AQUIFER TESTS IN THE FLOOD-PLAIN ALLUVIUM AND SANTA FE GROUP AT THE RIO GRANDE NEAR CAÑUTILLO, EL PASO COUNTY, TEXAS

By Edward L. Nickerson

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CONTENTS

FIGURES

FIGURES - Concluded

TABLE

CONVERSION FACTORS

Figures for measurements in this report are given in inch-pound units only. The following table contains factors for converting to metric units:

Multiply inch-pound units	By	To obtain metric units
cubic foot per day (ft^3/day)	0.02832	cubic meter per day (m^3/day)
foot (ft)	0.3048	meter (m)
foot per day (ft/day)	0.3048	meter per day (m/day)
foot per mile (ft/mi)	0.3048	meter per mile (m/mi)
foot squared per day (ft^2/day)	0.09290	meter squared per day (m^2/day)
mile (mi)	1.609	kilometer (km)
acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)
gallon (gal)	3.785	liter (L)
gallon per minute (gal/min)	0.06309	liter per second (L/s)

Temperature in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) using the equation:

$$°F = 9/5\ (°C) + 32$$

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

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ABSTRACT

An aquifer system consisting of the Rio Grande flood-plain alluvium and Santa Fe Group underlying the southern Mesilla Valley in Doña Ana County, New Mexico, and El Paso County, Texas, has become an important source of water for municipal and agricultural uses. The Rio Grande is hydraulically connected to the shallow flood-plain alluvium. Determination of aquifer properties is essential in order to evaluate the potential for ground water to meet increasing water demand and the potential streamflow depletion of the Rio Grande caused by ground-water development. The aquifer system at the Cañutillo well field hydrologic section was divided into a shallow, upper intermediate, lower intermediate, and deep zone on the basis of geohydrologic characteristics. Aquifer properties of specific zones at the test site were determined from a series of multiple-well aquifer tests conducted from December 3, 1985, through January 20, 1986.

Water within the shallow zone generally occurs under unconfined conditions and within the upper intermediate, lower intermediate, and deep zones under leaky-confined conditions. The estimated hydraulic diffusivity of the shallow zone is 175,000 feet squared per day. Estimated aquifer properties of the upper intermediate zone from 97 to 200 feet below land surface are as follows: (1) transmissivity, 2,600 feet squared per day; (2) storage coefficient, 4.3×10^{-4}; (3) hydraulic conductivity, 26 feet per day; and (4) vertical hydraulic conductivity of the upper confining unit, 0.16 foot per day. Estimated aquifer properties of the deep zone are as follows: (1) transmissivity, less than or equal to 4,700 feet squared per day; (2) storage coefficient, less than or equal to 4.3×10^{-4}; (3) hydraulic conductivity, less than or equal to 11 feet per day; and (4) vertical hydraulic conductivity of the upper confining layer, less than 0.01 foot per day.

INTRODUCTION

The aquifer system underlying the southern Mesilla Valley in Doña Ana County, New Mexico, and El Paso County, Texas, has become an important source of water supply for municipal and agricultural uses. Ground-water withdrawals from the Rio Grande flood-plain alluvium and Santa Fe Group aquifer system have increased significantly since development began in 1945. Estimated ground-water withdrawals from 1945 through 1980 range from a minimum pumpage rate of about 1,000 acre-ft/yr (acre-feet per year) in 1945 to about 70,000 acre-ft/yr in 1978 (White, 1983, fig. 6). Initial ground-water development primarily was from shallow irrigation wells completed at depths of less than 200 ft (feet) deep. Ground-water withdrawals from most irrigation wells serve as a supplemental source of water for local irrigation demand. Withdrawals may vary both seasonally and annually depending upon available surface-water allotments from the Rio Grande.

In 1956, the City of El Paso Water Utilities began to develop deep production wells (completed at depths greater than 200 ft) at the Cañutillo well field along the Rio Grande near Cañutillo, Texas (fig. 1). By 1980, withdrawals from deep municipal wells by the City of El Paso and other local communities and industries were estimated by White (1983) to be about 27,000 acre-ft/yr.

Purpose and Scope

The purpose of this report is to identify stream-aquifer relations, present aquifer-test results, and evaluate aquifer properties in the lower Mesilla Valley at the Cañutillo well field. Aquifer properties evaluated are transmissivity, storage coefficient, and hydraulic conductivity with emphasis on vertical hydraulic conductivity of confining units. Determination of aquifer properties is essential to evaluate potential ground-water supplies for increasing water demand and potential streamflow depletion of the Rio Grande due to ground-water development.

Method of Investigation

A line of observation-well groups across the Cañutillo well field (hydrologic section A-A'), constructed in 1985 to monitor river stage and ground-water levels at the Rio Grande, is within the city of El Paso's Cañutillo well field approximately 3 miles north of Cañutillo, Texas (fig. 1). The section consists of a river-stage station on the Rio Grande and four observation-well groups aligned perpendicular to the Rio Grande (fig. 2). In December 1985 and January 1986, the U.S. Geological Survey conducted multiple-well aquifer tests of an aquifer system consisting of the flood-plain alluvium and the underlying Santa Fe Group.

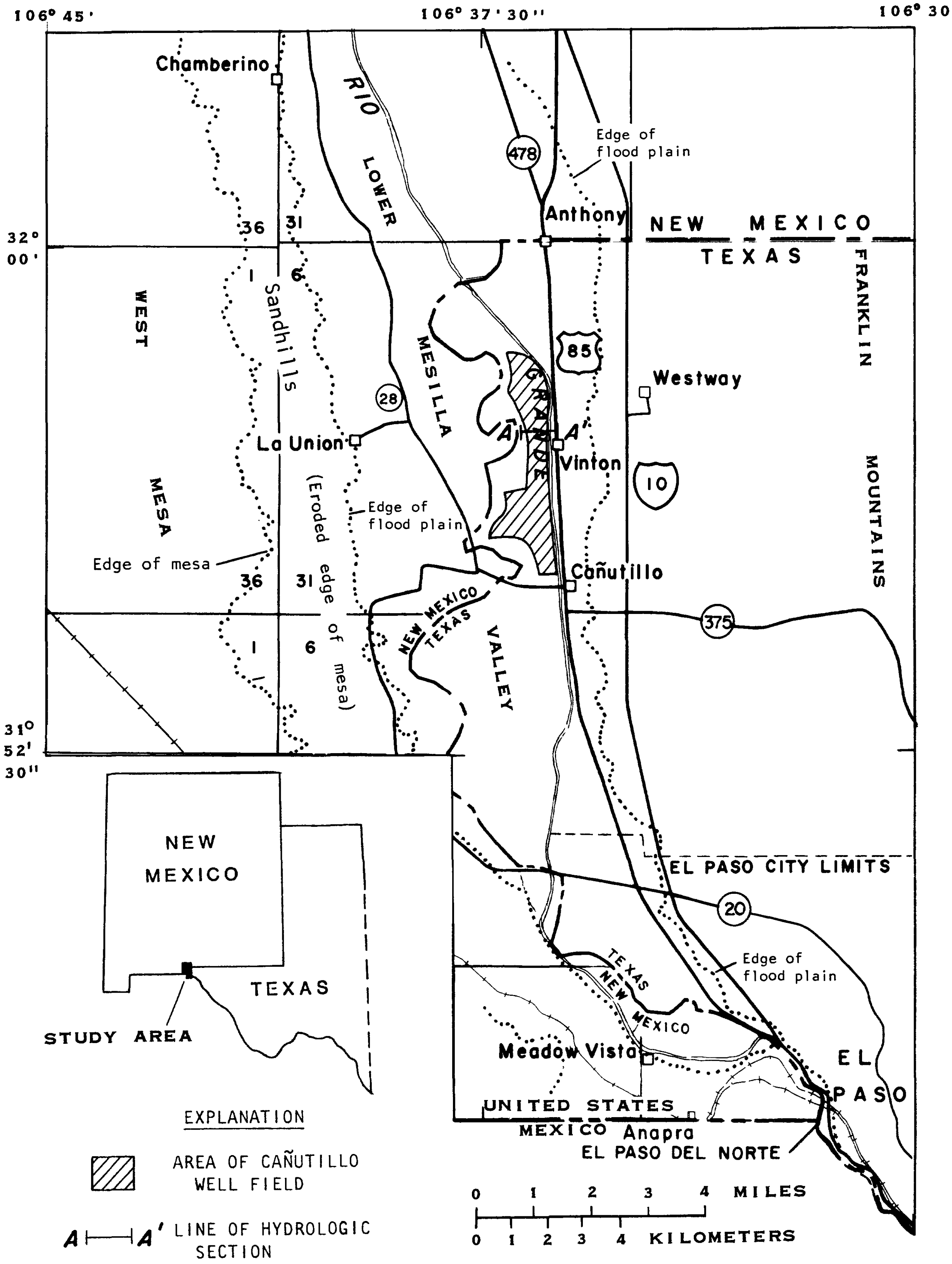


Figure 1.--Location of the Cañutillo well field (modified from Gates and others, 1984, fig. 2).

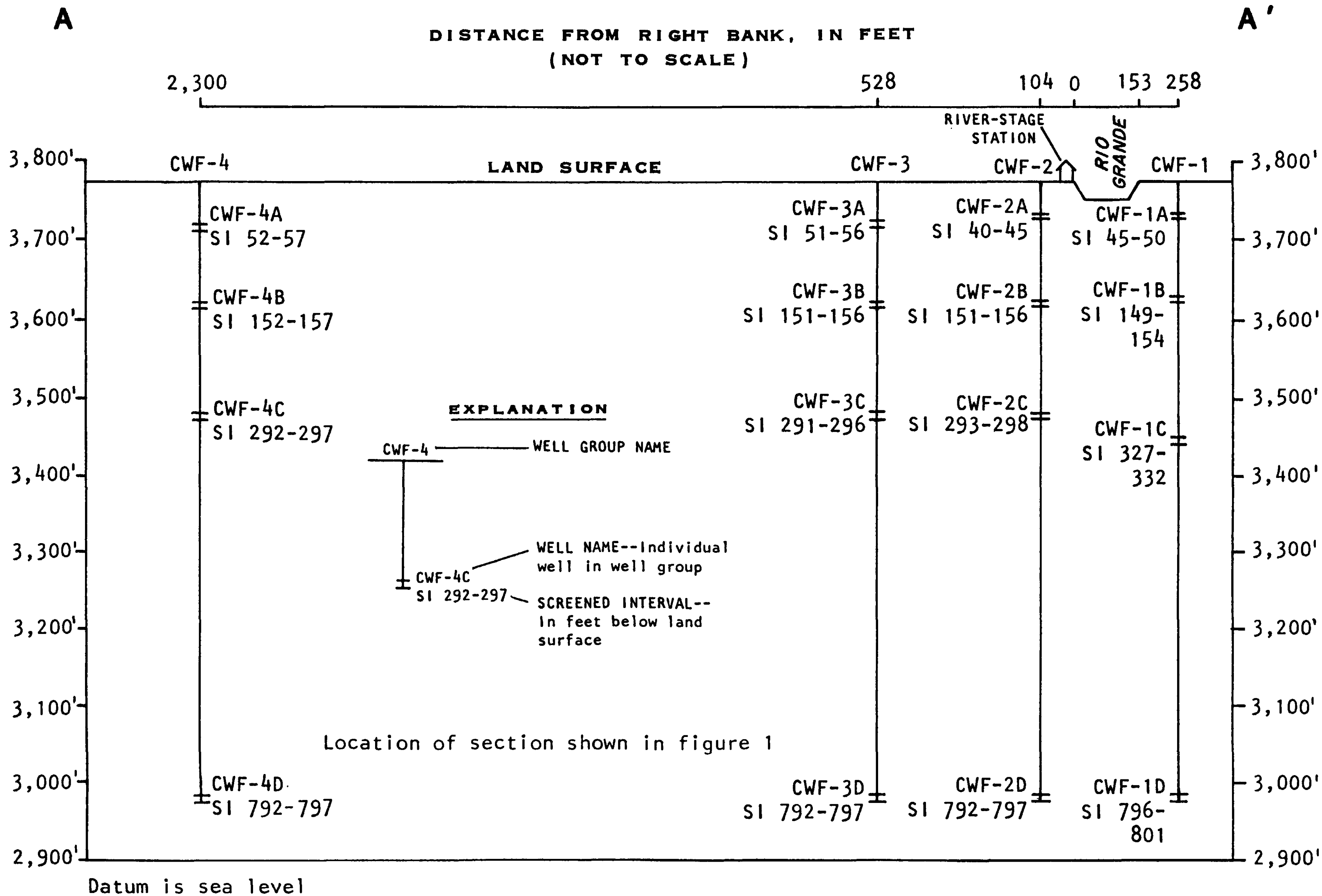


Figure 2.--Cañutillo well field hydrologic section (modified from Nickerson, 1986, fig. 27).

Well-Numbering System

The well-numbering system used in this report is the same as that used by the Texas Department of Water Resources (fig. 3). Under this system, which is based on latitude and longitude, each 1-degree quadrangle in the State is given a two-digit number from 01 through 89. These are the first two digits of the well number. El Paso County is in parts of quadrangles 48 and 49. Each 1-degree quadrangle is subdivided into $7\frac{1}{2}$-minute quadrangles that are each given a two-digit number from 01 to 64. These are the third and fourth digits of the well number. Each $7\frac{1}{2}$-minute quadrangle is further subdivided into $2\frac{1}{2}$-minute quadrangles that are each given a single digit number ranging from 1 through 9. This is the fifth digit of the well number. Finally, each well within a $2\frac{1}{2}$-minute quadrangle is given a two-digit number in the order in which the well was inventoried, starting with 01. These are the last two digits of the well number. In addition to the seven-digit well number, a two-letter prefix identifies the county; the prefix for El Paso County is JL.

Acknowledgments

This study was conducted in cooperation with the New Mexico State Engineer Office, City of El Paso, U.S. Section--International Boundary and Water Commission, U.S. Bureau of Reclamation, and City of Las Cruces. The author expresses appreciation to Thomas Cliett, El Paso Water Utilities Department, for special cooperation and assistance.

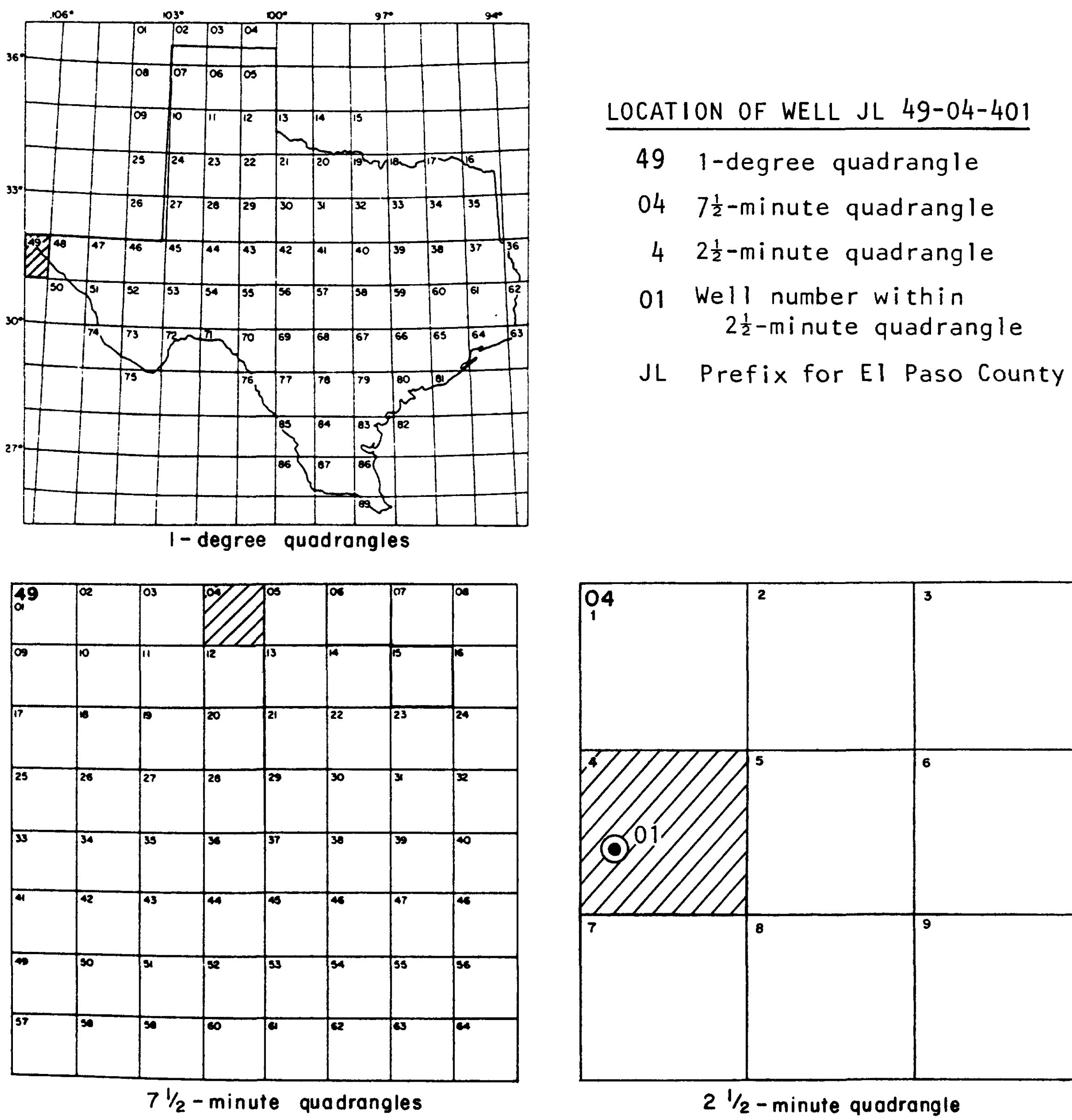


Figure 3.--System of numbering wells in Texas.

GEOHYDROLOGY

The southern Mesilla Valley ground-water system primarily consists of a basin-fill aquifer composed of unconsolidated alluvial deposits. The aquifer system may be divided into two main geologic units: the Quaternary-Tertiary Santa Fe Group and the Quaternary Rio Grande flood-plain alluvium (King and others, 1971). The Santa Fe Group is an intermontane basin-fill unit composed of alluvial deposits of Miocene to middle Pleistocene age. These alluvial deposits of clay, silt, sand, and gravel may reach depths of more than 1,000 ft (Leggat and others, 1962, p. 10). The Rio Grande flood-plain alluvium overlies the Santa Fe Group and consists of clay, silt, sand, and gravel that generally are less than 125 ft thick and were deposited by the Rio Grande from late Pleistocene to Holocene time (Wilson and others, 1981, p. 27).

It is difficult to distinguish between the Rio Grande flood-plain alluvium and the upper part of the Santa Fe Group because of similar lithology. Previous investigations (Leggat and others, 1962; Alvarez and Buckner, 1980; Gates and others, 1984) generally have divided the Rio Grande flood-plain alluvium and Santa Fe Group aquifer system into three zones. The shallow, intermediate, and deep zones were distinguished by the following criteria: (1) differences in lithology, (2) characteristic responses of borehole-geophysical logs, (3) chemical quality of the water, and (4) differences in water levels under the stress of pumping. The shallow zone primarily consists of gravel and coarse sand. The intermediate zone is characterized by alternating sand and silty clay lenses with finer sand and less gravel than the shallow zone. The deep zone consists of a relatively uniform fine to medium sand with some silt and clay, which extends down to the top of a thick limestone conglomerate and clay marking the base of the aquifer system.

The aquifer system at the test site is divided into a shallow, upper intermediate, lower intermediate, and deep zone on the basis of borehole-geophysical logs and lithologic samples collected at the Cañutillo well field hydrologic section (Nickerson, 1986). Division of the aquifer system at the test site is similar to previous investigations in the southern Mesilla Valley. However, the shallow zone is thinner, and the intermediate zone is subdivided into a clayey upper intermediate zone and a sandy lower intermediate zone. Specific depth intervals and lithologic descriptions of aquifer zones are limited to the test site.

Shallow Zone

The shallow zone is approximately 80 ft thick and primarily consists of poorly sorted gravel and coarse- to medium-grained sand with thin, interbedded, discontinuous clay lenses. The Rio Grande flood-plain alluvium probably extends to the base of the shallow zone. The Rio Grande partially penetrates the shallow zone, to which it is hydraulically connected (Alvarez and Buckner, 1980, p. 5).

Upper Intermediate Zone

The top of the upper part of the intermediate zone is about 80 ft below land surface; the thickness ranges from approximately 130 ft at well group CWF-1 to 160 ft at well group CWF-4. The upper part of the intermediate zone consists of alternating layers of fine- to coarse-grained sand, silty clay, and some gravel. Sand beds in the intermediate zone are predominately medium to fine grained and have numerous silty clay lenses. Borehole-geophysical logs indicate that individual clay lenses are not continuous at the test site.

Lower Intermediate Zone

The top of the lower part of the intermediate zone is about 250 ft below land surface; the thickness ranges from approximately 190 ft at well group CWF-1 to 270 ft at well group CWF-4. Sand beds in the lower part of the intermediate zone are predominately medium to fine grained with few silty clay lenses. Locally, the lower intermediate zone is separated from the deep zone by a thick clay layer. This clay layer is as much as 60 ft thick at well group CWF-3 and thins to about 20 ft to the west at well group CWF-4.

Deep Zone

The top of the deep zone is about 460 to 500 ft below land surface; the thickness ranges from approximately 430 feet at well group CWF-1 to 520 ft at well group CWF-4. The deep zone consists of a relatively uniform fine sand and some silt and clay. The limestone conglomerate (Leggat and others, 1962) underlying the deep zone is considered to be the base of the aquifer system and is assumed to be relatively impermeable. The top of the limestone conglomerate in borehole CWF-1D is at a depth of about 890 ft. The top of the conglomerate in test holes west of CWF-1D dips about 4 degrees to the west or about 370 ft/mi (feet per mile).

AQUIFER TESTS

Aquifer tests of the shallow, upper intermediate, and deep zones were conducted at the Cañutillo well field hydrologic section from December 3, 1985, through January 20, 1986. Production wells at the Cañutillo well field and controlled changes in river stage on the Rio Grande were used to stress specific zones within the aquifer system. Aquifer response to pumpage and changes in river stage were monitored in selected observation wells within the shallow, upper intermediate, and deep zones. The location of control wells (pumped wells) and observation-well groups at the aquifer-test site is shown in figure 4. Aquifer zones and aquifer-test wells at the Cañutillo well field hydrologic section are shown in figure 5. Records of selected aquifer-test wells are listed in table 1.

Shallow Zone

An abrupt change in Rio Grande stage (surface-water level) was used to conduct an aquifer test of the shallow zone for a 4-day period from January 16 through 20, 1986. Aquifer conditions were constant prior to the stage change. No pumpage from nearby wells completed in the shallow zone occurred prior to or during the test period. Pretest trends showed a constant river stage and steady water levels in observation wells completed in the shallow flood-plain alluvium.

The Rio Grande partially penetrates the shallow flood-plain alluvium and flows in a north-south direction perpendicular to the Cañutillo well field hydrologic section. Rio Grande stage is recorded at a river-stage station on the right bank at the Cañutillo well field hydrologic section. An abrupt rise in river stage of about 1.6 ft caused by a scheduled upstream water release was recorded on January 16, 1986, at approximately 0400 hours (24-hour time). The elevated stage was maintained for several days. Some fluctuation in stage of about 0.4 ft occurred after the initial rise. Water levels were monitored in observation wells CWF-1A, CWF-2A, and CWF-3A completed within the shallow zone at distances of 105, 104, and 528 ft, respectively, from the river (table 1).

The abrupt change in Rio Grande stage was analyzed to evaluate the stream-aquifer relation and determine the hydraulic diffusivity of the shallow zone. Rio Grande stage and water levels in observation wells CWF-1A, CWF-2A, and CWF-3A are shown in figure 6. The rapid response of ground-water levels to the abrupt rise in river stage indicates significant hydraulic connection between the river and the shallow zone.

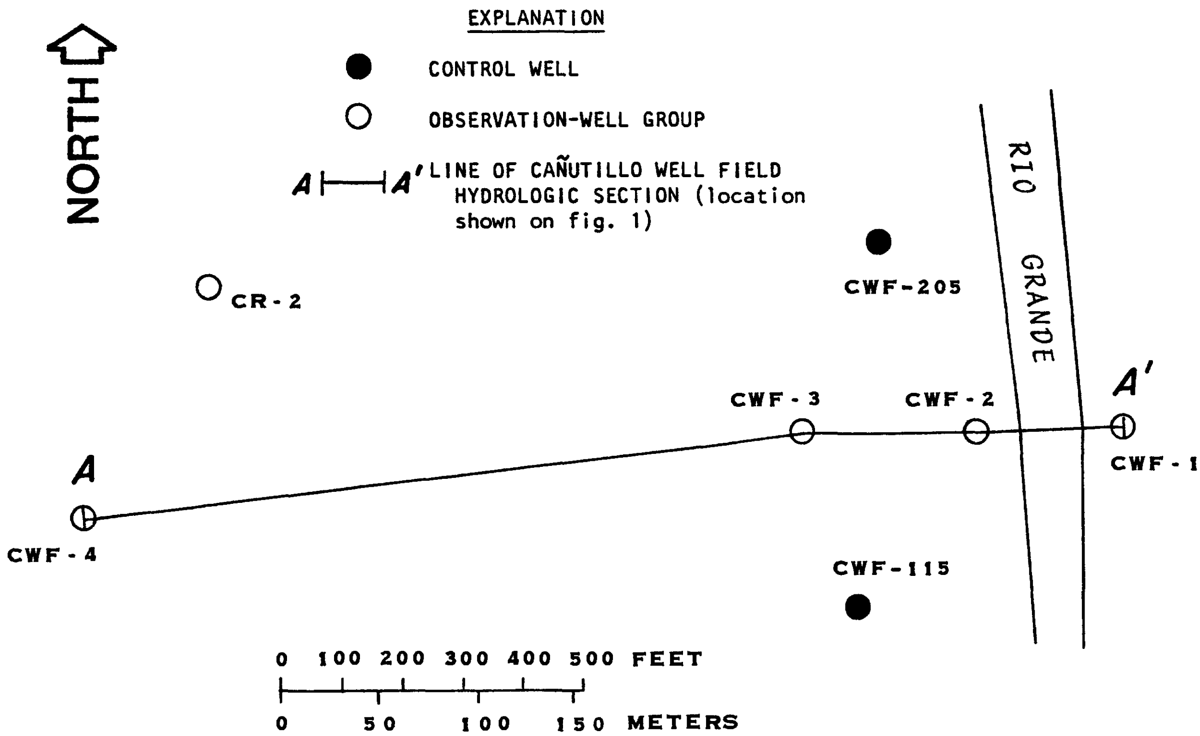
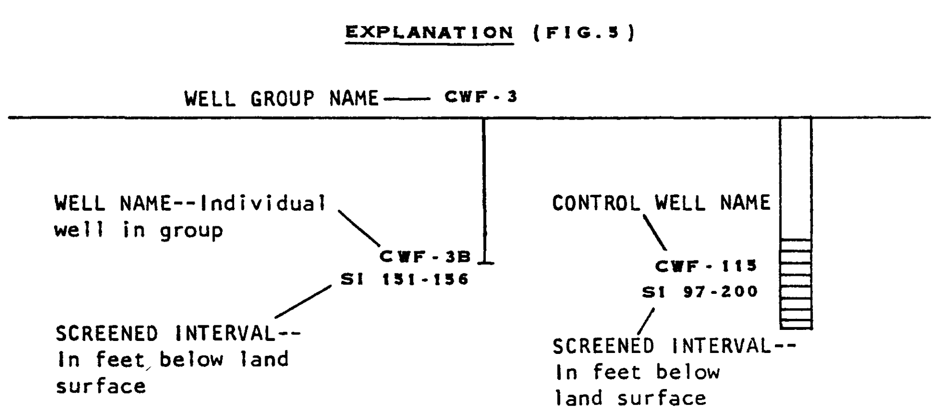


Figure 4.--Location of control wells and observation-well groups at the aquifer-test site.



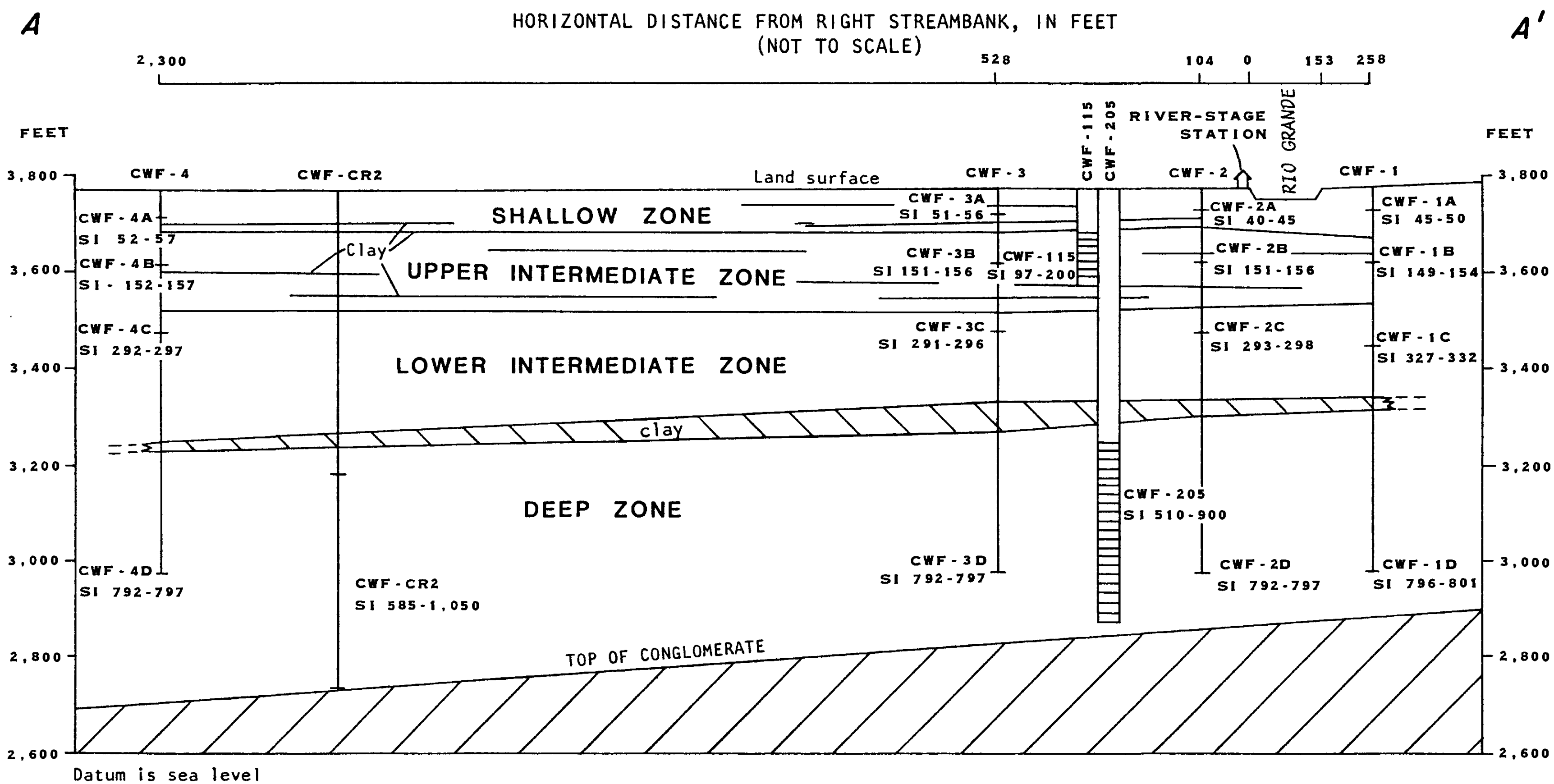


Figure 5.--Aquifer zones and aquifer-test wells at the Cañutillo well field hydrologic section.

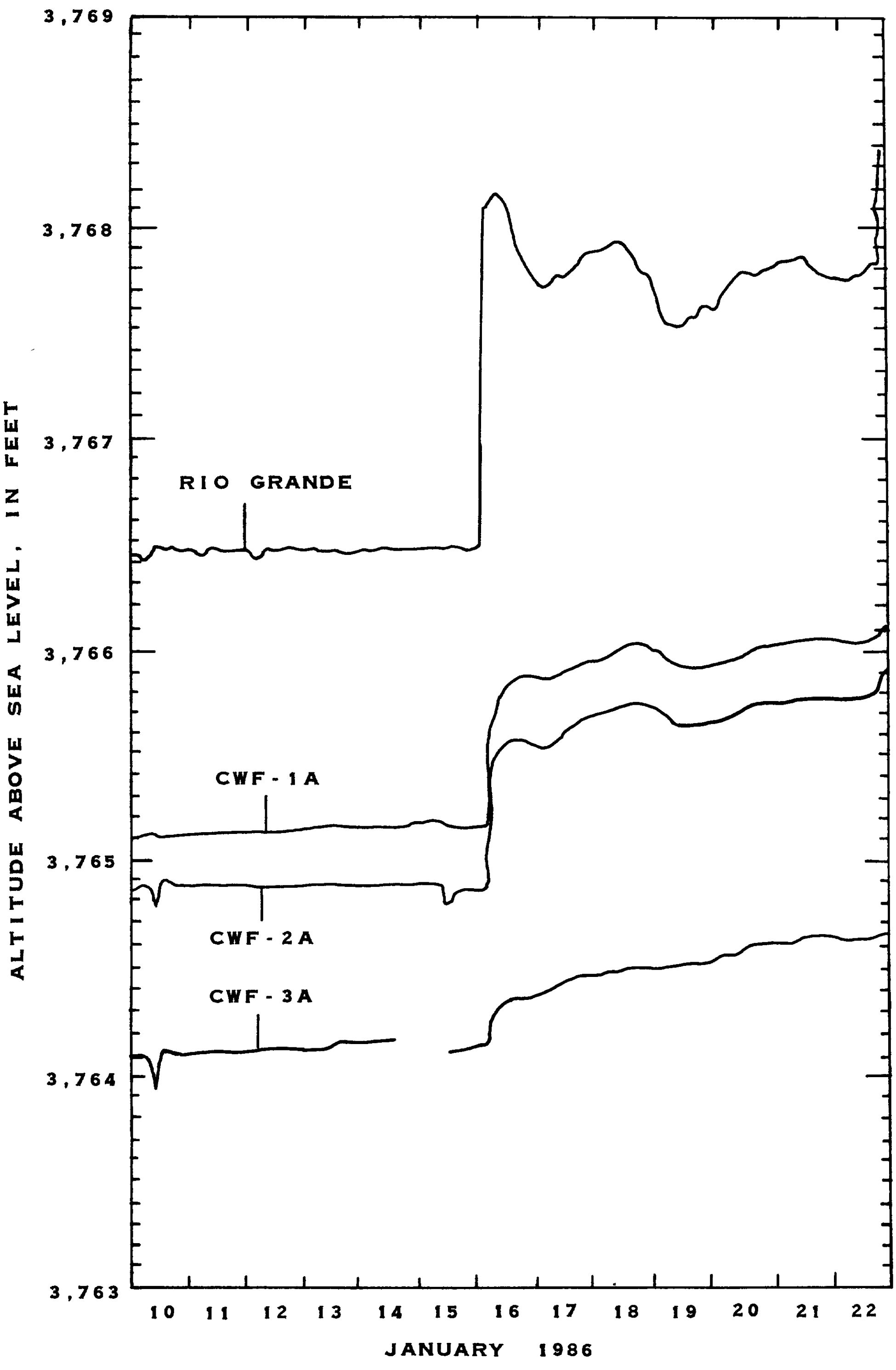


Figure 6.--Rio Grande stage and water levels in observation wells CWF-1A, CWF-2A, and CWF-3A, January 10-22, 1986.

Table 1.—Records of selected aquifer-test wells

[Altitude is in feet above sea level]

Aquifer test	Well location number	Control well name	Observation-well name	Altitude of land surface (feet)	Screened interval (feet below land surface)	Distance from control point to observation well (feet)
Shallow	—	Rio Grande[1]	—	—	—	—
zone	JL 49-04-478	—	CWF-1A	3,776.7	45-50	[2]105
	JL 49-04-474	—	CWF-2A	3,773.6	40-45	[3]104
	JL 49-04-470	—	CWF-3A	3,773.8	51-56	[3]528
Upper	JL 49-04-423	CWF-115	—	3,775.9	97-200	—
intermediate	JL 49-04-479	—	CWF-1B	3,776.7	149-154	780
zone	JL 49-04-475	—	CWF-2B	3,773.5	151-156	503
	JL 49-04-470	—	CWF-3A	3,773.8	51-56	429
	JL 49-04-471	—	CWF-3B	3,773.8	151-156	429
	JL 49-04-467	—	CWF-4B	3,770.6	152-157	1,912
Deep	JL 49-04-401	CWF-205	—	3,774.0	510-900	—
zone	JL 49-04-481	—	CWF-1D	3,776.7	796-801	737
	JL 49-04-477	—	CWF-2D	3,773.5	792-797	516
	JL 49-04-473	—	CWF-3D	3,773.8	792-797	491
	JL 49-04-469	—	CWF-4D	3,770.6	792-797	2,080
	JL 49-04-419	—	CWF-CR2	3,772.5	585-1,050	1,659

[1] For the purpose of aquifer-test analysis the Rio Grande is considered the control point for the shallow zone.

[2] Control point is left bank of Rio Grande.

[3] Control point is right bank of Rio Grande.

Hydraulic diffusivity of the shallow zone was determined by an aquifer test using the channel method with constant drawdown (Lohman, 1979, p. 41). This method, which requires a sudden change in river stage by a constant amount, is based upon the following assumptions: (1) The stream is along an infinite straight line and fully penetrates an artesian aquifer; (2) the aquifer is semi-infinite in extent; (3) the head in the stream is abruptly changed from zero to some value s_o at time t = o; (4) the direction of ground-water flow is perpendicular to the direction of the stream; and (5) the drawdown in the aquifer is derived from changes in storage by drainage after time t = o (Stallman, 1962, p. 126).

The measured aquifer response to change in river stage (fig. 6) is potentially affected by partial penetration of the river, armoring of the streambed by fine-grained sediments, and vertical anisotropy between the streambed and the screened interval in the observation wells. Partial penetration of the river affects flow lines in the aquifer and produces vertical components of ground-water flow near the stream. To minimize these potential effects, the abrupt change in head in observation well CWF-2A, located 104 ft from the river, was substituted for river stage. The water level in observation well CWF-2A and the abrupt change in head (s_o) during the aquifer test are shown in figure 7.

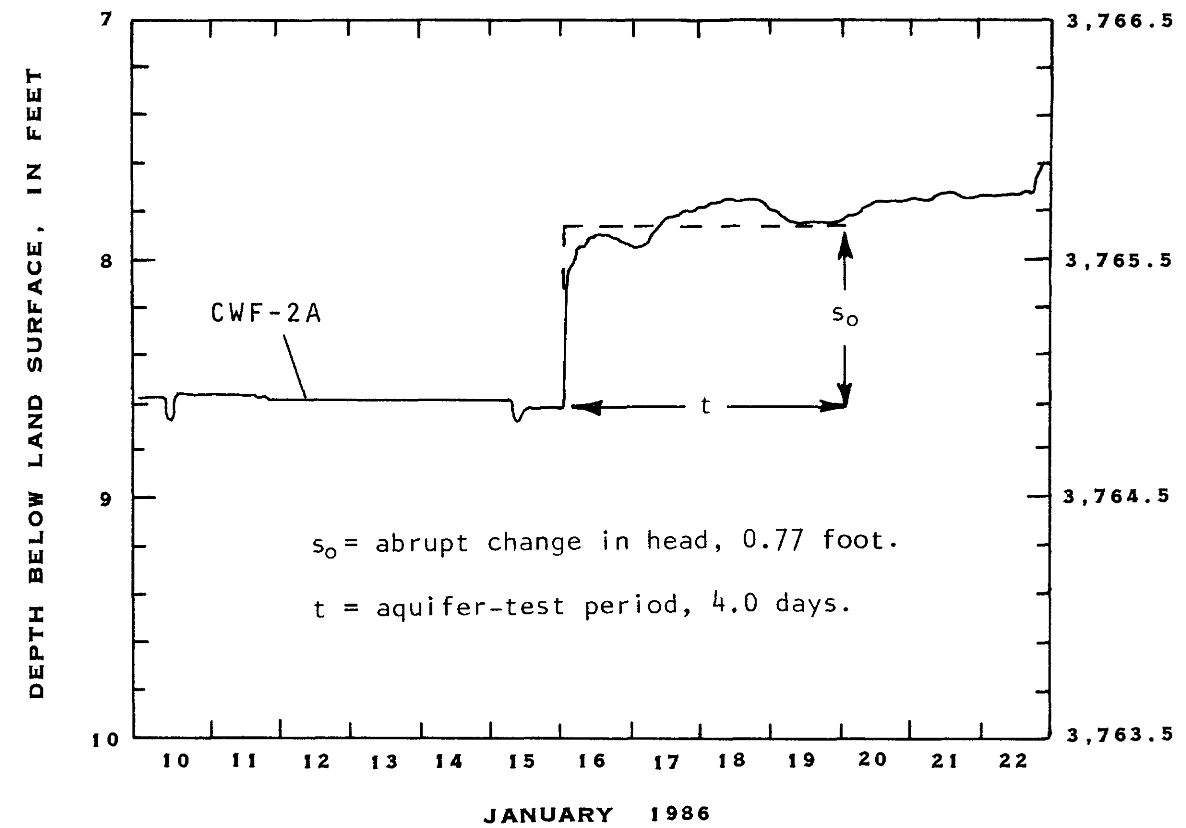


Figure 7.--Water level in observation well CWF-2A and the abrupt change in head (s_o) during the aquifer-test period (t).

The logarithmic plot of water-level drawdown in observation well CWF-3A divided by the abrupt change in head in observation well CWF-2A (s/s_o) during an aquifer test of the shallow zone is shown in figure 8. Negative values for drawdown in observation well CWF-3A (s) and the abrupt change in head in observation well CWF-2A (s_o) represent a rise in water levels. The type-curve function of d(u)h versus u^2 for channel method with constant drawdown was matched to late-time drawdown in CWF-3A (fig. 8). Drawdown in CWF-3A at comparatively large values of time and distance provides the most reliable basis for analysis (Stallman, 1962, p. 129). Determination of the exact reference time for the stage change is difficult and may affect accuracy of early-time drawdown ratios.

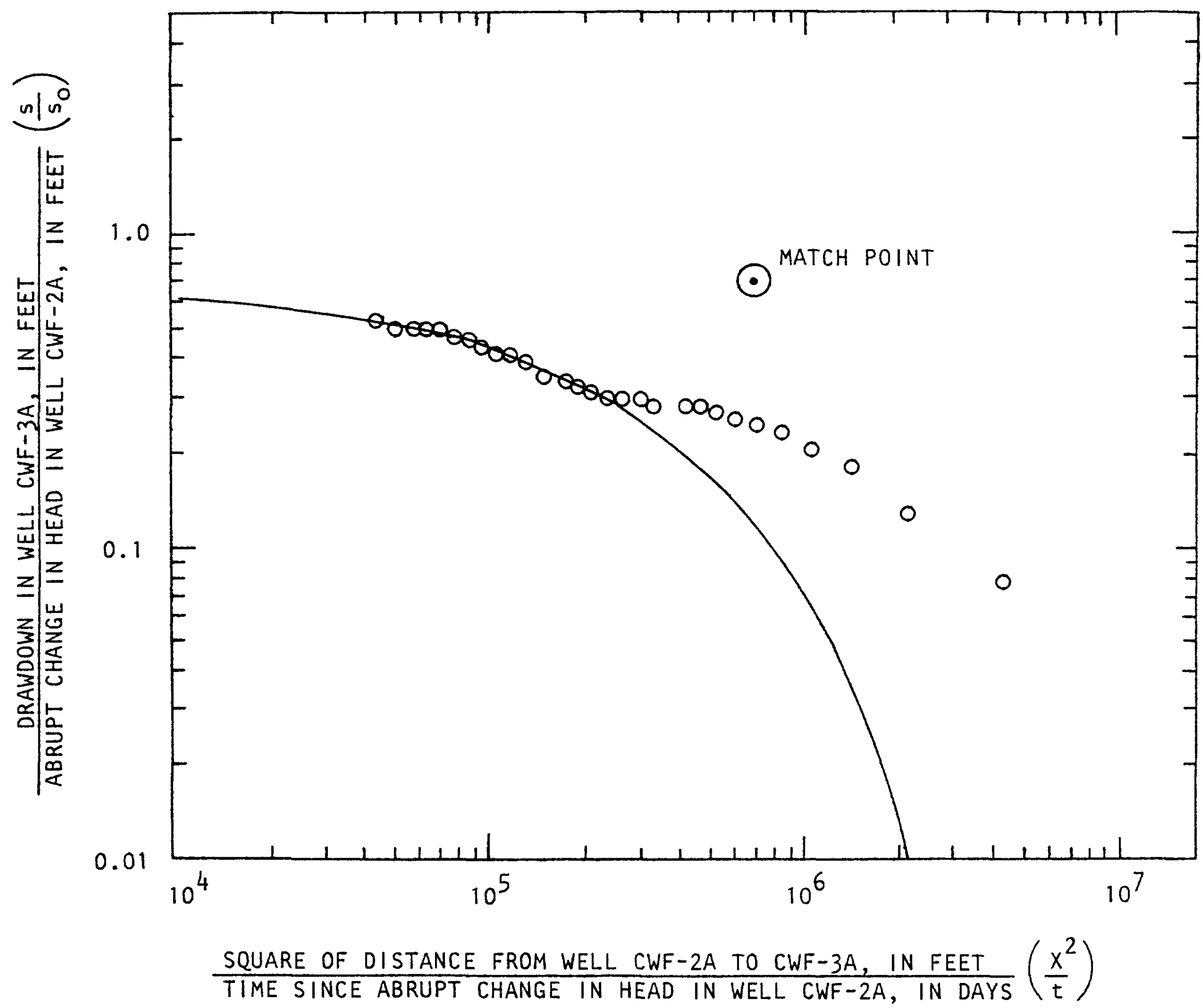


Figure 8.--Logarithmic plot of water-level drawdown in observation well CWF-3A divided by the abrupt change in head in observation well CWF-2A (s/s_o) during an aquifer test of the shallow zone, January 16-20, 1986.

The estimated hydraulic diffusivity (T/S) of the shallow zone is calculated using the following equation (Lohman, 1979, p. 40):

$$u^2 = \frac{x^2 S}{4Tt} \qquad (1)$$

Solving for T/S, we obtain

$$T/S = \frac{x^2/t}{4u^2} = \frac{7.0 \times 10^5}{4 \times 1} = 175{,}000 \text{ ft}^2\text{/day} \qquad (2)$$

where T/S = hydraulic diffusivity, in ft^2/day (feet squared per day);

x = distance from observation well CWF-2A to observation well CWF-3A, in ft (424);

t = time at match point, in days; and

u^2 = function from type curve at match point = 1.

The estimated hydraulic diffusivity of 175,000 ft^2/day is considered a tentative estimate and should be used with caution. Some fluctuation in head after the initial rise in observation well CWF-2A did occur. The abrupt change in head (s_o) of 0.77 ft is considered minimal and represents the mean value during the period of analysis. The effects of delayed yield are uncertain and may affect aquifer-test results.

Borehole-geophysical logs and lithologic samples show the shallow zone to consist primarily of gravel and coarse sand with some clay. Large hydraulic-diffusivity values are typical of shallow, coarse-grained alluvium. The estimates of specific yield from previous studies range from 0.10 (Leggat and others, 1962, p. 34) to 0.25 (Conover, 1954, p. 103). However, thin clay lenses in the shallow zone may cause leaky-confined conditions at depth. Vertical anisotropy of the aquifer may result in an apparent storage coefficient much smaller than the estimated specific yield.

Upper Intermediate Zone

An aquifer test of the upper part of the intermediate zone was conducted for an 8-day period from December 3 to 11, 1985. Water levels were relatively steady prior to the test period. Pumpage from nearby wells completed in the stressed zone was discontinued 17 days prior to the aquifer test. Pretest water-level trends were steady, with a slight decline in static water levels recorded in all observation wells. Some pumpage did occur below the stressed zone within the lower intermediate zone. Barometric pressure was monitored prior to and during the aquifer test. No significant water-level change due to fluctuation in barometric pressure was observed.

Control well CWF-115 is completed within the upper intermediate zone. The screened interval is from 97 to 200 ft below land surface (fig. 5). The well annulus is sealed with cement grout from land surface to a depth of 77 ft; a gravel pack extends from 77 to 200 ft below land surface. The pump intake is set at about 160 ft below land surface. The control well was pumped for an 8-day period, starting on December 3, 1985, at 1200 hours. Maximum drawdown was 116 ft in the control well, the static water level was 12.76 ft below land surface, and the pumping water level was 129 ft below land surface. The discharge rate was relatively constant at an average discharge of 436 gal/min (gallons per minute). Well discharge from the electric turbine pump was monitored with a flowmeter. Discharge water was piped away from the test site to the Cañutillo well field pumping station.

Water-level drawdown within the stressed zone was measured in observation wells CWF-1B, CWF-2B, CWF-3B, and CWF-4B at distances of 780, 503, 429, and 1,912 ft, respectively, from control well CWF-115. Drawdown also was measured in observation well CWF-3A completed above the stressed zone (shallow zone) at a distance of 429 ft from the control well (table 1). Measured drawdown was adjusted for the estimated change in static water level on the basis of the pretest water-level trend. A multiple-well plot of water-level drawdown in observation wells during the aquifer test of the upper intermediate zone is shown in figure 9.

A flowmeter survey was conducted in control well CWF-115 during a short-term pump test on March 2, 1987. Flowmeter spin rates indicated water was cascading from the top of the well screen at 97 ft below land surface to the pumping water level at about 124 ft below land surface (K.E. Stevens, U.S. Geological Survey, oral commun., 1987). Some dewatering of the stressed zone during the aquifer test may have occurred at the control well but did not extend out to the observation wells.

Aquifer properties of the upper intermediate zone were evaluated for a confined aquifer receiving leakage across confining beds. During the aquifer test, the stressed zone received water from leakage through clay lenses above the stressed interval. Water-level drawdown in observation well CWF-3A (fig. 9), completed above the stressed interval, indicated leakage of water from the shallow zone to the upper intermediate zone. Unsteady water levels in observation well CWF-3C, completed below the stressed zone, did not allow for detection of possible drawdown. Effects of partial penetration in the pumped well are considered negligible due to restricted vertical movement of water by confining clay layers above and below the screened interval. The slight separation of drawdown curves at early time (fig. 9) indicated that the effects of partial penetration are insignificant.

The multiple-well drawdown plot in figure 9 shows a response to stress typical of a leaky-confined aquifer. Separation of individual drawdown curves at late time is caused by vertical leakage. Steady vertical flow through the confining layers is attained late in the test when drawdown curves become relatively flat and approach a constant drawdown value.

The Hantush-Jacob method for leaky-confined aquifers with vertical movement (Lohman, 1979, p. 30) was used to analyze the drawdown data. This method is applicable when the aquifer receives water from leakage through the confining beds and this leakage from storage in the confining beds is negligible. Hantush-Jacob-type curves (Lohman, 1979, pl. 3A) were matched to the multiple-well drawdown plot, and a common match point was selected (fig. 9).

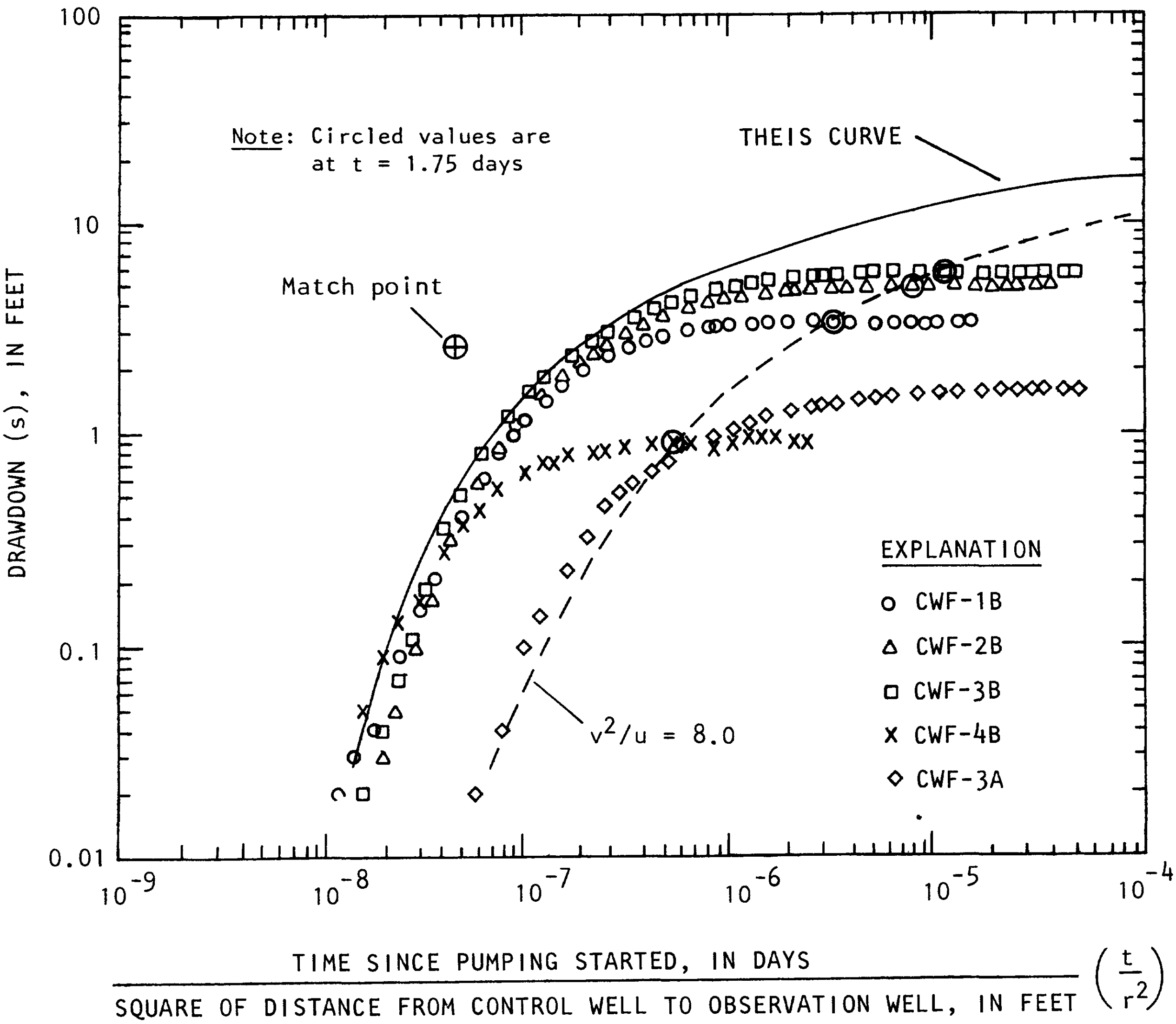


Figure 9.--Logarithmic plot of water-level drawdown in observation wells during an aquifer test of the upper intermediate zone, December 3-11, 1985.

Transmissivity (T), storage coefficient (S), horizontal hydraulic conductivity (K), and vertical hydraulic conductivity (K') are calculated using the following equations (Lohman, 1979, p. 31):

$$T = \frac{Q}{4\pi s} \times L(u,v) = \frac{83{,}936 \times 1}{4 \times 3.14 \times 2.6} = 2{,}600 \text{ ft}^2/\text{day} \qquad (3)$$

where T = transmissivity, in ft^2/day;

Q = average well discharge, in ft^3/day (cubic feet per day) (83,936);

π = 3.14;

s = drawdown at match point, in ft (2.6); and

$L(u,v)$ = leakance function from type curve at match point = 1.

$$S = 4T\,\frac{t/r^2}{1/u} = 4 \times 2{,}600 \times \frac{4.1 \times 10^{-8}}{1.0} = 4.3 \times 10^{-4} \qquad (4)$$

where S = storage coefficient (dimensionless);

t = time at match point, in days;

r = distance from control well to observation well, in ft; and

$1/u$ = function from type curve at match point = 1.

$$K = T/b = 2{,}600/98 = 26 \text{ ft/day} \qquad (5)$$

where K = horizontal hydraulic conductivity, in ft/day (feet per day); and

b = aquifer thickness, assumed thickness of sands penetrated by control well CWF-115, in ft (98).

$$K' = S \times \frac{v^2/u}{t} \times b' = \frac{4.3 \times 10^{-4} \times 8 \times 84}{1.75} = 0.16 \text{ ft/day} \qquad (6)$$

where K' = vertical hydraulic conductivity, in ft/day;

v^2/u = leakance function from type-curve match at constant time, in days (v^2/u = 8 at t = 1.75 days); and

b' = thickness of confining unit (84 ft), assumed equal to thickness of sand-clay sequence (Wilson and White, 1984, p. 26) from water table to top of screened interval in control well CWF-115.

The estimated transmissivity, storage-coefficient, and horizontal hydraulic-conductivity values are considered good on the basis of steady aquifer conditions and a good type-curve match to measured drawdown. The estimated horizontal hydraulic conductivity represents an average value for all sand layers within the stressed zone. Hydraulic conductivity for individual sand lenses may vary.

The estimated vertical hydraulic conductivity of the upper confining unit (0.16 ft/day) is considered a tentative estimate. It is difficult to determine the effective thickness of the upper confining unit. Borehole-geophysical logs (Nickerson, 1986) indicate a series of relatively thin interfingering clay lenses above the pumped zone. Vertical leakage of water to the pumped zone is initially restricted by the individual clay lens immediately above the screened interval at control well CWF-115. However, drawdown in the pumped zone extends laterally beyond individual discontinuous clay lenses. Vertical leakage during late-time drawdown probably is a function of the entire sand-clay sequence above the stressed interval. The calculated vertical hydraulic conductivity of the upper confining unit represents an average value for the sand-clay sequence.

Vertical hydraulic conductivity of the sand and clay sequence overlying the pumped zone also was estimated between CWF-3A and CWF-3B using the ratio method described by Neuman and Witherspoon (1972). This method uses the ratio between drawdown in the confining unit and drawdown in the stressed zone at early time to determine leakage from the confining unit. The sand-clay sequence above the pumped zone restricts vertical flow and therefore may be evaluated as a confining unit relative to the pumped zone. An estimated vertical hydraulic conductivity of 0.16 ft/day was calculated for the confining unit using the following equations (Neuman and Witherspoon, 1972):

$$\frac{s'}{s} = \frac{0.10 \text{ ft (CWF-3A)}}{1.59 \text{ ft (CWF-3B)}} \text{ at } t = 0.0174 \text{ day } [t/r^2 = 9.45 \times 10^{-8}] \tag{7}$$

$$\frac{s'}{s} = 0.06$$

where s' = drawdown in observation well CWF-3A (confining unit) at t = 0.0174 day (25 minutes); and

s = drawdown in observation well CWF-3B (pumped zone) at t = 0.0174 day.

$$t_D = \frac{Tt}{r^2S} = \frac{2,600 \times 0.0174}{429^2 \times 4.3 \times 10^{-4}} = 0.57 \qquad (8)$$

$$t_D' = 0.30$$

where t_D = dimensionless time factor for pumped zone;

T = estimated transmissivity of 2,600 ft^2/day, based on aquifer test;

t = time since pumping started, in days (0.0174);

r = distance from control well CWF-115 to observation well CWF-3A, in ft;

S = storage coefficient (4.3×10^{-4}), based on aquifer test; and

t_D' = dimensionless time factor for confining unit at t_D = 0.57 and s'/s = 0.06 (Neuman and Witherspoon, 1972, p. 1289, fig. 3).

$$\alpha' = \frac{t_D' \, Z^2}{t} = \frac{0.30 \times 41^2}{0.0174} = 29,000 \text{ ft}^2/\text{day} \qquad (9)$$

where α' = hydraulic diffusivity of unpumped zone, in ft^2 /day; and

Z = vertical coordinate, confining unit sand-clay thickness 41 ft, clay thickness 8 ft.

$$K' = \alpha'Ss' = 29,000 \times 5.5 \times 10^{-6} = 0.16 \text{ ft/day} \qquad (10)$$

where K' = vertical hydraulic conductivity of the confining unit in the unpumped zone between the screened intervals in CWF-3A and control well CWF-115; and

Ss' = specific storage of the confining unit (5.5×10^{-6}/ft), calculated as the weighted mean specific storage of the vertical coordinate, where the specific storage of clay is assumed to be 10^{-5}/ft (Wilson and White, 1984, p. 28), and the specific storage of sand in the confining unit is assumed to be the same as sand in the pumped zone (4.4×10^{-6}/ft).

The ratio method was designed to evaluate vertical hydraulic conductivity of discrete confining layers. It needs to be noted that because this method was applied to the sand-clay sequence of the unpumped zone to estimate the effective vertical hydraulic conductivity (0.16 ft/day) of the entire confining unit, it does not represent individual clay layers. The results are in agreement with those obtained by the Hantush-Jacob method.

It is difficult to assign vertical leakage to individual clay lenses. The estimated vertical hydraulic diffusivity of 29,000 ft^2/day represents the effective diffusivity of the entire sand-clay sequence between observation well CWF-3A and the pumped zone. If vertical leakage during early-time drawdown is assigned entirely to the estimated 8 ft of clay in the sand-clay sequence, the vertical hydraulic diffusivity of the clay is 1,100 ft^2/day. The estimated vertical hydraulic conductivity of the clay only is 0.01 ft/day, using the vertical hydraulic diffusivity of 1,100 ft^2/day and an estimated specific storage for clay of 10^{-5} (Wilson and White, 1984, p. 28).

Deep Zone

An aquifer test of the deep zone was conducted for an 8-day period from January 7, 1986, to January 15, 1986. Aquifer conditions were relatively steady prior to the test period. Pumpage from nearby wells completed in the stressed zone was reduced to a minimum 60 days prior to the aquifer test. Discharge from nearby wells increased for a short period prior to the test but was then reduced back to a relatively constant discharge during the test period. A rise in static water levels occurred prior to the aquifer test. No significant water-level change due to fluctuation in barometric pressure was measured.

Control well CWF-205, completed within the deep zone, has a screened interval from 510 to 900 ft below land surface. The control well was pumped for 8 days, starting on January 7, 1986, at 1000 hours. Due to a power failure, the pump was off for about 3 hours on January 10 from 1012 to approximately 1315 hours. The discharge rate was relatively constant, at an average discharge of 1,709 gal/min. Well discharge from the electric turbine pump was monitored with a flowmeter. Discharge water was piped away from the test site to the Cañutillo well field pumping station.

Water-level drawdown within the stressed zone was measured in observation wells CWF-1D, CWF-2D, CWF-3D, CWF-4D, and CWF-CR2 at distances of 737, 516, 491, 2,080, and 1,659 ft, respectively, from control well CWF-205 (table 1). Measured drawdown was adjusted for the estimated change in static water level on the basis of the pretest water-level trend. A multiple-well plot of water-level drawdown in observation wells during the aquifer test of the deep zone is shown in figure 10. Drawdown prior to the intermittent pump failure at 3.0 days is shown in this plot.

Aquifer properties of the deep zone were evaluated for a confined aquifer with a fully penetrating control well. The relatively uniform fine sand in the deep zone is confined by a thick upper clay layer (fig. 5). Leakage of water through the confining layer from the intermediate zone to the deep zone is therefore considered to be small. The lower confining unit consists of limestone conglomerate and clay, which serve as the base of the aquifer. It is assumed to be relatively impermeable.

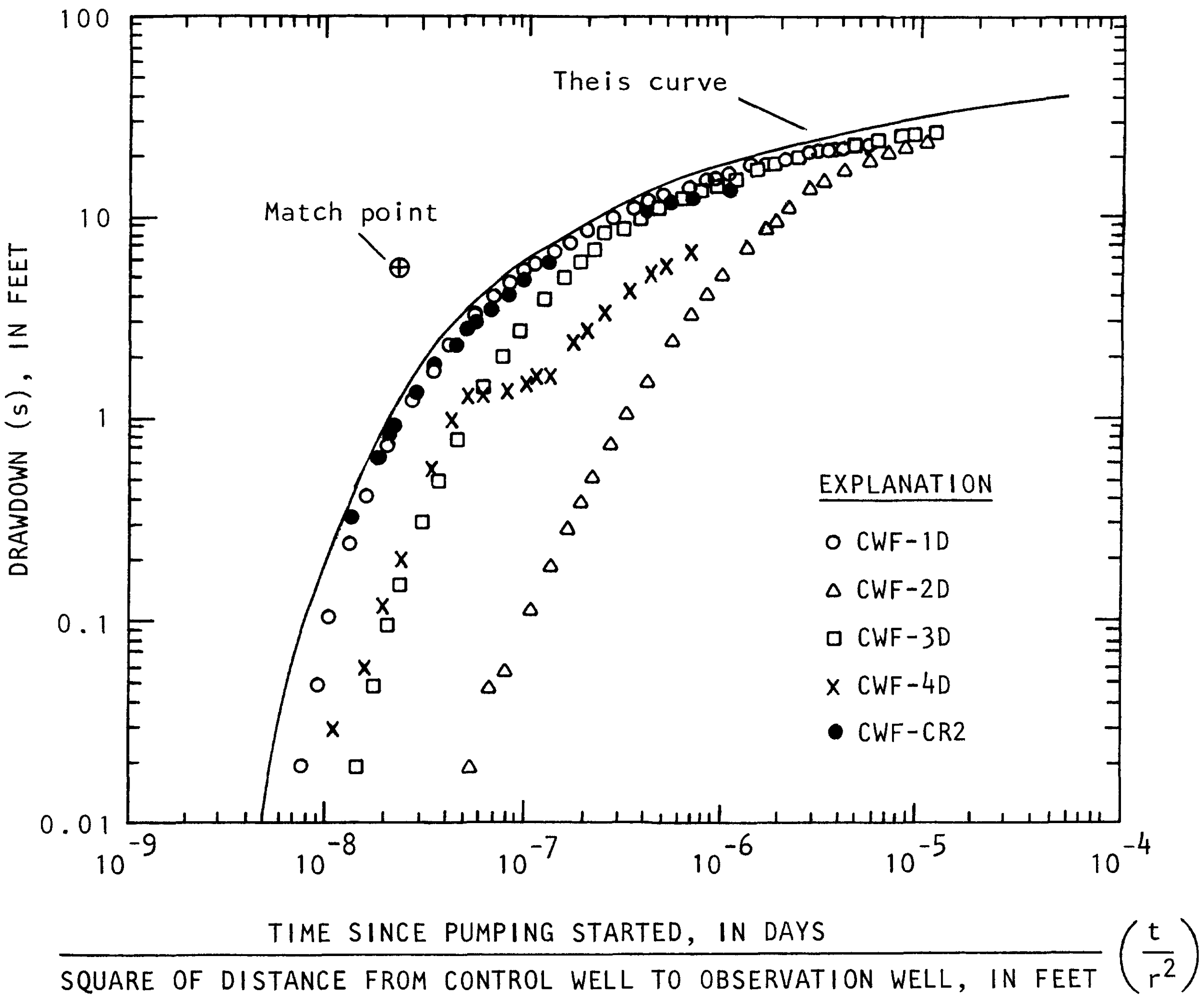


Figure 10.--Logarithmic plot of water-level drawdown in observation wells during an aquifer test of the deep zone, January 7-10, 1986.

The multiple-well drawdown plot in figure 10 shows a delayed drawdown response in observation wells CWF-2D, CWF-3D, and CWF-4D. Individual drawdown curves are separated during early-time drawdown and begin to merge toward a common curve late in the test. Observation wells CWF-1D, CWF-2D, CWF-3D, and CWF-4D are completed with a 5-ft screened interval in the lower part of the stressed zone and may not be representative of the entire deep zone during early-time drawdown. Observation well CWF-CR2, which has a large screened interval (585-1,050 ft) completed throughout the stressed zone, is assumed to exhibit a representative response.

Aquifer properties of the deep zone were evaluated for a confined aquifer with nonsteady radial flow and no vertical movement (Lohman, 1979, p. 15). The Theis-type curve was fit to the envelope of the drawdown curves to estimate a maximum transmissivity and storage value. The type-curve match point is shown in figure 10.

Transmissivity (T), storage coefficient (S), and horizontal hydraulic conductivity (K) are calculated using the following equations (Lohman, 1979, p. 15):

$$T = \frac{Q}{4\pi s} \times W(u) = \frac{329{,}005 \times 1}{4 \times 3.14 \times 5.6} = 4{,}700 \text{ ft}^2/\text{day} \qquad (11)$$

where T = transmissivity, in ft^2/day;

Q = average well discharge, in ft^3/day (329,005);

s = drawdown at match point, in ft (5.6); and

$W(u)$ = well function of u at match point = 1.

$$S = \frac{4Ttu}{r^2} = \frac{4T\ t/r^2}{1/u} = \frac{4 \times 4{,}700 \times 2.3 \times 10^{-8}}{1} = 4.3 \times 10^{-4} \qquad (12)$$

where S = storage coefficient (dimensionless);

t = time at match point, in days;

r = distance from control well to observation well, in ft; and

$1/u$ = function from type curve at match point = 1.

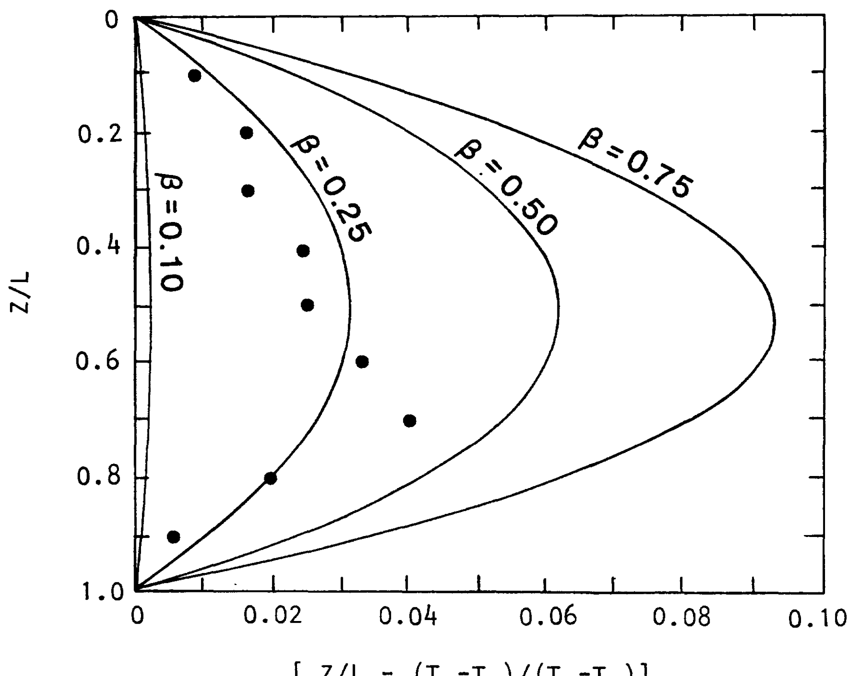
$$K = T/b = 4{,}700/440 = 11 \text{ ft/day} \qquad (13)$$

where K = horizontal hydraulic conductivity, in ft/day; and

b = aquifer thickness, thickness of deep zone at control well CWF-205, in ft (440).

The estimated values for aquifer properties are considered poor on the basis of delayed early-time drawdown and limited late-time data due to pump failure. The cause of delayed drawdown in observation well CWF-2D, CWF-3D, and CWF-4D shown in figure 10 is unknown. Effects of borehole storage in the observation wells and partial penetration of the control well are negligible. Borehole storage is only significant at time, $t < 0.002$ day (Reed, 1980, p. 39). The control well almost fully penetrates the aquifer; the nearest observation well is at a radius of 491 ft. The effects of partial penetration are therefore negligible for all rates of vertical to horizontal hydraulic conductivity greater than about 0.002 (Reed, 1980, fig. 2.3, p. 13). Drawdown in the observation wells may have a delayed response similar to that of a partially penetrating control well if well yields within the stressed zone are disproportionally greater above the screened intervals in the observation wells. Delayed drawdown also may be due to inadequate development of the observation wells.

Vertical ground-water movement transports heat by convection and causes curvature in the thermal gradient of the earth. Bredehoeft and Papadopulos (1965) derived the differential equation for steady one-dimensional (vertical) flow of heat and fluid through isotropic, homogeneous, saturated, porous media. Vertical flow of ground water can be detected from the thermal profile of a well where temperatures in the well are in equilibrium with the surrounding aquifer (Sorey, 1971). Temperature distributions in the well can then be matched with published type curves to estimate vertical ground-water velocity through a confining layer. Temperature distribution across the clay layer separating the lower intermediate and deep zones at observation well CWF-3D was determined from a temperature log conducted on December 10, 1986. The calculated temperature-ratio distribution in CWF-3D from 440 to 500 ft below land surface was plotted with β-type curves from Bredehoeft and Papadopulos (1965). The β-type-curve match is shown in figure 11.



where: Z = vertical coordinate below initial depth, in feet;

L = total vertical length of temperature profile interval, in feet (60);

T_Z = temperature at any depth Z, in degrees Celsius;

T_O = uppermost temperature measurement at $Z=0$, in degrees Celsius; and

T_L = lowermost temperature measurement at $Z=L$, in degrees Celsius.

Figure 11.--Nondimensional plots of temperature-ratio distribution in observation well CWF-3D from 440 to 500 feet below land surface, matched with β-type curves from Bredehoeft and Papadopulos (1965).

Downward leakage of water across the clay layer was estimated using the temperature profile method described by Sorey (1971). Vertical ground-water velocity (Vz) and vertical hydraulic conductivity (K') were calculated using the following equations:

$$Vz = \beta k/Lc_o p_o = \frac{0.25 \times 2 \times 10^{-3} \times 2,835}{1,829 \times 1 \times 1} = 0.0008 \text{ ft/day} \qquad (14)$$

where Vz = vertical ground-water velocity as specific discharge (darcian velocity), in ft/day;

β = type-curve match to temperature-ratio distribution = 0.25 (fig. 11);

k = thermal conductivity of solid-fluid complex (2×10^{-3} calorie per second-centimeter °C);

L = temperature interval length 60 ft (1,829 centimeters);

c_o = specific heat of fluid (1.0 calorie per gram °C);

p_o = density of fluid (1.0 gram per cubic centimeter); and

2,835 = conversion from centimeter per second to ft/day.

$$K' = \frac{Vz}{dh/dz} = \frac{0.0008}{11.2/60} = 0.004 \text{ ft/day} \qquad (15)$$

where K' = vertical hydraulic conductivity, in ft/day;

dh = head difference across confining layer between intermediate zone (CWF-3C) and deep zone (CWF-3D), 11.2 ft on December 10, 1986, at 1400 hours assumed to be representative of the long-term head difference; and

dz = thickness of confining layer, in ft (60).

SUMMARY AND CONCLUSIONS

The aquifer system at the Cañutillo well field hydrologic section was divided into a shallow, upper intermediate, lower intermediate, and deep zone. Aquifer properties of specific zones at the test site were determined from a series of multiple-well aquifer tests conducted from December 3, 1985, through January 20, 1986. The estimated hydraulic diffusivity of the shallow zone is 175,000 ft^2/day. Estimated aquifer properties of the upper intermediate zone from 97 to 200 feet below land surface are: (1) transmissivity, 2,600 ft^2/day; (2) storage coefficient, 4.3×10^{-4}; and (3) hydraulic conductivity, 26 ft/day. Estimated aquifer properties of the deep zone are: (1) transmissivity, less than or equal to 4,700 ft^2/day; (2) storage coefficient, less than or equal to 4.3×10^{-4}; and (3) hydraulic conductivity, less than or equal to 11 ft/day.

The Rio Grande is hydraulically connected to the shallow flood-plain alluvium. Water moves from the river to the aquifer in response to the head difference (hydraulic gradient) between river stage and water levels in the shallow zone. Water generally occurs within the shallow zone under unconfined (water-table) conditions and within the upper intermediate, lower intermediate, and deep zones under leaky-confined conditions. Vertical movement of water from the shallow zone to the upper intermediate zone is restricted by the sand-clay sequence within the aquifer with an estimated vertical hydraulic conductivity of 0.16 ft/day. The vertical hydraulic conductivity of individual clay lenses may be as small as 0.01 ft/day. Vertical movement of water from the lower intermediate zone to the deep zone is restricted by a thick clay layer with an estimated vertical hydraulic conductivity of less than 0.01 ft/day.

SELECTED REFERENCES

Alvarez, H.J., and Buckner, A.W., 1980, Ground-water development in the El Paso region, Texas, with emphasis on the resources of the lower El Paso Valley: Texas Department of Water Resources Report 246, 346 p.

Bredehoeft, J.D., and Papadopulos, I.S., 1965, Rates of vertical groundwater movement estimated from the earth's thermal profile: Water Resources Research, v. 1, no. 2, p. 325-328.

Conover, C.S., 1954, Ground-water conditions in the Rincon and Mesilla Valleys and adjacent areas in New Mexico: U.S. Geological Survey Water-Supply Paper 1230, 200 p.

Gates, J.S., White, D.E., and Leggat, E.R., 1984, Preliminary study of the aquifers of the lower Mesilla Valley in Texas and New Mexico by model simulation: U.S. Geological Survey Water-Resources Investigations Report 84-4317, 21 p.

Heath, R.C., 1983, Basic ground-water hydrology: U.S. Geological Survey Water-Supply Paper 2220, 85 p.

King, W.E., and Hawley, J.W., 1975, Geology and ground-water resources of the Las Cruces area, New Mexico, in Las Cruces Country: New Mexico Geological Society Guidebook, 26th Field Conference, p. 195-204.

King, W.E., Hawley, J.W., Taylor, A.M., and Wilson, R.P., 1971, Geology and ground-water resources of central and western Doña Ana County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Hydrologic Report 1, 64 p.

Leggat, E.R., Lowry, M.E., and Hood, J.W., 1962, Ground-water resources of the lower Mesilla Valley, Texas and New Mexico: Texas Water Commission Bulletin 6203, 191 p.

Lohman, S.W., 1979, Ground-water hydraulics (3d ed.): U.S. Geological Survey Professional Paper 708, 70 p.

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

McLean, J.S., 1980, Aquifer tests in the Gallup Sandstone near Yah-ta-hey, New Mexico: U.S. Geological Survey Water-Resources Investigations 80-25, 25 p.

Myers, R.G., and Orr, B.R., 1985, Geohydrology of the aquifer in the Santa Fe Group, northern West Mesa of the Mesilla Basin near Las Cruces, New Mexico: U.S. Geological Survey Water-Resources Investigations Report 84-4190, 37 p.

SELECTED REFERENCES - Concluded

Neuman, S.P., and Witherspoon, P.A., 1972, Field determination of the hydraulic properties of leaky multiple aquifer systems: Water Resources Research, v. 8, no. 5, October 1972, p. 1284-1298.

Nickerson, E.L., 1986, Selected geohydrologic data for the Mesilla Basin, Doña Ana County, New Mexico, and El Paso County, Texas: U.S. Geological Survey Open-File Report 86-75, 59 p.

Reed, J.E., 1980, Type curves for selected problems of flow to wells in confined aquifers: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 3, Chap. B3, 106 p.

Sorey, M.L., 1971, Measurement of vertical groundwater velocity from temperature profiles in wells: Water Resources Research, v. 7, no. 4, August 1971, p. 963-970.

Stallman, R.W., 1962, Constant head nonsteady state, no recharge, in Theory of aquifer tests: U.S. Geological Survey Water-Supply Paper 1536-E, p. 126-131.

Stallman, R.W., 1971, Aquifer-test design, observation, and data analysis: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 3, Chap. B1, 26 p.

White, D.E., 1983, Summary of hydrologic information in the El Paso, Texas, area, with emphasis on ground-water studies, 1903-80: U.S. Geological Survey Open-File Report 83-775, 77 p.

Wilson, C.A., and White, R.R., 1984, Geohydrology of the central Mesilla Valley, Doña Ana County, New Mexico: U.S. Geological Survey Water-Resources Investigations 82-555, 144 p.

Wilson, C.A., White, R.R., Orr, B.R., and Roybal, G.R., 1981, Water resources of the Rincon and Mesilla Valleys and adjacent areas, New Mexico: New Mexico State Engineer Technical Report 43, 514 p.

DEFINITION OF TERMS

AQUIFER - A consolidated or unconsolidated rock formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs.

CONFINING BED - A layer of material having very small hydraulic conductivity that restricts the movement of water into and out of an aquifer.

DRAWDOWN - The reduction in head at a point caused by the withdrawal of water from an aquifer.

HYDRAULIC CONDUCTIVITY - The capacity of a porous medium to transmit water. It is expressed as the volume of water at the existing kinematic viscosity that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow.

HYDRAULIC GRADIENT - Change in head per unit of distance measured in the direction of the steepest change.

SPECIFIC YIELD - The ratio of the volume of water that will drain under the influence of gravity to the volume of saturated material.

STORAGE COEFFICIENT - The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head.

TRANSMISSIVITY - The rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient.

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