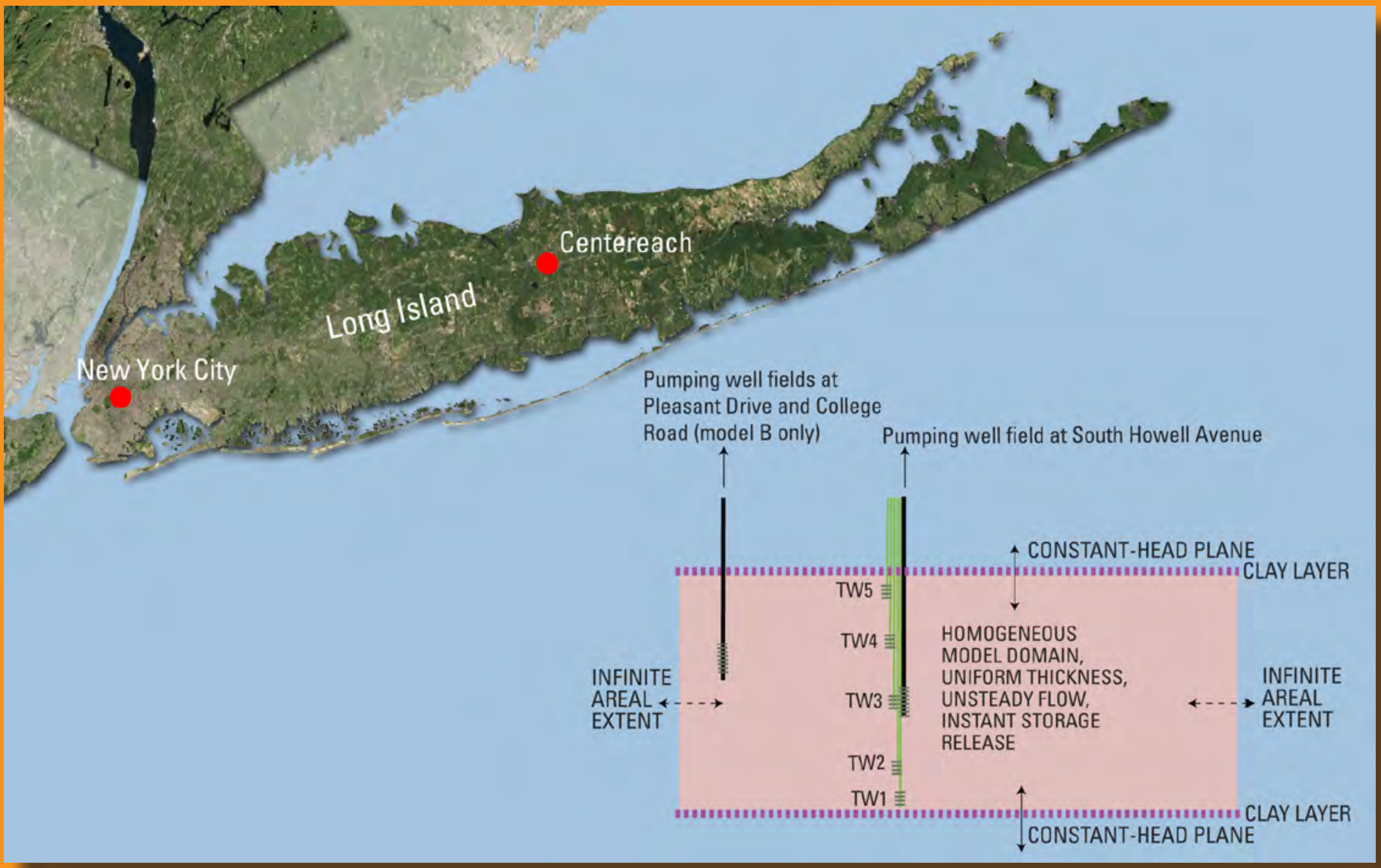
Prepared in cooperation with the Suffolk County Water Authority

Hydraulic Properties of the Magothy and Upper Glacial Aquifers at Centereach, Suffolk County, New York



Scientific Investigations Report 2009–5190

U.S. Department of the Interior
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Cover. Aerial photograph of Long Island, New York showing location of Centereach, and conceptual diagram showing structural boundaries, flow boundaries, and wells.”

Hydraulic Properties of the Magothy and Upper Glacial Aquifers at Centereach, Suffolk County, New York

By Paul E. Misut and Ronald Busciolano

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KEN SALAZAR, Secretary

U.S. Geological Survey
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Contents

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Conversion Factors, Datums, and Abbreviations

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.6093	kilometer (km)
kilometer (km)	0.6214	mile (mi)
	Area	
square mile (mi^2)	259	hectare (ha)
square mile (mi^2)	2.59	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
gallon (gal)	0.003785	cubic meter (m^3)
	Flow rate	
gallon per minute (gal/min)	0.06309	liter per second (L/s)
gallon per minute (gal/min)	0.001440	million gallons per day (Mgal/d)
	Density	
pound per cubic foot (lb/ft^3)	16.0185	kilogram per cubic meter (kg/m^3)
	Specific capacity	
gallon per minute per foot [(gal/min)/ft]	0.2070	liter per second per meter [(L/s)/m]
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)
	Hydraulic gradient	
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
	Transmissivity*	
foot squared per day (ft^2/d)	0.0929	meter squared per day (m^2/d)
	Leakance	
foot per day per foot [(ft/d)/ft]	1	meter per day per meter [(m/d)/m]
inch per year per foot [(in/yr)/ft]	83.3333	millimeter per year per meter [(mm/yr)/m]

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C=(°F-32)/1.8$$

Vertical coordinate information is referenced to North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

*Transmissivity: The standard unit for transmissivity is cubic foot per day per square foot times foot of aquifer thickness [(ft^3/d)/ft^2]ft. In this report, the mathematically reduced form, foot squared per day (ft^2/d), is used for convenience.

List of Acronyms and Abbreviations

BLS	below land surface
LST	local standard time
NOAA	National Oceanic and Atmospheric Administration
NWIS	National Water Information System
SCWA	Suffolk County Water Authority
TW	test well
USGS	U.S. Geological Survey

Hydraulic Properties of the Magothy and Upper Glacial Aquifers at Centereach, Suffolk County, New York

By Paul E. Misut and Ronald Busciolano

Abstract

Horizontal and vertical hydraulic conductivity, transmissivity, and storativity of the aquifer system at Centereach, New York, were estimated using analytical multiple-well aquifer test models and compared with results of numerical regional flow modeling and hydrogeologic framework studies. During the initial operation of production well S125632 in May 2008, continuous water-level and temperature data were collected at a cluster of five partially penetrating observation wells, located about 100 feet (ft) from S125632, and at observation well S33380, located about 10,000 ft from S125632. Data collection intervals ranged from 30 seconds to 30 minutes and analytical model calibration was conducted using visual trial-and-error techniques with time series parsed to 30-minute intervals. The following assumptions were applied to analytical models: (1) infinite aerial extent, (2) homogeneity, (3) uniform 600-ft aquifer thickness, (4) unsteady flow, (5) instantaneous release from storage with the decline in head, (6) no storage within pumped wells, (7) a constant-head plane adjacent to bounding confining units, and (8) no horizontal component of flow through confining units.

Preliminary estimates of horizontal and vertical hydraulic conductivity of 50 ft per day horizontal and 0.5 ft per day vertical were extrapolated from previous flow modeling and hydrogeologic framework studies of the Magothy aquifer. Two applications were then developed from the Hantush analytical model. Model A included only the pumping stress of S125632, whereas model B included the concurrent pumping stresses from two other production well fields (wells S66496 and S32551). Model A provided a sufficient match to the observed water-level responses from pumping, whereas model B more accurately reproduced water levels similar to those observed during non-pumping of S125632, as well as some effects of interference from the concurrent pumping nearby. In both models, storativity was estimated to be 0.003 (dimensionless) and the Hantush leakage parameter “1/B” was estimated to be 0.00083 ft^{-1}. Representation of leakage across the overlying confining layer was likely complicated by: (1) irregularities in surface altitude and (2) groundwater recharge due to rainfall during the aquifer test.

Introduction

Groundwater is the sole source of freshwater in central and eastern Long Island. Because of the ever-increasing demand for potable water, studies have been conducted to provide information on the likely consequences of continued or expanded pumping of the aquifers in many areas. For example, estimates of aquifer properties are needed for delineation of groundwater flow paths, evaluation of optimal pumping rates and other aspects of well field design and maintenance, and prediction of local-scale water-level changes in response to pumping stresses. Previously published estimates of the hydraulic properties of aquifers on Long Island, N.Y., (Koszalka, 1980, Misut and Feldman, 1996, and Buxton and Shernoff, 1999) provide a general range of values and a regionalized view but lack detail.

In 2007, the U.S. Geological Survey (USGS), in cooperation with the Suffolk County Water Authority (SCWA), began a program to estimate the hydraulic properties of the Magothy and upper glacial aquifers underlying Suffolk County, N.Y. (figs. 1 and 2), through water-level monitoring of water levels in observation wells at well fields and other locations, and development and calibration of analytical models of aquifers. The first area to be investigated as part of the aquifer-characterization program was near Centereach in western Suffolk County, and subjected to a 1-year study. It was determined that the data collected would conform to USGS standards and be posted to the USGS National Water Information System (NWIS, available at http://waterdata.usgs.gov, accessed October 10, 2008) because the data would enhance other modeling and hydrogeologic database activities in the Suffolk County area. Water levels were monitored for a year prior to the initial operation of production well S125632 at South Howell Avenue on May 7, 2008. Development of numerical models was beyond the scope of this study.

The purpose of this report is to (1) describe the geohydrology of the Centereach area: (2) describe the development, calibration, and sensitivity analysis of the analytical models of the multiple-well aquifer test, and (3) compare analytical model results with results from other studies, including those from regional groundwater flow model studies. The report describes an aquifer test conducted

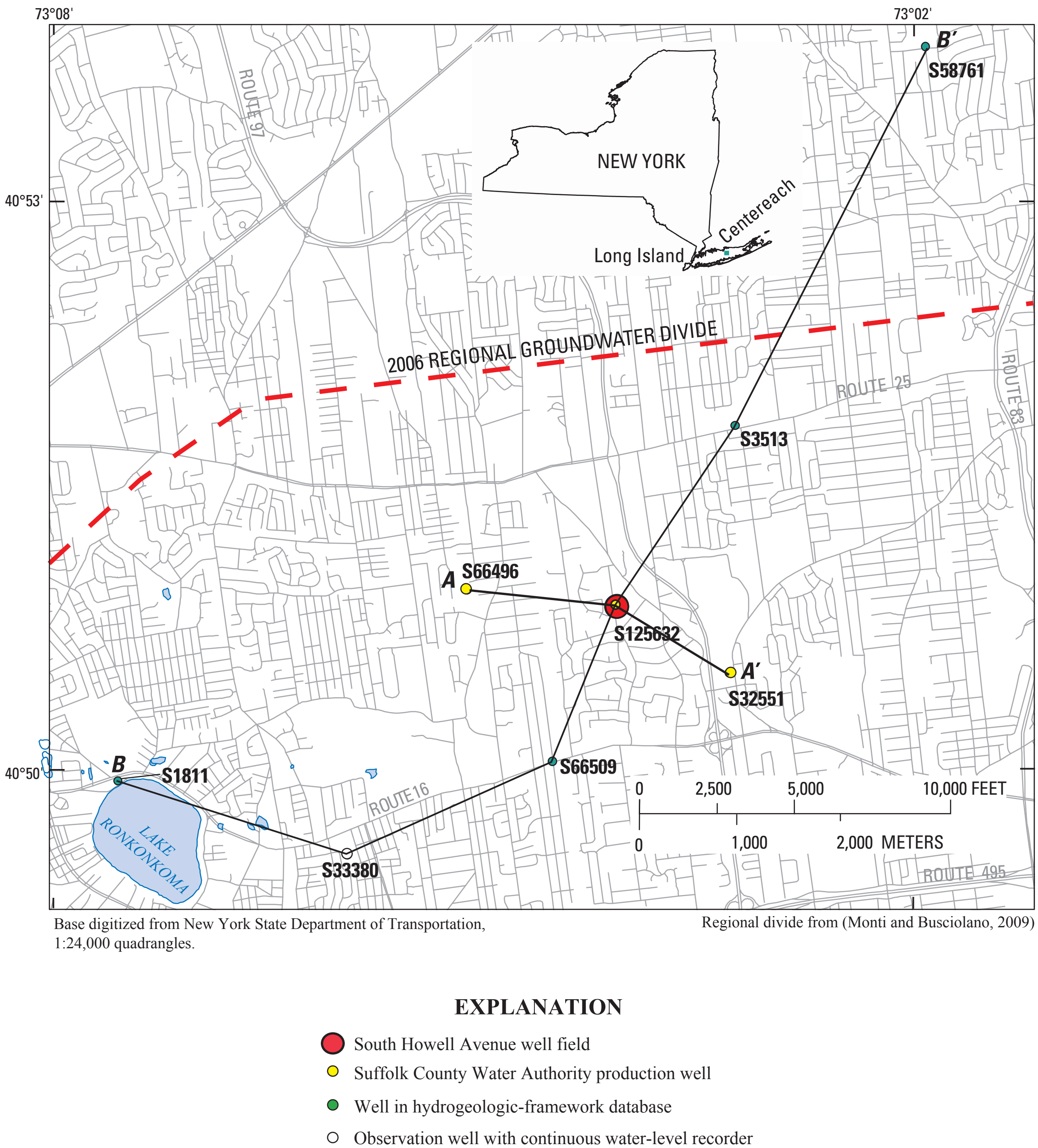

Figure 1. Location of well S125632, regional groundwater divide, and other wells along sections *A–A′* and *B–B′*.

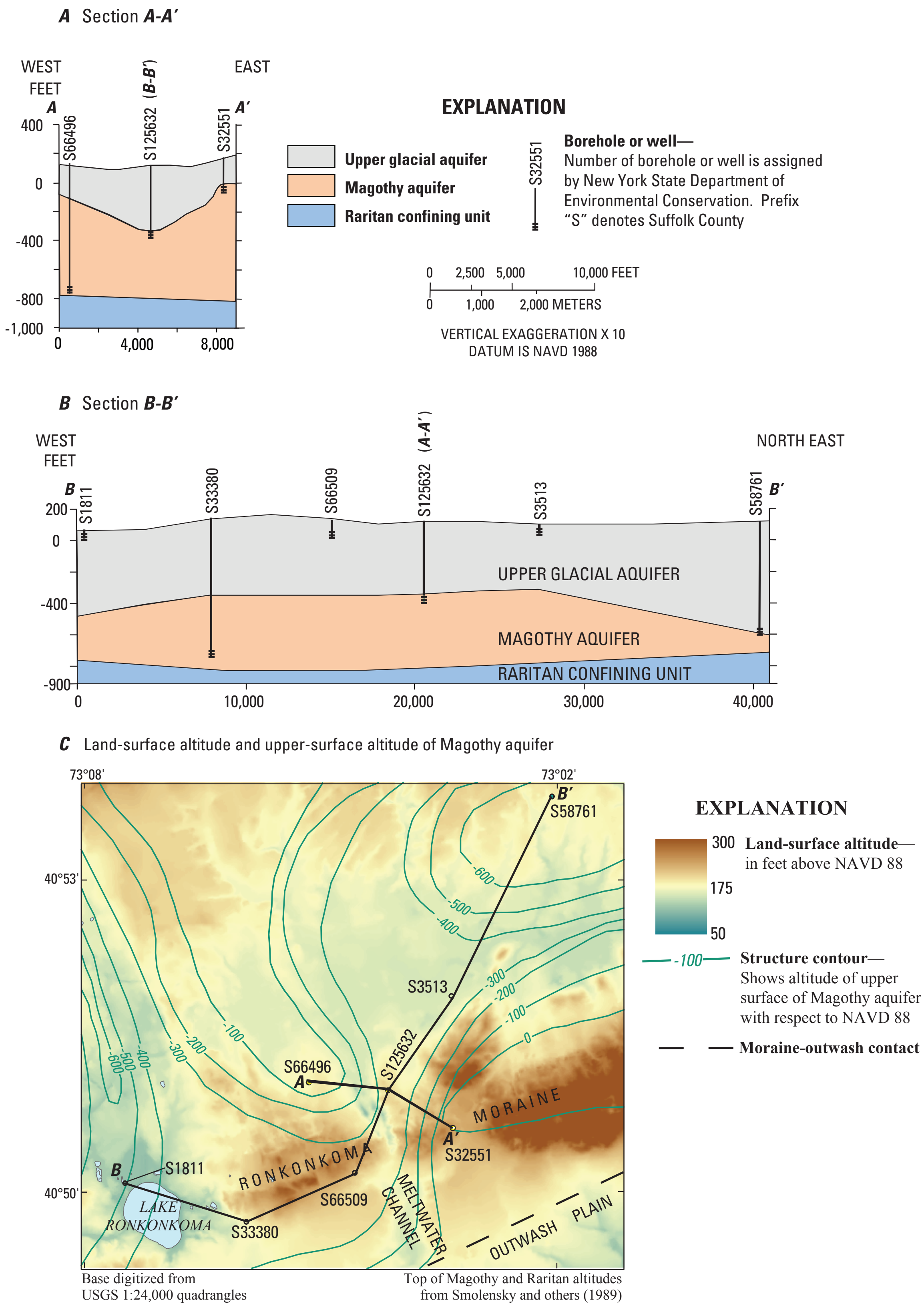

Figure 2. Depths of wells completed in the upper glacial aquifer and the Magothy aquifer along sections (A) *A–A′* and (B) *B–B′* and (C) map showing altitude of the upper surface of the Magothy aquifer.

May 4–12, 2008, by pumping one well and observing responses at five observation wells. The report also provides tables of well characteristics, hydrogeologic sections with geophysical logs, maps of pertinent surface altitudes, and observed and simulated water-level hydrographs of the aquifer test.

Description of Study Area and Wells

Production well S125632 at the South Howell Avenue well field, operated by the SCWA, is located about 2 miles south of the groundwater divide of the regional Long Island groundwater flow system (fig. 1). Well S125632 lies at the approximate center of section A–A′ (fig. 1); it is 4,700 ft east of production well S66496 and 4,300 ft west of production well S32551. Wells S125632 and S66496 usually are pumped one at a time because simultaneous pumping over-pressurizes the distribution zone. Production well S32551 provides water to a higher-altitude distribution zone, which is isolated by valves from pressure-feedback effects related to pumping of the S125632.

The study area is underlain by a 1,200-ft-thick sequence of clay, silt, sand, and gravel deposits that overlie southeastward sloping consolidated bedrock of Precambrian age (Smolensky and others, 1989). The sequence of unconsolidated deposits consists of several geohydrologic units ranging in age from late Cretaceous to Pleistocene. These units, from deepest to shallowest, are the Lloyd aquifer and the Raritan confining unit of Cretaceous age, the Magothy aquifer of Cretaceous age, and the upper glacial aquifer of Pleistocene age (fig. 2). No regional confining unit is present between the upper glacial and Magothy aquifers in the study area. The Lloyd aquifer and the overlying Raritan confining unit are not discussed further because the aquifer test had a negligible effect on water levels within the Lloyd aquifer as a result of its extensive confinement by the Raritan confining unit. The sequence from the Raritan confining unit up to the upper glacial aquifer is depicted along sections A–A′ and B–B′ in figure 2. In the upper part of the upper glacial aquifer, the aquifer generally acts as an unconfined aquifer; below about 100 ft, the upper glacial and Magothy aquifers generally act as confined or semi-confined aquifers due to numerous clay layers interspersed through the system.

The test well S125632 is just east of a former glacial meltwater channel in the Ronkonkoma moraine (fig. 2C) and penetrates the Magothy aquifer. The upper surface of the Magothy aquifer has a valley shape and a local maximum depth of nearly 500 ft (fig. 2A). The test well is located near the axis of the valley in the Magothy. Section A–A′ is transverse to this valley. At well S125632, section B–B′ is longitudinal to the valley in the upper surface of the Magothy aquifer and rotated about 30 degrees clockwise from the meltwater channel.

Previous studies estimated the average horizontal hydraulic conductivity (K_h) of the upper glacial aquifer at 270 ft/d with anisotropy of 10:1 (Smolensky and others, 1989); K_h of morainal deposits was estimated to be about half that of outwash deposits. Well S125632 is within the moraine (fig. 2C); however, it hydraulically affects outwash areas, such as the meltwater channel to the west. The screened interval of well S125632 appears to be near the top of the Magothy aquifer (Smolensky and others, 1989), probably less than 10 ft below the contact with the upper glacial aquifer. The Magothy aquifer in this area is reported to have a K_h of 50 ft/d and an average vertical hydraulic (K_v) conductivity of 0.5 ft/d (Smolensky and others, 1989).

Observation Wells

Five 4-in.-diameter steel-cased observation wells (TW1–TW5, fig. 3), about 100 ft from well S125632, were instrumented to record water-level and temperature data at 30-min intervals for a year preceding an aquifer test, at 30-s intervals during the test, and at 30-min intervals following the test. Elevations of land surface and measuring points (top-of-casing) were measured by USGS with global positioning equipment on May 21, 2008. Vertical distances between test-well screened intervals range from 60 to 120 ft (table 1). Each of the test wells, described below, is expected to respond uniquely during an aquifer test due to the presence of interspersed clay layers (table 2) that affect rates of groundwater flow toward the pumped well screen (fig. 4).

- Well TW1 is screened from 745 to 785 ft below land surface (BLS); this interval represents the lower part of the Magothy aquifer.
- Well TW2 is screened from 645 to 685 ft BLS, within the middle of the Magothy aquifer.
- Well TW3 is screened from 485 to 525 ft BLS, near the top of Magothy aquifer, in the same horizon as the screened interval of well S125632 screen.
- Well TW4 is screened from 330 to 370 ft BLS, within the upper glacial aquifer.
- Well TW5 is screened from 210 to 250 ft BLS, and its background water level before the aquifer test was about 55 ft above sea level, similar to an interpolation from a 2006 regional water-table map by Monti and Busciolano (2009).

Water levels in all observation wells may be affected by SCWA pumping at other well fields, including College Road (S32551) and Pleasant Drive (S66496), (fig. 2).

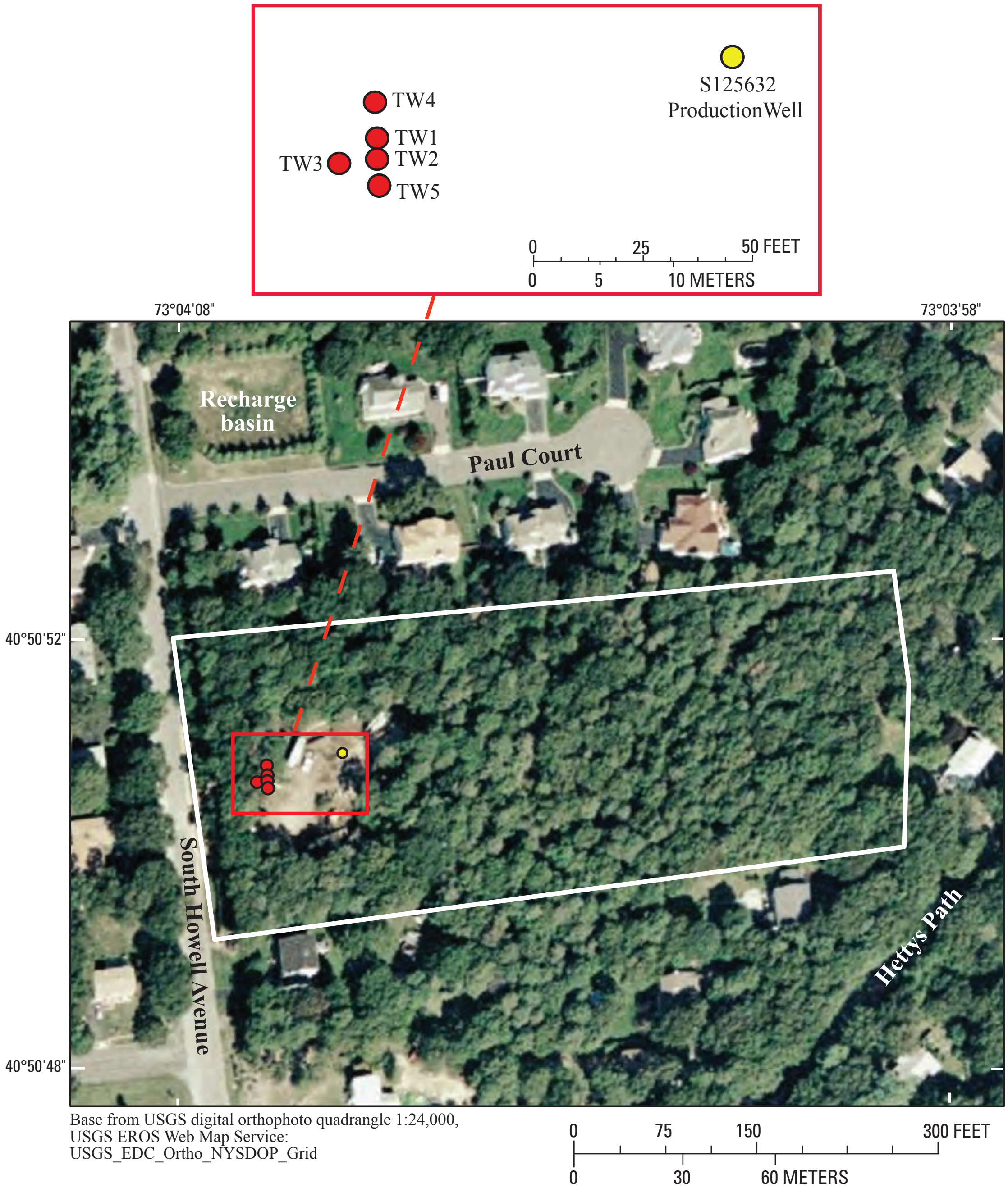

Figure 3. Aerial photograph of South Howell Avenue well field and detail showing distances between test wells TW1–TW5.

Table 1. Altitude of screened intervals of test wells at South Howell Avenue well field in Centereach, Suffolk County, N.Y.

[All values are in feet above and below (-) land surface and below (-) NAVD 88. Locations are shown in figure 3]

Well	Land-surface altitude	Screened interval	Depth (below land surface)	Depth (below NAVD 88)
TW1	121.40	Top	745	623.60
		Bottom	785	663.60
TW2	121.58	Top	645	523.42
		Bottom	685	563.42
TW3	121.03	Top	485	363.97
		Bottom	525	403.97
TW4	121.48	Top	330	208.52
		Bottom	370	248.52
TW5	121.51	Top	210	88.49
		Bottom	250	128.49

Table 2. Driller's log for well S125632 (formerly test hole S-117926T), South Howell Avenue well field in Centereach, Suffolk County, N.Y.

[From Steven Colabufo, Suffolk County Water Authority, written commun., 2008]

Depth below land surface (feet)	Description
0–5	Loam
5–25	Loam, sand and gravel
25–185	Sand and gravel
185–195	Clay, silt, and fine sand
195–235	Sand and gravel
235–250	Clay, silt, and sand; orange
250–255	Sand
255–270	Clay and silt; white
270–310	Medium sand; white
210–350	Medium-coarse sand, very thin layers; white clay
350–398	Fine sand and silt; orange and gravel
398–419	Medium-fine sand, silt, and clay
419–424	Dark gray clay
424–453	Fine sand and silt
453–460	Clay "hard"
460–510	Fine sand and silt
510–513	Clay
513–530	Medium-fine sand, some silt
530–532	Clay
532–575	Layers, fine sand and silt; silt
575–596	Medium-fine sand and silt
596–610	Clay; white
610–625	Sand and gravel, silt and clay
625–645	Clay, silt, stones, some sand
645–705	Sand and gravel, some silt
705–723	Red and white clay; hard
723–773	Fine-medium sand, silt and clay
773–775	Clay
775–818	Fine-medium-coarse sand, gravel, stones, silt and clay
818–820	Clay and gravel
820–860	Fine sand and silty clay

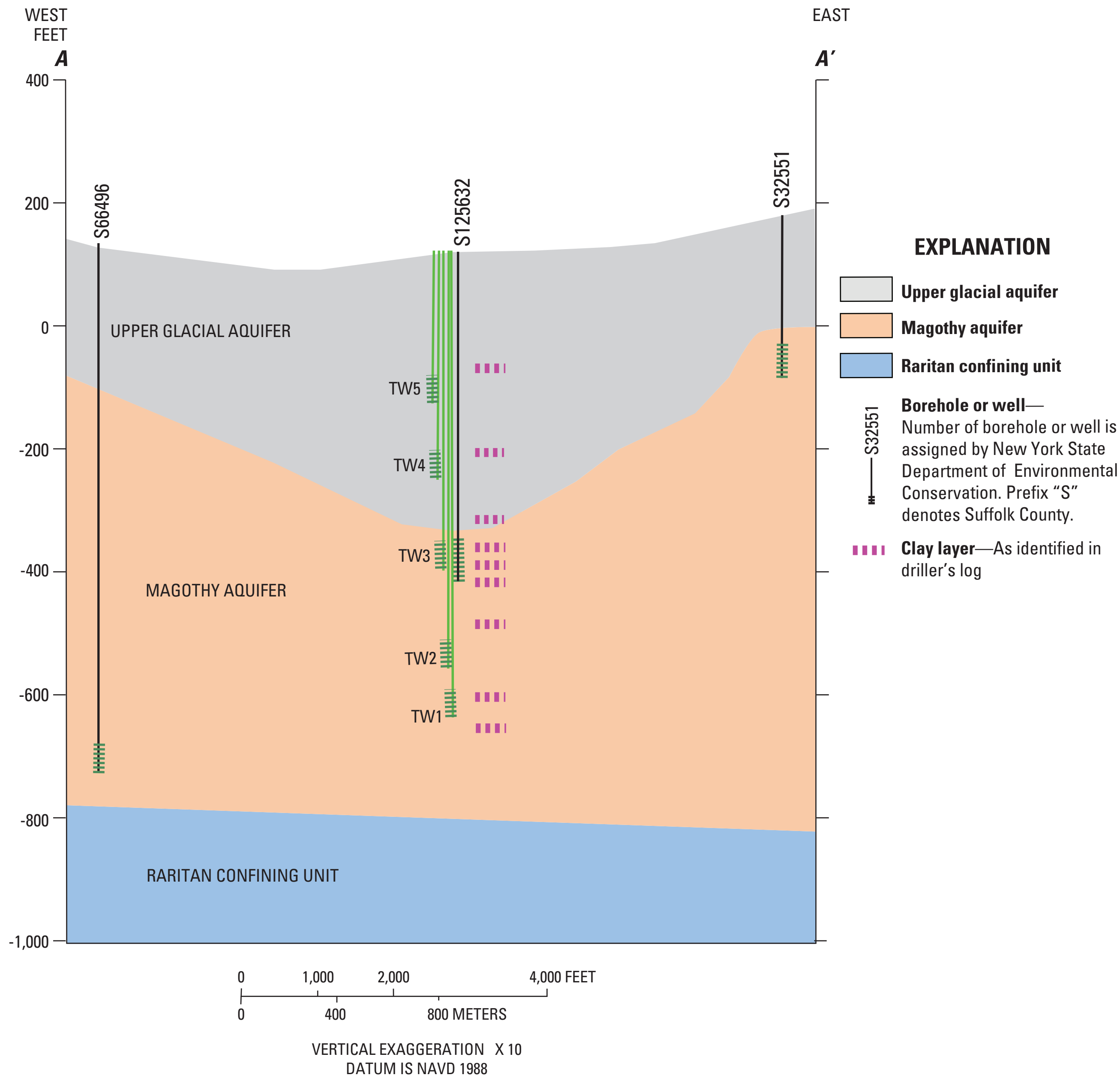

Figure 4. Vertical section *A–A′* showing screened intervals of test wells TW1–TW5 and well S125632, and clay layers identified in driller's log.

Production Wells

Production well S125632 was constructed during 2007–08. A specific-capacity test was run on November 9, 2006. The well was developed for a total of 80 hours, and the measured specific capacity was 22.08 [gal/min]/ft at a pumping rate of 1,005 gal/min. The screen is 40 ft long and 10 inches in diameter with 0.055-in. slots; it was installed between 481.7 and 522 ft below land surface. A simplified diagram of the well construction is shown in figure 5. The 116-ft gravel pack is filled with a mixture of 50-percent grade 2 Ricci well gravel and 50-percent grade 3 Ricci well gravel (Ricci Brothers Sand Company, accessed October 10, 2008, at http://www.riccisand.com/pages/well_gravel.html).

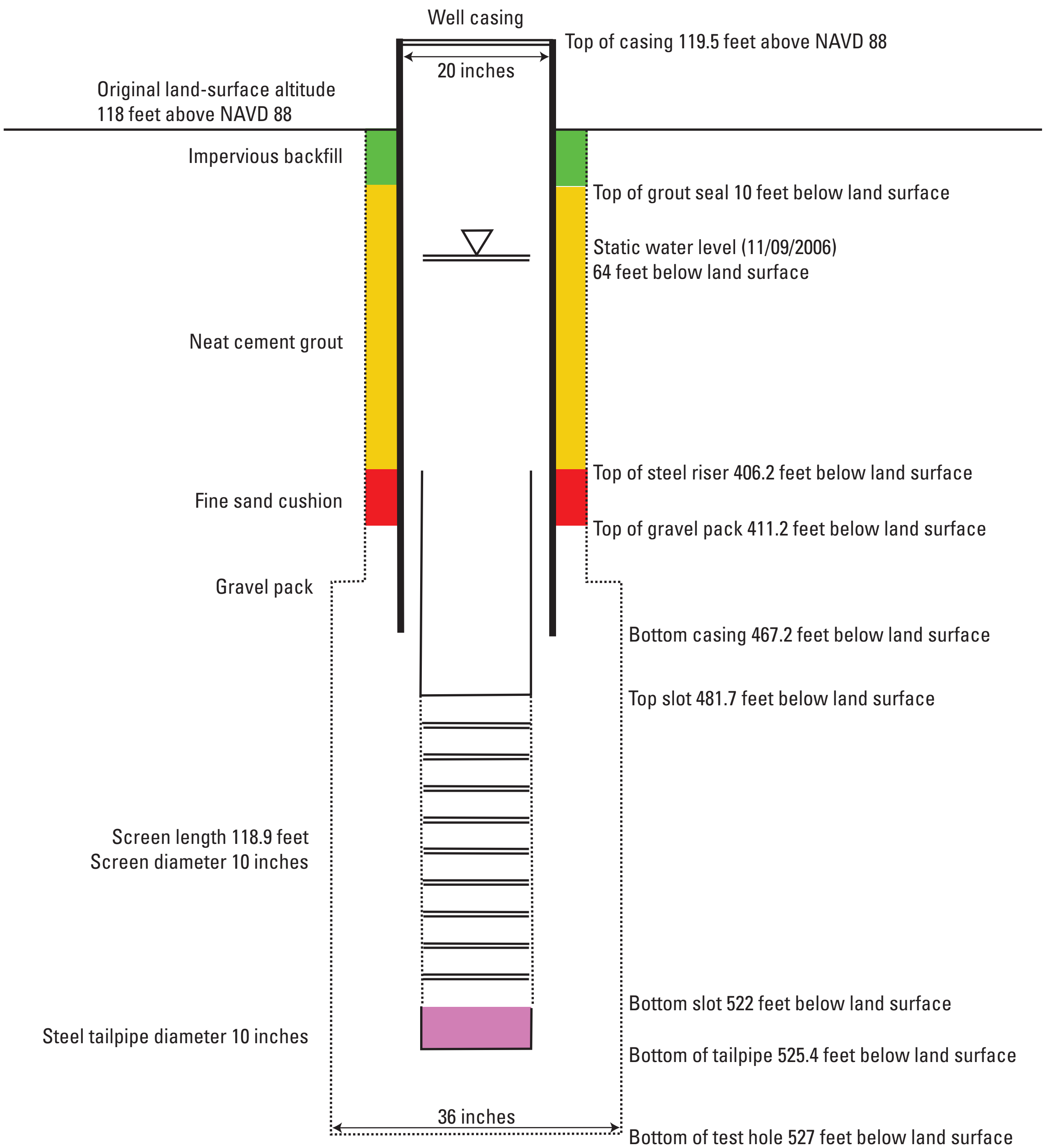

Figure 5. Construction characteristics of well S125632.

Two other well fields had a muted effect on the water-level response testing the observation wells. The Pleasant Drive well field (at well S66496, fig. 1) provides water for SWCA distribution zones 12 and 15; water that is provided to zone 15 results in distribution pressure feedback at the aquifer test well (S125632), whereas water provided to distribution zone 12 does not. Venturi flow meters are placed at points of distribution-zone entry after waters from several wells are mixed and treated; records of pump on-and-off times are maintained. The withdrawals from screened intervals are estimated from the Venturi flow-meter measurements, which are apportioned by periods of well operations and ratios of pump capacity (table 3). The construction characteristics of wells at Pleasant Drive (S66496) and College Road (S32551, fig. 1) are similar to those of well S125632.

Hydraulic Properties of the Aquifer System

Aquifer hydraulic properties may be estimated by observing the response to pumping stress and using these data to develop and calibrate aquifer-test models. Model characteristics, including hydraulic property values, initially may be assigned through interpolation or extrapolation of the results of previous studies. During model calibration, as observed response data are compared with model responses, model hydraulic property values are adjusted to improve matches to the observed data. Finally, model sensitivity analysis, whereby a fully calibrated model is subjected to a comprehensive series of tests, may be conducted to improve the assumptions incorporated into the model, thereby

Table 3. Screened interval, and well capacity of wells at well fields near Centereach, Suffolk County, N.Y.

[Depths are in feet. gal/min, gallons per minute. Locations are shown in fig. 1]

Well field and well number	Land-surface altitude (NAVD 88)	Screened interval	Depth below land surface	Depth below NAVD 88	Capacity (gal/min)
South Howell Avenue					
S125632	121.399	Top	481.7	-363.60	1,100
		Bottom	522	-423.60	
Pleasant Drive					
S66946	40	Top	726	-686	1,300
		Bottom	766	-726	
S39347	127	Top	135	-8	1,200
		Bottom	175	-48	
S42760	127	Top	134	-7	1,200
		Bottom	174	-47	
College Road					
S32552	177	Top	203	-26	1,000
		Bottom	243	-66	
S54473	169	Top	322	-153	1,400
		Bottom	362	-193	
S32551	173	Top	205	-32	1,000
		Bottom	245	-72	

improving results, and to compare the results with results from previous modeling studies.

The models calibrated in this study were developed theoretically by Hantush and Jacob (1955) and Hantush (1964), and were originally intended to be used without a computer. However, computers have facilitated the incorporation of a high level of complexity into model applications. A complex time-series of pumping stresses at well S125632 is represented in the model, and some of the models described here also represent additional stresses from neighboring production wells.

Aquifer Test

The construction of well S125632 was completed on May 4, 2008. At this time, the SCWA delayed its normal operation of the well in order to carry out an aquifer test with three 72-hour periods: a preliminary resting period, a pumping period, and a recovery period. On May 14, SCWA resumed normal unscheduled operation of the well field. During the aquifer test, neighboring wells were operated normally. SCWA recorded the time series of pumpage at each of its well fields (Appendix A) and USGS measured water levels and temperature at observation wells.

Well-Field Pumpage and Pressure Data

Well field pumpage into the SCWA distribution system was affected by the local daily water-demand cycle, which peaks in the early morning hours of summer at the onset of automatic lawn sprinkling (fig. 6). As distribution zone pressure decreases, well pumps automatically turn on, resulting in pressure increase; furthermore, if zone pressure decreases during pumping, pumpage increases slightly due to more efficient pump operation. A 72-hour resting (non-pumping) period began on May 4 to ensure stable water levels in the aquifer at the beginning of a 72-hour pumping period, which formed the basis of hydraulic property estimates. During the pumping period, pumping was maintained at a relatively stable discharge rate for 72 hours (fig. 6). The pumping period was followed by a recovery period of 72 hours, then by normal operation of the well field, with well S125632 turned off pending further well field work. There were several short periods of pumping of well S125632 on May 10 during the 72-hour recovery period, possibly due to an error in the pump shutoff control. For several hours on May 5 and May 12, during the rest and recovery periods, the South Howell Avenue well field was depressurized upstream from a check valve connection to distribution zone 12.

Inspection of the time-pumpage and pressure graph (fig. 6) of the South Howell Avenue well field in conjunction with the corresponding graph of the Pleasant Drive well field indicates some hydraulic interference. The South Howell Avenue well field lies at the approximate center of section A–A′ (fig. 1). Well S125632 of the South Howell Avenue well field and well S66496 of the Pleasant Drive well field both provide water to SCWA distribution zone 12 and tend to be pumped one at a time because simultaneous pumping over-pressurizes the distribution zone. During the later part of the aquifer test period on May 9 and 10 (fig. 6), pressure at S125632 is slightly above average and total pumpage from the Pleasant Drive well field is reduced.

The College Road well field (S32551) solely provides water to the higher-altitude distribution zone 15, which is isolated by closed valves from pressure feedback effects within zone 12. Therefore, the effects of well interference between the South Howell Avenue well field and the College Road well field are of a more random nature than those effects between the South Howell Avenue well field and the Pleasant Drive well field. However, all well fields are subject to the effects of the local daily water-demand cycle.

Observation-Well Data

Water-level records of the six USGS wells along section B–B′ (fig. 1) are available from the National Water Information System (NWIS, http://waterdata.usgs.gov). Well S33380, about 10,000 ft southwest of section A–A′ (fig. 1), has a long-term periodic record starting in 1968 (fig. 7A) and a continuous record from July 1, 2007 (fig. 7B). This well is screened deep in the Magothy aquifer, appears to have a more direct hydraulic connection to well S66496 than to the aquifer test well (S125632), and shows a slight response (fig. 7) to pumping at the Pleasant Drive well field (S66496) (fig. 1).

Water levels and water temperatures at South Howell Avenue observation wells TW1 through TW5 were measured at 30-minute intervals before and after the aquifer test and at 30-second intervals during the preliminary resting, pumping, and recovery periods of the pumping test from May 4 to 13. Inspection of the 30-second data reveals a 2-hour period on May 10, during the recovery period, when pumping occurred (17:00–19:00, fig. 8). The water levels in five test wells (TW–TW5) during the pumping and recovery period (May 3–15) are plotted in figure 9. In addition to a 2-hour pumping pulse on May 10 at S125632, there were two short pumping pulses on May 11 and 12. These pulses were not recorded as pumpage from the pump house (fig. 6) because these waters were wasted to a sump at the well field, because of a valve failure (Steven Colabufo, oral commun., 2008) and did not pass through the discharge meter. There were also numerous other minor influences on TW1 through TW5 by pumping of distant wells other than S125632, and seasonal water level decline. Water levels were not corrected for these influences due to the small relative magnitude of change in comparison to change resulting from the aquifer test.

A storm with a barometric-pressure drop of about 10 millibars and a rainfall of about 1 inch coincided with

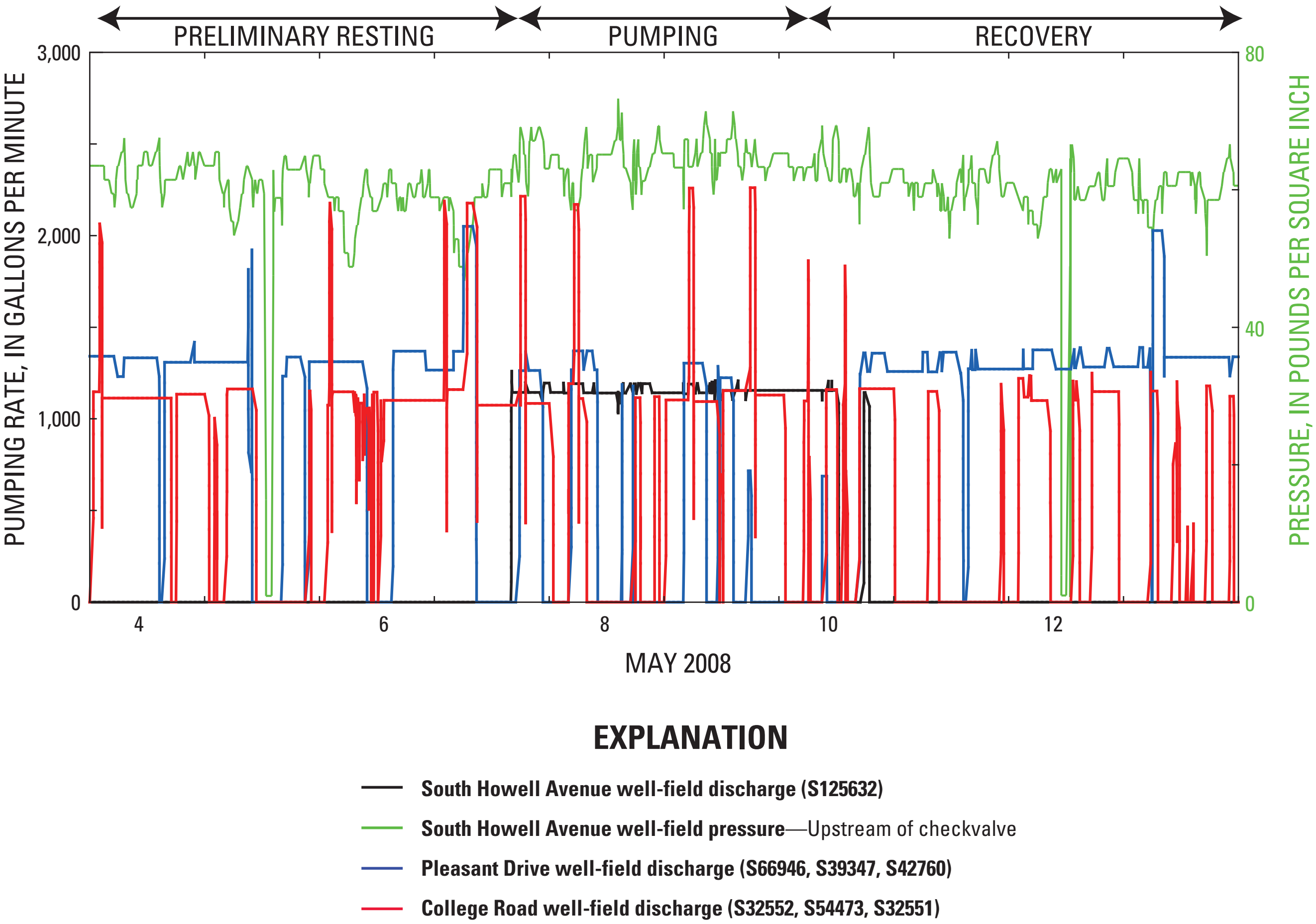

Figure 6. Pumpage and pressure during 72-hour aquifer test at South Howell Avenue, Pleasant Drive, and College Road well fields, beginning on May 4, 2008. (Data shown in Appendix A.)

the pumping phase of the aquifer test. Water levels and barometric pressure at observation wells during the resting, pumping, and recovery periods (May 3–12) are plotted in figure 10. Barometric pressure and rainfall amounts were recorded at the USGS Point Lookout gaging station on Long Island, N.Y. (available at http://waterdata.usgs.gov/usa/nwis/uv?site_no=01310740, accessed June 1, 2008). Appendix B lists hourly precipitation recorded at the National Oceanic and Atmospheric Administration (NOAA) weather station at Islip airport, located about 3 mi southwest of Centereach (NOAA Satellite and Information Service, 2008). The most distinct barometric pressure effect occurs from about May 3, 22:00 to May 5, 13:00 when a maximum water-level increase of about 0.1 ft was observed in any well. Water-levels were not corrected for barometric variation or storm recharge due to the small relative magnitude of change in comparison to change resulting from the aquifer test.

Model Theory and Application

The Hantush model (1964) was chosen for its ability to represent aquifer-system characteristics that have the greatest effects on water-level response at observation wells TW1 to TW5 to pumping stress at S125632. Model calibration began with parameter values taken used in previous studies, then continued with adjustments and representation of additional complexities aimed at improving the match of simulated water levels to observed data. Horizontal and vertical hydraulic conductivity, transmissivity, and storativity were estimated inversely in this way. Finally, model sensitivity analysis, whereby a fully calibrated model is subjected to a comprehensive series of tests, was conducted to improve understanding of assumptions incorporated in the model and the resulting implications, and to compare results with those of previous studies.

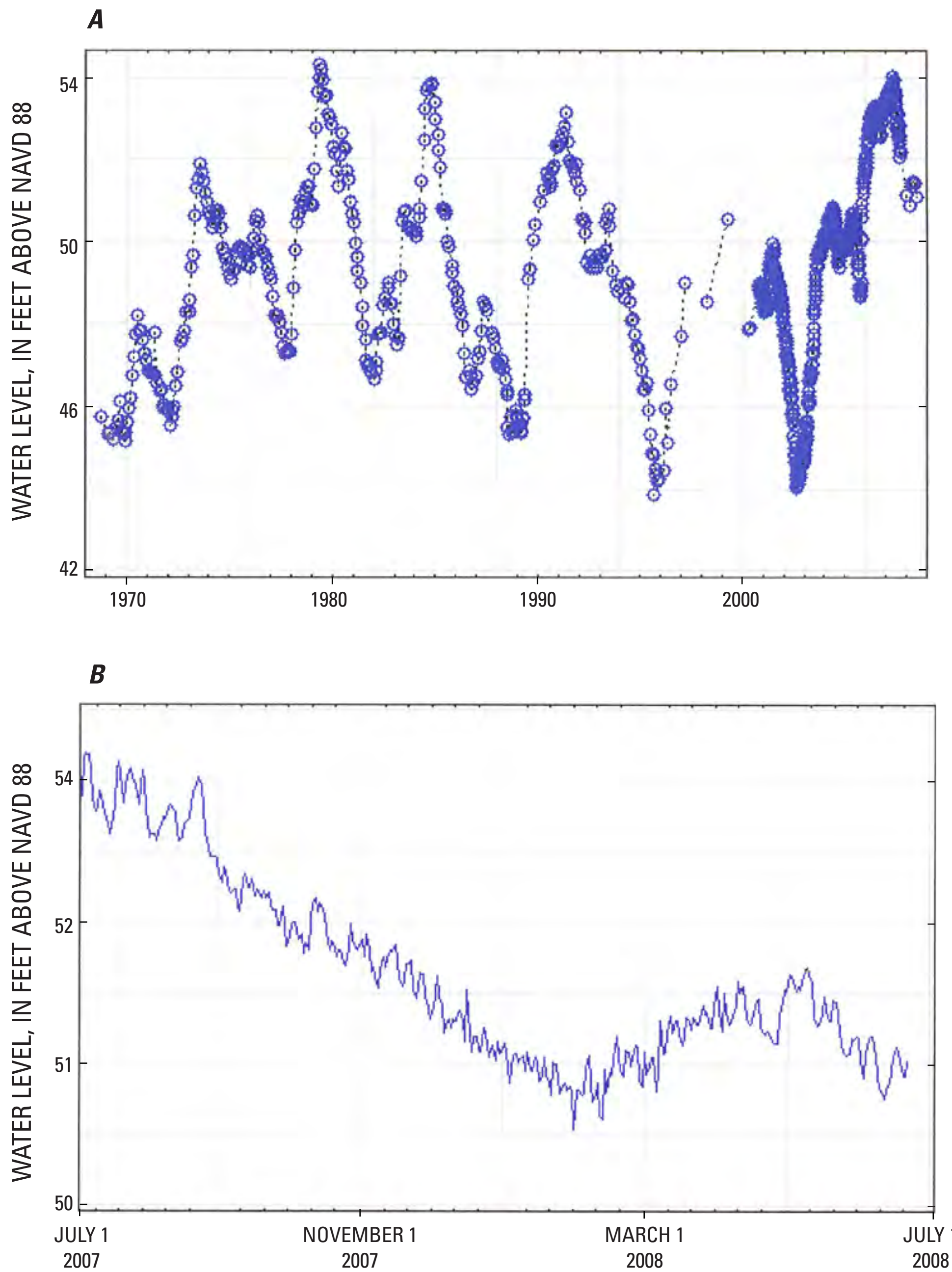

Figure 7. Water levels in well S33380, 10,000 feet southwest of the production well, in the (A) monthly-value record, 1968–2008, and (B) daily-value record, July 2007 through June 2008.

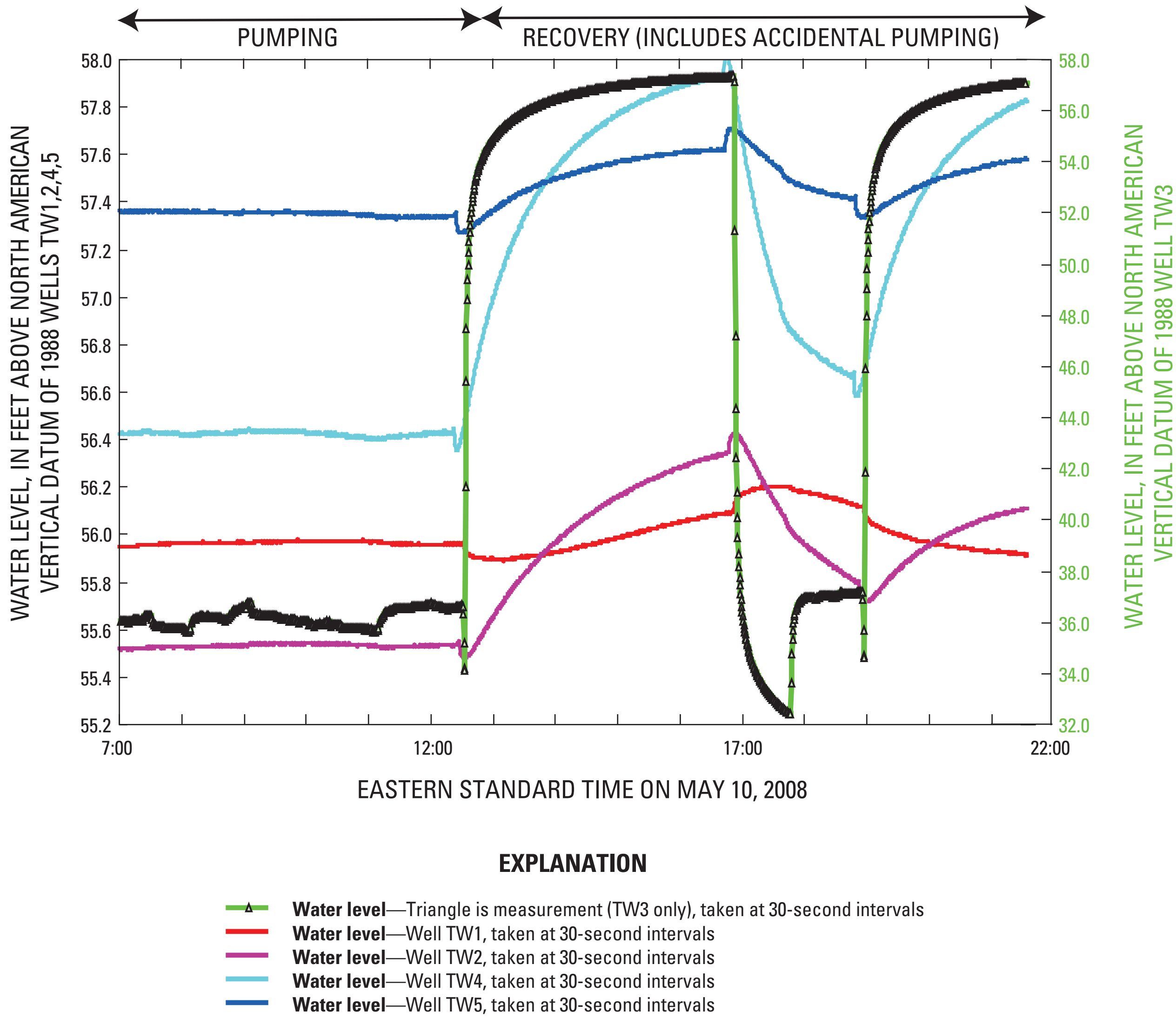

Figure 8. Water levels in Suffolk County Water Authority test wells TW1–TW5, May 10, 2008.

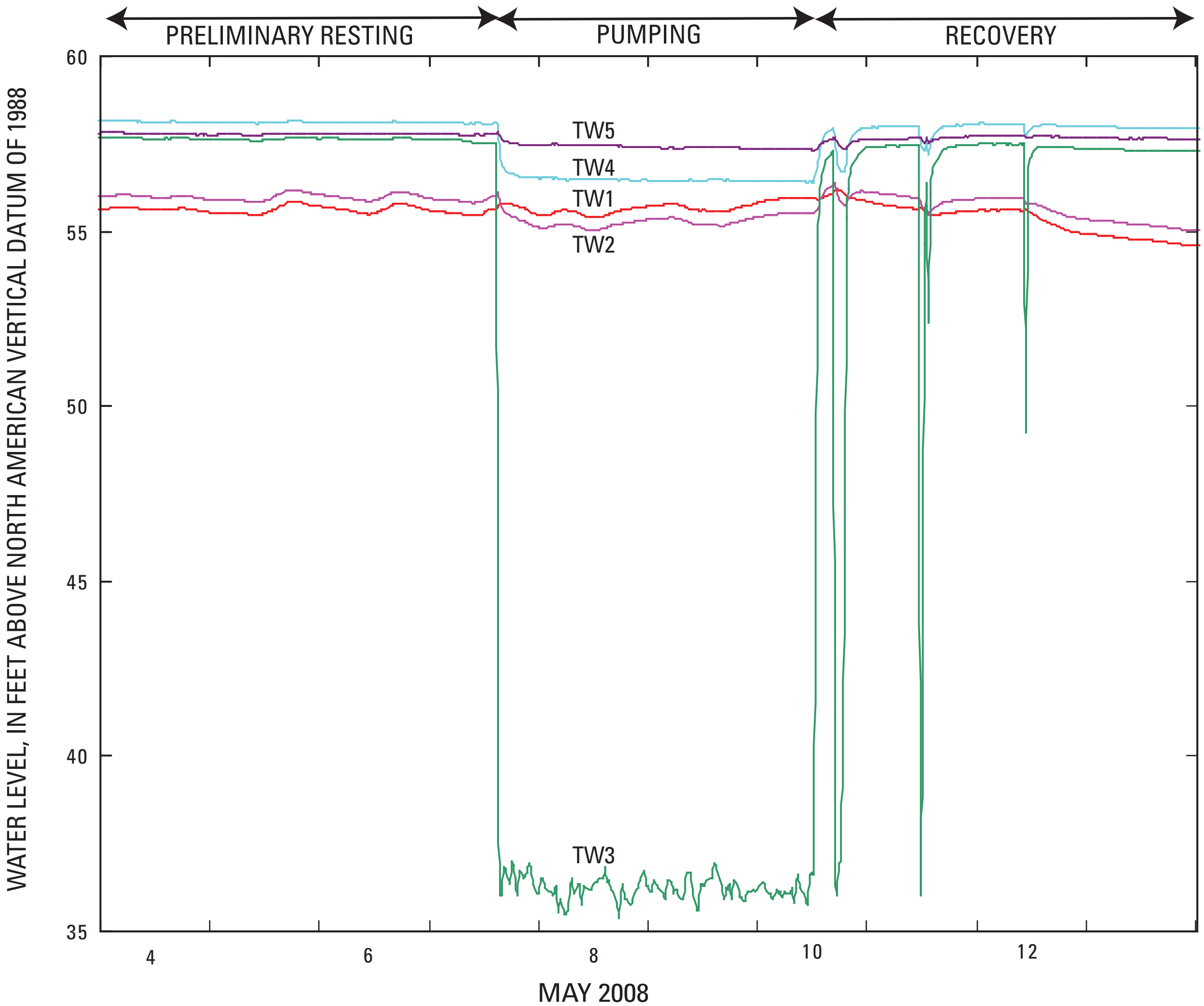

Figure 9. Water levels in Suffolk County Water Authority test wells TW1–TW5, May 4–13, 2008.

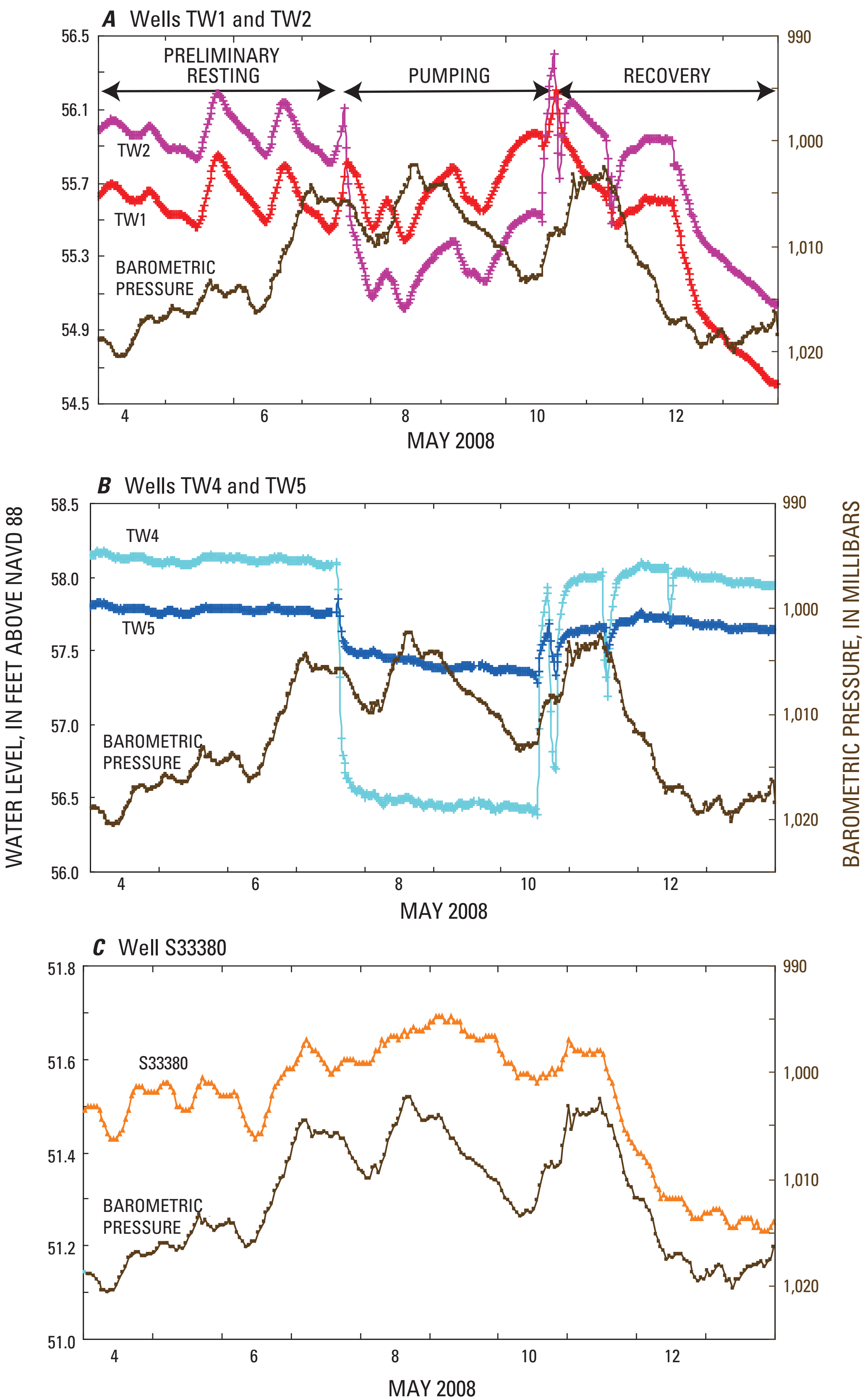

Figure 10. Water levels and barometric pressure at Suffolk County Water Authority test wells and S33380, during aquifer test, May 4–13, 2008, in (A) Wells TW1 and TW2, (B) Wells TW4 and TW5, and (C) Well S33380.

Theory

Hantush and Jacob (1955) derived the following analytical model for predicting displacement in response to pumping in a homogeneous, isotropic, leaky confined aquifer, assuming steady flow:

$$s = \frac{Q}{4\pi T} \int_{u}^{\infty} e^{\left(-y - r^2 / 4B^2 y\right)} \frac{dy}{y} \tag{1}$$

where

- B is the Hantush leakage parameter [LENGTH],
- Q is pumping rate [LENGTH^3/TIME],
- r is radial distance [LENGTH],
- s is displacement [LENGTH],
- T is transmissivity [LENGTH^2/TIME],
- u is a time parameter [DIMENSIONLESS], and
- y is distance [LENGTH].

B is defined as follows:

$$B = \sqrt{\frac{Tb'}{K'}} \tag{2}$$

where

- b' is confining unit thickness [LENGTH], and
- K' is vertical hydraulic conductivity of the confining unit [LENGTH/TIME].

The integral expression in the displacement equation can be abbreviated as exponential integral function $w(u, r/B)$, where u is defined as follows:

$$u = \frac{r^2 S}{4Tt} \tag{3}$$

where

- S is storativity [DIMENSIONLESS], and
- t is time [TIME].

Therefore, we can write the displacement equation compactly as follows:

$$s = \frac{Q}{4\pi T} w(u, r/B) \tag{4}$$

Hantush (1964) extended the displacement equation to represent the effects of partial penetration of pumping and observation well screens, anisotropy in hydraulic conductivity, and leakage across top and bottom aquifer boundaries. Corrections for a partially-penetrating observation well, anisotropy, and leakage are included as follows:

$$s = \frac{Q}{4\pi T}\left(w(u, r/B) + \frac{2b}{\pi(1-d)} \sum_{n-1}^{\infty} \frac{1}{n}\left(\sin(\frac{n\pi l}{b}) - \sin(\frac{n\pi d}{b}) \right) \cdot \cos(\frac{n\pi z}{b}) \cdot w(u, \sqrt{\left(\frac{r}{B}\right)^2 + \frac{K_z}{K_r}\left(\frac{n\pi l}{b}\right)^2}\,) \right) \tag{5}$$

where

- b is aquifer thickness [LENGTH],
- d is depth to top of observation well screen [LENGTH],
- l is depth to bottom of observation well screen [LENGTH],
- K_r is radial hydraulic conductivity [LENGTH/TIME],
- K_z is vertical hydraulic conductivity [LENGTH/TIME], and
- z is depth to the well screen opening [LENGTH].

The correction for a partially-penetrating pumping well is included as follows:

$$s = \frac{Q}{4\pi T}\left(w(u, r/B) + \frac{2b^2}{\pi^2(1-d)(l'-d')} \sum_{n^2}^{\infty} \frac{1}{n^2}\left(\sin(\frac{n\pi l}{b}) - \sin(\frac{n\pi d}{b}) \right) \cdot \left(\sin(\frac{n\pi l'}{b}) - \sin(\frac{n\pi d'}{b}) \right) \cdot w(u, \sqrt{\left(\frac{r}{B}\right)^2 + \frac{K_z}{K_r}\left(\frac{n\pi r}{b}\right)^2}\,) \right) \tag{6}$$

where

- d' is depth to top of pumping well screen [LENGTH], and
- l' is depth to bottom of pumping well screen [LENGTH].

Application

Two alternative model applications were developed as follows: model A was configured with only the pumping stress of S125632 and model B was configured with additional pumping stresses of the two other wells, S66496 and S32551 (screen depths given in table 3) (Appendix C). The following assumptions (fig. 11) were incorporated into both models: (1) infinite areal extent; (2) homogeneity; (3) uniform 600-ft thickness; (4) flow is unsteady; (5) water is released instantaneously from storage with the decline of head; (6) no storage within the pumped well, upper and lower clay layers indentified in drillers log (table 2, fig. 4) are underlain and overlain by a constant-head plane source to represent leakage; and (7) leakage is vertical across confining layers. Representation of leakage across the overlying confining layer was likely oversimplified as a result of the following: (1) generalized model geometry and (2) lack of representation of groundwater recharge due to a rainfall during the aquifer test. Precise representation of these characteristics would require numerical methods which were beyond the scope of this study. The hydraulic conductivity of the aquifer system in which the pumped well is screened was initially specified to be 50 ft/d horizontal and 0.5 ft/d vertical, typical values for the Magothy aquifer, equivalent to previous estimates by McClymonds and Franke (1972) and Koszalka (1980). The aquifer was assumed to have a thickness of 600 ft and is comprised of part Magothy and part upper glacial deposits. Transmissivity was initially specified at 30,000 ft^2/d.

Model calibration was conducted by using the AQTESOLV software version 4 (http://www.aqtesolv.com/) and visual trial-and-error techniques with time series parsed to 30-minute intervals, and water levels were converted to displacement (drawdown) from the initial levels of May 2, 12:00 am. Models A and B were matched to positive displacements in log-log scaling (figs. 12 and 13). The slight negative displacements observed were due to factors such as rainfall, irrigation, and barometric pressure decrease, and are not representable in log space, nor are they theoretically possible to simulate with the Hantush model as applied. Calibration of wells TW3 and TW4 during periods of S125632 pumping was emphasized because TW3 and TW4 are the wells most directly affected by S126532 (Appendix C).

Neither model was able to entirely reproduce the fine-scaled details observed in displacements. There appear to be the following slight regional displacements that were not modeled: (1) positive displacement (water-level decline) that typically occurs on Long Island as a result of relatively

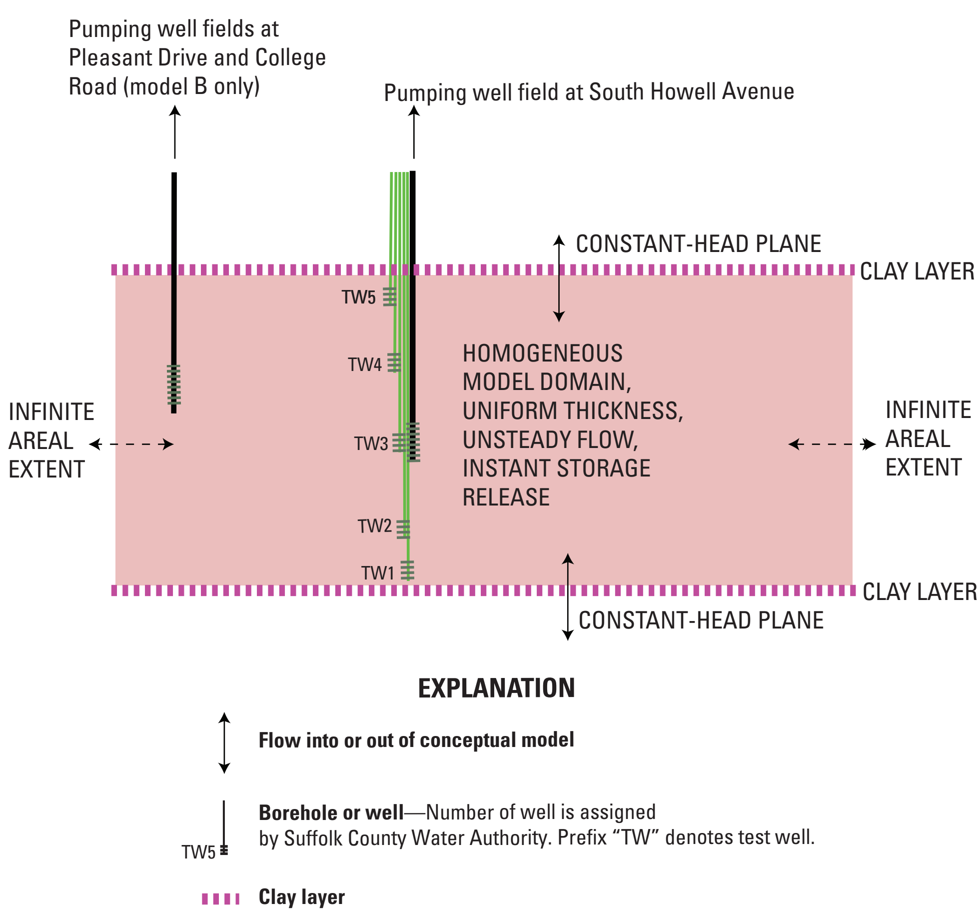

Figure 11. Conceptual diagram of aquifer-test models.

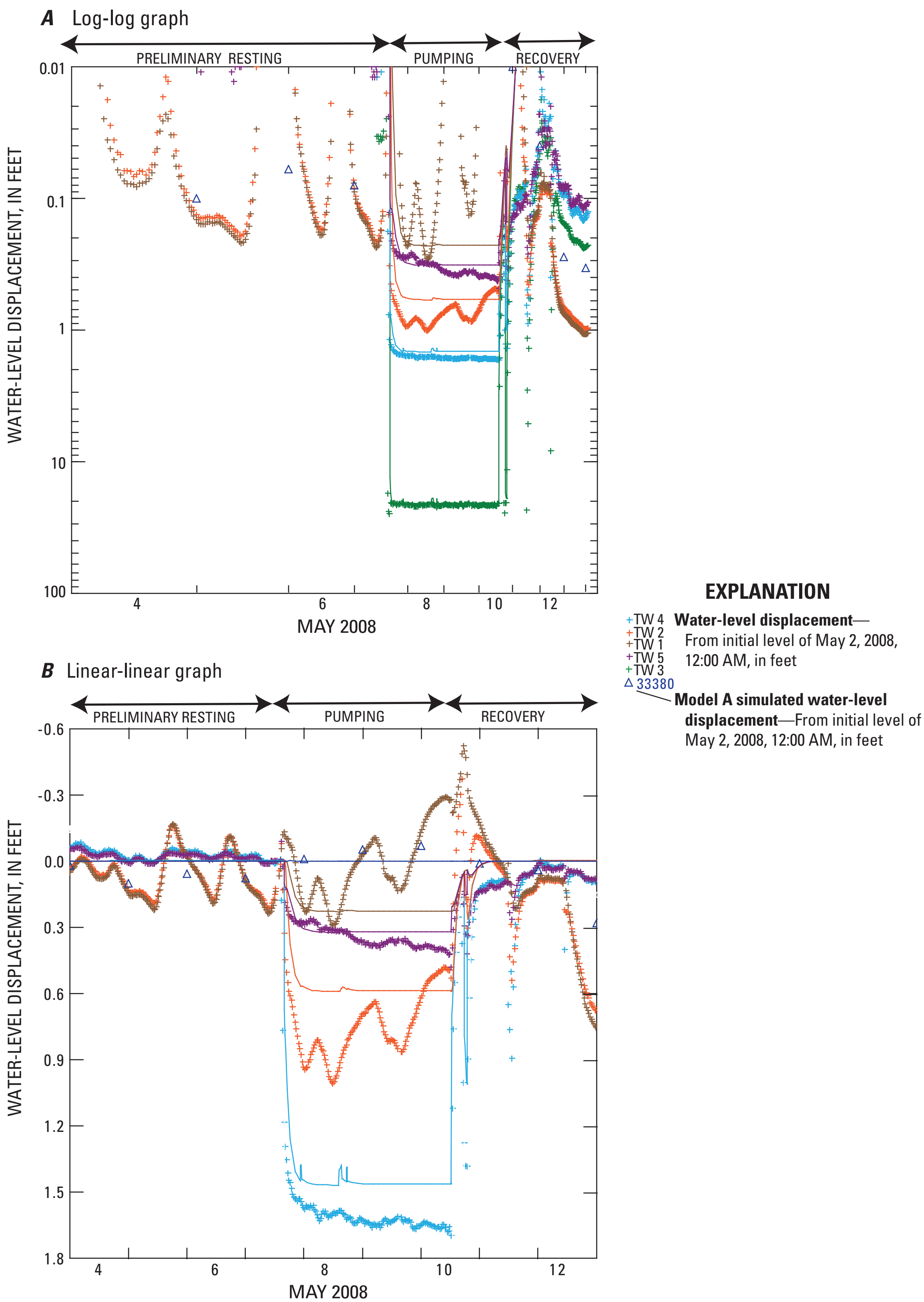

Figure 12. Simulated and observed displacement in test wells TW1–TW5 and observation well S33380 during an aquifer test at well S125362 (Model A), May 4–12, 2008, in (A) log-log graph, and (B) linear-linear graph.

high levels of pumpage and low levels of groundwater recharge during the summer growing season; (2) negative displacement (water-level increase) that occurred as a cold front passed through the area on May 7–12, causing water levels to increase as a result of barometric pressure decrease and rainfall (fig. 10); and (3) daily shallow-well water-level oscillations that may be due to residential timed irrigation systems or domestic-water disposal in septic systems. During the recovery period, there appear to be the following localized displacements that were not modeled: (1) on May 11 and 12, there were three rapid positive displacements that likely were correlated with short periods of pumping that were not recorded in the SCWA South Howell Avenue well field (S125632) pumpage data, (2) a rapid negative displacement occurred during the early part of the recovery period in shallow wells TW1 and TW2, which may be attributed to disposal of S125632 pumpage at an onsite recharge sump during a failure of the water-treatment system (Steven Colabufo, Suffolk County Water Authority, oral commun., 2008.) It is unlikely that most of the non-modeled fine-scale displacements can be represented efficiently with an analytical model such as that described by Hantush (1964). More efficient modern methods such as numerical flow modeling may be a more fruitful approach, but that was beyond the scope of this study.

Hydraulic properties of the aquifer system at Centereach, as estimated by calibrations (figs. 11 and 12) of both model A (Hantush and Jacob, 1955) and model B (Hantush, 1964), were as follows:

- Transmissivity: 30,000 ft^2/d,
- Anistropy ratio of K_v to K_h : 0.01 [dimensionless],
- Storativity: 0.003 [dimensionless],
- Confining layer leakage parameter “1/B”, also known as the aquifer loss coefficient: 0.00083 ft^{-1}.

Hydraulic conductivity of the 600-ft thick aquifer system centered at S125632 and including TW1-5 is estimated to be about 50 ft/d horizontal and 0.5 ft/d vertical, typical values for the Magothy aquifer. The K_h estimate of 50 ft/d horizontal and 0.5 ft/d vertical agrees with previous hydrogeologic framework and flow modeling studies of the Magothy aquifer (McClymonds and Franke, 1972; Koszalka, 1980; Misut and Feldman, 1996; and Buxton and Shernoff, 1999). However, some highly permeable glacial sands likely were included within the upper part of the modeled aquifer system, indicating that the aquifer system directly affected by pumping of S125632, as conceptualized to include parts of the both the

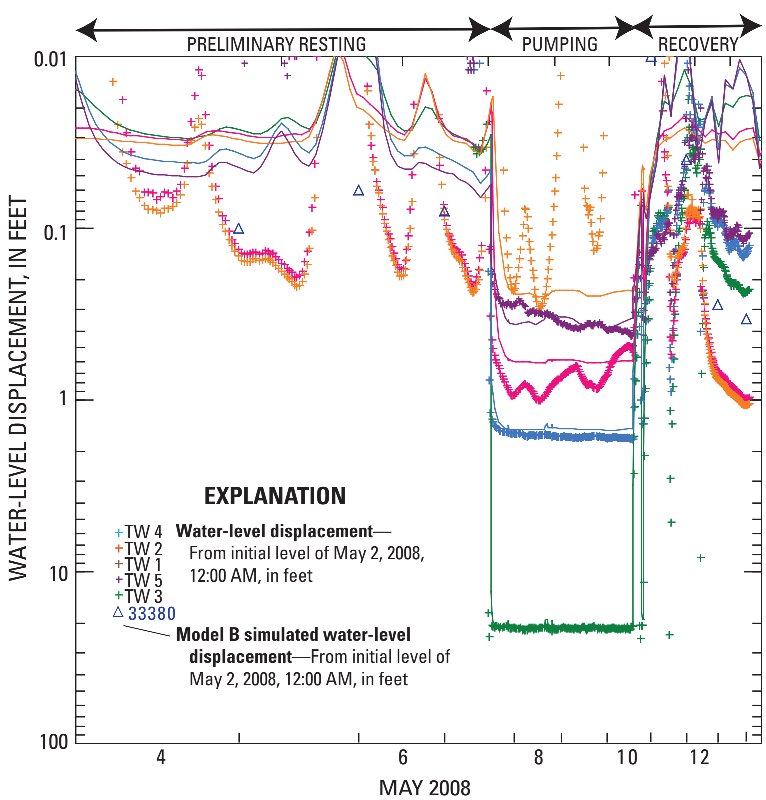

Figure 13. Simulated and observed displacement in test wells TW1–TW5 and S33380 during an aquifer test at well S125362 (Model B), May 4–12, 2008, in a log-log graph.

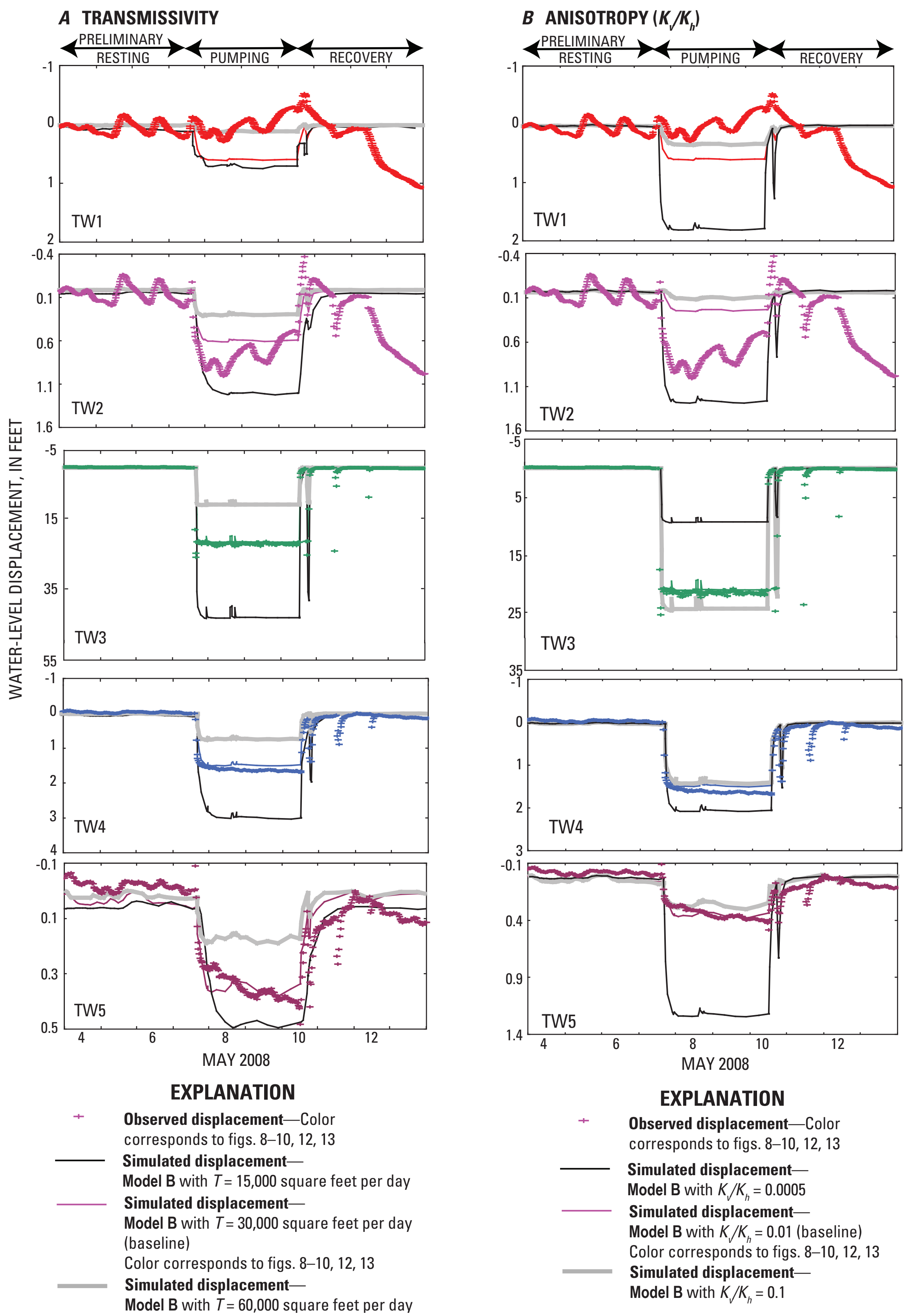

Figure 14. Simulated and observed displacement for a sensitivity analysis of model B for (A) transmissivity *(T)*, (B) ratio of vertical to horizontal hydraulic conductivity *(K_v/K_h)*, (C) Hantush leakage parameter, and (D) storativity *(S)* at test wells TW1–TW5, May 4–12, 2008. (Data shown in Appendixes C and D.)

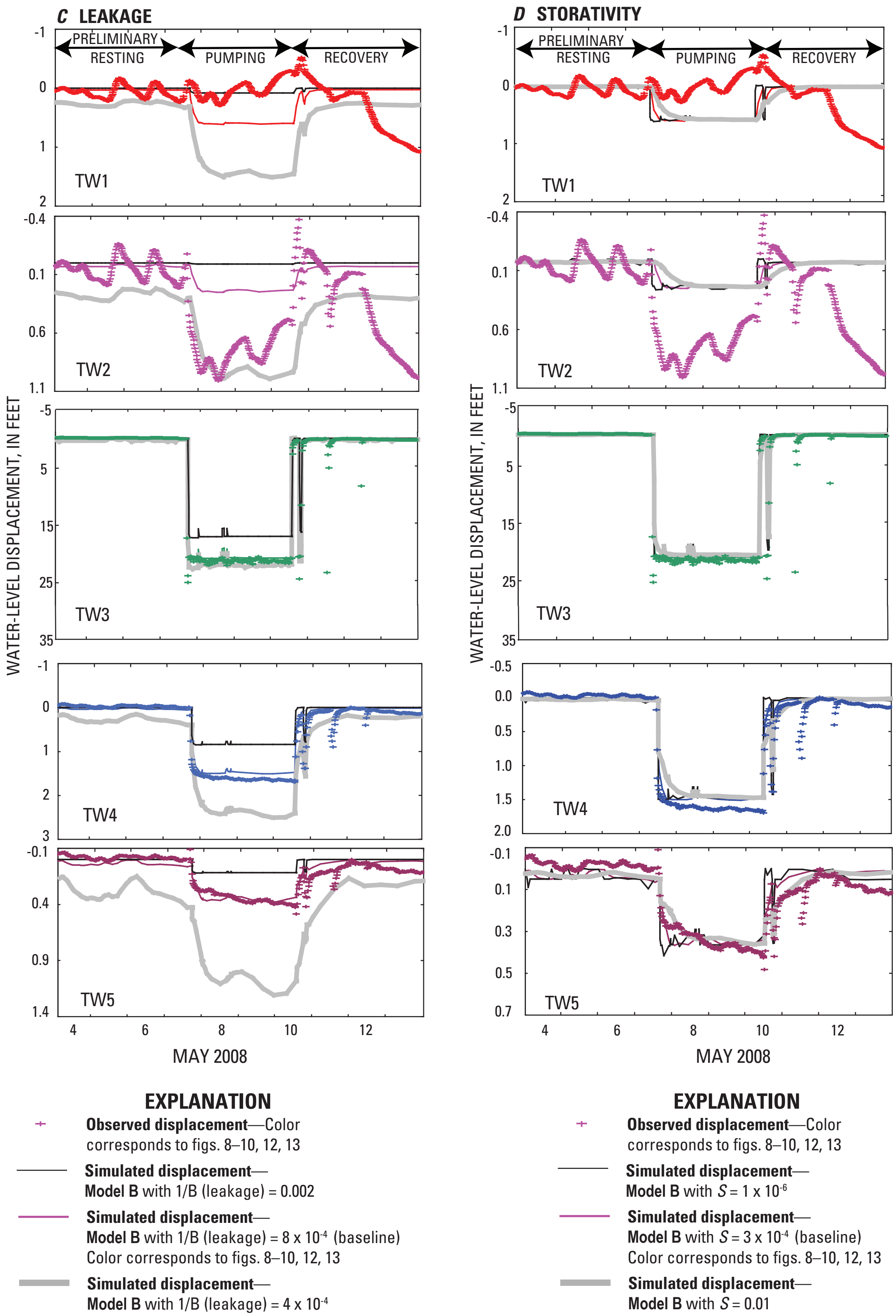

Figure 14. Simulated and observed displacement for a sensitivity analysis of model B for (A) transmissivity *(T)*, (B) ratio of vertical to horizontal hydraulic conductivity *(K_v/K_h)*, (C) Hantush leakage parameter, and (D) storativity *(S)* at test wells TW1–TW5, May 4–12, 2008. (Data shown in Appendixes C and D.)—Continued

glacial and Magothy aquifers, is less hydraulically conductive than previously estimated.

The accuracy of the hydraulic-property estimates was tested through sensitivity analysis (Appendixes C and D) of the following model parameters: transmissivity, anisotropy (ratio of K_v to K_h), leakage, and storativity to displacement at TW1–5.

The following transmissivity range was incorporated into the model: 15,000 ft^2/d (low value) to 30,000 ft^2/d (baseline) to 60,000 ft^2/d (high value). The low value resulted in greater displacement than the baseline, and the high value resulted in lesser displacement than the baseline in all TW wells (fig. 13). Doubling or halving transmissivity effectively doubled or halved the simulated displacement in all wells.

The following anisotropy range was incorporated into the model: 0.0005 (low value) to 0.01 (baseline) to 0.1 (high value). The low value resulted in greater displacement than the baseline and the high value resulted in lesser displacement than the baseline for all TW wells except TW3, in a fashion similar to the transmissivity results (fig. 13) The opposite effect of parameter variation occurred at TW3 because of the vertical proximity of TW3 to the stress at S125632.

The following leakage (1/B) range was simulated: 0.002 (high value) to 0.0008 (baseline) to 0.004 (low value). The low value resulted in greater displacement than the baseline, and the high value resulted in lesser displacement than the baseline for all TW wells (fig. 13). As leakage of water across the upper and lower confining layers (fig. 14) increases, displacement in the TW wells decreases because a less severe hydraulic gradient is necessary to produce the leakage.

The following storativity range was incorporated into the model: 0.01 (high value) to 0.0003 (baseline) to 1×10^{-6} (low value). The low value resulted in lesser displacement than the baseline, and the high value resulted in greater displacement than the baseline on the drawdown side of TW well responses but produced the opposite on the recovery side (fig. 13). In general, greater storativity values resulted in smoother responses, whereas lesser storativity values resulted in exaggerated transient response.

Summary and Conclusions

Hydraulic properties for a well field in Centereach, N.Y., were estimated through analysis of an aquifer test, and results were compared with the results of other studies. A cluster of five partially penetrating test wells about 100 ft from the pumped well were instrumented to record water level and temperature at 30-second intervals during the test. Model conceptualization and calibration were done through visual trial and error. Two alternative models based on the Hantush analytical type curve were developed. Model A was configured with only the pumping stress of the test well (S125632), whereas model B was configured with additional pumping stresses at two other well fields (S66496 and S32551). Model A provided a sufficient match to the observed responses to pumping of well S125632, whereas model B adds representation of well interference from concurrent pumping at nearby Suffolk County Water Authority wells.

Hydraulic conductivity of the depth interval in which the pumped well is screened was estimated to be about 50 ft/d (horizontal) and 0.5 ft/d (vertical); these values are typical for the Magothy aquifer in this part of Suffolk County. Estimated aquifer transmissivity, based on an assumed unit thickness of 600 ft, is 30,000 ft^2/d. Estimated storativity is 0.003 (dimensionless), the ratio of vertical to horizontal hydraulic conductivity is 0.01, and the Hantush-Jacob leakage parameter 1/B is 0.00083 (per foot). Representation of leakage through the overlying confining layer was likely oversimplified in these models as a result of simplified geometry.

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Appendix

Note: (Click on the links below to retrieve the Appendix files)

Appendix A. *Well-field pumpage and pressure data*

Appendix B. *Hourly precipitation at the National Oceanic and Atmospheric Administration (NOAA) Islip weather station, Suffolk County, N.Y., May 4–13, 2008*

Appendix C. *Model Archives A and B (AQTESOLV input and output files)*

Appendix D. *Simulated values of displacement in test wells TW1–TW5 for sensitivity analysis*

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