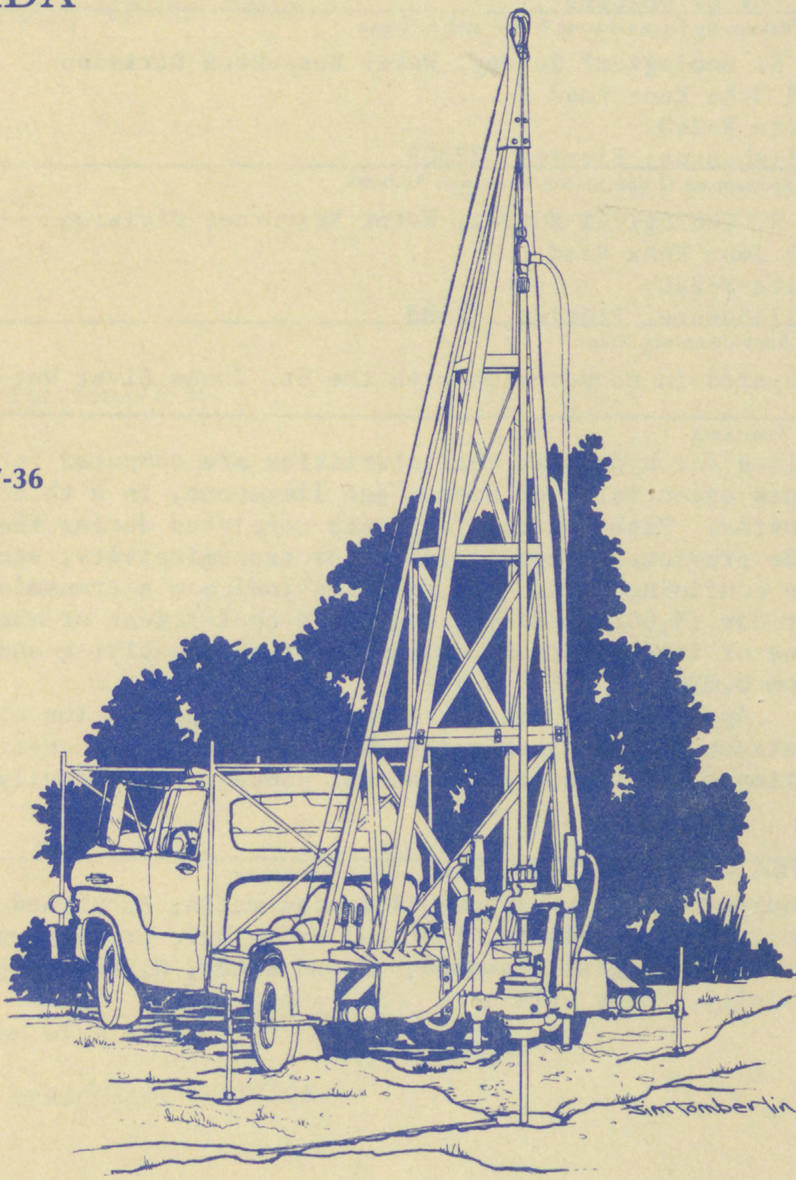
AQUIFER TEST ANALYSES FOR THE FLORIDAN AQUIFER IN FLAGLER, PUTNAM, AND ST. JOHNS COUNTIES, FLORIDA



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16. Abstracts

Values for hydraulic characteristics are computed for the Floridan aquifer which consists essentially of Eocene age limestone, in a three-county area of northeastern Florida. Eighteen aquifer tests completed during the investigation and several tests made previously were analyzed for transmissivity, storage coefficient, and leakance of the confining beds. The analyses indicate a transmissivity of about 60,000 feet squared per day (5,600 m^2/d) and a storage coefficient of about 0.0008 for the aquifer in the area of investigation. Leakance for the overlying and underlying confining beds ranges from 0.0002 to 0.016 day^{-1}.

Applications presented include the generation of drawdown curves for pumping time, distance from a discharging well, and depth of penetration into the aquifer; and to estimate the seasonal and annual pumpage in a heavily pumped farming area.

17. Key Words and Document Analysis. 17a Descriptors

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U. S. GEOLOGICAL SURVEY

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1977

UNITED STATES DEPARTMENT OF THE INTERIOR

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AQUIFER TEST ANALYSES FOR THE FLORIDAN AQUIFER
IN FLAGLER, PUTNAM, AND ST. JOHNS COUNTIES, FLORIDA

By
C. B. Bentley

ABSTRACT

The Floridan aquifer in Flagler, Putnam, and St. Johns Counties of northeastern Florida consists primarily of limestone beds of the Ocala Group and the underlying Avon Park and Lake City Limestones, all of Eocene age. New data from eighteen aquifer tests were analyzed for transmissivity, storage coefficient, and leakance. In addition, the data and results of several tests made previously were analyzed and used to determine hydraulic characteristics of the Floridan aquifer. The test analyses indicate that the aquifer has a transmissivity of about 60,000 feet squared per day and a storage coefficient of about 0.0008. Leakance, a property of the overlying and underlying confining beds, ranges from 0.00023 day^{-1} northwest of Palatka to 0.016 day^{-1} in the farming area near East Palatka.

The transmissivity, storage coefficient, and leakance can be used to generate curves showing drawdown with time at any distance from a well that is discharging at any selected constant rate and at any depth of penetration into the aquifer. A method is outlined whereby the total amount of well discharge in the farming area near Hastings can be estimated on a seasonal and on an annual basis. This estimate can be compared with actual discharge figures, when they become available, to compute an estimate of the amount of leakage into the aquifer.

INTRODUCTION

Purpose and Scope

Almost all of the water supplies in St. Johns, Flagler, and Putnam Counties, Florida, are obtained from wells that tap the Floridan aquifer. Withdrawals of water to meet the needs of agriculture and expanding population have resulted in an overall decline of the potentiometric surface of the aquifer throughout the area and the development of extensive cones of depression near the centers of heavy pumping. An increase in the chloride concentration of water in conjunction with this decline indicates that saltwater gradually is contaminating the fresh-water zones in some parts of the aquifer (Bermes, Leve and Tarver, 1963a, p. 87-90).

Future development and proper management of the water supply depend on an accurate assessment of the hydraulic characteristics of the aquifer.

The U. S. Geological Survey, as part of a cooperative water-research program with the St. Johns River Water Management District, performed the aquifer tests needed to make such an assessment. This report describes the hydraulic characteristics of the aquifer as determined by these aquifer tests, with emphasis on the farming area in eastern Putnam and southwestern St. Johns Counties. The test results then were used to estimate the amount of pumpage causing the cone of depression in the area.

Location and Setting

Flagler, Putnam, and St. Johns Counties are in northeastern Florida (fig. 1). These counties lie between the Atlantic Ocean on the east and the Central Highlands on the west. Metropolitan Jacksonville bounds the area on the north. The principal communities are St. Augustine, Palatka, and Bunnell (fig. 3). Agriculture, timber harvesting for pulp production, and tourism in coastal areas are the main sources of income in the three counties.

The climate is humid subtropical with warm, wet summers and mild, relatively dry winters. The topography generally is flat, and slopes are gentle. The St. Johns River drains all of the area except for land near the coast.

Previous Investigations

Hydrologic and geologic data have been collected in the area during the last several decades by the U. S. Geological Survey, and by private and state agencies. Geology and the occurrence of ground water have been described by Matson and Sanford (1913), Sellards and Gunter (1913), Collins and Howard (1928), Stringfield (1936), Cooke (1945), Unklesbay (1945), Vernon (1951), Stringfield and Cooper (1951), and Black and Brown (1951). Preliminary reports on the ground-water resources of Flagler County (Bermes, 1958), St. Johns County (Tarver, 1958), and Putnam County (Leve, 1958) were prepared by the U. S. Geological Survey and published by the Florida Geological Survey. The most detailed and comprehensive investigation of the geology and ground water of the three counties was made by Bermes, Leve, and Tarver (1963a) of the U. S. Geological Survey. The investigation and companion report containing the basic data (Bermes, Leve, and Tarver, 1963b) were published by the Florida Geological Survey.

Leve (1968) described the stratigraphy and hydrology of the Floridan aquifer in northeast Florida. Personnel of the Florida Department of Natural Resources obtained records of wells and collected some field data in 1970. Their findings have not been published. A report by Plappert, Johnson, and Helping (in press 1977) of the Florida Department of Environmental Regulation summarizes the results obtained through implementation of a geophysical logging program in the farming area of

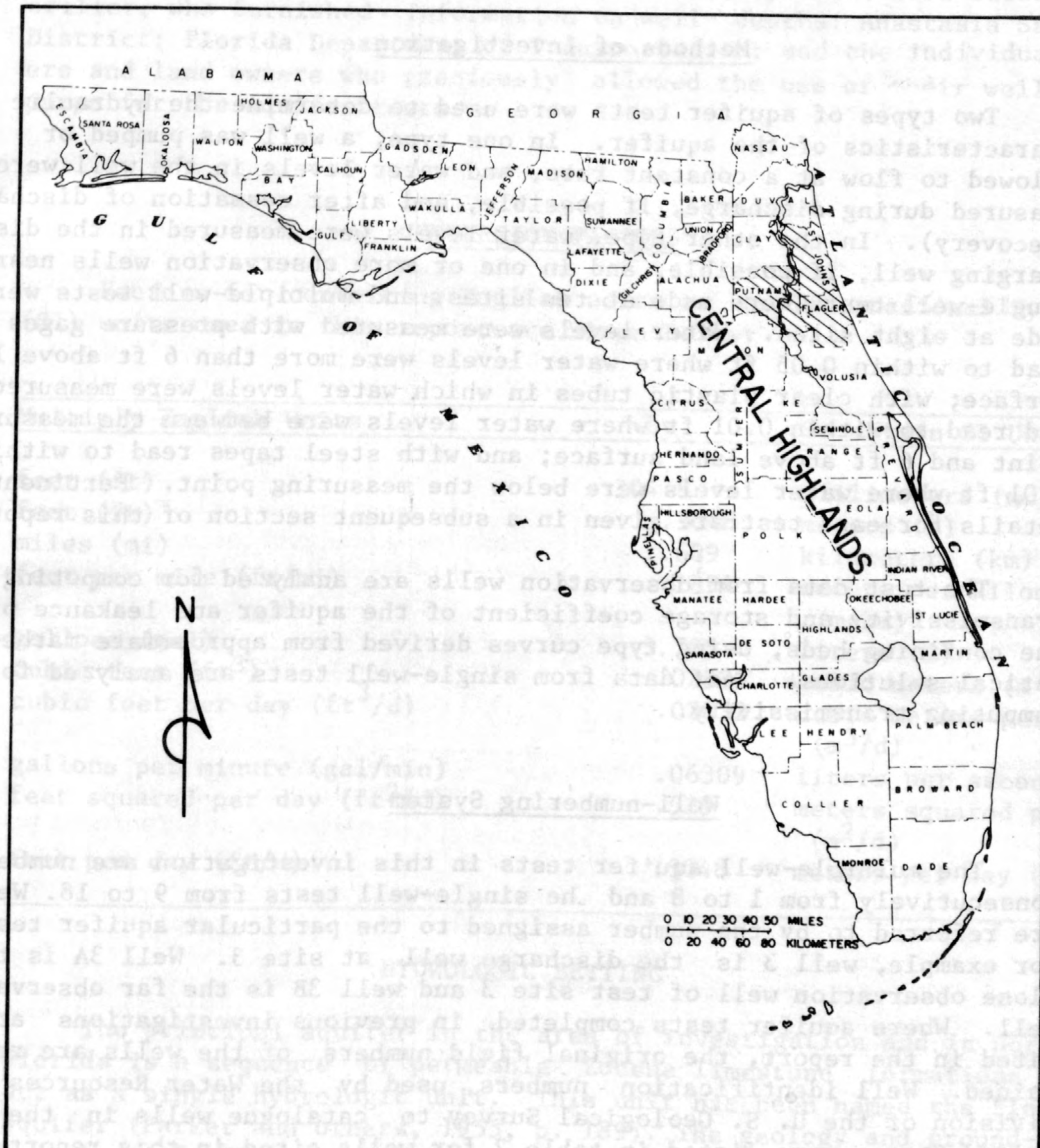


FIGURE 1.--Location of Flagler, Putnam, and St. Johns Counties

eastern Putnam and southwestern St. Johns Counties and includes the data that were obtained.

Methods of Investigation

Two types of aquifer tests were used to determine the hydraulic characteristics of the aquifer. In one type, a well was pumped or allowed to flow at a constant rate, and water levels in the well were measured during discharge, if possible, and after cessation of discharge (recovery). In the other type, water levels were measured in the discharging well, if possible, and in one or more observation wells nearby. Single-well tests were made at ten sites, and multiple-well tests were made at eight sites. Water levels were measured with pressure gages and read to within 0.05 ft where water levels were more than 6 ft above land surface; with clear plastic tubes in which water levels were measured and read to within 0.01 ft where water levels were between the measuring point and 6 ft above land surface; and with steel tapes read to within 0.01 ft where water levels were below the measuring point. Pertinent details for each test are given in a subsequent section of this report.

The test data from observation wells are analyzed for computing transmissivity and storage coefficient of the aquifer and leakance of the confining beds, using type curves derived from appropriate mathematical solutions. Test data from single-well tests are analyzed for computing transmissivity.

Well-numbering System

The multiple-well aquifer tests in this investigation are numbered consecutively from 1 to 8 and the single-well tests from 9 to 18. Wells are referred to by the number assigned to the particular aquifer test. For example, well 3 is the discharge well at site 3. Well 3A is the close observation well of test site 3 and well 3B is the far observation well. Where aquifer tests completed in previous investigations are cited in the report, the original field numbers of the wells are retained. Well identification numbers, used by the Water Resources Division of the U. S. Geological Survey to catalogue wells in the United States, are listed in table 2 for wells cited in this report.

Acknowledgments

The investigation was conducted as part of an ongoing cooperative program with the St. Johns River Water Management District (SJRWMD). Particular acknowledgment is given to Dennis Auth, former Executive Director, SJRWMD, for his encouragement and support, and to Douglas Munch and Bruce Ripy, SJRWMD, for their assistance in the selection of test sites and in supplying basic data relative to the investigation.

In addition, the writer gratefully acknowledges the cooperation of the following individuals, firms, and governmental agencies for their assistance: Frank H. Crum, of Leggette, Brashears, and Graham, consulting ground-water geologists, who furnished data on aquifer tests made at Palm Coast Community wells; ITT Community Development Corporation, who permitted the use of the Palm Coast Community data; Bill Wilson, well driller, who furnished information on well depths; Anastasia Sanitary District; Florida Department of Transportation; and the individual farmers and land owners who graciously allowed the use of their wells and pumps for the aquifer tests.

CONVERSION FACTORS

Factors for converting English units to the International System (SI) units used in this report are shown below:

Multiply English Units	By	To obtain SI Units
feet (ft)	304.8	millimeters (mm)
feet (ft)	.3048	meters (m)
miles (mi)	1.609	kilometers (km)
feet per mile (ft/mi)	.1894	meters per kilometer (m/km)
gallons (gal)	3.785	liters (L)
cubic feet (ft^3)	.02832	cubic meters (m^3)
cubic feet per day (ft^3/d)	.02832	cubic meters per day (m^3/d)
gallons per minute (gal/min)	.06309	liters per second (L/s)
feet squared per day (ft^2/d)	.929	meters squared per day (m^2/d)
feet per day (ft/d)	.3048	meters per day (m/d)

HYDROLOGIC SETTING

The principal aquifer in the area of investigation and in northern Florida is a sequence of permeable Eocene limestone formations which act as a single hydrologic unit. This unit has been named the Floridan aquifer (Parker and others, 1955, p. 189). The geology and ground-water hydrology of Flagler, Putnam, and St. Johns Counties are described by Bermes, Leve, and Tarver (1963a), and a summary of their description is given in table 1. Ground water generally occurs under water-table or unconfined conditions in the undifferentiated Pleistocene and Holocene deposits, and under artesian or confined conditions in the undifferentiated Miocene or Pliocene deposits and in lenses of sand, shell, and limestone in the underlying Hawthorn Formation. In many areas, where the lower permeable beds in the Hawthorn Fomation are not separated by impermeable layers from the Eocene formations, they are considered as part of the Floridan aquifer. The water in the aquifer generally is

Table 1.--Geologic units and their water-bearing characteristics (After Bermes, Leve, Tarver, 1963a).

Geologic Age	Geologic Unit	Thickness (ft) 1/	Lithology	Water-bearing Characteristics
Holocene and Pleistocene	Surficial deposits	20-140	Discontinuous sand, clay, and shell beds	Sand and shell deposits locally supply moderate amounts of water to wells.
Pliocene or Late Miocene	Undifferentiated marine deposits	20-100	Interbedded lenses of sand, shell, and silty clay	Yields moderate amounts of artesian and non-artesian water to wells. Relatively impermeable clays with those in Hawthorn Formation serving as confining beds for artesian water in Floridan aquifer.
Middle Miocene	Hawthorn Formation	0-200	Phosphatic sandy clay and marl interbedded with phosphorite pebbles, phosphatic sand, and phosphatic sandy limestone	Yields moderate amounts of artesian water to wells. Clays and marls serve as confining beds for artesian water in Eocene formations and basal sand and limestone beds in Hawthorn Formation.
Late Eocene	Ocala Group 2/: Crystal River Formation	50-200 (Ocala Group): 0-100	Homogeneous sequence of chalky and granular limestones	Floridan aquifer: Supplies large quantities of artesian water to wells and is the principal source of water in the area.
	Ocala Group 2/: Williston Formation	50-200 (Ocala Group): 0-50		
	Ocala Group 2/: Inglis Formation	50-200 (Ocala Group): 50-110		
Middle Eocene	Avon Park Limestone	155-235	Alternating beds of massive gradular, and chalky limestone and dense dolomite	Floridan aquifer: Water-bearing permeable limestone beds separated by relatively impermeable limestone and dolomite.
	Lake City Limestone	230+		

1/ Variation in thickness shown in more detail on figure 2.

2/ The classification and nomenclature of the geologic units conform to the usage of the Florida Geological Survey and not necessarily to that of the U. S. Geological Survey.

under sufficient artesian pressure to cause many wells that are open to the aquifer to flow either seasonally or year around, but, because of heavy pumpage in farming areas, the potentiometric surface of the aquifer is below land surface in some areas and many wells do not flow. The potentiometric surface, which is the level to which water would rise in tightly cased wells that penetrate an artesian aquifer, ranged from about 10 ft below land surface near Armstrong in the farming area to more than 20 ft above land surface in areas distant from discharging wells. Bermes, Leve, and Tarver (1963a, p. 25-27) noted that some water-bearing zones in the aquifer are separated by relatively impermeable limestone and dolomite beds which can retard the vertical movement of water.

The formations dip northward at about 9 ft/mi (Bermes, Leve, and Tarver, 1963a, fig. 9, p. 34). A fault that extends northward from Lake George into north central Putnam County has a maximum vertical displacement of 75 ft (fig. 28). The thicknesses of the geologic units vary throughout the area of investigation. To a large extent the thickness variation is due to erosion, and some of the units have been completely eroded in some areas (fig. 2).

In many areas of Flagler, Putnam, and St. Johns Counties the Floridan aquifer contains saline water, probably sea water that entered the formations either at the time of deposition or subsequently when sea level was much higher than at present. In most areas the freshwater zones are in the upper 200-300 ft of the aquifer, and the saline water is deeper. Water from deep wells in areas where the Floridan aquifer is heavily pumped frequently contains chloride concentrations in excess of 1000 mg/L (milligrams per liter).

Generally, wells which tap the Floridan aquifer are cased from land surface to the top of, or a few feet into the aquifer, with the remainder of the hole left open.

AQUIFER TEST DATA

Eighteen aquifer tests, eight with a single discharging well and one or more observation wells, and ten with only a discharging well, were made during this investigation. The locations, as well as those of previous tests, are shown on figure 3. The pertinent results of the tests are summarized in table 2 at the end of this section.

Test wells were pumped at the design rate of discharge of pumps used, which were generally the well owners' pumps. Pumping rates ranged from 41 to 790 gal/min. A portable suction pump with a maximum discharge of 120 gal/min was used in test wells that were not already equipped with a pump. Flowing wells that were not equipped with pumps were allowed to flow during the discharge phase and were shut in during recovery. Flows ranged from 67 to 660 gal/min.

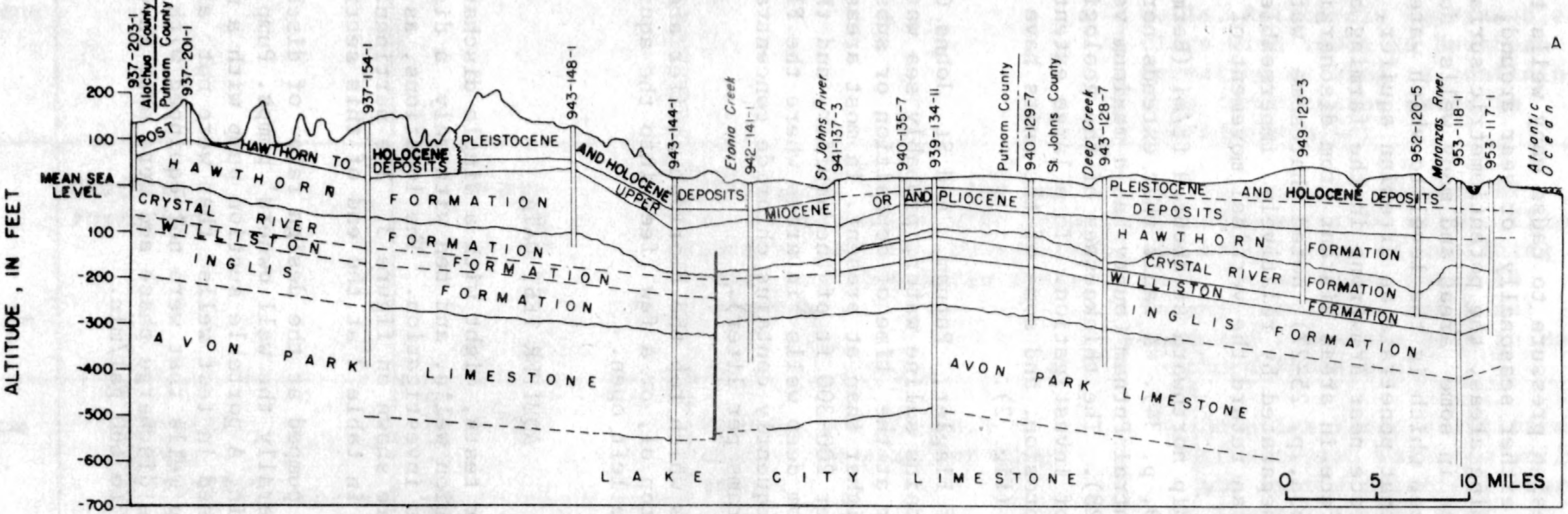
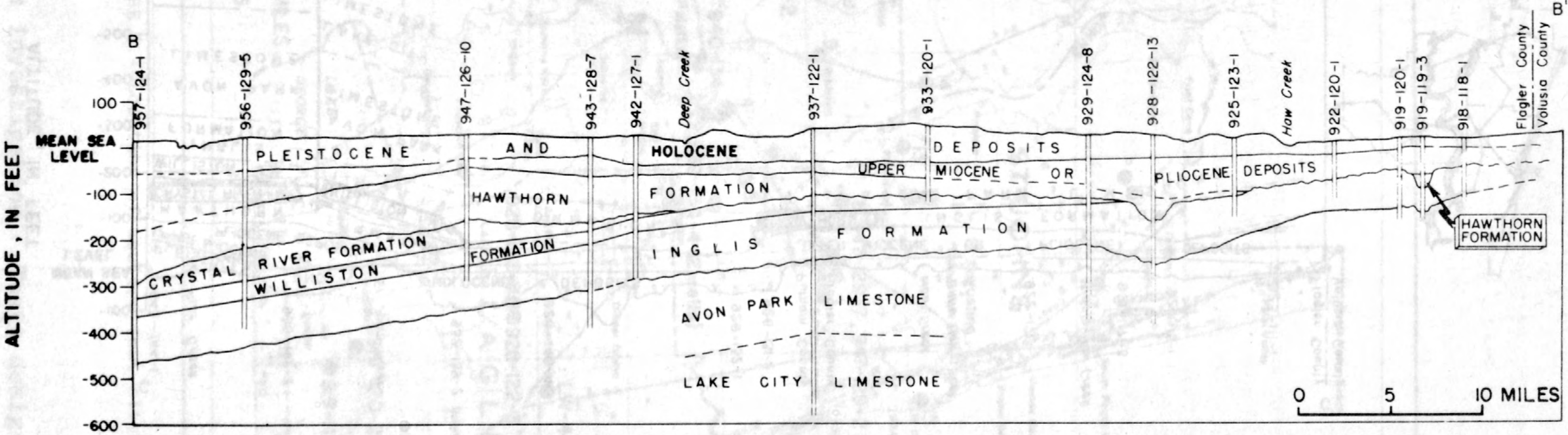
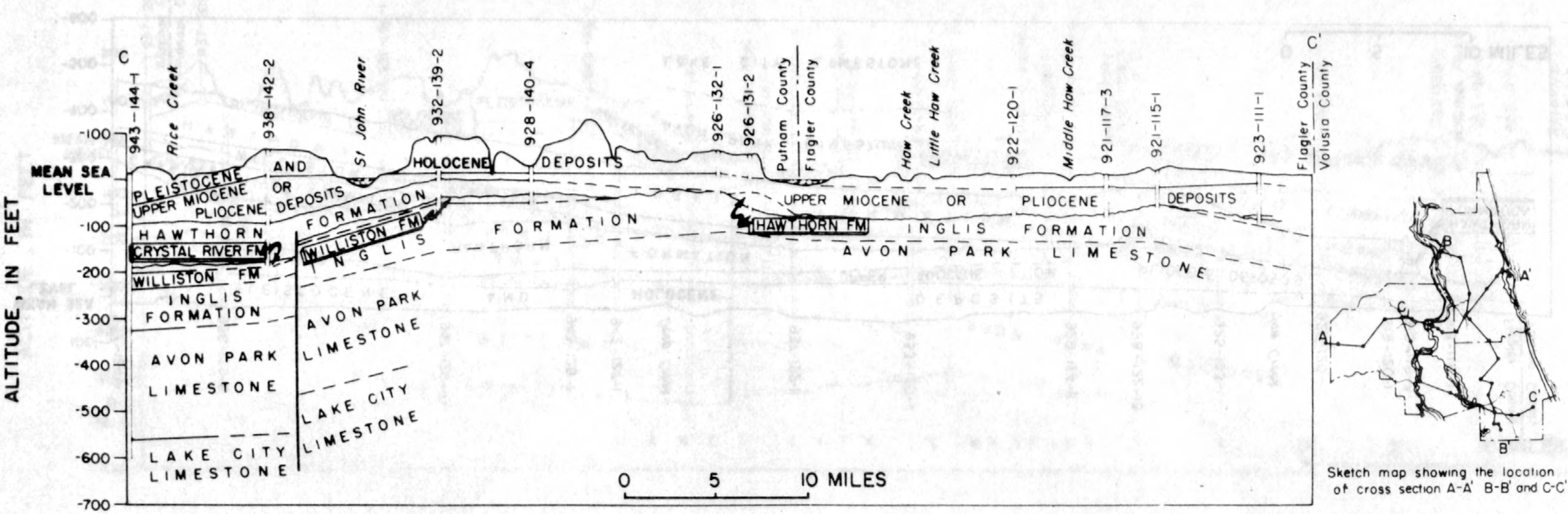


Figure 2.--Generalized geologic sections showing formations penetrated by wells. (From Bermes, Leve, and Tarver, 1963a, figure 6.)


B
B'
ALTITUDE, IN FEET
100
MEAN SEA LEVEL
-100
-200
-300
-400
-500
-600
957-124-1
956-129-5
947-126-10
943-128-7
942-127-1
Deep Creek
937-122-1
933-120-1
929-124-8
928-122-13
925-123-1
Haw Creek
922-120-1
919-120-1
919-119-3
918-118-1
Flagler County
Volusia County
PLEISTOCENE AND HOLOCENE DEPOSITS
UPPER MIOCENE OR PLIOCENE DEPOSITS
HAWTHORN FORMATION
CRYSTAL RIVER FORMATION
WILLISTON FORMATION
INGLIS FORMATION
AVON PARK LIMESTONE
LAKE CITY LIMESTONE
HAWTHORN FORMATION
0
5
10 MILES


C
C'
ALTITUDE, IN FEET
MEAN SEA LEVEL
100
100
200
300
400
500
600
700
943-144-1
Rice Creek
938-142-2
St John River
932-139-2
928-140-4
926-132-1
926-131-2
Putnam County
Flagler County
Haw Creek
Little Haw Creek
922-120-1
Middle Haw Creek
921-117-3
921-115-1
923-111-1
Flagler County
Volusia County
HOLOCENE
AND
DEPOSITS
PLEISTOCENE
OR
UPPER MIOCENE
PLIOCENE
DEPOSITS
UPPER MIOCENE
OR
PLIOCENE
DEPOSITS
HAWTHORN
FORMATION
FORMATION
HAWTHORN FM
CRYSTAL RIVER FM
WILLISTON FM
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LAKE CITY
LIMESTONE
LAKE CITY
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0
5
10 MILES
A
A'
B
B'
C
C'
Sketch map showing the location of cross section A-A' B-B' and C-C'

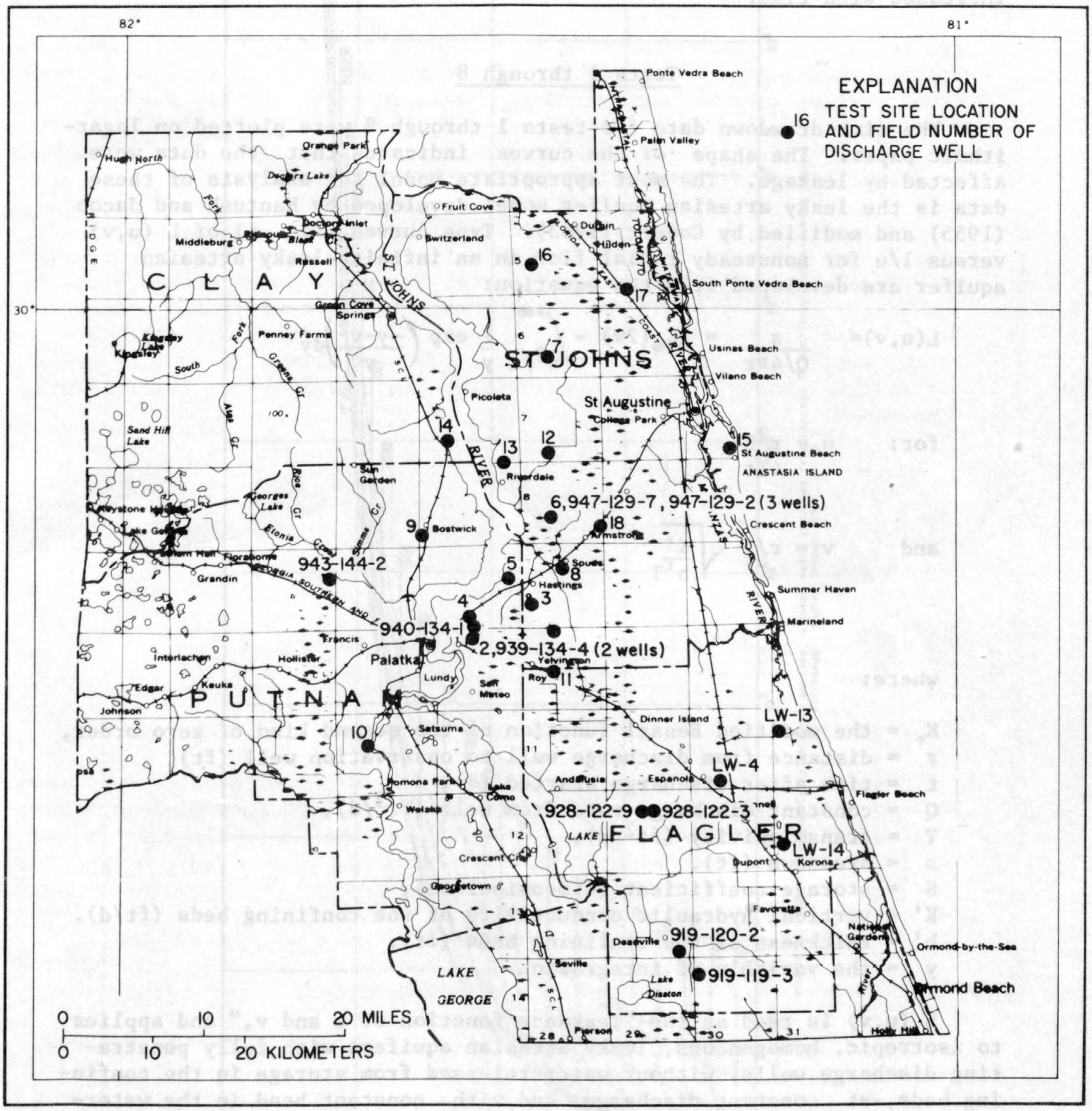

FIGURE 3.--Location of aquifer test sites.

(Tests 1-18 completed in this investigation. Tests designated by seven-digit number completed by Bermes, Leve, and Tarver, 1963a. Tests LW-4, LW-13, and LW-14 completed by Leggette, Brashears, and Graham, written commun., 1976.)

The tests lasted only a few hours because the effect of leakance generally was detected in the drawdown at the observation wells by a flattening of the drawdown versus time curve during the first 2 or 3 hours of testing. The wells were pumped or allowed to flow at a constant discharge rate until, in most instances, the drawdown no longer increased with time.

Tests 1 through 8

The time-drawdown data for tests 1 through 8 were plotted on logarithmic paper. The shape of the curves indicated that the data were affected by leakage. The most appropriate model for analysis of these data is the leaky artesian aquifer model developed by Hantush and Jacob (1955) and modified by Cooper (1963). Type curves (fig. 4) of L (u,v) versus 1/u for nonsteady radial flow in an infinite leaky artesian aquifer are developed from the equation:

$$L(u,v) = \frac{s}{Q/4\pi t} = 2K_0(2v) - \int_{v^2/u}^{\infty} \frac{1}{y} \exp\left(\frac{-y-v^2}{y}\right) dy \qquad (1)$$

for: $u = \frac{r^2 S}{4Tt}$

and $v = r/2 \sqrt{\frac{K'}{b'T}}$

where:

K_0 = the modified Bessel function of the second kind of zero order,
r = distance from discharge well to observation well (ft),
t = time after discharge started (d),
Q = constant discharge rate from well (ft^3/d),
T = transmissivity (ft^2/d),
s = drawdown (ft),
S = storage coefficient (dimensionless),
K' = vertical hydraulic conductivity of the confining beds (ft/d).
b' = thickness of the confining beds (ft),
y = the variable of integration.

L (u,v) is read as the "leakance function of u and v," and applies to isotropic, homogeneous, leaky artesian aquifers with fully penetrating discharge wells, without water released from storage in the confining beds, at constant discharge, and with constant head in the water-table aquifer that overlies the confining beds. The transmissivity of an aquifer is defined as the rate of flow of water at the prevailing kinematic viscosity through a unit width of the aquifer and extending

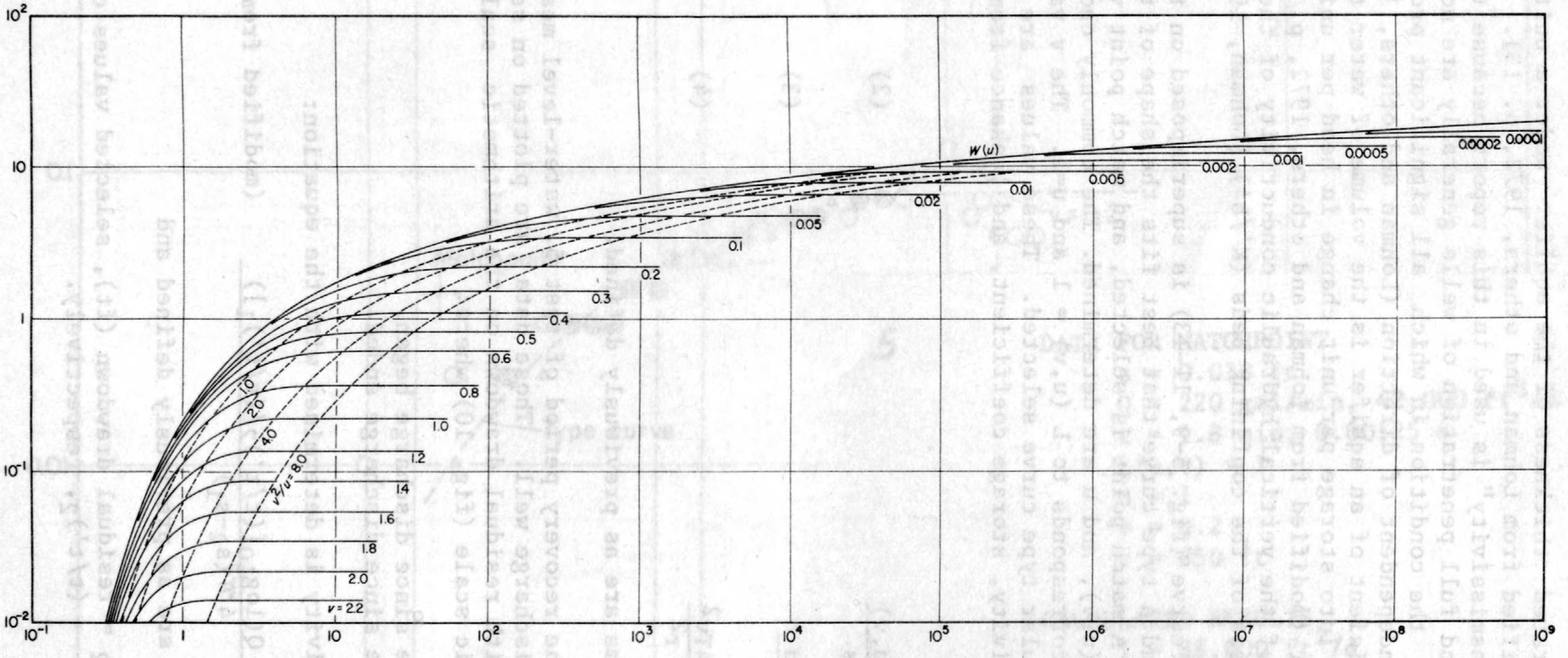

FIGURE 4.--Type curves for leaky artesian aquifer, without water released from storage in confining beds and with constant discharge. (After Lohman, 1972, pl. 3.)

the full saturated thickness of the aquifer under a unit hydraulic gradient (modified from Lohman and others, 1972, p. 13). The term "observed transmissivity" is used in this report because the conditions of isotropy and full penetration of wells generally are not met. Isotropy is defined as the condition in which all significant properties of the aquifer are independent of direction (Lohman and others, 1972, p. 9). The storage coefficient of an aquifer is the volume of water that is released from or taken into storage per unit change in head per unit surface area of the aquifer (modified from Lohman and others, 1972, p. 13). Leakance is the ratio of the vertical hydraulic conductivity of the confining beds to the thickness of the confining beds (K'/b') [Lohman, 1972, p. 30].

The data curve (fig. 5-9, 11-13) is superimposed on the family of type curves and a type curve that best fits the shape of the data curve is selected. A match point is selected, and match point values of s, t (or t/r^2), L (u,v), and u are determined. The commonly chosen matchpoint is one that corresponds to L (u,v) = 1 and u=1. The v value is given by the particular type curve selected. These values are used to solve for transmissivity, storage coefficient, and leakance from the following equations:

$$T = \frac{Q\,L(u,v)}{4\pi s} \qquad (2)$$

$$S = \frac{4\,T\,u}{r^2/t} \qquad (3)$$

$$K'/b' = \frac{4Tv^2}{r^2} \qquad (4)$$

where all terms are as previously defined.

During the recovery period of test 5, water-level measurements were made in the discharge well. Those data are plotted on semi-logarithmic graph paper with residual drawdown on the arithmetic scale and t/t' on the logarithmic scale (fig. 10) where:

t = time since discharge began,
t' = time since discharge ended.

The transmissivity is determined with the equation:

$$T = \frac{2.3\,Q(\log_{10}[(t/t')_2/(t/t')_1])}{4\pi(s_2-s_1)} \quad \text{(modified from Theis, 1935)}$$

where T and Q are as previously defined and

s_1 and s_2 = residual drawdown (ft), selected values of $(t/t')_1$ and $(t/t')_2$, respectively.

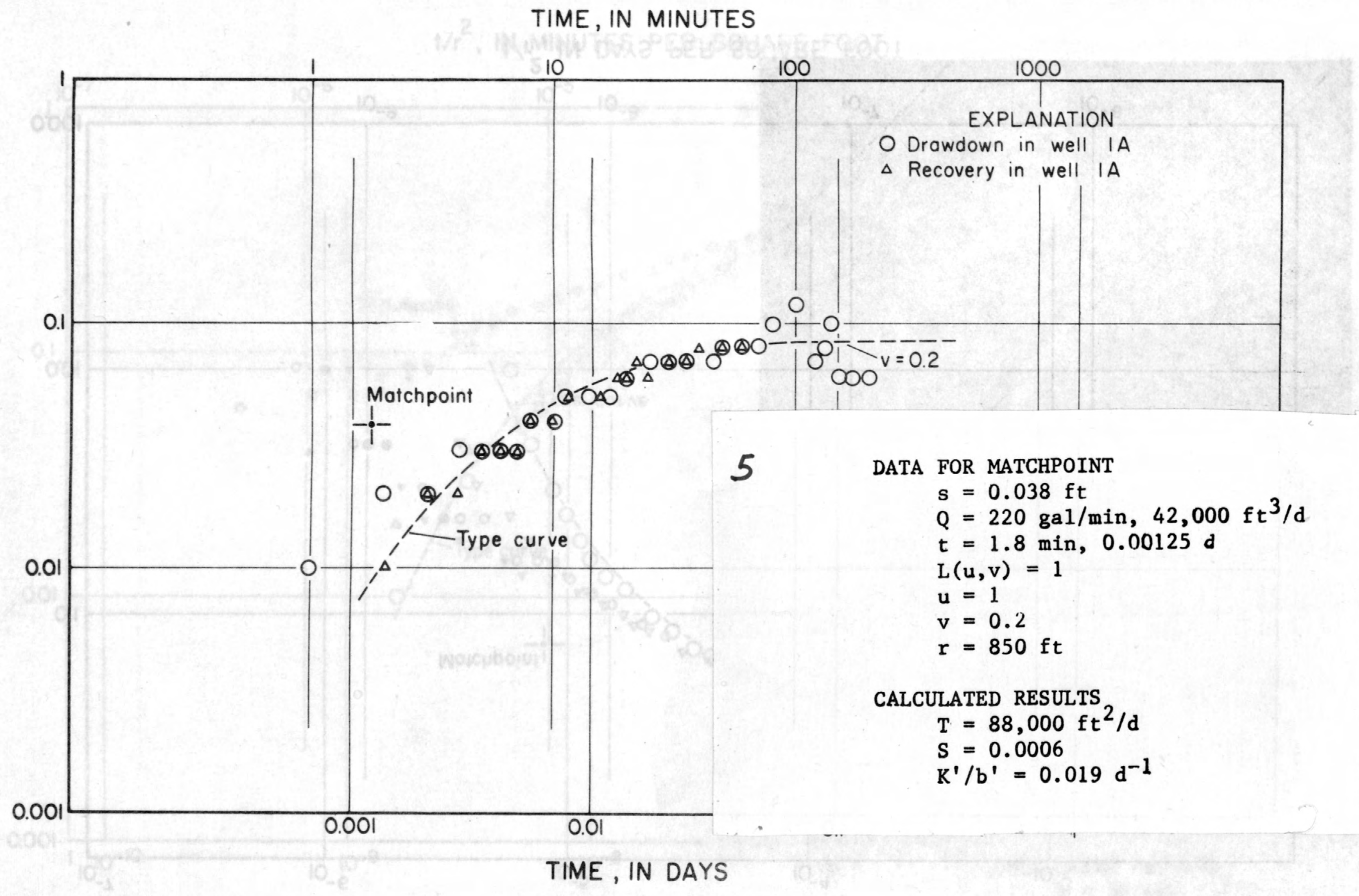

FIGURE 5.--Drawdown and recovery data from aquifer test 1.

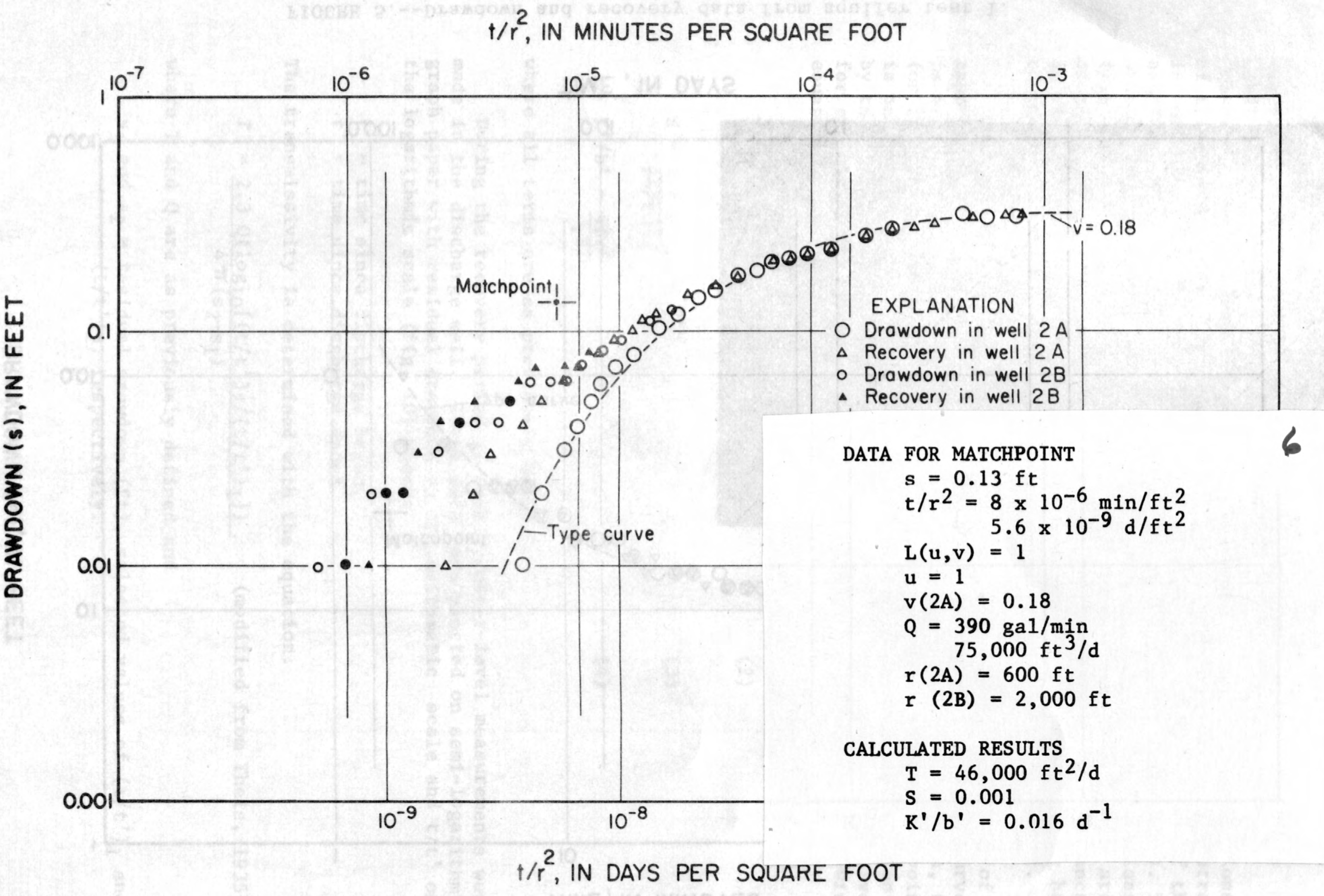

FIGURE 6.--Drawdown and recovery data from aquifer test 2.

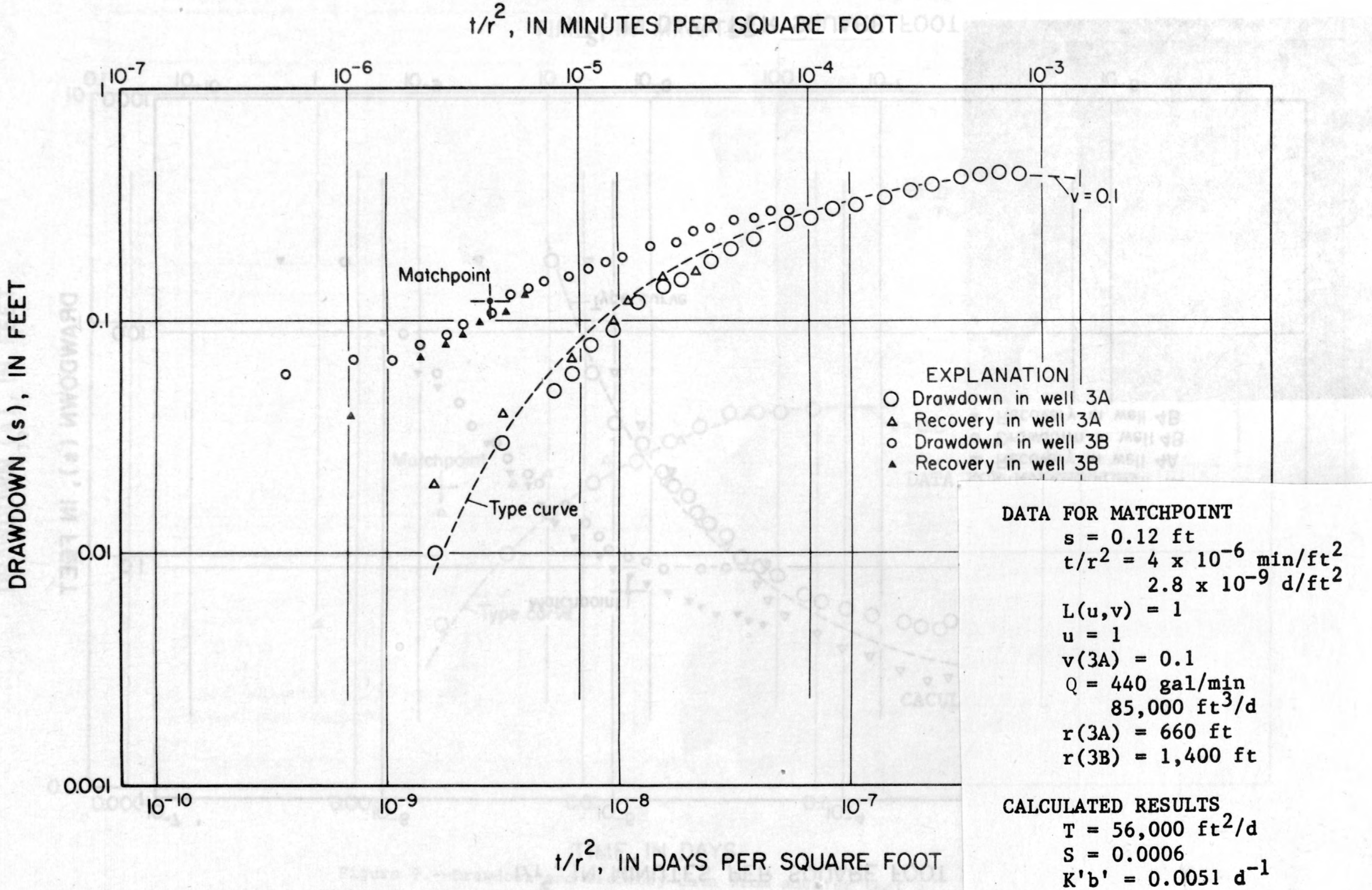

Figure 7.--Drawdown and recovery data from aquifer test 3.

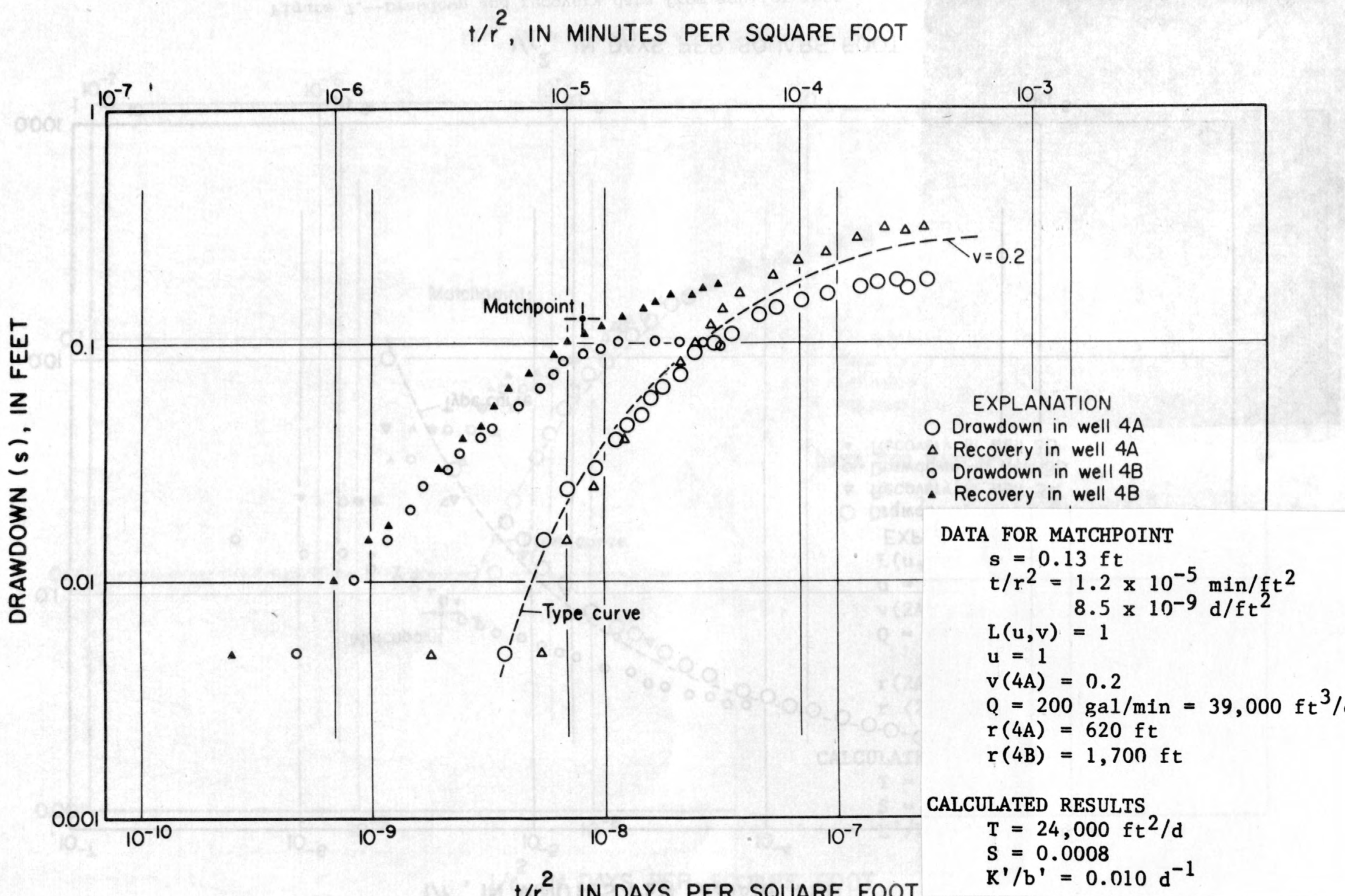

Figure 8.--Drawdown and recovery data from aquifer test 4.

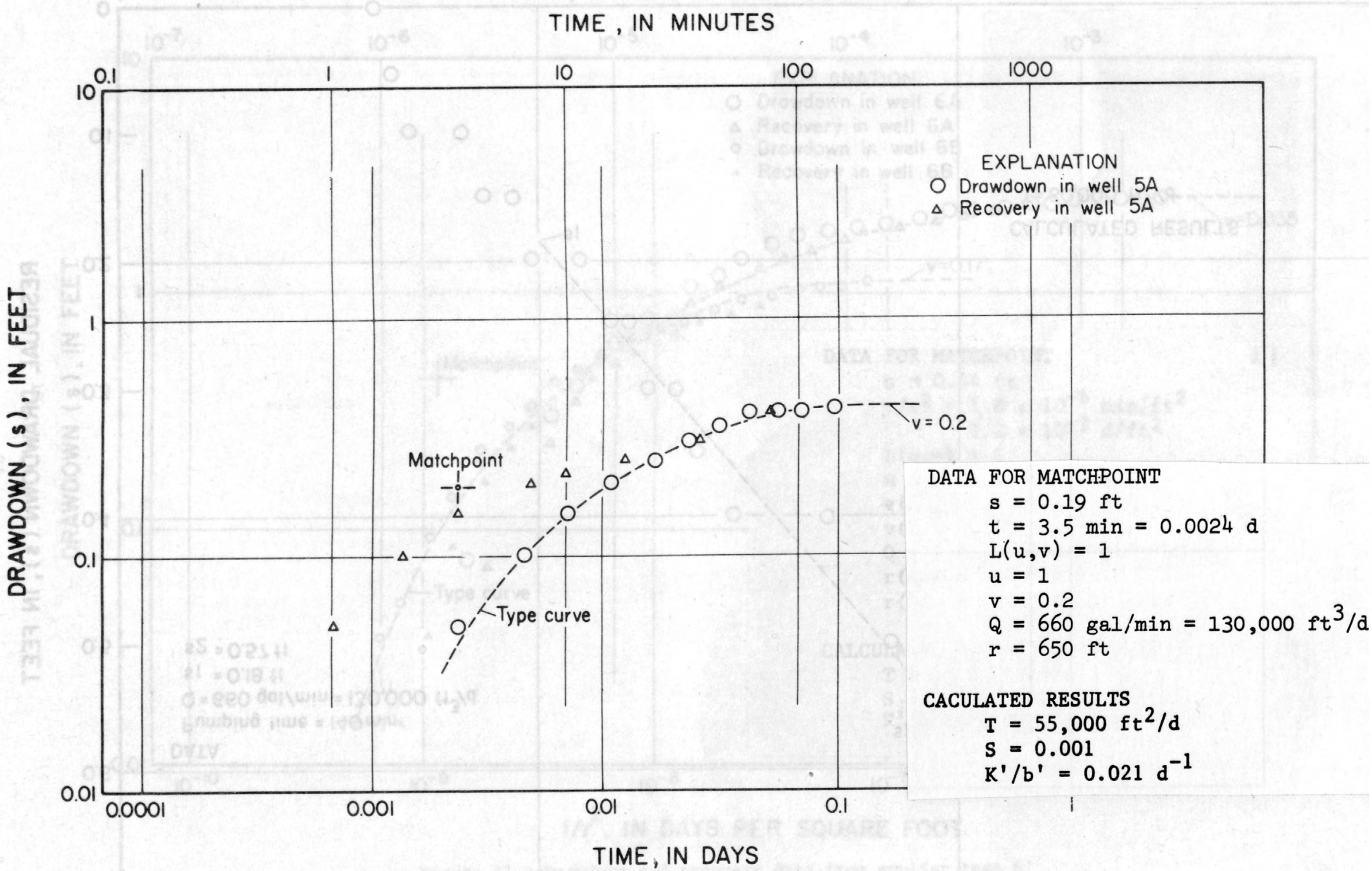

Figure 9.--Drawdown and recovery data from aquifer test 5.

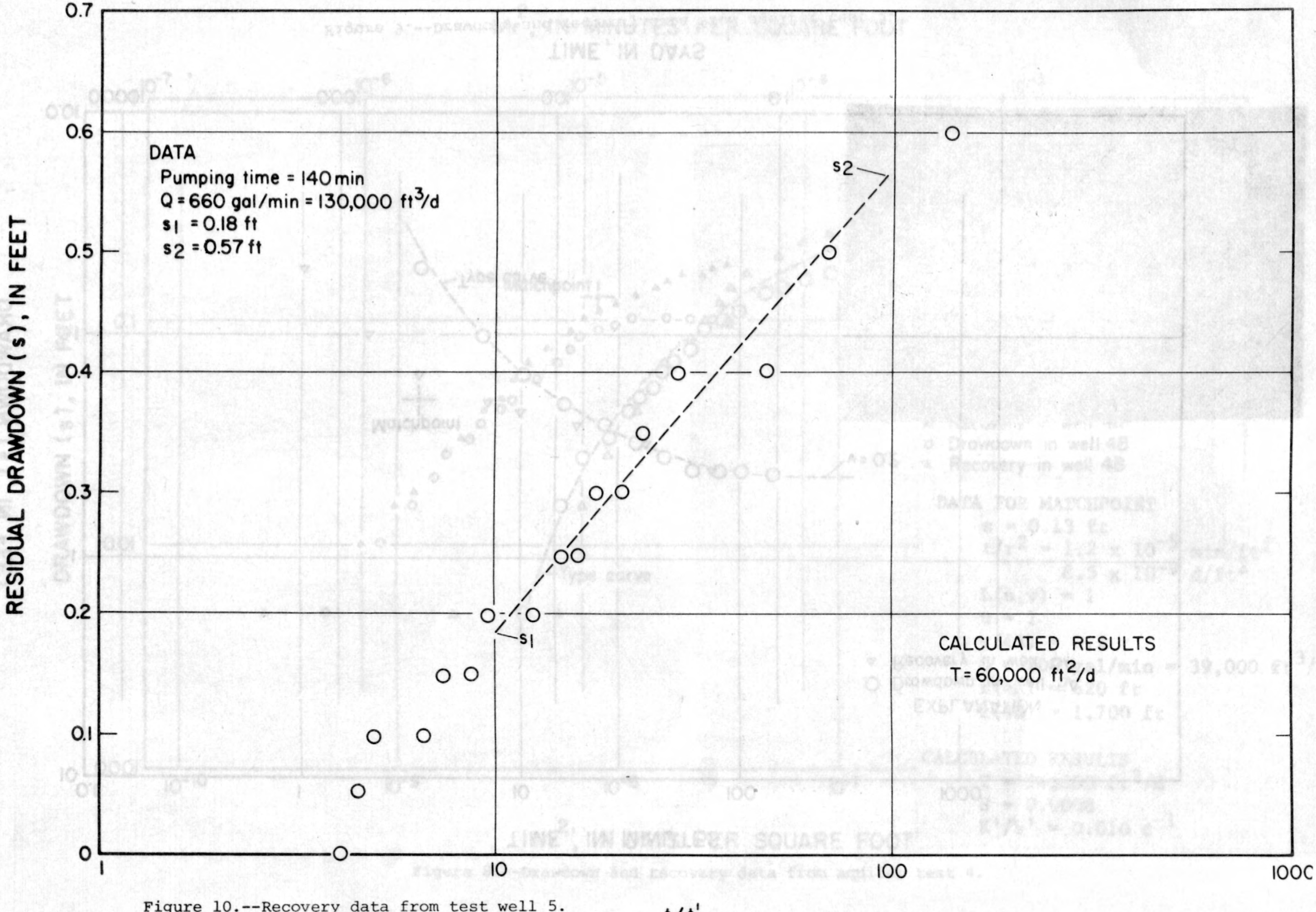

Figure 10.--Recovery data from test well 5.

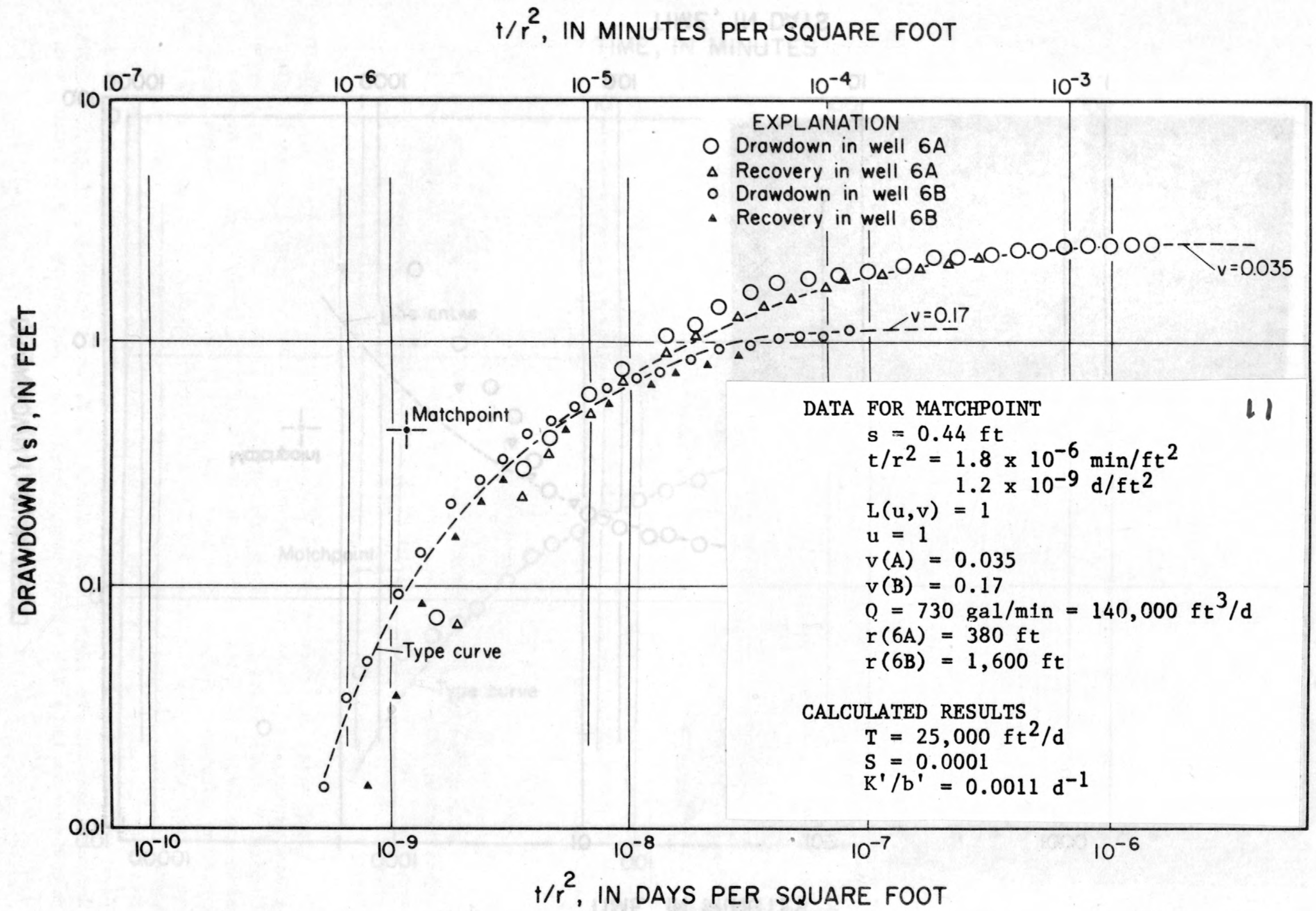

Figure 11.--Drawdown and recovery data from aquifer test 6.

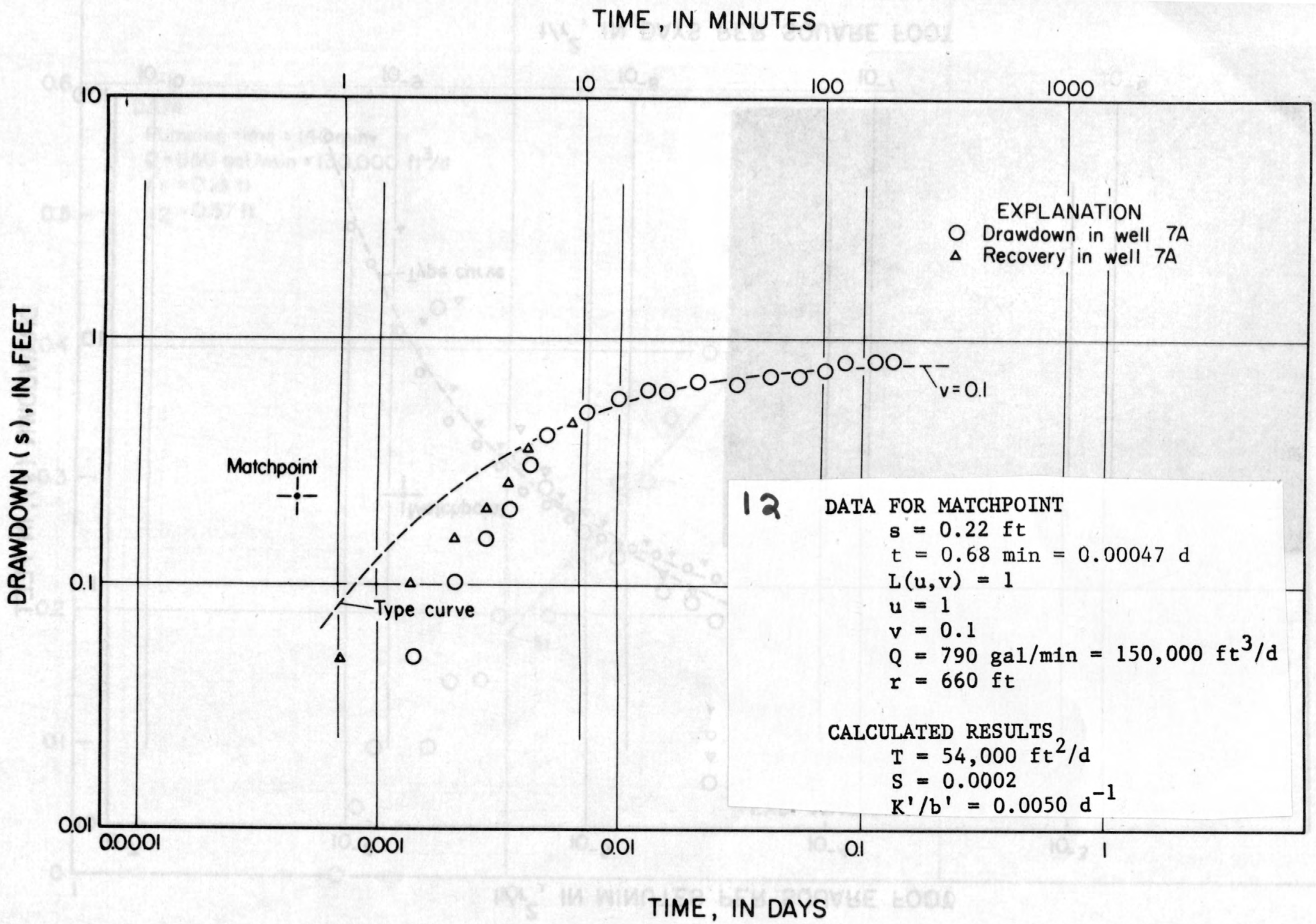

Figure 12.--Drawdown and recovery data from aquifer test 7.

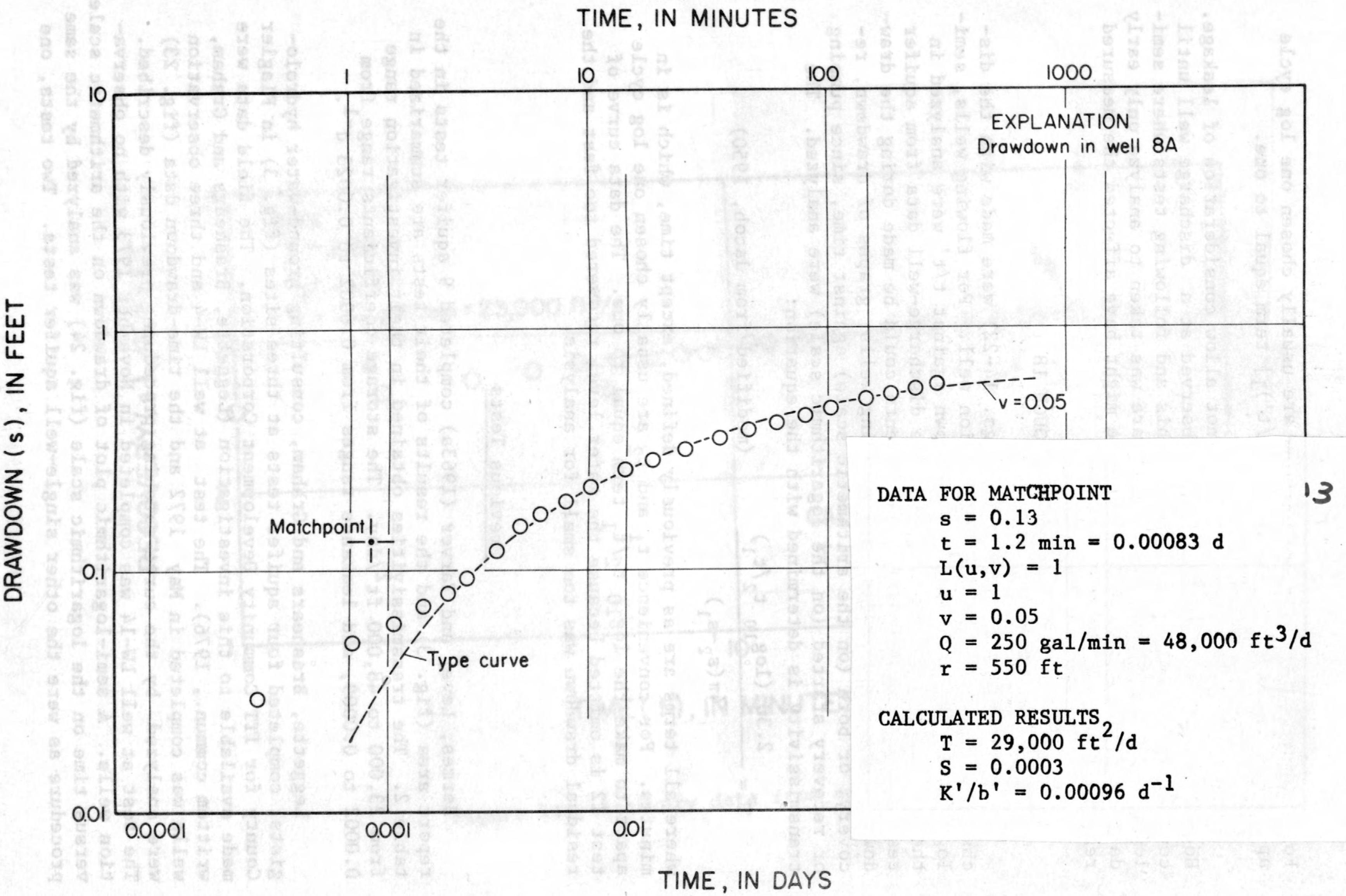

Figure 13.--Drawdown data from aquifer test 8.

For convenience $(t/t')_1$ and $(t/t')_2$ are usually chosen one log cycle apart to make the $\log_{10}[(t/t')_2/(t/t')_1]$ term equal to one.

This method of analysis does not allow consideration of leakage. However, leakage effects were not observed at a discharge well until considerable time had passed. In this and following tests where semi-logarithmic techniques were used, care was taken to analyze only early data, prior to the time when leakage might have affected the measured response.

TESTS 9 THROUGH 18

Aquifer tests 9 through 18 (figs. 14-22) were made with the discharge well serving as the observation well. For flowing wells, semi-logarithmic plots of residual drawdown against t/t' were analyzed in the same manner as was done with the discharge-well data from aquifer test 5. Where water-level measurements could be made during the drawdown and recovery phases at nonflowing wells, graphs of drawdown, recovery, or both (on the arithmetic scale) against time, since pumping or recovery started (on the logarithmic scale) were analyzed. The transmissivity is determined with the equation:

$$T = \frac{2.3Q\,(\log_{10} t_2/t_1)}{4\pi(s_2-s_1)} \qquad \text{(modified from Jacob, 1950)}$$

where all terms are as previously defined, except time, which is in minutes. For convenience t_1 and t_2 are usually chosen one log cycle apart to make the $\log_{10} t_2/t_1$ term equal to one. The data curve of test 12 is omitted because the water level recovered too fast and the residual drawdown was too small for analysis.

Previous Tests

Bermes, Leve, and Tarver (1963a) completed 9 aquifer tests in the report area (fig. 3) and the results of their tests are summarized in table 2. The transmissivities obtained in their investigation range from 23,000 to 48,000 ft^2/day. The storage coefficients range from 0.0002 to 0.0009, and leakance ranges from 0.0002 to 0.0023 d^{-1}.

Leggette, Brashears and Graham, consulting ground-water hydrologists, completed four aquifer tests at three sites (fig. 3) in Flagler County for ITT Community Development Corporation. The field data were made available to this investigation (Leggette, Brashears and Graham, writtem commun., 1976). The test at well LW-4 and three observation wells was completed in May 1972 and the time-drawdown data (fig. 23) were analyzed by the curve-matching procedure previously described. The test at well LW-14 was completed in November 1973 with no observation wells. A semi-logarithmic plot of drawdown on the arithmetic scale versus time on the logarithmic scale (fig. 24) was analyzed by the same procedure as were the other single-well aquifer tests. Two tests, one

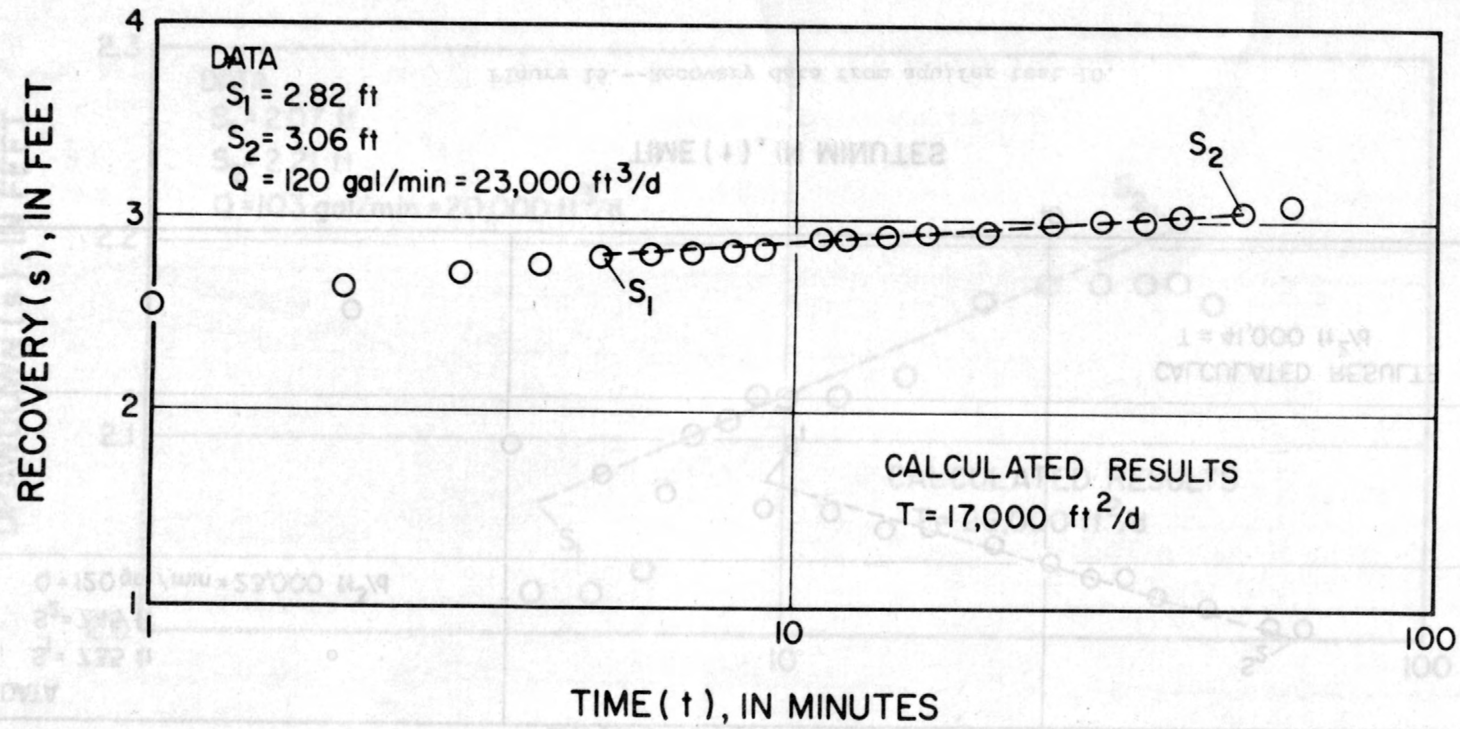

Figure 14.--Recovery data from aquifer test 9.

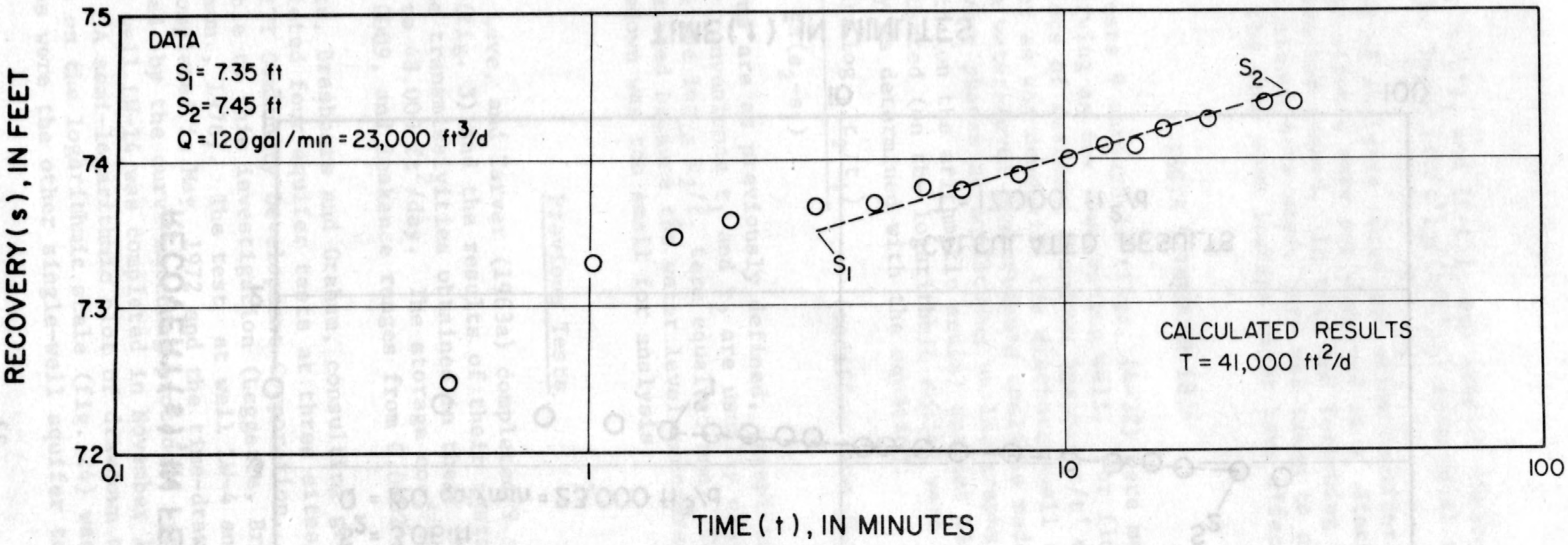

Figure 15.--Recovery data from aquifer test 10.

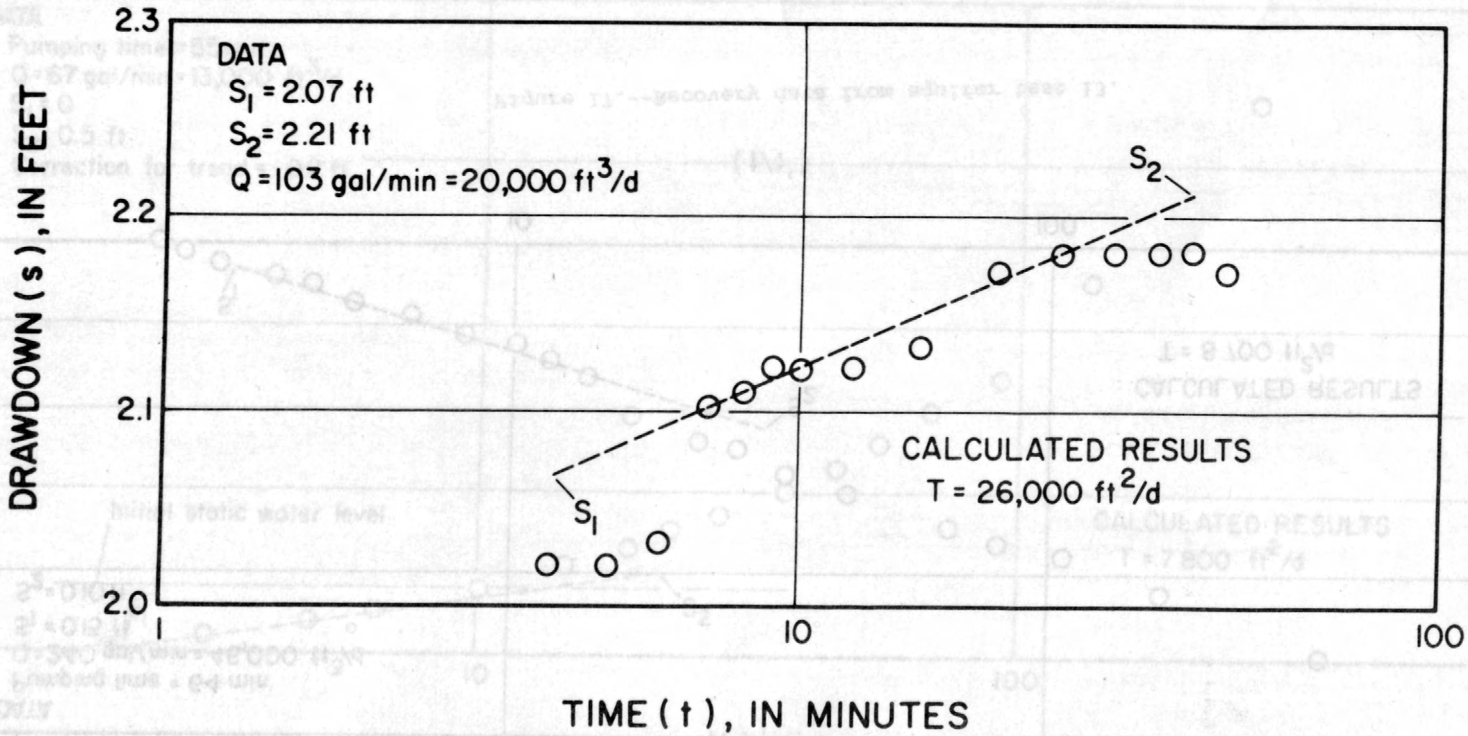

Figure 16.--Drawdown data from aquifer test 11.

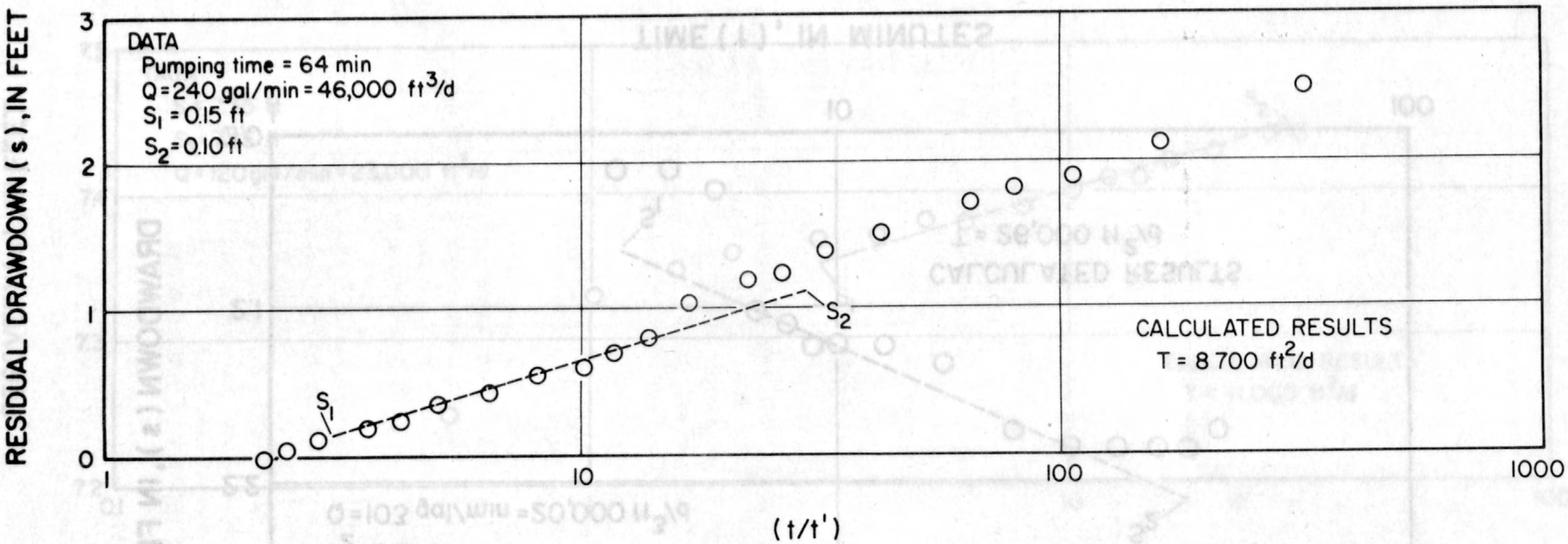

Figure 17.--Recovery data from aquifer test 13.

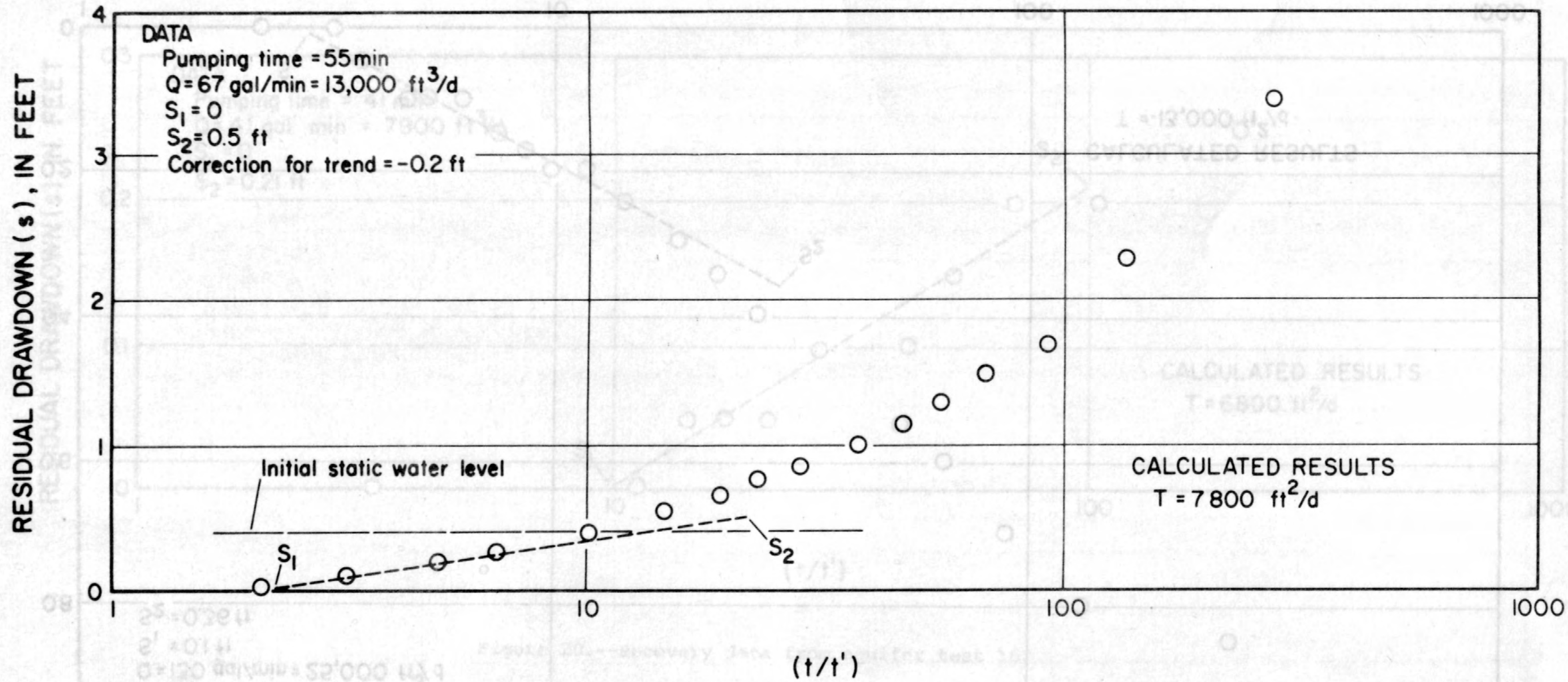

Figure 18.--Recovery data from aquifer test 14.

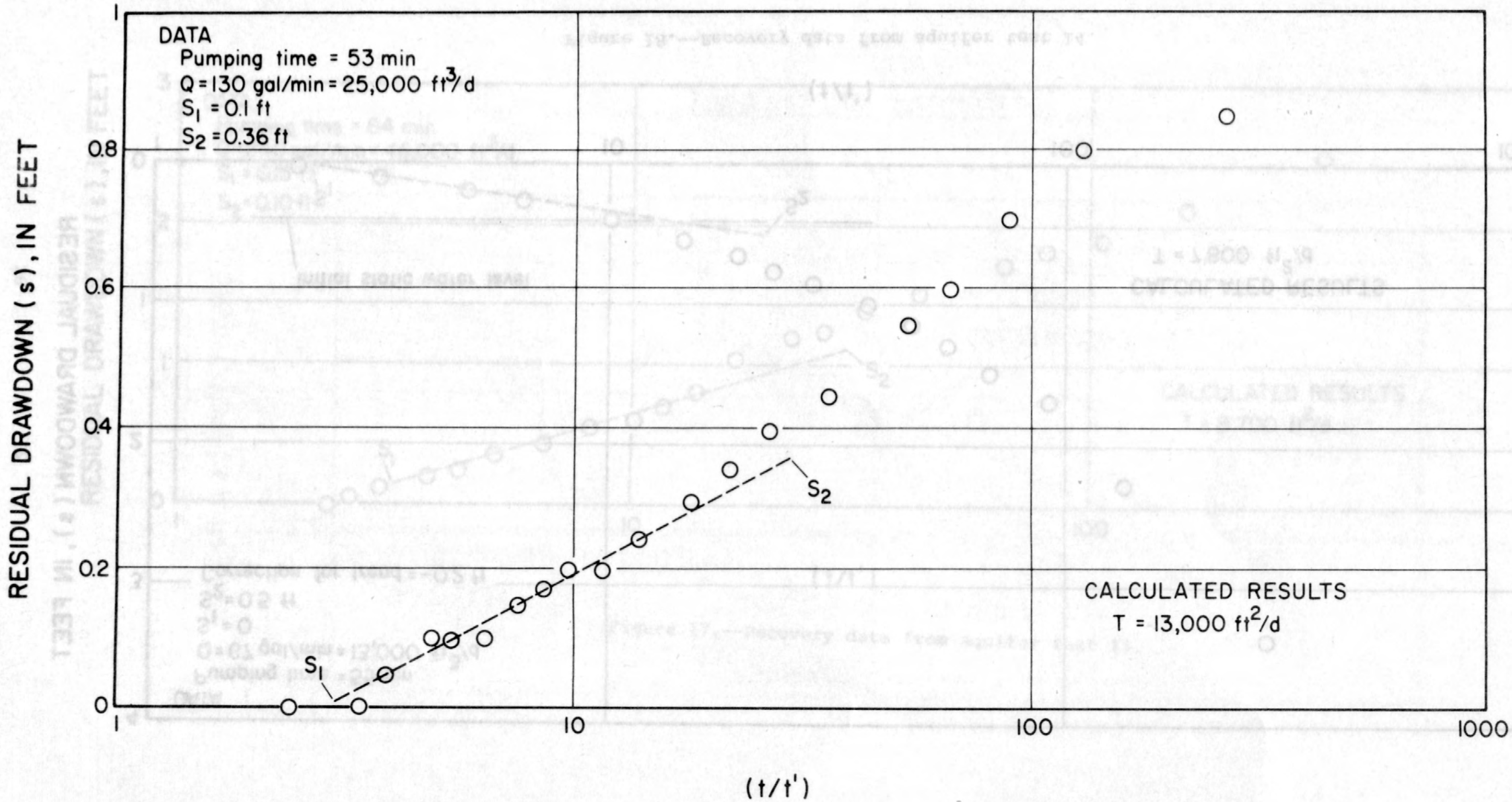

Figure 19.--Recovery data from aquifer test 15.

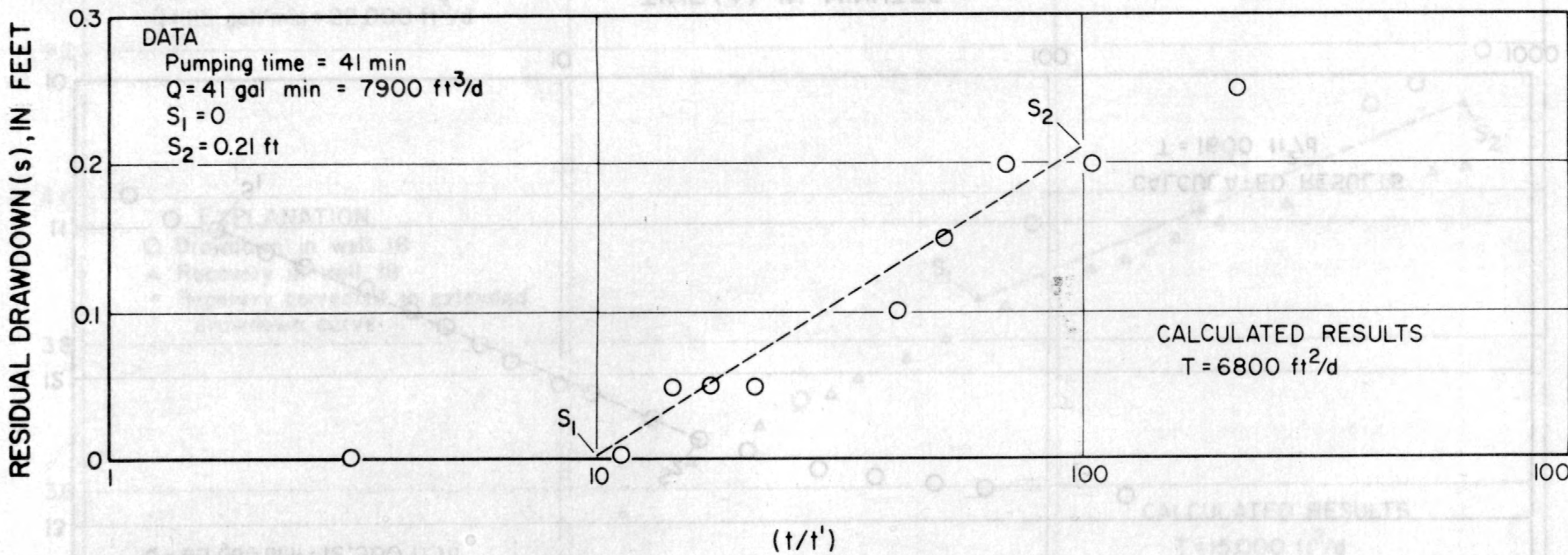

Figure 20.--Recovery data from aquifer test 16.

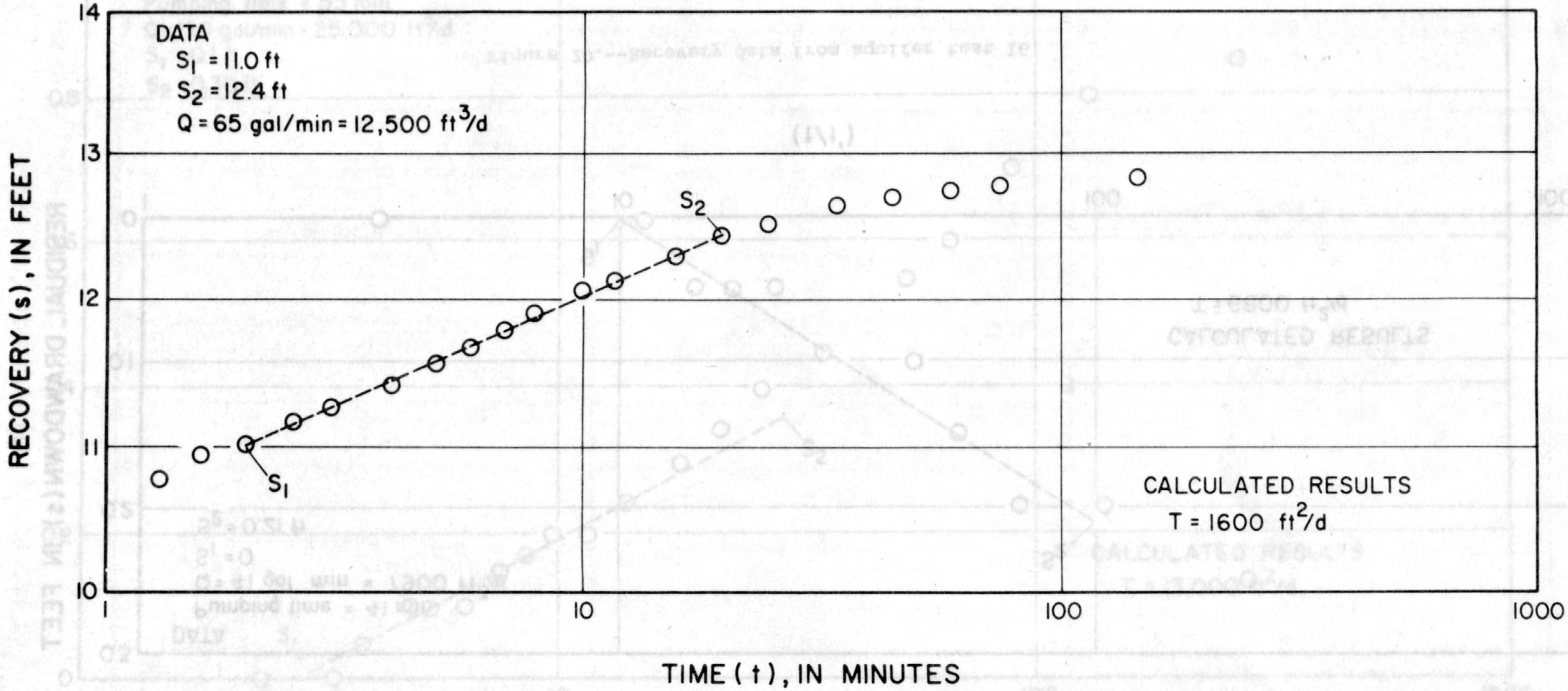

Figure 21.--Recovery data from aquifer test 17.

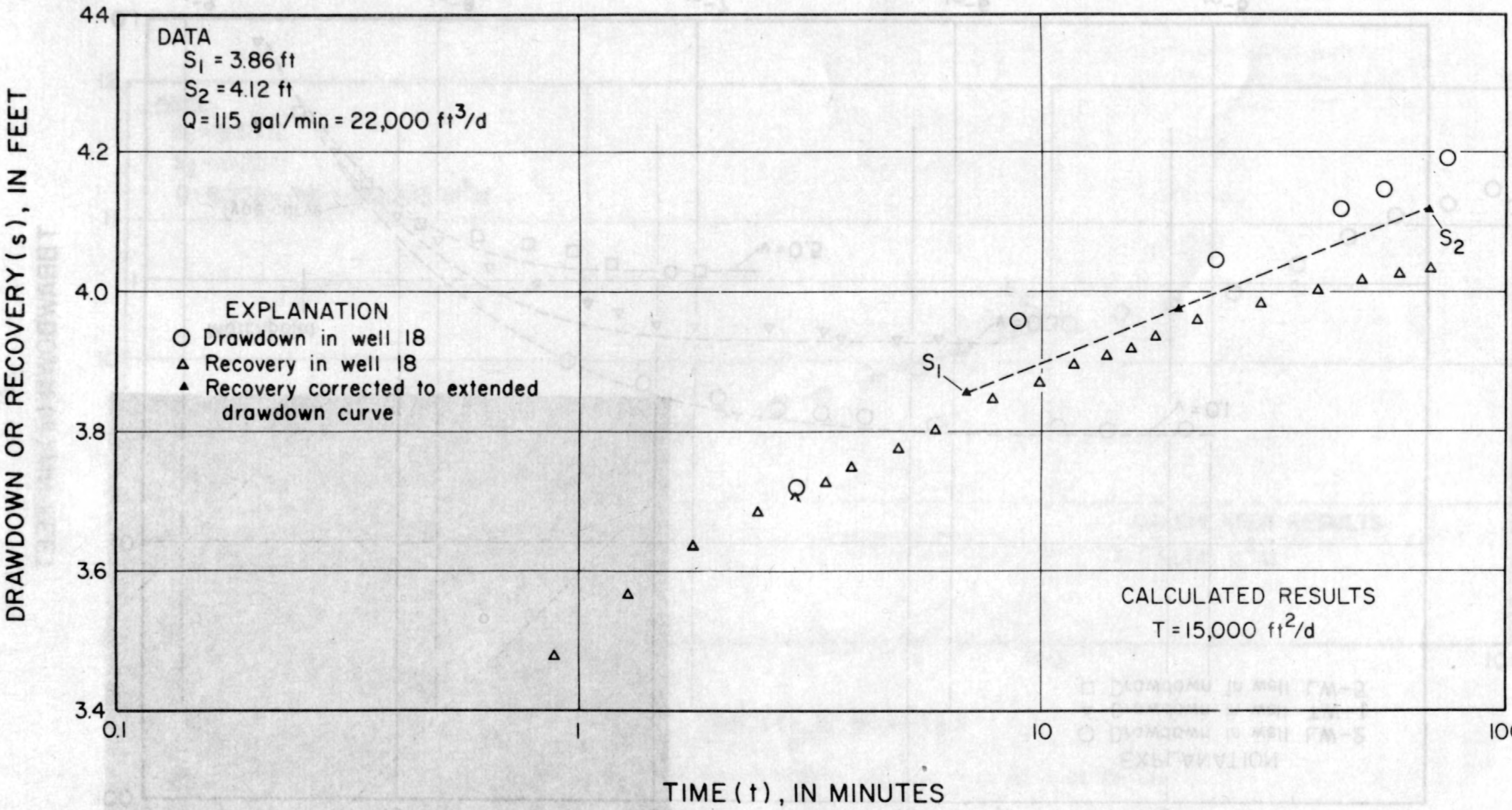

Figure 22.--Drawdown and recovery data from aquifer test 18.

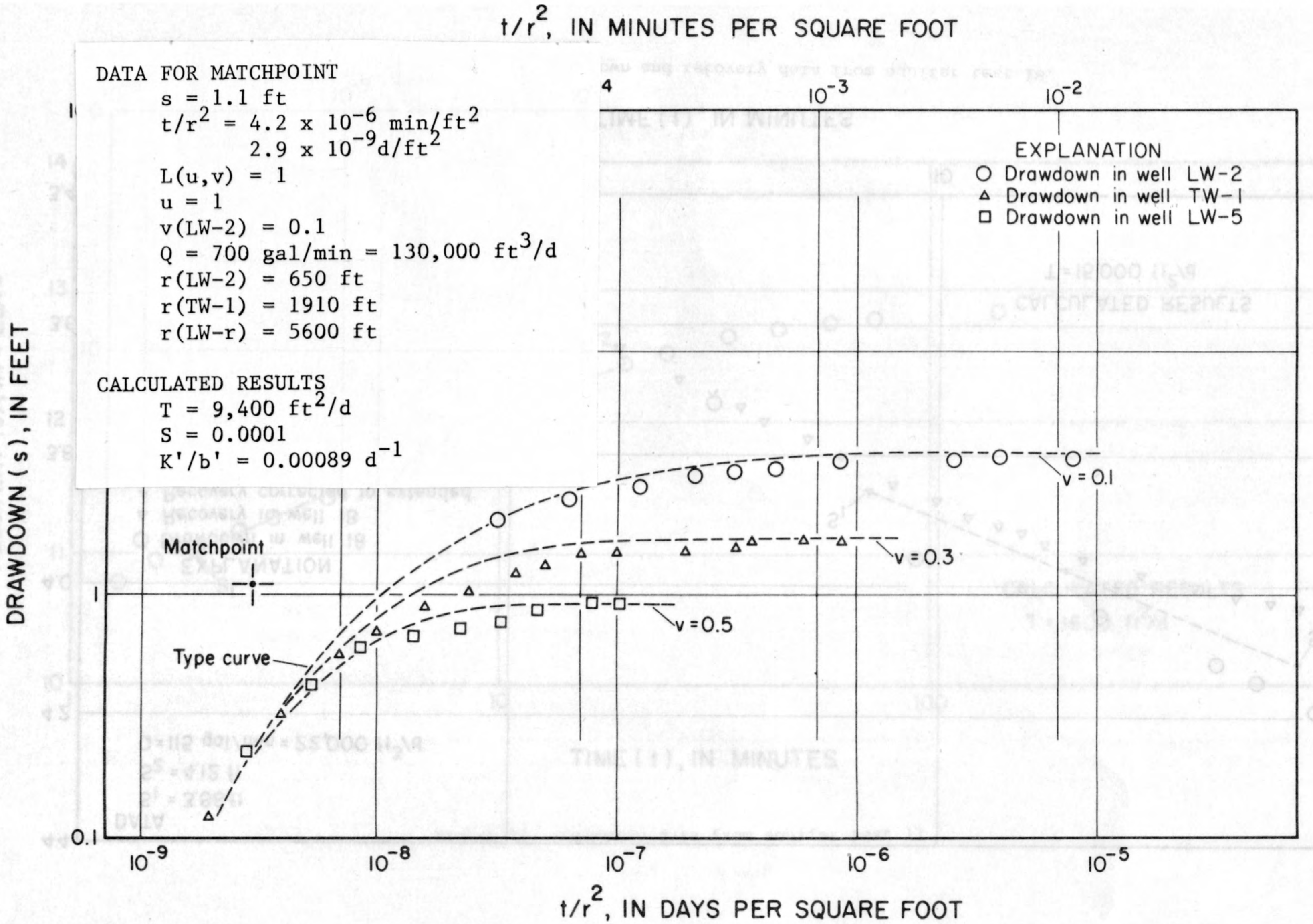

Figure 23.--Drawdown data from aquifer test at well LW-4.

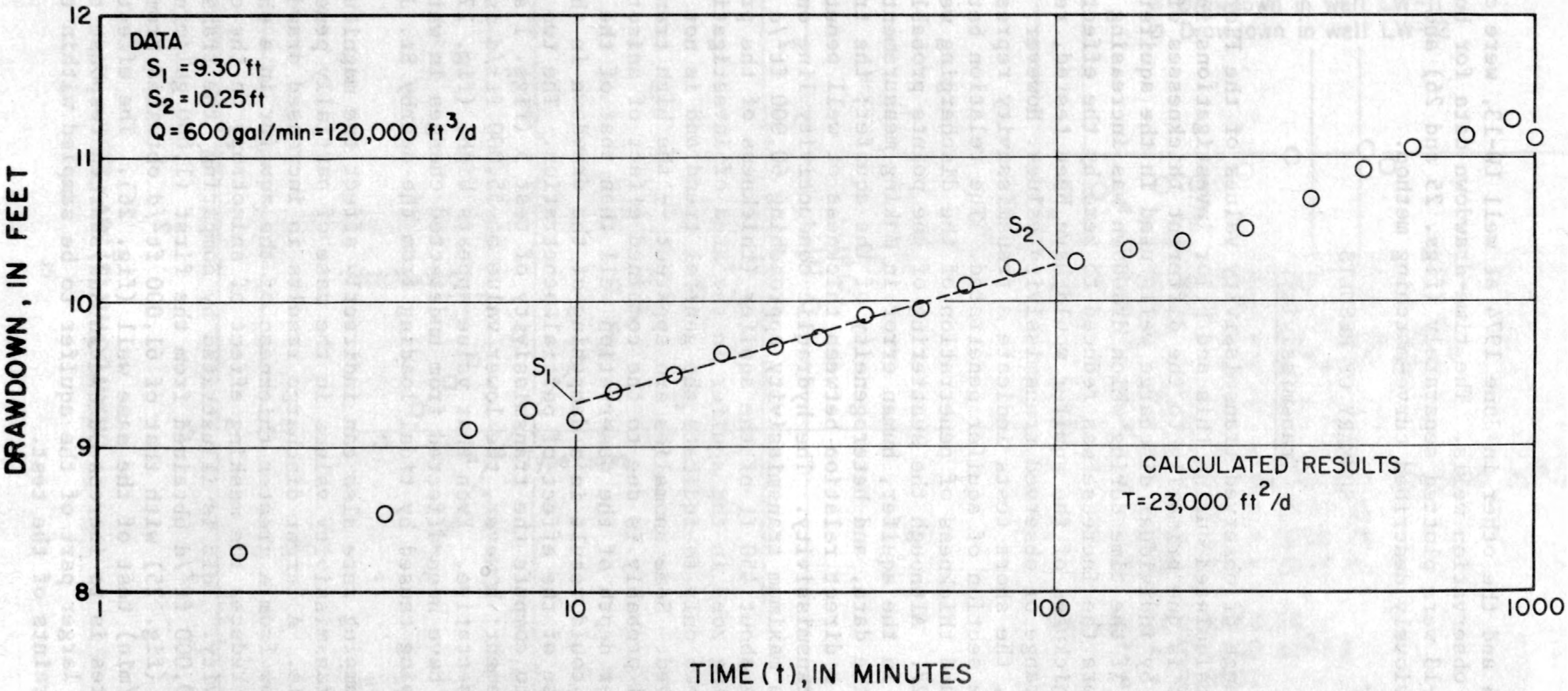

Figure 24.--Drawdown data from aquifer test at well LW-14.

in May 1974 and the other in June 1974 at well LW-13, were completed with three observation wells. The time-drawdown data for both tests at well LW-13 were plotted separately (figs. 25 and 26) and analyzed by the previously described curve-matching method.

SUMMARY OF RESULTS

Transmissivity

The range of observed transmissivity values of the Floridan aquifer that were calculated during this and prior investigations in the area of this report is due primarily to the different thicknesses of the aquifer penetrated by individual discharge wells used in the aquifer tests. Theoretically, if the time during which drawdown was increasing had been long enough before the increase was reduced to zero by the effect of leakage, the full thickness of the aquifer would have been tested, resulting in a decreased range of observed transmissivity values. However, because of anisotropy, the short tests indicate a transmissivity representative of only the section of aquifer penetrated. The relation between transmissivity and thickness of penetration of the discharging well is shown on figure 27. Although the scattering of the points probably is due to anisotropy in the aquifer, human error in making measurements and in analyzing the data, and heterogeneity of the aquifer; the trend of the data shows a direct relation between thickness of well penetration and observed transmissivity. The hydraulic conductivity line on figure 27 indicates a maximum transmissivity approaching 60,000 ft^2/d in wells penetrating about 450 ft of the aquifer (thickness of the principal water-bearing zone in the aquifer in the area of investigation). The line is shown only to indicate the general trend and is not statistically derived. Some anomalies are apparent -- the high transmissivity from test 1 probably is due to the combined effect of anisotropy and the much greater depth of the observation well than that of the discharging well which could result in a dampening of the drawdown in the observation well because of the effect of partial penetration. The two methods that were used to compute the transmissivity of test 5 (figs. 1 and 10) are in close agreement; however, the lower value of 55,000 ft^2/d is believed more representative. Even that value appears high, (fig. 27) and the data could have been affected from undetected changes in water levels during pumping caused by tidal loading from the nearby St. Johns River.

The pumping rate also can indirectly affect tne magnitude of the observed transmissivity values in the case of partially penetrating discharge wells. A larger discharge results in increased drawdown which induces flow from a greater thickness of the aquifer in a shorter time period and reduces the masking effect of anisotropy on the calculated transmissivity. This is illustrated by comparing the transmissivity value of 50,000 ft^2/d obtained from the first (1,000 gal/min) test of well LW-13 (fig. 25) with that of 61,000 ft^2/d obtained from the second (1,400 gal/min) test of the same well (fig. 26). The effect of higher pumping rates is to increase drawdown and shorten response time, thereby allowing a larger part of the aquifer to be sampled within the practical time constraints of the test.

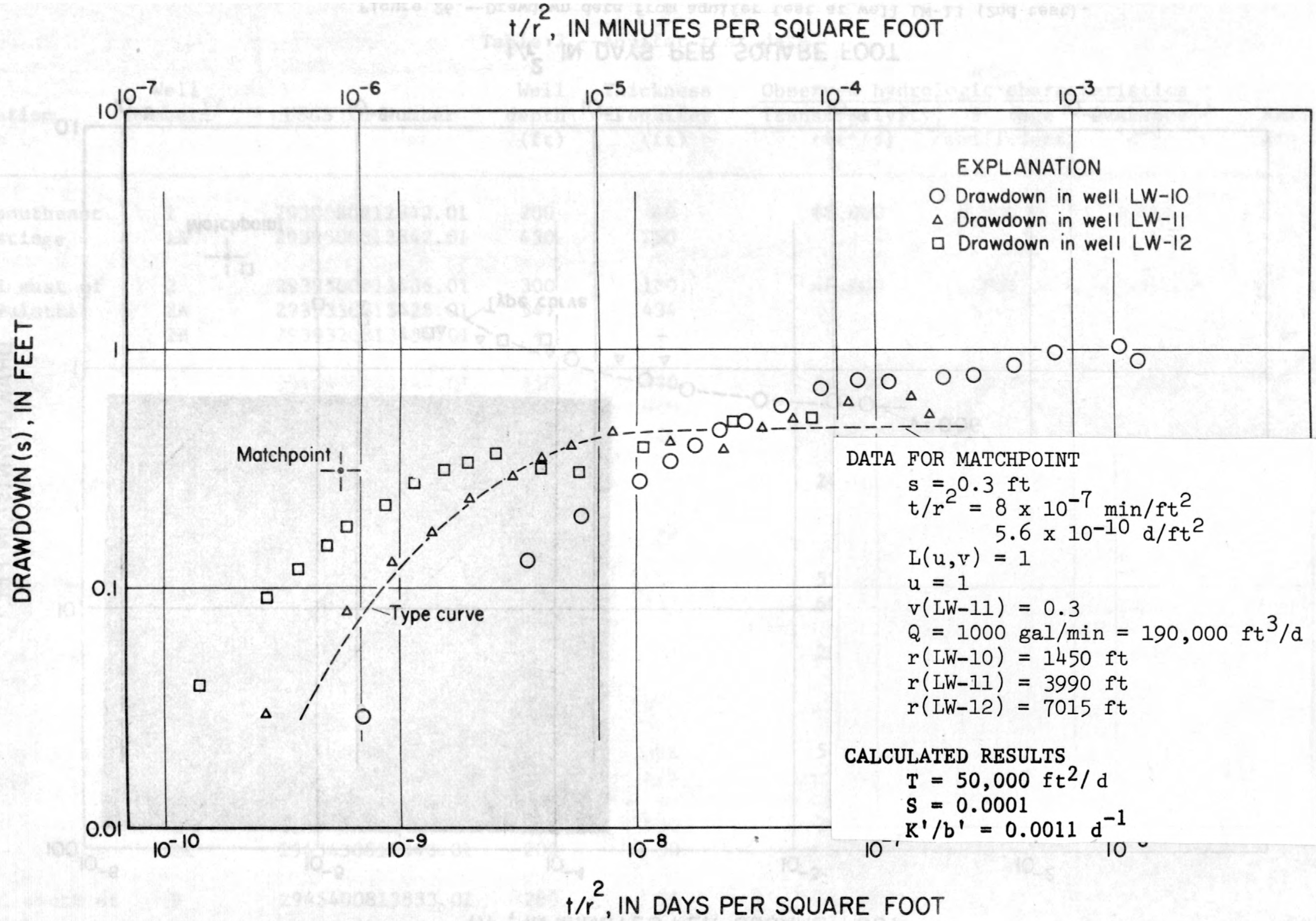

Figure 25.--Drawdown data from aquifer test at well LW-13 (1st test).

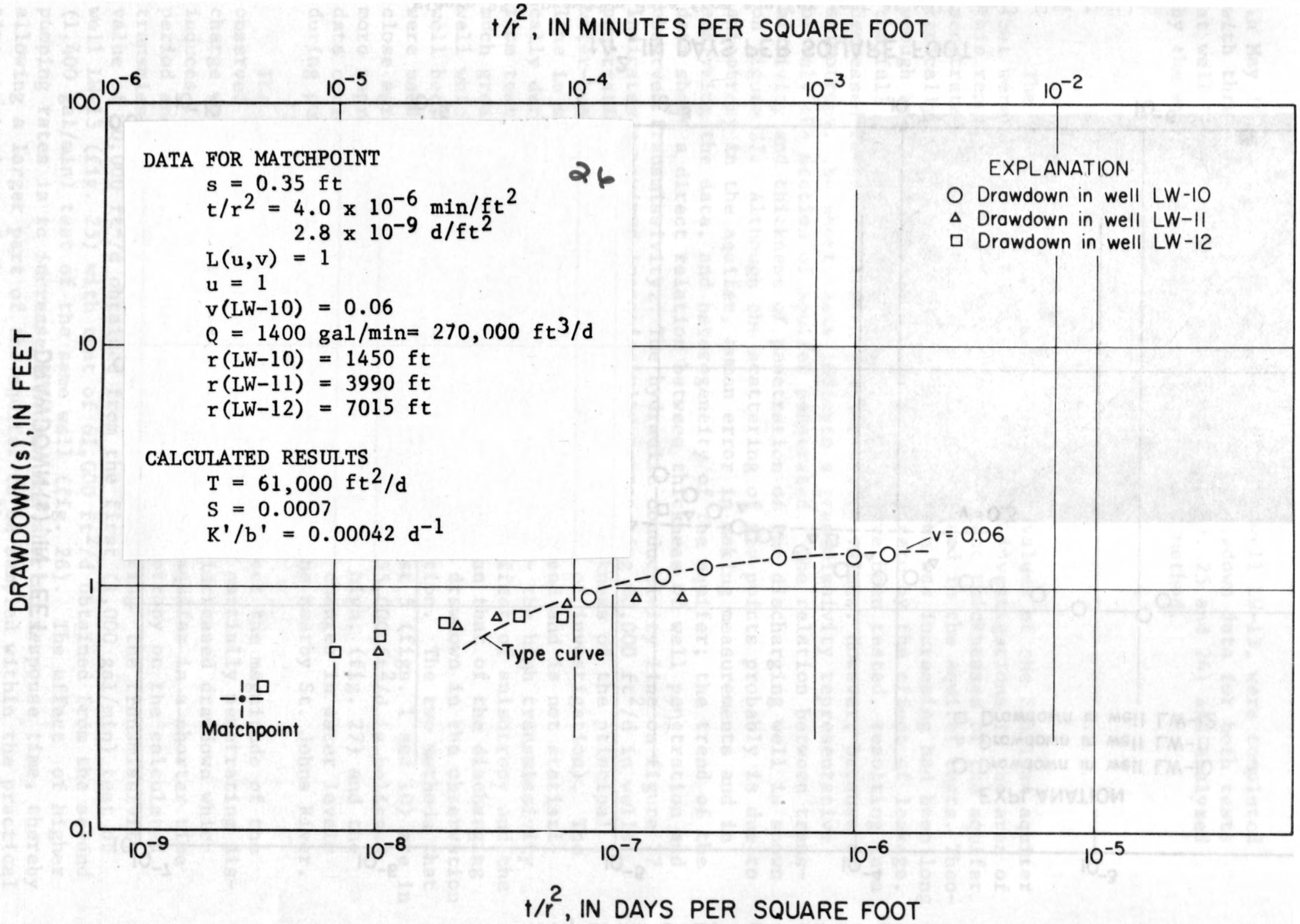

Figure 26.--Drawdown data from aquifer test at well LW-13 (2nd test).

Table 2.--Aquifer test data

Location	Well Number 1/	USGS ID Number	Well depth (ft)	Thickness of aquifer (ft)	Observed hydrologic characteristics: Transmissivity, (ft^2/d)	Storage coefficient,	Leakance 2/ d^{-1}	Ref. fig.
3 mi southeast	1	2939580812842.01	200	40	88,000	0.0006	0.019	
of Hastings	1A	2939500812842.01	450	250				5
1.2 mi east of	2	2939300813436.01	300	180	46,000	.001	.016	
East Palatka	2A	2939330813428.01	547	434				
	2B	2939320813458.01	–	–				6
2 mi south of	3	2940490812944.01	550	430	56,000	.0006	.0051	
Hastings	3A	2940490812952.01	610	480				
	3B	2940530812927.01	568	420				7
1.5 mi northeast	4	2940330813502.01	250	130	24,000	.0008	0.010	
of East Palatka	4A	2940320813455.01	–	–				
	4B	2940450813515.01	222	90				8
2 mi west of	5	2942570813247.01	300	150	55,000 &	.001	.021	9 &
Hastings	5A	2942550813240.01	300	150	60,000 5/			10
3 mi northwest of	6	2947480812906.01	302	130	25,000	.0001	.0011	
Armstrong	6A	2947520812905.01	325	150				
	6B	2947480812924.01	325	150				11
7 mi northeast of	7	2957250812910.01	525	325	54,000	.0002	.0050	
Picolata	7A	2957300812930.01	525	325				12
Spuds	8	2943430812833.01	280	100	29,000	.0003	.00096	
	8A	2943430812840.01	280	50				13
0.5 mi south of	9	2945400813833.01	260	70	17,000	–	–	
Bostwick								14

Table 2.--Aquifer test data (cont)

Location	Well Number[1]	USGS ID Number	Well depth (ft)	Thickness of aquifer (ft)	Observed hydrologic characteristics: Transmissivity, (ft^2/d)	Storage coefficient,	Leakance[2] d^{-1}	Ref. fig.
10 mi south of Palatka	10	2932340814241.01	295	240	41,000	-	-	15
Roy	11	2937160812936.01	405	250	26,000[6]	-	-	16
4 mi northeast Riverdale	12	2951060812909.01	400	200	(data not used in analysis)			--
1.5 mi north of Riverdale	13	2950280813309.01	300	70	8,700	-	-	17
10 mi south of Greencove Springs	14	2951440813717.01	340	80	7,800	-	-	18
St. Augustine Beach	15	2951320811648.01	248	55	13,000	-	-	19
4 mi southwest of Durbin	16	3003540813012.01	362	40	6,800[6]	-	-	20
9 mi north of St. Augustine	17	3000480812333.01	258	10	1,600	-	-	21
1.5 mi northeast Armstrong	18	2946120812534.01	306	150	15,000	-	-	22
3 mi northwest of Armstrong	947-129-7[3]	Indeterminate	310	70	23,000	.0002	.00020	--
	947-129-5	Indeterminate	295	55				
3 mi northwest of Armstrong	947-129-2	Indeterminate	500	260	39,000	.0006	-	
	947-129-3	2947480812923.01	505	265				--
6.5 mi west of Bunnell	928-122-3	2928170812220.01	345	215	36,000	.0005	.00070	
	927-121-2	2927000812157.01	300	120				--

Table 2.--Aquifer test data (cont)

Location	Well Number[1/]	USGS ID Number	Well depth (ft)	Thickness of aquifer (ft)	Observed hydrologic characteristics: Transmissivity, (ft^2/d)	Storage coefficient,	Leakance[2/] d^{-1}	Ref. fig.
7 mi west of	928-122-9	2928460812233.01	495	335	37,000	.0009	-	
Bunnell	928-122-11	2928460812236.01	490	330				--
1.5 mi south-	919-120-2	2919550812009.01	175	75	25,000	.0002	.0023	
east of Dean-	919-119-3	2919550811951.01	188	80				--
ville								
3.5 mi south-	918-118-3	2919020811856.01	350	290	37,000	-	-	
east of Dean-	919-118-2	2919150811840.01	164	104				--
8.5 mi north-	943-144-2	2943010814428.01	564	384	37,000	0.0009	0.00023	
west of Palatka	945-143-2	Indeterminate	348	168				--
2 mi northeast	940-134-1	2940250813400.01	452	300	37,000	-	-	
of East Palatka	940-133-1	2940250813358.01	155	25				
	940-134-3	2939550813445.01	452	320				--
1.2 mi east of	939-134-4	2939330813428.01	547	434	48,000	-	-	
East Palatka								--
1.5 mi east of	LW4 [4/]	2930360811714.01	172	49	9,400	.0001	.00089	
Espanola	LW2	2930360811724.01	260	111				
	TW1	2930360811736.01	310	163				
	LW5	2929470811743.01	170	44				23
7 mi northeast	LW13	2933250811248.01	330	153	50,000 &	.0001 &	.0011 &	
of Bunnell	LW10	2933270811225.01	398	190	61,000[7/]	.0007[7/]	.00042[7/]	25 &
	LW11	2933150811313.01	285	101				26
	LW12	2933140811324.01	235	105				

Table 2.--Aquifer test data (cont)

Location	Well Number1/	USGS ID Number	Well depth (ft)	Thickness of aquifer (ft)	Observed hydrologic characteristics Transmissivity, (ft^2/d)	Storage coefficient,	Leakance2/ d^{-1}	Ref. fig.
3 mi southeast of Bunnell	LW14	2926160811314.01	223	121	23,000	-	-	24

1/ See p. 4 for explanation of well numbering system. First well listed in each group is discharge well, followed by observation wells.

2/ Leakance values represent total leakance through overlying and undelying confining beds and may be effected by vertical movement of water upward toward the zone of well penetration through semi-permeable zones within the aquifer.

3/ 7-digit numbers designate tests by Bermes, Leve, and Tarver (1963a, table 5).

4/ Test numbers prefixed by "LW" designate tests by Leggett, Brashears and Grahm (written commun., 1976).

5/ Transmissivity computed by two methods for test 5.

6/ Transmissivity values for tests 11 and 16 are estimates because of poorly defined data curves (figs. 16 & 20).

7/ Two sets of hydrologic characteristics determined from two tests of site LW13.

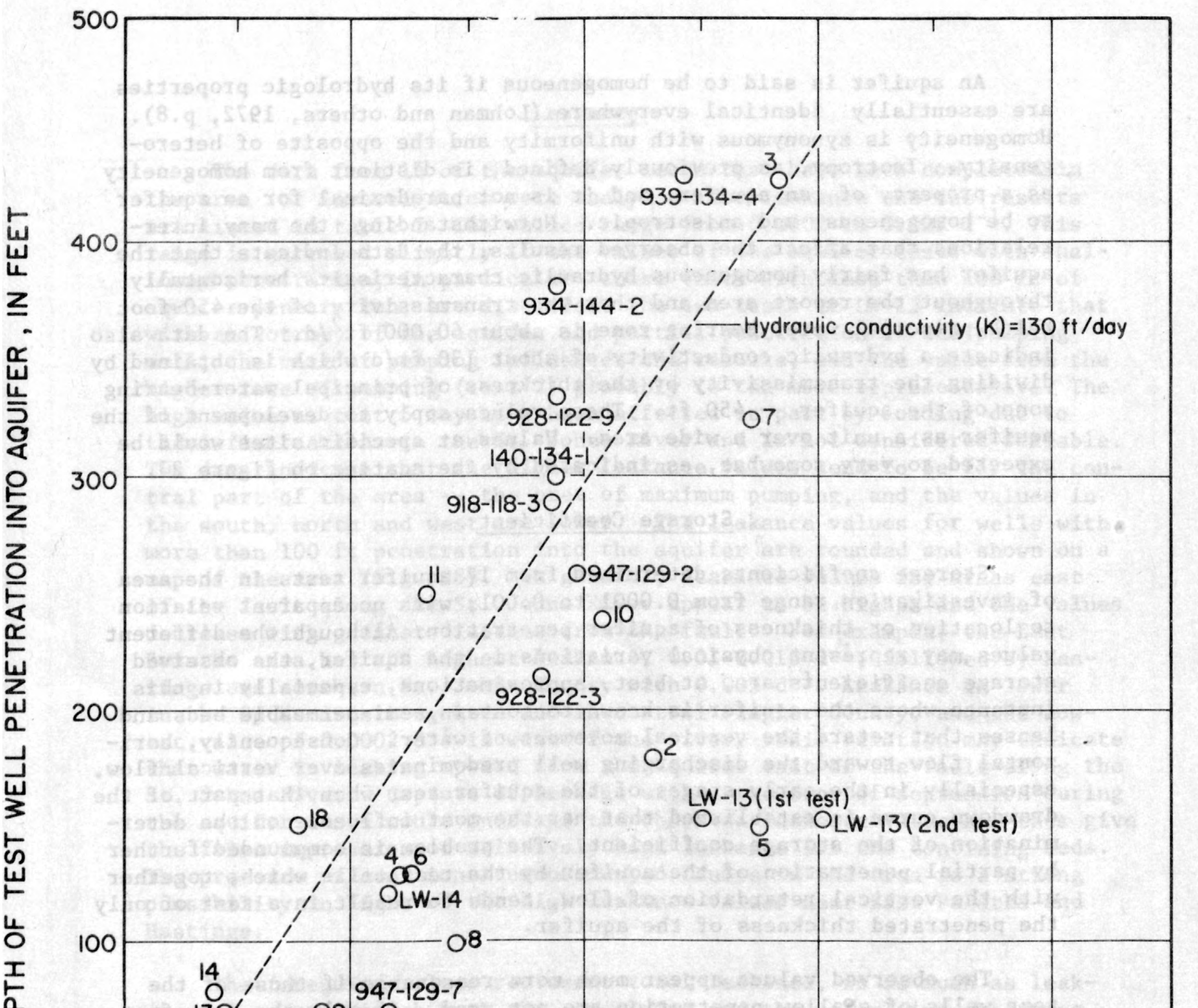

Figure 27.--Observed transmissivity versus depth of well penetration from aquifer tests.

An aquifer is said to be homogeneous if its hydrologic properties are essentially identical everywhere (Lohman and others, 1972, p.8). Homogeneity is synonymous with uniformity and the opposite of heterogeneity. Isotropy, as previously defined, is distinct from homogeneity as a property of an aquifer, and it is not paradoxical for an aquifer to be homogeneous and anisotropic. Notwithstanding the many interrelations that affect the observed results, the data indicate that the aquifer has fairly homogeneous hydraulic characteristics horizontally throughout the report area and that the transmissivity of the 450-foot thick principal water bearing zone is about 60,000 ft^2/d. The data also indicate a hydraulic conductivity of about 130 ft/d which is obtained by dividing the transmissivity by the thickness of principal water-bearing zone of the aquifer -- 450 ft. These values apply to development of the aquifer as a unit over a wide area. Values at specific sites would be expected to vary somewhat, as indicated by the scatter on figure 27.

Storage Coefficient

Storage coefficients determined from 17 aquifer tests in the area of investigation range from 0.0001 to 0.001, with no apparent relation to location or thickness of aquifer penetration. Although the different values may represent physical variations in the aquifer, the observed storage coefficients are, at best, approximations, especially in this instance where the aquifer is known to contain semi-permeable beds and lenses that retard the vertical movement of water. Consequently, horizontal flow toward the discharging well predominates over vertical flow, especially in the early stages of the aquifer test when that part of the drawdown curve is established that has the most influence on the determination of the storage coefficient. The problem is compounded further by partial penetration of the aquifer by the test wells which, together with the vertical retardation of flow, tends to result in a test of only the penetrated thickness of the aquifer.

The observed values appear much more reasonable if those of the test wells of shallow penetration are not used. If only the data from test wells which penetrate 150 ft or more of the aquifer are used in this analysis and if the coefficient from the higher discharge test at site LW-13 is accepted at that location, eight of the nine tests so resticted give storage coefficients within the 0.0005 to 0.001 range, and five of the values are at 0.0006 and 0.0009. Only the data from test 7 appear to be anomalous.

On the basis of the foregoing, a storage coefficient of 0.0008 for the Floridan aquifer in the area of this report is considered to be the best estimate.

Leakance

The data from 15 of the aquifer tests that have been completed in the area of investigation were analyzed for leakance and the results are listed in table 2. The values range from 0.0002 to 0.021 d^{-1}. This range is narrowed slightly if the values of the aquifer tests with shallower penetration, in particular those tests with less than 100 ft of aquifer penetration, are discarded. The two tests at LW-13 indicate that with anisotropy of the aquifer and partial penetration of the pumping well, the rate of pumping influences the results, and the value from the higher rate of pumping (test 2) probably is the more representative. The high value at test 5 may have been affected in part by loading due to tidal fluctuations in the St. Johns River and is not considered reliable. The data indicate that the higher leakance values tend to be for the central part of the area -- the area of maximum pumping, and the values in the south, north and west are lower. The leakance values for wells with more than 100 ft penetration into the aquifer are rounded and shown on a map of the area (fig. 28). In general, leakance values for areas east of the fault along the St. Johns River appear to be higher and the values decrease with greater distance from the fault. For example, the East Palatka area has the highest leakance, 0.01-0.016 d^{-1}; followed by Hastings and northern St. Johns County with 0.005 d^{-1}. Leakance is lower in the Spuds-Armstrong area and in central Flagler County, and the lowest value of 0.0002 d^{-1} is west of the river. This relation may indicate that water is leaking upward from the aquifer east of the fault along the St. Johns River. Capture of leakage within the cone of depression during the aquifer tests would increase the observed leakance value and thus give the false impression of relatively high leakance for the confining beds. The presence of additional undocumented faults in the area is a strong possibility in light of the high leakance values near East Palatka and Hastings.

The foregoing values represent total leakance, in as much as leakage may occur through both the overlying and the underlying confining beds. Furthermore, C. H. Tibbals (written commun., 1976) of the U. S. Geological Survey has recognized the possibility that vertical movement of water through the semi-permeable zones of an anisotropic aquifer toward a partially penetrating pumping well may have the same effect on drawdown as does leakage. The leakance values for the East Palatka, Hastings, and northern St. Johns County areas are too large for the overlying confining beds alone and appear to reflect the presence of large amounts of leakage from underlying or internal sources during the testing period. Hence none of the leakance values should be used to compute recharge to the aquifer through the overlying confining beds.

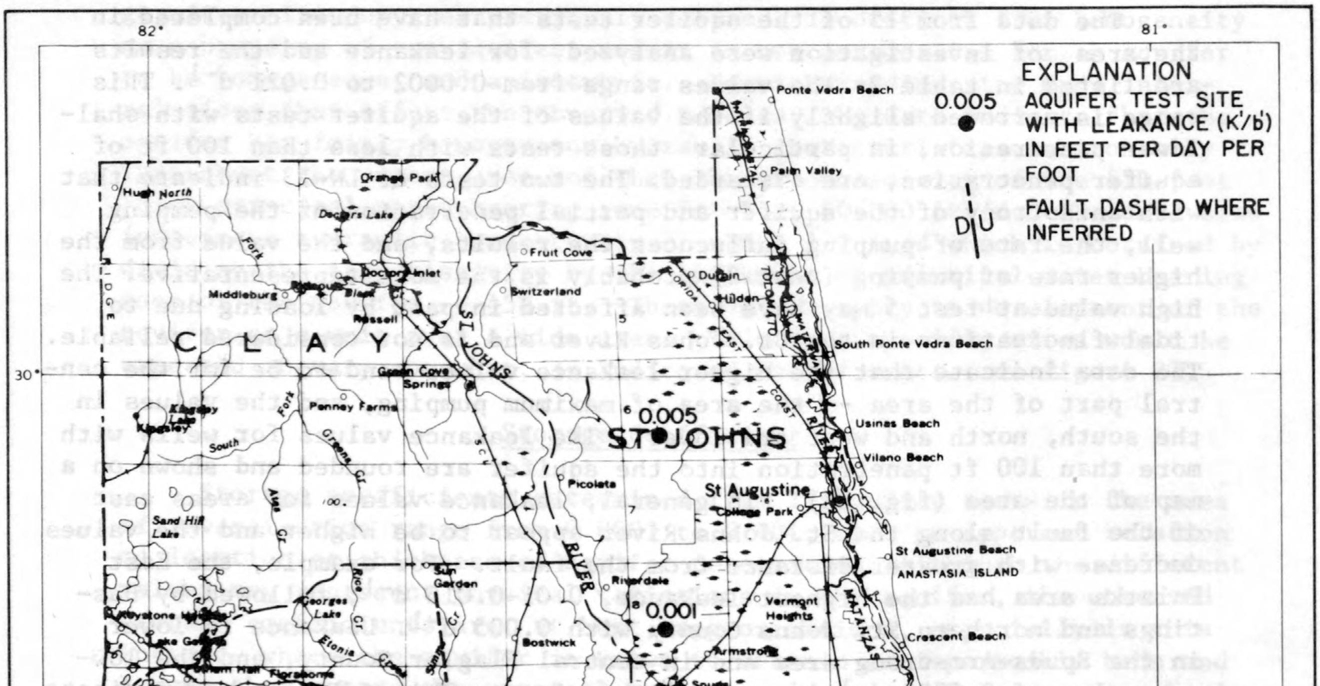

Figure 28.--Leakance values from aquifer tests for wells with more than 100 feet penetration.

APPLICATION OF RESULTS

Well Design

In areas where salinity of water is a problem, it often is desirable to know how deep a well should be drilled to obtain a specific amount of water, or how much water a well drilled or plugged back to a specific depth will produce, or how much drawdown will occur in time and with distance from the discharging well. That information can be determined by using the hydraulic information in this report. The mathematical solutions that were used to determine transmissivity, storage coefficient, and leakance can also be used to construct theoretical curves of drawdown with time and distance for a particular discharge. For example, an approximation of transmissivity (T) for a given depth of aquifer penetration can be selected from the trend line for hydraulic conductivity of figure 27; storage coefficient (S) of 0.0008 has been estimated for the report area; and an approximate leakance value (K'/b') can be selected from figure 28. By inserting these values along with the desired discharge (Q) and distance (r) into the formulas described in test 1 of the aquifer test data section of this report, drawdown (s), time (t) and the appropriate type curve are determined. Just as a match point was selected by the curve-matching procedure, the match point by T and S is used to correctly position a logarithmic overlay on the family of type curves (fig. 5) and a hypothetical drawdown data curve can be traced onto the overlay from the appropriate type curve defined by v. By varying discharge and distance, an unlimited number of drawdown curves can be generated for a particular well. For the case of multiple pumping wells, the calculated drawdown at any point is the sum of individual well drawdowns at that point by the principle of superposition.

Estimates of Withdrawals

One of the basic formulas of ground-water flow is

$$Q=TIL \qquad (7)$$

where Q is the volume of water that is moving through a cross-sectional area of width L at a hydraulic gradient I, and T is the transmissivity of the aquifer. Figure 29 is a map showing potentiometric contours as of March-April 1975 drawn through the heavily pumped farming area of southwest St. Johns County and northeast Putnam County (written commun., Douglas Munch, SJRWMD, 1976). The ground-water gradient is obtained by dividing the contour interval (5 ft) by the average horizontal distance between contours, which is about 14,000 ft between the 15 ft and 10 ft contours. The width of the cross section, indicated by the length of the dashed line halfway between the two contour lines is about 190,000 ft. A transmissivity of 60,000 ft^2/d has been determined for the aquifer.

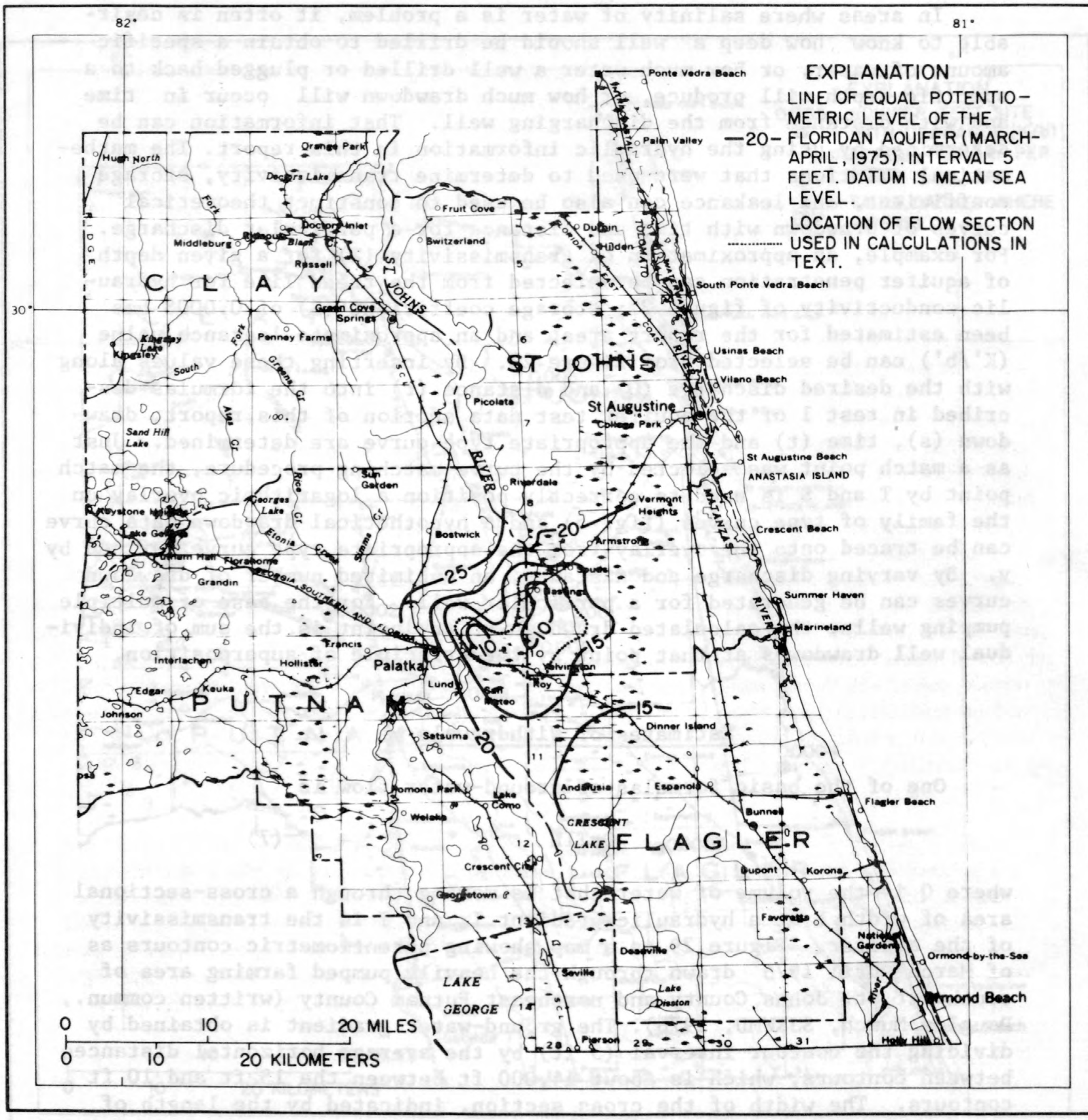

Figure 29.--Potentiometric map of the farming area in southwest St. Johns County and northeast Putnam County.

Solving for Q indicates 4,100,000 ft^3/d of water moving through the cross section into the farming area at the time this potentiometric map was made. That amount represents an estimate of the minimum amount of water that is being discharged by wells in the area. It does not include the additional water that is leaking into the aquifer through the confining beds between the computation section and the center of the cone of depression. Variation in seasonal pumpage affects the potentiometric surface in the area; consequently, this method could be applied seasonally to determine both the seasonal fluctuation in pumpage and the annual pumping rate. When actual water-use figures become available, the total pumpage for the farming area can be compared with the above estimate to calculate the approximate amount of leakage into the aquifer.

Evaluation of Drawdown

The transmissivity also can be used with water-level data to evaluate the drawdown of a well or well field over a period of time. In the case of the previously discussed farming area, water levels during spring have been about at the same elevation for the past eight years according to unpublished data collected by the U. S. Geological Survey. They probably will remain at the same level indefinitely unless the rate of discharge changes noticeably, because the discharge of water from wells in a leakey artesian aquifer is supplied initially from storage within the aquifer, and in the long term, from leakage through the overlying and underlying confining beds. This recharge in the form of leakage causes the water level to stabilize when the entire discharge of the wells is derived from leakage (Walton, 1970, p. 144). In the heavily pumped area around East Palatka and Hastings, the annual discharge by wells as of 1975 roughly equaled recharge to the aquifer by leakage from above and below (or the net change in the amount of leakage due to pumping), and water levels had stabilized.

CONCLUSIONS

Based on the aquifer tests analyzed, and considering the Floridan aquifer on a regional scale, it has relatively homogeneous hydraulic characteristics throughout the area of investigation. On a local scale, however, these characteristics would be expected to vary. Generally, observed transmissivity is about 60,000 ft^2/d, and the storage coefficient is about 0.0008. Leakance, which is a function of the vertical hydraulic conductivity and thickness of the overlying and underlying confining beds, ranges from 0.0002 d^{-1} northwest of Palatka to 0.016 d^{-1} in the farming area near East Palatka as determined from tests on wells penetrating more than 100 ft of the aquifer. The leakance values may be high, however, because of the effects of anisotropy of the aquifer and partially penetrating discharge wells. Transmissivity appears to increase with increasing depth of well penetration into the aquifer to a thickness of about 450 ft. However, in some areas where salinity is a problem, deep wells may tap salty water. Consequently, wells in those areas should be no deeper than necessary to obtain the desired yield of water. The mathematical-graphical procedure used in this investigation to analyze the test data for transmissivity, storage coefficient, and leakance can be used to determine the drawdown characteristics of a well or group of wells for various discharge rates and depths of penetration into the aquifer for any time and any distance from the center of discharge.

The hydrologic characteristics of the aquifer should be used with the water-level, salinity, and water-use data, collected on a continuous basis, and with the hydrologic information gained from such sources as down-hole geophysical logging, to develop a more complete understanding of the aquifer system. The ability to predict how the aquifer will respond to different pumping stresses over prolonged periods of time requires a thorough knowledge of the system.

SELECTED REFERENCES

Bermes, B. J., 1958, Interim report on the ground-water resources of Flagler County, Florida: Florida Geol. Survey Inf. Circ. 13, 32p.

Bermes, B. J., Leve, G. W., and Tarver, G. R., 1963a, Geology and ground-water resources of Flagler, Putnam and St. Johns Counties, Florida: Florida Geol. Survey Rept. Inv. 32, 97p.

______, 1963b, Ground-water records of Flagler, Putnam, and St. Johns Counties, Florida: Florida Geol. Survey Inf. Circ. 37, 89 p.

Black, A. P. and Brown, Eugene, 1951, Chemical character of Florida's water-1951: Florida State Board Cons. Div. Water Survey and Research Paper 6, 119 p.

Collins, W. D. and Howard, C. S., 1928, Chemical character of water of Florida: U. S. Geol. Survey Water Supply Paper 596-G, p. 177-233.

Cooke, C. W., 1945, Geology of Florida: Florida Geol. Survey Bul. 29, 339p.

Cooper, H. H., Jr., 1963, Type curves for nonsteady radial flow in an indefinite leaky artesian aquifer, in Bentall, Ray, compiler, short-cuts and special problems in aquifer tests: U.S. Geol. Survey Water-Supply Paper 1545-C, p. C-48-C55.

Ferris, J. G., Knowles, D. B., Brown, R. H., and Stallman, R. W., 1963, Theory of aquifer tests: U. S. Geol. Survey Water-Supply Paper 1536-E, 174 p.

Hantush, M. S. and Jacob, C. E., 1955, Nonsteady radial flow in an infinite leaky aquifer: Am. Geophys. Union Trans., v. 36, no. 1, p.95-100.

Jacob, C. E., 1950, Flow of ground water, chapter 5 in Rouse, Hunter, ed., Engineering hydraulics: New York, John Wiley and Sons, p.321-386.

Leve, G. W., 1958, Interim report on the ground-water resources of Putnam County, Florida: Florida Geol. Survey Inf. Circ. 15, 33p.

_______, 1968, The Floridan aquifer in northeast Florida: Ground Water, Urbana, III., v. 6, no. 2, p. 19-29.

Lohman, S. W., 1972, Ground-water hydraulics: U. S. Geol. Survey Prof. Paper 708, 70 p.

Lohman, S. W., and others, 1972, Definition of selected ground-water terms -- revisions and conceptual refinements: U. S. Geol. Survey Water-Supply Paper 1988, 21 p.

Matson, G. C., and Sanford, Samuel, 1913, Geology and ground waters of Florida: U. S. Geol. Survey Water-Supply Paper 319, 445 p.

Parker, G. G., Ferguson, G. E., and Love, S. K., and others, 1955, Water resources of southeastern Florida, with special reference to the geology and ground water of the Miami area: U. S. Geol. Survey Water-Supply Paper 1255, 965 p.

Plappert, J. J., Johnson, R. A., and Helping, C. L., 1977, Report on geophysical logging of selected wells in eastern Putnam and St. Johns Counties (Florida): Florida Dept. Environmental Regulation, in press. 13 p.

Sellards, E. H., and Gunter, Herman, 1913, The artesian water supply of eastern and southern Florida: Florida Geol. Survey 5th Ann. Rep., p. 103-290.

Stringfield, V. T., 1936, Artesian water in the Florida peninsula: U. S. Geol. Survey Water-Supply Paper 773-C, p. 115-195.

______, 1966, Artesian water in Tertiary limestone in the southeastern states: U. S. Geol. Survey Prof. Paper 517, 226 p.

Stringfield, V. T., and Cooper, H. H., Jr., 1951, Geologic and hydrologic features of an artesian spring east of Florida: Florida Geol. Survey Rep. Inv. 7, pt. 2, p. 61-72.

Tarver, G. R., 1958, Interim report on the ground water resources of St. Johns County, Florida: Florida Geol. Survey Inf. Circ. 14, 36 p.

Theis, C. B., 1935, The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using ground-water storage: Am. Geophys. Union Trans., v. 16, pt. 2, p. 519-524.

_____, 1938, The significance and nature of the cone of depression in ground-water bodies: Econ. Geology, v. 33, no. 8, p. 889-902.

Unklesbay, A. G., 1945, Ground-water investigation at St. Augustine, Florida: U. S. Geol. Survey open-file report, 57 p.

Vernon, R. G., 1951, Geology of Citrus and Levy Counties, Florida: Florida Geol. Survey Bull. 33, 256 p.

Walton, W. C., 1970, Ground-water resource evaluation: New York, McGraw-Hill, 664 p.

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