UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

RESULTS OF AN AQUIFER TEST NEAR LYNNDYL, UTAH

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U.S. GEOLOGICAL SURVEY

OPEN-FILE REPORT 82-514

Prepared in cooperation with the
UTAH DEPARTMENT OF NATURAL RESOURCES AND ENERGY,
DIVISION OF WATER RIGHTS

Salt Lake City, Utah
1982

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AQUIFER-TEST TERMINOLOGY

Term	Notation	Unit	Reference
Diffusivity of aquifer	(α =K/Ss)	feet squared per day (L^2/T)	Neuman and Witherspoon, 1969a, p. 803.
Diffusivity of confining bed	(α' =K'/Ss')	feet squared per day (L^2/T)	Do.
Dimensionless time	(t_D)	dimensionless	Neuman and Witherspoon, 1972, p. 1294.
Drawdown or recovery in aquifer	(s)	feet (L)	Lohman, 1972, p. VI-VII.
Drawdown or recovery in confining bed	(s')	feet (L)	Do.
Elapsed time or timelag	(t)	minutes (T)	Do.
Hydraulic conductivity	(K)	feet per day (L/T)	Lohman, 1972, p. 6.
Leakage parameter	(β)	dimensionless	Neuman and Witherspoon, 1969b, p. 818; Lohman, 1972, p. VI-VII.
Radius from pumped well to observation well	(r)	feet (L)	Neuman and Witherspoon, 1969a, p. 803.
Specific storage of aquifer	(Ss)	$\frac{1}{\text{feet}}(L^{-1})$	Lohman, 1972, p. 32.
Specific storage of confining bed	(Ss')	$\frac{1}{\text{feet}}(L^{-1})$	Do.
Storage coefficient	(S)	dimensionless	Lohman, 1972, p. 8.
Thickness of aquifer	(b)	feet (L)	Neuman and Witherspoon, 1969a, p. 803; Lohman, 1972, p. VI-VII.
Thickness of confining bed	(b')	feet (L)	Lohman, 1972, p. 30.
Transmissivity	(T)	feet squared per day (L^2/T)	Lohman, 1972, p. 6.
Vertical distance above bottom of confining bed	(z)	feet (L)	Neuman and Witherspoon, 1969a, p. 803.
Vertical hydraulic conductivity of the confining bed	(K')	feet per day (L/T)	Lohman, 1972, p. 30.

CONVERSION FACTORS

Inch-pound Unit (Multiply)	Inch-pound Abbreviation	(by)	Metric Unit (to obtain)	Metric Abbreviation
Acre	--	0.4047	square hectometer	hm^2
		0.004047	square kilometer	km^2
Foot	ft	0.3048	meter	m
Foot per day	ft/d	0.0929	meter per day	m/d
Gallon per minute	gal/min	0.06309	liter per second	L/s
Inch	in.	25.40	millimeter	mm
		2.540	centimeter	cm
Mile	mi	1.609	kilometer	km
Square foot	ft^2	0.0929	square meter	m^2
Square foot per day	ft^2/d	0.0929	square meter per day	m^2/d
Square mile	mi^2	2.59	square kilometer	km^2

Water temperature is given in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by the following equation: $°F=1.8(°C)+32$.

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

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ABSTRACT

An aquifer test was conducted near Lynndyl, Utah, to determine the hydraulic characteristics of a deep artesian aquifer and its associated confining bed. A well completed in the aquifer was pumped continuously for 25 days and measurements of drawdown and recovery were made in 34 observation wells located within a 10-mile radius of the pumped well. Data from the tests were analyzed using the Hantush modified and Neuman and Witherspoon ratio methods for leaky confined aquifers in which the storage of water in the confining beds was taken into account.

The aquifer transmissivity was calculated to be 12,700 feet squared per day, and the storage coefficient was 6.4×10^{-5}. Calculated average vertical hydraulic conductivity of the confining bed was about 6×10^{-3} foot per day with the specific storage of the confining bed calculated to be 5.4×10^{-6} per foot.

INTRODUCTION

During February and March, 1981, the U.S. Geological Survey conducted an aquifer test near Lynndyl, Utah (fig. 1). The test was part of a comprehensive study of ground water in the Sevier Desert being made by the Geological Survey in cooperation with the Utah Department of Natural Resources and Energy, Division of Water Rights. The purpose of the test was to evaluate the hydraulic characteristics of a deep artesian aquifer and its associated confining bed identified in previous studies by Mower (1961) and Mower and Feltis (1968). Results of the test were used to construct and calibrate a digital-computer model that will be used to predict future changes in the ground-water system that would result from any ground-water development scheme. The location of the pumped well and observation wells monitored during the test are shown in figure 1, and pertinent information about each well is listed in table 1. Wells used to conduct the test are privately owned. The authors extend thanks to these well owners for granting access to their wells and property during the test.

WELL-NUMBERING SYSTEM

The system of numbering wells in Utah is based on the cadastral land-survey system of the U.S. Government. The number, in addition to designating the well, describes its position in the land net. By the land-survey system, the State is divided into four quadrants by the Salt Lake base line and meridian, and these quadrants are designated by the uppercase letters A, B, C, and D, indicating the northeast, northwest, southwest, and southeast quadrants, respectively. Numbers designating the township and range (in that order) follow the quadrant letter, and all three are enclosed in parentheses.

The number after the parentheses indicates the section, and is followed by three letters indicating the quarter section, the quarter-quarter section, and the quarter-quarter-quarter section--generally 10 acres;[1] the letters a, b, c, and d indicate, respectively, the northeast, northwest, southwest, and southeast quarters of each subdivision. The number after the letters is the serial number of the well within the 10-acre tract. If a well cannot be located within a 10-acre tract, one or two location letters are used and the serial number is omitted. Thus (C-15-5)27dcc-1 designates the first well constructed or visited in the SW¼SW¼SE¼ sec. 27, T. 15 S., R. 5 W. The numbering system is illustrated in figure 2.

DESCRIPTION OF THE AQUIFERS

Ground water in the area occurs in unconsolidated deposits of clay, silt, sand, and gravel ranging in age from Pliocene to Holocene. The unconsolidated deposits are underlain by semiconsolidated to consolidated conglomerates of Tertiary age (Mower and Feltis, 1968, table 2). The saturated unconsolidated deposits form a complex, multiple aquifer system that has been divided by Mower (1961, p. C-94) into two general aquifers; the shallow artesian aquifer and the deep artesian aquifer. Lithology and aquifer boundaries as delineated by the authors are shown on a generalized geologic section (fig. 3). The aquifer boundaries shown in figure 3 generally agree with those shown by Mower and Feltis (1968, pl. 3). Data used to compile the geologic section shown in figure 3 were obtained from drillers' logs in the files of the U.S. Geological Survey, Salt Lake City, Utah.

Hydraulic coefficients for both the shallow and deep artesian aquifers have been reported by Mower (1961, p. C-94) and Mower and Feltis (1968, table 8). They were calculated from aquifer tests using standard methods described by Theis (1935), Cooper and Jacob (1946), Hantush and Jacob (1955), and Theis, Brown, and Meyer (1963). Their (Mower and Feltis) reported values of transmissivity (T) for the shallow artesian aquifer ranged from about 4,700 to 47,000 feet squared per day and for the deep artesian aquifer from about 2,000 to 27,000 feet squared per day. The average of their reported storage coefficients (S) for the shallow artesian aquifer was 3.3×10^{-4} and for the deep artesian aquifer was 6.7×10^{-4}.

DESCRIPTION OF TEST PROCEDURES AND METHODS USED TO ANALYZE THE DATA

The test consisted of a 25-day pumping period and a 26-day recovery period. Well (C-15-4)19ccc-1 (table 1 and fig. 1) was pumped continuously for 25 days, beginning February 2, 1981. The discharge from the well remained almost constant at 5,400 gallons per minute during the entire pumping period. For several months prior to the test and for 26 days after pumping ceased, water levels were measured in 34 wells. Those measurements were too numerous to include in this report, but are available at the office of the U.S. Geological Survey, Water Resources Division, 1745 West 1700 South, 1016 Administration Building, Salt Lake City, Utah.

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[1]Although the basic land unit, the section, is theoretically 1 square mile, many sections are irregular. Such sections are subdivided into 10-acre tracts, generally beginning at the southeast corner, and the surplus or shortage is taken up in the tracts along the north and west sides of the section.

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Drawdowns were calculated by subtracting water levels during the test from the water levels prior to the test. The drawdowns then were corrected for linear water-level trends and barometric fluctuations. During recovery, more data were available to generate logarithmic-trend corrections for projected drawdown, which were considered to be more accurate than linear trends established from the limited number of water-level measurements prior to pumping. Therefore, measurements of recovery above the projected drawdown were used in the analytical procedures, although drawdown data generally agreed with recovery data.

Analytical methods used to calculate hydraulic coefficients for the aquifers and confining beds were based on methods applicable to leaky confined aquifers in which the storage of water in the confining beds is taken into account. Discussion of the current theories of flow in leaky aquifer systems can be found in Neuman and Witherspoon (1969a, b), and Lohman (1972, p.30-34).

Methods developed to analyze leaky artesian systems with the release of water from storage in the confining beds include the "Hantush Modified Method" described by Lohman (1972, p. 32), and the "Ratio Method" described by Neuman and Witherspoon (1972, p. 1284). The Hantush modified method was used to obtain values of T and S for the deep artesian aquifer and both methods were used together to obtain an estimate of the vertical hydraulic conductivity (K') and specific storage (Ss') of the confining bed.

The Hantush modified method involves plotting drawdown or recovery in the pumped aquifer against time on log-log graph paper and matching the resultant curve to a set of type curves (Lohman, 1972, pl. 4). Values of T and S can be obtained from the procedure and a value for K'Ss' can be calculated. To calculate K'Ss', it is assumed that all the leakage to the artesian aquifer is derived from the overlying confining bed, and that the underlying conglomerate (fig. 3) is virtually impermeable.

The Neuman and Witherspoon ratio method involves comparing the recovery in the confining bed to the recovery in the aquifer at the same location and time. Because there were no wells completed only in the confining bed, wells perforated near the base of the shallow aquifer were used in the analysis. Data from these wells were assumed to represent the recovery in the upper part of the confining bed. According to Neuman and Witherspoon (1972, p. 1289), the analysis depends very little on the actual magnitude of the recovery in the confining bed; however, it does depend significantly on the time lag (t) between the start of the test and the time when water levels in the confining bed begin to respond.

RESULTS OF THE TEST

Water-level recovery in seven wells completed in the deep artesian aquifer is shown in figure 4. The recoveries shown are a function of time, since pumping stopped (t), divided by the squared distance (r^2) of each well from the pumped well--that is, t/r^2. Under nonleaky conditions, the plots of t/r^2 for all wells should form one continuous curve (Riley and McClelland, 1971, p. 28). However, the plotted values (fig. 4) form a family of curves that generally show recovery at a given value of t/r^2 decreasing with distance from the pumped well. Riley and McClelland (1971, p. 28a) attributed this departure to leakage from confining beds. The plot for well (C-15-4)20caa-1 (not shown in fig. 4) does not fit the general trend; this well is near the edge of the confining bed, where the shallow and deep artesian aquifers are not well separated (fig. 3).

Data from the seven wells shown in figure 4 were analyzed using the Hantush modified method for leaky aquifers with release of water from the overlying confining bed. Data from well (C-15-4)20caa-1 was not shown in figure 4 or used in the analysis because it reflects boundary effects near the edge of the confining bed. When fitting the data to the Hantush type curves, more weight was given to the early data that were assumed to be more representative of the effects of vertical leakage from storage in the confining bed. The values at later times tend to plot above the Hantush curves; approaching a steady leakage from the overlying aquifer with decreased contribution from storage in the confining bed. The curve matching shown in figure 4 yields a match point with the values $H(u,\beta)=1$, $=0.1$, $s=6.5$ feet, and $t/r^2=1.25 \times 10^{-8}$ day per foot squared. This match point yields a solution for transmissivity of 12,700 feet squared per day and a storage coefficient of 6.4×10^{-5}.

The equation for a leaky aquifer with storage in the confining bed (Lohman, 1972, p. 32) can be solved for the product of the vertical hydraulic conductivity of the confining bed and the specific storage of the confining bed: $K'Ss'=16TS\beta^2/r^2$. A plot of β^2 versus r^2 was constructed using the values in figure 4, and the slope of a line through the points was found to be: $\beta^2/r^2 = 2.5 \times 10^{-9}$ per foot squared. The value of K'Ss' was, therefore, 3.2×10^{-8} per day.

Recovery (s) versus t/r^2 for four observation wells that are completed near the base of the shallow aquifer and are located near observation wells completed in the deep aquifer are shown in figure 5. Therefore, recovery in the confining bed (s') and recovery in the deep aquifer (s) were measured at the same locations. Data from these four wells were analyzed using the Neuman and Witherspoon ratio method. The method was applied to the minimum and maximum values of recovery and produced nearly identical results. As indicated in figure 5, the magnitude of the recovery at the base of the shallow aquifer was less than 0.25 foot. Results of the ratio method for one time period are summarized in table 2.

Table 2.—Results of Neuman and Witherspoon ratio method for calculating vertical diffusivity (K'/Ss') of the confining bed

[See p. 6 for explanation of location numbers; see p. 4 for explanation of other table headings.]

Location	T (ft^2/d)	S	r (ft)	t (min)	t_D	s'/s	t'_D	z (ft)	K'/Ss' (ft^2/d)
(C-15-5)15dad-2	12,700	6.4×10^{-5}	12,830	26,008	22	0.0028	0.065	400	576
26baa-2	12,700	6.4×10^{-5}	8,800	26,075	46	.0043	.075	540	1,208
27dcc-2	12,700	6.4×10^{-5}	14,600	25,991	17	.0045	.077	580	1,435
33dcb-2	12,700	6.4×10^{-5}	21,900	25,982	7	.014	.11	430	1,127
							Average (rounded)		1,100

The Hantush modified method and the Neuman and Witherspoon ratio method can both be used to solve for the vertical hydraulic conductivity of the confining bed when the specific storage (Ss') of the confining bed is known. To estimate specific storage, the average value of K'/Ss' from the ratio method (table 2) and the value of K'Ss' from the Hantush modified method were solved simultaneously, giving a value for specific storage of 5.4×10^{-6} per foot. The value of specific storage was then substituted into the two equations to obtain a solution for K' of 6×10^{-3} foot per day. Gamma-ray logs of wells in the area indicate that the average aggregate thickness of the most permeable sand and gravel layers in the deep artesian aquifer is approximately 200 feet. This indicates that the average horizontal hydraulic conductivity of the aquifer is about 60 feet per day, or about 10,000 times as great as the vertical hydraulic conductivity of the confining bed. The specific storage of the aquifer is likewise estimated to be 3×10^{-7} per foot. This value is somewhat small, though possible, indicating that the estimated thickness of the sand and gravel may be too large. The specific storage of the confining bed is about 18 times as large as the specific storage of the aquifer, indicating that significant amounts of water are contributed by the confining bed before steady leakage is established.

SUMMARY AND CONCLUSIONS

The unconsolidated deposits in the Lynndyl area consist of at least two artesian aquifers separated by a thick confining layer consisting of clay and silt, with some sand and gravel. The confining layer, which consists of relatively fine-grained sediments allows movement of water between the two artesian aquifers, and can release large quantities of water from storage. The transmissivity of the deep artesian aquifer was calculated to be 12,700 feet squared per day and the storage coefficient was 6.4×10^{-5}. Calculations of vertical hydraulic conductivity of the confining bed using the Hantush modified method and the ratio method together indicate a value of about 6×10^{-3} foot per day. This is about 10,000 times less than the estimated hydraulic conductivity of the deep artesian aquifer. The compressive specific storage of the confining bed was calculated to be 5.4×10^{-6} per foot, about 18 times greater than the compressive specific storage of the deep artesian aquifer.

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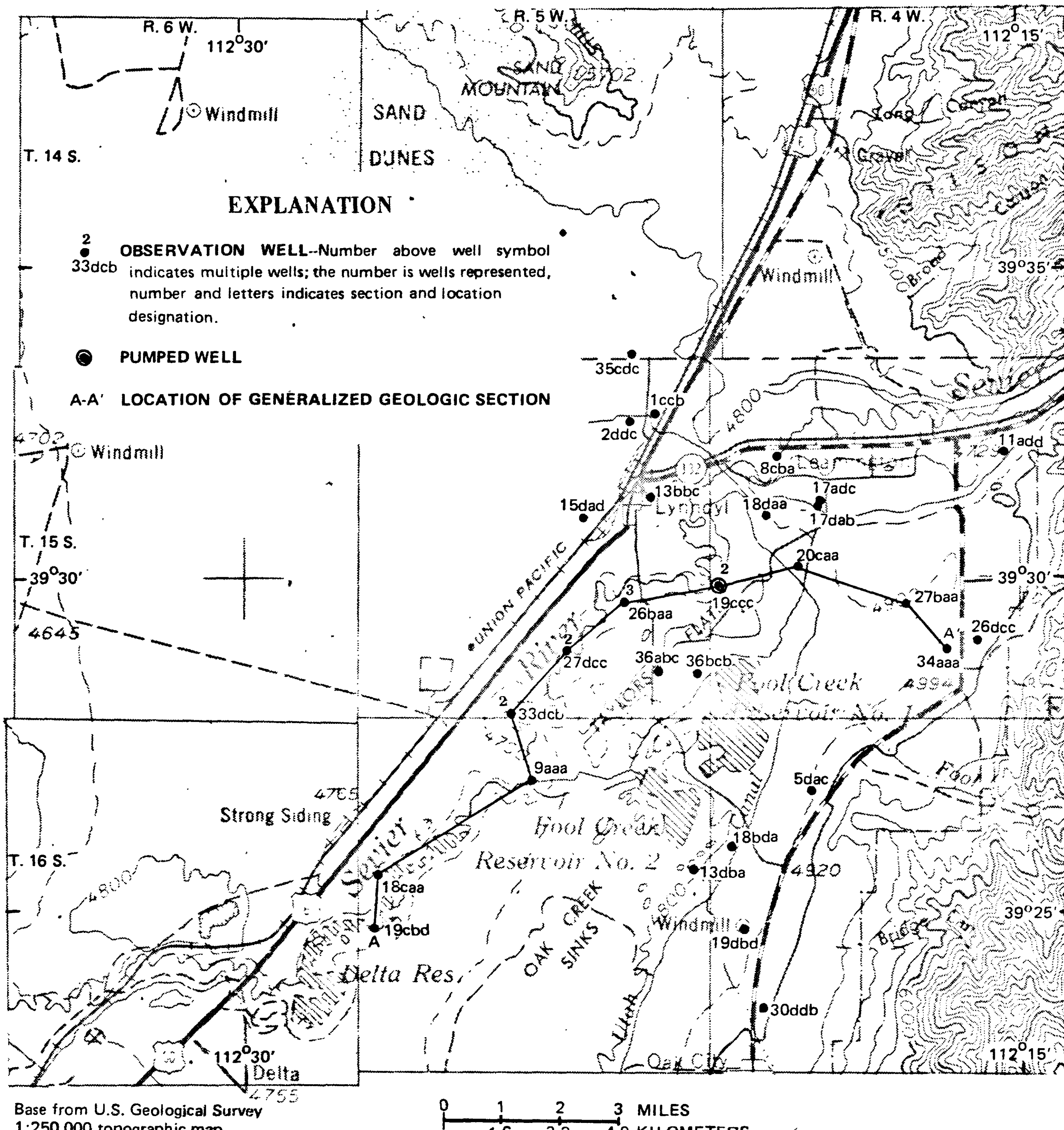

Figure 1.—Location of pumped well and observation wells monitored during test.

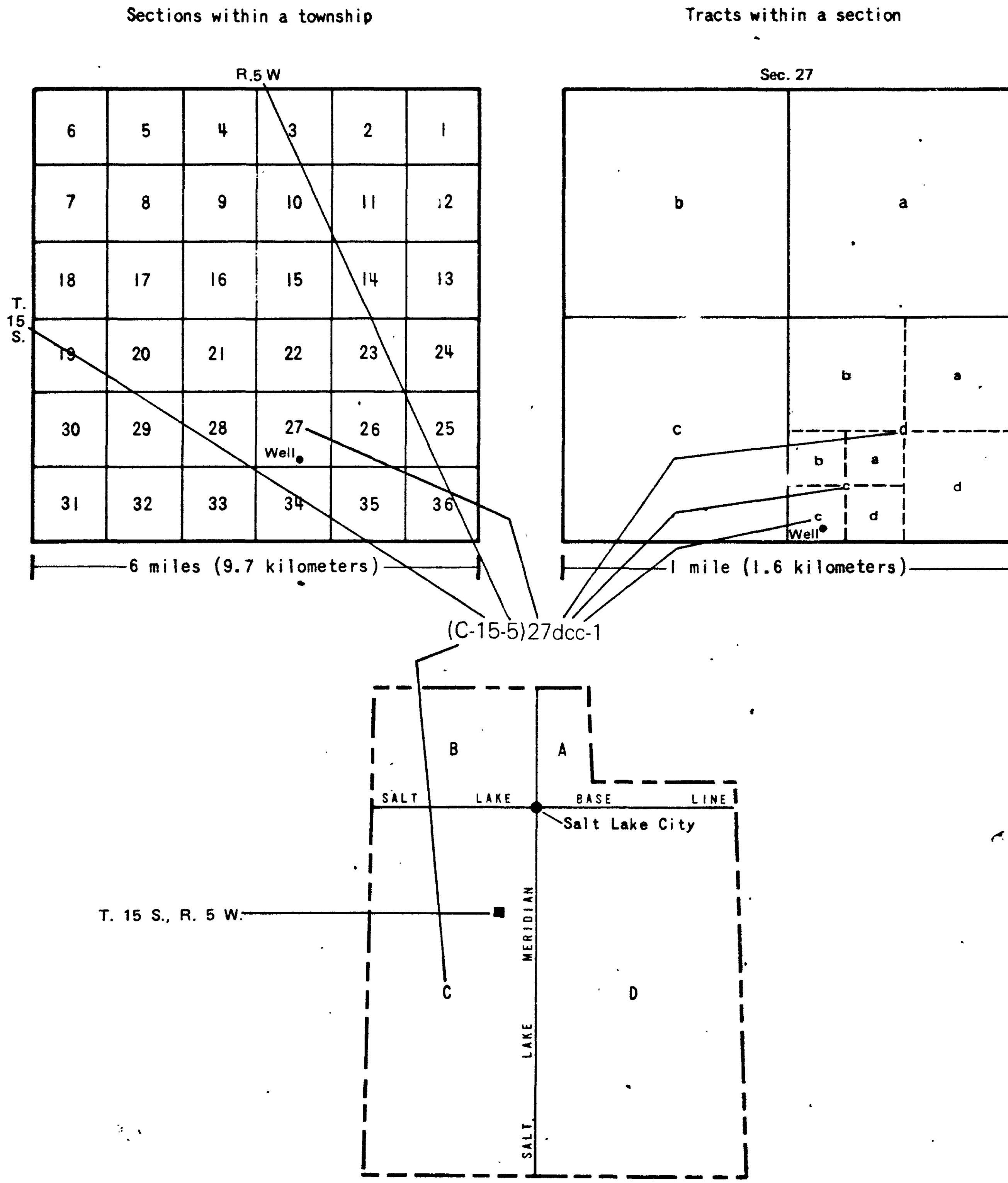

Figure 2.—Well-numbering system used in Utah.

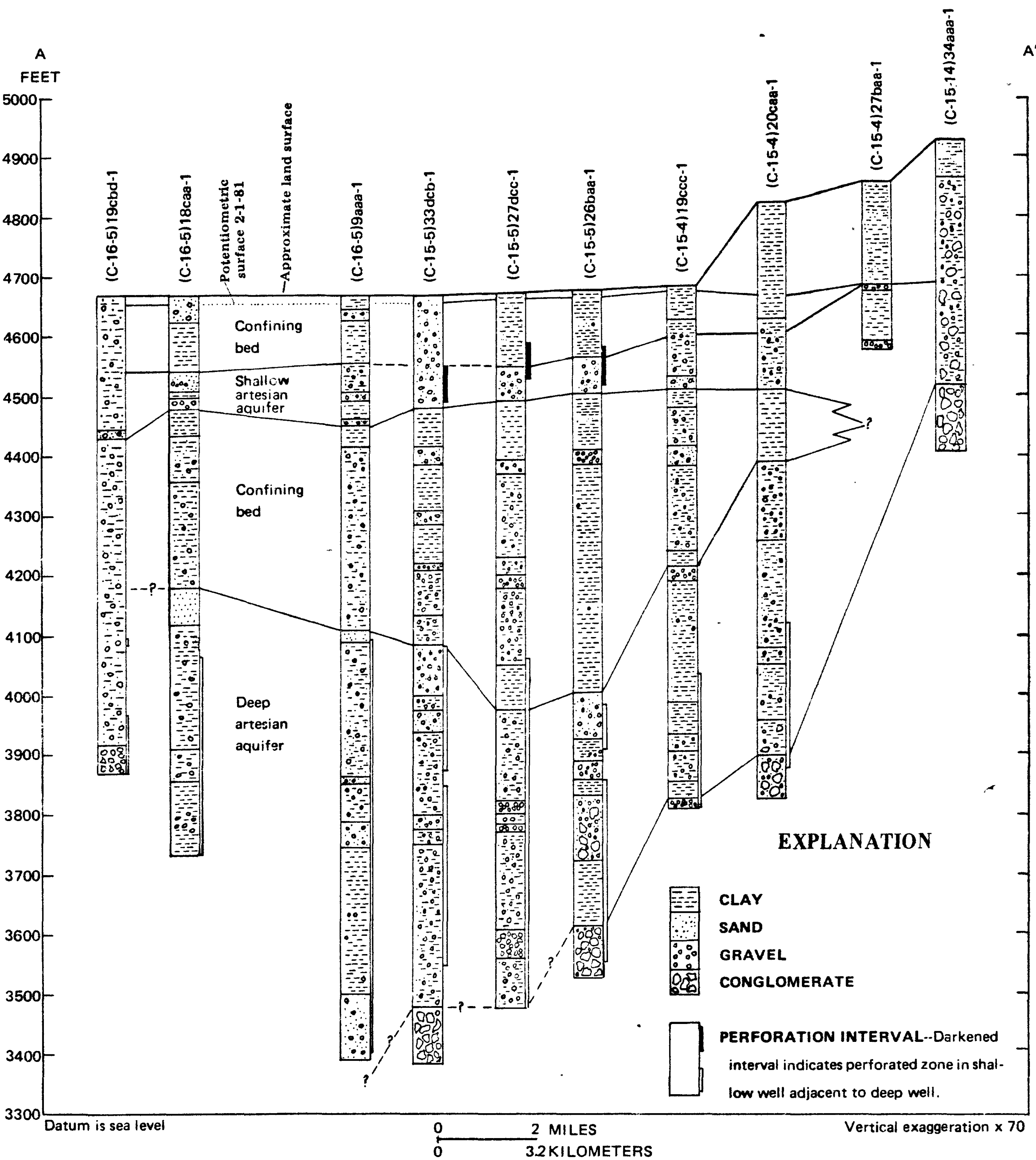

Figure 3.—Generalized geologic section near Lynndyl, Utah showing lithology and aquifer boundaries.

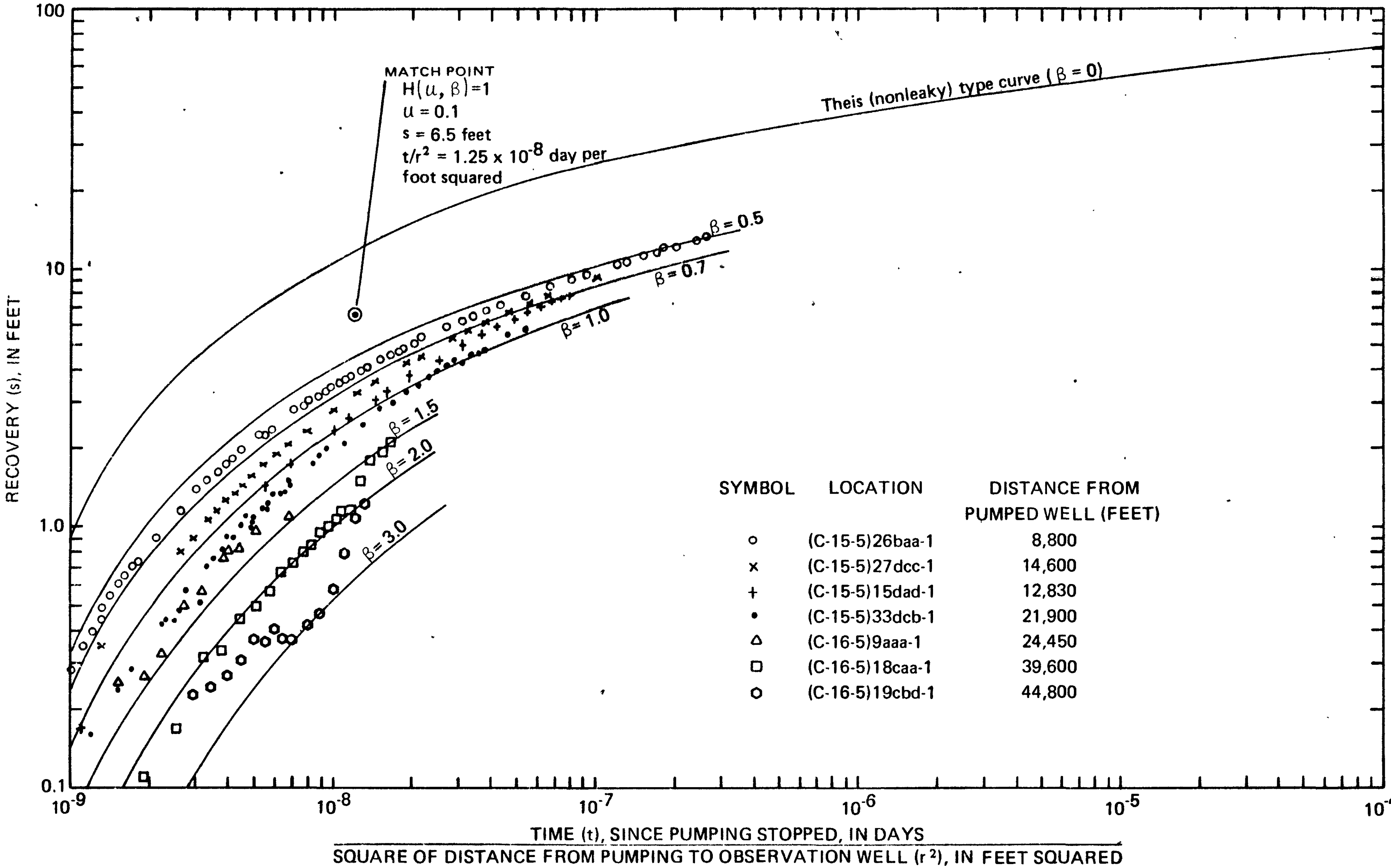

Figure 4.—Relationship of s versus t/r^2 for seven wells completed in the deep artesian aquifer.

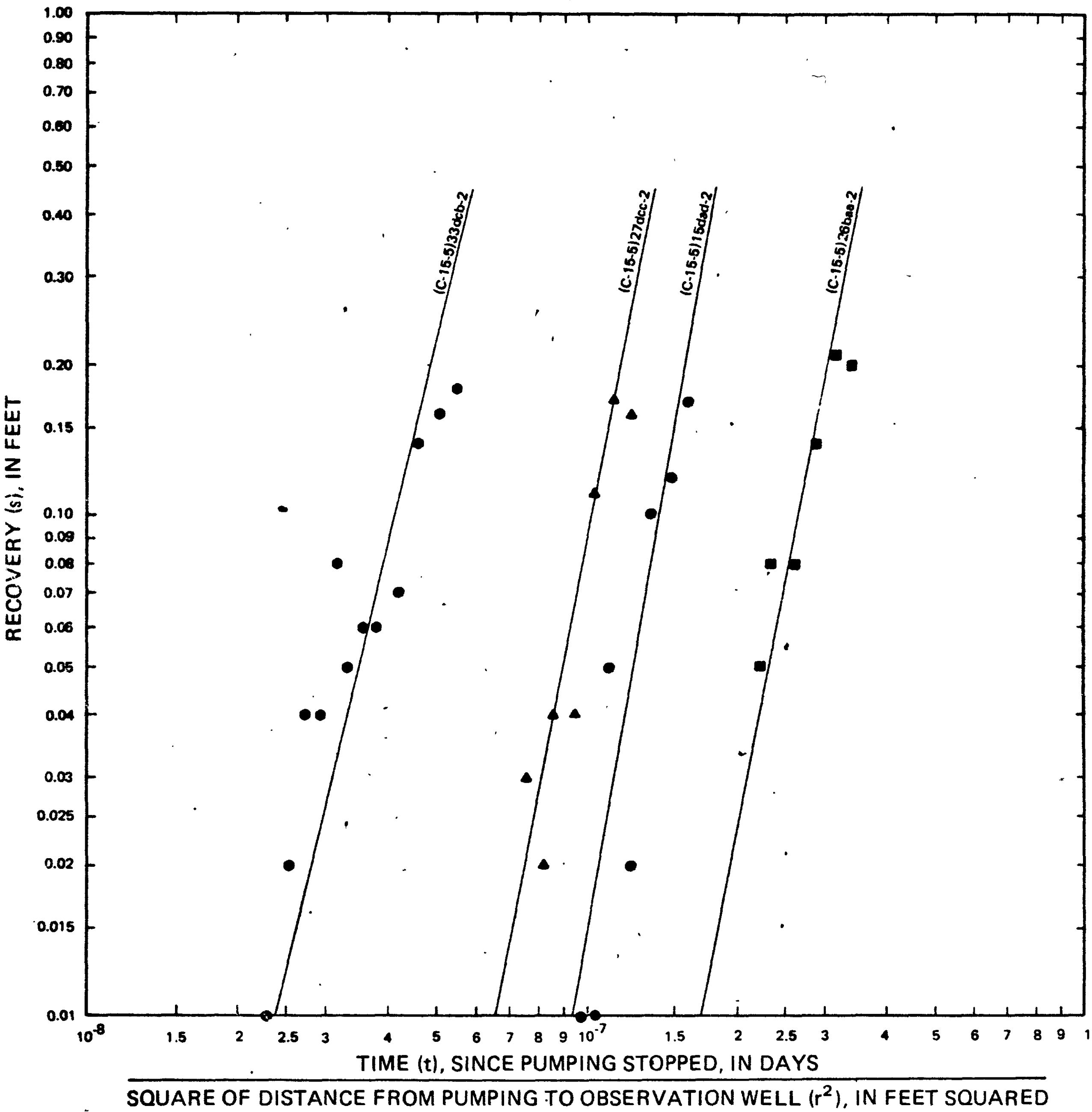

Figure 5.—Relationship of s versus t/r^2 in four observation wells completed near the base of the shallow artesian aquifer.