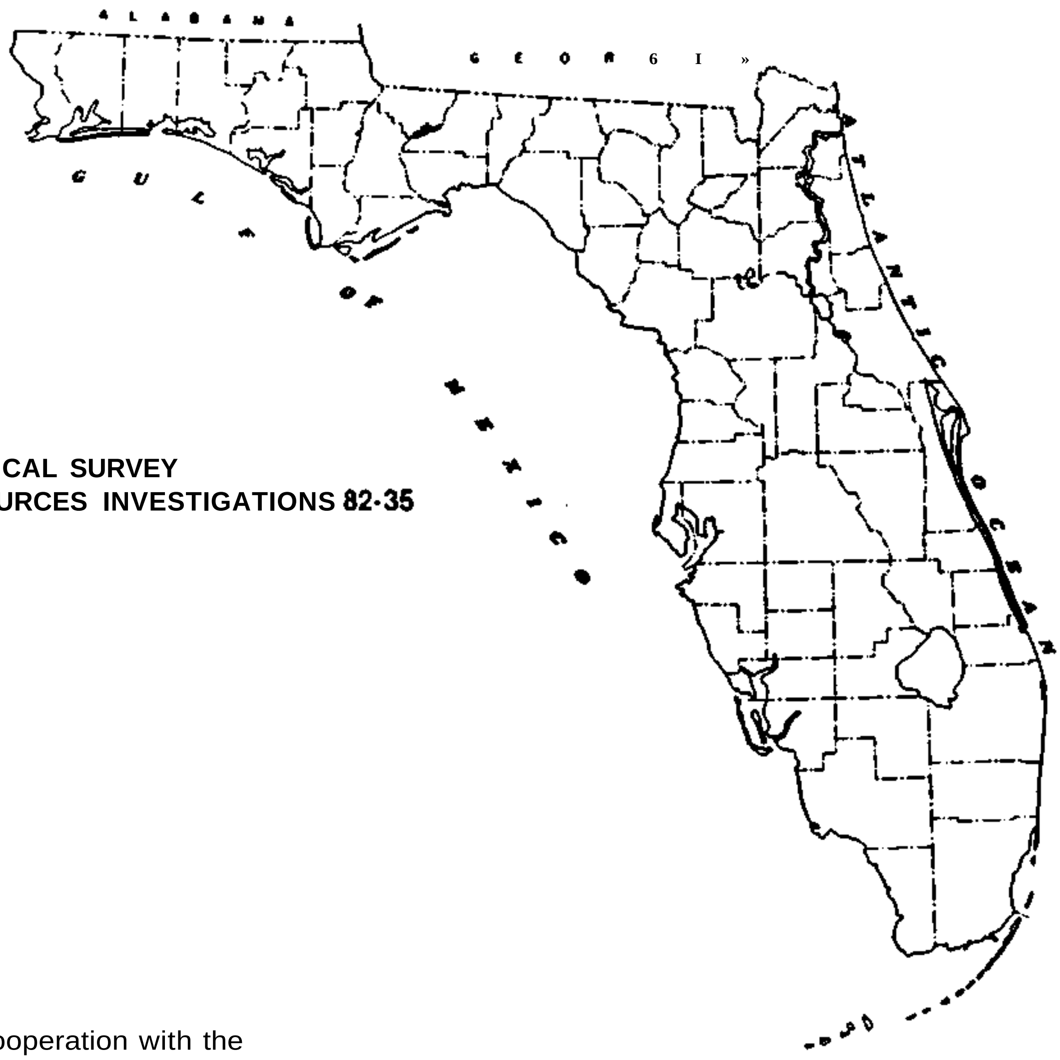
# AQUIFER TEST RESULTS, GREEN SWAMP AREA, FLORIDA





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An aquifer test conducted in the Green Swamp area December 15-16, 1975 was designed to stress the uppermost part of the Floridan aquifer so that the leakage characteristics of the overlying confining bed could be determined.

A well tapping the upper part of the Floridan aquifer was pumped at a rate of about 1,040 gal/min for 35 hours; drawdown was measured in the Floridan aquifer and in two horizons in the confining bed. Analysis of the data indicates that the transmissivity of the upper 160 feet of the Floridan is about 13,000 $ft^2$/d, the storage coefficient is about 2.5 x 10"$^{1}$*, and the overlying confining bed leakance coefficient is about 2 x 10~$^{2}$ to 2.5 x 10~$^{2}$d"$^{1}$. The vertical hydraulic diffusivity of the confining bed ranged from 610 $ft^2$/d to 16,000 $ft^2$/d.

Results of the test indicate that, in the area of the test site, a Floridan aquifer well field would induce additional recharge to the Floridan. As a result of that increased recharge, water levels in the surficial aquifer would tend to stand lower, runoff from the area would tend to be less, and, perhaps, evapotranspiration would be less than normal.

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By C. H. Tibbals and H. F. Grubb

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## CONVERSION FACTORS

For use of readers who prefer to use metric units, conversion factors for terms used in this report are listed below:

| Multiply | By | To obtain |
|---|---|---|
| foot (ft) | 0.3048 | meter (m) |
| foot squared per day ($ft^2/d$) | 0.0929 | meter squared per day ($m^2/d$) |
| cubic foot per day ($ft^3/d$) | 0.02832 | cubic meter per day ($m^3/d$) |
| gallon per minute (gal/min) | 0.06309 | liter per second (L/s) |
| mile (mi) | 1.609 | kilometer (km) |
| inch (in) | 25.40 | millimeter (mm) |
| inch per year (in/yr) | 25.40 | millimeter per year (mm/yr) |

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, called NGVD of 1929, is referred to as sea level in this report.

## SYMBOLS AND DIMENSIONS

| Symbol | Dimensions | Description |
|---|---|---|
| $H(u,\beta)$ | ---------- | H function of $u,\beta$. |
| $K$ | ft/d | Horizontal hydraulic conductivity of aquifer. |
| $K',K''$ | ft/d | Vertical hydraulic conductivity of confining beds. |
| $K_o$ | ---------- | Modified Bessel function of second kind, zero order. |
| $L(u,v)$ | ---------- | L function of $u,v$. |
| $S,S_sb$ | ---------- | Storage coefficient of aquifer. |
| $S',S_s'b'$ | ---------- | Storage coefficients of confining beds. |
| $S'',S_s''b''$ | ---------- | |
| $S_s,S_s',S_s''$ | $ft^{-1}$ | Specific storage of aquifer and confining beds, respectively. |
| $T,Kb$ | $ft^2/d$ | Transmissivity of aquifer. |
| $b$ | ft | Thickness of aquifer. |
| $b',b''$ | ft | Thickness of confining beds. |
| $e$ | ---------- | Base of Naperian logarithms, 2.71828. |
| $r$ | ft | Radial distance to observation well from pumped well. |
| $s$ | ft | Drawdown in aquifer. |
| $s'$ | ft | Drawdown in confining bed. |
| $t$ | min | Time since pumping started. |
| $t_D$ | ---------- | $Tt/Sr^2$. Dimensionless time factor for aquifer. |
| $t'_D$ | ---------- | $K't/S_s'z^2$. Dimensionless time factor for confining bed. |
| $u$ | ---------- | Variable of integration, $\frac{r^2S}{4Tt}$. |
| $x$ | ---------- | Variable of integration, $r\sqrt{\frac{K'}{Tb'}}$ |
| $y$ | ---------- | Variable of integration. |
| $z$ | ft | Vertical distance from bottom of confining bed piezometer to top of aquifer. |
| $\pi$ | ---------- | 3.1416. |
| $\infty$ | ---------- | Infinity. |

| Symbol | Dimensions | Description |
|---|---|---|
| $\beta$ | ---------- | $\frac{r}{4b}\left(\sqrt{\frac{K'S'_s}{TS}}+\sqrt{\frac{K''S''_s}{TS}}\right)$ Dimensionless leakance parameter. |
| $T/S, K/S_s$ | $ft^2/d$ | Hydraulic diffusivity of aquifer. |
| $K'/S'_s, K''/S''_s$ | $ft^2/d$ | Vertical hydraulic diffusivity of confining beds. |
| $K'/b'$ | $d^{-1}$ | Leakance coefficient of confining bed. |
| $K'S'_s, K''S''_s$ | $d^{-1}$ | Leakance characteristic of confining beds. |

AQUIFER TEST RESULTS, GREEN SWAMP AREA, FLORIDA

By C. H. Tibbals and H. F. Grubb

## ABSTRACT

An aquifer test conducted in the Green Swamp area December 15-16, 1975 was designed to stress the uppermost part of the Floridan aquifer so that the leakage characteristics of the overlying confining bed could be determined.

A well tapping the upper part of the Floridan aquifer was pumped at a rate of about 1,040 gal/min for 35 hours; drawdown was measured in the Floridan aquifer and in two horizons in the confining bed. Analysis of the data indicates that the transmissivity of the upper 160 feet of the Floridan is about 13,000 $ft^2/d$, the storage coefficient is about $2.5 \times 10^{-4}$, and the overlying confining bed leakance coefficient is about $2 \times 10^{-2}$ to $2.5 \times 10^{-2} d^{-1}$. The vertical hydraulic diffusivity of the confining bed ranged from 610 $ft^2/d$ to 16,000 $ft^2/d$.

Results of the test indicate that, in the area of the test site, a Floridan aquifer well field would induce additional recharge to the Floridan. As a result of that increased recharge, water levels in the surficial aquifer would tend to stand lower, runoff from the area would tend to be less, and, perhaps, evapotranspiration would be less than normal.

# INTRODUCTION

The Green Swamp area in central Florida (fig. 1) is recognized as a recharge area for the Floridan aquifer (Pride and others, 1966; Grubb, 1977; Grubb and Rutledge, 1978; and Rutledge and Grubb, 1978). However, only small amounts of recharge actually occur to the Floridan because, in spite of relatively thin and permeable confining beds (Grubb, 1977), there is, at present (1982), very little downward hydraulic gradient to induce water' to leak downward from the surficial aquifer into the Floridan. Because of the permeable nature of the surficial aquifer and confining bed materials, it is probable that, if the downward gradient could be increased by pumping from the Floridan, additional recharge could be induced. The source of additional recharge water would be derived from reduced surface runoff, and perhaps, reduced evapotranspiration.

The purpose of this study is to determine hydraulic properties of the Floridan aquifer and overlying confining materials in an area where additional downward leakage, or recharge, can be induced. To determine those hydraulic properties, an aquifer test was conducted. The layout of the test site is shown in figure 2 and the wells used are described in table 1. The Floridan aquifer pumped well and observation wells are 200 feet deep. The purpose of such relatively shallow well construction is to concentrate the hydraulic effects of pumping in the upper part of the Floridan aquifer so the effects of the pumping on induced downward leakage are maximized.

The study was conducted in cooperation with the Southwest Florida Water Management District.

## Well-Numbering System

The observation wells at the test site are assigned field reference numbers that indicate their distance and direction from the pumped well and the depths to which they were drilled. For example, well 31W200 is 31 feet west of the pumped well and is 200 feet deep. In table 1, the field reference numbers are cross-referenced to other numbers by which the wells are identified in U.S. Geological Survey computer files.

Two wells 10 miles north of the test site, referred to in the text, are listed by their local name in table 1 and cross-referenced to their computer file numbers.

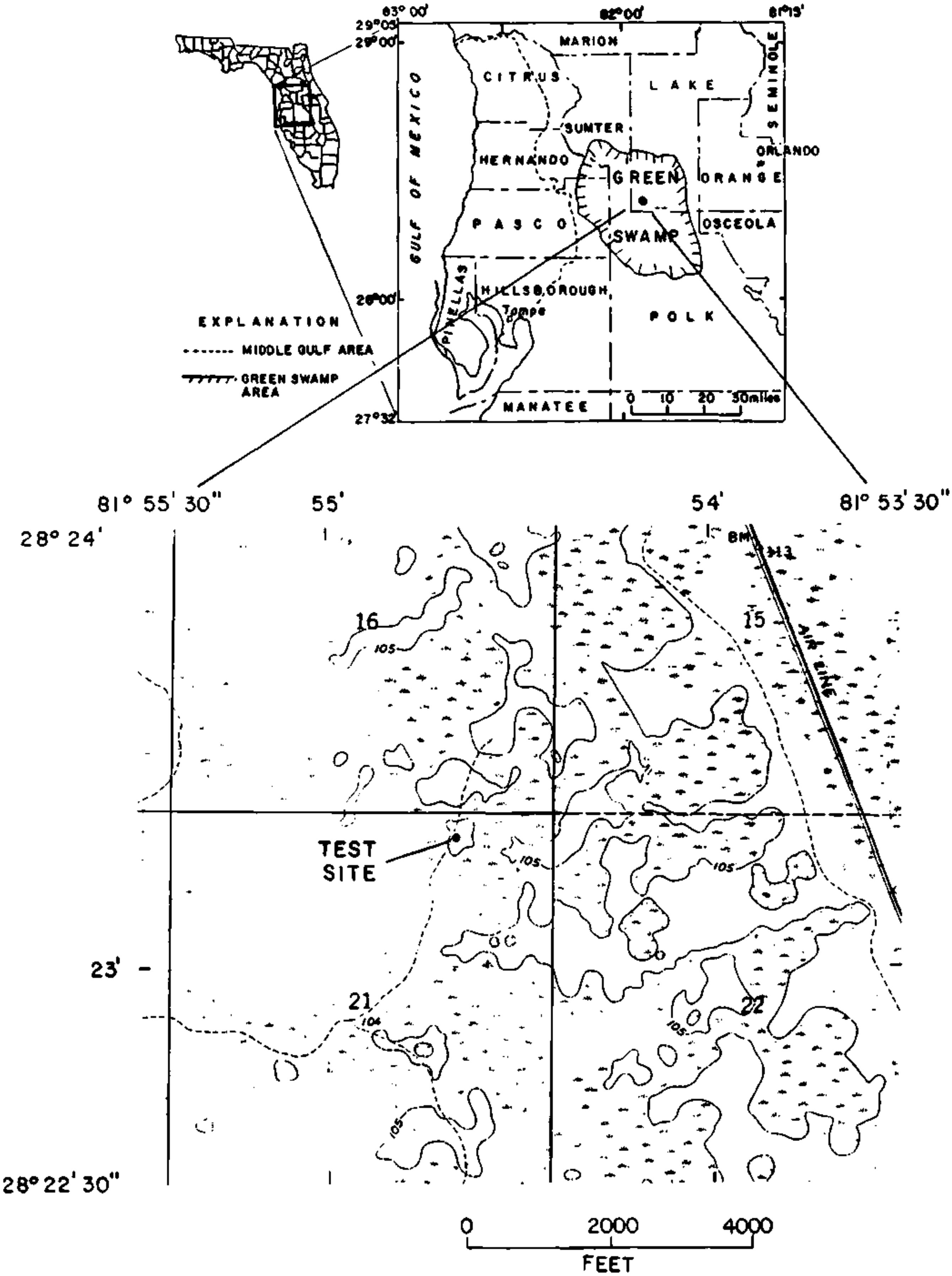


Figure 1.--Location of Green Swamp and area of aquifer test site

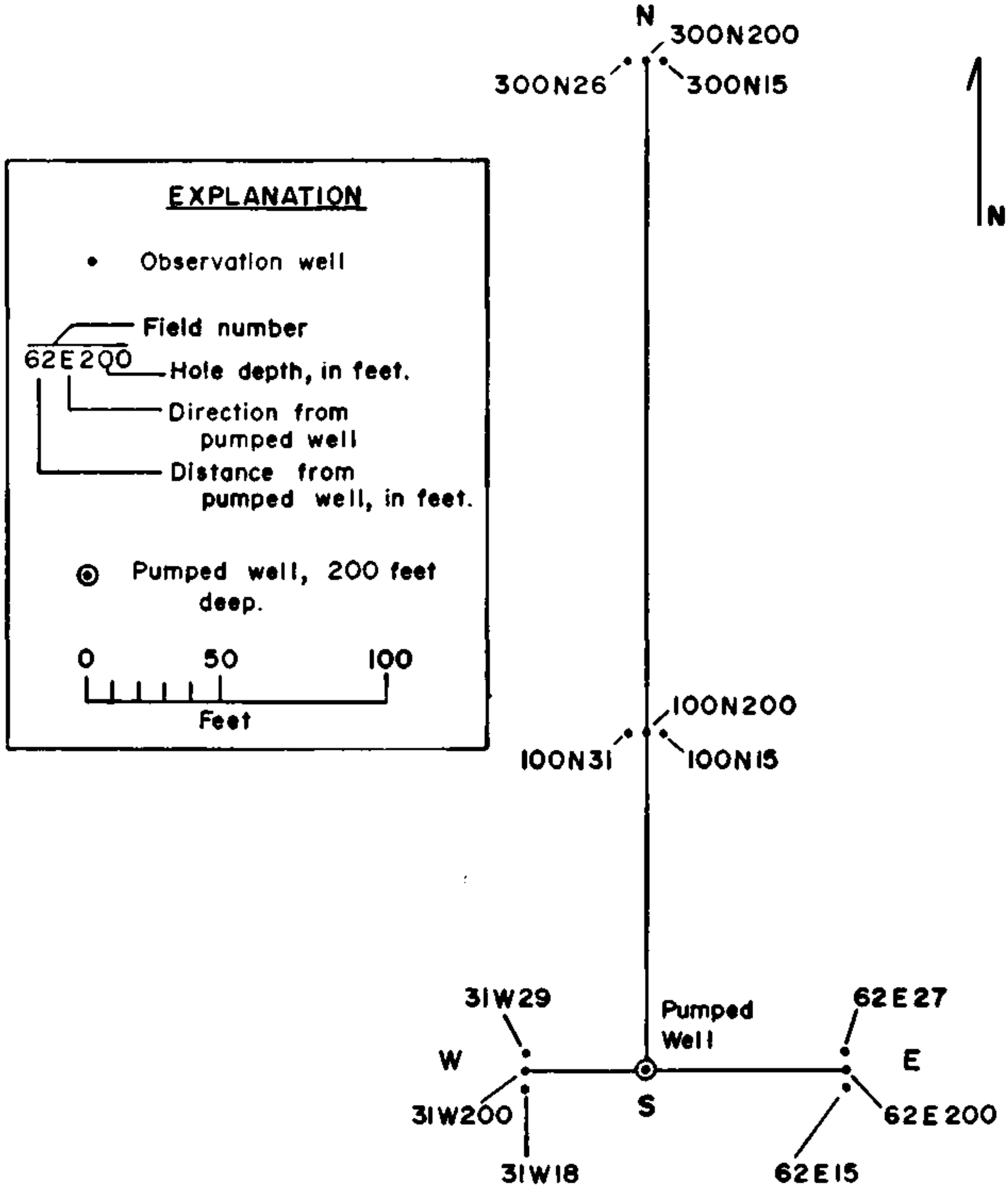


Figure 2.--Locations of wells at aquifer test site and geologic sections S-N and W-E.

Table 1.--Physical description of wells

| Field No. (see fig. 2) | Local office No. | U.S. Geological Survey computer file No. | Hole depth (ft) | Well depth (ft) | Casing depth (ft) | Casing diameter (in) | Distance from pumped well (ft) | Altitude of land surface in feet above sea level | Prepumping static water level, in feet above sea level 12-15-75 |
|---|---|---|---|---|---|---|---|---|---|
| Pumped well | LK7501 | 282318081544002 | 200 | 192 | 66.0 | 8 | - | 105.92 | - |
| 31W18 | LK752W | 282318081544005 | 18.0 | 17.7 | 14.7 | 2 | 31 | 105.06 | 103.02 |
| 31W29 | LK753W | 282318081544006 | 29.4 | 29.4 | 27.0 | 2 | 31 | 104.83 | 103.00 |
| 31W200 | LK751W | 282318081544003 | 200 | 190 | 64.0 | 4 | 31 | 105.42 | 102.88 |
| 62E15 | LK752E | 282318081544008 | 15.0 | 15.0 | 12.0 | 2 | 62 | 105.64 | 103.04 |
| 62E27 | LK753E | 282318081544009 | 26.7 | 26.7 | 24.3 | 2 | 62 | 105.68 | 103.04 |
| 62E200 | LK751E | 282318081544004 | 200 | 200 | 68.5 | 4 | 62 | 105.62 | 102.84 |
| 100N15 | LK753N | 282318081543802 | 15.3 | 15.3 | 12.3 | 2 | 100 | 105.82 | 103.02 |
| 100N31 | LK755N | 282319081543803 | 30.0 | 30.0 | 27.6 | 2 | 100 | 105.81 | 102.95 |
| 100N200 | LK751N | 282319081543801 | 200 | 200 | 64.0 | 4 | 100 | 106.02 | 102.87 |
| 300N15 | LK754N | 282321081543802 | 14.8 | 14.8 | 11.8 | 2 | 300 | 105.00 | 103.07 |
| 300N26 | LK756N | 282321081543803 | 27.0 | 27.0 | 24.6 | 2 | 300 | 105.24 | 103.08 |
| 300N200 | LK752N | 282321081543801 | 200 | 192 | 37.0 | 4 | 300 | 105.48 | 102.88 |
| Midway shallow | - | 283204081544902 | - | 30 | 17 | 6 | 10 mi | 103.51 | 100.45 |
| Midway deep | - | 283204081544901 | - | 73 | 63 | 6 | 10 mi | 103.51 | 100.20 |

## HYDROGEOLOGIC SETTING

The test site is swampy, poorly drained, and has little topographic relief (fig. 1). The altitude of land surface in the general area of the test site ranges from slightly more than 100 feet to slightly more than 105 feet. A railroad grade to the northeast of the test site rises to about 113 feet above sea level.

Figure 3 shows geologic formations in the study area. The surficial aquifer generally consists of about 40 feet of post-Miocene fine to very fine quartz sand that grades downward into very slightly clayey sand and silt. The surficial aquifer, especially the basal part, acts as a confining bed for the underlying Floridan aquifer.

The water table in the surfical aquifer is at or near land surface. The surficial aquifer is recharged by local rainfall. Water leaves the surficial aquifer by evapotranspiration, by seepage to swamps that, in turn, drain into more well-defined stream channels, and by downward leakage to the Floridan aquifer. Of the 52 in/yr average annual rainfall that occurs in the Green Swamp area, about 40 in/yr is lost to evapotranspiration, about 10 in/yr runs off, and about 2 in/yr leaks downward to the Floridan (Grubb and Rutledge, 1978).

The surficial aquifer is underlain by the Eocene limestones that comprise the Floridan aquifer. At the test site, the top of the Floridan is at a depth of about 40 feet (fig. 3). The upper 60 feet of the Floridan is relatively porous limestone and, at least, the next 100 feet of the aquifer consists of relatively less porous clayey limestone. A caliper log of the pumped well showed that most of the cavities occur at depths between 72 and 100 feet. A flowmeter survey conducted during preliminary test pumping of the pumped well indicated that virtually no flow entered the pumped well below about 100 feet.

The potentiometric surface of the Floridan aquifer at the test site is almost at the same level as the water table in the surficial aquifer. The hydrograph of water levels in wells 31W29 and 31W200 (fig. 4) shows that, from November 1 to December 31, 1975, (with the exception of the aquifer test period), the head difference between the surficial aquifer and Floridan aquifer ranged from less than 0.1 foot to about 0.3 foot.

## AQUIFER TEST

### Well Construction

The pumped well is 6 inches in diameter, steel cased to 66 feet, and completed as open hole, by cable tool method, to 200 feet. After drilling, unremoved rock cuttings filled the bottom 8 feet of hole.

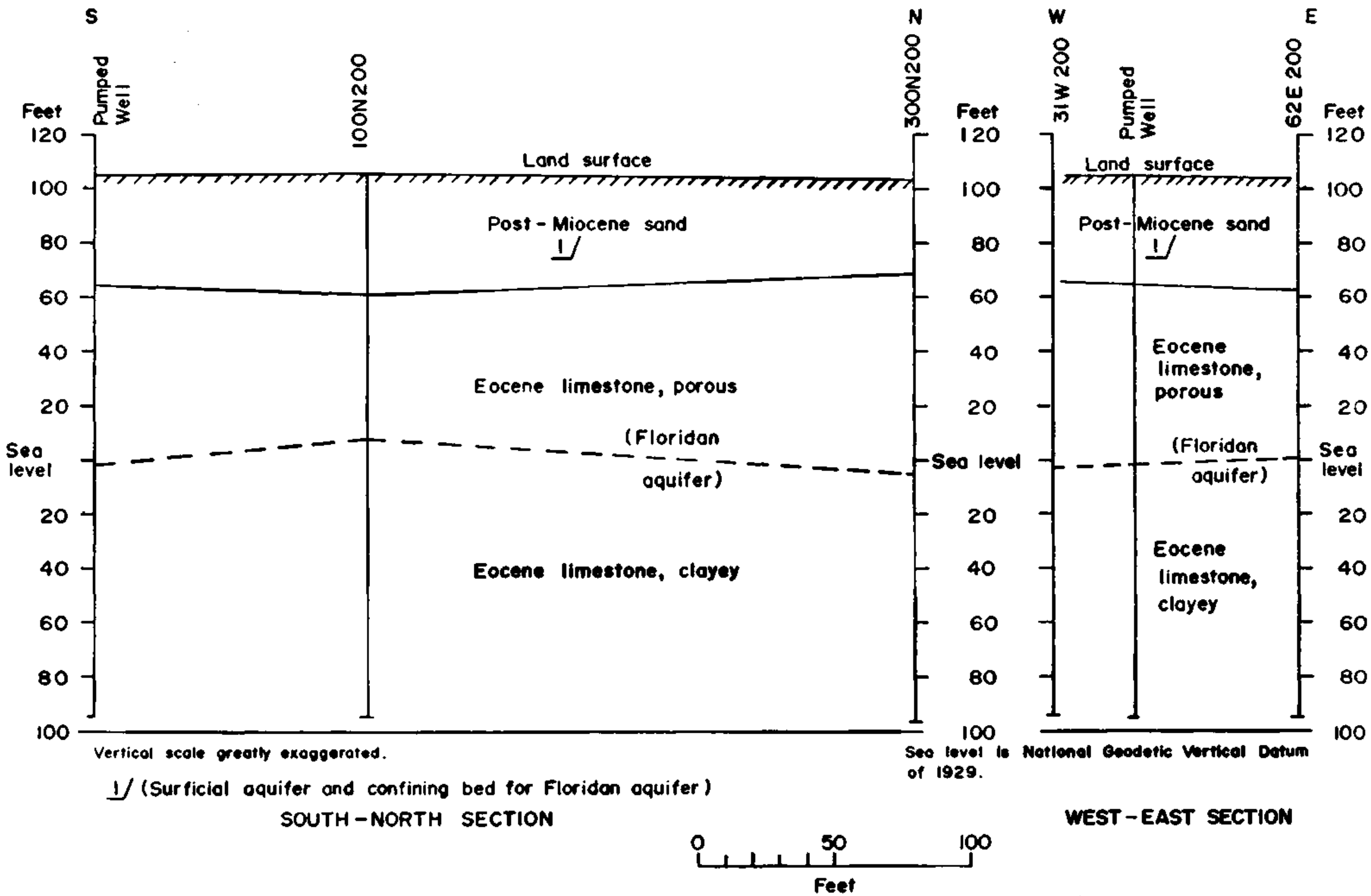


Figure 3.--Generalized geology at aquifer test site.

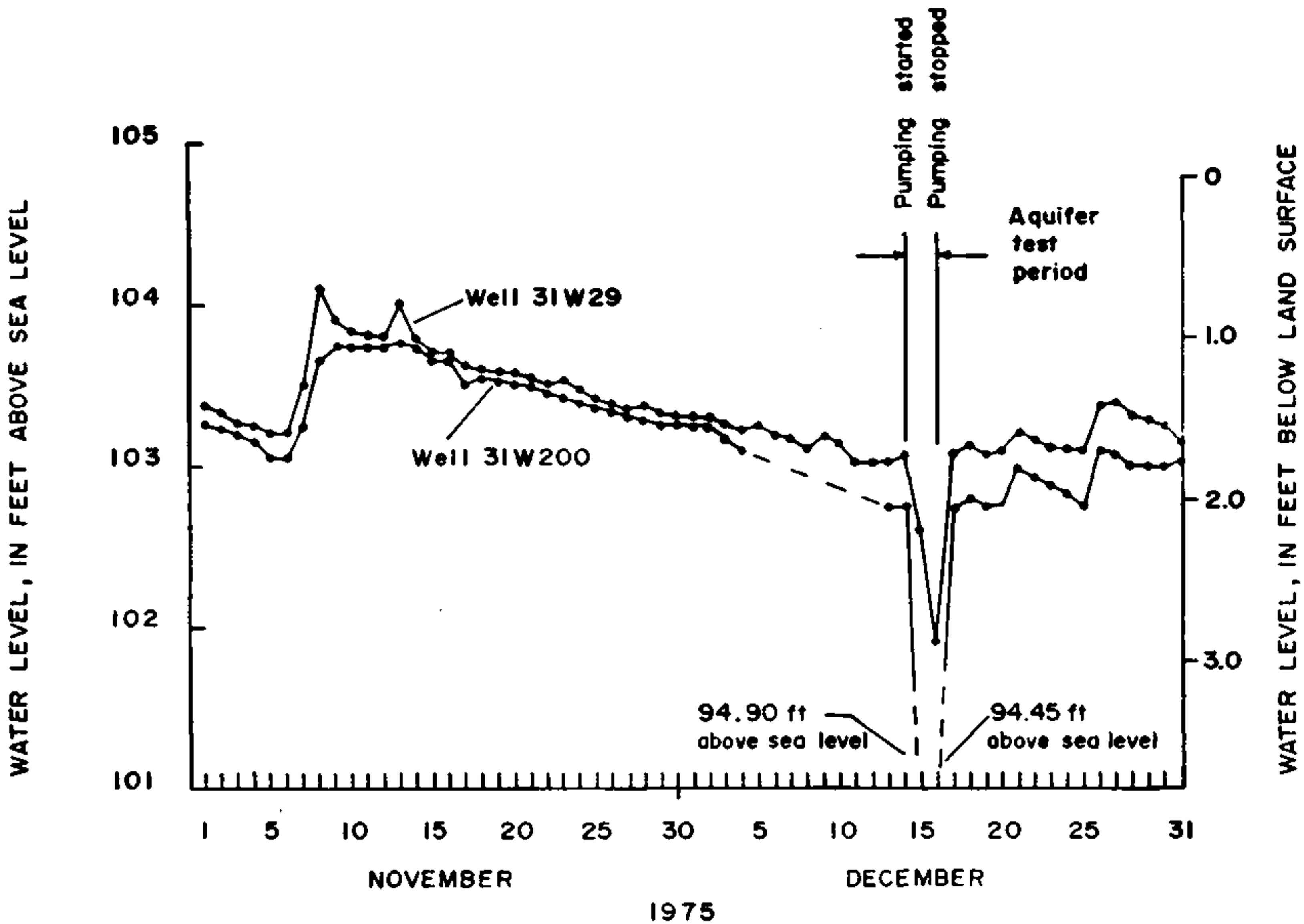


Figure 4.--Water levels in observation wells 31W29 and 31W200, November 1 to December 31, 1975.

The four 4-inch-diameter Floridan aquifer observation wells are of similar construction to that of the pumped well (table 1). Well 300N200 is cased to only 37 feet because the steel casing could not be driven further.

Four intermediate-depth observation wells were drilled, by power auger, to depths that range from about 27 to 30 feet (table 1). The wells are cased with 2-inch-diameter plastic pipe and fitted with 30-inch-long, 1¼-inch-diameter screens with No. 7 slot size. After the casings and screens were placed in the boreholes, the boreholes were backfilled with cuttings.

Four shallow wells were drilled, by power auger, to depths that range from about 15 to 18 feet (table 1). The wells are cased with 2-inch-diameter plastic pipe and fitted with 36-inch-long, 1¼-inch-diameter screens with No. 60 mesh size. After the casings and screens were placed in the boreholes, the boreholes were backfilled with cuttings.

## Data Collection

The observation wells were equipped with automatic water-level recorders for the test. A deep and shallow pair of wells (Midway Deep and Midway Shallow) 10 miles north of the pumped well (table 1) were also equipped with water-level recorders. These wells were used to monitor the trend of water levels (fig. 5) in an area unaffected by pumping so that, if necessary, corrections could be made to the drawdown data. No corrections were necessary because, during the period of the test, there was very little change in regional ground-water levels.

Rainfall was measured at Clermont 11 miles northeast of the aquifer test site. Barometric pressure was measured at Orlando 35 miles east-northeast of the aquifer test site.

The pumped well was equipped with a diesel-powered turbine pump. The discharge water was piped to a swamp about 200 feet west of the pumped well. The surficial aquifer underlying the swamp was saturated and the discharge water apparently left the area by surface drainage ways. The swamp, in turn, drained to the west, away from the test site. Water levels in the swamp were monitored but did not rise appreciably during the aquifer test. The pump discharge was measured by periodically reading an in-line totalizing flowmeter at measured intervals. The difference in flowmeter readings divided by the time interval is calculated as the average discharge for the time interval measured.

The aquifer test began at 10:25 a.m., December 15, 1975. The pumped well was pumped for 35 hours at an almost constant rate of 1,040 gal/min. Drawdown was measured in each observation well at intervals that ranged from a few seconds during the early part of the test to once per hour after the first few hours of pumping. The drawdown data are plotted in figures 6 to 8, and figures 10 to 16.

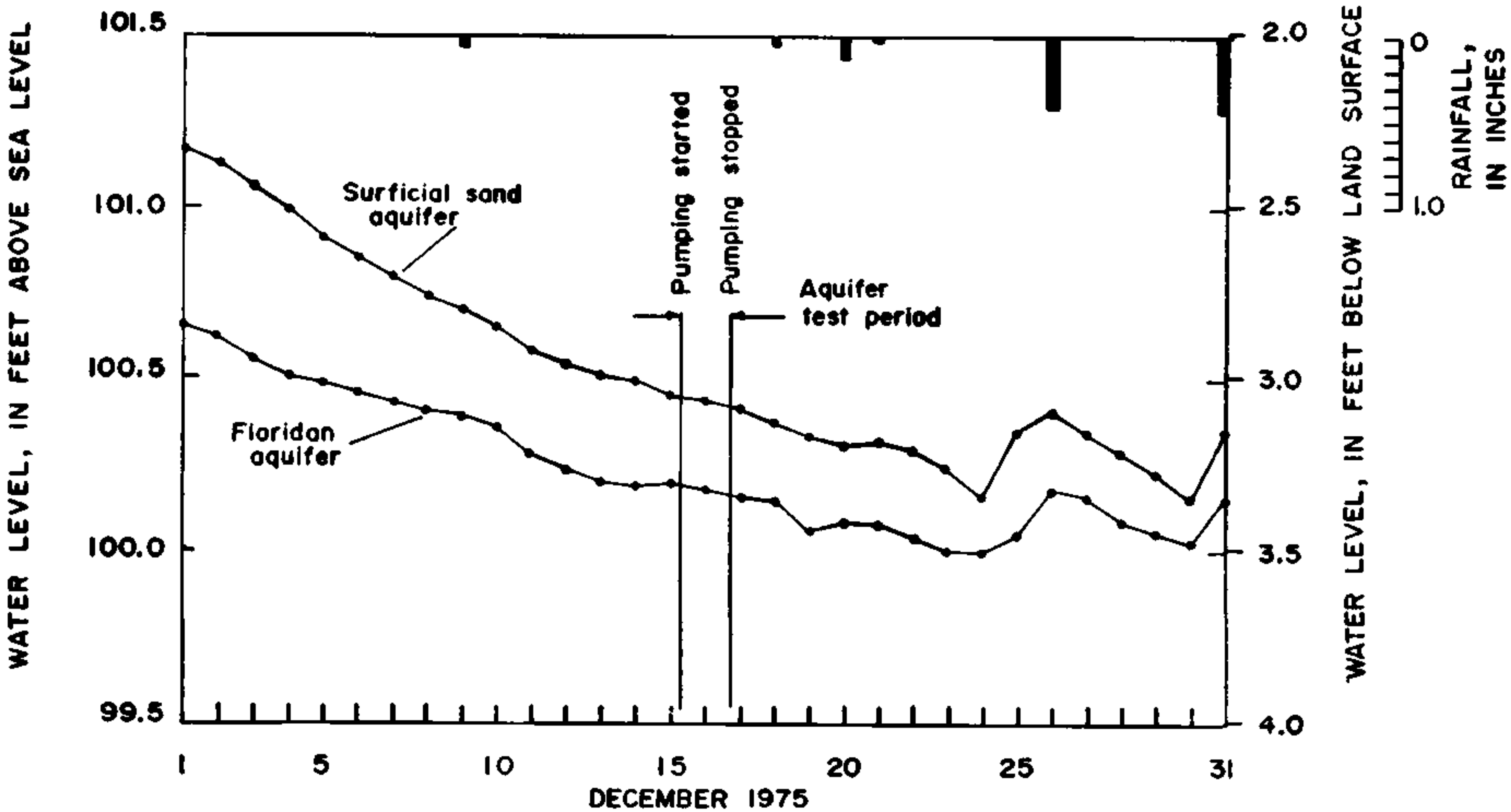


Figure 5.--Water levels in Floridan aquifer well (Midway Deep) and in surficial aquifer well (Midway Shallow) 10 miles north of aquifer test site, and rainfall at Clermont 11 miles northeast of aquifer test site, December 1-31, 1975.

## Data Analysis

The materials that overlie the pumped aquifer at the test site are comprised of fine to very fine sand that grades downward into slightly clayey sand and silt. These materials only slightly retard the downward movement of water from the surficial aquifer to the Floridan. Thus, the Floridan is semiconfined and downward leakage to the Floridan readily occurs when the head in the aquifer is lowered due to pumping (fig. 4).

The analytical models selected to analyze the test use the concept of an artesian aquifer overlain by leaky confining beds. The Floridan aquifer nonsteady-state, or time-drawdown data are analyzed by two methods: (1) the Hantush (1960) modified leaky-artesian method that takes into account the effects of water leaking into the pumped aquifer from overlying and underlying confining beds and, also, the effects of water coming out of storage in the confining beds and, (2) the Hantush and Jacob (1955) leaky artesian method that takes into account the effects of leakage through an overlying confining bed.

Steady-state, or distance-drawdown Floridan aquifer data are analyzed by the Jacob (1946) method which takes into account the effects of leakage through a confining bed.

The confining bed water-level drawdown data are analyzed by the Neuman and Witherspoon (1972) ratio method for leaky confining beds.

### Hantush (1960) Modified Leaky Artesian Method and Hantush and Jacob (1955) Leaky Artesian Method

The time-drawdown data for the Floridan aquifer observation wells are plotted in figure 6. Each drawdown observation, s, is plotted on logarithmic paper against the time, t, since pumping started divided by $r^2$, the square of the distance of the observation well from the pumped well. The resulting family of drawdown curves is matched to the family of Hantush (1960) logarithmic type curves of the function H $(u,\beta)$ versus 1/u (Hantush, 1961). Note that the equation that determines the leakance characteristic, $K'S_s'$ (fig. 6), is proportional to the square of the ratio $^{\beta}/r$. Therefore, it follows that each drawdown response curve of s versus $t/r^2$ should match a Hantush type curve whose $\beta$ value is such that the ratio of $^{\beta}/r$ remains approximately the same for each curve that is matched. This is shown by the table inset in figure 6. The common matchpoint coordinates and calculations and the resulting aquifer and confining bed hydraulic coefficients are shown in figure 6 and are summarized in table 2.

The family of drawdown curves are matched also to the family of Cooper (1963) type curves of L (u,v) versus 1/u that describe equations presented by Hantush and Jacob (1955). The values of the matchpoint

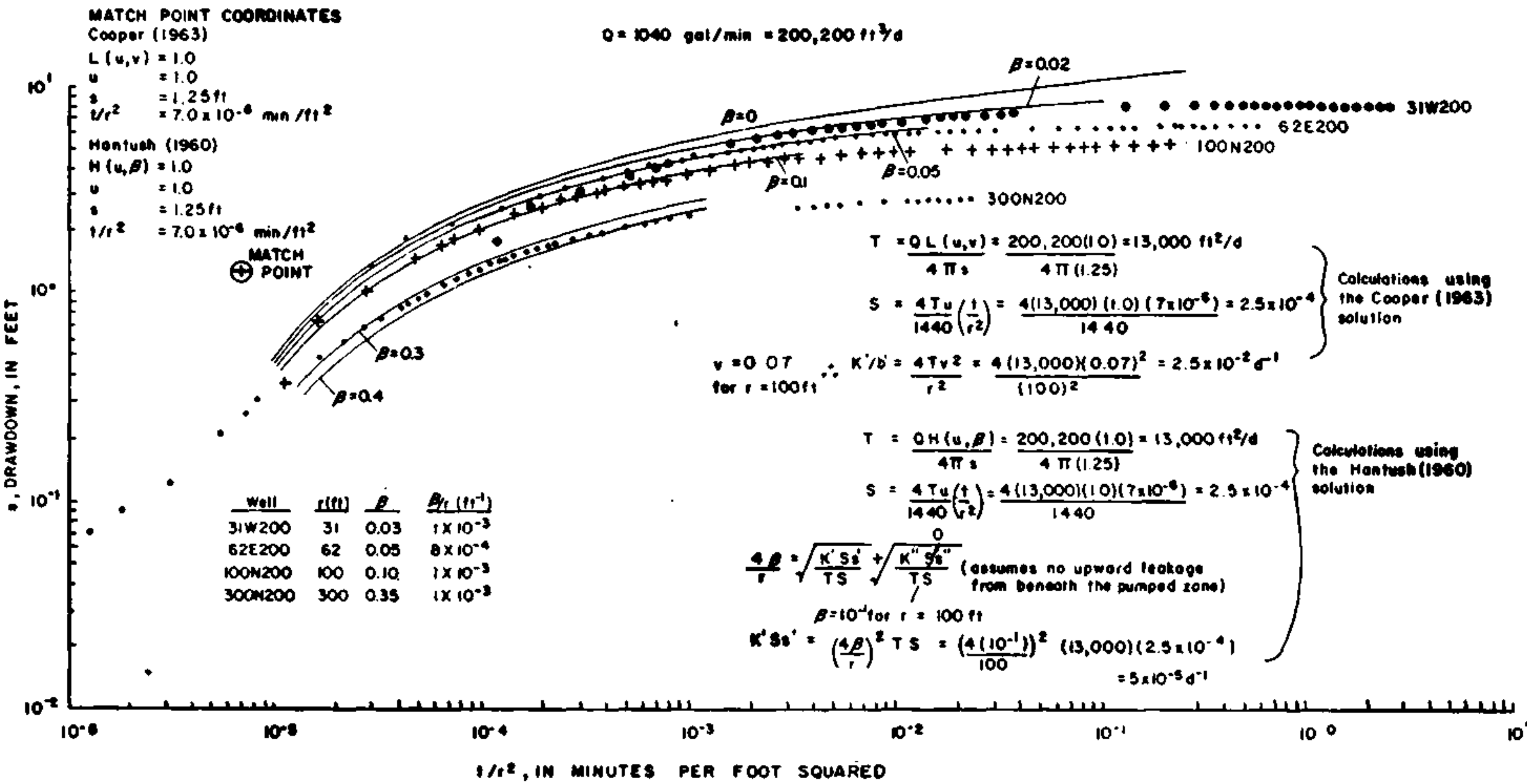


Figure 6.--s versus $t/r^2$ for Floridan aquifer observation wells.

Table 2.--Summary of aquifer test results

| Method of analysis | Aquifer coefficients<br>T<br>($ft^2/d$) | <br>S | Confining bed coefficients<br>[1]$K'S'_s$<br>($d^{-1}$) | <br>[1]$K'/b'$<br>($d^{-1}$) | <br>$K'/S'_s$<br>($ft^2/d$) | <br>r<br>(ft) | <br>z<br>(ft) |
|---|---|---|---|---|---|---|---|
| Hantush, 1960 (nonsteady-state, leaky artesian, confining bed storage) | 13,000 | $2.5 \times 10^{-4}$ | $5 \times 10^{-5}$ | - | - | - | - |
| Hantush and Jacob, 1955 (nonsteady-state, leaky artesian, no confining bed storage) | 13,000 | $2.5 \times 10^{-4}$ | - | $2.5 \times 10^{-2}$ | - | - | - |
| Jacob, 1946 (steady-state leaky artesian) | 13,000 | - | - | $2 \times 10^{-2}$ | - | - | - |
| Neuman and Witherspoon, 1972 (ratio method to determine hydraulic diffusivity of confining bed) | - | - | -- | - | 7,100 | 31 | 21 |
| | | | | | 640 | 31 | 9.4 |
| | | | | | 16,000 | 62 | 29 |
| | | | | | 3,000 | 62 | 17 |
| | | | | | 8,600 | 100 | 31 |
| | | | | | [2]43,000 | 100 | 16 |
| | | | | | 3,300 | 300 | 22 |
| | | | | | 610 | 300 | 10 |

[1] Confining bed coefficient also reflects upward leakage effects from beneath the pumped zone of the aquifer. See text.

[2] Value too high. See text.

coordinates derived are identical to those obtained by use of the Hantush (1961) type curves, therefore the determination of transmissivity and storage coefficient are the same. However, instead of the leakage characteristic, $K'S_s'$, derived by the Hantush (1960) method, the leakage coefficient, $K'/b'$, is obtained. The aquifer and confining bed coefficients are shown on figure 6 and are summarized in table 2.

Note that, in the equations that describe confining bed leakage (fig. 6), it is assumed that all leakage takes place through the overlying confining bed. This assumption may not be valid because the pumped well only partially penetrates the pumped aquifer. The interval of the pumped aquifer below about 100 feet is comprised of clayey limestone. A flowmeter log of the well (while pumping) indicates that virtually no water enters the borehole below about 100 feet. These data indicate that the pumped aquifer is less permeable below the 100 foot depth but it does not preclude diffuse upward leakage into the pumped zone during the test. Thus, the leakage characteristic $K'S_s'$ and the leakage coefficient $K'/b'$ derived in the analyses (fig. 6) should be considered as, at least potentially, lump sum figures that incorporate the effects of upward and downward leakage.

An additional source of error in this analysis is due to the fact that, during the test, there was drawdown in the surficial aquifer caused by pumping from the Floridan (fig. 4). The Hantush (1960) modified method and the Hantush and Jacob (1955) method assume that the head in sub- and supradjacent aquifers remains constant during the test. The effect of drawdown in the surficial aquifer upon the aquifer test type-curve matching procedure causes the values of match point coordinates s and $t/r^2$ to be slightly higher and $\beta$ to be slightly lower with respect to $H(u,\beta)$ and u than they would be had the head in the surficial aquifer remained constant. The higher values of s and $t/r^2$ cause the calcalculated values of transmissivity and leakance characteristic to be slightly low and that for the storage coefficient to be slightly high. Nevertheless, it is believed that the aquifer coefficients of transmissivity and storage, confining bed leakance characteristic $K'S_s'$, and confining bed leakage coefficient $K'/b'$ are the best estimates that can be obtained by analysis of the nonsteady-state data.

### Jacob (1946) Leaky Artesian Method

The distance-drawdown data for the Floridan aquifer observation wells are plotted in figure 7. Figure 6 shows that, after a period of time, the drawdown in each of the observation wells appeared to stabilize. This indicates that a relatively steady-state condition had been reached. Thus, in accordance with the method described by Jacob (1946), the final, or steady-state drawdown observation in each well, is plotted on logarithmic paper against the distance of the observation well from the pumped well (fig. 7). The data are then matched to the Bessel function logarithmic type curve of $K_0(x)$ versus x whose tabular values

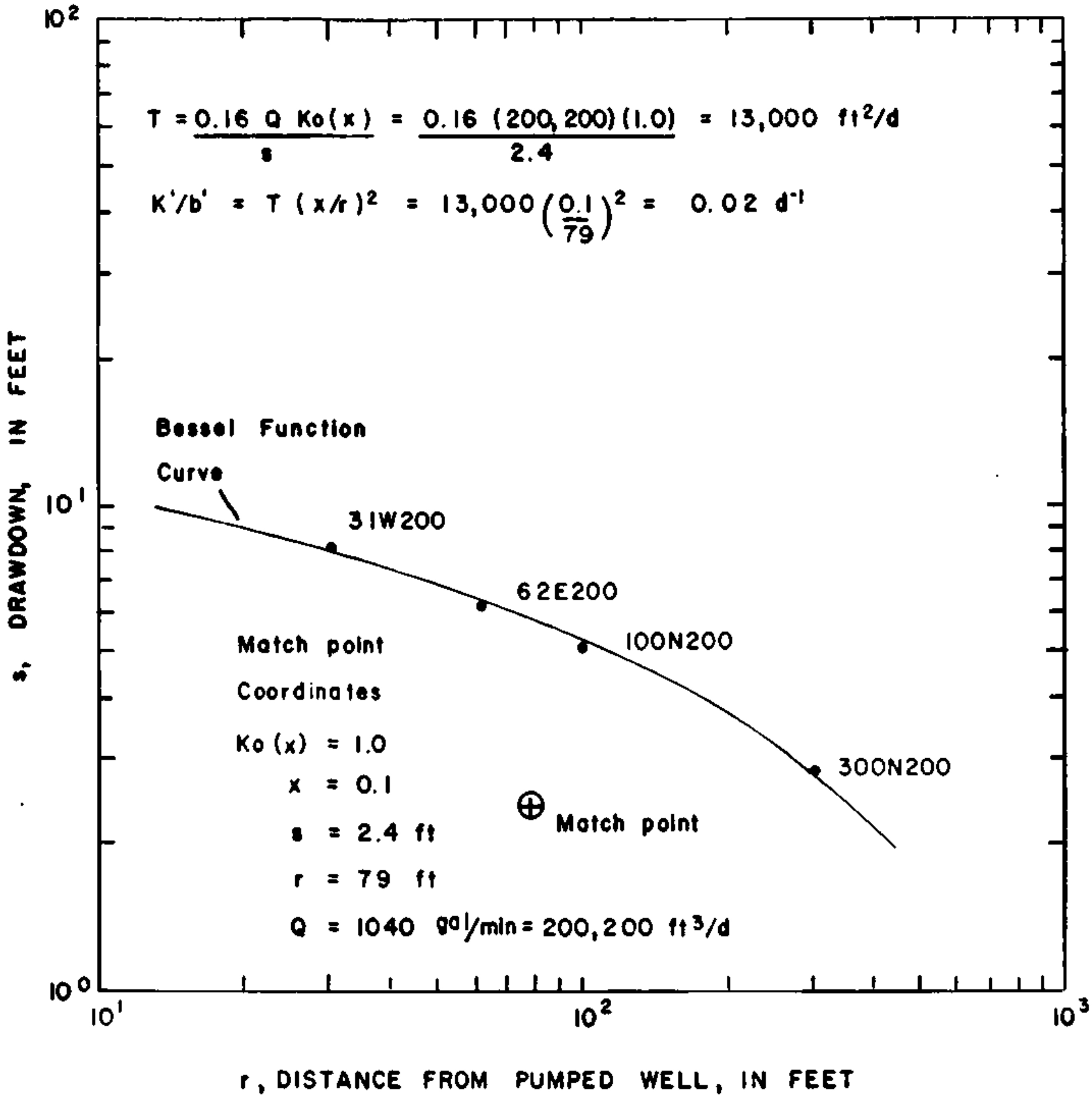


Figure 7.--s versus r for Floridan aquifer observation wells.

are given in Ferris and others (1962, table 4). The common matchpoint coordinates and calculations are shown in figure 7. The resulting aquifer and confining bed hydraulic coefficients are shown in figure 7 and are summarized in table 2. The confining bed leakage coefficient, $K'/b'$, is considered as, potentially, a lump sum coefficient that includes the effects of upward leakage.

Drawdown in the surficial aquifer during the test (fig. 4) causes this analysis to be somewhat in error in the same manner as that discussed in the previous section on the Hantush (1960) modified method.

## Neuman and Witherspoon (1972) Ratio Method

The Neuman and Witherspoon (1972) ratio method, hereafter referred to as the ratio method, involves the determination of confining bed hydraulic diffusivity ($K'/S_s'$) by the analysis of the hydraulic response measured in a confining bed caused by pumping from a sub- or supradjacent aquifer. This method differs from those of Hantush (1960), Hantush and Jacob (1955), and Jacob (1946) in which confining bed hydraulic characteristics are determined by analyzing the hydraulic response measured in the pumped aquifer.

Drawdowns in the confining bed (measured in the shallow and intermediate-depth wells) are divided by drawdowns in the pumped aquifer; those ratios, $s'/s$, are plotted on logarithmic paper against the time, $t$, since pumping started (figs. 8 and 10-16). The appropriate ratio method $t_D$ type curve (fig. 9) to which the ratio data are matched is calculated, as shown in the figures, by using the estimates of aquifer transmissivity and storage coefficient previously determined (table 2).

The curve-matching procedure for the ratio method is unlike the procedure as described by Ferris and others (1962, p. 94-98). Note that in the equation that determines which of the $t_D$ curves in the family of curves of $s'/s$ versus $t'_D$ (fig. 9) is to be used, the value of $t_D$ is directly proportional to $t$, time since pumping started. This means that as $t$ becomes large, the calculated value of $t_D$ also becomes large. Therefore, each observation of $s'/s$ which, necessarily, is that measured at a different time, could, theoretically, be matched to a different $t_D$ type curve. Therefore, the shape of the $s'/s$ versus $t$ data curve is not relevant, in terms of a match, to the shape of a $t_D$ type curve. The shape of the $s'/s$ versus $t$ data curve is, however, valuable in a diagnostic sense and is discussed in the following paragraph.

The ratio method of analysis entails the determination of the time, $t$, at which a pressure transient is first detected in a confining bed observation well or piezometer. Subsequent measurements of drawdown in the confining bed are more likely to be affected by the effects of throughflow from, in this test, a higher level in the surficial aquifer. If throughflow occurs or begins to occur, the pressure transient is no longer truly transient but is approaching a state of dynamic equilibrium.

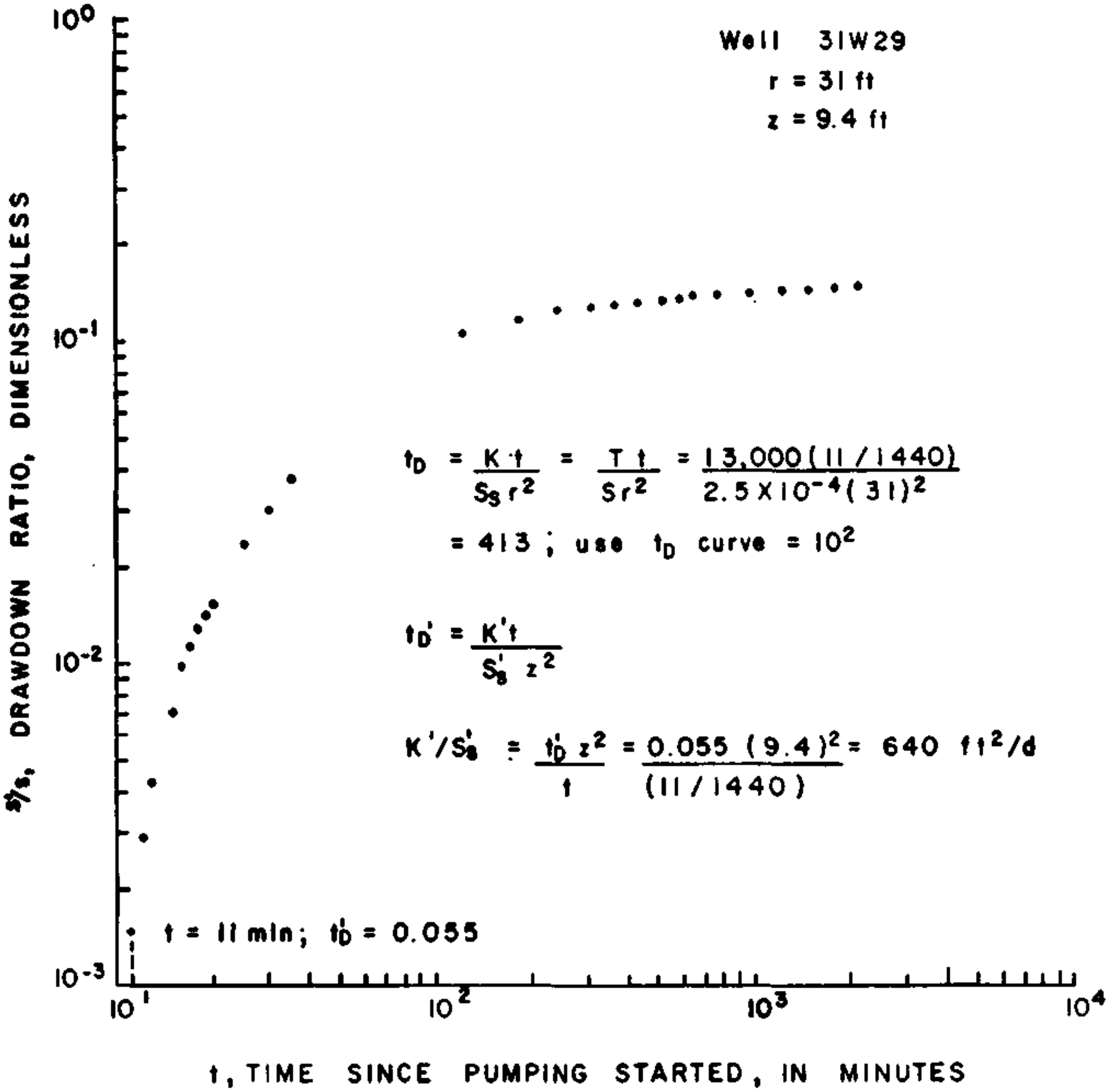


Figure 8.--s'/s versus t, ratio of drawdown in well 31W29 to drawdown in well 31W200 versus time.

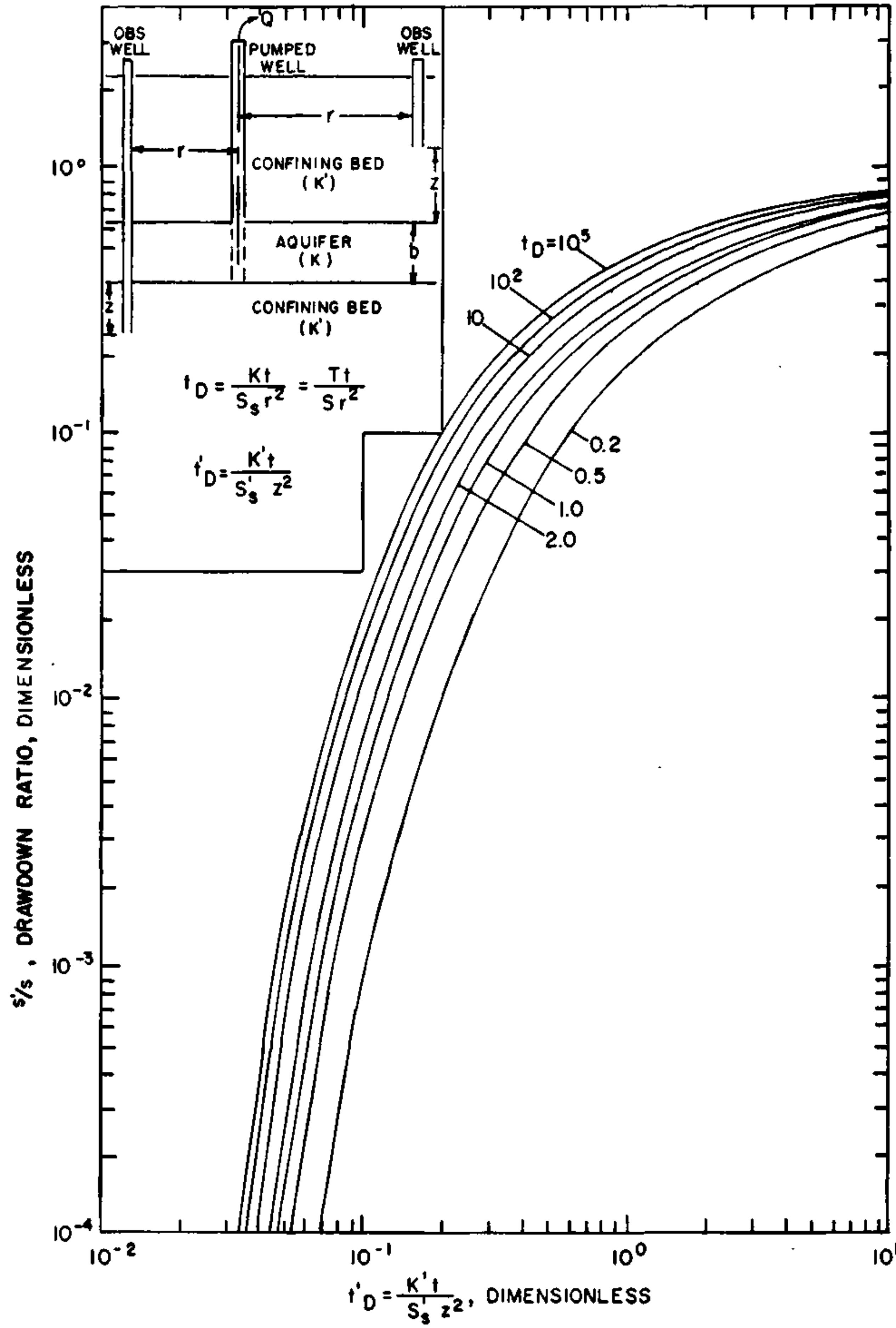


Figure 9.--Type curves of s'/s versus $t'_D$ (from Neuman and Witherspoon, 1972).

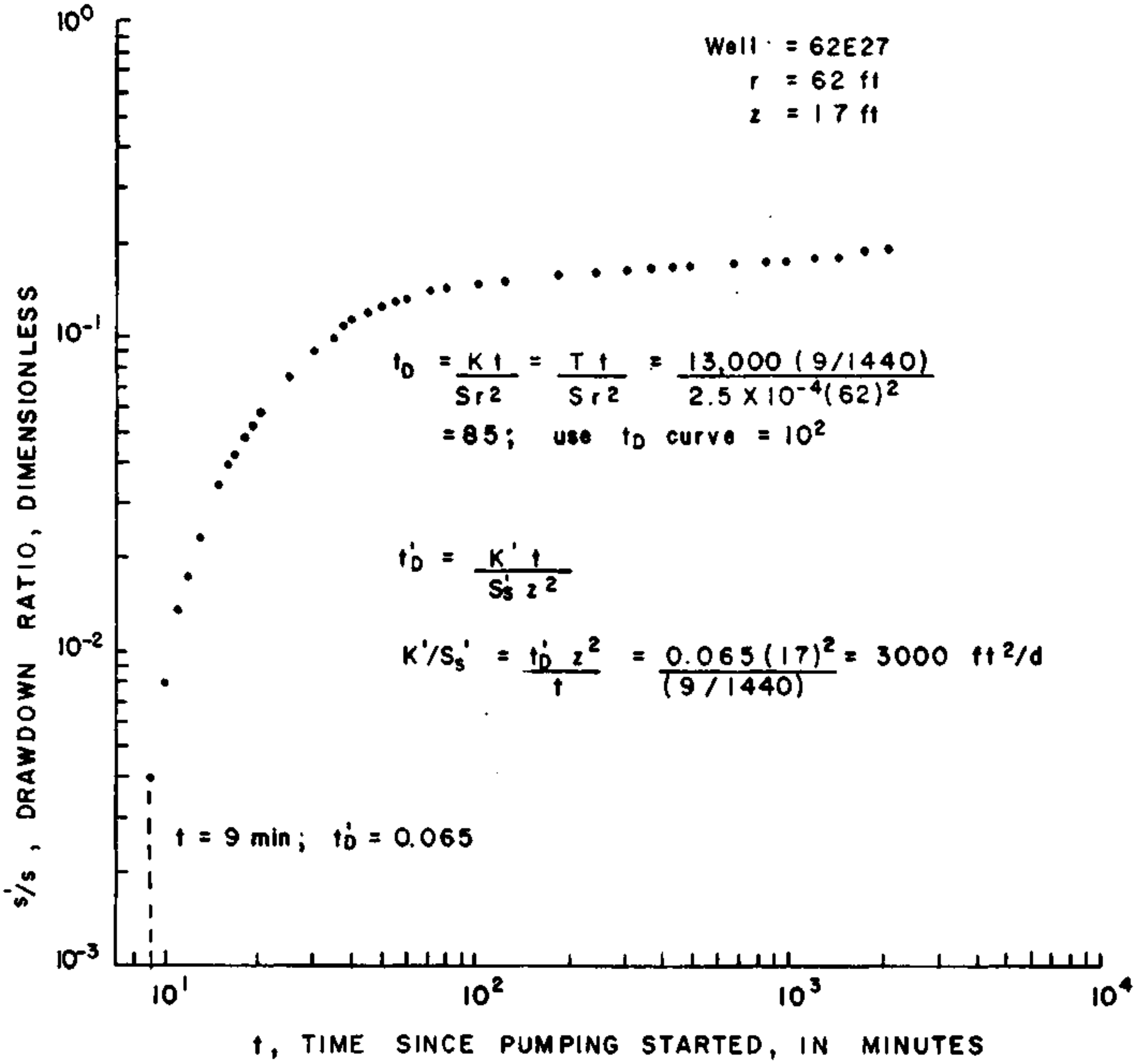


Figure 10.--s'/s versus t, ratio of drawdown in well 62E27 to drawdown in well 62E200 versus time.

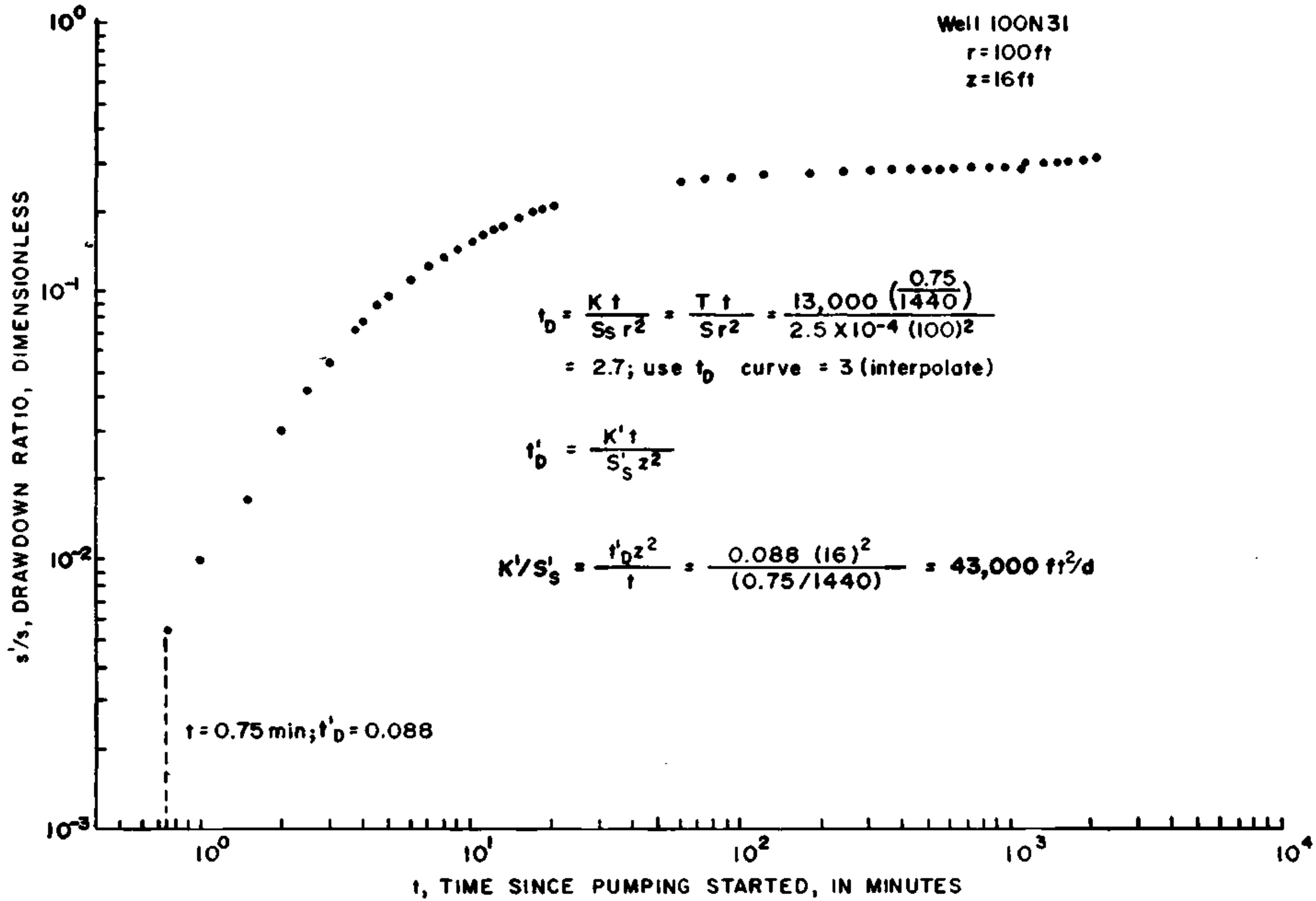


Figure 11.--s'/s versus t, ratio of drawdown in well 100N31 to drawdown in well 100N200 versus time.

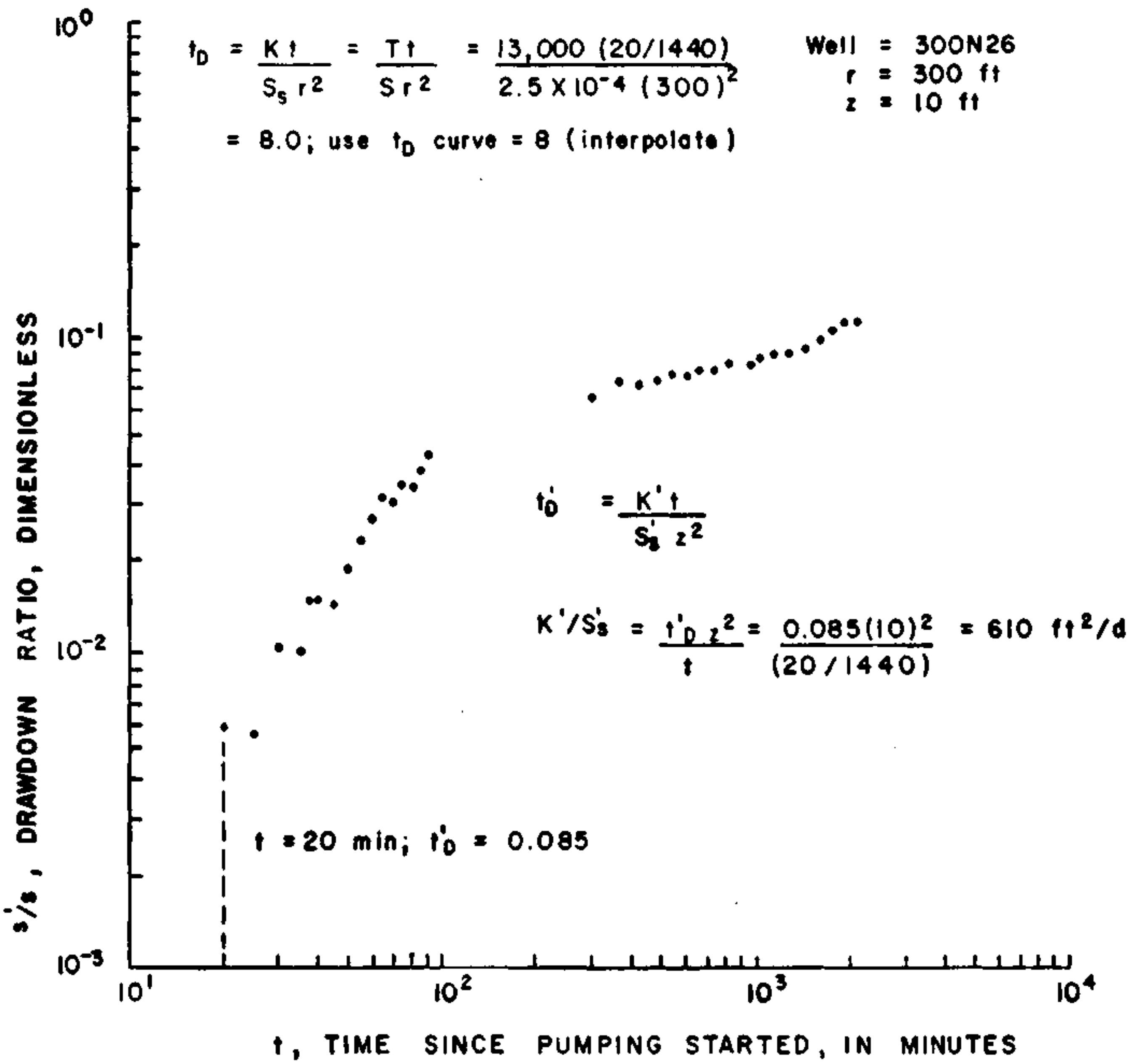


Figure 12.--s'/s versus t, ratio of drawdown in well 300N26 to drawdown in well 300N200 versus time.

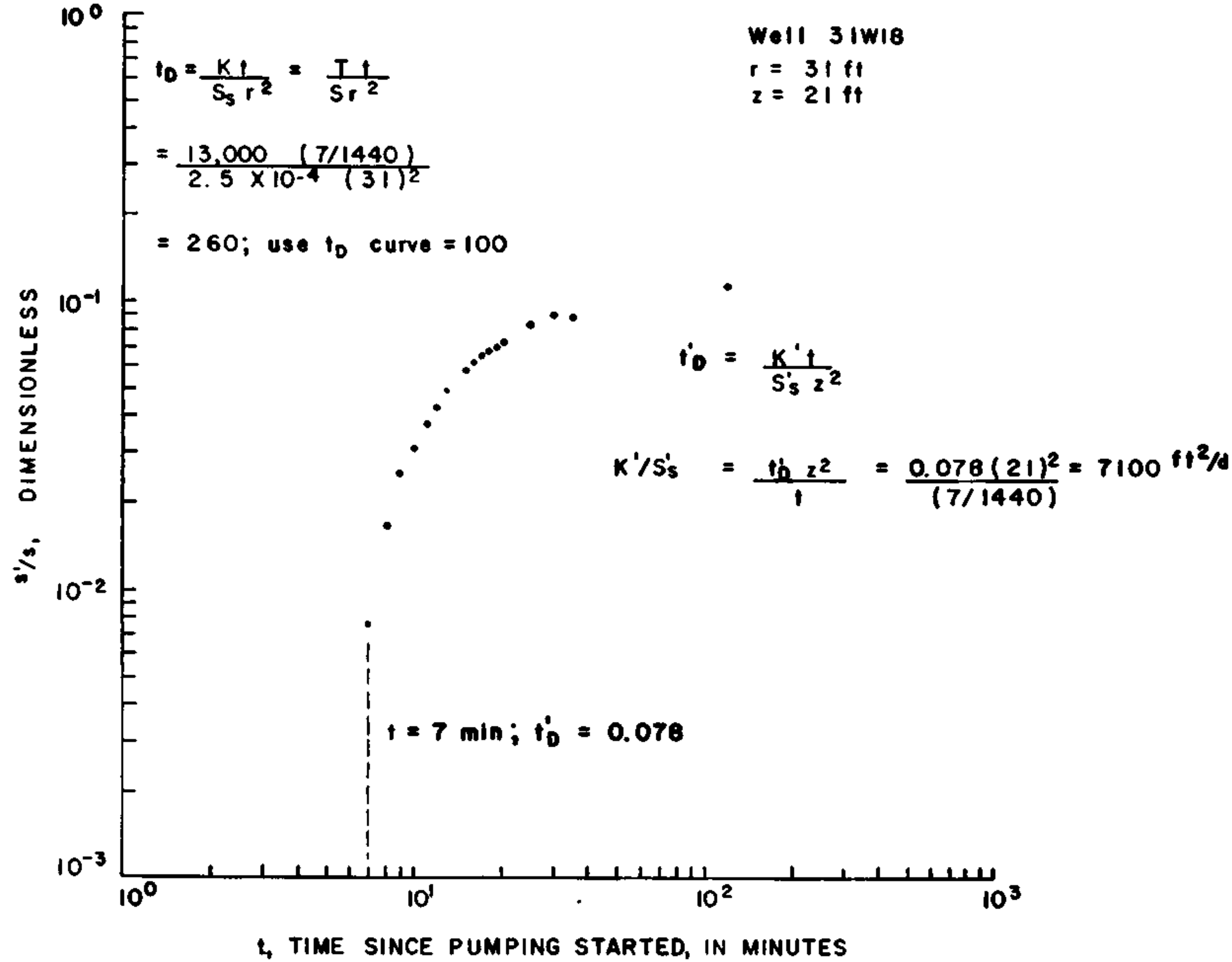


Figure 13.--s'/s versus t, ratio of drawdown in well 31W18 to drawdown in well 31W200 versus time.

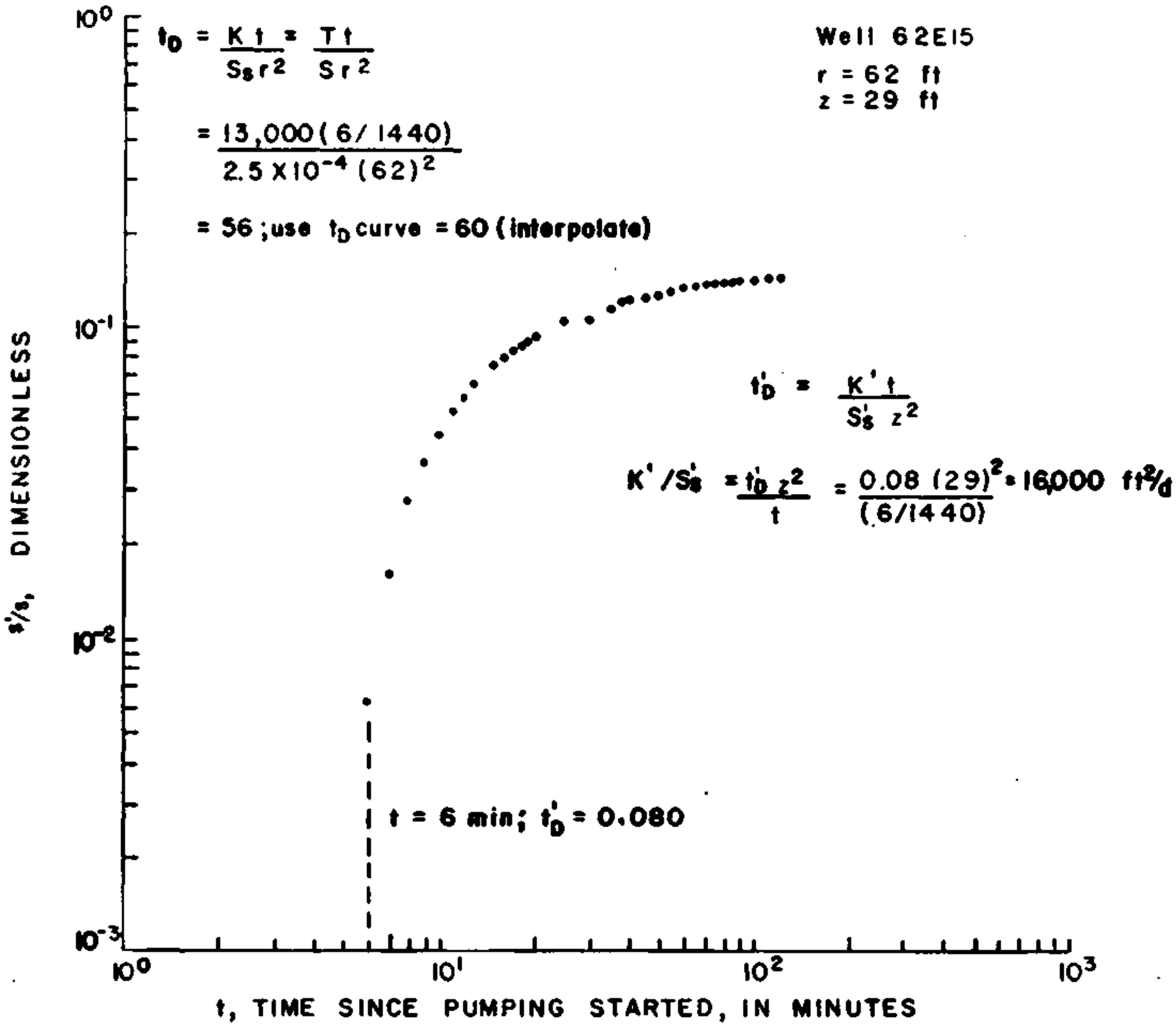


Figure 14.--s'/s versus t, ratio of drawdown in well 62E15 to drawdown in well 62E200 versus time.

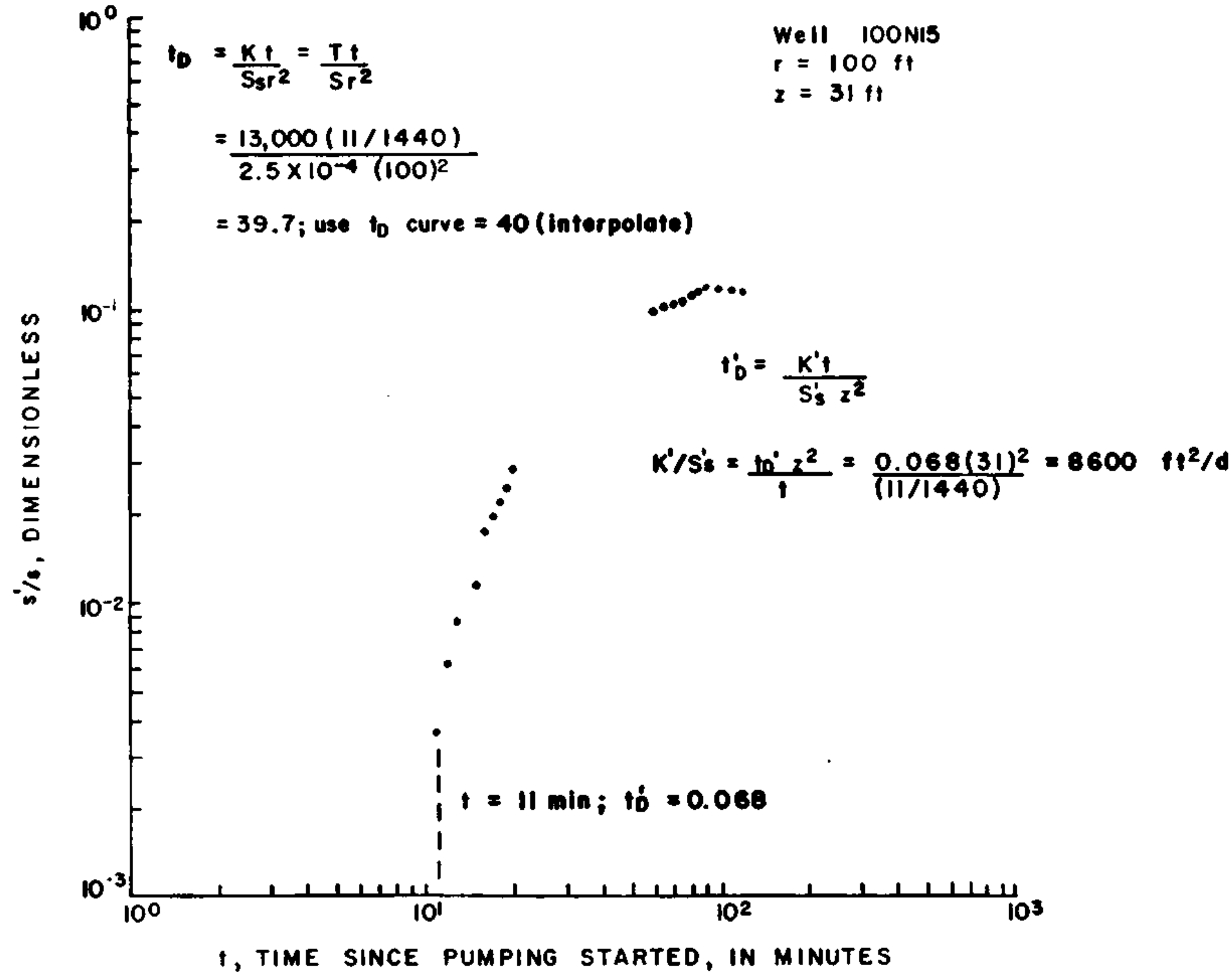


Figure 15.--s'/s versus t, ratio of drawdown in well 100N15 to drawdown in well 100N200 versus time.

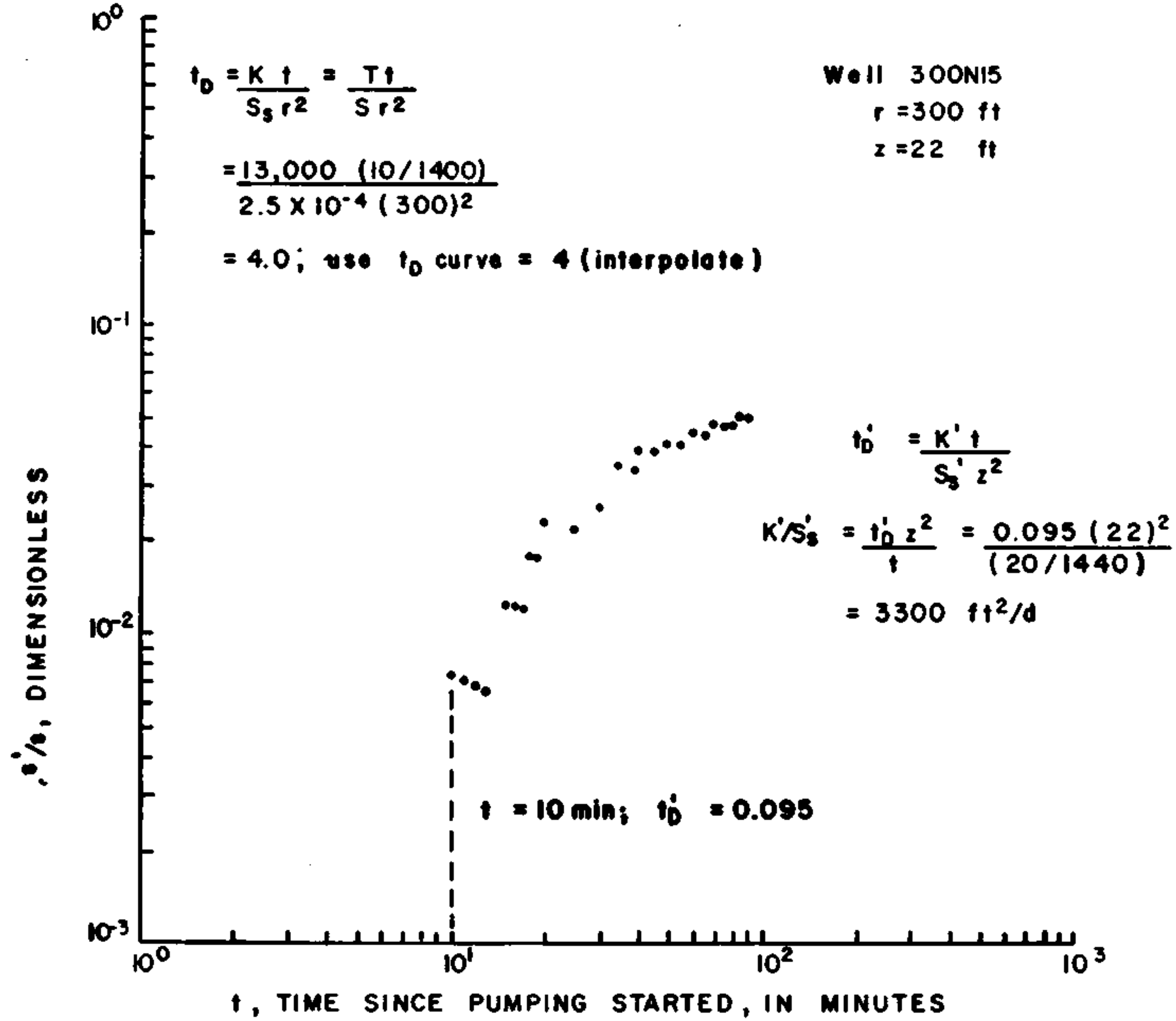


Figure 16.--s'/s versus t, ratio of drawdown in well 300N15 to drawdown in well 300N200 versus time.

To detect possible throughflow, the s'/s versus t data curve is overlain by the family of s'/s versus $t'_D$ type curves; the trace of the data curve should cross the family of $t_D$ curves in the direction of increasing values of $t_D$. If the trace of the data curve follows a $t_D$ curve or crosses the family of $t_D$ curves in the direction of decreasing $t_D$, it means that either throughflow is affecting the drawdown response in the confining bed or the interval of the confining bed tapped by the piezometer is in direct hydraulic connection with the pumped aquifer to the extent that no effective confining material exists between the piezometer and the pumped aquifer. The latter condition probably exists at well 100N31 (fig. 11) and is reflected in the relatively high calculated value of hydraulic diffusivity (table 2 and fig. 17).

The curve-matching procedure consists of overlaying the s'/s versus t data curve (fig. 8) with the family of s'/s versus $t'_D$ type curves (fig. 9) making sure that the s'/s axes are held parallel and equivalent. The type curves are moved horizontally so that the first nonzero s'/s data point is intersected by the appropriate $t_D$ curve whose value was previously calculated. The value of $t'_D$ is determined at the point of intersection and, by rearranging the equation that describes $t'_D$ (fig. 8), the hydraulic diffusivity, $K'/S'_s$, is calculated.

The hydraulic diffusivity value determined at a shallow or intermediate-depth observation well represents the average hydraulic diffusivity for the interval of the confining bed represented by the vertical distance, z, between the top of the pumped aquifer and the bottom of the screened interval of the observation well. The $K'/S'_s$ values determined from the shallow observation well data tend to be higher than values determined from the intermediate-depth wells (fig. 17). This is not considered anomalous. However, note that at well sites 31W29 (fig. 8), 62E27 (fig. 10), 300N26 (fig. 12), 31W18 (fig. 13), 62E15 (fig. 14), and 300N15 (fig. 16) drawdown was detected in the shallow wells before drawdown was detected in the intermediate-depth wells. As mentioned previously, the intermediate-depth well 100N31 was probably in direct hydraulic connection with the pumped aquifer; therefore drawdown was detected in that well before it was detected in the shallower well, 100N15. It is possible that drawdown was detected in the shallow wells sooner than in the intermediate-depth wells because less permeable, slightly more clayey sand at depth is discontinuous in the horizontal plane or is breached in the vertical direction. Such discontinuity or breaches would allow a pressure transient to propagate upward and cause drawdown in the shallow sand before a pressure transient could propagate through the less permeable clayey sand though there was less vertical distance for the pressure transient to travel.

Reverse water-level fluctuations (buildup rather than drawdown), though not shown, were observed in both the shallow and intermediate depth observation wells at very early times, t. It is believed that this is essentially a mechanical response rather than a hydraulic

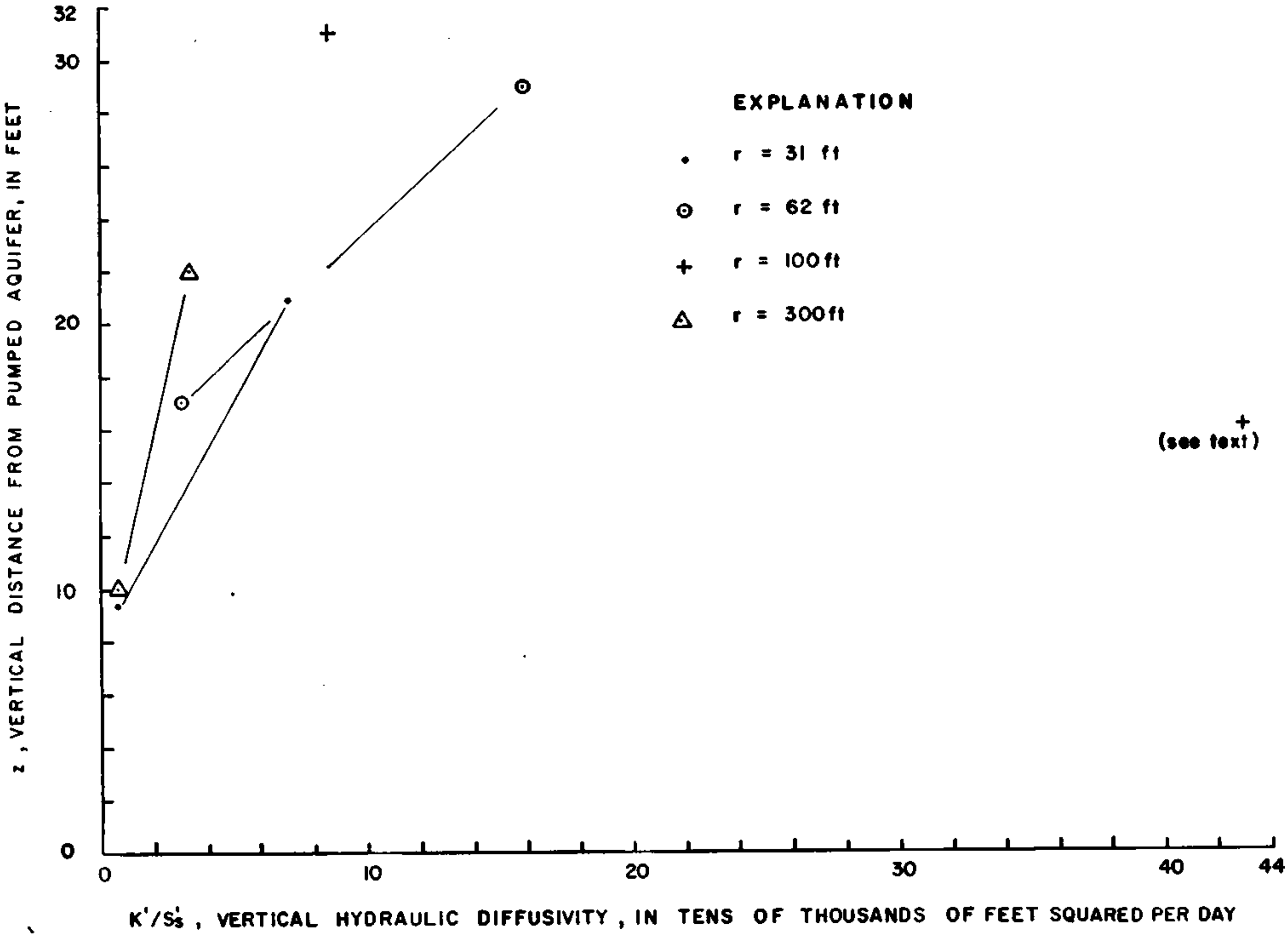


Figure 17.--Vertical hydraulic diffusivity, $K'/S'_s$, of confining bed versus vertical distance, z, from pumped aquifer.

response. Nevertheless, it is possible that the time, t, at which a positive value of drawdown is determined (thus signaling the arrival of the pressure transient) could be too large, and thus the calculated values of hydraulic diffusivity could be too small.

## SUMMARY AND CONCLUSIONS

The Floridan aquifer at the aquifer test site is overlain by a surficial aquifer that consists of about 40 feet of fine to very fine sand that, from the surface, grades downward into slightly clayey sand and silt. The materials that comprise the surficial aquifer also serve to confine the Floridan and only slightly retard the downward movement of water to the Floridan. However, the heads in the surficial aquifer and the Floridan are very nearly the same. Therefore, under nonpumping conditions the downward hydraulic gradient is small and only small amounts of water recharge the Floridan.

An aquifer test was designed and conducted to stress the uppermost part of the Floridan aquifer so that the leakage characteristics of the overlying confining bed could be determined. The Floridan aquifer was pumped at a nearly constant rate of 1,040 gal/min for 35 hours. Drawdown was measured in four Floridan aquifer observation wells at radial distances of 31, 62, 100, and 300 feet. Drawdown was also measured in the surficial aquifer in shallow and intermediate-depth observation wells at the same locations as the Floridan aquifer observation wells.

The drawdown data obtained from the Floridan aquifer observation wells are analyzed by the nonsteady-state leaky artesian methods of Hantush (1960) and the Hantush and Jacob (1955) and the steady-state leaky artesian method of Jacob (1946).

Results of the Floridan aquifer drawdown data analyzed are: T, transmissivity, (13,000 $ft^2/d$); S, storage coefficient, ($2.5 \times 10^{-4}$); $K'/b'$, confining bed leakance coefficient, ($2 \times 10^{-2}$ to $2.5 \times 10^{-2} d^{-1}$); and $K'S_s'$, confining bed leakance characteristic ($5 \times 10^{-5} d^{-1}$).

The surficial aquifer drawdown data are analyzed for vertical hydraulic diffusivity, $K'/S_s'$, using the ratio method of Neuman and Witherspoon (1972). The hydraulic diffusivity values ranged from 610 $ft^2/d$ to 16,000 $ft^2/d$. The higher values of hydraulic diffusivity represent the shallow sand and the lower values represent the slightly more clayey sands at depth.

The relatively rapid drawdown of water levels in the surficial aquifer in response to pumping of the Floridan indicate that, in the area of the test site, a Floridan aquifer well field would induce additional recharge to the Floridan. As a result of that increased recharge, water levels in the surficial aquifer would tend to stand lower, runoff from the area would tend to be less, and, perhaps, evapotranspiration would be less than normal.

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