AQUIFER-TEST ANALYSIS OF THE UPPER AQUIFER OF THE POTOMAC-RARITAN-MAGOTHY AQUIFER SYSTEM, UNION BEACH BOROUGH, MONMOUTH COUNTY, NEW JERSEY

By Amleto A. Pucci, Jr., Daryll A. Pope, and Tamara Ivahnenko

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CONVERSION FACTORS

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

Multiply inch-pound unit	By	To obtain metric unit
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
gallon (gal)	0.003785	cubic meter (m^3)
foot per day (ft/d)	0.3048	meter per day (m/d)
square foot per day (ft^2/d)	0.0929	square meter per day (m^2/d)
gallon per minute (gal/min)	0.06308	liter per second (L/s)

Sea Level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Sea Level Datum of 1929."

LIST OF SYMBOLS

Symbols	Dimensions	Description
K	LT^{-1}	Hydraulic conductivity of main aquifer
K', K"	LT^{-1}	Vertical hydraulic conductivity of semipervious confining layers
L(u,v)	---	Leakance function of u, v
Q	L^3T^{-1}	Pumping rate
S	---	Storage coefficient
T	L^2T^{-1}	Transmissivity
b'	L	Thickness of confining layer
r	L	Radial distance from pumping well
s	L	Drawdown
t	T	Time since pumping began or stopped
u	----	$r^2 S/4Tt$
v	---	$\frac{r}{2}\left(\frac{K'}{b'T}\right)^{1/2}$
π	---	3.1416

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ABSTRACT

The hydraulic properties of the upper aquifer of the Potomac-Raritan-Magothy aquifer system and of the overlying and underlying confining units were determined by an aquifer test in the vicinity of Union Beach Borough, New Jersey. The April 1986 test included the pumping of 2 test wells for 72 hours at a combined discharge rate of 1,375 gallons per minute, and the measurement of water levels in 10 wells. No single, lateral recharge boundary affected the observed water-level changes. Assuming leaky artesian conditions, the average transmissivity and storage coefficient of the upper aquifer are 7,754 square feet per day and 4.4×10^{-4}, respectively. The leakance of the combined confining units ranges from 3.0×10^{-5} to 7.6×10^{-5} feet per day per foot. On the basis of lithologic samples from a recently drilled nearby well, the overlying and underlying confining units were assumed to have similar hydraulic properties. By using this assumption, the vertical hydraulic conductivity of the confining units ranges from 0.010 to 0.027 feet per day.

INTRODUCTION

Background

Because of increasing population and development within the study area (fig. 1), the regional demand for water for public supply, industrial, and agricultural use has increased greatly in recent years. Because of these large withdrawals, ground-water levels throughout the study area have declined considerably, causing significant changes in the regional ground-water flow system. In some areas, water-level declines have caused large cones of depression, the reversal of natural ground-water flow directions, and localized flow of saltwater into freshwater aquifers (Leahy and others, 1987, p. 42).

Protection of the ground-water resources of the upper aquifer of the Potomac-Raritan-Magothy aquifer system is a primary concern in the northern Coastal Plain of New Jersey. Saltwater intrusion has caused the closing of five public-supply wells screened in the upper aquifer--three wells in the Borough of Keyport and two wells in the Borough of Union Beach, New Jersey (fig. 1) (Schaefer and Walker, 1981). Additional knowledge of the hydrogeologic conditions in the area is needed to improve understanding of the nature of the intrusion problem.

An aquifer test, conducted near Keyport and Union Beach, New Jersey, from April 22 to 28, 1986, was used to estimate (1) the transmissivity, hydraulic conductivity, and storage coefficient for the upper aquifer of the Potomac-Raritan-Magothy aquifer system; (2) the leakance of the confining units; and (3) the location of any aquifer recharge boundaries in the area.

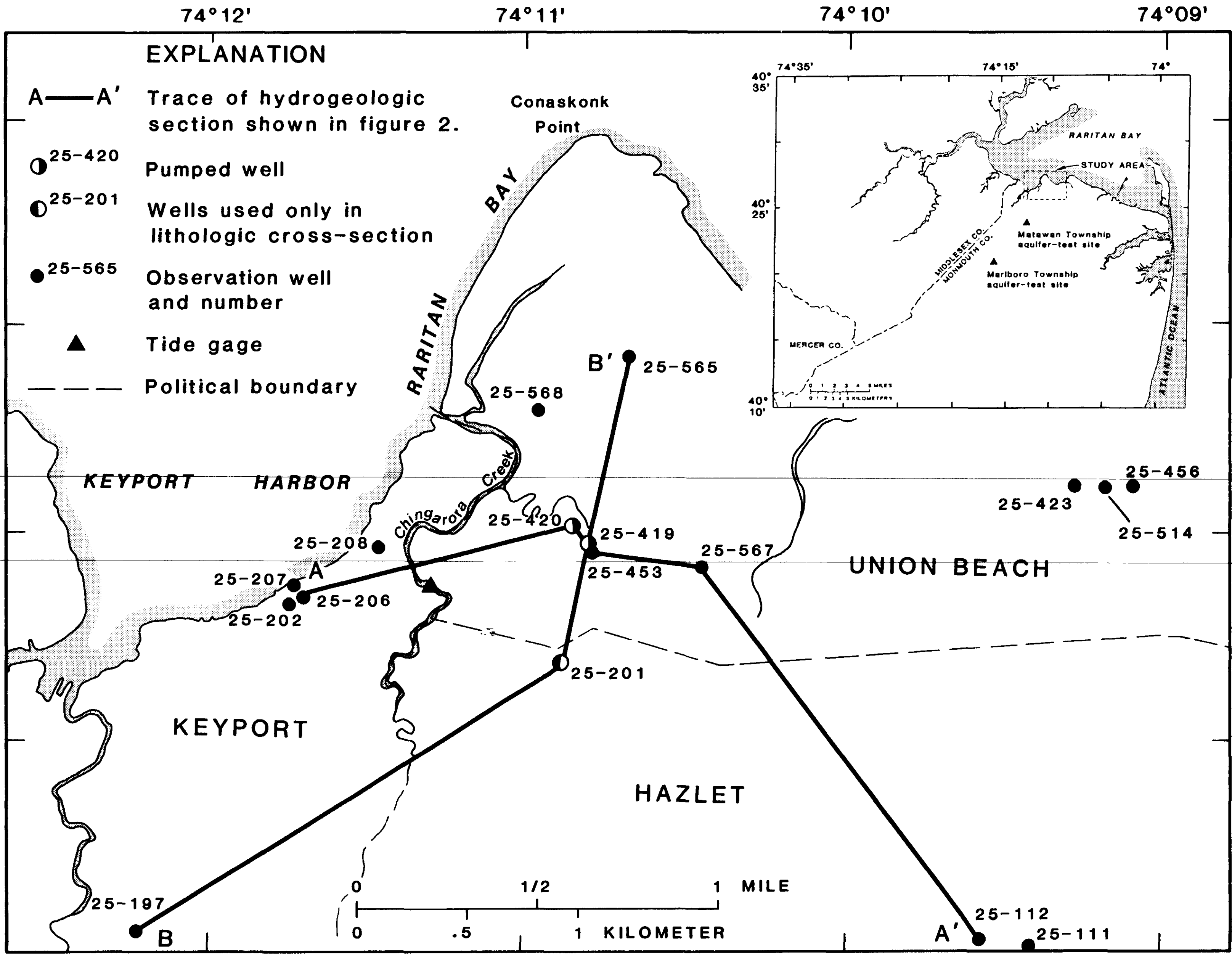

Figure 1.--Location of wells in Union Beach aquifer-test area, and hydrogeologic sections (A-A', B-B').

The aquifer test included 2 pumped wells owned by the Union Beach Water Department and 10 observation wells (fig. 1). In addition, a single-well recovery test of the middle aquifer of the Potomac-Raritan-Magothy aquifer system was conducted at the aquifer-test site. The aquifer-test area includes approximately 6 square miles of near-shore communities, bordered to the north by Raritan Bay (fig. 1).

Purpose and Scope

The primary purpose of this report is to present the results of the aquifer-test analysis. The report also contains information about the hydrogeologic conditions of the test site, construction details of the wells used in the test, and the general testing procedure.

Well-Numbering System

The well-numbering system used in this report has been used by the New Jersey District of the U.S. Geological Survey since 1978. The first part of the number is a county code and the second part is a sequential number of the well within the county. The code for Monmouth County, 25, is used in this report. For example, well number 25-202 represents the 202nd well inventoried in Monmouth County.

Acknowledgments

Mr. Richard Pitcher, Superintendent of Public Works for the Borough of Union Beach, and the Borough Council allowed the aquifer test to be conducted at the Union Beach Water Department site, allowed the use of their production wells for the test, and permitted the installation of an observation well on Borough property. Mr. David G. Knowles, P.E., Technical Manager for the Bayshore Regional Sewerage Authority, and the Authority Commissioners permitted the drilling of a borehole and the installation of an observation well at their Union Beach plant. Mr. James Anderson, Manager of Environmental Affairs for the Jersey Central Power and Light Co., permitted the installation of an observation well at their Union Beach site. Mr. Aaron Seligson, of Bay Ridge Realty Corp., permitted the modification of a well in Keyport for use as an observation well. Mr. John Kennedy, Business Administrator for the Borough of Keyport, and the Borough Council permitted the use of several Borough wells as observation wells for the test. Mr. Michael Walsh, P.E., General Manager of the Shorelands Water Company of Hazlet, New Jersey, made available a company well for water-level monitoring and agreed to modify pumping rates from the West Keansburg production wells to meet the test requirements. Mr. John Downes, P.E., Senior Project Engineer for International Flavor and Fragrance, allowed monitoring of three company wells at Union Beach. Barometric pressure data were provided by the National Oceanic and Atmospheric Administration, National Weather Service. Mr. Richard Dalton, Chief, Bureau of Geology and Topography, New Jersey Geological Survey, provided the drilling services for one borehole and three observation wells.

GENERAL HYDROLOGY

Geologic Framework

Hydrogeologic conditions in the area of the Union Beach aquifer-test are fairly uniform. The Potomac-Raritan-Magothy aquifer system is the principal water-bearing system in the area. In the study area, the aquifer system consists of the upper and middle aquifers, and the associated confining units (table 1). The upper aquifer is confined by an overlying and underlying confining unit. The underlying confining unit separates the upper aquifer from the middle aquifer. Figure 2 shows two hydrogeologic sections of the test area; these sections are based on drillers' and geophysical logs of wells reported by Gronberg and others (in press).

In the study area, the upper confining unit is approximately 200 feet thick (fig. 2), and it is composed primarily of sediments of the Merchantville Formation; however, in the eastern part of the study area, the Woodbury Clay may be a part of this confining unit (R. Dalton, Bureau of Geology and Topography, New Jersey Geological Survey, oral commun., 1987). The Merchantville Formation is composed of glauconite beds, and thin- to thick-bedded sequences of micaceous clays and clayey silts (Zapecza, 1984, p. 19); the Woodbury Clay is a clayey silt (Zapecza, 1984, p. 19).

In the study area, the upper aquifer of the Potomac-Raritan-Magothy aquifer system is approximately 70 feet thick (fig. 2), and it is stratigraphically equivalent to the Old Bridge Sand Member of the Magothy Formation. The aquifer is composed of medium sands interbedded locally with clayey silt (Farlekas, 1979, p. 22). Schaefer and Walker (1981, p. 16) indicate that the upper aquifer crops out beneath, and is in direct hydraulic connection, with Raritan Bay.

Near the test site, the confining unit directly beneath the upper aquifer is 150 to 200 feet thick (fig. 2), and it is primarily equivalent to the Woodbridge Clay Member of the Raritan Formation, a thin- to thick-bedded sequence of micaceous silt and clay. Locally, the confining unit may include the overlying clayey lithofacies of the Sayreville Sand Member and the South Amboy Fire Clay Member, both of the Raritan Formation (Farlekas, 1979, p. 22).

In the test area, the middle aquifer of the Potomac-Raritan-Magothy aquifer system is more than 40 feet thick (fig. 2), and it is stratigraphically equivalent to the Farrington Sand Member of the Raritan Formation. This aquifer, which lies beneath the confining unit just described, is composed of sand and gravel; locally, it contains clay beds.

Hydrologic Setting

Two prominent factors on the local flow system are the regional cones of depression, which are caused by pumping, and Raritan Bay. Water-level measurements made in 1983 for wells within these cones of depression in the Keyport-Union Beach area showed that water levels in the upper aquifer were about 30 feet below sea level, and about 90 feet below sea level in the middle aquifer (Eckel and Walker, 1986, plates 2 and 3). These water-level altitudes indicate that there is a potential for ground water to flow from

Table 1.--Geologic and hydrogeologic units of the Potomac-Raritan-Magothy aquifer system in the study area

[Modified from Zapecza (1984, fig. 3)]

System	Geologic unit		Hydrogeologic unit	
Cretaceous	Woodbury Clay		Merchantville-Woodbury confining unit	Confining unit
	Merchantville Formation			
	Magothy Formation	Cliffwood beds	Potomac-Raritan-Magothy aquifer system[1]	
		Morgan beds		
		Amboy Stoneware Clay Member		
		Old Bridge Sand Member		Upper aquifer
	Raritan Formation	South Amboy Fire Clay Member		Confining unit
		Sayreville Sand Member		
		Woodbridge Clay Member		
		Farrington Sand Member		Middle aquifer
		Raritan fire clay		Confining unit
Jurassic and Triassic	Newark Supergroup and diabase intrusives		Bedrock	Bedrock
Lower Paleozoic and Precambrian	Igneous and metamorphic rocks			

[1] The lower aquifer of the Potomac-Raritan-Magothy aquifer system is not mappable within the study area of this report.

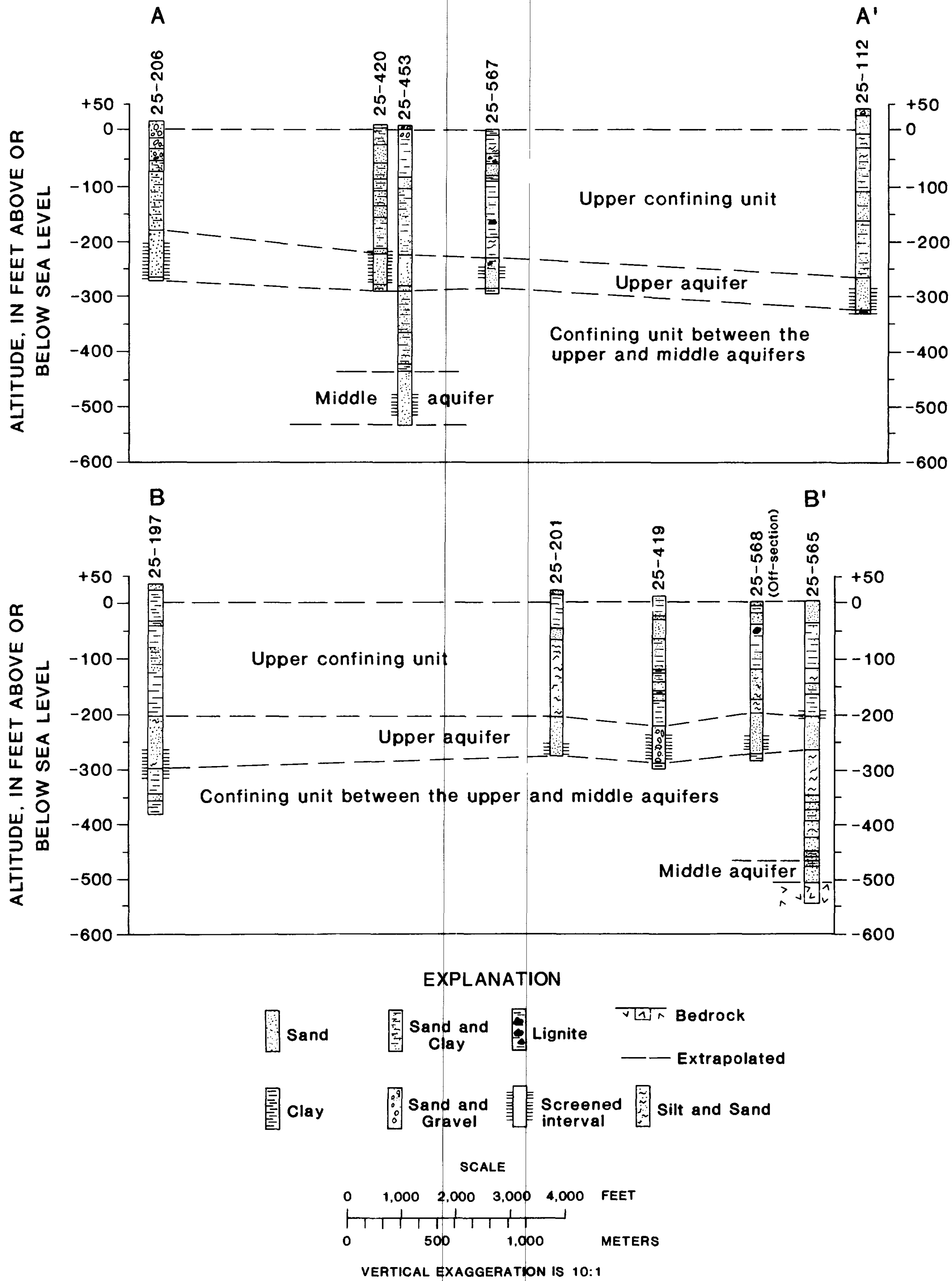

Figure 2.--Hydrogeologic sections showing lithology and well screen intervals at the Union Beach aquifer-test site.

the upper aquifer into the middle aquifer in the Keyport-Union Beach area. As part of the New Jersey Regional Aquifer-System Analysis, the flow through the overlying confining unit and into the upper aquifer was calculated to be 0.5 to 1.0 inch per year in the Union Beach area (Mary Martin, U.S. Geological Survey, written commun., 1987). Martin also calculated flow from the upper aquifer through the underlying confining unit and into the middle aquifer to be about 0.5 inch per year. Raritan Bay is a major constant-head flow boundary.

Leggette, Brashears, and Graham, Inc. (1962) conducted a 7-day aquifer test of the upper aquifer in Matawan Township, 3.2 miles southwest of the Union Beach test area (fig. 1), and collected drawdown data in three observation wells spaced 590, 1,000, and 2,020 feet from a well pumping 1,100 gal/min (gallons per minute). Based on data from this aquifer test, Pucci and others (in press) estimate that the average aquifer transmissivity is 5,600 ft^2/d (square feet per day), the storage coefficient is 2.6×10^{-4}, and the range of values for combined leakance of the overlying and underlying confining units is about 1.5×10^{-5} 1/d (feet per day per foot). The horizontal hydraulic conductivity estimated for the upper aquifer at this test site is 67 ft/d (feet per day).

In 1972, a 24-hour test of the middle aquifer was conducted in Marlboro Township, 6.5 miles southwest of the Union Beach test site (fig. 1) (A.C. Schultes and Sons, Inc., written commun., 1972), using a well pumped at 1,236 gal/min and an observation well 600 feet away. Pucci and others (in press) estimated that the transmissivity of the aquifer is 9,800 ft^2/d, the storage coefficient is 1.0×10^{-4}, and the vertical hydraulic conductivity of the overlying confining unit is 0.1 ft/d. The estimated horizontal hydraulic conductivity for this test was 100 ft/d.

AQUIFER TEST

General Description of the Test-Area Wells and Aquifer-Test Data

The locations of the wells in the Union Beach aquifer test are shown in figure 1; details of well construction are listed in table 2. The screen intervals for various wells also are shown in figure 2. Wells 25-419 and 25-420 were used as pumping wells for the test. Wells 25-565, 25-567, and 25-568 were drilled and completed as observation wells in the upper aquifer by the New Jersey Geological Survey. An additional seven existing wells (25-202, 25-206, 25-207, 25-208, 25-197, 25-514, and 25-112) completed in the upper aquifer were used as observation wells. Well 25-453 was used to monitor water levels in the middle aquifer. A tide gage was installed on Chingarora Creek in Keyport (fig. 1). A record of barometric pressure for the area is reported in Plate 4 (National Oceanic and Atmospheric Administration, written comm., 1986).

Shoreline Water Company production wells (25-112 and 25-111) in Hazlet Township were inactive for several weeks before and during the aquifer test, because of decreased seasonal demand and maintenance. Wells 25-423 and 25-456 at the International Flavor & Fragrance plant, 1.4 miles east of the test site, pumped 1,650,000 gallons (191 gal/min average) on a production-

Table 2.--Methods of water-level measurement, distance from pumping center, and construction of wells used in Union Beach aquifer test

[Altitude refers to distance below sea level except for land surface, which is above sea level. A double dash indicates missing data; U.S.G.S., U.S. Geological Survey; WD, Water Department]

New Jersey well number	Owner	Local name	Latitude	Longitude	Date well constructed
25-567	U.S.G.S.	Union Beach Water Tower Well	40°26'30"	74°10'29"	04-01-86
25-568	U.S.G.S.	Jersey Central Power & Light	40°26'52"	74°11'00"	04-07-86
25-565	U.S.G.S.	Conaskonk Pt.	40°27'04"	74°10'51"	10-11-85
25-208	Infern-o-therm, Inc.	Infern-O-1	40°26'30"	74°11'29"	00-00-00
25-206	Keyport Borough WD	Keyport 4	40°26'25"	74°11'45"	00-00-39
25-207	Keyport Borough WD	Keyport 6	40°26'26"	74°11'44"	04-01-70
25-202	Keyport Borough WD	Keyport 5	40°26'24"	74°11'45"	12-01-55
25-419	Union Beach WD	UBWD 1 1962	40°26'32"	74°10'49"	08-15-62
25-420	Union Beach WD	UBWD 2 1969	40°26'34"	74°10'51"	05-16-69
25-453	Union Beach WD	UBWD 3 1977	40°26'32"	74°10'51"	08-15-77
25-197		Keyport 7	40°25'35"	74°12'14"	10-27-76
25-514	Int. Flavor Frag., Inc.	IFF-2R	40°26'41"	74°09'11"	05-28-83
25-112	Shorelands WC Inc.	W. Keansbury 2	40°25'37"	74°09'33"	04-27-60

[1] "PW" indicates pumped well; centroid of pumping between wells 25-419 and 25-420, which are 277 feet apart

[2] Well 25-453 is screened in the middle aquifer of the Potomac-Raritan-Magothy aquifer system; all other wells are screened in the upper aquifer

Note: Wells 25-419 and 25-420 are 277 feet apart.

Table 2.--Methods of water-level measurement, distance from pumping center, and construction of wells used in Union Beach aquifer test--Continued.

[Altitude refers to distance below sea level except for land surface, which is above sea level. A double dash indicates missing data; U.S.G.S., U.S. Geological Survey; WD, Water Department]

New Jersey well number	Method of water level measurement	Screen diameter (inches)	Distance from pumping centroid (feet)	Altitude of land surface (feet)	Altitude of hole bottom (feet)	Altitude range of screen interval (feet)	Altitude range of aquifer depth (feet)
25-567	Digital recorder	4	1,735	10	287	240-260	225-280
25-568	Digital recorder	4	2,130	10	278	235-255	190-265
25-565	Analog recorder	4	2,665	10	545	201-211	200-260
25-208	Electric tape	--	3,035	15	285	-- -285	-- - --
25-206	Digital recorder	8	4,320	14	271	211-235	186-271
25-207	Digital recorder	12	4,340	11	287	236-266	167-267
25-202	Steel tape	10	4,500	20	247	184-247	181- --
25-419	Air line gage and electric tape	10	PW[1]	10	300	225-275	215-280
25-420	Air line gage and electric tape	12	PW	10	289	252-279	187-280
25-453[2]	Air line gage	12	100	10	542	470-522	452-528
25-197	Digital recorder	12	8,650	35	379	269-319	205-311
25-514	Electric tape	10	7,400	10	317	256-302	245-309
25-112	Digital recorder	10	8,170	44	327	268-308	265-326

demand schedule during the entire test period. During the test, the nearest major ground-water withdrawal from the upper aquifer was in Keansburg Borough, 3.2 miles east of the test site.

The production well (25-453), screened in the middle aquifer at the Union Beach test site, was shut down 24 hours before the test, and water-level altitudes were recorded from that time through the entire aquifer test drawdown and recovery periods (144 hours). The pumping rate from this well, as measured from the production plant meter, was 700 gal/min during the hour before shutdown, and averaged 445 gal/min during the previous 24-hour period of on-demand pumping. Water-level measurements, made during the first 24 hours after pumping stopped, showed well 25-453 recovered 32 feet, and slowly recovered 2 more feet in 144 more hours (plate 2).

Records indicate that the water level in well 25-453 in the middle aquifer recovered to 74.5 feet below sea level. In well 25-419, the water level in the upper aquifer, measured just prior to the test was 15.5 feet below sea level. Thus, a head difference of approximately 68 feet existed between the upper and middle aquifers at the beginning of the test.

Test Procedure

The pumping phase of the aquifer test began on April 22, 1986 and ended on April 25, 1986. Wells 25-419 and 25-420, which are 277 feet apart (fig. 1) were pumped continuously for 72 hours. The pumped wells were then shut down and recovery was monitored through April 28. During the first 5 hours of the test, the combined pumping rate decreased 3 percent and, thereafter, varied no more than 1 percent. The average pumping rate, measured by mechanical flowmeter, was 635 gal/min from well 25-419 and 740 gal/min from well 25-420.

Digital- and analog-recorder measurements began approximately 3.5 days prior to the test and continued for approximately 7.5 days after the designated recovery period of 72 hours. Air-line and tape measurements began approximately 30 hours before the start of pumping and continued for 6 days.

Wells 25-112, 25-197, 25-202, 25-206, 25-207, 25-208, 25-514, 25-565, 25-567, and 25-568 were used as observation wells in the upper aquifer; well 25-453 was used as an observation well in the middle aquifer. Water levels in the two pumped wells were measured by air line and electric tape; water levels in well 25-453 were measured by air line. Water levels were recorded by digital recorders at 5-minute intervals in wells 25-112, 25-197, 25-206, 25-207, 25-567, and 25-568; by an analog recorder in 25-565. Water levels were measured by an electric tape in wells 25-208 and 25-514 and by steel tape in well 25-202 (table 2). A digital recorder also was installed at the tide gage. Graphs of water-level altitudes, as measured from land surface datum for each well, are presented in plates 1-3.

Data Reduction

Water-level fluctuations caused by tidal effects are discernable in the water-level records for several observation wells. The amplitude of these fluctuations was approximately 3 to 4.5 feet for wells near the shore of Raritan Bay (25-202, 25-206, and 25-207) (fig. 1) and decreased with distance from the shore. Water-level altitudes measured during the drawdown and recovery periods of the aquifer test were adjusted to eliminate the effect of tidal fluctuations. Estimates of the water-level trend were made by connecting the midpoints of the sequential fluctuations of the measured hydrograph, and then visually smoothing the line (plates 1-3). Success in filtering the tidal effects from the water-level data depended partially on the frequency of the measurements.

Water-level drawdown was computed as the difference between the estimated water-level altitude (from the smoothed hydrograph) during the drawdown period and the reference water-level altitude. The reference water-level altitude is the water-level altitude that would have occurred in the absence of test pumping. The reference water level for the drawdown part of the test was estimated from pretest pumping and post-recovery water-level data. During the test period, seasonal and regional water-level changes caused a steady change in the reference water level in each observation well--approximately 0.5 foot. Water-level recovery was computed as the difference between the water-level altitude that would have occurred with continued pumping, and the estimated water-level altitude (from the smoothed hydrograph) during the recovery period. Significant effects of barometric pressure on water levels were not discernable.

Analytical Results

Type-curve and straight-line graphical methods were used to analyze the data. For each observation well, the water-level changes due to pumping, s (in feet), are plotted on a log-log scale against time of observation divided by the squared distance to the pumped well; t/r^2, (in days per square foot)(figs. 3-9). For the two pumped wells, water levels (in feet) are plotted against the logarithm of time (in minutes) (figs. 10 and 11). For well 25-453, water levels measured during the pretest shutoff in the middle aquifer also are plotted in semilogarithmic form (fig. 12).

In the observation wells, the log-log plots of drawdown or recovery over time are below the Theis curve, indicating that water from a recharge source affected the water levels during the aquifer test. The two possible sources of recharge that were considered are (1) recharge due to direct aquifer contact with surface water nearby in Raritan Bay, and (2) recharge caused by leakance (leaky artesian aquifer). Inspection of the lithologic logs (fig. 2) show that direct contact with streams in the vicinity was not a viable possibility. Stallman's type-curve analysis of transient aquifer response (Ferris and others, 1962, p. 146; Lohman, 1972, pl. 9, p. 59) was used to evaluate possible recharge boundaries. The approximate match of the data to these type curves and further analysis did not indicate that a recharge boundary was within the radius of influence for the test. Variation in water levels from test pumping are seen in well 25-197 which is located 8,650 feet away from the test wells (plate 3). The radius of influence, therefore, extended at least 8,650 feet from the test wells, and 5,000 feet into Raritan Bay.

The leaky artesian-aquifer type curve developed by Hantush and Jacob (1955), modified by Cooper (1963), and illustrated by Lohman (1972, pl. 3), was used to assess recharge caused by leakance. The match between this type

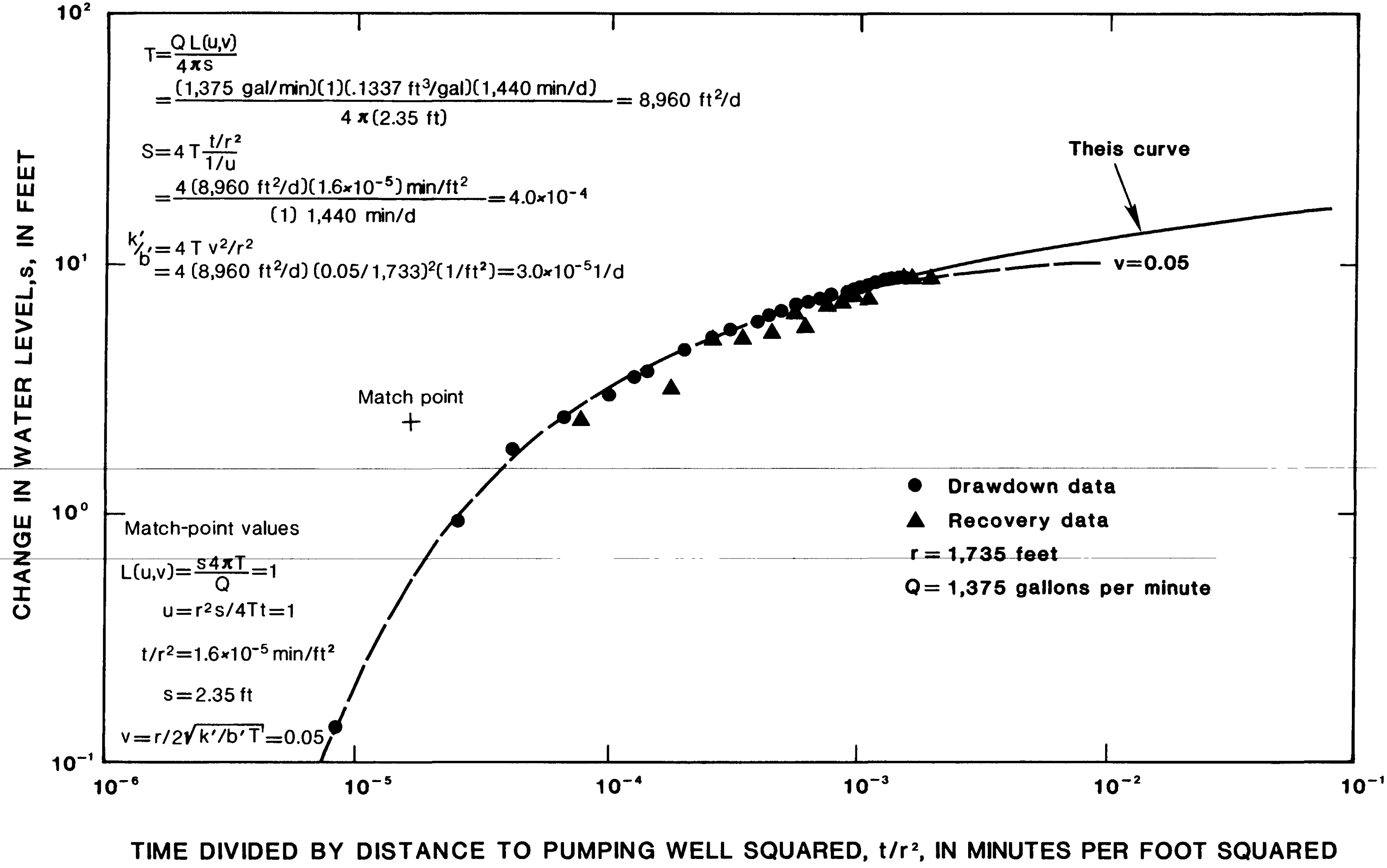

Figure 3.--Logarithmic plot of drawdown and recovery of water level over time in observation well 25-567.

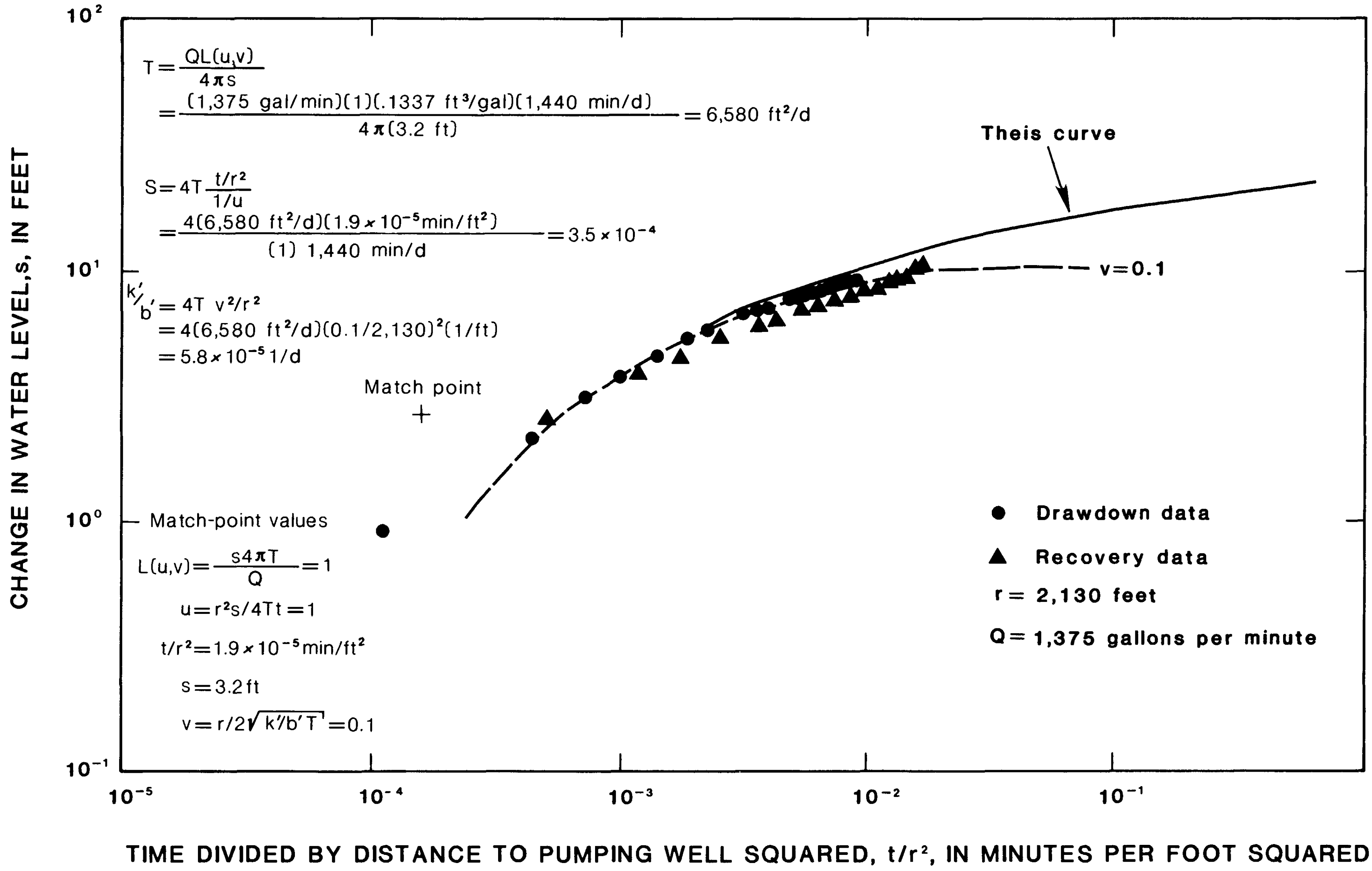

Figure 4.--Logarithmic plot of drawdown and recovery of water level over time in observation well 25-568.

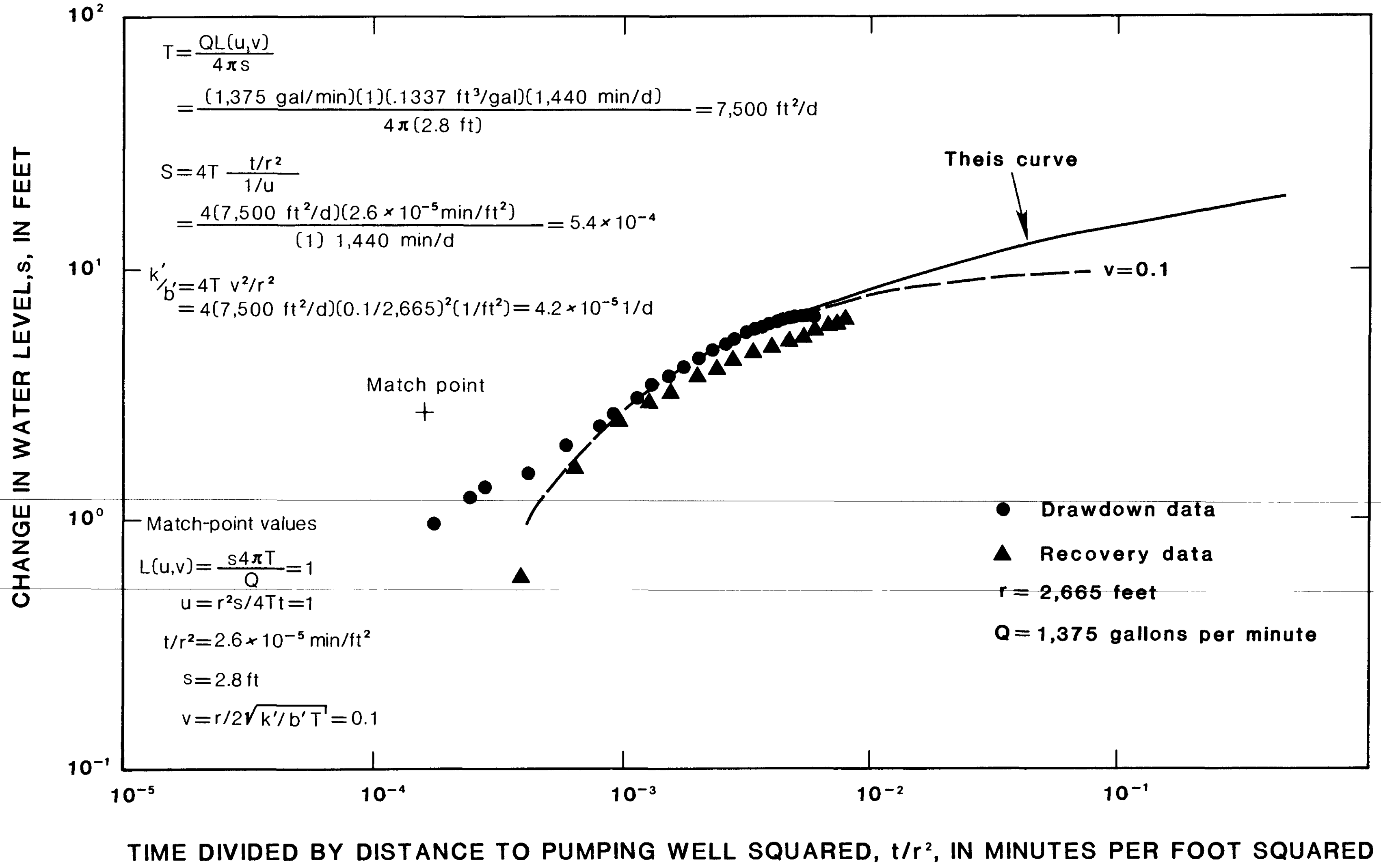

Figure 5.--Logarithmic plot of drawdown and recovery of water level over time in observation well 25-565.

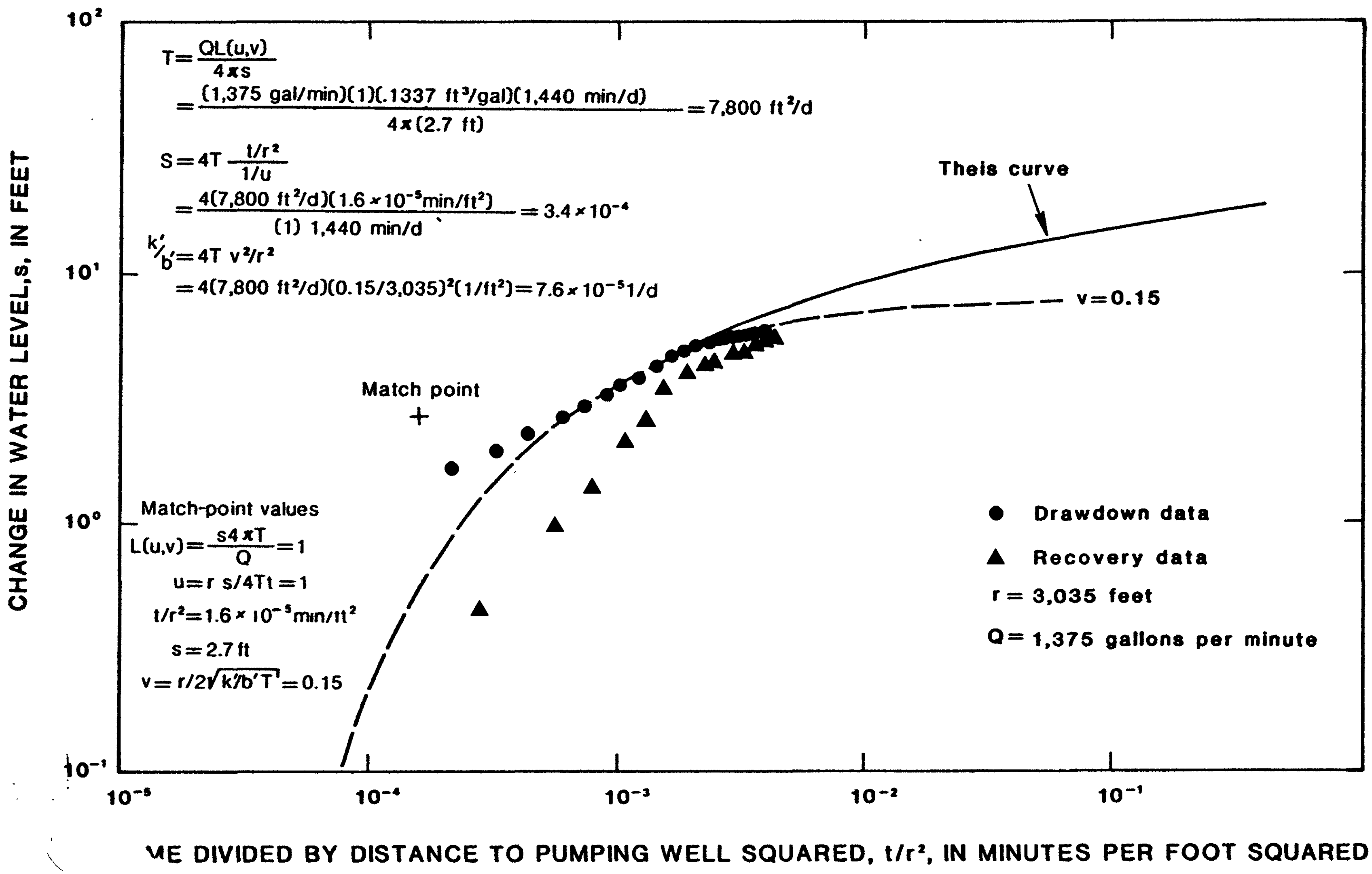

Figure 6.--Logarithmic plot of drawdown and recovery of water level over time in observation well 25-208.

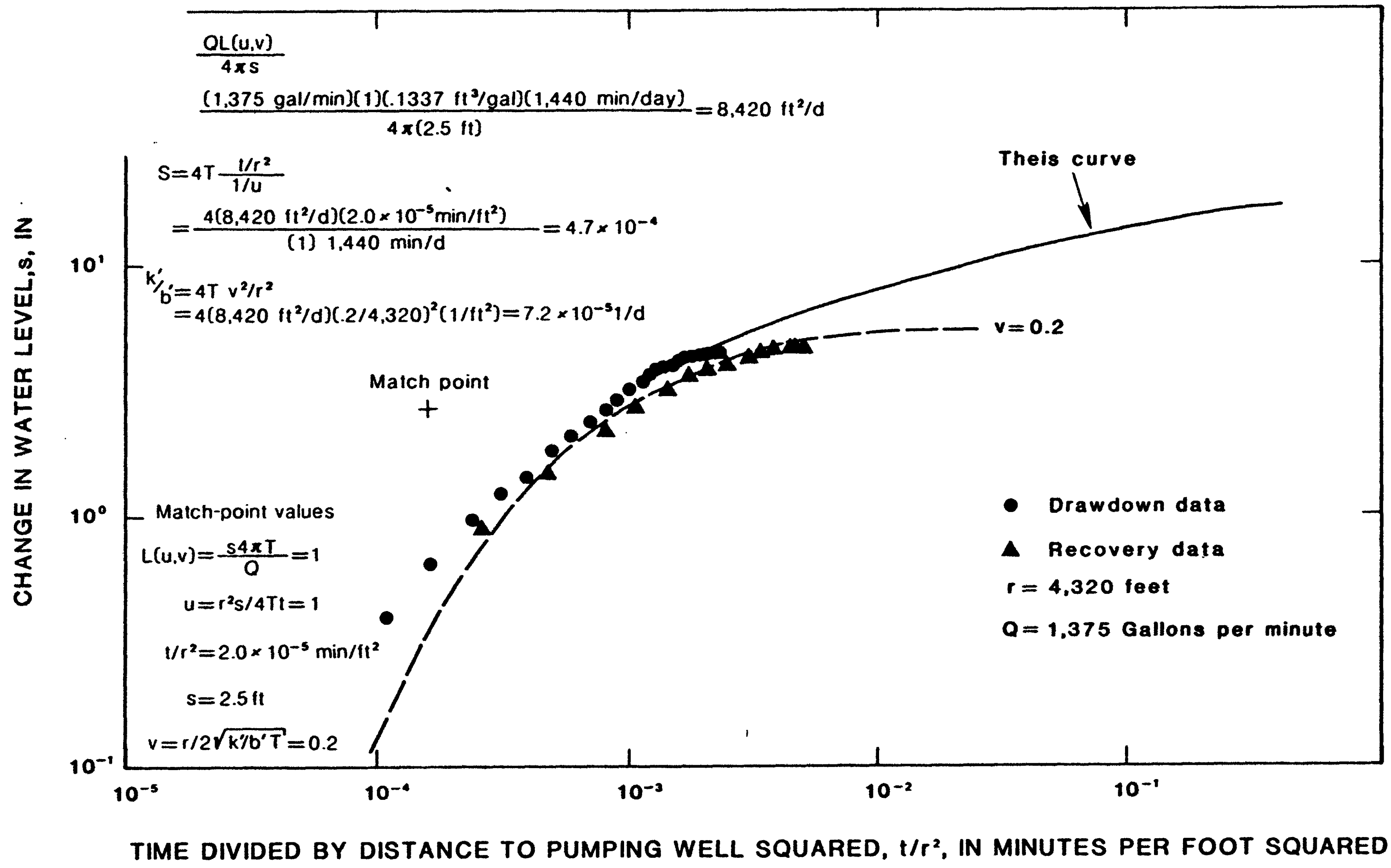

Figure 7.--Logarithmic plot of drawdown and recovery of water level over time in observation well 25-206.

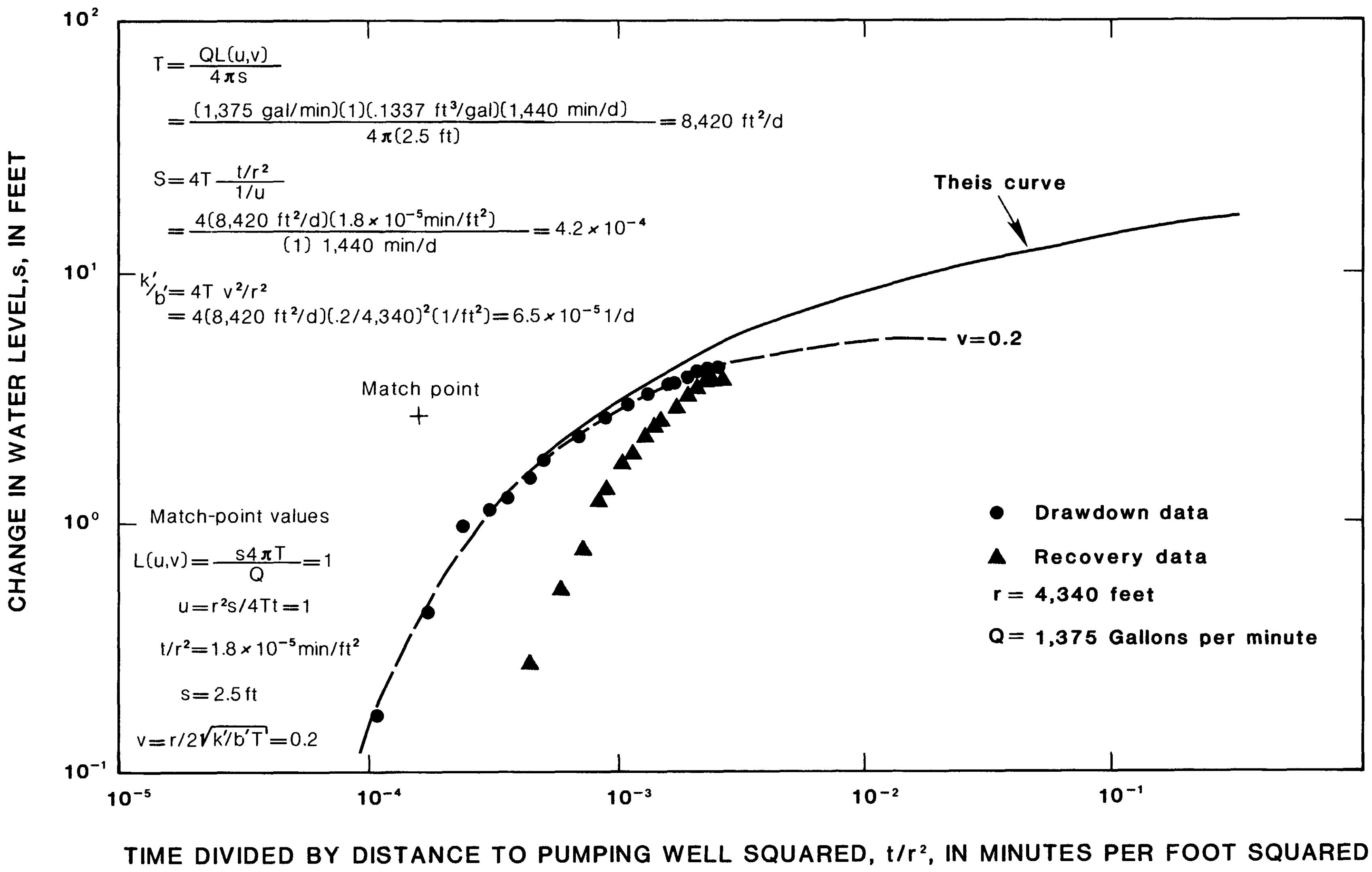

Figure 8.--Logarithmic plot of drawdown and recovery of water level over time in observation well 25-207.

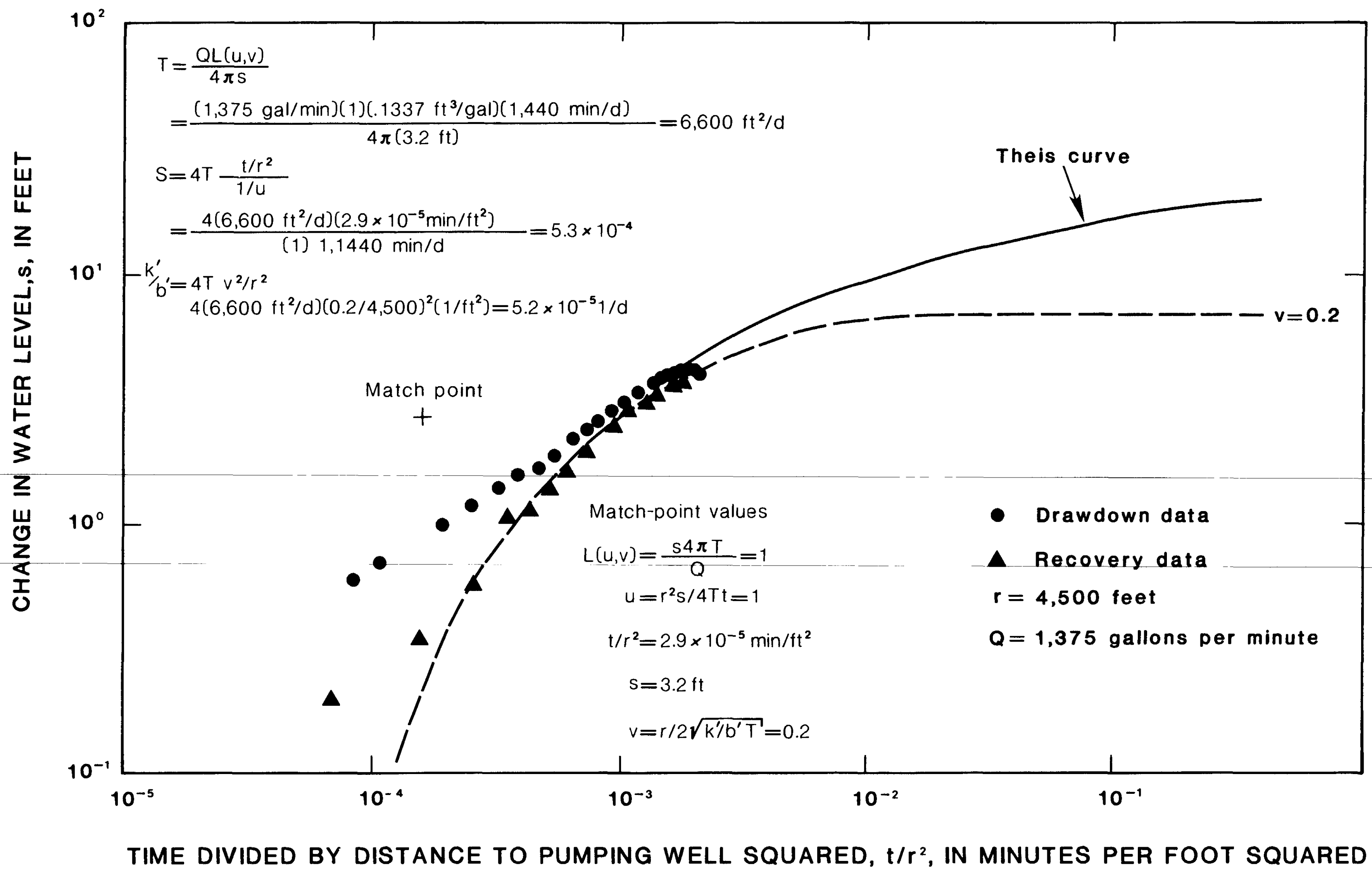

Figure 9.--Logarithmic plot of drawdown and recovery of water level over time in observation well 25-202.

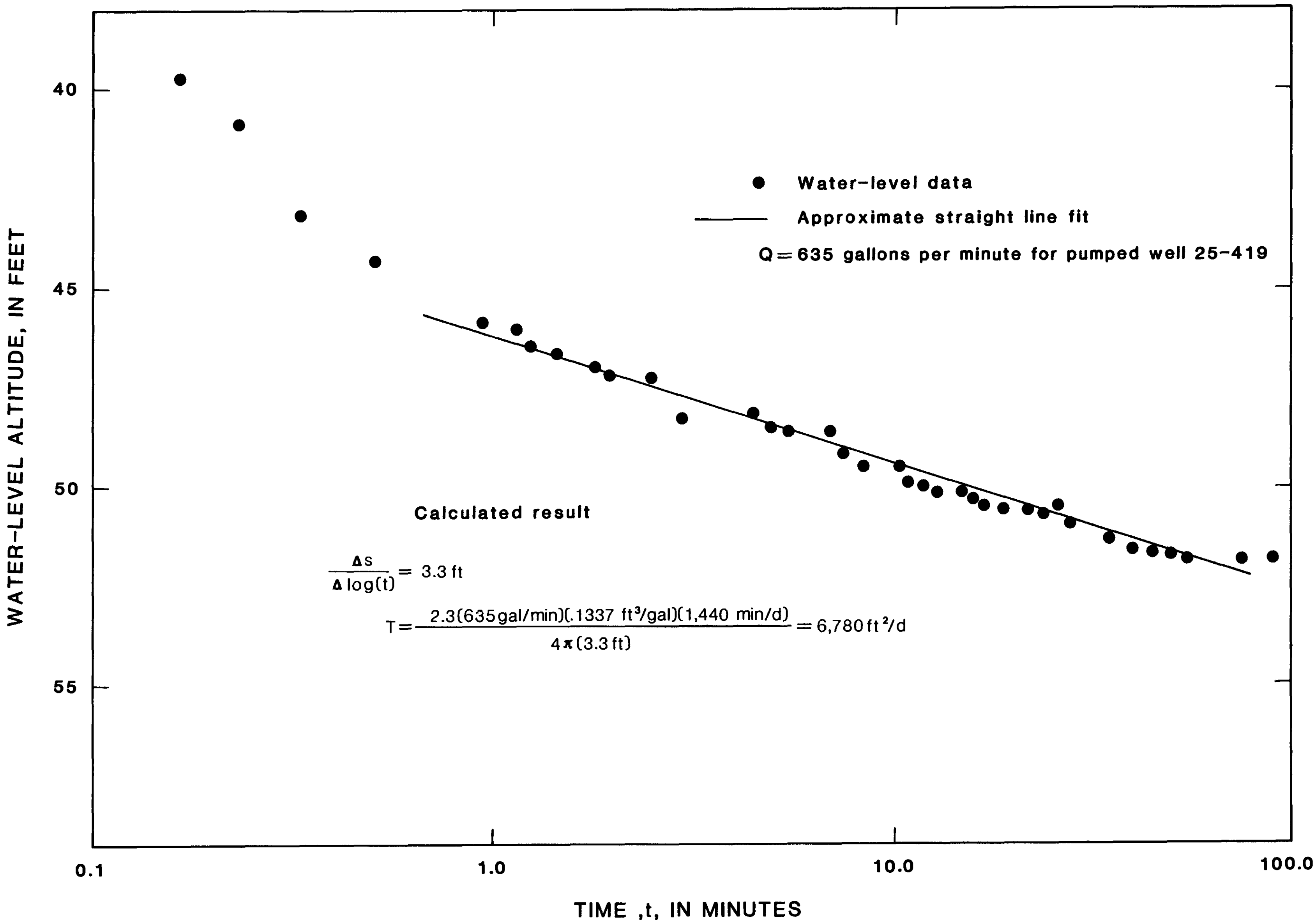

Figure 10.--Semilogarithmic plot of drawdown of water-level altitude over time in pumped well 25-419.

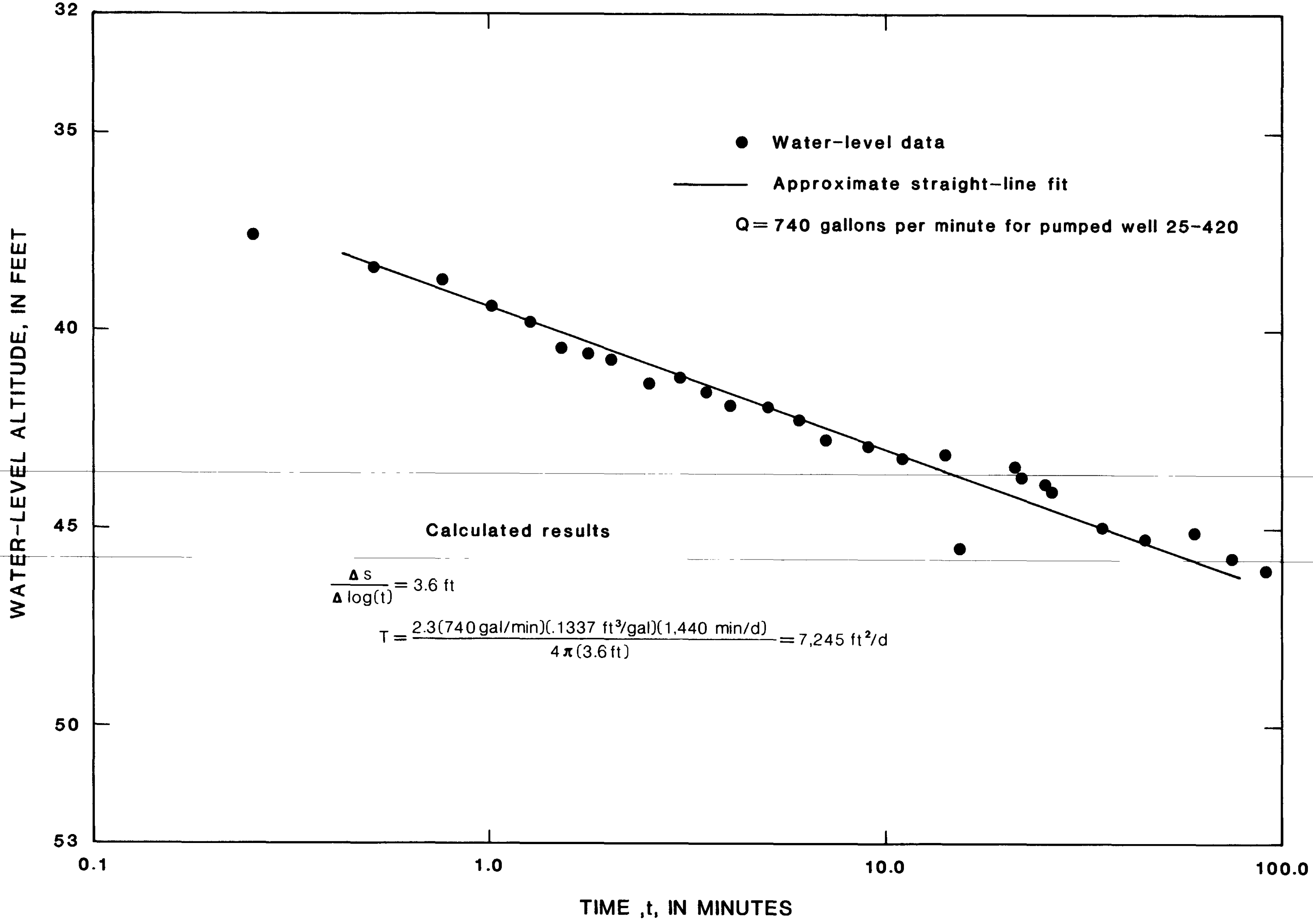

Figure 11.--Semilogarithmic plot of drawdown of water-level altitude over time in pumped well 25-420.

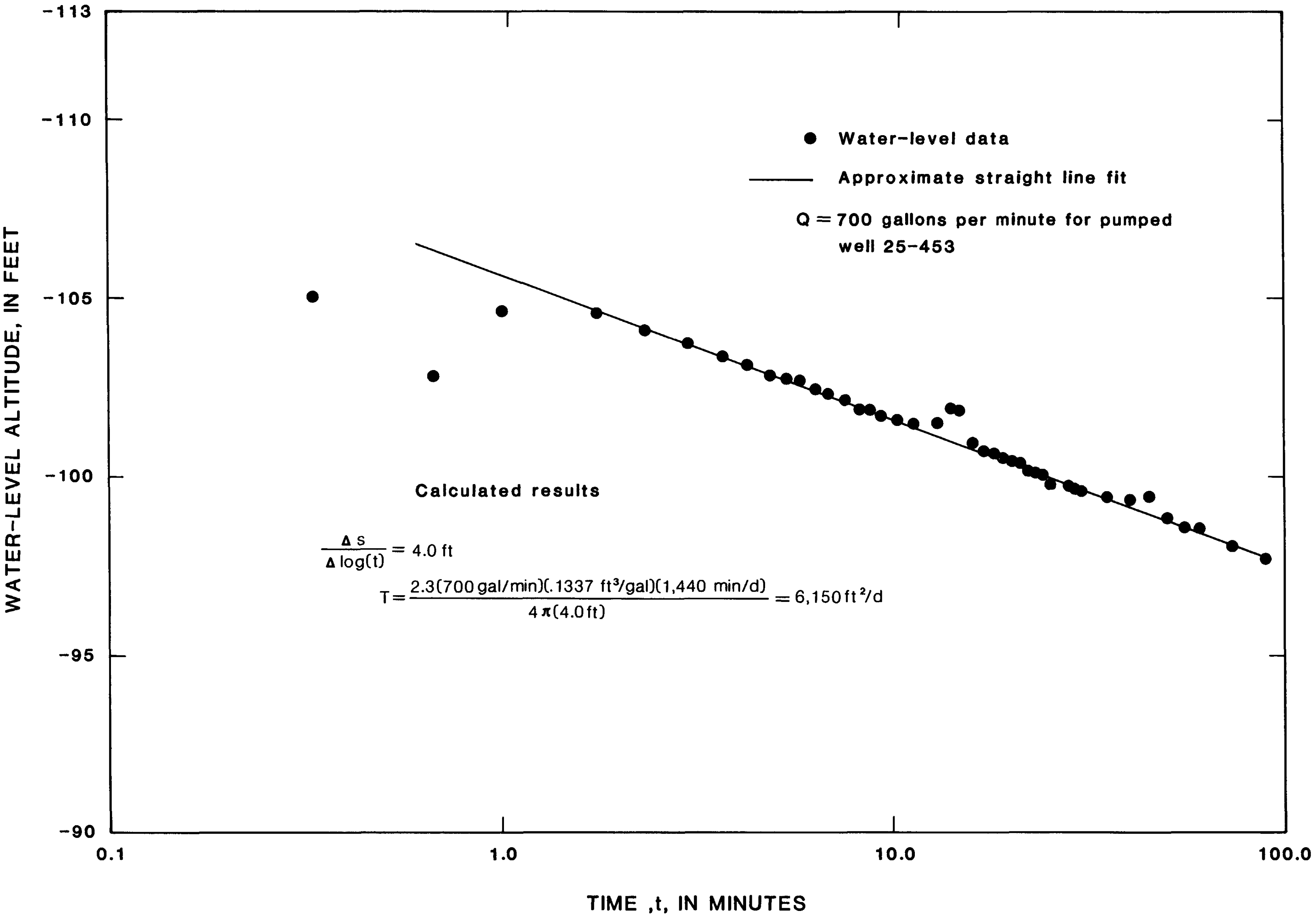

Figure 12.--Semilogarithmic plot of recovery of water-level altitude over time in observation well 25-453.

curve and the drawdown data appears to be appropriate. Therefore, the recharge source is diffuse leakage through the confining units and not recharge due to a direct contact between the aquifer and Raritan Bay.

The type curve that best fits the shape of the estimated data curve for each observation well is indicated by the dashed lines in figures 3-9. Drawdown data were used to fit the type curves; the type curves generally correspond to the recovery data. Each figure shows the selected matchpoint values from the type curves, including water-level change, s; time divided by the squared distance to the center of pumping, t/r^2; the leakance function, L(u,v), where u and v are the arguments of the leakance function. Further definition of these symbols appears in the front of this report. These matchpoint values were used to solve for transmissivity, storage coefficient, and leakance using methods defined in the literature (Lohman, 1972, p. 30).

Because the two pumped wells (25-419 and 25-420) are close to one another, the two pumped wells were assumed to be one well located at one pumping center to simplify the analyses. This assumption was evaluated using the theory of superposition and the Theis formula. The theory of superposition states that water-level changes at any point in a confined aquifer, where more than one well is pumped, will be equal to the sum of the drawdowns for each pumped well (Reilly and others, 1984). The Theis formula, which assumes no leakage, was used to calculate drawdowns (Reed, 1980, Solution 1). Because the Theis formula assumes no leakage, the predicted water-level changes are greater than the expected water-level changes in a leaky aquifer for the same pumping conditions. Intuitively, the observed drawdown should be bounded between the drawdowns caused by the two pumped-well arrangements. In the first arrangement, the drawdowns in observation well 25-567, caused by the combined pumping at the centroid location, was calculated. In the second arrangement, the predicted drawdowns for observation well 25-567 caused by the individual pumps were calculated. Discrepancies in the predicted drawdown for the two arrangements were different by only about 0.1 percent at any time. Therefore, the treatment of the two pumped wells as a single pumped well was judged acceptable and used in the analysis.

As stated in the principle of superposition, the drawdowns in the pumped wells was the combined result of pumping each well. Therefore, a correction was needed to determine the drawdown interference from the other pumped well 277 feet away. This was done by calculating the drawdown that would have occurred from one pumped well at the distance of 277 feet. These drawdowns were calculated using a leaky-aquifer model program (Reed, 1980; Solution 4), and assuming a transmissivity of 7,500 ft^2/d. These values were subtracted from the measured drawdown in the other pumped well. The corrected drawdown in the pumped wells was analyzed by the semilogarithmic method of Cooper and Jacob (1946) (figs. 10 and 11). (Note that the pumping rates used in the analysis of the pumped wells is the discharge rate for that well alone.)

Aquifer Hydraulic Properties

Table 3 summarizes the results of the analysis of the Union Beach aquifer test. Hydraulic conductivities were determined by dividing the calculated transmissivities by the approximate aquifer thickness, which, in the test area is 76 feet.

Water-level changes in the seven observation wells that were closest to the two pumping wells were analyzed. The computed values of transmissivity from these wells ranged from 6,580 to 8,960 ft^2/d, with a median value of 7,800 ft^2/d and an average value of 7,754 ft^2/d.

Transmissivities calculated from the drawdown data in the two pumped wells were 6,780 and 7,245 ft^2/d. These values are within the same range as those computed from the data for the seven observation wells. Scatter in the estimated transmissivities is due to the variable thicknesses and varying conductive properties of the aquifer, as well as to probable small errors in measurements. An analysis of the distribution of transmissivities did not determine that the variation could be explained by anisotropy of the aquifer (Hantush, 1966).

Transmissivities calculated for wells 25-206 and 25-207, in the western part of the test area, were 8,420 ft^2/d. Transmissivities calculated from wells 25-202 and 25-208, also in the western part of the area, were 6,600 and 7,800 ft^2/d, respectively. The low transmissivity value calculated for well 25-202 may reflect a lack of success in separating out the water-level trend from the other components of the hydrograph. The measurements in well 25-202 were fewer and irregularly timed. The highest aquifer transmissivity, 8,960 ft^2/d, was determined from data for well 25-567--the only observation well located to the east and the observation well closest to the pumped wells. The hydraulic conductivities of 86 ft/d to 117 ft/d are consistent with typical values for the aquifer material (Lohman, 1972, p. 53). Storage coefficients range from 3.4×10^{-4} to 5.4×10^{-4} and average 4.4×10^{-4}.

The transmissivity range is slightly greater than the value of 5,600 ft^2/d determined for the upper aquifer at the Matawan Township aquifer-test site (fig. 1). The hydraulic conductivities are higher than the 67-ft/d hydraulic conductivity calculated for the Matawan Township test. The range of storage coefficient values is slightly greater than, but comparable to the value of 2.6×10^{-4} determined at the Matawan Township test site (Pucci and others, 1987).

The semilogarithmic method of Hantush and Jacob (1955) was used to analyze the recovery data for well 25-453, screened in the middle aquifer. The 700 gal/min pumping rate for the hour prior to shutdown was used. The estimated transmissivity of the middle aquifer is 6,150 ft^2/d. This transmissivity is less than the 9,800-ft^2/d value reported for the middle aquifer at Marlboro Township (Pucci and others, 1987). Because the thickness of the aquifer at the Union Beach test site is not known, the horizontal hydraulic conductivity could not be calculated. Test pumping the upper aquifer did not interfere with the recovery of water levels in the middle aquifer, which indicates that the confining unit separating the middle and upper aquifer is relatively impermeable.

Table 3.--Results from Union Beach aquifer test[1]

Well number	Transmissivity (feet squared per day)[5]	Hydraulic conductivity (feet per day)	Storage coefficient (dimensionless)	Leakance (feet per day per foot)
25-567	8,960	117	4.0×10^{-4}	3.0×10^{-5}
25-568	6,580	86	3.5×10^{-4}	5.8×10^{-5}
25-565	7,500	98	5.4×10^{-4}	4.2×10^{-5}
25-208	7,800	102	3.4×10^{-4}	7.6×10^{-5}
25-206	8,420	110	4.7×10^{-4}	7.2×10^{-5}
25-207	8,420	110	4.2×10^{-4}	6.5×10^{-5}
25-202	6,600	86	5.3×10^{-4}	5.2×10^{-5}
25-419[3]	6,780	89	-	-
25-420[3]	7,245	95	-	-
25-453[2,4]	6,150	-	-	-

[1] Analysis by the straight-line method of Hantush and Jacob (1955)
[2] Well screened in the middle aquifer
[3] Indicates analysis of drawdown data only for the pumped well
[4] Indicates analysis of recovery data only for the pumped well
[5] Transmissivity values rounded

Confining-Unit Properties

The leakances of the confining units were determined from the type-curve analyses. The combined leakances range from 3.0×10^{-5} to 7.6×10^{-5} 1/d, average 5.6×10^{-5} 1/d (table 3), and have no spatial pattern. The range of these values is greater than the leakances determined at the Matawan test site (approximately 1.5×10^{-5} 1/d) (Pucci and others, in press). The leakances represent composite values, inasmuch as leakage may occur through both the overlying and underlying confining units. An assumption in this analysis was that no water is released from storage in the confining unit, although as noted by Cooper (1963), leakage from the confining unit is derived largely from storage in the confining units. Where leakage does occur, this method of analysis is better than the Theis-curve analysis alone. Because the overlying and underlying confining units have similar lithology, based on evidence from the borehole drilled near the test site (well 25-565, fig. 2), the overlying and underlying confining units are assumed to be hydraulically similar. Therefore, the vertical hydraulic conductivity of the confining unit was estimated using the combined thickness of these confining units (approximately 350 feet). In this case, the vertical hydraulic conductivities of the confining units range from 0.010 to 0.027 ft/d.

SUMMARY

An aquifer test was conducted during April 1986, at the Union Beach Water Department well field in Union Beach Borough, New Jersey, to determine the hydraulic properties of the upper aquifer of the Potomac-Raritan-Magothy aquifer system and its confining units. The test included the pumping of 2 test-wells for 72 hours at a combined discharge rate of 1,375 gal/min, and measurement of water levels in 10 observation wells screened in the upper aquifer. Drawdown data from 7 of the 10 observation wells were used for the aquifer test analysis. Based on type-curve analysis, the aquifer is not affected by recharge from a lateral recharge boundary. The distribution of transmissivity values shows that the aquifer is heterogeneous. The average transmissivity, calculated from observation well data, is 7,754 ft^2/d; the average storage coefficient is 4.4×10^{-4}. The interpretation of the aquifer test and the lithology from borehole logs for the area show that the aquifer consists of permeable material overlain and underlain by extensive overlying and underlying confining units that have a low leakance.

Water levels during the aquifer test were affected by leakage through the confining units. The average leakance was calculated to be 5.6×10^{-5} 1/d. The vertical hydraulic conductivity of the combined confining-unit material was calculated to range from 0.010 to 0.027 ft/d.

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