhere on Long Island.) Vertical conductivity was 6 ft/d for the silty sand, 130 ft/d for the sand, and 15 ft/d for the sand and clay layer. Specific yield was 0.18, and specific storage 0.5×10^{-4}. It is not clear whether the field data support this fine a distinction between the several geologic layers because the shape of the drawdown curves for wells screened in the sand layer can be manipulated by changing the vertical conductivity of the silty sand independent of the conductivity of the sand itself. A comparison of modeled and actual drawdowns and recovery data at this site is given in figure 11. Curves for wells A3 and B3 could not be matched within the 10-percent-margin-of-error criterion discussed earlier, perhaps owing to the large variability in geologic composition at this site.

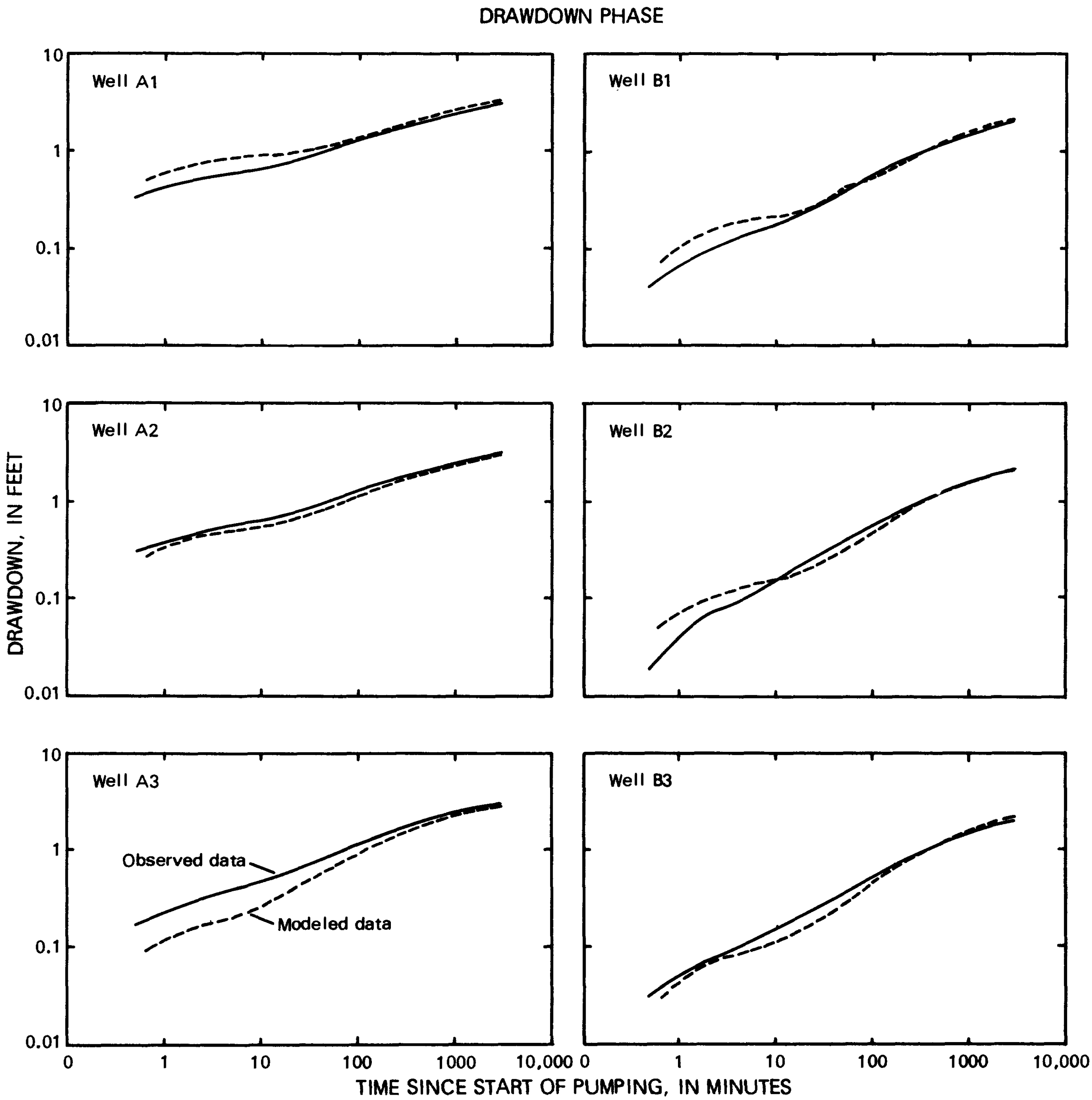
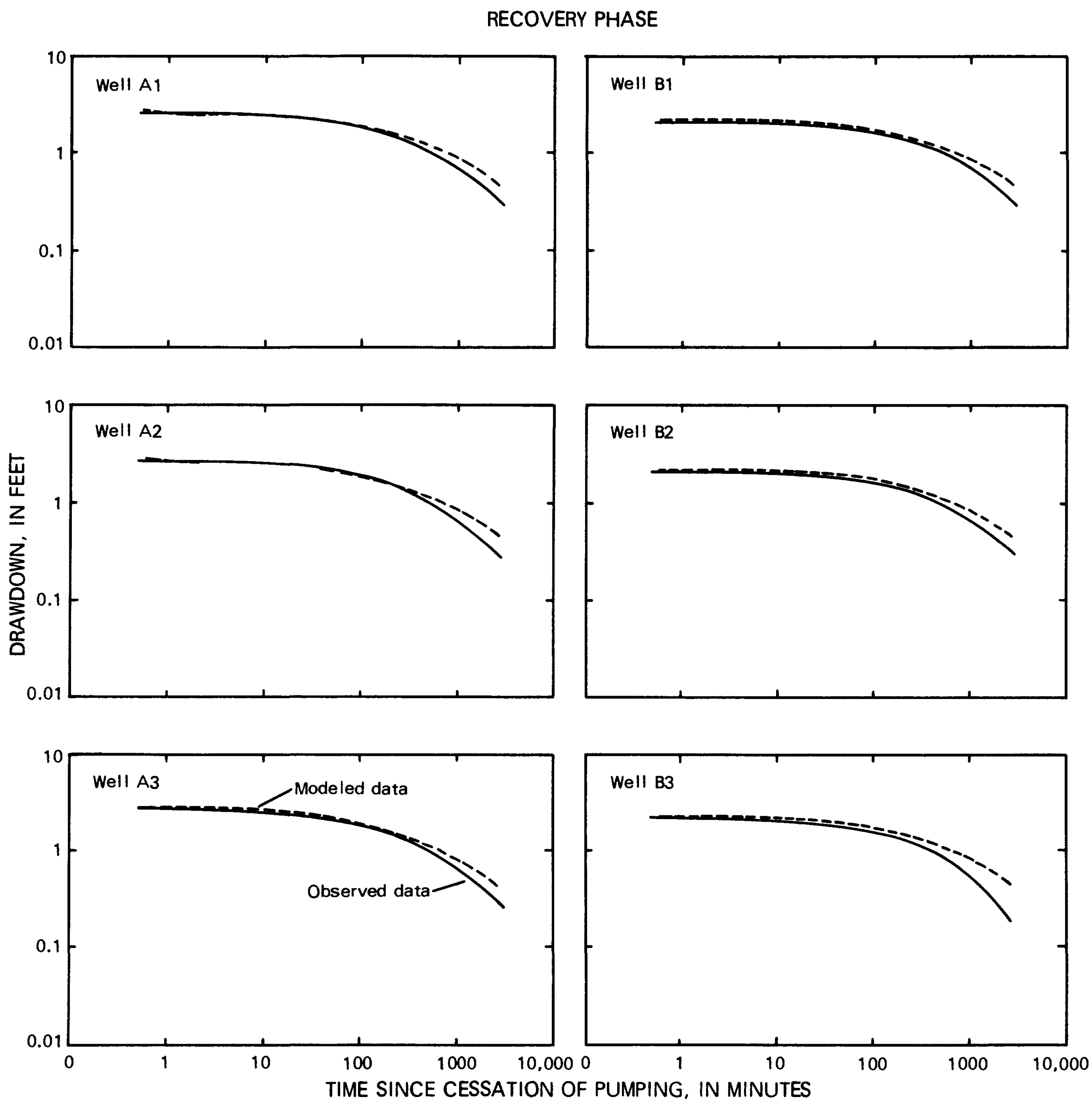


Figure 9.--Comparison of simulated drawdown and recovery data



with field measurements, Seaford site.

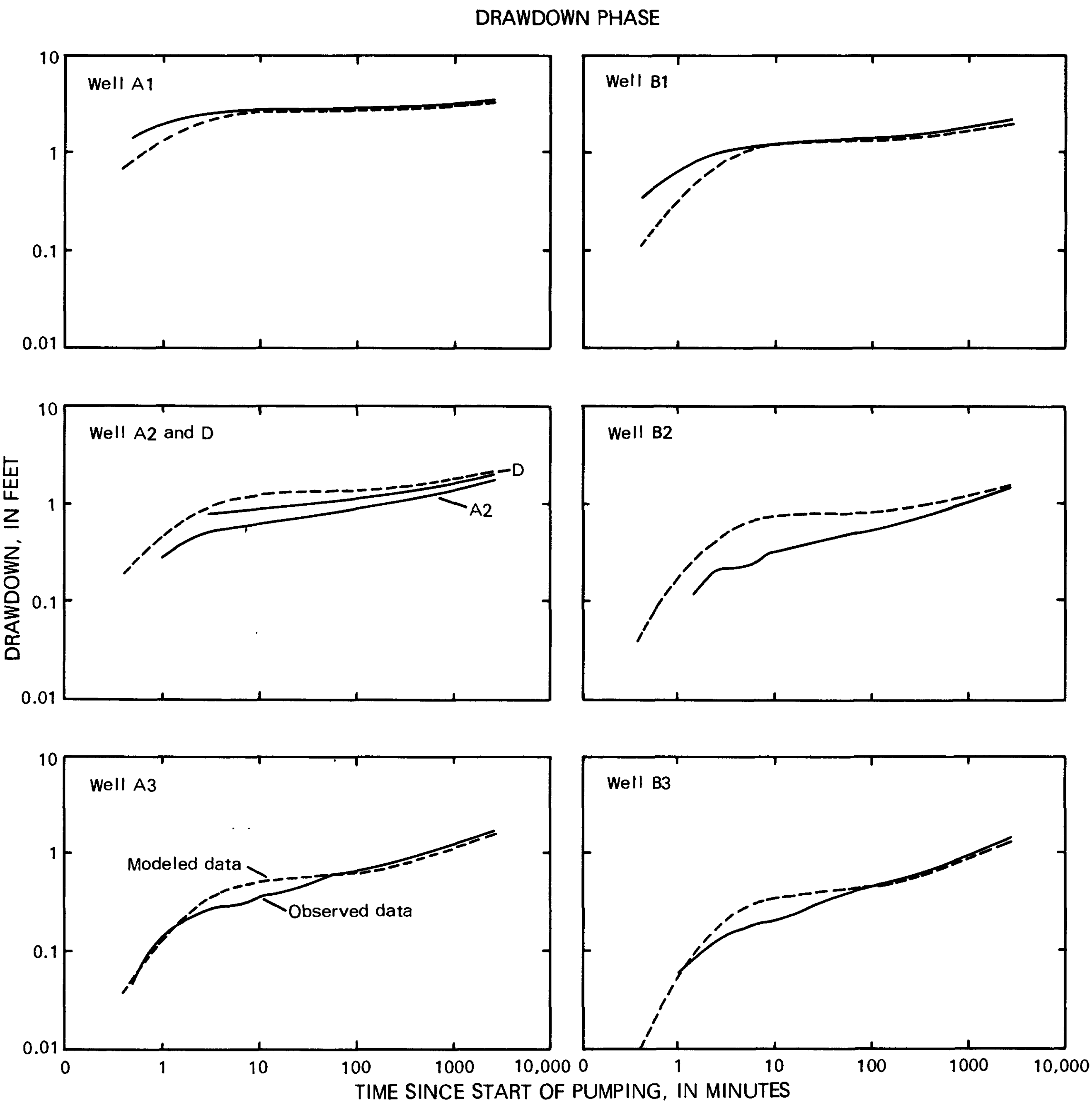
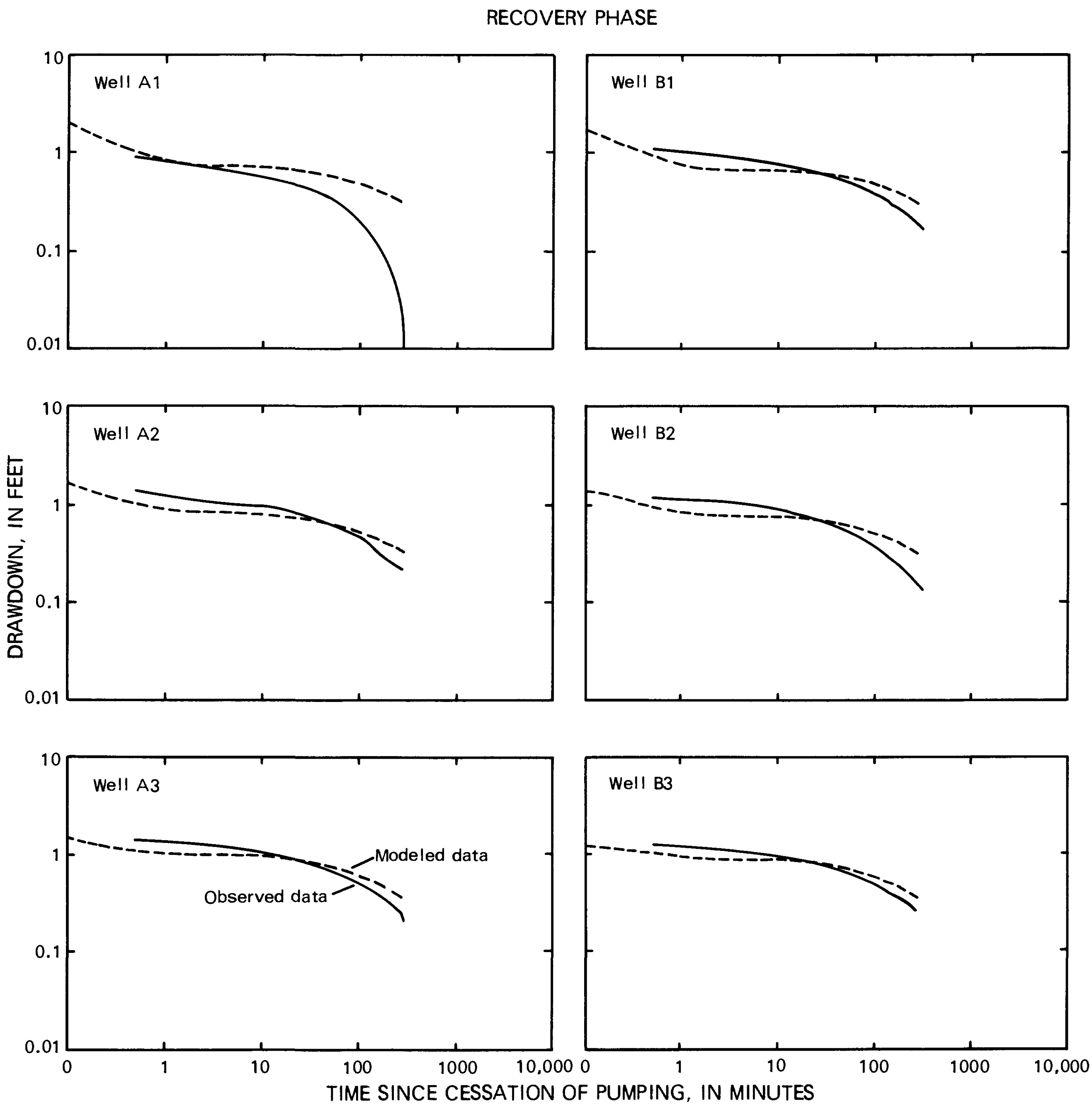


Figure 10.--Comparison of simulated drawdown and recovery data



with field measurements, Lynbrook site.

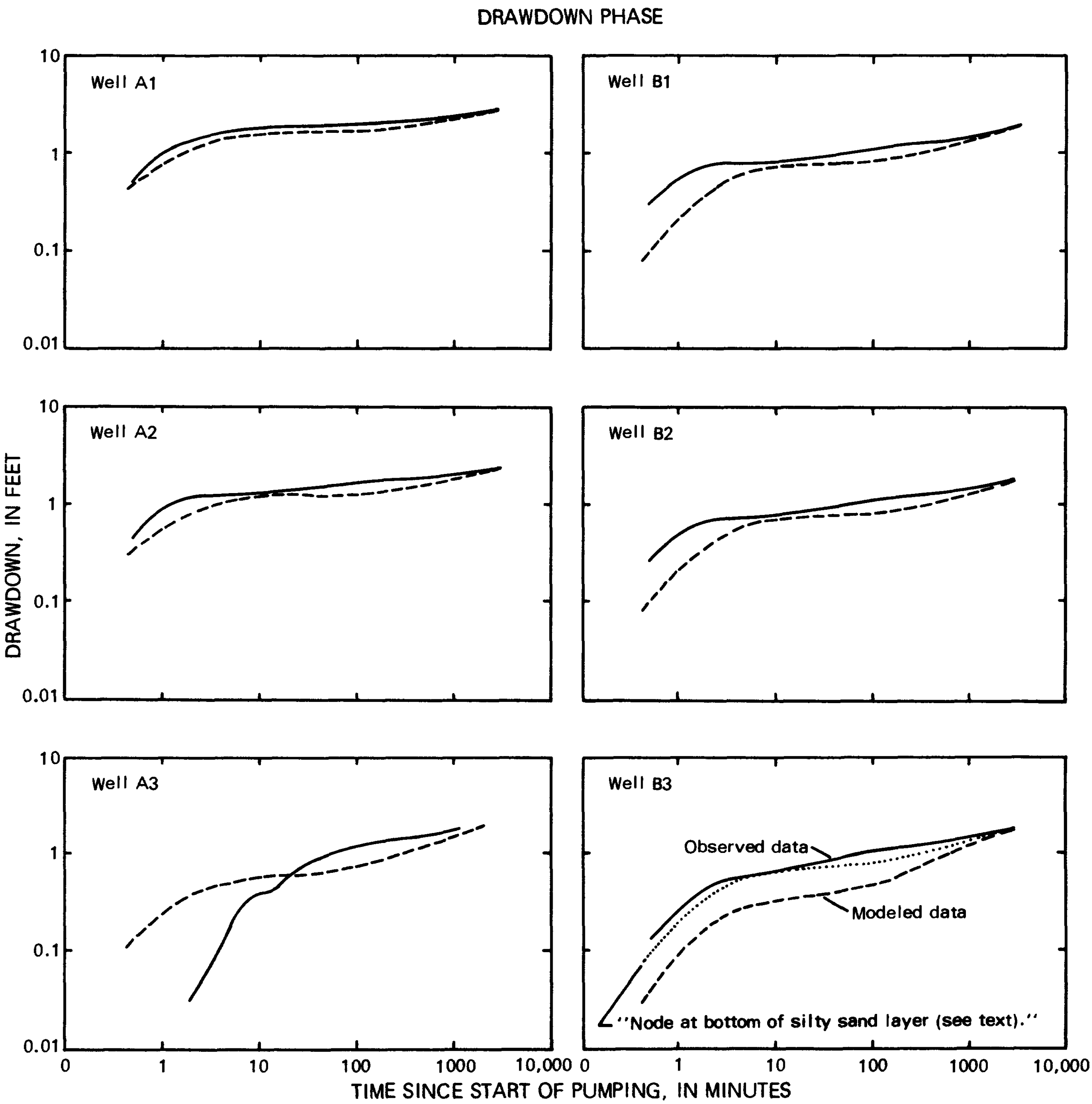
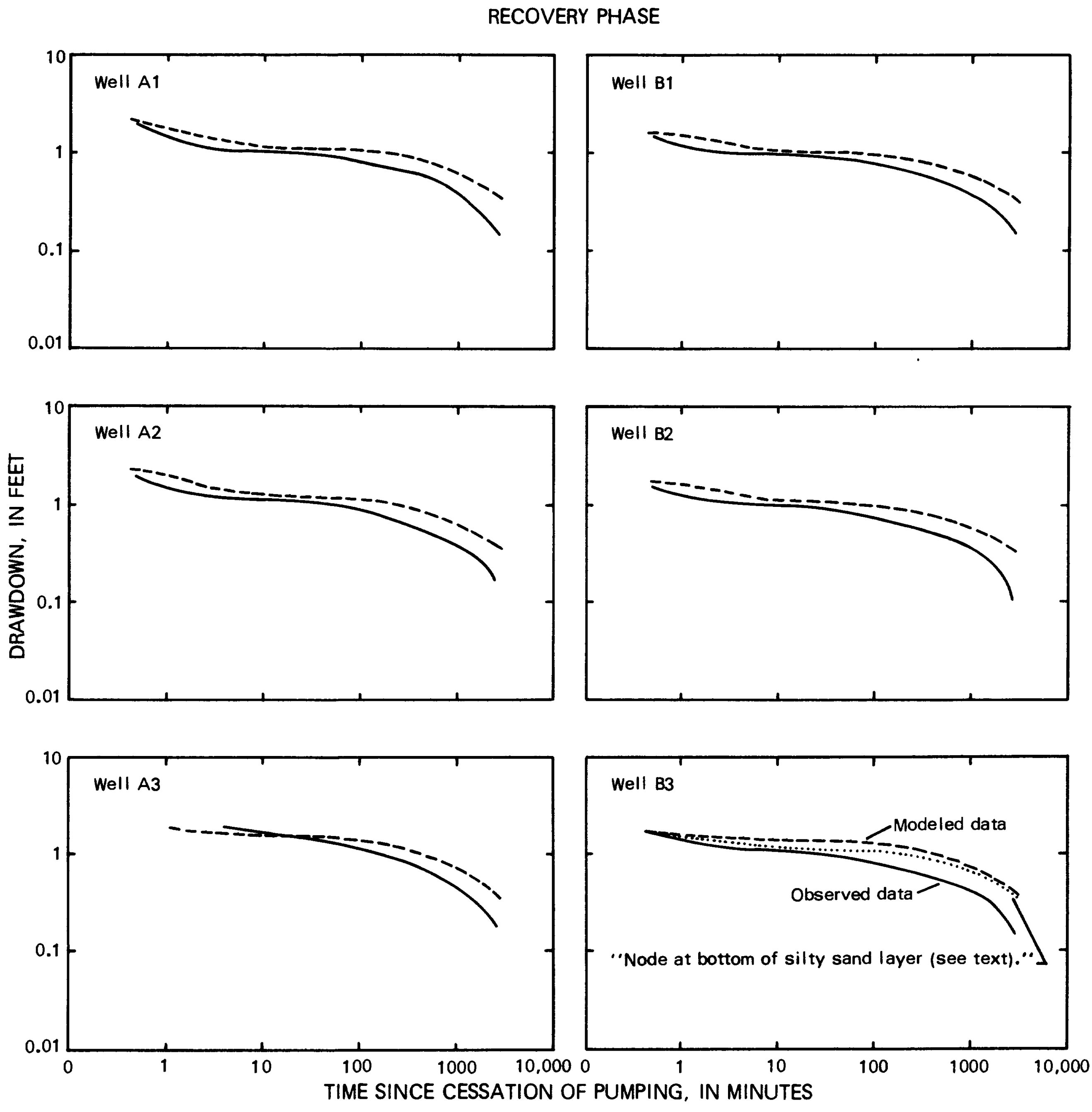


Figure 11.--Comparison of simulated drawdowns and recovery data



with field measurements, East Rockaway site.

COMPARISON OF RESULTS FROM DIFFERENT METHODS OF ANALYSIS

A summary of "best guess" estimates of aquifer parameters obtained from the various solution techniques for the three sites and regional estimates from the literature for southern Nassau County are given in table 6.

The simple analytical methods discussed earlier can be useful in quickly obtaining a rough estimate of aquifer parameters, but caution must be used when applying the solution to a system that does not closely fit the assumptions. However, even an order-of-magnitude knowledge of T and S_y can be useful in a curve-matching analysis or as a starting point for numerical modeling.

An analysis that uses Stallman's type curves, on the other hand, tends to give a range of values rather than a specific number. Because the curves are matched on a well-by-well basis, each well may yield a different value, and, as a result, the values may be too scattered to be useful without additional information. However, an estimate from the simple analytical solutions, from previously published reports, and from knowledge of lithology, as depicted in driller's logs, can make it possible to bracket a probable range for values of hydraulic conductivity and storage coefficient. Within this framework, the type curves can provide reasonably accurate estimates of aquifer parameters, as indicated by data in table 6. When the range of T and S_y values from the Stallman curve-matching technique was narrowed on the basis of other information, the resulting values were fairly consistent and in close agreement with the final model results.

One advantage of the numerical model over other methods described is that it computes the drawdowns for all wells at a site simultaneously. Because water levels at the wells are interrelated in the model, just as in the real system, the simulation is based on the one set of coefficients that produces the best fit for the whole site, rather than for individual wells.

Theoretically, each site should have a unique solution--a single combination of values that will enable the model to simulate the real-world drawdowns accurately. The six head values at observation wells were by themselves sufficient to determine such a solution at the Seaford and Lynbrook sites, the two sites having simple geologic settings. (As a consequence of radial symmetry, wells B2, C, and D were represented in the model as a single data point.)

The East Rockaway site, on the other hand, may not have a unique solution. Like the other two sites, this one has six wells, but the East Rockaway site has at least eight unknown factors--horizontal and vertical hydraulic conductivity in each of the three layers plus specific yield and specific storage. The geologic layers are not uniform across the area; that is, the silty sand layer at the top may not be continuous or horizontal or of uniform thickness. However, uniformity of those layers must be assumed in the model. Also, there is a possibility that well B3, supposedly screened at the top of the water table, is actually deeper than reported. This possibility can be observed by examination of figure 10, which indicates that during the first 45 minutes of pumping, drawdowns in the water-table well 100 ft from the pumping well were actually greater than in the water-table well 50 ft away.

Table 6.--Comparison of aquifer parameters obtained by methods described.

Site	Simple analytical solution	Average of selected values from Stallman type-curve method[a]	Estimates from finite-element simulations	Literature*
	METHOD			
		Hydraulic conductivity, feet/day		
Seaford	315	308	300	[b]130 - 260
Lynbrook	166	175	140	[c]270
East Rockaway	310	380	[d]380	[e]360 - 420
		Ratio of horizontal to vertical hydraulic conductivity (K_r/K_z), dimensionless		
Seaford	--	2.5	2.4	[c]10
Lynbrook	--	7	7	[f]10 - 24
East Rockaway	--	16	[d]2.9	[g]1.8 - 2.8
		Specific yield, dimensionless		
Seaford	0.24	0.20	0.15	[g]0.18
Lynbrook	0.16	0.18	0.23	[h]0.24
East Rockaway	0.21	0.13	0.18	[i]0.1 - 0.3

* Regional estimate for southern Nassau; no specific site.
[a] Represents values associated with storage coefficients from 0.1 to 0.3.
[b] McClymonds and Franke, 1972.
[c] Franke and Cohen, 1972
[d] For sand layer only.
[e] Obtained using transmissivity data from Getzen (1977) and an average saturated thickness of 50 ft for upper glacial aquifer.
[f] Franke and Getzen, 1975.
[g] Getzen, 1977.
[h] Perlmutter and Geraghty, 1963.
[i] Lohman, 1972.

However, in the simulation, a node at the bottom of the silty sand layer (rather than at the top of the layer) produced a simulated drawdown curve that matched the shape of the measured drawdown data curve closely. Clearly then, these complications affect the confidence placed on results obtained for the East Rockaway site.

Another advantage of the model is its flexibility in representing the varied geometry of the system and the position of the observation wells. Stallman's solution was developed only for a pumping well screened in the lower 30 percent of the saturated thickness of an aquifer and for observation wells screened at 0, 50, 75, 90, or 100 percent of this thickness above the base, although it is possible to generate type curves for any degree of penetration (Dagan, 1967). In contrast, the finite-element model allows both pumping and observation wells to be screened at any interval. A disadvantage of the numerical model is that, to have this flexibility, it is more complex and requires a computer.

The model can compute the drawdown at any location on the site and at any depth and for any given time. This feature was useful in evaluating the importance of the decrease in saturated thickness during the tests at the Seaford and East Rockaway sites. While model nodes representing the well screen indicated drawdowns of as much as 20 ft, nodes at the free surface directly above showed drawdowns of only 2 or 3 feet. Thus, the assumption of constant saturated thickness was reasonable.

SUMMARY AND CONCLUSIONS

Drawdown data from three aquifer test sites several miles apart in southern Nassau County, N.Y., were analyzed to determine the horizontal and vertical hydraulic conductivity and specific yield at each site. Methods of analysis included simple analytical treatments, the Stallman type-curve analysis, and a Galerkin finite-element simulation. Results from analytical and Stallman type-curve methods were used as the basis for further refinement by the numerical model. Confidence in the accuracy of the values increased as the analysis proceeded from the simpler to the more complex methods. However, all the methods proved useful, and most of the results were in the same range (table 6).

The Stallman type-curve method tended to yield a broad range of values for each aquifer property, but the accuracy of the method was improved when additional information on specific yield was used to eliminate improbable values. The model analysis had the advantages of representing the geology of the test sites in greater detail, allowing for releases from elastic storage and incorporating data from all six observation wells at a site simultaneously. However, it greatly increased the complexity, time, and cost of analysis. Although the model analysis only refined the estimates obtained by other methods, it significantly increased the level of confidence that may be placed in the results.

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TABLE 7.--AQUIFER-TEST DATA, SEAFORD SITE, NASSAU COUNTY, NEW YORK

A. Pumping well

B. Annular-space well

C. Well A1

D. Well A2

E. Well A3

F. Well B1

G. Well B2

H. Well B3

I. Well C

J. Well D

Table 7.--Aquifer test data, Seaford site, Nassau County, N.Y.

Time since start of pumping (min)	Time since end of pumping (min)	Drawdown (ft)
A. Pumping Well		
0	--	0
3	--	17.65
4	--	17.86
6	--	18.04
8	--	18.10
10	--	18.21
15	--	18.51
20	--	18.64
30	--	18.88
45	--	19.16
60	--	19.23
90	--	19.43
120	--	19.47
180	--	19.65
240	--	19.84
300	--	19.81
360	--	19.86
420	--	19.88
480	--	19.99
540	--	20.08
600	--	20.09
660	--	20.11
720	--	20.14
840	--	20.20
960	--	20.21
1080	--	20.20
1200	--	20.19
1320	--	20.20
1440	--	20.30
1560	--	20.29
1680	--	20.31
A. Pumping Well--continued		
1800	--	20.29
1920	--	20.63
2040	--	20.78
2160	--	20.87
2280	--	20.90
2400	--	20.91
2520	--	21.03
2640	--	21.04
2760	--	21.05
2880	--	21.10
2880.5	0.5	2.26
2882	2	2.71
2883	3	2.71
2884	4	2.71
2886	6	2.66
2888	8	2.64
2890	10	2.58
2895	15	2.50
2900	20	2.48
2910	30	2.34
2925	45	2.27
2940	60	2.06
2970	90	1.88
3000	120	1.73
3060	180	1.53
3180	300	1.19
3330	420	1.04
4290	1410	0.53
5730	2850	0.30
7200	4320	0.15

Table 7.--Aquifer test data, Seaford site, Nassau County, N.Y.--continued

Time since start of pumping (min)	Time since end of pumping (min)	Drawdown (ft)	Time since start of pumping (min)	Time since end of pumping (min)	Drawdown (ft)
B. Annular Space Well			B. Annular Space Well--continued		
0	--	0	1920	--	17.62
4	--	15.35	2040	--	17.72
6	--	15.43	2160	--	17.82
8	--	15.52	2280	--	17.88
10	--	15.59	2400	--	17.92
15	--	15.81	2520	--	17.98
20	--	15.95	2640	--	18.04
30	--	16.11	2760	--	17.98
45	--	16.19	2880	--	18.06
60	--	16.38	2880.5	0.5	3.31
90	--	16.56	2881	1	3.16
120	--	16.70	2882	2	2.96
180	--	16.76	2883	3	2.76
240	--	16.84	2884	4	2.71
300	--	16.87	2886	6	2.71
360	--	16.93	2888	8	2.66
420	--	16.95	2890	10	2.61
480	--	17.08	2895	15	2.56
540	--	17.11	2900	20	2.46
600	--	17.08	2910	30	2.35
660	--	17.11	2925	45	2.21
720	--	17.22	2940	60	2.07
840	--	17.06	2970	90	1.89
960	--	17.26	3000	120	1.72
1080	--	17.31	3060	180	1.54
1200	--	17.24	3180	300	1.39
1320	--	17.28	3330	420	1.06
1440	--	17.39	4290	1410	0.54
1560	--	17.37	5730	2850	0.25
1680	--	17.40	7200	4320	0.11
1800	--	17.35			

Table 7.--Aquifer test data, Seaford site, Nassau County, N.Y.--continued

Time since start of pumping (min)	Time since end of pumping (min)	Drawdown (ft)	Time since start of pumping (min)	Time since end of pumping (min)	Drawdown (ft)
C. Well A1			C. Well A1--continued		
0	--	0	2880.5	0.5	2.62
0.5	--	0.33	2881	1	2.52
1	--	0.42	2882	2	2.49
2	--	0.50	2883	3	2.47
3	--	0.55	2884	4	2.45
4	--	0.57	2886	6	2.42
6	--	0.61	2888	8	2.39
8	--	0.63	2890	10	2.37
10	--	0.67	2895	15	2.32
15	--	0.73	2900	20	2.28
20	--	0.79	2910	30	2.09
30	--	0.88	2925	45	2.08
45	--	1.00	2940	60	2.01
60	--	1.09	2970	90	1.85
90	--	1.23	3000	120	1.74
120	--	1.35	3060	180	1.55
180	--	1.52	3120	240	1.51
240	--	1.65	3180	300	1.30
300	--	1.76	3240	360	1.20
360	--	1.85	3300	420	1.11
420	--	1.93	3360	480	1.05
480	--	2.00	3420	540	0.99
540	--	2.07	3480	600	0.93
600	--	2.12	3540	660	0.88
660	--	2.19	3600	720	0.84
720	--	2.22	3720	840	0.77
840	--	2.32	3840	960	0.70
960	--	2.40	3960	1080	0.65
1080	--	2.45	4080	1200	0.60
1200	--	2.51	4200	1320	0.56
1320	--	2.56	4320	1440	0.51
1440	--	2.58	4440	1560	0.48
1560	--	2.63	4560	1680	0.46
1680	--	2.67	4680	1800	0.43
1800	--	2.70	4800	1920	0.41
1920	--	2.74	4920	2040	0.39
2040	--	2.79	5040	2160	0.38
2160	--	2.83	5160	2280	0.36
2280	--	2.86	5280	2400	0.34
2400	--	2.88	5400	2520	0.33
2520	--	2.89	5520	2640	0.31
2640	--	2.91	5640	2760	0.30
2760	--	2.93	5760	2880	0.30
2880	--	2.95			

Table 7.--Aquifer test data, Seaford site, Nassau County, N.Y.--continued

Time since start of pumping (min)	Time since end of pumping (min)	Drawdown (ft)
D. Well A2		
0	--	0
0.5	--	0.30
1	--	0.37
2	--	0.44
3	--	0.49
4	--	0.52
6	--	0.57
8	--	0.59
10	--	0.62
15	--	0.69
20	--	0.74
30	--	0.85
45	--	0.97
60	--	1.07
90	--	1.23
120	--	1.36
180	--	1.54
240	--	1.69
300	--	1.80
360	--	1.89
420	--	1.97
480	--	2.04
540	--	2.11
600	--	2.17
660	--	2.22
720	--	2.27
840	--	2.36
960	--	2.43
1080	--	2.50
1200	--	2.56
1320	--	2.61
1440	--	2.65
1560	--	2.68
1680	--	2.72
1800	--	2.75
1920	--	2.79
2040	--	2.84
2160	--	2.87
2280	--	2.91
2400	--	2.93
2520	--	2.94
2640	--	2.96
2760	--	2.98
2880	--	2.99
D. Well A2--continued		
2880.5	0.5	2.71
2881	1	2.64
2882	2	2.61
2883	3	2.59
2884	4	2.57
2886	6	2.52
2888	8	2.54
2890	10	2.47
2895	15	2.42
2900	20	2.36
2910	30	2.27
2925	45	2.17
2940	60	2.07
2970	90	1.92
3000	120	1.78
3060	180	1.59
3120	240	1.42
3180	300	1.31
3240	360	1.20
3300	420	1.12
3360	480	1.05
3420	540	0.99
3480	600	0.92
3540	660	0.88
3600	720	0.84
3720	840	0.75
3840	960	0.70
3960	1080	0.64
4080	1200	0.60
4200	1320	0.55
4320	1440	0.53
4440	1560	0.49
4560	1680	0.47
4680	1800	0.44
4800	1920	0.42
4920	2040	0.40
5040	2160	0.38
5160	2280	0.36
5280	2400	0.34
5400	2520	0.33
5520	2640	0.32
5640	2760	0.30
5760	2880	0.29

Table 7.--Aquifer test data, Seaford site, Nassau County, N.Y.--continued

Time since start of pumping (min)	Time since end of pumping (min)	Drawdown (ft)	Time since start of pumping (min)	Time since end of pumping (min)	Drawdown (ft)
E. Well A3			E. Well A3--continued		
0	--	0	2880.5	0.5	2.77
0.5	--	0.18	2881	1	2.72
1	--	0.23	2882	2	2.68
2	--	0.30	2883	3	2.66
3	--	0.34	2884	4	2.64
4	--	0.37	2886	6	2.60
6	--	0.41	2888	8	2.57
8	--	0.45	2890	10	2.54
10	--	0.48	2895	15	2.48
15	--	0.56	2900	20	2.44
20	--	0.61	2910	30	2.34
30	--	0.72	2925	45	2.24
45	--	0.85	2940	60	2.15
60	--	0.96	2970	90	1.95
90	--	1.12	3000	120	1.83
120	--	1.25	3060	180	1.64
180	--	1.43	3120	240	1.47
240	--	1.56	3180	300	1.34
300	--	1.70	3240	360	1.22
360	--	1.81	3300	420	1.14
420	--	1.88	3360	480	1.06
480	--	1.96	3420	540	1.01
540	--	2.01	3480	600	0.95
600	--	2.06	3540	660	0.90
660	--	2.13	3600	720	0.84
720	--	2.18	3720	840	0.77
840	--	2.28	3840	960	0.71
960	--	2.35	3960	1080	0.66
1080	--	2.42	4080	1200	0.61
1200	--	2.48	4200	1320	0.57
1320	--	2.53	4320	1440	0.52
1440	--	2.58	4440	1560	0.49
1560	--	2.63	4560	1680	0.46
1680	--	2.67	4680	1800	0.43
1800	--	2.70	4800	1920	0.41
1920	--	2.74	4920	2040	0.39
2040	--	2.78	5040	2160	0.37
2160	--	2.82	5160	2280	0.36
2280	--	2.85	5280	2400	0.34
2400	--	2.87	5400	2520	0.33
2520	--	2.89	5520	2640	0.31
2640	--	2.91	5640	2760	0.30
2760	--	2.92	5760	2880	0.28
2880	--	2.94			

Table 7.--Aquifer test data, Seaford site, Nassau County, N.Y.--continued

Time since start of pumping (min)	Time since end of pumping (min)	Drawdown (ft)	Time since start of pumping (min)	Time since end of pumping (min)	Drawdown (ft)
F. Well B1			F. Well B1--continued		
0	--	0	2880.5	0.5	2.05
0.5	--	0.04	2881	1	2.02
1	--	0.70	2882	2	2.00
2	--	0.10	2883	3	1.99
3	--	0.12	2884	4	1.97
4	--	0.13	2886	6	1.95
6	--	0.15	2888	8	1.94
8	--	0.16	2890	10	1.93
10	--	0.17	2895	15	1.90
15	--	0.22	2900	20	1.87
20	--	0.24	2910	30	1.82
30	--	0.31	2925	45	1.78
45	--	0.38	2940	60	1.72
60	--	0.44	2970	90	1.63
90	--	0.54	3000	120	1.54
120	--	0.63	3060	180	1.42
180	--	0.77	3120	240	1.31
240	--	0.87	3180	300	1.22
300	--	0.97	3240	360	1.13
360	--	1.04	3300	420	1.06
420	--	1.07	3360	480	1.00
480	--	1.12	3420	540	0.94
540	--	1.23	3480	600	0.90
600	--	1.28	3540	660	0.84
660	--	1.33	3600	720	0.81
720	--	1.37	3720	840	0.74
840	--	1.46	3840	960	0.68
960	--	1.53	3960	1080	0.63
1080	--	1.59	4080	1200	0.59
1200	--	1.64	4200	1320	0.54
1320	--	1.69	4320	1440	0.52
1440	--	1.73	4440	1560	0.49
1560	--	1.78	4560	1680	0.46
1680	--	1.82	4680	1800	0.43
1800	--	1.85	4800	1920	0.42
1920	--	1.89	4920	2040	0.40
2040	--	1.93	5040	2160	0.38
2160	--	1.96	5160	2280	0.36
2280	--	1.99	5280	2400	0.35
2400	--	2.02	5400	2520	0.33
2520	--	2.04	5520	2640	0.32
2640	--	2.06	5640	2760	0.30
2760	--	2.08	5760	2880	0.28
2880	--	2.08			

Table 7.--Aquifer test data, Seaford site, Nassau County, N.Y.--continued

Time since start of pumping (min)	Time since end of pumping (min)	Drawdown (ft)	Time since start of pumping (min)	Time since end of pumping (min)	Drawdown (ft)
G. Well B2			G. Well B2--continued		
0	--	0	2880.5	0.5	2.07
0.5	--	0.02	2881	1	2.05
1	--	0.04	2882	2	2.03
2	--	0.07	2883	3	2.01
3	--	0.08	2884	4	2.00
4	--	0.10	2886	6	1.99
6	--	0.12	2888	8	1.97
8	--	0.14	2890	10	1.96
10	--	0.15	2895	15	1.93
15	--	0.20	2900	20	1.90
20	--	0.23	2910	30	1.85
30	--	0.28	2925	45	1.81
45	--	0.35	2940	60	1.75
60	--	0.42	2970	90	1.66
90	--	0.52	3000	120	1.66
120	--	0.61	3060	180	1.44
180	--	0.74	3120	240	1.33
240	--	0.85	3180	300	1.23
300	--	0.93	3240	360	1.15
360	--	1.01	3300	420	1.08
420	--	1.08	3360	480	1.01
480	--	1.14	3420	540	0.96
540	--	1.20	3480	600	0.91
600	--	1.25	3540	660	0.86
660	--	1.31	3600	720	0.83
720	--	1.35	3720	840	0.76
840	--	1.43	3840	960	0.70
960	--	1.50	3960	1080	0.64
1080	--	1.56	4080	1200	0.61
1200	--	1.62	4200	1320	0.56
1320	--	1.67	4320	1440	0.53
1440	--	1.73	4440	1560	0.50
1560	--	1.77	4560	1680	0.47
1680	--	1.81	4680	1800	0.45
1800	--	1.84	4800	1920	0.43
1920	--	1.88	4920	2040	0.41
2040	--	1.92	5040	2160	0.39
2160	--	1.95	5160	2280	0.37
2280	--	1.98	5280	2400	0.35
2400	--	2.01	5400	2520	0.34
2520	--	2.03	5520	2640	0.33
2640	--	2.05	5640	2760	0.32
2760	--	2.07	5760	2880	0.31
2880	--	2.09			

Table 7.--Aquifer test data, Seaford site, Nassau County, N.Y.--continued

Time since start of pumping (min)	Time since end of pumping (min)	Drawdown (ft)
	H. Well B3	
0	--	0
0.5	--	0.03
1	--	0.05
2	--	0.07
3	--	0.09
4	--	0.10
6	--	0.12
8	--	0.14
10	--	0.15
15	--	0.19
20	--	0.22
30	--	0.28
45	--	0.35
60	--	0.42
90	--	0.52
120	--	0.59
180	--	0.73
240	--	0.83
300	--	0.93
360	--	1.02
420	--	1.08
480	--	1.15
540	--	1.20
600	--	1.26
660	--	1.31
720	--	1.36
840	--	1.44
960	--	1.50
1080	--	1.58
1200	--	1.63
1320	--	1.68
1440	--	1.71
1560	--	1.75
1680	--	1.79
1800	--	1.82
1920	--	1.86
2040	--	1.89
2160	--	1.93
2280	--	1.96
2400	--	1.99
2520	--	2.01
2640	--	2.03
2760	--	2.05
2880	--	2.06
	H. Well B3--continued	
2880.5	0.5	2.02
2881	1	2.01
2882	2	2.00
2883	3	1.98
2884	4	1.97
2886	6	1.95
2888	8	1.94
2890	10	1.93
2895	15	1.90
2900	20	1.87
2910	30	1.82
2925	45	1.78
2940	60	1.73
2970	90	1.64
3000	120	1.56
3060	180	1.32
3120	240	1.20
3180	300	1.10
3240	360	1.02
3300	420	0.96
3360	480	0.89
3420	540	0.83
3480	600	0.79
3540	660	0.75
3600	720	0.71
3720	840	0.64
3840	960	0.58
3960	1080	0.53
4080	1200	0.48
4200	1320	0.45
4320	1440	0.38
4440	1560	0.35
4560	1680	0.32
4680	1800	0.30
4800	1920	0.28
4920	2040	0.26
5040	2160	0.25
5160	2280	0.23
5280	2400	0.21
5400	2520	0.20
5520	2640	0.19
5640	2760	0.18
5760	2880	0.19

Table 7.--Aquifer test data, Seaford site, Nassau County, N.Y.--continued

Time since start of pumping (min)	Time since end of pumping (min)	Drawdown (ft)	Time since start of pumping (min)	Time since end of pumping (min)	Drawdown (ft)
I. Well C			I. Well C--continued		
0	--	0	2880.5	0.5	2.78
0.5	--	0.31	2881	1	2.69
1	--	0.39	2882	2	2.67
2	--	0.48	2883	3	2.64
3	--	0.53	2884	4	2.62
4	--	0.56	2886	6	2.58
6	--	0.61	2888	8	2.55
8	--	0.64	2890	10	2.53
10	--	0.67	2895	15	2.47
15	--	0.74	2900	20	2.42
20	--	0.80	2910	30	2.33
30	--	0.91	2925	45	2.23
45	--	1.03	2940	60	2.14
60	--	1.14	2970	90	1.95
90	--	1.20	3000	120	1.81
120	--	1.43	3060	180	1.64
180	--	1.63	3120	240	1.48
240	--	1.78	3180	300	1.35
300	--	1.88	3240	360	1.24
360	--	1.94	3300	420	1.15
420	--	2.03	3360	480	1.07
480	--	2.11	3420	540	1.01
540	--	2.18	3480	600	0.95
600	--	2.24	3540	660	0.90
660	--	2.29	3600	720	0.85
720	--	2.35	3720	840	0.77
840	--	2.44	3840	960	0.71
960	--	2.51	3960	1080	0.65
1080	--	2.58	4080	1200	0.60
1200	--	2.64	4200	1320	0.56
1320	--	2.69	4320	1440	0.54
1440	--	2.73	4440	1560	0.50
1560	--	2.78	4560	1680	0.47
1680	--	2.82	4680	1800	0.45
1800	--	2.85	4800	1920	0.43
1920	--	2.89	4920	2040	0.40
2040	--	2.94	5040	2160	0.39
2160	--	2.93	5160	2280	0.36
2280	--	3.01	5280	2400	0.35
2400	--	3.03	5400	2520	0.34
2520	--	3.05	5520	2640	0.32
2640	--	3.07	5640	2760	0.31
2760	--	3.08	5760	2880	0.28
2880	--	3.09			

Table 7.--Aquifer test data, Seaford site, Nassau County, N.Y.--continued

Time since start of pumping (min)	Time since end of pumping (min)	Drawdown (ft)
J. Well D		
0	--	0
0.5	--	0.29
1	--	0.35
2	--	0.43
3	--	0.49
4	--	0.51
6	--	0.55
8	--	0.58
10	--	0.62
15	--	0.69
20	--	0.73
30	--	0.83
45	--	0.96
60	--	1.05
90	--	1.21
120	--	1.33
180	--	1.52
240	--	1.66
300	--	1.79
360	--	1.88
420	--	1.96
480	--	2.04
540	--	2.11
600	--	2.16
660	--	2.22
720	--	2.27
840	--	2.36
960	--	2.44
1080	--	2.51
1200	--	2.57
1320	--	2.62
1440	--	2.65
1560	--	2.70
1680	--	2.74
1900	--	2.77
1920	--	2.81
2040	--	2.86
2160	--	2.89
2280	--	2.92
2400	--	2.96
2520	--	2.96
2640	--	2.99
2760	--	3.00
2880	--	3.01
J. Well D--continued		
2880.5	0.5	2.71
2881	1	2.66
2882	2	2.63
2883	3	2.62
2884	4	2.60
2886	6	2.57
2888	8	2.53
2890	10	2.51
2895	15	2.46
2900	20	2.41
2910	30	2.32
2925	45	2.21
2940	60	2.12
2970	90	1.95
3000	120	1.81
3060	180	1.65
3120	240	1.48
3180	300	1.36
3240	360	1.25
3300	420	1.15
3360	480	1.09
3420	540	1.01
3480	600	0.96
3540	660	0.91
3600	720	0.86
3720	840	0.79
3840	960	0.71
3960	1080	0.66
4080	1200	0.61
4200	1320	0.57
4320	1440	0.53
4440	1560	0.50
4560	1680	0.48
4680	1800	0.45
4800	1920	0.42
4920	1040	0.40
5040	2160	0.38
5160	2280	0.37
5280	2400	0.35
5400	2520	0.33
5520	2640	0.32
5640	2760	0.31
5760	2880	0.28