GROUND-WATER CONDITIONS IN THE COTTONWOOD-WEST OAKLEY FAN AREA, SOUTH-CENTRAL IDAHO

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CONVERSION FACTORS

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

Multiply	By	To obtain
acre	4,047	square meter
acre-foot (acre-ft)	1,233	cubic meter
cubic foot per day (ft^3/d)	0.02832	cubic meter per day
foot (ft)	0.3048	meter
foot squared per day (ft^2/d)	0.0929	meter squared per day
gallon per minute (gal/min)	0.06309	liter per second
inch (in.)	25.40	millimeter
micromho (μmho)	1.000	microsiemens
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer

Concentrations of chemical constituents are reported in mg/L (milligrams per liter) or μg/L (micrograms per liter). Milligrams and micrograms per liter, within the range of values presented in this report, are numerically equal to parts per million and parts per billion. Milliequivalents per liter are the milligrams of a constituent per liter divided by the atomic weight of the constituent and multiplied by the constituent charge.

Temperature in °C (degrees Celsius) can be converted to °F (degrees Fahrenheit) as follows:

$$°F = (1.8)(°C) + 32$$

NGVD of 1929 (National Geodetic Vertical Datum of 1929): The term "National Geodetic Vertical Datum of 1929" replaces the formerly used term "mean sea level" to describe the datum for altitude measurements. The geodetic datum is derived from a general adjustment of the first-order leveling networks in both the United States and Canada. For convenience in this report, the datum also is referred to as "sea level."

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ABSTRACT

The Cottonwood-West Oakley Fan area occupies nearly 210 square miles in Cassia County, south-central Idaho. Intensive ground-water development has resulted in rapid water-level declines and establishment of two critical ground-water areas.

A northwest-trending fault is nearly coincident with the boundary between the two critical ground-water areas. Southwest of the fault, water levels in the limestone are as much as 200 feet higher than those in the silicic volcanics aquifer northeast of the fault, which indicates the fault is an effective barrier to ground-water movement. Results of an aquifer test made in a well completed in limestone southwest of the fault further indicate no hydraulic connection with the silicic volcanics aquifer northeast of the fault.

Water levels in wells completed in the limestone and silicic volcanics aquifers have declined 5 and 5.5 feet per year since 1977. Ground-water withdrawals in 1980 were about 60,000 acre-feet from the silicic volcanics aquifer and, between 1977 and 1982, have averaged about 5,300 acre-feet per year from the limestone aquifer.

Annual recharge to the silicic volcanics aquifer probably is between about 10,000 and 26,000 acre-feet; recharge to the limestone aquifer probably is near 4,000 acre-feet.

Limited water-quality data indicate the ground water in both aquifers is chemically suitable for irrigation and domestic use. Geochemical evidence suggests that some ground water in silicic volcanics northeast of the fault has moved upward from underlying limestone. Sampled ground water in limestone southwest of the fault and in silicic volcanics northeast of the fault bears geochemical imprints of the respective host rocks.

INTRODUCTION

The Cottonwood-West Oakley Fan area occupies nearly 210 mi^2 in Cassia County, south-central Idaho. Altitudes range from about 4,100 ft to nearly 7,900 ft above sea level. Except for small valley lowlands, the southwestern half is mountainous and not suited for agriculture. The northeastern half is flat and consists of prime agricultural land heavily dependent on ground water for irrigation.

Irrigated agriculture and livestock raising are the economic base of the area. Early farms and ranches were located along Foothills Road (fig. 1) to utilize water from springs along the base of the Rock Creek Hills. Irrigation water also was diverted from streams flowing from Rock Creek Hills. From 1959 to about 1961, intensive development of ground water resulted in rapid declines in water levels. In 1962, the Idaho Department of Water Resources established the Cottonwood CGWA (Critical Ground Water Area), shown in figure 1.

In the late 1960's, large tracts of land in the West Oakley Fan area (fig. 1) were released by the Federal government for development under the Desert Land Entry Act of 1877. Rapid, widespread development for farming had significant impact on the ground-water resources and, in 1982, the Idaho Department of Water Resources established the West Oakley Fan CGWA.

Purpose and Scope

The purpose of this study was to determine present (1982) ground-water conditions in the Cottonwood-West Oakley Fan area. Resulting information will aid the Idaho Department of Water Resources in establishing pumping rates necessary to manage ground-water resources.

The scope of study included: (1) Compile geologic and hydrologic data; (2) update the well inventory; (3) estimate ground-water withdrawals; (4) measure water levels in wells during the nonirrigation season; (5) define the hydraulic influence of a fault that traverses the study area; (6) collect data on ground-water quality to determine the suitability of the water for use and, if possible, to help define the hydraulic relation between adjacent aquifers of different rock types on opposite sides of the fault; (7) conduct an aquifer test to determine hydraulic characteristics in the vicinity of the fault; (8) estimate annual volume of precipitation in the drainage area; and (9) determine the relation of ground-water recharge to withdrawals.

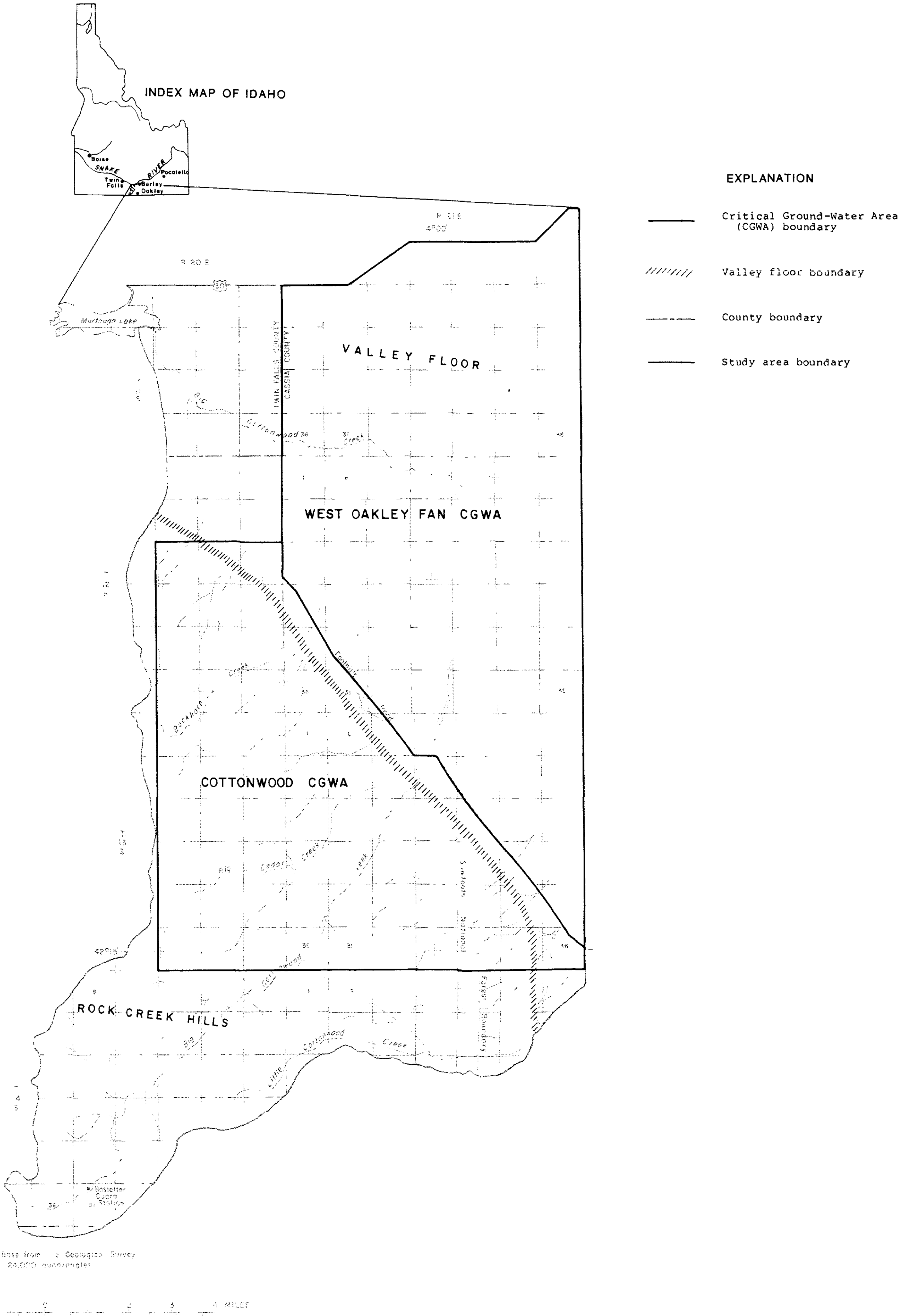


Figure 1. -- Location of study area.

Acknowledgments

The authors express their gratitude to citizens in the Cottonwood-West Oakley Fan area for their cooperation in allowing access to their wells and property for collection of data necessary for this study. Special thanks to Mr. Merle Wolverton of Golden Valley Land and Cattle Company for the use of his well in an aquifer test, and to Mr. Stan Szczepanowski and others of the Idaho Department of Water Resources, for their cooperation and assistance in collecting field data and allowing access to their records.

Previous Work

Crosthwaite (1969) included the present study area in his investigation of the Goose Creek and Rock Creek basins. The study covered 1,630 mi^2 of mountains and gently rolling plains extending from Nevada and Utah into Idaho. The area discussed in the present study accounts for about 10 percent of Crosthwaite's study area.

Crosthwaite (1969) determined that four water-bearing formations have been developed and consist of Paleozoic limestone, Miocene Idavada Volcanics, Holocene and Pleistocene basalt of the Snake River Group, and Holocene and Pleistocene alluvium. Crosthwaite (1969) also reported that about 35,000 acre-ft of ground water was pumped annually from about 80 wells in the Cottonwood-West Oakley Fan areas during 1961-65, which resulted in water-level declines ranging from a few feet to several tens of feet.

With the exception of a few deep wells drilled in the mid-1950's, ground-water development on the West Oakley Fan was limited to shallow domestic wells completed in a perched alluvial aquifer; extensive development for irrigation began in the late 1960's and 1970's (Crosthwaite, 1969, p. 40). From the time of early agricultural development, water for irrigation on the West Oakley Fan was pumped from wells along Foothills Road on the western side of the valley or was diverted from streams originating in the Rock Creek Hills and imported to the West Oakley Fan in ditches. Limited data indicated no change in water levels in the shallow wells because seepage infiltration and recharge from the imported water tended to offset pumpage withdrawals.

In the 1970's, the Idaho Department of Water Resources began to monitor ground-water levels in observation wells throughout the valley. In 1978, they conducted an aquifer test while monitoring water levels on both sides of the fault (hereafter referred to informally as the Foothills Road fault) separating the Cottonwood and West Oakley Fan CGWA's. Results of the test showed no change in hydraulic conditions in the vicinity of the fault.

Well-Numbering System

The numbering system used by the U.S. Geological Survey in Idaho indicates the location of wells within the official rectangular subdivision of the public lands, with reference to the Boise base line and meridian. The first two segments of the number designate the township and range. The third segment gives the section number, followed by three letters, which indicate the ¼ section (160-acre tract), the ¼-¼ section (40-acre tract), the ¼-¼-¼ section (10-acre tract); and the serial number of the well within the tract. Quarter sections are lettered A, B, C, and D in counterclockwise order from the northeast quarter of each section (fig. 2). Within the quarter sections, 40-acre and 10-acre tracts are lettered in the same manner. Well 11S-21E-2ADD1 is in the SE¼SE¼NE¼ sec. 2, T. 11 S., R. 21 E., and was the first well inventoried in that tract.

GEOLOGIC UNITS AND THEIR WATER-BEARING CHARACTERISTICS

For purposes of this report, geologic formations in the Cottonwood-West Oakley Fan area are divided into (1) undifferentiated pre-Tertiary sedimentary rocks, (2) Tertiary silicic volcanics, (3) Tertiary sedimentary rocks, (4) Quaternary and Tertiary basalts, and (5) Quaternary alluvium. Areal distribution and descriptions of these units are shown in figure 3. A diagrammatic cross section showing relation of major rock units in the study area to the Foothills Road fault is presented in figure 4.

Pre-Tertiary sedimentary rocks, which consist chiefly of limestone and other marine deposits, are exposed in the Rock Creek Hills and are thought to underlie the Tertiary silicic volcanics. The pre-Tertiary sedimentary rocks, hereafter referred to as limestone, yield as much as 3,500 gal/min of water to irrigation wells along the fault zone at the northeastern edge of the Rock Creek Hills.

Tertiary silicic volcanics (locally called rhyolite), which consist chiefly of welded ash flows of the Idavada Volcanics, are exposed throughout the Rock Creek Hills and underlie the West Oakley Fan. The silicic volcanics yield between about 550 and 1,800 gal/min of water to irrigation wells.

Tertiary sedimentary rocks, which consist chiefly of clay, sand, and gravel deposits of the Salt Lake Formation, are only locally exposed in the southern part of the study area. This unit is not an important aquifer.

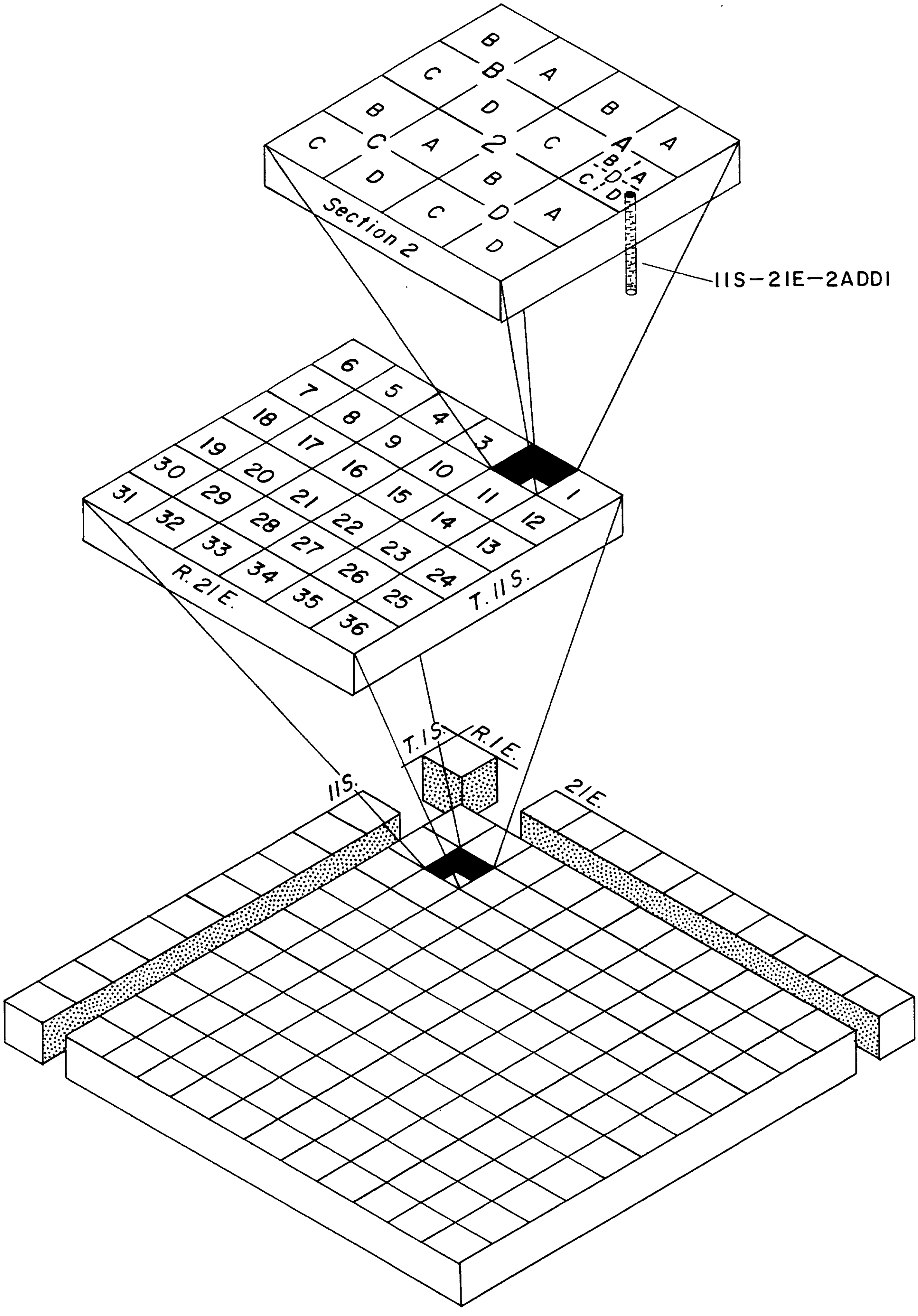
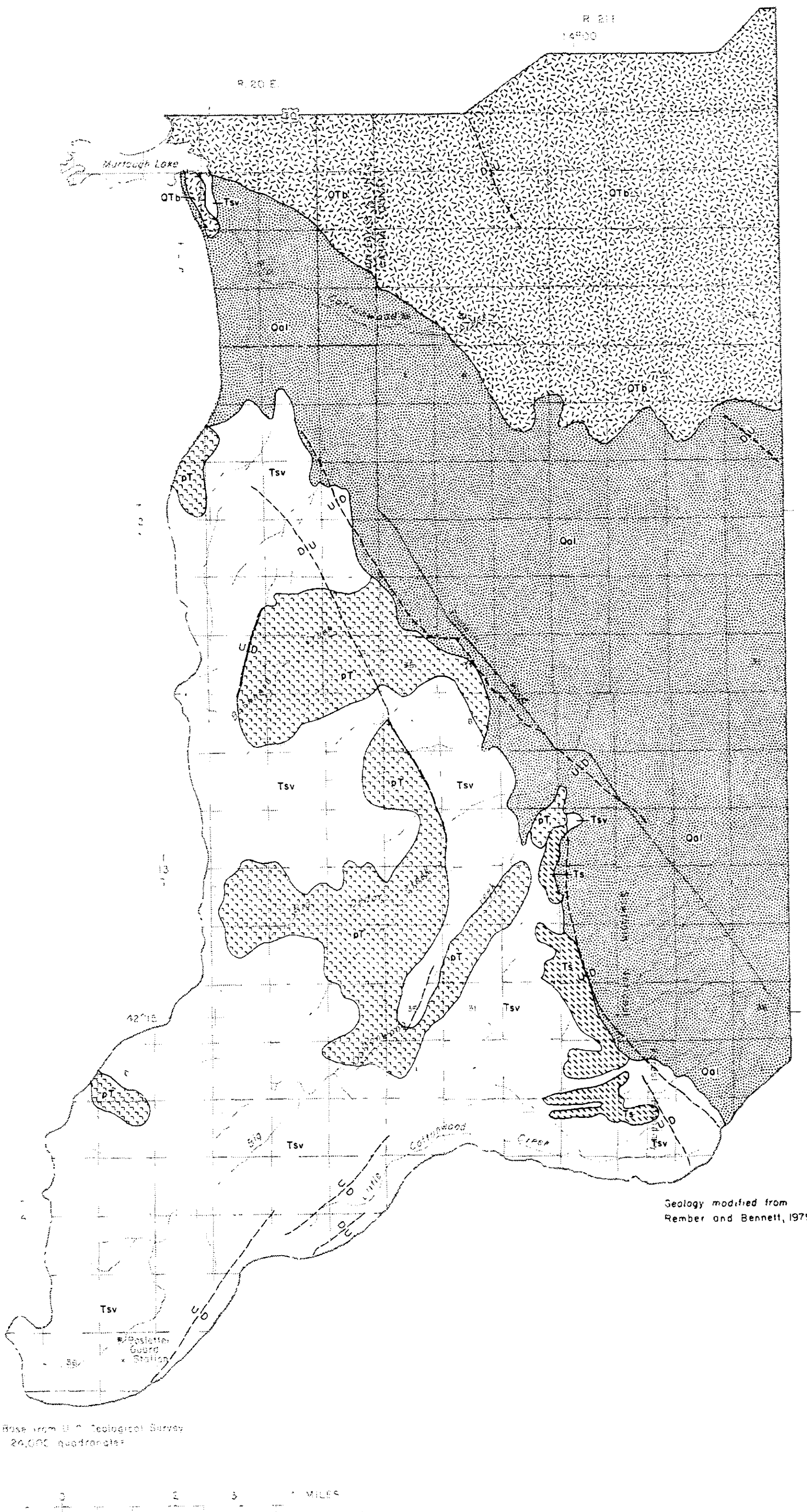


Figure 2. -- Well-numbering system.



CORRELATION OF MAP UNITS

Unit	Epoch	Period
Qal	Holocene and Pleistocene	QUATERNARY
QTb	Pleistocene and Pliocene	QUATERNARY / TERTIARY
Ts	Pliocene	TERTIARY
Tsv	Miocene	TERTIARY
pT	Pre-Tertiary	

DESCRIPTION OF MAP UNITS

Qal QUATERNARY ALLUVIUM--Unconsolidated deposits of clay, silt, sand, and gravel; includes alluvial fan deposits

QTb QUATERNARY AND TERTIARY BASALTS--Chiefly olivine basalts of the Snake River Group and Glenns Ferry Formation; includes some interbedded silt, sand, and gravel deposits

Ts TERTIARY-SEDIMENTARY ROCKS--Stream and lake deposits of clay, sand, and gravel of the Salt Lake Formation

Tsv TERTIARY SILICIC VOLCANICS--Chiefly welded ash flows, bedded tuffs, and lava flows of rhyolite and latitic composition of the Idavada Volcanics

pT PRE-TERTIARY SEDIMENTARY ROCKS, UNDIFFERENTIATED--Predominantly marine deposits of limestone; includes some quartzite

GEOLOGIC CONTACT

INFERRED FAULT--U, upthrown side; D, downthrown side

STUDY AREA BOUNDARY

Figure 3. -- Generalized geology.

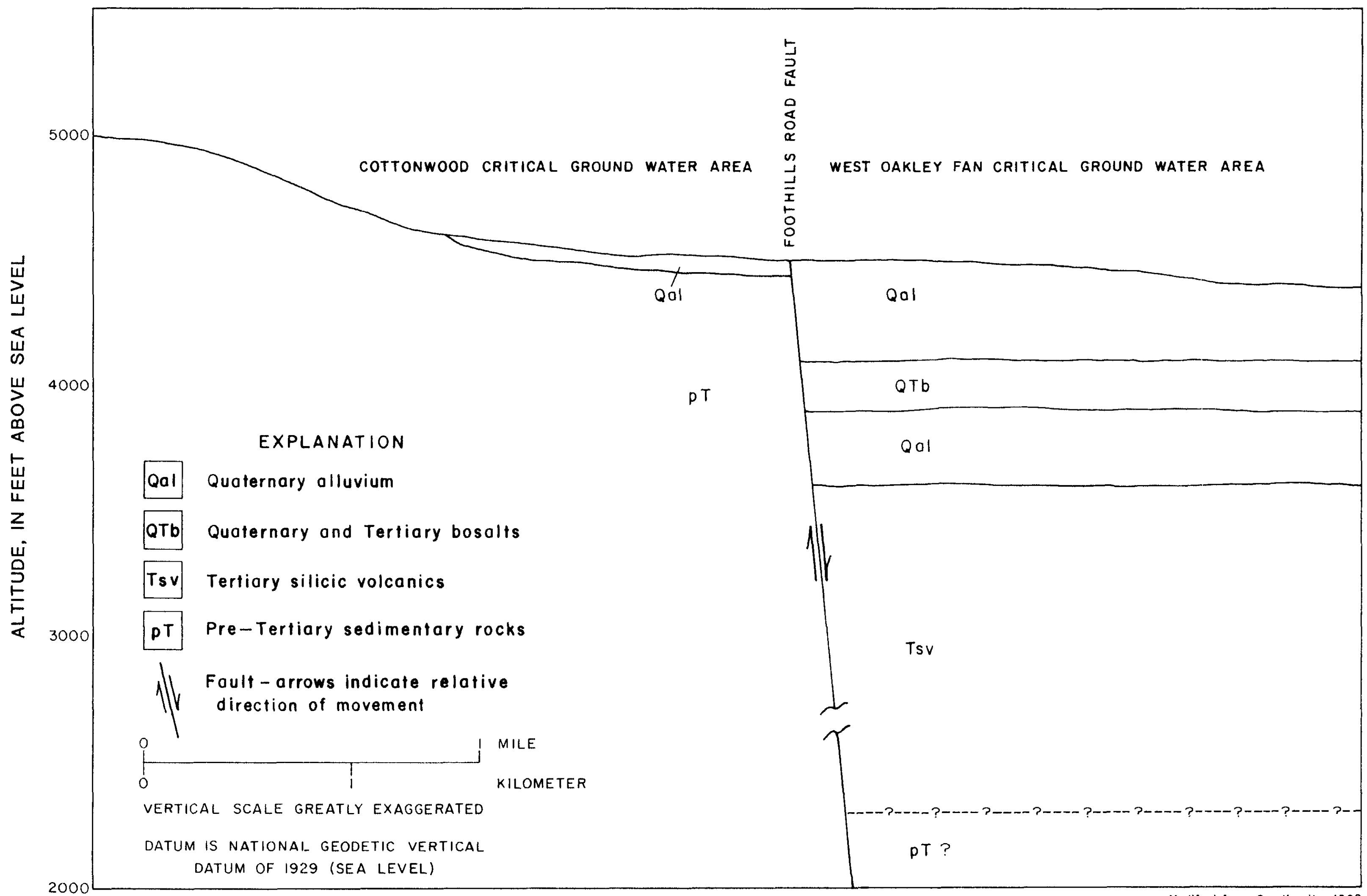


Figure 4. -- Diagrammatic geologic cross section of the study area.

Quaternary and Tertiary basalts consist primarily of olivine basalt flows of the Snake River Group and Glenns Ferry Formation. The basalts are exposed in the northern part of the study area, underlie and interfinger with the alluvium, and overlie the silicic volcanics in the southern part of the area. The basalts yield between about 500 and 2,000 gal/min of water to irrigation wells.

Quaternary alluvium, which consists chiefly of unconsolidated clay, silt, sand, and gravel deposits, overlies the basalts and is exposed throughout the lowlands. The alluvium yields small to moderate amounts of water to irrigation wells.

GROUND WATER

Occurrence and Movement

Ground water in the study area occurs primarily in perched zones in the alluvium, under confined conditions in the limestone and silicic volcanics, and under unconfined conditions in the basalts. Water is contained in intergranular spaces in sand and gravel in the alluvium; in fractures and weathered zones in the limestone; and in voids, fractures, joints, and interflow zones in the silicic volcanics and basalts.

Water-level measurements obtained in wells (table 1) in the spring of 1982, prior to the start of the irrigation season, were used to draw the potentiometric contour map in figure 5. In general, ground water moves perpendicular to the contour lines. Potentiometric contours southwest of Foothills Road fault are for the limestone aquifer; northeast of the fault, for the silicic volcanics aquifer; and in the northern part of the study area, for the basalt aquifer.

Low hydraulic gradients, lack of good altitude control, and areal distribution of wells do not permit accurate contouring of the potentiometric surface for the limestone aquifer; however, the general direction of movement is implied. Ground water in the limestone aquifer first moves away from the recharge area toward Foothills Road, then in two inferred directions--northwest and generally to the east. Ground-water withdrawals in the Cottonwood CGWA probably have distorted the potentiometric surface for the limestone aquifer to give this apparent condition, and the direction of the natural hydraulic gradient prior to development for irrigation cannot be determined from the data.

Table 1.--Records of wells

[Altitude: From U.S. Geological Survey topographic map; Well finish: P, perforated, X, open hole; --, no data available]

Well number	Altitude of land surface (feet above sea level)	Reported depth of well (feet below land surface)	Casing		Well finish	Water level	
			Diameter (inches)	Feet below land surface to first perforation		Feet below land surface[1]	Date measured (1982)
11S-21E- 2ADD1	4,331	505	--	18	X	457.44	3-17
2DDD1	4,365	640	20	40	X	456.85	3-11
3DDA1	4,319	530	24	50	X	443.00	3-17
11ADD1	4,385	537	20	17	X	476.30	3-16
11DAA1	4,390	600	24	19	X	481.65	3-16
12DDA1	4,480	900	20	24	X	562.90	3-16
15BBA1	4,339	614	20	51	X	491.98	3-16
16BBC1	4,321	562	--	33	X	400	3-17
23ABB1	4,409	900	--	--	--	499.30	3-17
23CBC1	4,392	---	--	--	--	484	3-17
23DCC1	4,375	1,055	20	21.5	X	461.11	3-17
24ADD1	4,405	710	--	21	X	491	3-17
25AAA1	4,376	965	20	55.5	X	459.80	3-17
33BBB1	4,323	475	22	21	X	340.90	3-18
11S-22E-17CBB1	4,368	510	20	30	X	450.45	3-18
21BCC1	4,310	570	16	285	X	388.6	3-18
12S-20E-11ADC1	4,338	1,600	20	229	X	295.45	3-11
25BCA1	4,625	1,185	20	59	X	301.45	3-16
25CBB1	4,683	---	--	--	--	366	4-21
25DDD1	4,610	1,115	16	525	X	510.44	5- 7
26DAA1	4,675	780	16	--	--	352	4-21
12S-21E- 2DAA1	4,361	936	6	907	X	409.37	2- 7
5BCB1	4,308	1,200	20	28	X	265.00	3-16
14CCB1	4,375	2,052	22	350	P	358	3- 9
16BDA1	4,361	1,195	20	144	X	293.15	3-17
18BCD1	4,387	1,750	20	289.5	X	330.5	3-16
18CCC1	4,432	1,160	20	282	X	340.7	3-16
25CCC1	4,410	1,870	20	1,029	X	355.59	3-17
26CCC1	4,436	1,115	22	1,110	X	375.12	3-17
28CCB1	4,450	1,740	20	395	P	382.01	3-17
31BCA1	4,578	1,000	16	795	--	239	3- 9
33BBC1	4,476	1,320	20	260	P	403.5	3-17
34DAA1	4,462	1,765	20	228	P	403.55	3-17
35ADD1	4,420	1,047	20	200	X	366.47	3-17
12S-22E-18ACD1	4,352	---	18	--	--	358.4	3-17
13S-21E- 5BCB1	4,660	1,350	20	216	X	329.21	3-17
5CBC1	4,710	790	20	209	X	369.58	4-21
5CCB1	4,680	1,000	20	22	X	347.81	3-17
8BAD1	4,680	1,050	20	79	X	345.97	4-22
8BDD1	4,708	1,025	20	150	X	320.53	3-17
8CBA1	4,785	750	20	213	X	451.53	3-17
18BBC1	4,954	850	16	80	X	587	3- 8

[1]Water levels reported to nearest foot or tenth of a foot were measured by the Idaho Department of Water Resources.

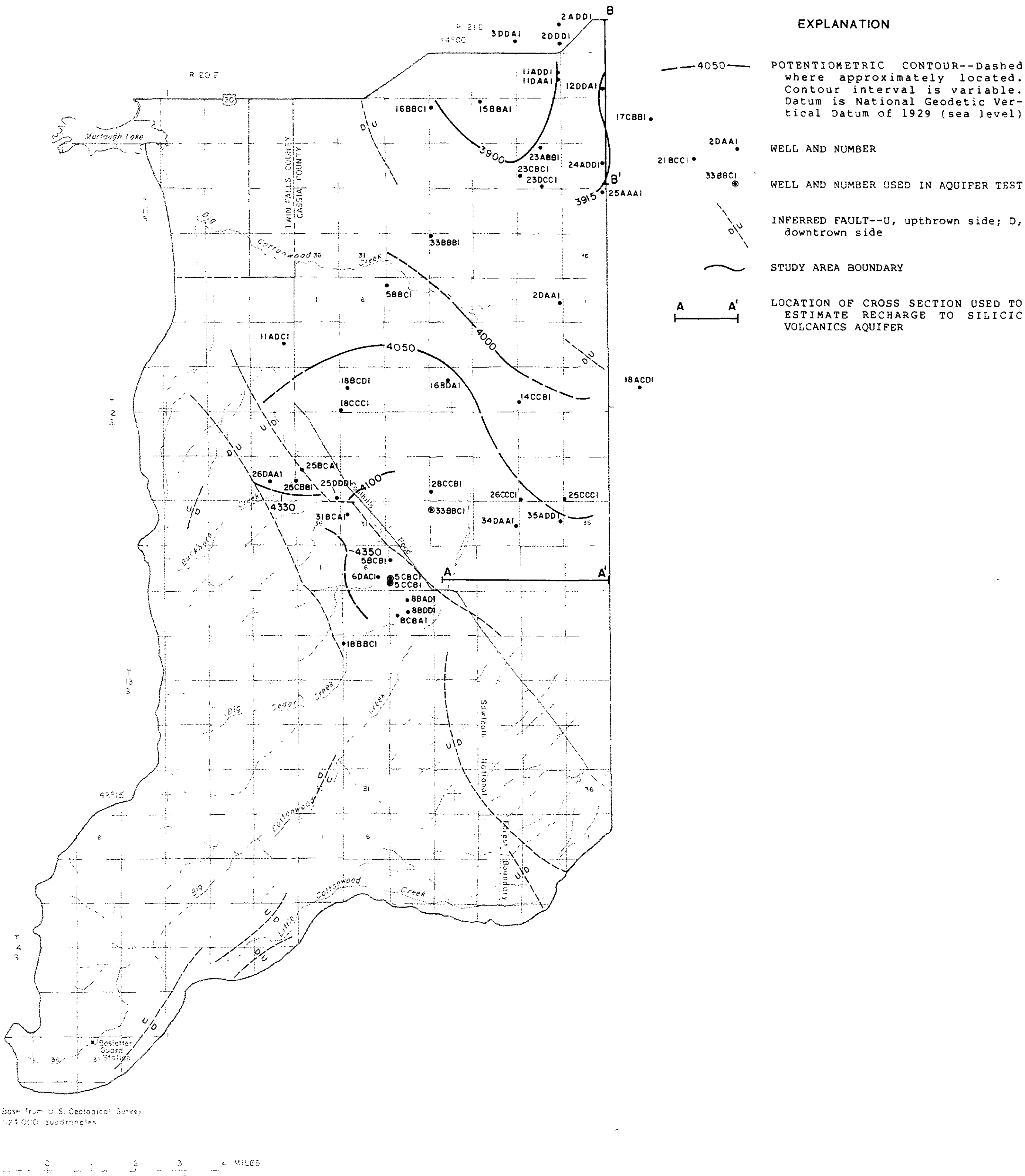


Figure 5. -- Potentiometric surface, March 1982.

Northeast of the road, water levels in wells completed in the silicic volcanics aquifer are about 200 ft lower than those measured in wells completed in the limestone aquifer. Foothills Road is nearly coincident with the location of the Foothills Road fault, which displaces the limestone downward to the northeast (Anderson, 1931, p. 23-67). The relation of the limestone and silicic volcanics aquifers and the fault is shown in figure 4. The 200-ft head differential over such a short horizontal distance strongly suggests the fault in that vicinity is an effective ground-water barrier and that no hydraulic connection is implied between the limestone and silicic volcanics aquifers. The barrier effect is probably the result of (1) permeable limestone in the southwestern upthrown block being positioned next to relatively impermeable silicic volcanics in the northeastern downthrown block and (2) low hydraulic conductivity in the fault zone.

Ground-water movement in the silicic volcanics and basalt aquifers is generally northward. Although not shown in figure 5, local perched water zones occur; however, they are not continuous or interconnected throughout the study area.

Water-Level Fluctuations

Ground-water levels in the study area fluctuate in response to withdrawals for irrigation. Long-term seasonal water-level fluctuations for two wells, one completed in the limestone aquifer and the other in the silicic volcanics aquifer, are shown in figure 6. Each year, water levels in both wells begin to decline at the start of pumping, generally in late spring; continue to decline through the irrigation season; reach an annual low at the end of the season, at which time they begin an abrupt rise; continue to rise through fall, winter, and early spring; and reach an annual peak just prior to the start of the next irrigation season.

In addition to seasonal fluctuations, a downward trend of the water level in both wells is apparent and probably indicates an imbalance between recharge and discharge in both aquifers. Water levels in well 12S-21E-2DAA1, completed in the silicic volcanics aquifer, have declined at a rate of about 5.5 ft/yr since 1977. Water levels in well 13S-21E-18BBC1, completed in the limestone aquifer, have declined about 5 ft/yr during the same period.

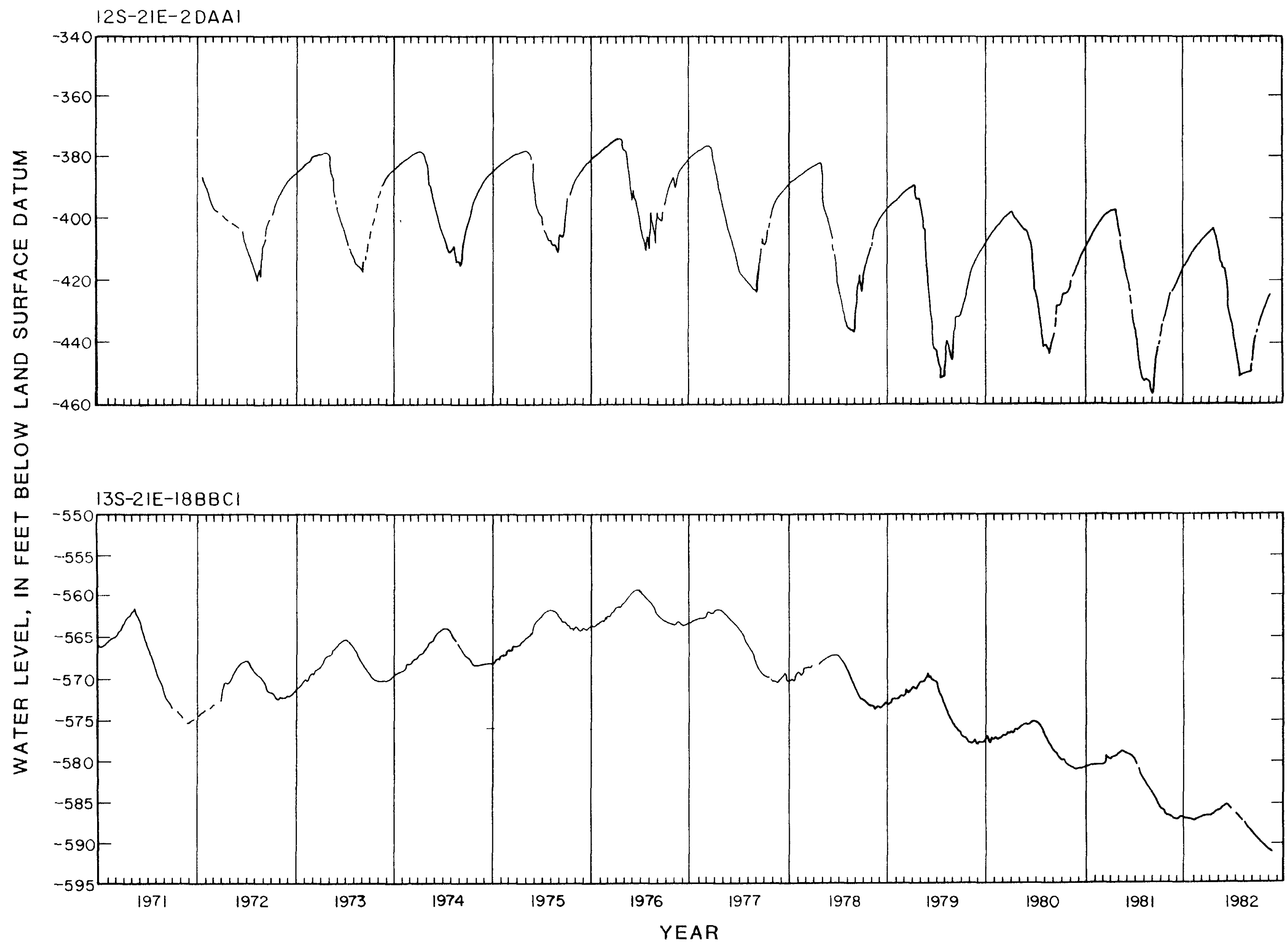


Figure 6. -- Water levels in wells 12S - 21E - 2DAA1 and 13S - 21E - 18BBC1. (Dashed lines represent missing record)

Aquifer Characteristics

Transmissivity, an aquifer characteristic, is a measure of the capacity of an aquifer to transmit water. Transmissivity is the rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient (Lohman, 1972, p. 6). Storage coefficient, another aquifer characteristic, is the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head (Lohman, 1972, p. 8). Transmissivity and storage coefficient may be estimated by interpretation of data from aquifer tests or by application of other empirical methods.

In April 1982, an aquifer test was made in well 13S-21E-5CBC1, completed in limestone southwest of Foothills Road. The well was pumped continually for 24 hours at an average rate of 1,920 gal/min. Attempts to measure the water level in the test well were only partly successful because of cascading water and obstructions in the well. Maximum drawdowns in water levels in observation well 13S-21E-6DAC1, located 1,215 ft northwest of the test well, and observation well 13S-21E-5CCD1, located 1,315 ft southeast of the test well, were 0.57 and 0.56 ft, respectively. During the test, no measurable drawdown of water level was observed in well 12S-21E-33BBC, completed in silicic volcanics on the northeast side of the Foothills Road fault about 7,000 ft away from the test well. Although pressure changes in a confined aquifer owing to pumping could be apparent for considerable distance from a pumped well, such small changes that occurred during the test would likely be masked by other changes caused by pumping wells in the valley or even by changes in atmospheric pressure.

Although results of the aquifer test made in conjunction with this study, as well as those of an earlier test (Paul Castelin, Idaho Department of Water Resources, written commun., 1978) were not conclusive, neither showed any hydraulic connection across the fault that separates the limestone aquifer from the silicic volcanics aquifer.

More conclusive evidence the fault acts as an effective barrier between the two aquifers is the nearly 200-ft difference in hydraulic heads measured in nearby wells on either side of the fault. Even if some seepage across the fault does occur as a result of the 200-ft hydraulic head difference, low hydraulic conductivity in the fault zone is evident, and unrestricted communication between wells on either side of the fault probably is not apparent.

Interpretation of data from the aquifer test shows that transmissivities in the limestone aquifer near the test well range from about 1.0×10^5 to 1.1×10^5 ft^2/d. Storage coefficients range from 0.014 to 0.016. Discussion of computational methods used to determine transmissivities and storage coefficients and graphical representations of these methods (figs. 9-12) are contained in the supplemental section.

Relation Between Recharge and Discharge

Lack of data on water levels and aquifer characteristics and the absence of any adequate hydrologic boundaries across which ground-water underflow can be determined preclude the presentation of a competent water budget for the study area. Although some ground-water discharge as underflow is indicated for both aquifers, data are insufficient to quantify the amount. For the purpose of this discussion, all discharge from both aquifers is considered to be by withdrawals from wells.

Recharge

The main sources of recharge to aquifers in the study area are precipitation, underflow from adjacent areas, and infiltration of surface water.

Precipitation estimates for the study area were based on 1980 U.S. Weather Bureau records at Burley and Oakley, 15 mi northeast and 8 mi southeast of the study area, and on storage-gage data collected at Bostetter Guard Station (1966-72) near the drainage divide in the Rock Creek Hills. Precipitation in 1980 was near long-term averages for all three stations. Total annual precipitation for the entire study area is about 160,000 acre-ft. The Rock Creek Hills overlying the limestone aquifer receive about 80,000 acre-ft/yr of precipitation; the remaining 80,000 acre-ft/yr falls on the West Oakley Fan and valley floor overlying the silicic volcanics aquifer.

On the basis of a water-budget study for the period 1912-80 in the eastern Snake River Plain that considered evaporation losses, transpiration by native vegetation, and variations in local hydrogeologic characteristics, ground-water recharge from annual precipitation ranges from less than 2 percent to slightly greater than 5 percent of the total precipitation (L. C. Kjelstrom, U.S. Geological Survey, oral commun., 1983). On the basis of this estimate, potential recharge from precipitation to aquifers in the study area could range from about 1,600 to about 4,000 acre-ft/yr.

Recharge to the limestone aquifer from infiltration of precipitation in the Rock Creek Hills is probably nearer 5 percent of the total, or about 4,000 acre-ft/yr. This relatively large amount of recharge is postulated because of the thin soil cover and extensive faulting in the Rock Creek Hills, both of which contribute to greater water infiltration rates and negate losses by evaporation and transpiration. No other source of recharge to this aquifer is apparent.

Recharge to the silicic volcanics aquifer from nearly 11 in. average annual precipitation on the valley floor may be less than 2 percent. Sondregger (1929, p. 1164) reported that in semiarid areas where annual precipitation is 11 in. or less, recharge to underlying aquifers probably is minimal. For the purposes of this discussion, annual recharge to the silicic volcanics aquifer from precipitation probably ranges from near zero to about 2 percent of the total precipitation, or between zero and about 2,000 acre-ft.

Although water-level data are not complete over the entire study area, potentiometric-surface contours in figure 5 indicate most of the recharge to the silicic volcanics aquifer originates in the mountains in the southeast part of the study area and moves generally north before different pumping intensities distort the ground-water flow lines. Across line A-A' in figure 5, the volume of underflow is proportional to the hydraulic gradient and the aquifer transmissivity and can be calculated by the method used by Walton (1962, p. 20):

$$Q = TIL$$

where

Q = volume of underflow,
T = aquifer transmissivity,
I = hydraulic gradient, and
L = length of line A-A'.

The hydraulic gradient can be determined from contour lines in figure 5; aquifer transmissivity can be estimated by using pumping rates and water-level drawdown reported on available drillers' logs (Theis, Brown, and Meyer, 1963, p. 338). Using the above equation, data from figure 5, and aquifer transmissivities estimated between 14,600 and 26,000 ft^2/d, underflow across line A-A' could range from about 9,000 to 16,000 acre-ft/yr.

Figure 5 indicates that some recharge occurs as ground-water underflow across the eastern boundary in the northeast corner of the area where flow has been induced by the development of a pumping depression. Although this amount of recharge is more difficult to quantify, estimates may be obtained using the same procedure as above. For a range of transmissivities between 1,500 and 82,000 ft^2/d across line B-B' in figure 5, underflow could range from less than 100 to about 7,000 acre-ft/yr. By using an average value for transmissivity in this area, underflow would be near 1,000 acre-ft/yr owing primarily to the low hydraulic gradient indicated by existing water-level data. Some additional underflow may occur across the eastern boundary between A-A' and B-B'; however, the volume is probably small and cannot be estimated using data available in this report.

Some surface water flows into the area in Big Cottonwood and Big Cedar Creeks. Discharge records for the period 1910-14 for Big Cottonwood Creek above Big Cedar Creek indicate about 8,000 acre-ft/yr for that station. However, most of the flow occurs during the spring as runoff from melting snow. During these periods of high flow (April and May), a considerable amount of the flow is discharged to Murtaugh Lake and is not available for recharge to the local aquifers. During the period of runoff, however, or when flows are diverted for irrigation, some water probably is recharged to the silicic volcanics aquifer near the southern boundary of the study area. Although the recharge cannot be quantified, the annual total probably is not great but could vary between about 500 and 1,000 acre-ft. Additional studies are needed to accurately quantify this amount. Total annual recharge to the silicic volcanics aquifer from precipitation and ground-water underflow probably is between about 10,000 and 26,000 acre-ft.

Discharge

Ground water is the principal source of irrigation and domestic supplies in the study area. Volumes of water pumped for domestic use are small compared with those pumped for irrigation. Therefore, as little or no data are available, no attempt was made to determine pumpage for domestic use.

Most irrigation water is obtained from wells that penetrate the silicic volcanics and basalt aquifers to depths ranging from several hundred to more than 2,000 ft. The limestone aquifer, penetrated by wells on the southwestern side of the valley, provides large volumes of water for irrigation of land northeast of Foothills Road via ditches and pipelines.

Ground water is used to irrigate about 35,800 acres of cultivated land in the study area (Idaho Department of Water Resources, written commun., 1982). Records of electrical power consumption for the 1980 irrigation season were used to compute the total amount of water withdrawn from silicic volcanics and basalt aquifers. The computation method described by Young and Harenberg (1971) was applied to electrical power-consumption and available pump-lift data for the study area. About 60,000 acre-ft of water was withdrawn from the silicic volcanics and basalt aquifers for irrigation in 1980. Owing to the apparent confinement of both aquifers and the nature of the overlying geology, for the purposes of this investigation, it is assumed that none of the irrigation water is returned to the ground-water system and that all the water withdrawn is consumptively used.

Maximum allowable pumpage from the limestone aquifer was set by court decree and is administered by the Idaho Department of Water Resources. The decree limits pumping to a 5-year average of 5,500 acre-ft/yr. Pumpage in the Cottonwood CGWA varies considerably from year to year. Reported annual pumpage for the period 1977-82 ranged from 3,300 to about 6,500 acre-ft. Average pumpage for the period was about 5,300 acre-ft/yr.

A summary of annual recharge estimates and discharge by pumpage for the Cottonwood and West Oakley Fan areas is shown in table 2. The apparent excess of withdrawals relative to recharge for each area is based on available data. However, an imbalance between the volume of recharge and that which is currently withdrawn is distinctly apparent from the water levels in wells that continue to decline under present pumping conditions. If all the data considered in determining the values in table 2 are accurate, discharge from pumpage presently exceeds recharge for both aquifers. In the West Oakley Fan, discharge in excess of estimated recharge ranged between 34,000 and 50,000 acre-ft/yr; in the Cottonwood area, using the average pumpage for 1977-82, discharge in excess of estimated recharge was about 1,300 acre-ft/yr. These net differences will be larger if discharge as underflow out of the area is also considered in an actual water budget. Under present pumping conditions, water levels in both aquifers will likely continue their present rates of decline until equilibrium is established. Should ground-water withdrawals increase, the rate of water-level decline also should increase proportionately.

Table 2.--Summary of annual recharge and discharge estimates

[Recharge from precipitation is the long-term average; underflow is based on 1982 data]

West Oakley Fan

	Range or best estimate (acre-feet per year)
Recharge	
Precipitation......................	0 - 2,000
Underflow from adjacent areas:	
Line A-A' (fig. 4)..............	9,000 - 16,000
Line B-B' (fig. 4)..............	100 - 7,000
Infiltration of surface water.....	500 - 1,000
TOTAL (rounded)........................	10,000 - 26,000
Discharge	
Ground-water pumpage (1980).......	60,000

Cottonwood

Recharge	
Precipitation......................	4,000
Discharge	
Ground-water pumpage (average, 1977-82)..............	5,300

Ground-Water Quality

Limited data on ground-water quality were collected during this study to ascertain the current suitability of the water for irrigation and domestic use and to determine whether geochemical evidence assists in characterizing aquifers northeast and southwest of the Foothills Road fault.

Table 3 lists the analytical results for water samples from seven wells that pump from aquifers known or thought to be dominated by either silicic volcanics or limestone. Figure 7 shows the well locations and selected water-quality characteristics.

The sampled well water is dilute; dissolved-solids concentrations range from 159 to 275 mg/L. The dissolved solids characteristically are dominated by calcium, bicarbonate (fig. 8) and, at two of the seven wells, by silica. Concentrations of magnesium, sodium, sulfate, and chloride do not exceed 10-15 mg/L except at downgradient site 1 (fig. 8), where the maximum value is 43 mg/L for chloride.

Measured water temperatures range from 17.5° to 39.5°C. Values more than a few degrees above 20°C generally imply a geothermal influence.

The sampled ground water is chemically suitable for both irrigation and domestic use, on the basis of criteria given by National Academy of Sciences, National Academy of Engineering (1972, p. 329-330, 335, and 341) and the U.S. Environmental Protection Agency (1975, p. 59570; 1977, p. 17146) for the constituents and properties listed in table 3. (Specific constituents and properties considered: for irrigation--boron, dissolved-solids concentration, and sodium; for domestic use--chloride, dissolved-solids concentration, fluoride, nitrate, pH, and sulfate.)

Because the predominant rock types on either side of the Foothills Road fault are chemically different, the ground water associated with them also could be expected to exhibit chemical differences. According to H. W. Young (U.S. Geological Survey, oral commun., 1982), the following ratio of chemical concentrations, in milligrams per liter, has proven useful in relating water and rock chemistry:

$$\frac{(\text{calcium}) \times (\text{bicarbonate})}{(\text{sodium}) \times (\text{silica})} .$$

Table 3.--Water-quality data for selected wells

(Chemical constituents in milligrams per liter except where noted; Aquifer: B, basalt; L, limestone; V, volcanics; < , less than; --, no data available]

Site No.	Well No.	Aquifer	Sample date (1982)	Specific conductance (μmhos)	pH (field)	Water temperature (°C)	Hardness as $CaCO_3$	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Sodium-Adsorption Ratio (SAR)	Potassium (K)	[1]Bicarbonate (HCO_3)	[1]Carbonate (CO_3)	Alkalinity	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Silica (SiO_2)	Ratio ($Ca \times HCO_3$) / ($Na \times SiO_2$)	Dissolved solids (calculated)	Nitrite plus nitrate as N	Phosphorus, total as P	Boron (B) (μg/L)
1	11S-21E- 9DDD1	B	6-30	433	7.9	17.5	170	42	16	17	0.6	4.2	140	0	[1]115	36	43	0.2	41	8	275	1.7	0.04	40
2	12S-20E-12DCC1	V	6- 9	285	7.8	25.0	110	38	4.8	13	.5	6.4	150	0	[1]123	14	9.8	.3	64	7	225	.24	.04	30
3	25BCA1	L	6- 8	271	7.8	20.5	130	38	8.4	10	.4	2.6	140	0	[1]115	11	7.5	.2	20	27	172	.24	.02	20
4	12S-21E-10DCC1	V	6-30	181	8.1	21.0	67	23	2.3	8.4	.5	5.3	88	0	[1] 72	6.0	8.5	.2	59	4	159	.43	.04	20
5	19DCC1	V(?)	6-10	278	7.6	39.5	120	37	6.9	11	.5	4.4	150	0	[1]123	15	5.3	.3	19	27	175	<.10	.02	30
6	27BCC1	V	6-10	261	8.6	23.5	120	37	7.0	9.9	.4	3.6	130	5	[1]115	15	6.5	.2	16	30	166	<.10	.02	20
7	13S-21E- 5CBC1	L	4-27	270	---	24.0	130	40	7.4	7.2	.3	3.8	---	--	[2]120	15	6.3	.3	16	52	168	<.10	<.01	20

[1] Field determination
[2] Lab determination

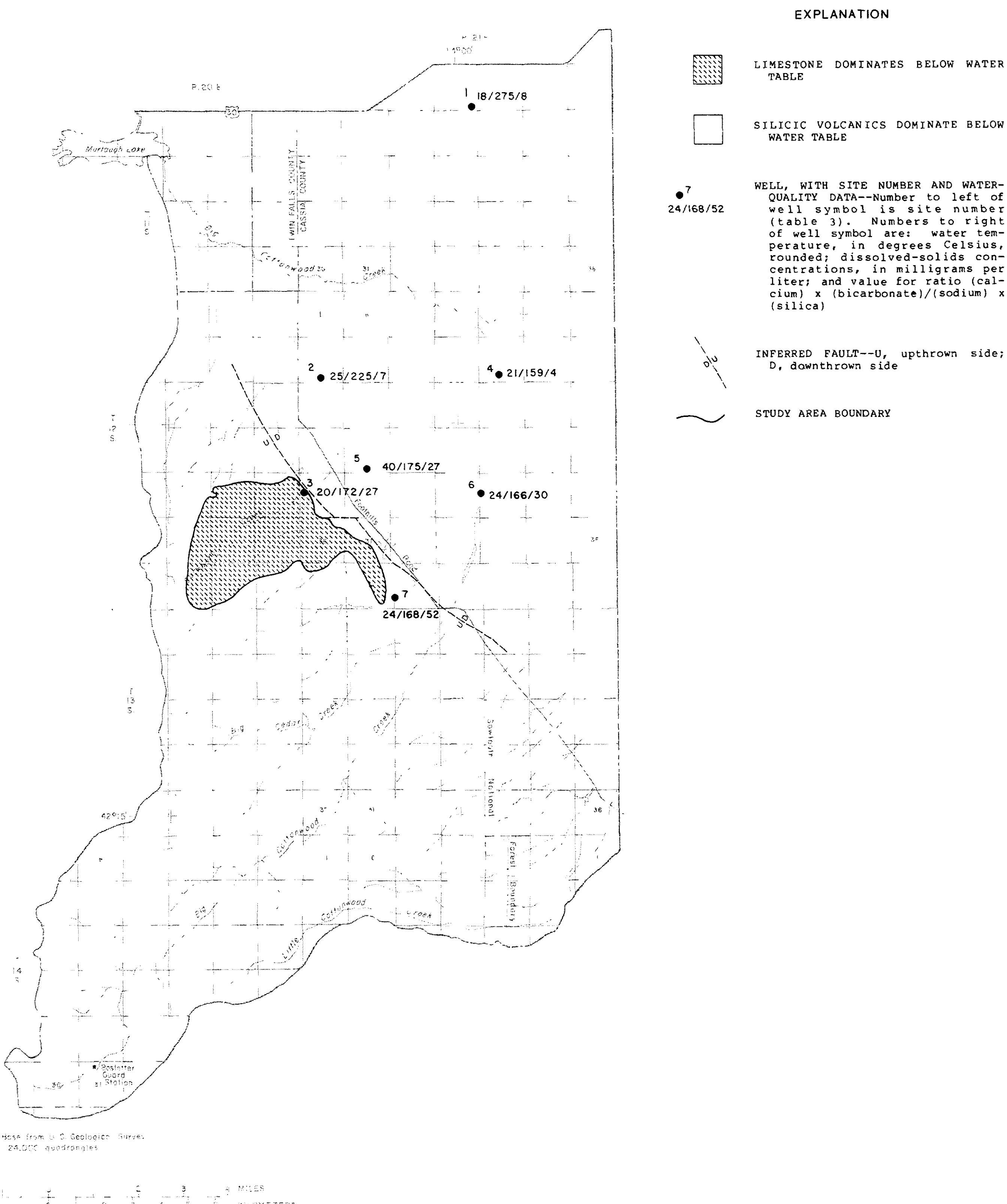


Figure 7. -- Well locations and selected water-quality characteristics for sampled well water.

EXPLANATION

Site numbers 1-7 correspond to those in table 3. Cation and anion percentages are based on milliequivalents per liter. Chemical symbols: Ca, calcium; Cl, chloride; CO_3, carbonate; HCO_3, bicarbonate; K, potassium; Mg, magnesium; Na, sodium; SO_4, sulfate

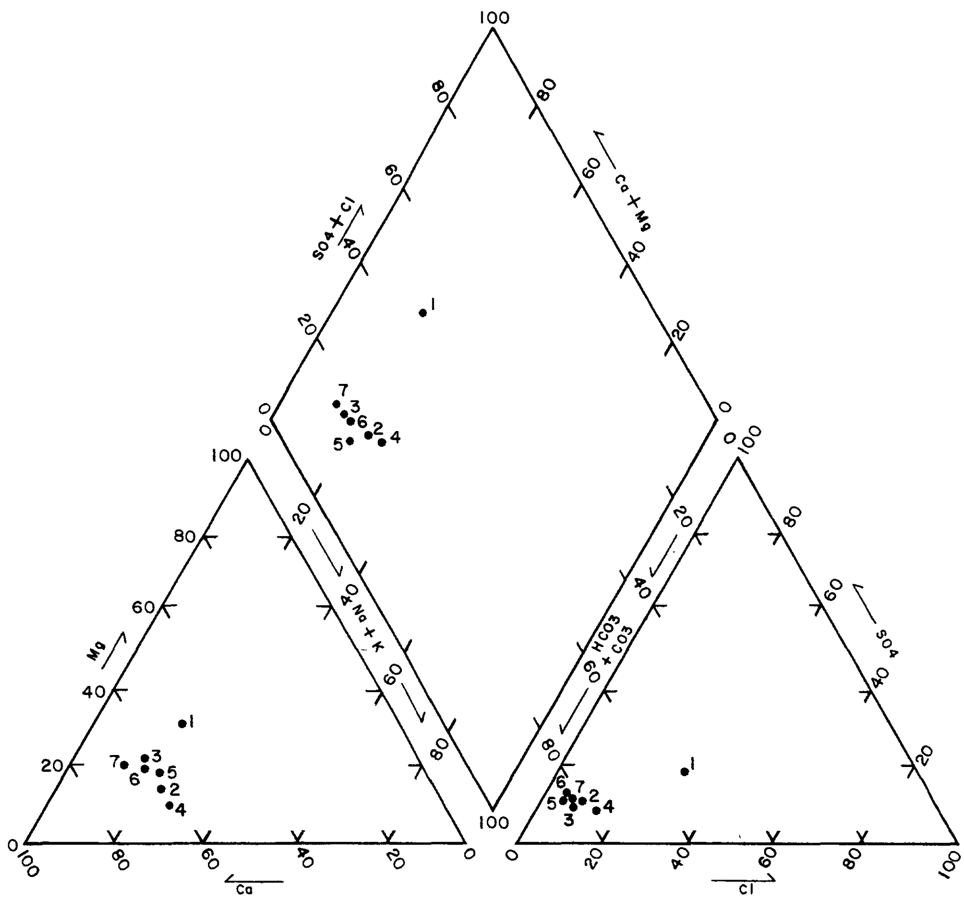


Figure 8. -- Proportions of major dissolved constituents.

A ratio greater than about 20 suggests a carbonate-rock setting (including limestone), whereas a ratio below 20 suggests a noncarbonate setting (including volcanic rocks). Ratios for the seven well waters are listed in table 3 and shown in figure 7; they range from 4 to 52.

Southwest of the Foothills Road fault, ground water from wells 3 and 7, both of which are completed in limestone, bears a geochemical imprint of the carbonate-rock setting (ratios 27 and 52). Across the fault on the downgradient side, where drillers' well logs indicate that silicic volcanics dominate, three of the five sampled well waters have low ratios that reflect the noncarbonate setting (values of 8, 7, and 4 for sites 1, 2, and 4; see fig. 7). At sites 5 and 6, however, the water has a carbonate-rock "signature" (ratios 27 and 30), despite the dominance of silicic volcanics.

Water-level data (fig. 6) indicate that the Foothills Road fault is a barrier to northeastward ground-water movement. Therefore, the geochemical imprint of carbonate rocks shown by water from wells 5 and 6 presumably is not related directly to limestone southwest of the fault.

Limestone probably underlies the silicic volcanics northeast of the fault, as shown in figure 4. The carbonate-rock signature and elevated temperature (39.5° and 23.5°C) of water at wells 5 and 6 support this postulation and suggest the presence of an area on the northeast side of the fault where warm ground water moves upward into the silicic volcanics from underlying limestone.

SUMMARY

Ground water in the study area occurs primarily in perched zones in the alluvium, under confined conditions in the limestone and silicic volcanics aquifers, and under unconfined conditions in the basalt aquifer. The perched zones, however, are not continuous or interconnected throughout the study area.

Direction of ground-water movement in the limestone aquifer is not well defined. Apparent movement is in two directions--one to the northwest and the other generally east. Results of the aquifer test made in a well completed in limestone southwest of the fault indicated no hydraulic connection with the silicic volcanics aquifer northeast of the fault. Transmissivities in the limestone aquifer near the test well range from 1.0×10^5 to 1.1×10^5 ft^2/d. Storage coefficients range from 0.014 to 0.016.

Water levels in wells completed in limestone and silicic volcanics aquifers have declined 5 and 5.5 ft/yr since 1977. About 60,000 acre-ft of water was withdrawn from the silicic volcanics and basalt aquifers for irrigation in 1980. Annual withdrawals from the limestone aquifer for the period 1977-82 ranged from 3,300 to 6,500 acre-ft and averaged about 5,300 acre-ft/yr.

Estimated total annual precipitation for the study area is about 160,000 acre-ft. Annual recharge to the silicic volcanics aquifer probably is between about 10,000 and 26,000 acre-ft; recharge to the limestone aquifer is probably near 4,000 acre-ft.

Limited data on water quality indicate that ground water from limestone and silicic volcanics is dilute; measured dissolved-solids concentrations range from 159 to 275 mg/L. The dissolved solids characteristically are dominated by calcium, bicarbonate, and, at some wells, silica. The sampled well water is chemically suitable for both irrigation and domestic use.

Geochemical evidence suggests that some of the ground water in silicic volcanics northeast of the Foothills Road fault has moved upward from underlying limestone. The remaining sampled water from wells tapping limestone southwest of the fault and silicic volcanics northeast of the fault bears the geochemical imprints of the respective host rocks.

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SUPPLEMENTAL SECTION

Results of the aquifer test made in April 1982 in well 13S-21E-5CBC1, completed in limestone west of Foothills Road, were corrected for aquifer recovery trends obtained from observation wells 13S-21E-5CCD1 and 6DAC1. These data were analyzed (figs. 9-12) using the Theis graphic solution for nonsteady radial flow without vertical movement (Lohman, 1972, p. 15-23) and Chow's method for the Theis equation for nonsteady-state flow in confined aquifers (Kruseman and DeRidder, 1979, p. 57-59).

Values obtained from these graphic solutions were substituted into the equations developed by Theis (1935, p. 519-524) for computation of transmissivity and storage:

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

where

- T = transmissivity, in feet squared per day,
- Q = pumping rate, in cubic feet per day,
- s = drawdown, in feet,
- $W(u)$ = exponential integral obtained from the Theis type curve plot or Chow's nomogram, and
- π = 3.14;

and

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

where

- S = coefficient of storage,
- T = transmissivity, in feet squared per day,
- r = distance between the pumped well and the observation well, in feet,
- t = time since pumping began, in days, and
- u = variable of the exponential integral $W(u)$ obtained from the Theis type curve or Chow's nomogram.

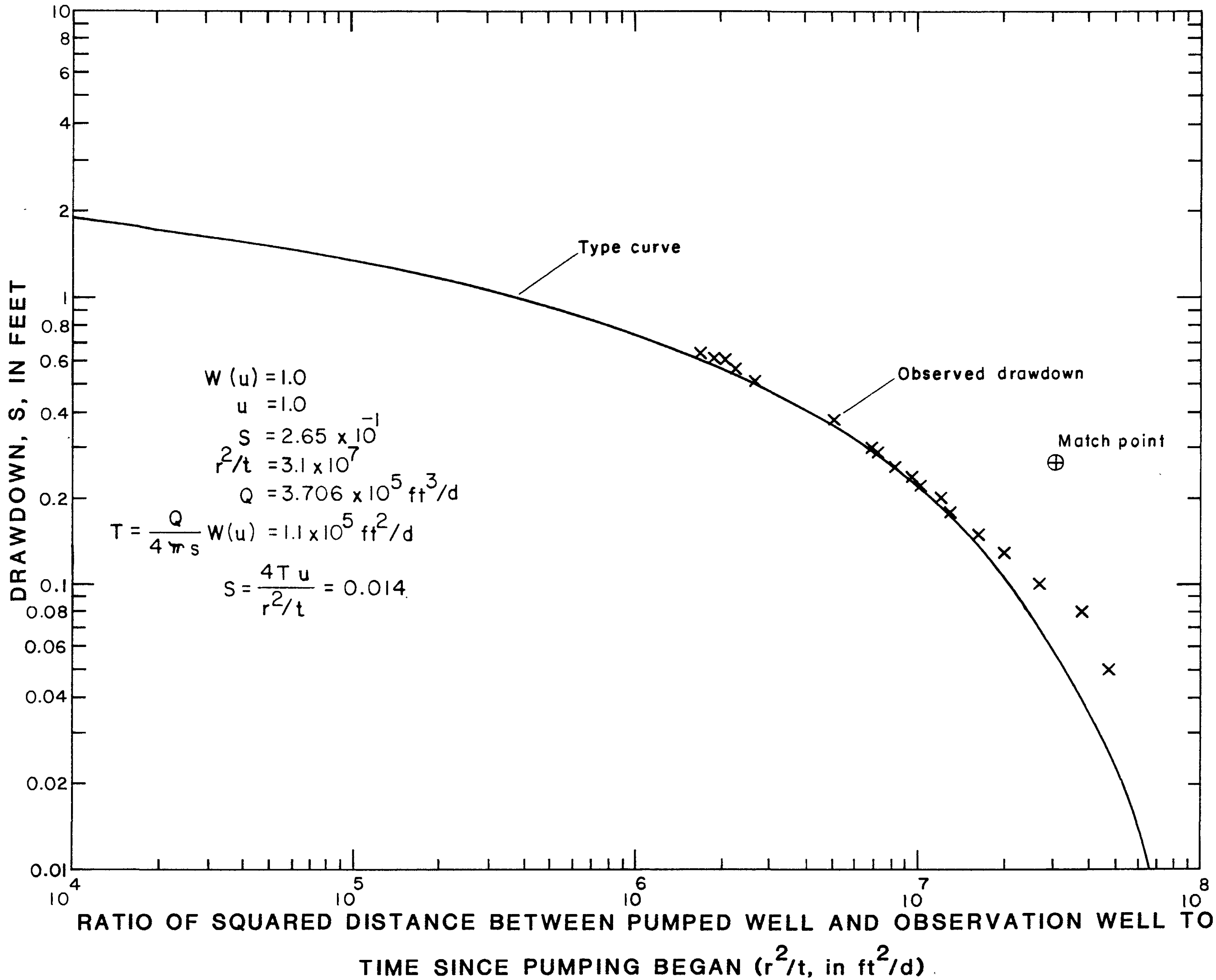

Figure 9. -- Drawdown data from well 13S - 21E - 5CCD1 (Theis type curve).

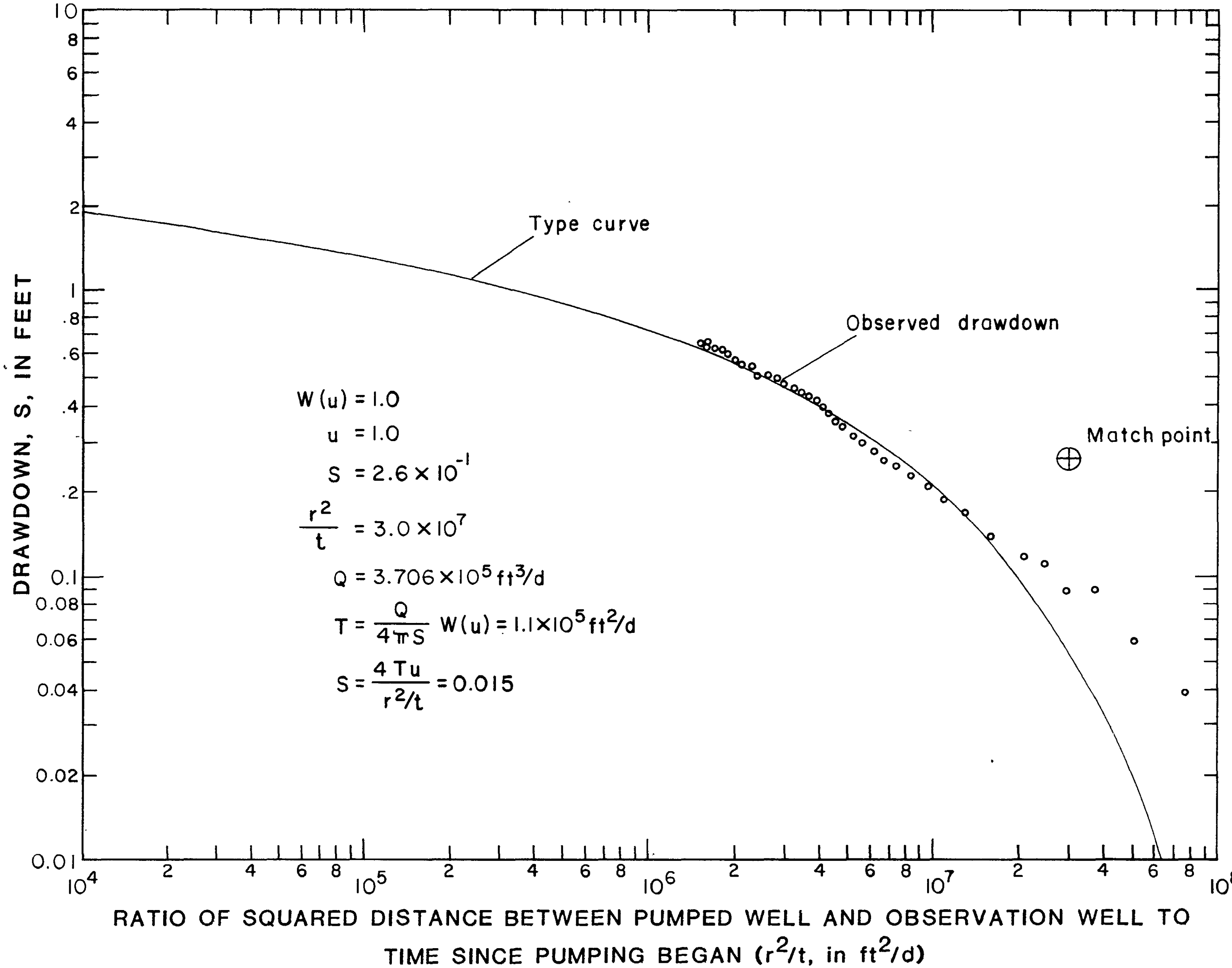

Figure 10. -- Drawdown data from well 13S - 21E - 6DAC1 (Theis type curve).

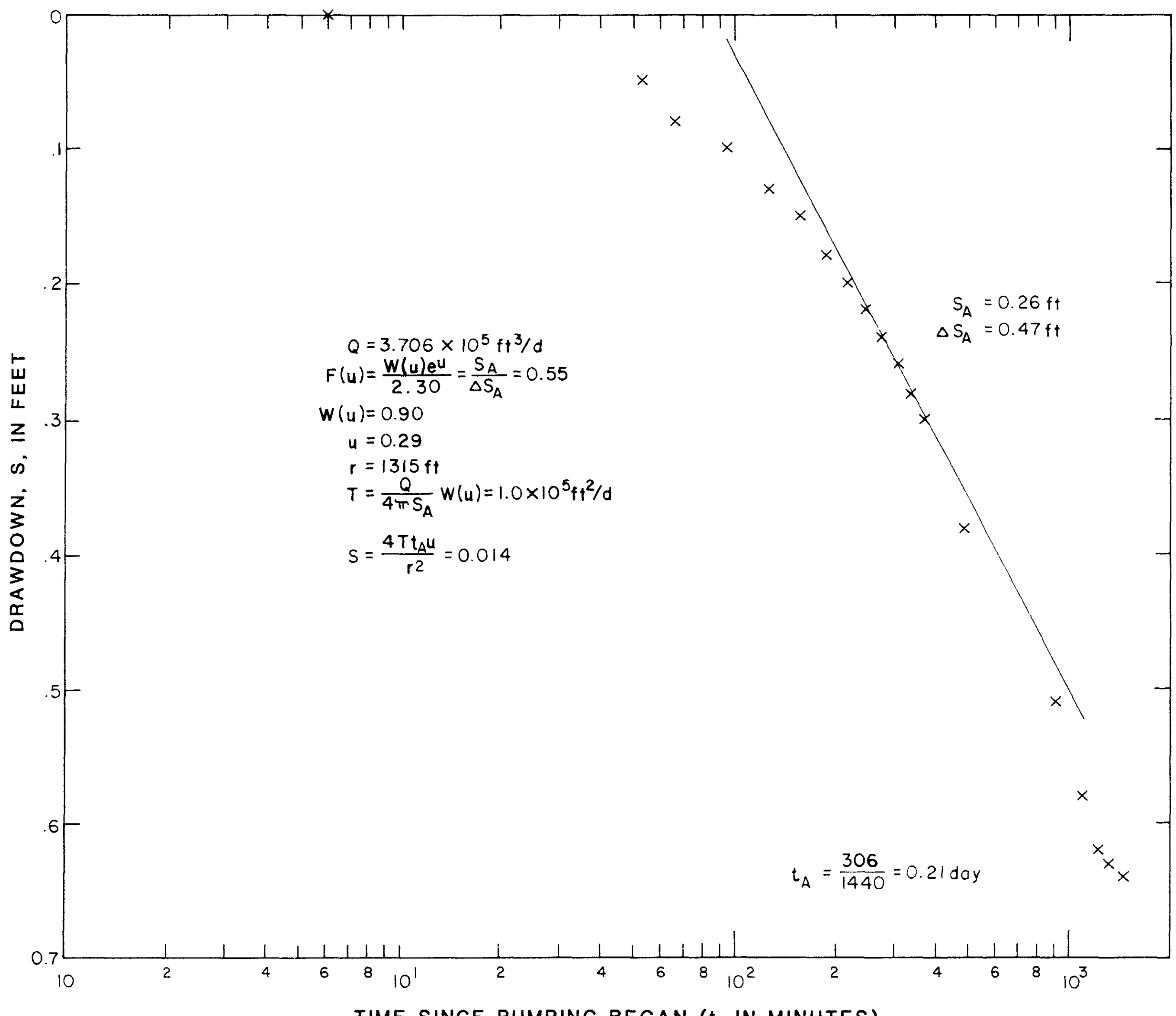

Figure 11. -- Drawdown data from well 13S - 21E - 5CCD1 (Chow's method).

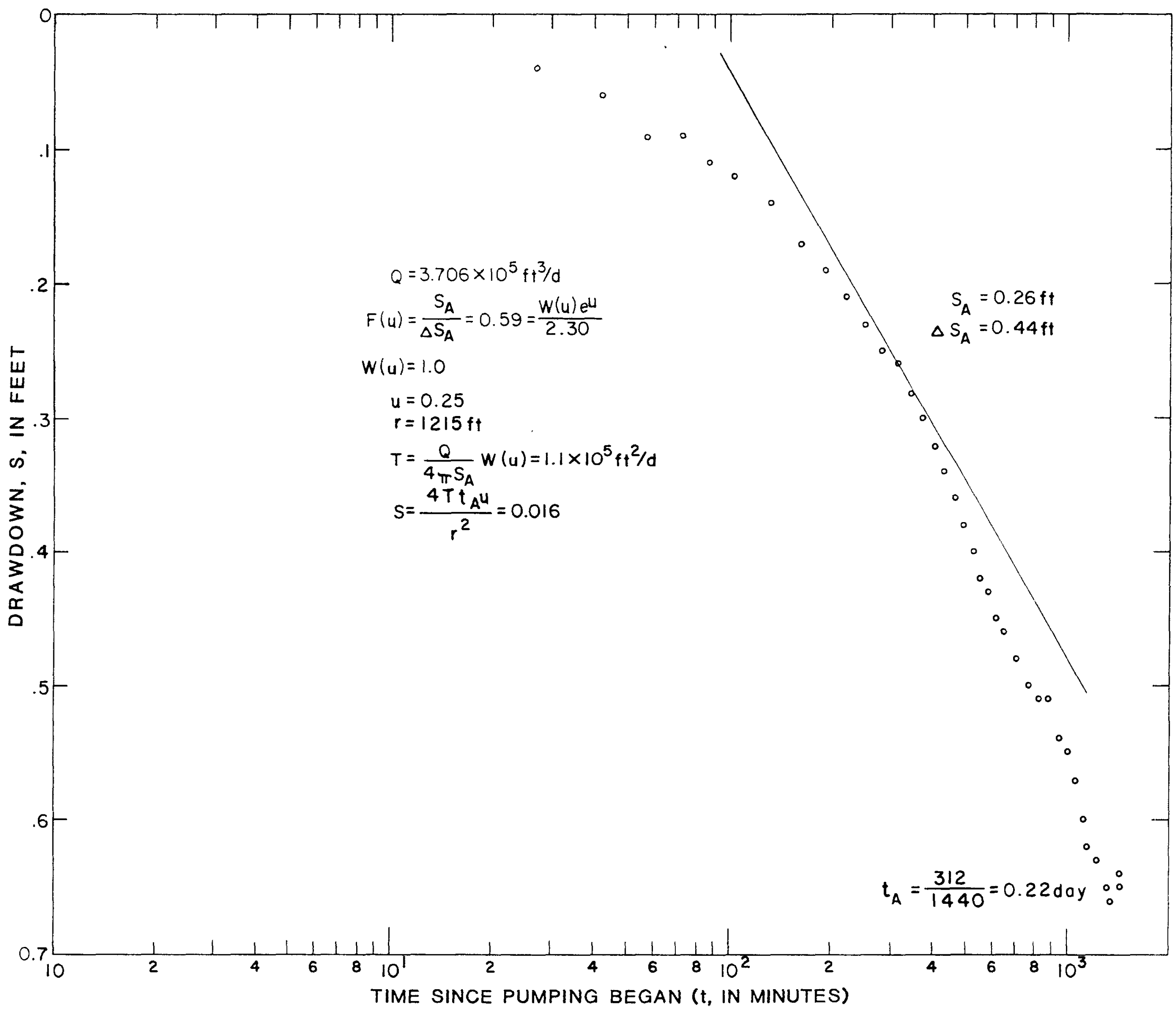

Figure 12. -- Drawdown data from well 13S - 21E - 6DAC1 (Chow's method).