AQUIFER-TEST EVALUATION AND POTENTIAL EFFECTS OF INCREASED GROUND-WATER PUMPAGE AT THE STOVEPIPE WELLS HOTEL AREA, DEATH VALLEY NATIONAL MONUMENT, CALIFORNIA

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CONVERSION FACTORS

For readers who prefer to use metric (International System) units rather than inch-pound units, the conversion factors for the terms used in this report are listed below:

Multiply inch-pound unit	By	To obtain metric unit
foot (ft)	0.3048	meter
foot squared per day (ft^2/d)	0.09290	meter squared per day
gallon	3.785	liter
gallon per minute (gal/min)	0.06308	liter per second
gallon per day (gal/d)	0.003785	cubic meter per day
inch (in.)	25.4	millimeter
mile	1.609	kilometer
square mile (mi^2)	2.590	square kilometer

Temperature is given in degrees Fahrenheit (°F), which can be converted to degrees Celsius (°C) by using the formula:

$$\text{Temp. °C} = (\text{temp. °F} - 32)/1.8$$

Abbreviations used:

mg/L, milligrams per liter	PVC, polyvinyl chloride
mV, millivolts	min, minute
ohm/m, ohms per meter	h, hour

ALTITUDE DATUM

"Sea level" in this report 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 mean sea level of 1929.

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ABSTRACT

Ground-water use in the Stovepipe Wells Hotel area in Death Valley National Monument is expected to increase significantly if the nonpotable, as well as potable, water supply is treated by reverse osmosis. During the peak tourist season, October through March, ground-water pumpage could increase by 37,500 gallons per day, or 76 percent. The effects of this additional pumpage on water levels in the area, particularly near a stand of phreatophytes about 10,000 feet east of the well field, are of concern.

In order to evaluate the effects of increased pumpage on water levels in the Stovepipe Wells Hotel area well field, two aquifer tests were performed at the well field to determine the transmissivity and storage coefficients of the aquifer. Analysis of the aquifer test determined that a transmissivity of 1,360 feet squared per day was representative of the aquifer. The estimated value of transmissivity and the storage-coefficient values that are representative of confined (1.2×10^{-4}) and unconfined (0.25) conditions were used in the Theis equation to calculate the additional drawdown that might occur after 1, 10, and 50 years of increased pumpage. The drawdown calculated by using the lower storage-coefficient value represents the maximum additional drawdown that might be expected from the assumed increase in pumpage; the drawdown calculated by using the higher storage-coefficient value represents the minimum additional drawdown.

Calculated additional drawdowns after 50 years of pumping range from 7.8 feet near the pumped well to 2.4 feet at the phreatophyte stand assuming confined conditions, and from 5.7 feet near the pumped well to 0.3 foot at the phreatophyte stand assuming unconfined conditions. Actual drawdowns probably will be somewhere between these values.

Drawdowns measured in observation wells during 1973-85, in response to an average pumpage of 34,200 gallons per day at the Stovepipe Wells Hotel well field, are similar to the drawdowns calculated by the Theis equation for the assumed increase in pumpage. The similarity of the measured and calculated drawdowns indicates that the values of transmissivity and storage coefficient determined for this study adequately represent the aquifer and that the calculated drawdowns are in close agreement.

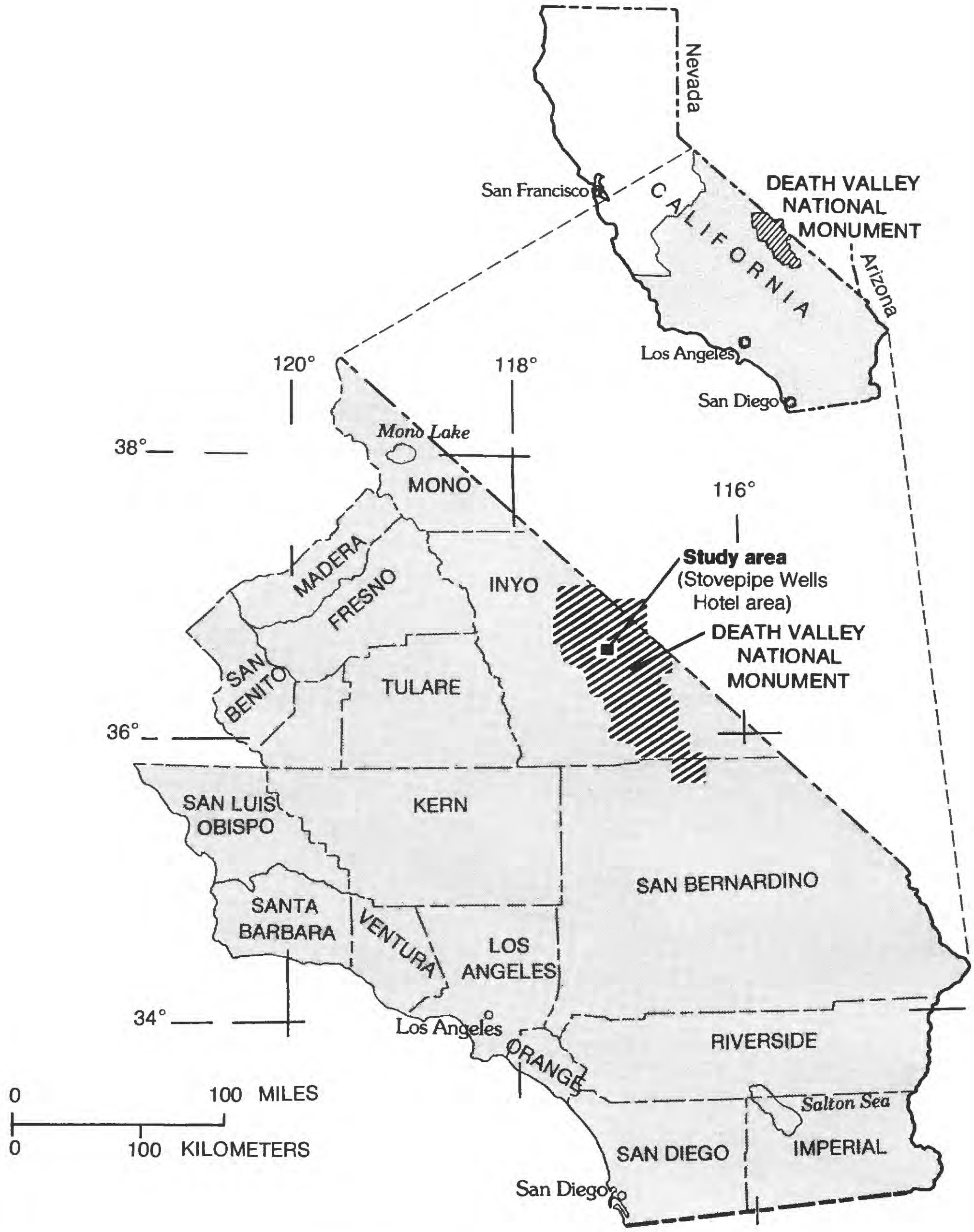


FIGURE 1. — Location of study area.

INTRODUCTION

The Stovepipe Wells Hotel area, a National Park Service facility in Death Valley National Monument (fig. 1), currently obtains its water supply from two production wells near the hotel. Both wells yield water with dissolved-solids concentrations of about 3,000 mg/L (milligrams per liter), which is six times the U.S. Environmental Protection Agency recommended limit of 500 mg/L for potable water supplies (U.S. Environmental Protection Agency, 1979). Because no other suitable sources of water are available, the potable water supply is treated by reverse osmosis (RO) to reduce the dissolved-solids concentration to acceptable levels.

In recent years, peak-season (October through March) usage of water treated by RO has been about 10,000 gal/d (gallons per day). The RO-treatment facility at Stovepipe Wells Hotel is only about 39 percent efficient; therefore, during the peak season, 25,500 gal/d is pumped from the RO production well (16S/44E-1C1) to produce 10,000 gallons of potable water. In addition to the potable supply, about 24,000 gal/d of untreated water, pumped from the saline production well (15S/44E-36Q2), is used during the peak season. The total pumpage requirement is 49,500 gal/d.

The National Park Service would like to use RO-treated water for all potable and nonpotable uses in the Stovepipe Wells Hotel area to reduce plumbing maintenance costs associated with the use of water with high dissolved-solids concentrations. Because of the 39-percent efficiency of the RO-treatment facility, the proposed conversion would require pumping about 61,500 gal/d of ground water to produce an additional 24,000 gal/d of treated water. Therefore, ground-water pumpage would increase by about 76 percent, or 37,500 gal/d, during the peak season. Although this increase in pumpage probably will occur incrementally as the quantity of nonpotable water that is treated is gradually increased over a period of time (G.D. Witucki, National Park Service, oral commun., 1987), an increase of 37,500 gal/d was used in this report.

There is concern that the increased pumpage could cause significant water-level declines in the Stovepipe Wells Hotel area. Of particular concern is the effect of water-level declines on a stand of phreatophytes, which depend on ground water for survival, about 2 miles east of Stovepipe Wells Hotel. Because of this concern, an evaluation of the effects of increased pumpage on water levels in the Stovepipe Wells Hotel area is needed.

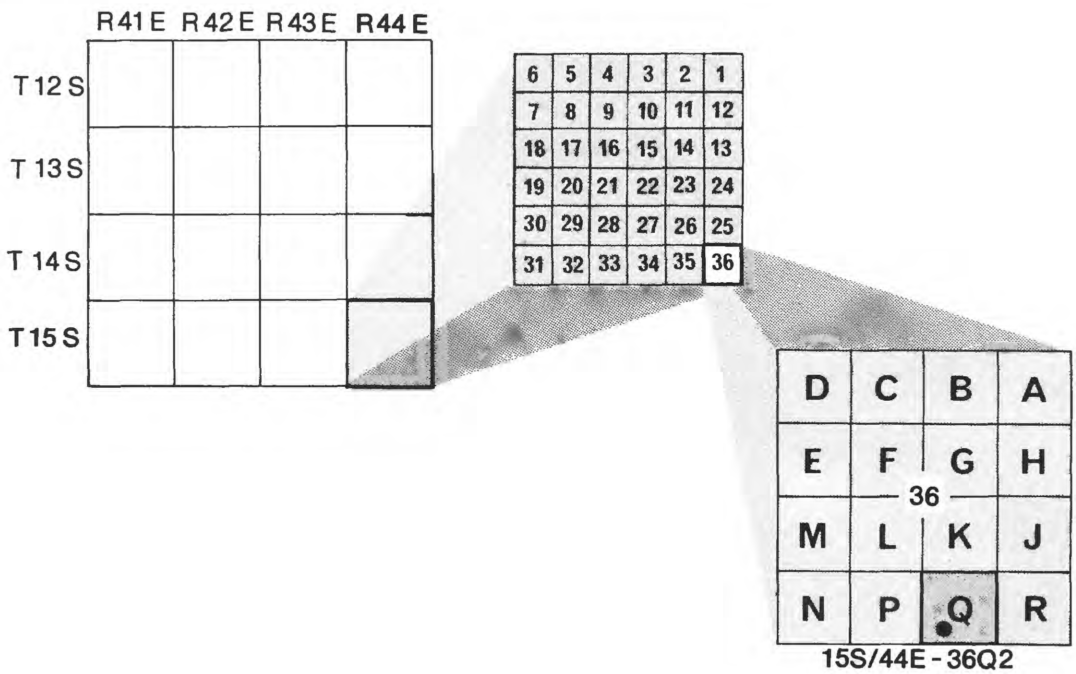
In 1986, the U.S. Geological Survey in cooperation with the National Park Service, made a preliminary evaluation of the potential water-level declines that would result from additional pumpage in the Stovepipe Wells Hotel area. In order to quantitatively evaluate the effects of additional pumpage, the transmissivity and storage coefficient of the aquifer need to be determined.

Purpose and Scope

This report describes the results of two aquifer tests in the Stovepipe Wells Hotel area and evaluates the potential for additional water-level declines caused by an increase in pumpage. The study involved constructing two observation wells near one of the production wells to monitor drawdown and recovery at two distances from the pumped well. Estimates of transmissivity and storage coefficient were obtained from analyses of the aquifer tests. These data were used to quantitatively estimate water-level declines that would occur after 1, 10, and 50 years at distances up to 2 miles from Stovepipe Wells Hotel in response to an increase in pumpage.

Well-Numbering System

Wells are numbered according to their location in the rectangular system for the subdivision of public lands. For example, in the number 15S/44E-36Q2, the part of the number preceding the slash indicates the township (T. 15 S.), the part between the slash and the hyphen indicates the range (R. 44 E.), the number between the hyphen and the letter indicates the section (sec. 36), and the letter (Q) indicates the 40-acre subdivision of the section, as shown in the diagram below. Within the 40-acre tract, wells are numbered serially as indicated by the final digit. The township and range lines are based on the Mount Diablo base line and meridian.



Description of Study Area

The Stovepipe Wells Hotel area is located on State Highway 190 in the northwestern part of Death Valley, about 200 miles northeast of Los Angeles, California (figs. 1 and 2). Death Valley is a northwestward-trending desert basin of about 8,700 mi^2 (square miles) in the Basin and Range physiographic province. Most of the valley floor, which is about 140 miles long and averages about 10 miles in width, is within the boundary of Death Valley National Monument. Altitudes in the national monument range from 282 feet below sea level at the lowest part of the valley floor to 11,049 feet above sea level in the mountains on the west side of the valley. Altitudes in the study area (fig. 2) range from about 25 feet below to 90 feet above sea level.

The climate in Death Valley is arid, and average annual rainfall on the valley floor is less than 2 inches. Average monthly temperatures range from 52 °F in January to 102 °F in July (Buono and Packard, 1982). Temperatures greater than 120 °F are common during the summer. Low humidity and moderate winds prevail in the area most of the time (Hunt and others, 1966).

Vegetation is sparse in Death Valley and is characterized by creosotebush and other shrubs and, at higher altitudes, by woodlands. Of particular importance to this study is a stand of phreatophytes, which are dependent on ground water, about 2 miles east of Stovepipe Wells Hotel (fig. 2). Phreatophytes in this stand include honey mesquite (*Prosopis juliflora*), arrowweed (*Pluchea sericea*), and fourwing saltbush (*Atriplex canescens*) (Buono and Packard, 1982).

Ground water is the only available local source of water for the Stovepipe Wells Hotel area. The Stovepipe Wells Hotel area is located on an alluvial fan at the base of Tucki Mountain, and the local aquifer is composed of unconsolidated gravel, sand, and clay. Available data indicate that the depth to water below land surface ranges from 23 feet at well 15S/44E-36G2 near the sand dunes to 148 feet at well 16S/44E-1C1 on the alluvial fan.

Ground-water quality in the area is poor. Dissolved-solids concentrations of water in 1980 ranged from 2,730 mg/L in saline production well 15S/44E-36Q2 to 8,790 mg/L in abandoned supply well 15S/44E-36K1. Sodium and chloride constitute more than 50 percent of the dissolved solids (Buono and Packard, 1982).

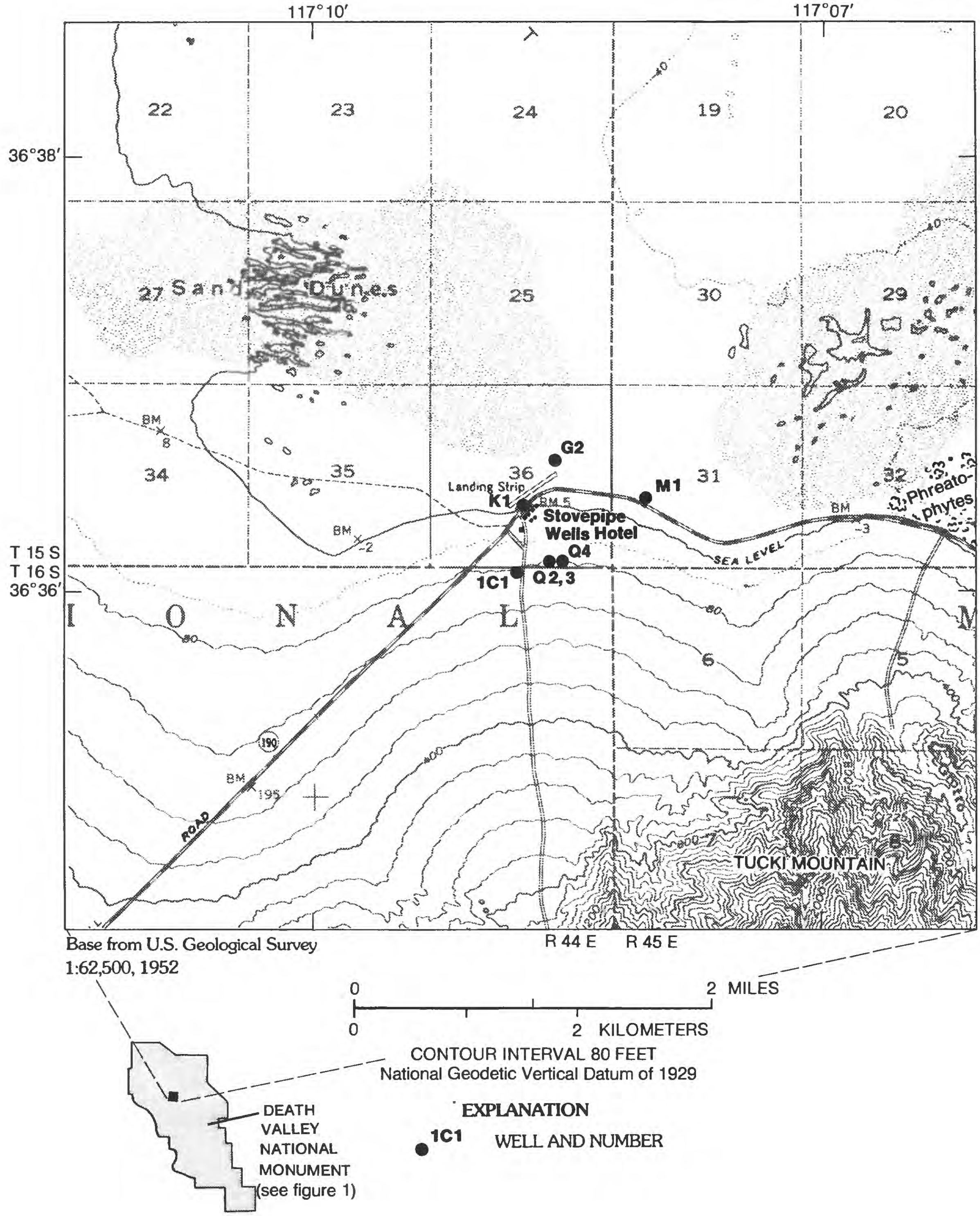


FIGURE 2. – Stovepipe Wells Hotel area and location of wells.

OBSERVATION-WELL CONSTRUCTION

Two observation wells were drilled by the U.S. Geological Survey near the Stovepipe Wells Hotel saline production well (15S/44E-36Q2) in order to measure water-level declines and recoveries at two distances from the production well. Well construction was completed April 22-24, 1986.

The observation wells are 25 feet (15S/44E-36Q3) and 100 feet (15S/44E-36Q4) east of the saline production well (fig. 2). The wells were drilled by the direct mud-rotary method to a depth of 300 feet below land surface, which is the reported depth of the production well, and cased with 2-inch PVC (polyvinyl chloride) casing. Observation well 15S/44E-36Q3 was perforated from 276 to 296 feet below land surface, and observation well 15S/44E-36Q4 was perforated from 269 to 289 feet below land surface. Because the perforated interval of the saline production well (15S/44E-36Q2) was unknown, location of the perforated intervals of the observation wells was based on the perforated interval (264 to 294 feet below land surface) of the RO production well (16S/44E-1C1). The annular space in both observation wells was filled with Monterey sand (medium-grained well-sorted sand) opposite the perforations and then backfilled with native material to land surface. A 5-foot bentonite seal was placed in the annular space about 20 feet above the perforations. Complete well-construction information is presented in table 1.

Table 1.--Well-construction data

[All depths, perforated interval, and bottom of seal are given as distance below land surface. Altitude of land surface is distance above sea level]

	Observation wells	
	15S/44E-36Q3	15S/44E-36Q4
Distance from saline production well, 15S/44E-36Q2 (feet).......	25	100
Date drilled.....................	April 23-24, 1986	April 22, 1986
Depth of hole (feet)..............	300	300
Diameter of hole (inches).........	6	6
Depth cased (feet)................	296	289
Casing diameter (inches)..........	2	2
Casing type.......................	Polyvinyl chloride	Polyvinyl chloride
Perforated interval (feet)........	276-296	269-289
Sand pack.........................	Monterey Sand	Monterey Sand
Seal..............................	Bentonite	Bentonite
Depth of bottom of seal (feet)....	256	249
Depth to water (feet)............	134.40	134.30
Date of water-level measurement...	April 24, 1986	April 24, 1986
Altitude of land surface (feet)...	80	80

Lithologic and geophysical logs for observation well 15S/44E-36Q4 are shown in figure 3. The logs indicate that the aquifer consists predominantly of fine to coarse gravel and sand with occasional cobbles and clay lenses. The lithologic log of the observation well is similar to the lithologic log of the RO production well (table 2).

Table 2.--Drillers' logs of reverse-osmosis production well (16S/44E-1C1) and 100-foot observation well (15S/44E-36Q4)

	Thickness (ft)	Depth (ft)
16S/44E-1C1. Drilled by Bill Belknap. Logged by driller. Altitude 90 ft; 8-in. steel casing; depth of hole 315 ft; depth of well 294 ft; perforated interval 264-294 ft. Drilling completed 9-9-73.		
Alluvium (size 0-18 in.), mixed	70	70
Boulders	3	73
Clay	5	78
Alluvium, mixed	24	102
Clay	10	112
Alluvium, mixed	31	143
Boulders	30	173
Sandy clay	2	175
Broken multicolored rock with bits of sandy clay	6	181
Sandy clay	4	185
Broken multicolored rock	4	189
Sand or sandy clay	6	195
Broken multicolored rock	16	211
Broken multicolored rock with thin layers of clay	104	315
15S/44E-36Q4. Drilled by U.S. Geological Survey. Logged by U.S. Geological Survey. Altitude 80 ft; 2-in. polyvinyl chloride casing; depth of hole 300 ft; depth of well 289 ft; perforated interval 269-289 ft. Drilling completed 4-23-86.		
Gravel, fine to coarse, up to 1/2 in. diameter, angular to subangular, some feldspars (60 percent); and sand, coarse, (40 percent)	20	20
Gravel, fine to coarse, up to 1 in. diameter, angular to subangular (75 percent). Cobbles, black basalt; sand, coarse; and clay, moderate yellowish brown, lenses at 46-48 ft and 52-54 ft (25 percent)	34	54
Gravel, fine to medium, up to 3/8 in. diameter, angular to subangular, some feldspars (70 percent). Sand, coarse; and cobbles, black basalt and moderate yellowish brown quartzite (30 percent)	16	70
Gravel, fine to medium, up to 3/8 in. diameter, angular to subangular (75 percent). Cobbles, black basalt and moderate yellowish quartzite; sand, coarse; and clay, moderate yellowish brown, lens at 85.5-86.6 ft (25 percent)	22	92
Clay, dark reddish brown, with some sand, fine	8	100
Gravel, fine to coarse, up to 1/2 in. diameter, angular to subangular, (65 percent). Sand, coarse; cobbles, black basalt; and clay, moderate yellowish brown, trace (35 percent)	30	130
Clay, moderate yellowish brown, with sand, fine	10	140
Gravel, fine to medium, up to 3/8 inch diameter, angular to subangular (40 percent). Sand, coarse; clay, lens at 186-190 ft, trace at other depths; and cobbles, black basalt, moderate yellowish brown quartzite, and white marble (60 percent)	70	210
Gravel, fine to medium, angular to subrounded (40 percent). Cobbles, moderate yellowish brown quartzite; sand, coarse; clay, trace, moderate yellowish brown (60 percent)	60	270
Gravel, fine to medium, angular to subrounded (40 percent). Cobbles moderate yellowish brown quartzite; sand, coarse; and clay, trace, moderate yellowish brown (60 percent)	19	289

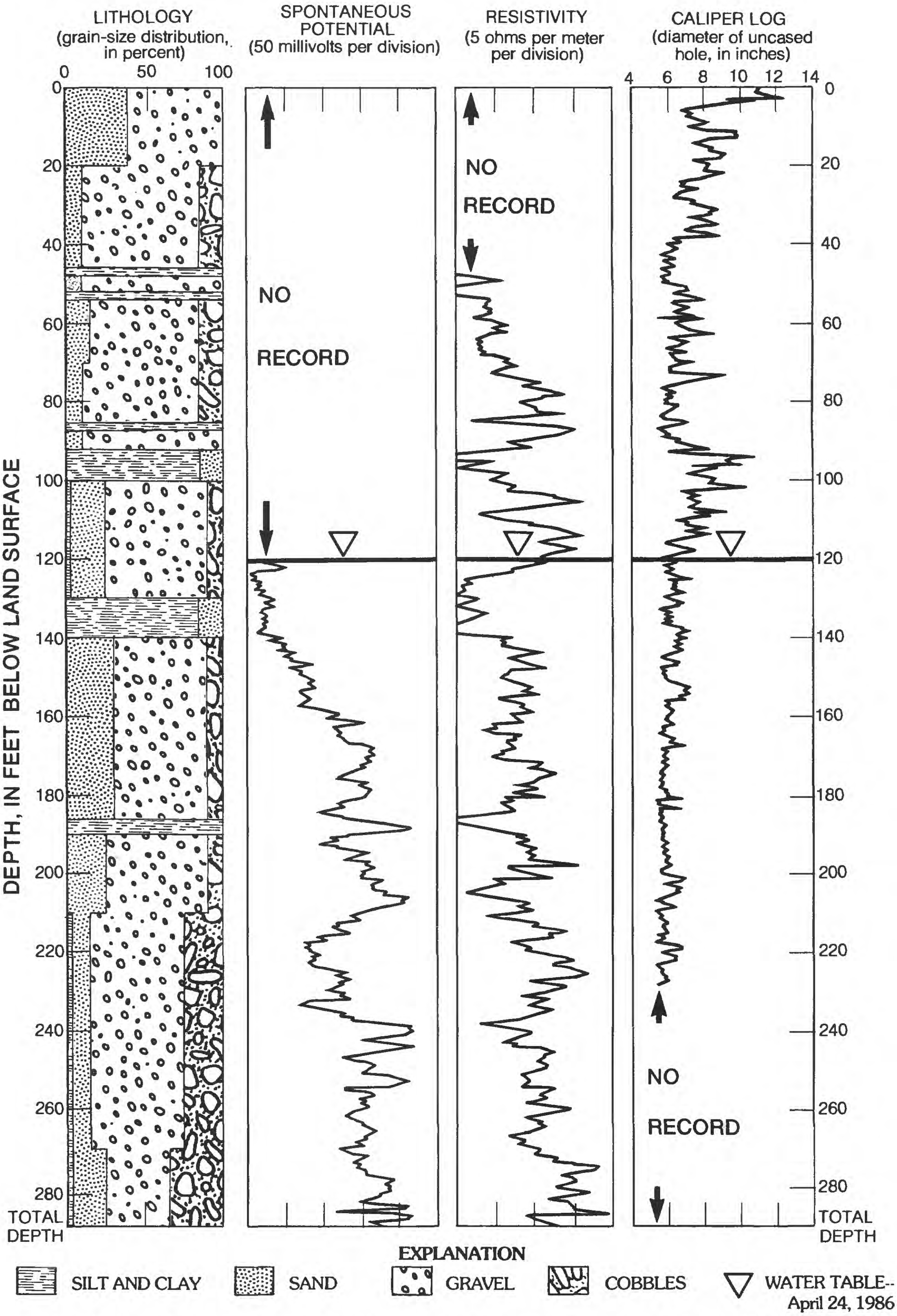


FIGURE 3. — Lithologic, geophysical, and caliper logs of observation well 15S/44E-36Q4. (Total depth of well is 289 feet.)

The RO production well and the saline production well both obtain most of their water from a predominantly gravel and sand layer that extends from about 150 to 300 feet below land surface (fig. 3). For the purposes of this report, this 150-foot layer of gravel and sand is considered the principal aquifer in the Stovepipe Wells Hotel area. Thin layers of clay that are present above and below this aquifer may at least partially confine the aquifer.

AQUIFER TEST

In order to evaluate effects of an increase in pumpage on water levels in the Stovepipe Wells Hotel area, the transmissivity and storage coefficient of the aquifer must be determined. Transmissivity is defined as the rate at which water of a prevailing kinematic viscosity is transmitted through a unit width of aquifer under a unit hydraulic gradient (Lohman, 1979, p. 6). The units of transmissivity used in this report are feet squared per day (ft^2/d). Storage coefficient is defined as the volume of water released from or taken into storage per unit surface area of aquifer per unit change in head (Lohman, 1979, p. 8). The storage coefficient is dimensionless. Water-level declines near a pumping well are inversely proportional to the transmissivity and storage coefficient. That is, the larger the transmissivity and storage-coefficient values, the smaller the water-level decline at any given distance from a pumped well.

Transmissivity and storage coefficient values were determined by evaluating two aquifer tests at the Stovepipe Wells Hotel well field conducted during May 19-21, 1986. The first test involved monitoring the pumping and recovery phases at the saline production well (15S/44E-36Q2) and two observation wells (15S/44E-36Q3 and 15S/44E-36Q4). The second test involved monitoring the pumping and recovery phases of the RO production well (16S/44E-1C1).

Aquifer-Test Design

The two aquifer tests at the Stovepipe Wells Hotel well field were divided into three phases: resting, pumping, and recovery (figs. 4-5). During the resting phase the production-well pump was turned off to allow the aquifer to recover to static conditions. The pumping phase involved pumping the production well at a constant rate for a set period of time or until water-level declines (drawdowns) stabilized. During this phase, water-level measurements were made at known times in the production well (and, in the saline-production-well test, also in two observation wells). The recovery phase involved turning off the production-well pump and measuring water levels until they had completely recovered to the levels recorded during the resting phase. The recovery of the water level is the difference between the actual measured level at a given time after pumping stopped and the projected pumping level (extended time-drawdown curve), which is the water level that would have been found at that same time had pumping continued (fig. 4).

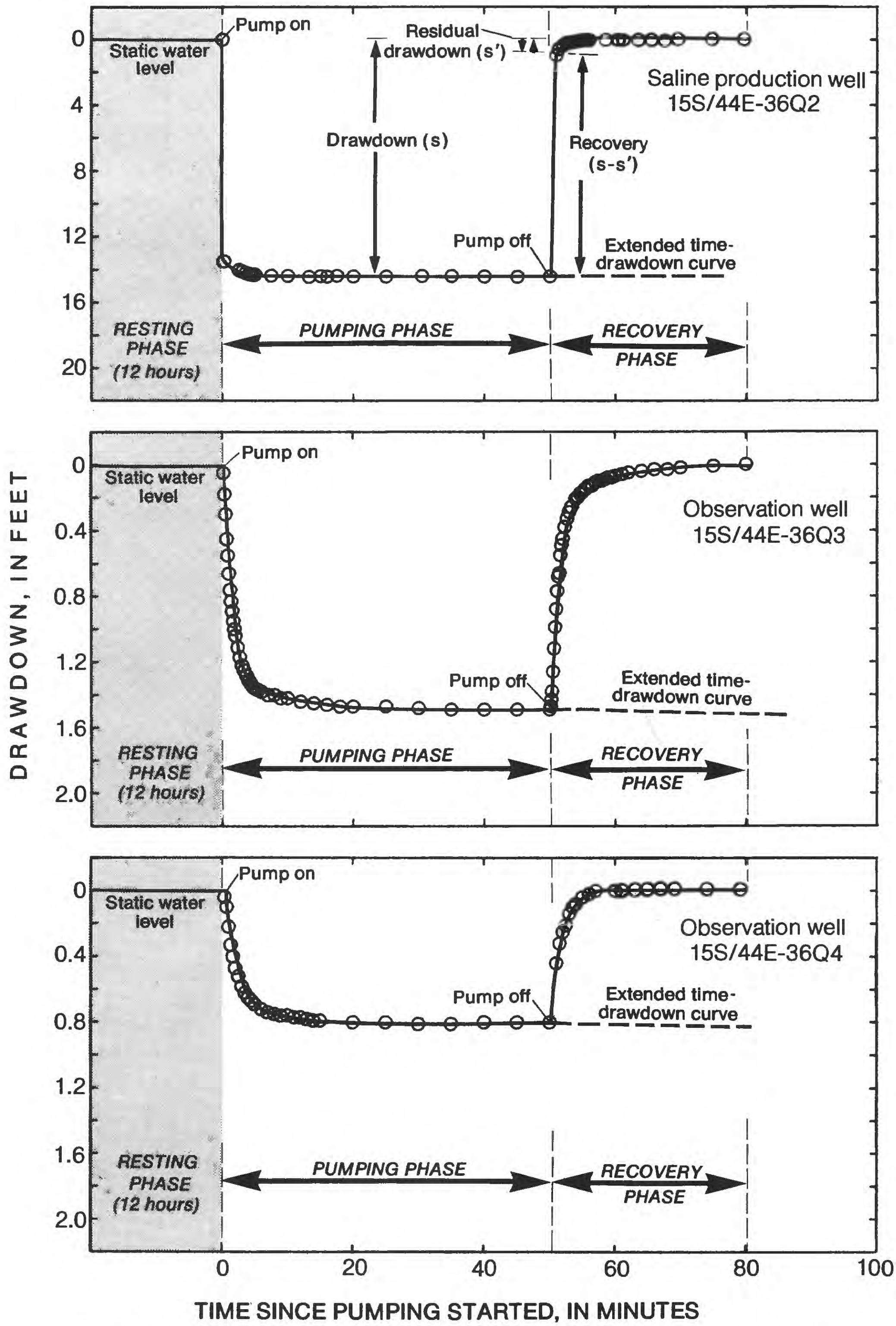


FIGURE 4. — Changes in water level during saline-production-well aquifer test. (Average discharge during pumping phase was 55 gallons per minute.)

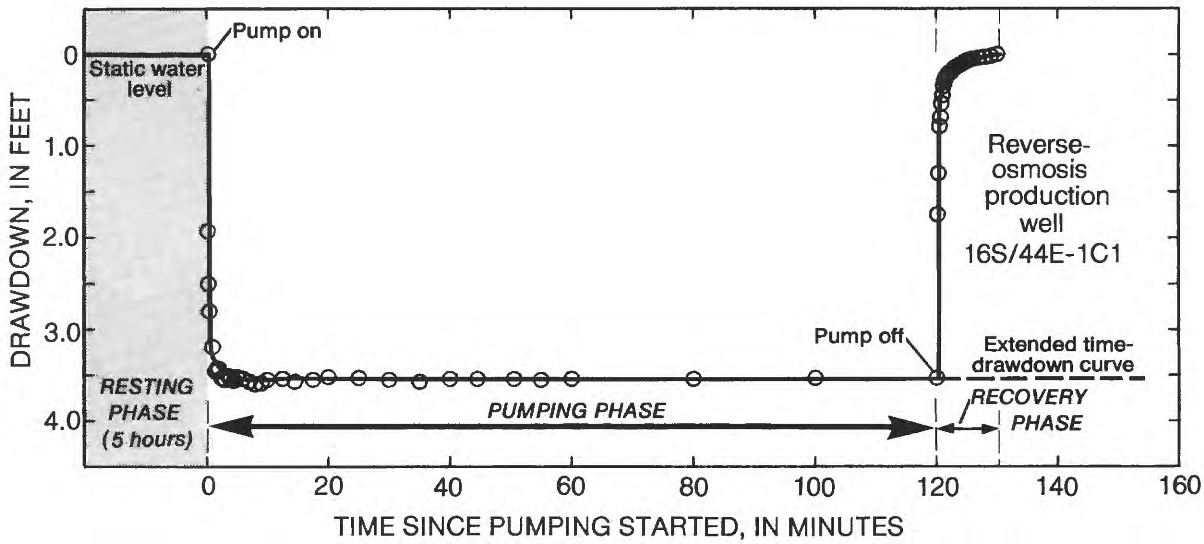


FIGURE 5. — Changes in water level during reverse-osmosis-production-well aquifer test. (Average discharge during the pumping phase was 26 gallons per minute.)

The first aquifer test was conducted at the saline production well May 19-20, 1986. The resting phase of the test was started at 9:00 a.m. on May 19 and was scheduled to last 24 hours. However, it was necessary to restart the pump after only 9 hours because the storage tank for the hotel facilities became empty. After pumping for about 4 hours to refill the storage tank, the pump was turned off again for about 11 1/2 hours. Water-level measurements made during the resting phase indicate that the aquifer had recovered to static conditions.

The pumping and recovery phases of the aquifer test at the saline production well each were originally designed to last 12 hours. The pumping phase started at 8:30 a.m. on May 20, but the pump on the saline production well malfunctioned and stopped after only 50 minutes of pumping. Inspection of the water-level data (fig. 4) indicates, however, that the water levels had already stabilized in the production well and in both observation wells after 20 minutes of pumping. To confirm that the water levels had stabilized, the pump was restarted after recovery, and water levels in the pumped well were monitored for 4 hours. The measured drawdown during this period did not exceed the value recorded at the 20-minute mark of the 50-minute pumping phase of the test. Average discharge for the 50-minute pumping phase was 55 gal/min (gallons per minute). During the recovery phase all wells completely recovered within 30 minutes after the pump stopped.

The changes in water level measured in the saline production well and in the two observation wells are shown in figure 4. Water levels in the saline production well and observation well 15S/44E-36Q4 were measured with electrical sounders. A pressure transducer and data logger were used to monitor continuous water levels in observation well 15S/44E-36Q3. Discharge was measured by an in-line flow meter at the pumped well. Maximum drawdowns for 15S/44E-36Q2, 15S/44E-36Q3, and 15S/44E-36Q4 were 14.43 feet, 1.49 feet, and 0.80 foot, respectively.

The second aquifer test was conducted at the RO production well on May 21, 1986. Only the RO production well was monitored during this test, because no observation wells are located close enough to the pumped well to measure water-level declines. The pump was turned off at 6:00 a.m., and the resting phase of the test lasted 5 hours. The pumping phase started at 11:00 a.m. and lasted 2 hours. Average discharge during the test was 26 gal/min. Water levels stabilized after about 10 minutes of pumping. After the pump was turned off, the recovery phase was completed in 10 minutes.

The changes in water level measured in the RO production well during the aquifer test are shown in figure 5. Water levels were measured with an electric sounder. Discharge was measured by an in-line flow meter at the RO-treatment facility. Maximum drawdown was 3.60 feet, which was attained after 8 minutes of pumping.

Methods of Analysis

The most commonly used methods for analyzing constant-discharge aquifer tests are the Theis and Jacob-Cooper methods. Both of these methods assume (1) the aquifer is homogeneous and isotropic, (2) the aquifer is infinite in horizontal extent, (3) the pumped well penetrates the entire thickness of the aquifer, (4) the diameter of the pumped well is very small, and (5) the water removed from storage is discharged instantaneously with decline in head.

Most aquifers are seldom as ideal as outlined above; however, these assumptions are most nearly met by confined aquifers at sites some distance from their boundaries. Aquifer tests on unconfined aquifers can be analyzed by these methods if (1) the aquifer is relatively coarse grained so that the effect of delayed drainage is not large, and (2) the pumping rate is not so high that a substantial part of the aquifer is dewatered.

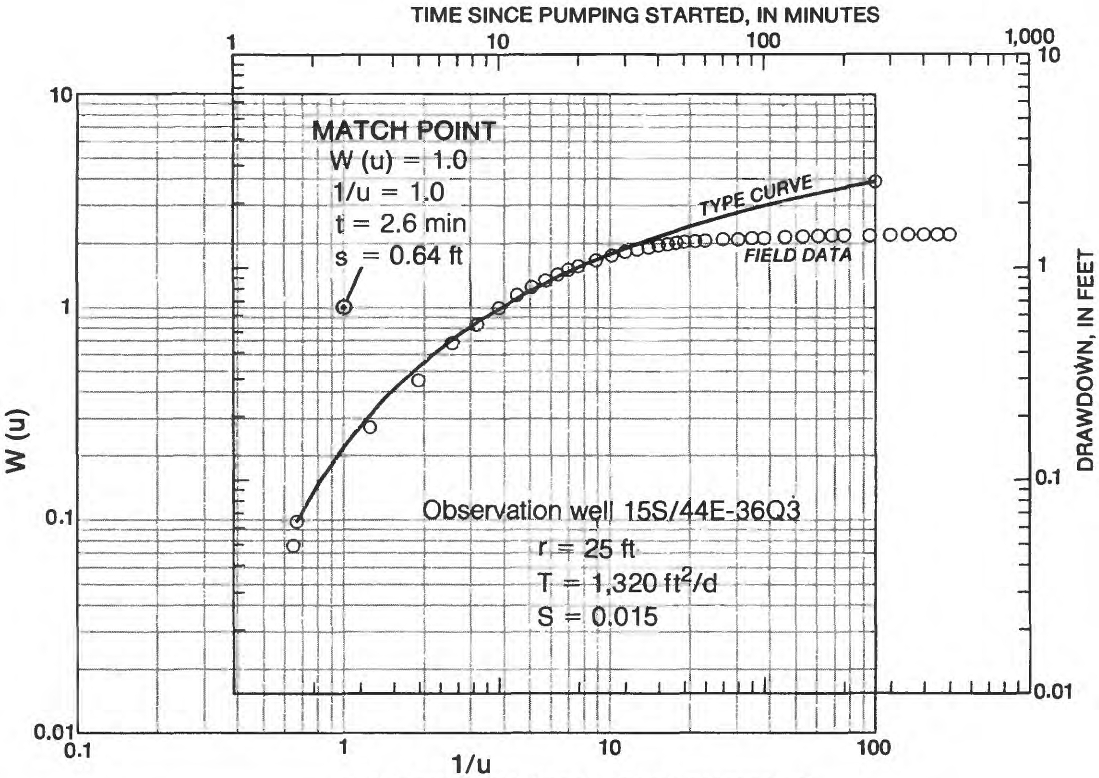
Theis method.--In its simplest form the Theis equation is:

$$s = \frac{Q}{4\pi T} W(u), \qquad [L] \qquad (1)$$

where s is drawdown [L], Q is the pumping rate [L^3T^{-1}], T is transmissivity [L^2T^{-1}], and $W(u)$ is the well function of u [dimensionless], which equals

$$-0.577216 - \log_e u + u - \frac{u^2}{2x2!} + \frac{u^3}{3x3!} - \frac{u^4}{4x4!} + \ldots$$

In this expression, $u = (r^2S)/(4Tt)$, where r is the distance from the pumped well to the observation well [L], S is the storage coefficient [dimensionless], and t is time since pumping started [T] (Lohman, 1979).



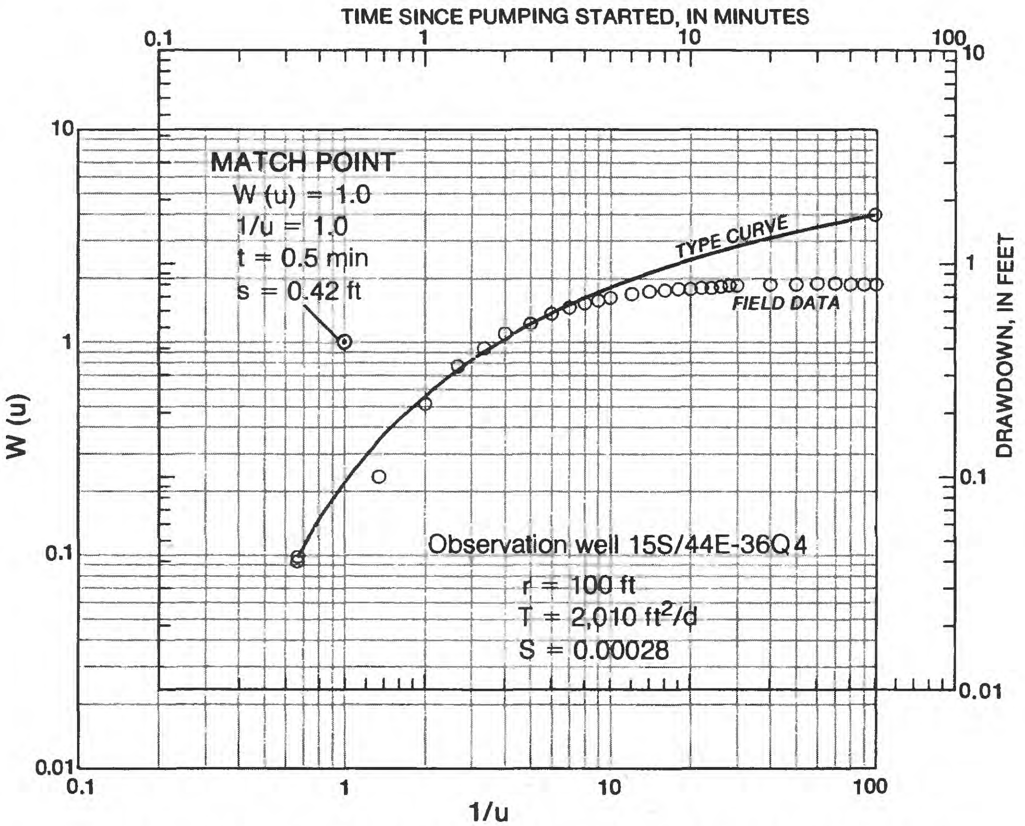


FIGURE 6. — Theis method of solution for data collected during saline-production-well aquifer test. (Symbols are defined in equation 1 in the text.)

The forms of the Theis equation used to determine the transmissivity and storage coefficient are:

$$T = \frac{QW(u)}{4\pi s} \qquad [L^2T^{-1}] \qquad (2)$$

and

$$S = \frac{4Ttu}{r^2}, \qquad \text{[dimensionless]} \qquad (3)$$

where the symbols are the same as defined in equation 1 (Lohman, 1979).

To solve for T and S, Theis devised a graphic method of solution that involves the use of a type curve. To apply this method, a data plot of drawdown versus time (field data) is matched to the type curve of $W(u)$ versus $1/u$. Both the field data and the type curve are plotted on logarithmic graph paper. A convenient match point is selected, and the values of s, t, $W(u)$, and $1/u$ are noted. These values then are substituted in equations 2 and 3, and the equations are solved for T and S.

The Theis method of solution for data collected at observation wells 15S/44E-36Q3 and -36Q4 and the RO production well (16S/44E-1C1) is shown in figures 6 and 7. The storage coefficient cannot be determined from the data collected at the RO production well because r (the distance from the pumped well) is equal to zero in equation 3.

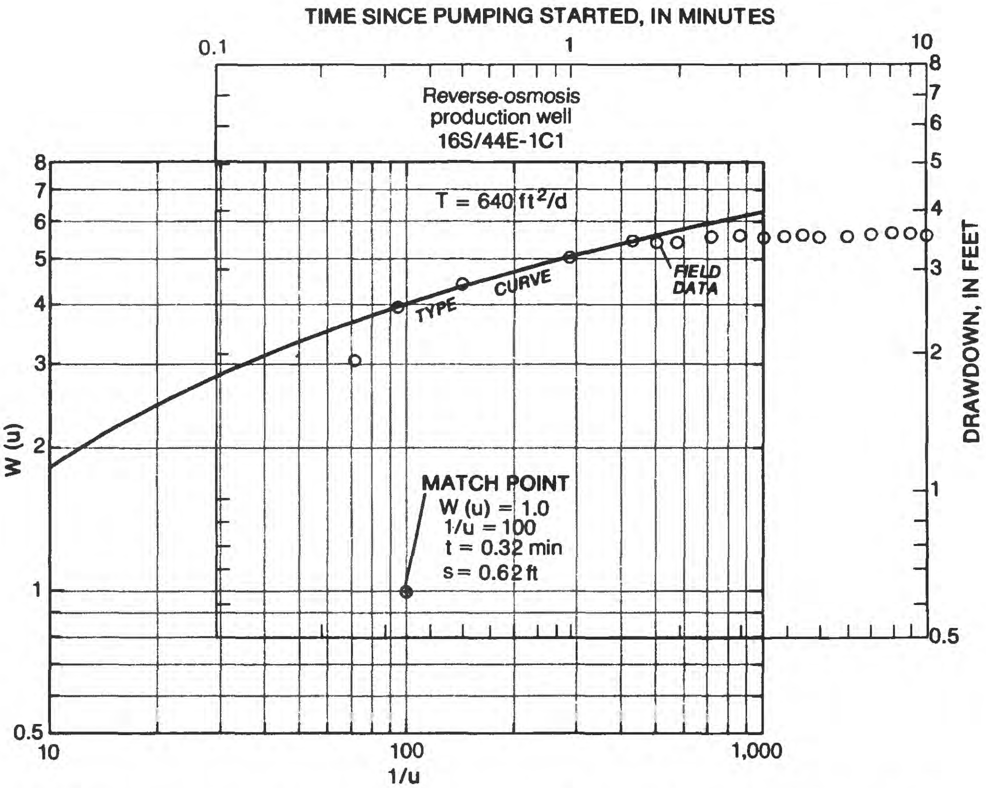


FIGURE 7. — Theis method of solution for data collected during reverse-osmosis-production-well aquifer test. (Symbols are defined in equation 1 in the text.)

Jacob-Cooper method.--The Jacob-Cooper method uses a modified form of the Theis equation. This method is based on the fact that when u is sufficiently small, the Theis equation can be modified to the following form without significant error:

$$s = \frac{2.3Q}{4\pi T} \log \frac{2.25Tt}{r^2S}, \qquad [L] \qquad (4)$$

where the symbols are the same as defined in equation 1.

The forms of the Jacob-Cooper equation used to determine the transmissivity and storage coefficient are:

$$T = \frac{2.3\ Q}{4\pi\Delta s} \qquad [L^2T^{-1}] \qquad (5)$$

and

$$S = \frac{2.25\ Tt_o}{r^2}, \qquad [dimensionless] \qquad (6)$$

where Δs is the drawdown across one log cycle [L], t_o is the time at the point where the straight line intersects the zero-drawdown line [T], and the other symbols are the same as in equation 1 (Lohman, 1979).

The Jacob-Cooper method is more convenient to use than the Theis method because it is solved using semilogarithmic paper instead of logarithmic paper, and under ideal conditions the data plot along a straight line rather than along a curve. For values of u less than about 0.05 the Jacob-Cooper method gives virtually the same results as the Theis method. Examination of the definition of u shows that this condition is usually satisfied when distance from the pumped well (r) is small and time (t) is large.

The Jacob-Cooper method of solution for data collected at all the wells used in both aquifer tests is shown in figures 8 and 9. As with the Theis method of solution, the storage coefficient cannot be determined from data collected at the pumped wells.

Jacob-Cooper recovery method.--The Jacob-Cooper method also can be used to analyze data collected during the recovery phase of an aquifer test. The analysis is virtually the same as for the pumping phase except that water-level recovery ($s - s'$) (fig. 4) is plotted versus time since pumping stopped (t') on semilogarithmic paper. The pumping rate (Q) used for the recovery method is equal to the average pumping rate during the pumping phase. Therefore, the recovery method has the advantage that drawdown variations resulting from slight variations in the pumping rate during the pumping phase do not occur during the recovery phase.

Water-level measurements made during the aquifer tests indicate that actual drawdowns are less than those predicted by the Theis curve at larger values of time (t). This type of deviation from the Theis curve generally reflects the presence of a lateral recharge boundary or a leaky aquifer. Because there are no apparent recharge boundaries in the Stovepipe Wells Hotel area, the departure from the Theis curve is probably the result of upward leakage of ground water from underlying sediments.

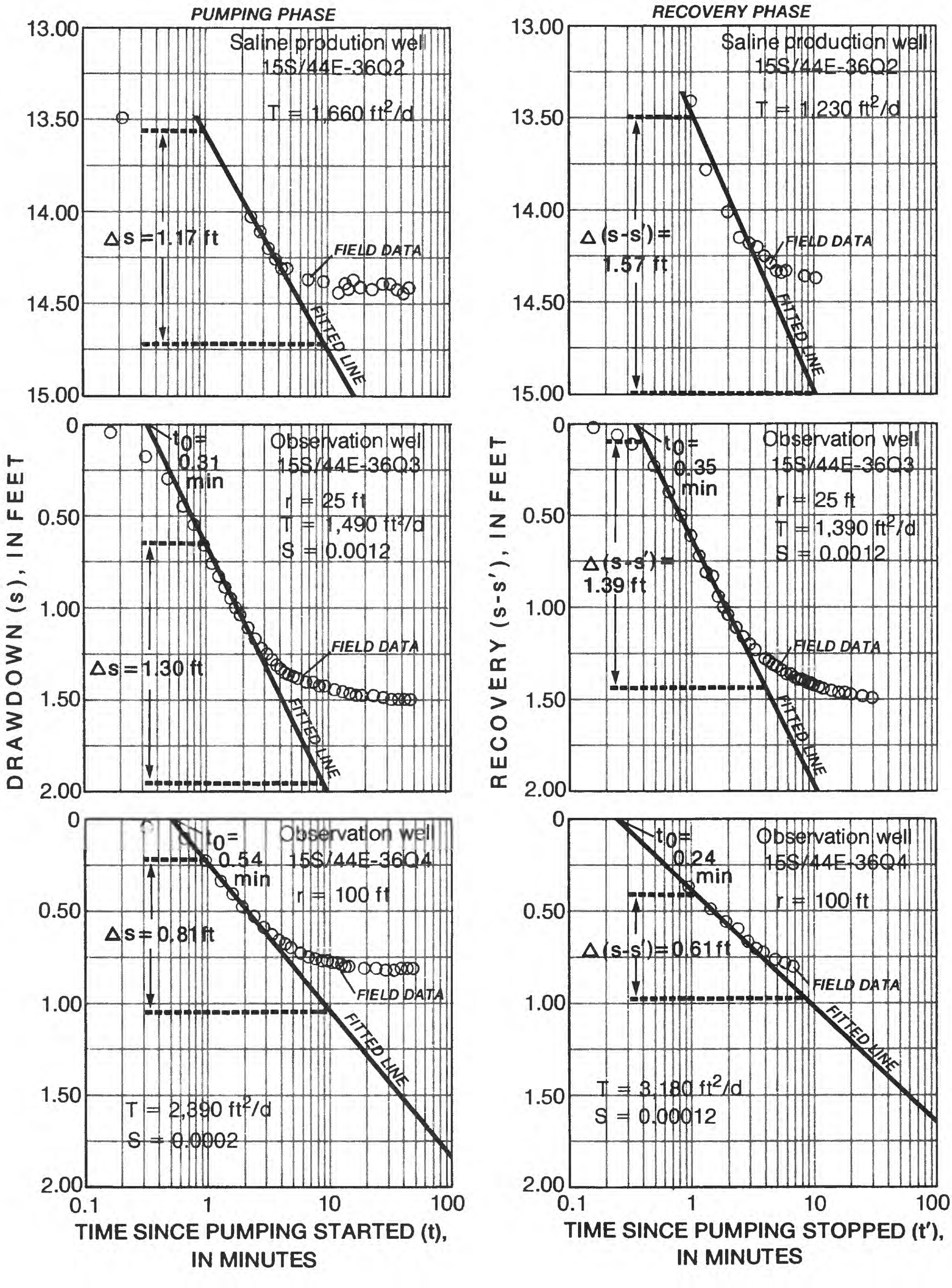


FIGURE 8. — Jacob-Cooper method of solution for data collected during the pumping and recovery phases of saline-production-well aquifer test. (Symbols are defined in equation 1 in the text.)

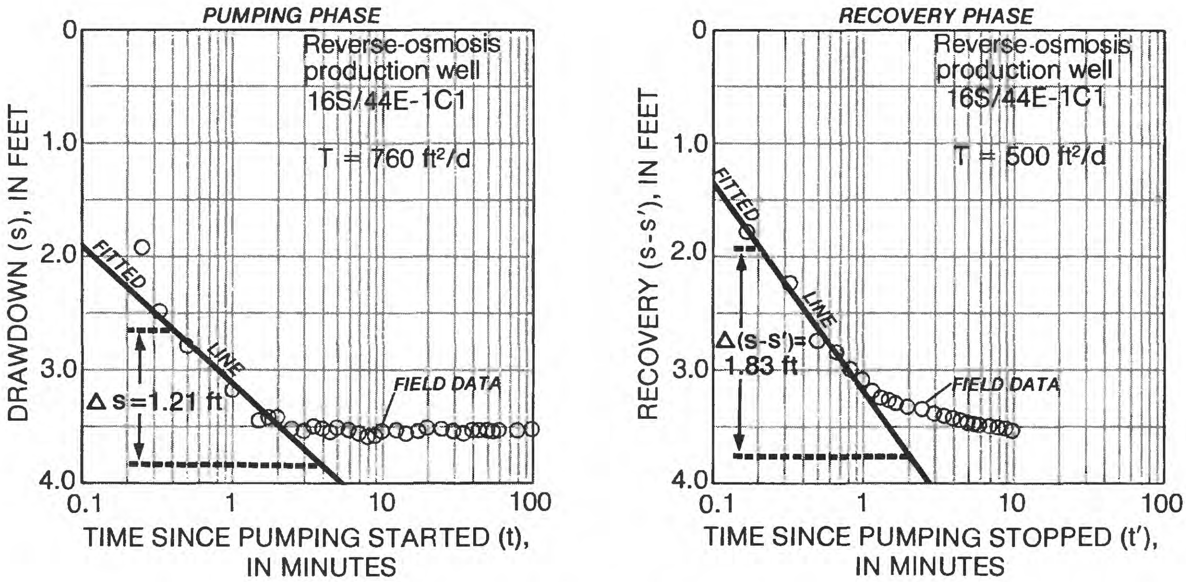


FIGURE 9. — Jacob-Cooper method of solution for data collected during the pumping and recovery phases of reverse-osmosis-production-well aquifer test. (Symbols are defined in equation 1 in the text.)

The transmissivity and storage coefficient of an aquifer affected by leakage may be solved by conventional methods of analysis based on the Theis equation if the data are collected close to the pumped well. In general, drawdown data collected early in an aquifer test are affected by leakage to a lesser degree than data collected at a later time (Neuman and Witherspoon, 1972, p. 1291). Analysis of drawdown data collected from wells at a distance from the pumped well and at later times tends to overestimate the transmissivity of the aquifer. Therefore, the transmissivity and storage-coefficient estimates from data collected early in the tests at the pumped wells and at the 25-foot observation well probably best represent the aquifer.

Hantush-Jacob method.--Another method of calculating the transmissivity and storage coefficient for an aquifer affected by leakage is the Hantush-Jacob method (Heath, 1983, p. 51). This method assumes that water leaks across confining beds with no effect on storage in the confining beds. The use of this method involves matching data plots of s versus t on logarithmic graph paper to a family of type curves of $W(u,r/\beta)$ versus $1/u$, where $W(u,r/\beta)$ is known as the leaky well function [dimensionless] (defined in Lohman, 1979, p. 32) (fig. 10). The four coordinates of the match point are substituted into the following equations to determine T and S:

$$T = \frac{QW(u,r/\beta)}{4\pi s} \qquad [L^2T^{-1}] \qquad (7)$$

and

$$S = \frac{4Ttu}{r^2}, \qquad [\text{dimensionless}] \qquad (8)$$

where $W(u,r/\beta)$ is defined above and the symbols are the same as defined in equation 1.

The Hantush-Jacob method of solution for data collected at observation wells 15S/44E-36Q3 and -36Q4 during the pumping phase of the saline-well aquifer test is shown in figure 10.

Aquifer-Test Results

Values of transmissivity and storage coefficient that were obtained using the Theis, Jacob-Cooper, Jacob-Cooper recovery, and Hantush-Jacob methods are summarized in table 3. As shown in the table, estimates of transmissivity range from 1,200 to 3,180 ft^2/d for the saline-production-well test and from 500 to 760 ft^2/d for the RO-production-well test. The average transmissivity calculated from data from the saline-production-well test for the different methods is 1,710 ft^2/d. This value probably is high because it includes the transmissivity values obtained using the Theis and Jacob-Cooper methods at the 100-foot observation well. Drawdown data collected from this well probably are affected by leakage; therefore, conventional methods of analysis based on the Theis equation overestimate the transmissivity. The transmissivity value obtained using the Hantush-Jacob method, which takes into account leakage, was significantly lower than the values obtained using conventional methods at the 100-foot observation well, but similar to values obtained using the several methods at the 25-foot observation well and at the pumped well. The average transmissivity obtained from the saline-production-well test is about 1,360 ft^2/d if the values from the Theis and Jacob-Cooper methods at the 100-foot observation well are not included.

The average value of transmissivity obtained using the different methods from the RO-production-well test is 630 ft^2/d. This value is significantly lower than the average transmissivity calculated from the saline-production-well test. Comparison of the geologic logs from the recently completed observation well (15S/44E-36Q4), which is near the saline production well, to the log of the RO production well (table 2) does not show any significant variations in lithology that could explain the differences in calculated transmissivity values. Because no observation wells are present near the RO production well to verify the calculated transmissivity values, the average value of 1,360 ft^2/d calculated from the saline-production-well test was used in the following section for computing projected drawdowns.

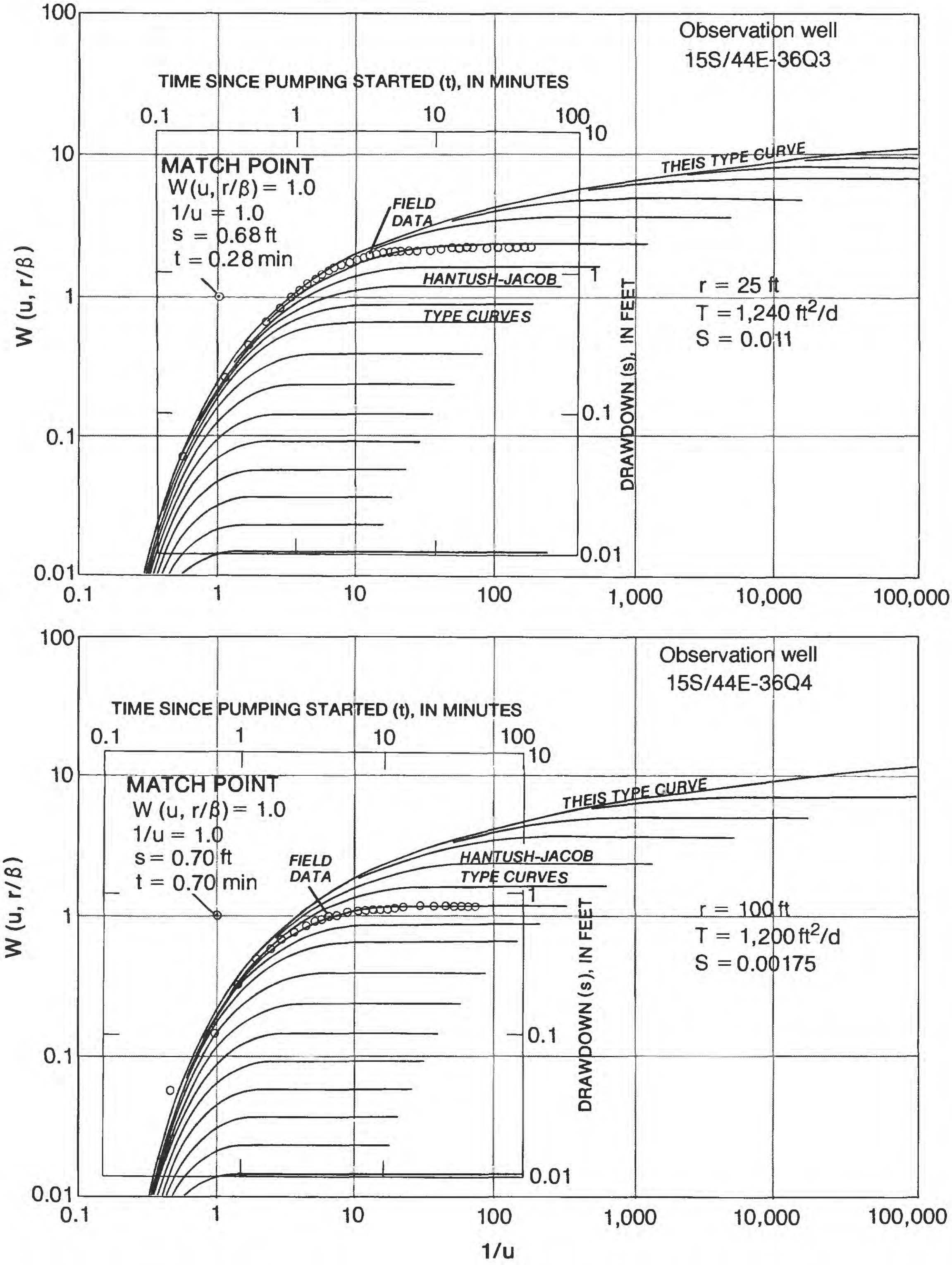


FIGURE 10. – Hantush-Jacob method of solution for data collected during saline-production-well aquifer test. (Symbols are defined in equation 1 in the text.)

Table 3.--Estimates of transmissivity and storage coefficient from aquifer tests

[--, no data available]

Well	Transmissivity (ft^2/d)		Storage coefficient (dimensionless)		Method of analysis
	Pumping phase	Recovery phase	Pumping phase	Recovery phase	
		Test 1.-- Saline production well			
Saline production well (15S/44E-36Q2)	1,660	1,230	--	--	Jacob-Cooper
25-foot observation well (15S/44E-36Q3)	1,490	1,390	1.2×10^{-3}	1.2×10^{-3}	Jacob-Cooper
	1,320	--	1.5×10^{-2}	--	Theis
	1,240	--	1.1×10^{-2}	--	Hantush-Jacob
100-foot observation well (15S/44E-36Q4)	2,390	3,180	2.0×10^{-4}	1.2×10^{-4}	Jacob-Cooper
	2,010	--	2.8×10^{-4}	--	Theis
	1,200	--	1.75×10^{-3}	--	Hantush-Jacob
		Test 2.--RO production well			
RO production well (16S/44E-1C1)	760	500	--	--	Jacob-Cooper
	640	--	--	--	Theis

Calculated values of storage coefficient range from 1.2×10^{-4} to 1.5×10^{-2} (table 3). As discussed in the preceding section of this report, values of storage coefficient could be determined only from data collected at the observation wells near the saline production well. These low storage coefficients suggest that the aquifer is confined. However, because of the short duration of the aquifer test, the calculated storage-coefficient values probably are lower than actual aquifer conditions. The geologic and geophysical logs of the observation wells (fig. 3) do not indicate that the aquifer is confined by an extensive clay layer; therefore, over a long period of time the response of the aquifer probably would more closely approximate that of an unconfined aquifer.

The storage coefficient of an unconfined aquifer is equivalent to the specific yield. The specific yield can be estimated for a particular aquifer by inspecting available geologic logs and assigning specific-yield values to different aquifer materials identified on the logs. Inspection of available geologic logs in the Stovepipe Wells Hotel area indicates that the aquifer consists predominantly of gravel and sand. French (1978, p. 10) estimated that gravel and sand aquifers have a specific yield of 0.25. This value of specific yield was selected as representative of unconfined conditions in the study area.

The lowest storage-coefficient value obtained from the aquifer-test data (1.2×10^{-4}) and the value estimated from the lithology of the aquifer material (0.25) both were used in the following section to estimate potential drawdowns. The drawdown calculated using the confined storage-coefficient value indicates the maximum drawdown that might be expected from the additional pumping, and the drawdown calculated using the unconfined storage-coefficient (specific yield) value indicates the minimum drawdown.

POTENTIAL DRAWDOWN

The Theis equation (eq. 1) provides a means of estimating the additional drawdown that might be expected from increased pumpage in the Stovepipe Wells Hotel area. This equation assumes no recharge; therefore, actual drawdowns are not likely to be as great as those calculated by the Theis equation if the aquifer receives recharge.

The assumed increase in pumpage in the Stovepipe Wells Hotel area is 37,500 gal/d during the peak season. To provide a conservative estimate of potential drawdown, this increase in peak-season pumpage was assumed to extend throughout the year. All the pumpage increase was assumed to occur at the saline production well (15S/44E-36Q2).

Figure 11, which is based on the Theis equation, shows the additional drawdown with distance from the saline production well due to the increase in pumpage (37,500 gal/d) after 1, 10, and 50 years. The maximum distance shown in the figure is 10,000 feet, which is the approximate distance of the phreatophyte stand from the saline production well. Additional increases in pumpage at the Stovepipe Wells Hotel well field or at other wells in the area would cause larger drawdowns than those shown in figure 11.

Potential additional drawdowns were calculated by using the average transmissivity value of 1,360 ft^2/d and both the lowest storage-coefficient value obtained from the aquifer-test data (1.2×10^{-4}) and the (higher) value (0.25) from estimated specific yield (fig. 11). The drawdowns calculated using the low storage-coefficient value represent the maximum additional drawdown that might be expected from the proposed increased pumpage; the drawdowns calculated by using the higher storage coefficient derived from specific yield represent the minimum additional drawdown. Calculated additional drawdowns after 50 years of pumping range from about 5.7 feet near the pumped well to 0.3 foot near the phreatophyte stand by using the higher storage coefficient, and from about 7.8 feet near the pumping well to 2.4 feet at the phreatophyte stand by using the lower storage-coefficient value (fig. 11). Actual drawdowns probably will be somewhere between those values.

To determine if the estimates of additional drawdowns are realistic, they were compared to drawdowns during 1973-85 that occurred in response to existing pumpage. During this 13-year period, all measured drawdowns in observation wells in the Stovepipe Wells Hotel area were less than 2 feet. The drawdown in the well closest to the phreatophyte stand (well 15S/45E-31M1) was 1.3 feet (fig. 12). Total pumpage for the 13-year period averaged 34,200 gal/d (Gary Jensen, National Park Service [RO-plant operator], oral commun., 1986). This value of pumpage is approximately the same as the increase in pumpage needed to provide water treated by RO for all uses. Therefore, the measured drawdown at well 15S/45E-31M1 can be compared to calculated drawdowns in figure 11.

Observation well 15S/45E-31M1 is about 3,500 feet northeast of the saline production well. Figure 11 shows that after 10 years of pumping, the calculated drawdown at a distance of 3,500 feet from the saline production well is 0.50 foot assuming unconfined conditions (storage coefficient of 0.25)

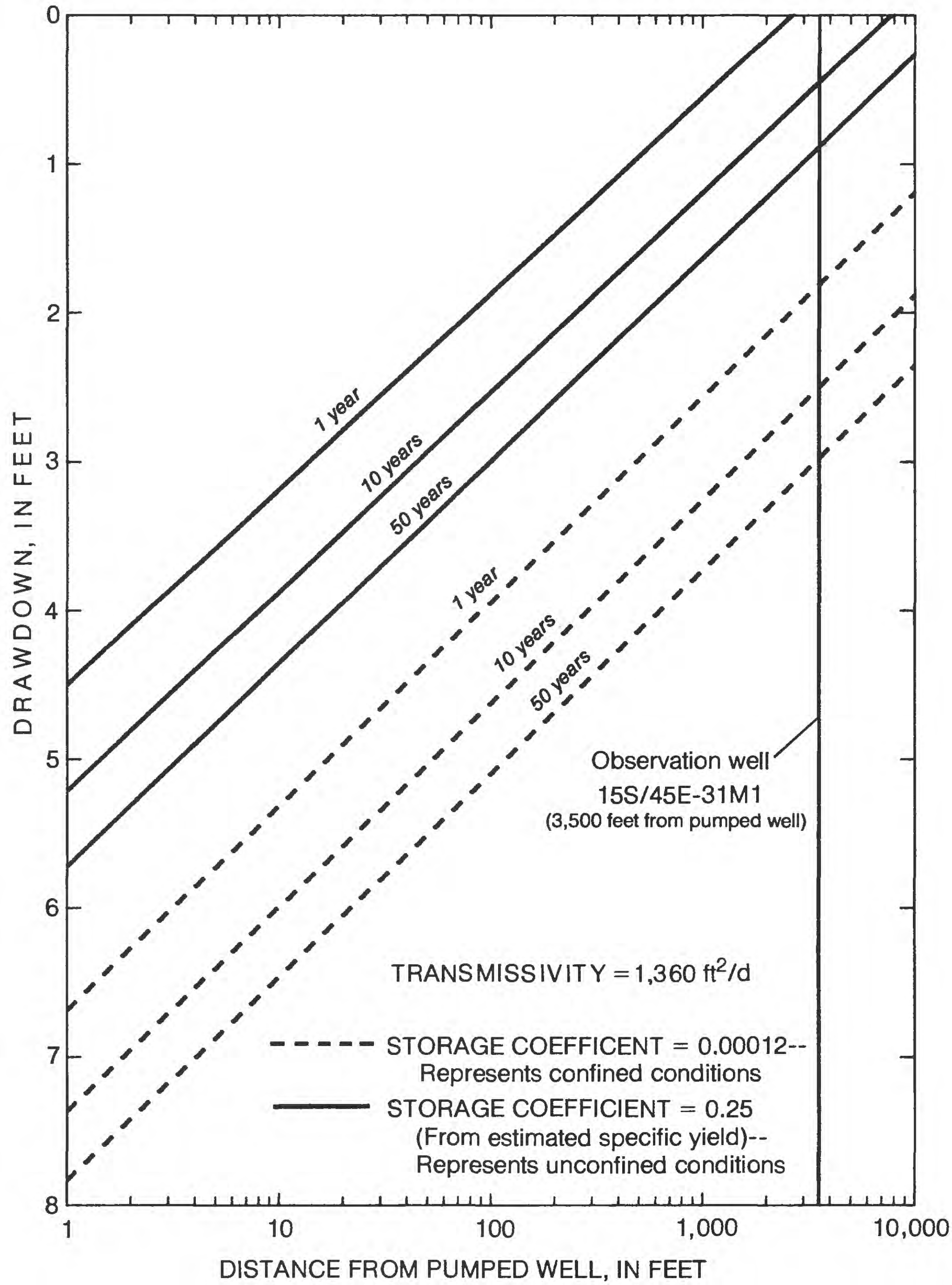


FIGURE 11. – Potential additional drawdown, for selected values of storage coefficient, at specified distances from the saline production well after 1, 10, and 50 years of increased pumpage.

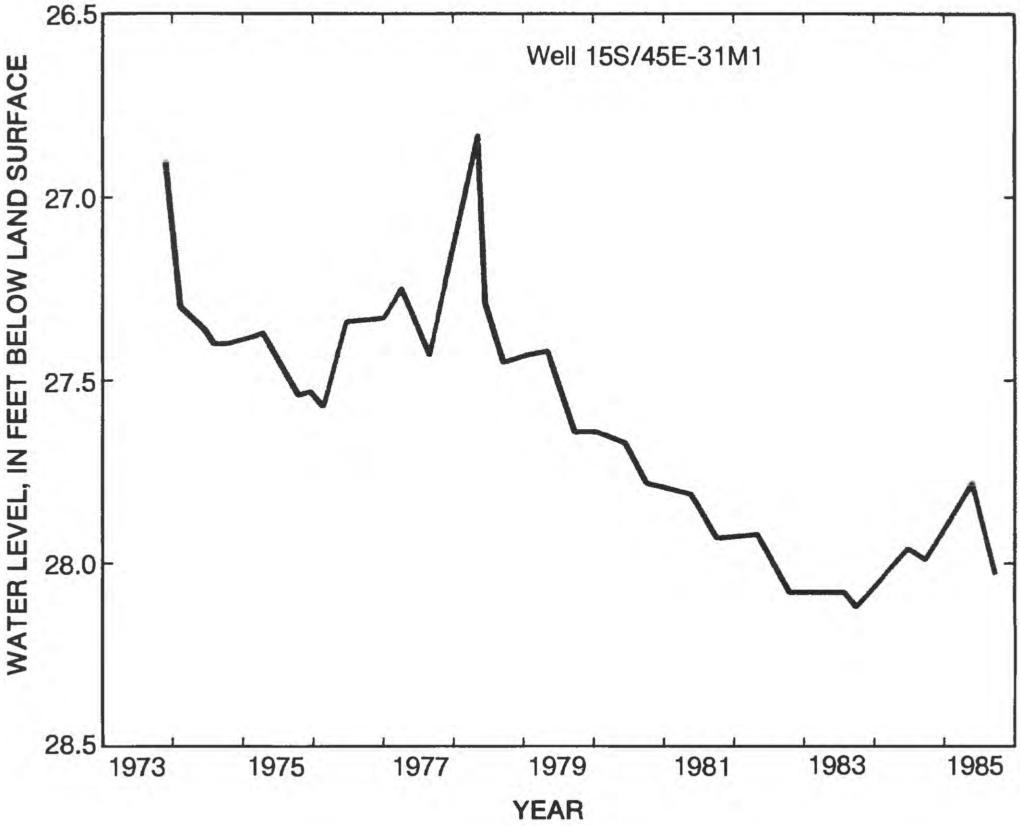


FIGURE 12. – Water-level hydrograph for well 15S/45E-31M1, 1973-85.

and 2.5 feet assuming confined conditions (storage coefficient of 1.2×10^{-4}). Calculated drawdowns after 13 years of pumping are not shown in figure 11, but they would be only slightly greater than those shown for 10 years. Therefore, the measured drawdown of 1.3 feet is within about 1 foot of both the minimum and maximum calculated drawdown. The similarity between measured and calculated drawdowns indicates that the values of transmissivity and storage coefficient used to calculate the distance-drawdown curves shown in figure 11 adequately represent the aquifer system and can be used to estimate additional drawdowns in the area.

SUMMARY AND CONCLUSIONS

The Theis equation was used to estimate additional drawdowns that might be expected from a 37,500-gal/d increase in peak-season pumpage at the Stovepipe Wells Hotel well field. The increase in peak-season pumpage was assumed to extend throughout the year in order to estimate the maximum additional drawdowns that might occur. This value of pumpage, the average transmissivity value obtained from the saline-production-well aquifer test (1,360 ft^2/d), and storage-coefficient values representative of confined (1.2×10^{-4}) and unconfined (0.25) conditions were input into the Theis equation to calculate the additional drawdown that might occur after 1, 10, and 50 years of pumping. The drawdown calculated by using the confined storage coefficient represents the maximum additional drawdown that might be expected from the assumed increase in pumpage; the drawdown calculated by using the unconfined storage coefficient represents the minimum additional drawdown.

If confined conditions are assumed, the calculated additional drawdowns after 50 years of pumping range from 7.8 feet near the pumped well (saline production well) to 2.4 feet at the phreatophyte stand about 10,000 feet east of the saline production well. If unconfined conditions are assumed, calculated additional drawdowns range from 5.7 feet near the pumped well to 0.3 foot at the phreatophyte stand. Actual drawdowns probably will be somewhere between these values. In either case, calculated additional drawdowns at the phreatophyte stand are small.

The calculated drawdowns presented here represent only the response of the aquifer to the increase in pumpage needed to provide potable water for all uses in the Stovepipe Wells Hotel area. These calculated drawdowns would be in addition to drawdowns resulting from existing pumpage. Additional increases in pumpage at the Stovepipe Wells Hotel well field or at other wells in the area would cause larger drawdowns.

Drawdowns measured in an observation well during 1973-85, in response to an average pumpage of 34,200 gal/d at the Stovepipe Wells Hotel well field, are similar to drawdowns calculated by the Theis equation for the increase in pumpage of 37,500 gal/d. The measured drawdown in the observation well was 1.3 feet and the calculated drawdown was 0.50 assuming unconfined conditions and 2.5 feet assuming confined conditions. The similarity of the measured and calculated drawdowns indicates that the values of transmissivity and storage coefficient determined for this study adequately represent the aquifer and that the calculated additional drawdowns are in close agreement. Continued water-level monitoring in the area would allow detection of potential problems should drawdowns be larger than predicted.

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