Analysis and Evaluation of Available Hydrologic Data for San Simon Basin, Cochise and Graham Counties, Arizona

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GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1619-DD

Prepared in cooperation with the
Arizona State Land Department

U. S. DEPARTMENT OF THE INTERIOR
March 3, 1849

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By NATALIE D. WHITE

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

ANALYSIS AND EVALUATION OF AVAILABLE HYDROLOGIC DATA FOR SAN SIMON BASIN, COCHISE AND GRAHAM COUNTIES, ARIZONA

By Natalie D. White

ABSTRACT

The San Simon basin is part of a northwest-trending structural trough that extends from near Rodeo, N. Mex., to Globe, Ariz. It is bounded by two nearly parallel chains of mountains—the Peloncillo Mountains to the east and the Chiricahua, Dos Cabezas, and Pinaleno Mountains to the northwest and west.

The objectives of the present study of the San Simon basin are to analyze the available hydrologic and geologic data by standard methods and to determine if the data are adequate for quantitative analysis. The study also suggests where more and better data and other methods of analysis may give more accurate results. The newly developed electrical-analog method is promising for future data analysis.

Nearly all the deposits in the San Simon basin are classified as older alluvial fill, which is divided for ease of discussion in this report into four geologic units—the "lower unit," the "blue clay unit," the "upper unit," and the "marginal zone." Hydrologically the lower unit constitutes the "lower aquifer," and the saturated part of the upper unit constitutes the "upper aquifer."

In the San Simon basin ground water occurs under artesian conditions in the lower aquifer below the blue clay unit, which serves as the confining layer. Ground water occurs under water-table conditions in the upper aquifer and also in the marginal zone where the upper and lower aquifers form a hydrologic unit. The movement of ground water in the basin generally is from the bordering mountain ranges toward the axis of the valley and along the axis from southeast to northwest. The major source of recharge to the aquifers probably is seepage from ephemeral streams near the mountain fronts. The lower (artesian) aquifer provides most of the water used for irrigation in the basin, and the upper aquifer provides water for stock and domestic purposes and for a small amount of irrigation.

Analysis of water-level data for the San Simon basin by means of contour maps of the altitude of the artesian-pressure surface and changes in the artesian pressure shows that pressure has declined more than 80 feet in the period 1915–60. Data also show that the water level in the upper aquifer is declining in response to the withdrawal of water in excess of the rate of replenishment.

INTRODUCTION

The U.S. Geological Survey has been collecting the transitory hydrologic data—data that can be collected only at a given instant and place—and the geologic data in the major irrigated basins of Arizona for many years as part of a statewide ground-water survey. Most of the work was done to keep records of changes in the hydrologic, and particularly the ground-water, regimens of these basins as increasing amounts of water were removed from ground-water reservoirs. The work was done largely in cooperation with the Arizona State Land Department and other State, Federal, and local agencies.

The statewide ground-water survey includes depth-to-water measurements, discharge measurements, the collection of drillers' logs and well-cutting samples, and the sampling of water for chemical quality-of-water analysis. The files in the Arizona district office of the Geological Survey, Ground Water Branch, contain a tremendous volume of these several types of data. In the past this information has been used to describe ground-water conditions in the basins as related to occurrence, movement, recharge, and discharge and to study the effects of ground-water withdrawal in excess of the rate of replenishment in the developed basins. Depth-to-water measurements have been used to construct hydrographs for individual wells and contour maps of the altitude and of the decline of the water table for a given area. Discharge measurements aid in the computation of specific capacities of wells and the total pumpage of ground water from the basins. Drillers' logs and well-cutting samples help to delineate the subsurface geology of the basins. Chemical-quality analysis of water samples from the aquifers supplements information from other sources concerning the geology and hydrology of the aquifer and determines the overall suitability of the water for various uses.

In addition to the statewide collection of transitory hydrologic data and geologic data, individual basins and problems have been investigated in varying degrees of detail. These studies include: (1) a more intensive local collection of data than is possible under the statewide program; (2) surface and subsurface geologic mapping; and (3) analysis of the available geohydrologic information. The time element often has been a limiting factor on the amount of data collected and the extent of analysis that could be accomplished during an investigation.

For the most part, the location of the water-bearing materials and a quasi-quantitative analysis of the ground-water resources of the major basins in Arizona have been accomplished, and it remains for the geohydrologist to find methods for obtaining more accurate and detailed quantitative solutions to the water problems. Specifically, the geohydrologist needs to be able to predict the future of the water resources in a basin as related to use, and in doing so, he must depend on analysis of available data for interpreting the changing conditions and concepts of the hydrology of an area.

Water problems related to inadequate supplies, equitable distribution of the available supply, and deterioration in quality of water may arise wherever accelerated development of water resources takes place. Quantitative solutions are needed for these problems, especially in arid and semiarid areas where the economy is expanding. Much research in ground-water hydrology is directed toward development of more exact methods for analyzing the water resources of these areas quantitatively. One means of solving such problems may be by increased utilization of available data in interpretative studies.

PURPOSE AND SCOPE

This report presents an analysis and interpretation of the geohydrology of the San Simon basin, Cochise and Graham Counties, Ariz., using information in the files and standard methods of analysis. The San Simon basin was selected because the volume and quality of data regarding its geology and hydrology were typical of many other moderately developed basins in southern Arizona. Sufficient information was available to describe the hydrology of the basin in general; on the other hand, the data differed considerably in density, accuracy, and period of record.

The study of the San Simon basin has two principal interrelated objectives: to determine whether the present available geohydrologic data and the standard methods of analysis can provide sufficient quantitative answers to the ground-water problems of the area, and to determine what additional data and methods of analysis are needed if these are not adequate. In addition, the synthesis of the data was made in such a way that analysis can be made by an electrical-analog model or any other new analytical method and compared to this analysis by standard methods.

The available geologic and hydrologic information on the San Simon basin form the basis for quantitative analysis of the ground-water characteristics of the principal units of the alluvial fill in the basin. The quality of water in the basin is not discussed.

LOCATION AND EXTENT OF THE AREA

The San Simon basin, in the southeast corner of Arizona (fig. 1), is part of a structural trough that extends northwestward from near Rodeo, N. Mex., to Globe, Ariz. The San Simon basin, as used in this report, is bounded on the southwest and west by the Chiricahua, Dos Cabezas, and Pinaleno Mountains, and on the east by the Peloncillo Mountains, which extend southeastward into New Mexico (pl. 1). Near the northwest end of the Peloncillo Mountains, the Whitlock Mountains project into the valley for several miles. To the north, the San Simon basin merges with the Safford Valley; the two basins are

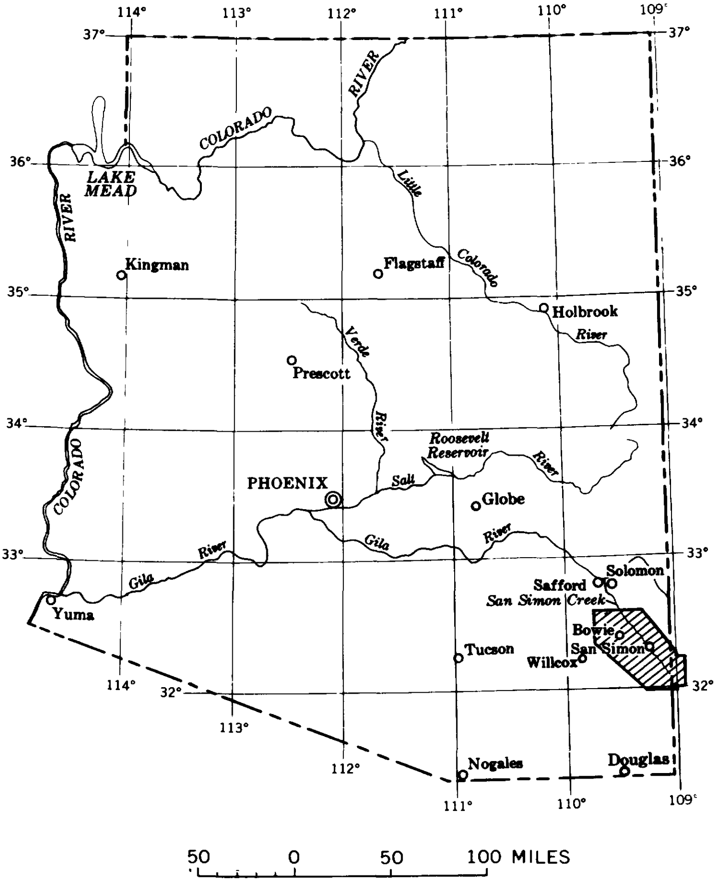

FIGURE 1.—Map of Arizona, showing location of San Simon basin as described in this report.

separated arbitrarily by the line between Tps. 9 and 10 S. The southern boundary of the San Simon basin is chosen arbitrarily as the east-west line between Tps. 16 and 17 S. The basin is 10 to 25 miles wide and about 60 miles long. The area is drained by San Simon Creek, which enters the upper or south end of the valley in New Mexico at an altitude of about 4,000 feet and flows into the Gila River in the Safford Valley near Solomon at an altitude of about 3,000 feet (fig. 1). The gradient of the valley is about 20 feet per mile; on the sides of the valley the slopes are much greater, and gradients of more than 100 feet per mile are common.

Development in the basin is centered around the towns of San Simon, near San Simon Creek on the east side of the basin, and Bowie, on the west side of the basin about 3 miles from the base of the Dos Cabezas Mountains (pl. 1). The two areas of development hereafter are referred to as the San Simon area and the Bowie area, respectively.

CLIMATE

The climate of the San Simon basin is typical of semiarid zones in general and of southeastern Arizona in particular. It is characterized by low precipitation, high summer temperatures, and low humidity which combine to cause high evaporation rates.

Recharge to the ground-water reservoir from direct precipitation on the desert floor probably is negligible. However, precipitation on the mountainous areas that bound the basin provides water for runoff—the most significant source of recharge to ground-water reservoirs in Arizona. For the most part, rainfall in the San Simon basin occurs in two characteristic patterns. Gentle rains, some lasting several days, are fairly common during December, January, and February; during July and August the rains are intense, short, and mostly local, although some summer rains may be regional. The winter rains furnish the most runoff for recharge to the ground-water reservoir, because the clear water produced by these slow rains can percolate into the ground faster than the silt-laden water resulting from torrential summer rains. (See Babcock and Cushing, 1942; Turner and others, 1943.)

The mean annual precipitation at San Simon and Bowie is about 8 and 10 inches, respectively (Smith, 1956). The mean annual temperature at San Simon is 61.6°F, and the mean monthly temperature ranges from 43.4° to 81.2°F; at Bowie the mean annual temperature is 64.2°F, and the mean monthly temperature ranges from 46.0° to 83.2°F (Smith, 1956). The periods of record on which these data are based are as follows:

Precipitation: San Simon, 1881–1916 and 1921–53; Bowie, 1899–1953.
Temperature: San Simon, 1903–08, 1913–16, and 1940–53; Bowie, 1902–53.

Evaporation is a function of temperature, wind movement, humidity, and barometric pressure and is a nearly continuous process. The U.S. Weather Bureau measures evaporation in a standard 4-foot pan at several stations in Arizona. Such measurements do not represent the evapotranspiration potential from land areas, but they provide an index to a characteristic of the climate that acts to limit the quantity of water available. The nearest evaporation stations to the San Simon basin are at Safford and Willcox (fig. 1). Table 1 shows evaporation and other climatic data (Smith, 1956) for these two stations; data on temperature, precipitation, and altitude are given for San Simon also for comparison. Evaporation at San Simon problably is about the same as that at Willcox and Safford.

In semiarid regions the amount of water that evaporates and transpires is less than that which would evaporate and transpire if it were available. Thornthwaite (1948) devised a method for computing potential evapotranspiration based on mean monthly temperatures

TABLE 1.—*Selected climatic data for Willcox, Safford, and San Simon, Cochise and Graham Counties, Ariz.*

[Data from Univ. Arizona Exp. Sta. Bull. 279]

Station	Altitude (feet above mean sea level)	Item [1]	Period of record	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Willcox	4,200	Precipitation, inches	1880–1953	0.81	0.92	0.74	0.22	0.23	0.33	2.23	2.54	1.14	0.65	0.65	0.90	11.36
		Temperature, °F	1903–53	41.3	44.9	49.1	55.7	63.6	72.8	77.6	73.6	70.6	60.2	49.0	41.8	58.4
		Evaporation, inches	1917–35	3.81	4.65	7.13	8.28	10.53	11.21	9.74	8.14	7.32	5.98	4.52	3.28	84.59
Safford	2,900	Precipitation, inches	1898–1953	.64	.72	.63	.32	.17	.29	1.70	1.72	1.05	.58	.64	.77	9.23
		Temperature, °F	1898–1953	43.4	48.8	53.1	61.2	69.3	78.8	83.6	81.1	77.2	64.0	55.0	44.4	63.4
		Evaporation, inches	1940–47	1.99	3.35	5.32	7.68	9.84	10.90	9.82	8.27	6.47	4.40	2.78	1.89	72.71
San Simon	3,608	Precipitation, inches	1881–1953 [2]	.53	.60	.61	.22	.15	.22	1.44	1.66	.75	.47	.44	.75	7.84
		Temperature, °F	1903–53 [3]	43.4	47.8	53.2	60.2	65.8	76.4	81.2	79.8	72.0	62.8	51.2	44.4	61.6

[1] Mean for period of record indicated.

[2] Period of record not continuous; 1916–21 missing.

[3] Period of record not continuous; 1908–13, 1916–40 missing.

and the latitude of the area. This method was used to compute the potential evapotranspiration shown in figure 2, whêre it is compared with mean monthly precipitation. Precipitation is in excess of potential evapotranspiration during only 3 months of the year, and even then the excess is small compared to the amount of potential evapotranspiration in excess of precipitation during the rest of the year.

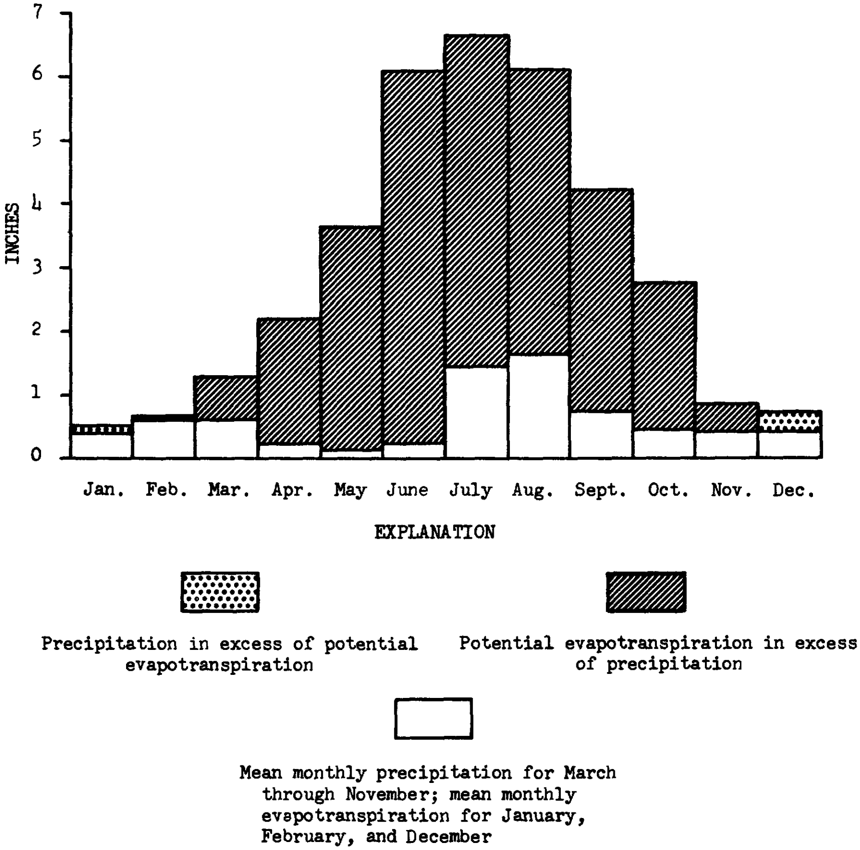

FIGURE 2.—Precipitation and potential evapotranspiration at San Simon, Ariz. Precipitation (mean monthly for the period 1881–1953) after Smith, 1956. Potential evaporation by Thornthwaite method.

Analysis of table 1 and figure 2 shows clearly the lack of water for recharge to the ground-water reservoir in the San Simon basin. The high evapotranspiration potential causes most of the precipitation to be returned to the atmosphere before it can reach the ground-water reservoir. If a method could be devised for capturing this water before it is evaporated or transpired, abundant water would be available for recharging the ground-water reservoir.

PREVIOUS INVESTIGATIONS

The geology and ground-water resources of the San Simon basin have been discussed in several reports which are listed chronologically and summarized below.

1919. Schwennesen, W. T., Ground water in San Simon Valley, Arizona and New Mexico, with a section on agriculture by R. H. Forbes: U.S. Geol. Survey Water-Supply Paper 425-A.

Describes the physiography and geology of the valley, the upper water horizon, and the deep artesian horizon of the San Simon and Bowie areas. The investigation, made in 1913 and 1915, included the measurement of the discharge and the pressure head for many of the artesian wells in the area.

1947. Cushman, R. L., and Jones, R. S., Geology and ground-water resources of the San Simon basin, Cochise and Graham Counties, Arizona, with a section on quality of water by J. D. Hem: U.S. Geol. Survey open-file report.

Describes the geology of the basin in relation to the occurrence of ground water and supplements the earlier report with additional water-level and discharge measurements. The report describes the chemical quality of the ground water in relation to use and in relation to recharge and source of dissolved matter.

1952. DeCook, K. J., San Simon basin, Cochise County, *in* Ground water in the Gila River basin and adjacent areas, Arizona—a summary, by L. C. Halpenny and others: U.S. Geol. Survey open-file report.

Summarizes available hydrologic data to spring 1952.

1957. Sabins, F. F., Geology of the Cochise Head and western part of the Vanar quadrangles, Arizona: Geol. Soc. America Bull., v. 68, p. 1315-1342.

Describes in detail the geology of the two quadrangles, which include a small part of the San Simon basin.

1958. Gillerman, Elliot, Geology of the central Peloncillo Mountains, Hidalgo County, New Mexico, and Cochise County, Arizona: N. Mex. Bur. Mines and Mineral Resources Bull. 57.

Describes the volcanic and the older sedimentary and granitic rocks of the Peloncillo Mountains which bound the San Simon basin on the northeast.

1959. Johnson, P. W., Test holes in southern Arizona valleys: Arizona Geological Society Southern Arizona Guidebook 2, April 2-6, p. 62-65.

Gives data on deep test holes drilled in the San Simon basin.

In addition to the above reports, the San Simon basin is included on the geologic map of Cochise County (Ariz. Bur. Mines, 1959).

HISTORY

Stock raising was the chief means of livelihood in the San Simon basin from about 1870, when the first white settlers came into the area, until about 1910, when artesian water was discovered. Before this time, ground water was obtained locally from shallow unconfined aquifers. The supply was sufficient for domestic and stock purposes and for the railroad at Bowie and San Simon. The water level in this shallow aquifer was as much as 70 feet below the land surface—too deep for economical pumping for agriculture with the equipment available at that time. A well several hundred feet deep, drilled in late 1910 for the Southern Pacific Railroad at San Simon, produced flowing water and led to the development of agriculture in the basin. Since 1910 the amount of water used and the acreage under cultivation have fluctuated with economic conditions.

Schwennesen (1919) stated that in 1915 there were 127 flowing wells capable of producing 11,000 acre-feet of water per year if allowed to flow continuously. Few wells were equipped with shutoff valves, and much of the water was wasted. During World War I agricultural development increased, and in 1919 about 1,200 acres of land was under cultivation. As the economy declined after World War I, many farms were abandoned, and in 1940 only 400 acres of land was cultivated in the basin. World War II caused another increase in agricultural prices, and in 1946 about 1,000 acres was irrigated with about 5,800 acre-feet of water from 140 artesian and 3 water-table wells (Cushman and Jones, 1947). Barr (1954) stated that about 12,000 acres was cultivated in the area in 1953. In 1956, the last year for which data are available, about 40,000 acre-feet of water was produced from artesian and water-table aquifers in the basin (Harshbarger and others, 1957).

WELL-NUMBERING SYSTEM

The well numbers used by the Geological Survey in Arizona are in accordance with the Bureau of Land Management's system of land subdivision. The land survey in Arizona is based on the Gila and Salt River meridian and base line, which divides the State into four quadrants (fig. 3). These quadrants are designated counterclockwise by the capital letters A, B, C, and D. All land north and east of the point of origin is in A quadrant; that north and west, in B quadrant; that south and west, in C quadrant; and that south and east, in D quadrant. The first digit of a well number indicates the township; the second, the range; and the third, the section in which the well is situated. The lowercase letters a, b, c, and d after the section number indicate the well location within the section. The first letter denotes a particular 160-acre tract (fig. 3); the second, the 40-acre tract; and the third, the 10-acre tract. These letters also are assigned in a counterclockwise direction, beginning in the northeast quarter. If the location is known within a 10-acre tract, three lowercase letters are shown in the well number. In the example shown, well number (D-4-5)19caa designates the well as being in the NE¼NE¼SW¼ sec. 19, T. 4 S., R. 5 E. Where there is more than one well within a 10-acre tract, consecutive numbers beginning with 1 are added as suffixes.

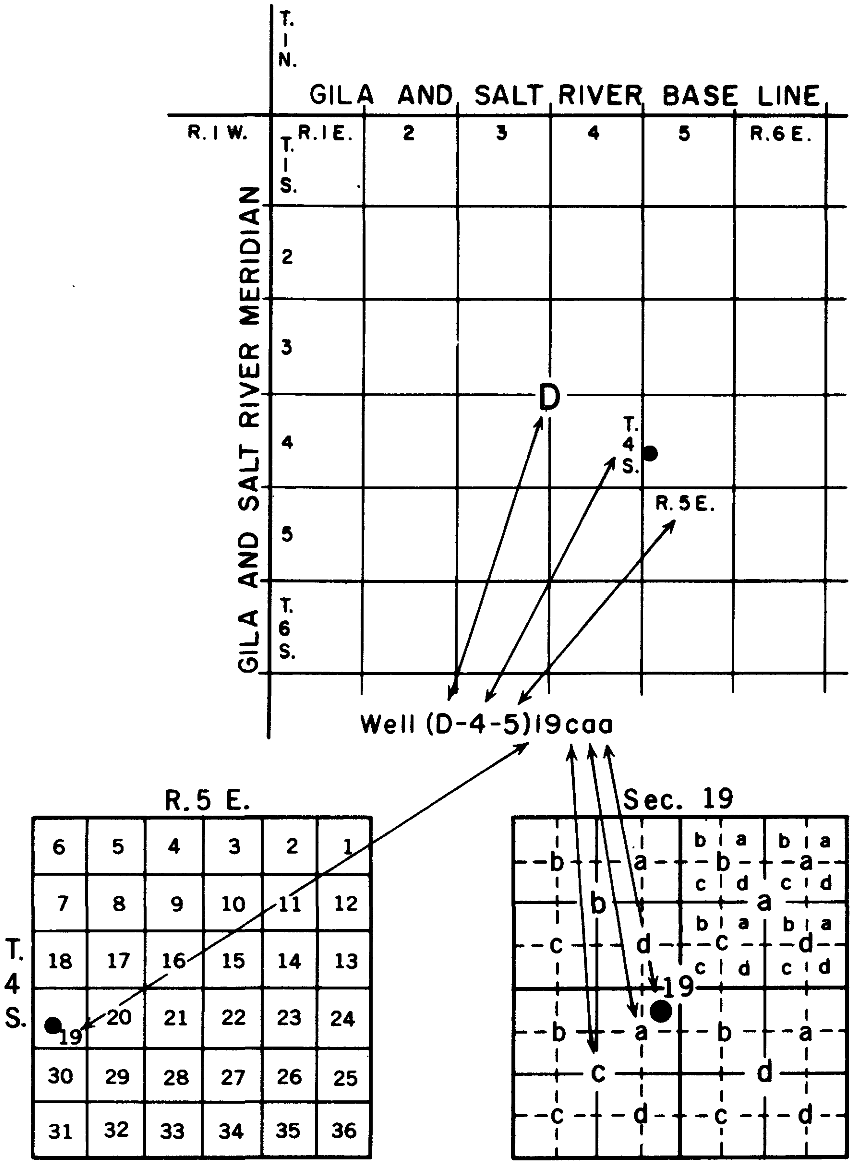

FIGURE 3.—Diagram showing well-numbering system in Arizona.

METHODS OF STUDY

DATA AVAILABLE

The quantity and quality of the hydrologic and geologic data collected by the U.S. Geological Survey in Arizona have been greatly dependent on the immediate purpose for which they were intended. The data collected for specific areal investigations are more detailed than those collected under the general statewide collection program. On the other hand, the statewide program has been responsible for most of the long-term records available for the State.

The collection of water records is an integral part of any investigation of the ground-water resources of an area, as these records provide a basis for detailed regional investigations. Large quantities of these data are available for most areas in the State. The geologic and hydrologic data used in this study were collected under the statewide ground-water survey or were available in published or open-file reports. With the exception of the small amount of information obtained on interference between water-table and artesian wells, no additional data were collected during this study, although additional data would have been useful.

The data available for the San Simon basin include: (1) Measurements of the pressure head in many artesian wells for the year 1915; (2) periodic water-level measurements made in selected wells in both the water-table and the artesian aquifers, many dating from the 1940's to 1960; (3) discharge measurements made in many wells, both flowing and pumped, throughout the basin; (4) drawdown measurements in some of the wells for which discharge measurements are available; (5) reconnaissance geologic mapping; (6) drillers' logs for many water wells and a few deep test holes; and (7) well cuttings from a few wells.

METHODS OF ANALYSIS

Several of the standard techniques generally used by the Survey for analyzing ground-water data have been utilized in the current project on San Simon basin. Hydrographs for selected wells in the basin were prepared using water-level measurements obtained over a period of years. These hydrographs show not only a trend of ground-water levels in relation to the pumping regimen but also the differences in trend that are functions of different aquifers. Contour maps of the altitude of the artesian-pressure surface have been prepared from water-level measurements in many wells for specified dates. One map shows the altitude of the artesian-pressure surface prior to substantial development in the area, and the contours indicate the direction of movement and the areas of recharge to the ground-water reservoir. By comparison with the map for the early date, contour maps of the altitude of the artesian-pressure surface for later dates (after development) indicate the changes in the direction of ground-water movement as a result of the pumping of ground water in specified areas. Maps showing the change in artesian pressure help to evaluate the trends in ground-water levels as related to the development of ground-water supplies in the basin. Both the "altitude" and the "change" maps help to delineate areas where ground-water conditions are the most conducive to future development. Analysis of the logs of wells in the basin adds to the knowledge of the subsurface geology and its relation to the ground-water regimen. A geologic section prepared from well logs gives a generalized picture of the subsurface strata in the basin. Some of the major subsurface characteristics of the basin are shown by means of maps constructed from the study of the logs. Analysis of data on the discharge and drawdown in wells determines the specific capacity for the individual well and provides some knowledge of the transmission characteristics of the aquifer.

These standard techniques for the analysis of ground-water data provided the means by which the water resources of the San Simon basin were appraised in the present study. Other standard techniques that were not used in the present study owing to lack of the data necessary to employ them include (1) the analysis of aquifer-test data which can give good information on the capacity of the aquifer to store and transmit water, and (2) the flow-net method for analyzing ground-water movement.

The electrical-analog methods (Skibitzke, 1960) developed recently were not utilized in the current analysis. However, these methods are of great interest and importance to the ground-water hydrologist, and a proposed project will analyze the data for San Simon basin in this manner. The electrical model for the San Simon basin has been constructed, and plans are underway to complete the analysis. The instrumentation for the electrical-analog method is based on the analogy between the flow of an electric current and laminar liquid flow and may be used to study the nonsteady response of a nonhomogeneous aquifer. The electrical-analog method provides a means of integrating large masses of data quantitatively, whereas the standard techniques described above can assimilate only relatively small amounts of data.

GEOLOGY IN RELATION TO GROUND WATER

GENERAL GEOLOGY OF THE BASIN

The San Simon basin is bounded by the Peloncillo, Chiricahua, Dos Cabezas, and Pinaleno Mountains, which are composed of volcanic, metamorphic, granitic, and indurated sedimentary rocks. Between these mountains, the San Simon basin is partly filled with alluvial and other water-laid deposits. The rocks in the bordering mountains probably extend beneath the valley floor and underlie the surface upon which the valley fill was deposited. Drillers' logs of water wells indicate that the maximum depth of the top of the bedrock is more than 2,000 feet along the axis of the valley (table 2). One oil-test well, (D–13–31)31dca, indicated a total depth to bedrock of about 2,800 feet, but no detailed log is available for this well. A previous estimate (Sabins, 1957) that the depth to bedrock at well (D–14–30)36 is more than 7,000 feet has been reevaluated, and drill cuttings previously thought to be alluvium were subsequently identified as volcanic tuff and agglomerate (L. A. Heindl, U.S. Geol. Survey, oral communication, 1960). In general, the valley fill is in a large shallow troughlike depression probably formed by differential uplift of the mountain blocks relative to the blocks underlying the basin. Near the mountain fronts, the sides of the trough probably are steeper than they are toward the axis.

TABLE 2.—*Drillers' logs of wells in San Simon basin, Cochise and Graham Counties, Ariz.*

	Thickness (ft)	Depth (ft)
(D-10-28)25d		
Drift sand	14	14
Adobe	35	49
Hard black sand	4½	53½
Water sand; little water	35	88½
Gumbo and green clay	153	241½
Black water sand; water	4	245½
Gray clay, squeezes	35	280½
Soft sandstone	63	343½
Lime, blue	14	357½
Hard sand	45	402½
Green shale	30	432½
Lime	½	433
Quicksand	35	468
Lime	½	468½
Peat and quicksand	38	506½
Sandstone	4	510½
Black shale and selenite	3	513½
Green shale	51	564½
Blue and white shale	50	614½
Shale and selenite	5	619½
Green and brown shale	18½	638
Light-colored shale and selenite	40	678
Green and brown shale	37	715
Crystallized lime; gypsum	5	720
Brown and green shale	15	735
Green shale	65	800
Brown shale with streaks of gypsum	105	905
Yellow shale, not sandy	25	930
Yellow and brown shale	78	1,008
Alternate layers dark and light brown and yellow shale	22	1,030
Brown shale	5	1,035
Lime or gypsum	7	1,042
Water gravel; some water	27	1,069
Brown shale and sandstone	15	1,084
Alternate layers of brown shale and gypsum	242	1,326
Brown sandy shale	110	1,436
Hard conglomerate	8	1,444
Hard rock	32	1,476
Hard conglomerate	24	1,500
Coarse sand	3	1,503
Conglomerate	13	1,516
Fine sand	3	1,519
Black sandstone	11	1,530
Light sand	2	1,532
Total	--------	1,532

	Thickness (ft)	Depth (ft)
(D-10-29)20		
Cemented gravel	12	12
Quicksand	30	42
Brown clay	6	48
Brown sand	45	93
Sand with sandstone shells	10	103
Brown sand	12	115
Brown clay	15	130
Hard conglomerate	6	136
Fine brown sand	19	155
Brown clay and boulders	18	173
Cemented gravel and boulders	20	193
Sandstone	5	198
Gravel	8	206
Sandy shale and shells	76	282
Blue shale	3	285
Blue and brown shale	11	296
Blue and brown shale with shells	29	325
Soft shale	18	343
Blue shale	30	373
Hard lime shells	9	382
Hard red rock; conglomerate	131	513
Total	--------	513
(D-11-29)26b		
Soil and sand	25	25
Water sand	20	45
Blue clay	5	50
Blue clay, shells gyp-little water	715	765
Hard rock	35	800
Total	--------	800
(D-12-28)23ccc		
Soil	5	5
Caliche	9	14
Clay	56	70
Blue clay	435	505
Red clay	30	535
Gravel	4	539
Clay and gravel	21	560
Sand and gravel	10	570
Sand, gravel with clay strata	30	600
Clay	20	620

TABLE 2.—*Drillers' logs of wells in San Simon basin, Cochise and Graham Counties, Ariz.*—Continued

	Thickness (ft)	Depth (ft)
(D-12-28)23ccc—Continued		
Sand and gravel with clay strata	25	645
Sand, gravel	15	660
Sand, gravel with clay	160	820
Cemented gravel	6	826
Gravel cemented with clay	14	840
Sand, gravel with clay strata	34	874
Congl. sand and gravel with clay	126	1,000
Total	--------	1,000
(D-12-28)35cdc2		
Top soil	4	4
Caliche	4	8
Sandy clay	20	28
Clay	7	35
Sand and gravel, dry	15	50
Clay	20	70
Clay and boulders	5	75
Clay	40	115
Sand and gravel	5	120
Sand and rock, hard	15	135
Clay with sand	31	166
Blue shale, sticky	29	195
Blue clay	38	233
Sand and gravel	22	255
Shale, sticky	13	268
Gravel and boulders	7	275
Shale, sticky	30	305
Clay and shale	60	365
Shale, sticky	110	475
Sand and gravel	20	495
Gravel and sand with clay streaks	10	505
Sand and gravel	89	594
Sand and fine gravel	6	600
Boulders	15	615
Hard sand rock	5	620
Total depth	--------	620
(D-13-28)7dbc		
Surface soil	20	20
Sand and boulders	28	48
Gravel and sand	57	105
Yellow clay	90	195
Clay and boulders	45	240
Sand	17	257
Hard boulders	59	316
Hard boulders and rock	25	341
Rock	35	376
Hard rock	24	400
Total	--------	400
(D-13-29)6cdb		
Clay fill	165	165
Blue shale	120	285
Clay	183	468
Sand and water raised to 100 feet	14	482
Blue clay	10	492
Sand and some water	6	498
Clay and gravel	7	505
Sand and water	7	512
Sand and clay	6	518

	Thickness (ft)	Depth (ft)
(D-13-29)6cdb—Continued		
Sand and water	8	526
Sand and clay	4	530
Sand	7	537
Sandstone	8	545
Gravel and water	23	568
Clay	10	578
Sand and gravel and clay	14	592
Sand, clay, water raised to 11 feet	36	628
Hard sandstone and clay	77	705
Hard sandstone and clay and water	55	760
Sand, gravel, clay and some water	40	800
Sand	174	974
Sand rock	37	1,011
Conglomeration of r. shale, b. shale, sand	9	1,020
Gray shale and sand	9	1,029
Bed sand with some red shale	22	1,051
Sand, hard streaks of quartz	147	1,198
Sandstone, very hard	27	1,225
Sand soft (some water)	50	1,275
Total	--------	1,275
(D-13-29)28bbc		
Sandy loam	3	3
Red clay	181	184
Blue shale	26	210
Fine sand—a seep of water	1	211
Blue clay	49	260
Coarse water sand and gravel	20	280
Sandy brown clay	87	367
Coarse water sand and gravel	13	380
Sandy brown clay	25	405
Hard sand rock	2	407
Red sandy clay	18	425
Hard sand rock	1	426
Red sandy clay	54	480
Conglomerate-rock and blue clay	50	530
Blue granite rock	17	547
Blue clay	8	555
Blue granite rock	15	570
Coarse water gravel	3	573
Hard conglomerate, rock and blue clay	39	612
Coarse water gravel	3	615
Hard conglomerate, rock and blue clay	40	655
Blue granite rock	5	660
Total	--------	660
(D-13-30)28acc		
Surface soil	4	4
Caliche	24	28
Caliche and boulders	44	72
Sand and small gravel	15	87
Clay and gypsum	113	200
Gypsum	40	240
Blue shale	408	648
Grey shale	113	761
Sand—hard	4	765
Congl. of soapstone, brown shale, little sandy	9	774
Congl. of sand, small gravel, and brown shale	14	788
Sand	2	790

TABLE 2.—*Drillers' logs of wells in San Simon basin, Cochise and Graham Counties, Ariz.*—Continued

	Thickness (ft)	Depth (ft)
(D-13-30)28acc—Continued		
Congl. of sand, quartz and shale streaks	50	840
Sand, soft, with quartz—water	12	852
Sandy quartz, hard streaks	13	865
Sand, soft with some boulders (water sand)	22	887
Sand, hard cemented with some large boulders	4	891
Sand, soft streaks, some water	39	930
Cemented sand, hard	68	998
Hard sand with blue shale streaks very thin	6	1,004
Brown shale, sandy	29	1,033
Sand gravel and granite wash, water	35	1,068
Brown shale	6	1,074
Sand, gravel and boulders	34	1,108
Rock with some broken sand (hard)	30	1,138
Rhyolite (very hard)	82	1,220
Rhyolite, boulders, quartz and some sand (white)	8	1,228
Granite boulders with some mica and brown shale	9	1,237
Shale	28	1,265
Conglomerate sand, boulders, quartz	45	1,310
Shale, red	7	1,317
Red shale and sand	16	1,333
Sand (water)	21	1,354
Total	--------	1,354
(D-13-31)21caa		
Red valley fill	55	55
Sandy shale	15	70
Sticky shale	15	85
Sandy—a little water	12	97
Gray soapy gumbo shale	38	135
Green gumbo, apple green	15	150
Gray gumbo shale	85	235
Water sand and water	8	243
Blue sandy shale	17	260
Blue gumbo shale	60	320
Light red shale with fine sand	10	330
White gumbo shale or bentonite	25	355
Light red sandy shale	15	370
Light gray shale	3	373
Light red conglomerate gravel—some sand	47	420
Conglomerate	20	440
Conglomerate, gravel, sand with clay	466	906
Rhyolite	374	1,280
Total	--------	1,280
(D-14-31)3aba		
Soil, clay and gravel	80	80
Sand, gravel and clay layers	80	160
Blue, brown and green clay	240	400
Sand, gravel and clay layers	335	735
Total	--------	735

	Thickness (ft)	Depth (ft)
(D-14-31)16dcc		
Gray clay	61	61
Light brown clay, some pebbles	17	78
Struck first water, 74 feet, raised to 68 feet.		
Brown clay, some gravel	10	88
Gravel showing caliche	10	98
Caliche	4	102
Gray clay	8	110
Blue clay	213	323
Gray clay	49	372
Sand and some water	3	375
Blue clay	9	384
Gray clay	10	394
Brown clay	26	420
Yellow clay showing some gravel	151	571
Sand, second flow to top; bucket test 10 gpm	3	574
Brown sand	10	584
Yellow clay	56	640
Yellow clay showing some sand	10	650
Yellow sticky clay	17	667
Sand showing some black shale	1	668
Yellow clay	15	683
Water sand, small flow	10	693
Yellow clay	5	698
Gray clay	16	714
Dry water sand	2	716
Yellow sticky clay	5	721
Sand, small flow	5	726
Medium hard gray clay	5	731
Yellow sticky clay	16	747
Small flow	5	752
Yellow clay	23	775
Dry water sand	4	779
Yellow clay	17	796
Yellow clay showing brown sand	20	816
Some sand showing gravel	2	818
Yellow clay	15	833
Dry sand, very hard	12	845
Yellow sticky clay	7	852
Yellow clay and sand, no water	5	857
Yellow sticky clay	25	882
Flow to the surface, 8 gpm	3	885
Sand, no water	23	908
Sand	15	923
Sand and gravel	5	928
Very fine sand, some clay and fine gravel, cemented	812	1,740
Cemented sand and gravel up to 3 or 4 inches	25	1,765
Cemented sand and clay	10	1,775
Cemented gravel up to 2 inches	5	1,780
Cemented sand and clay	25	1,805
Cemented sand, clay and gravel up to ¾ of an inch	5	1,810
Cemented sand, clay	20	1,830
Cemented sand and gravel, not much clay	5	1,835
Fine sand and clay cemented together	165	2,000
No water was encountered below 928 feet.		
Total	--------	2,000
(D-14-31)35bcc		
Top soil	108	108
Water gravel	4	112

TABLE 2.—*Drillers' logs of wells in San Simon basin, Cochise and Graham Counties, Ariz.*—Continued

(D-14-31)35bcc—Continued	Thickness (ft)	Depth (ft)
Caliche and red clay	38	150
Red clay	30	180
Blue clay	220	400
Bentonite clay	118	518
Water gravel	2	520
Conglomerate	105	625
Water gravel	6	631
Conglomerate	47	678
Water gravel	6	684
Conglomerate	24	708
Water gravel and sand	4	712
Conglomerate	11	723
Water gravel and sand	5	728
Conglomerate	4	732
Alternating layers	18	750
Conglomerate	25	775
Gravel	5	780
Conglomerate	20	800
Total	--------	800

(D-14-32)16cab	Thickness (ft)	Depth (ft)
Fill	4	4
Sandy clay	21	25
Gravel	3	28
Sandy clay	64	92
White sand	14	106
Sand rock	5	111
Sand with some clay	33	144
Gravel	5	149
Sand with some clay	52	201
Sand and gravel (water)	7	208
Hard, packed sand (some water)	22	230
Sand and gravel (water)	87	317
Sand, gravel and clay	11	328
Hard, packed sand (some water)	7	335
Sand and gravel (water)	77	412
Clay and gravel	8	420
Sand and gravel (water)	40	460
Rhyolite	5	465
Total	--------	465

The rocks comprising the two nearly parallel chains of mountains that border the San Simon basin are dense and generally impermeable and serve to retain the ground water in the trough. The valley fill that partly fills the trough between the mountain chains is referred to as the "older alluvium" (Cushman and Jones, 1947). The sand and gravel members of the older alluvium constitute the major aquifers and form the ground-water reservoir in the San Simon basin.

The ground-water storage capacity of the basin is controlled, to a large extent, by the thickness of the alluvium, which is in turn a function of the configuration of the bedrock floor. The highly generalized profile of the buried bedrock reflects the present paucity of information regarding depth to bedrock in the basin. Additional information about the thickness of the valley fill will improve the accuracy of the estimates of total ground-water storage in the basin. Test drilling together with seismic or other types of geophysical studies probably would be the best methods for obtaining this information.

Younger alluvial fill occurs in thin deposits along stream channels. It is not a significant aquifer in the basin and will not be discussed further in this report.

OLDER ALLUVIAL FILL

The discussion of the geology of the valley fill is based on rather meager data—reconnaissance surface geologic mapping by Cushman and Jones (1947) and interpretations from a small number of well logs. For this reason, the discussion given here is tentative; further data are needed for a more detailed determination of the character and extent of the valley fill. The general relationships of the various units are shown on the geologic section (fig. 4).

The older alluvial fill is composed of interfingering beds and lenses of clay, silt, sand, and gravel that were deposited by runoff from the surrounding mountains. Part of the older fill may have been deposited in lakes during a time when the basin was without exterior drainage. For the most part, the coarser deposits are near the mountains and the fine-grained sand and silt is at the lower elevations toward the axis of the valley.

For ease of discussion in this report, the older alluvial fill is divided into four geologic units—the "lower unit," the "blue clay unit," the "upper unit," and the "marginal zone." Hydrologically, the lower unit constitutes the "lower aquifer," and the saturated part of the upper unit constitutes the "upper aquifer."

LOWER UNIT

Logs of wells available for the San Simon basin indicate that the stream and lake-bed deposits of clay, silt, sand, and gravel that constitute the lower unit overlie the bedrock and in places are interbedded with volcanic debris. The water-bearing sand and gravel layers apparently interfinger with layers of dense clay throughout the unit. The thickness of the lower unit generally is unknown, but at places along the axis of the valley it is as much as 2,000 feet. The unit is continuous and covers the entire basin; along the edges of the basin in the marginal zone, the lower unit merges with the upper unit.

The lower unit forms the lower aquifer in the San Simon basin. It contains water under artesian pressure and is the source of most of the ground water used in the San Simon basin.

BLUE CLAY UNIT

A layer of dense blue clay overlies the lower unit, except in the marginal zone, and acts as an aquiclude. The top of the blue clay unit is at depths ranging from 60 to 200 feet below the land surface. The thickness of the unit was determined by superimposing maps, derived from drillers' logs, that show contours of the top and of the bottom of the blue clay. Contours of the thickness of the blue clay unit (pl. 2) show the clay body to be about 600 feet thick along the axis of the valley in the center of the basin. The blue clay unit extends across and along most of the basin and forms a body that is flattish, elongated, and surrounded, except to the northwest and southeast, by coarser materials. In the direction of the axis of the valley, the blue clay unit probably extends beyond the area shown on plate 2, but just how far is not known.

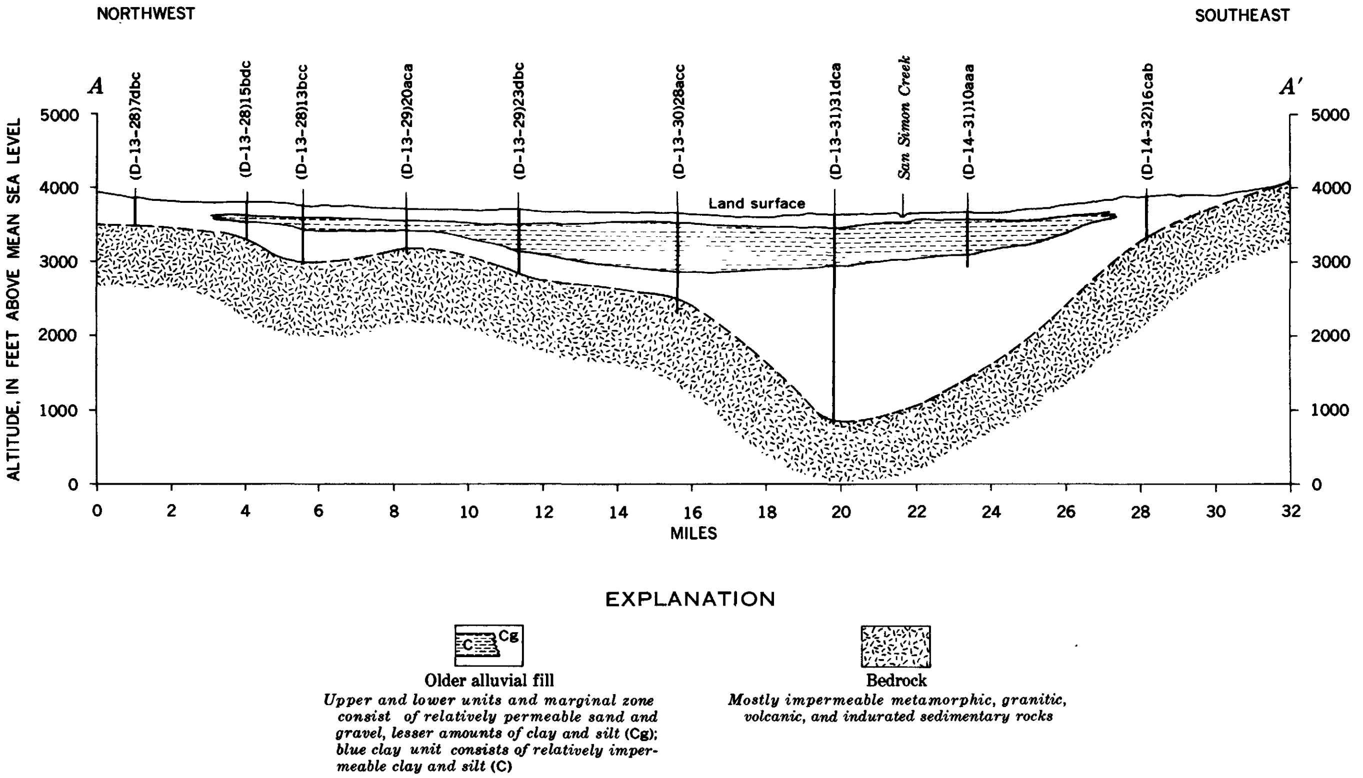

FIGURE 4.—Generalized geologic section along line *A–A′* shown in plate 1, San Simon basin, Cochise and Graham Counties, Ariz.

Plate 2 also indicates the approximate line along which the clay unit is presumed to pinch out toward the mountains marginal to the basin. Between this line and the buried mountain front, the upper and lower units merge to form the marginal zone.

The top of the blue clay generally follows the configuration of the land surface. Along the axis of the valley it dips gently at about 20 feet per mile to the northwest; from the sides of the valley toward the axis the gradients are considerably steeper.

UPPER UNIT

The upper unit overlies the blue clay unit and consists of unconsolidated stream deposits of silt, sand, and gravel that range in thickness from about 60 to 200 feet. These sediments are a continuous geologic unit throughout the San Simon basin. However, as a water-bearing formation, the unit is localized and may not contain usable quantities of water except in the San Simon area.

Where present, the water in the upper unit is under water-table conditions; the saturated part of the unit is designated the upper aquifer.

MARGINAL ZONE

Near the margins of the valley the blue clay unit pinches out, and the coarser deposits of the lower and upper units merge to form a continuous body of coarse deposits. Plate 2 shows the approximate line along which the clay pinches out. In a few places this line is fairly well defined, but in others the delineation is tentative owing to a lack of data. The area between this line and the buried mountain front is defined as the marginal zone.

Within the marginal zone, the separate artesian and water-table characteristics of the lower and upper aquifers have merged to form a single aquifer under water-table conditions.

GROUND WATER

Ground water has been defined as the water that is in the zone of saturation—a subsurface geologic stratum in which all the interstices in the rock are filled with water. Ground water is one phase of the hydrologic cycle—that part of the precipitation that has seeped downward and reached the zone of saturation.

For the most part, a geologic formation that stores water and transmits it to wells and springs in usable quantities is considered to be an aquifer. However, the quantity and quality of the ground water available depend upon the materials that make up the aquifer and upon its size and shape. Aquifers may be either water table or artesian. In a water-table aquifer the ground water is unconfined and free to move by gravity; the upper surface of the saturated zone is then called the water table. In an artesian aquifer the water is confined beneath relatively impermeable material and is under artesian pressure that causes water to rise in wells above the bottom of the confining bed. The imaginary surface to which water will rise in an artesian aquifer is called the piezometric or artesian-pressure surface.

In the San Simon basin, ground water is under artesian conditions in the lower aquifer and under water-table conditions in the upper aquifer and in the marginal zone, where the upper and lower aquifers form a hydrologic unit.

OCCURRENCE

The blue clay unit forms a confining layer which separates the upper water-table aquifer from the lower artesian aquifer. Ground water is under artesian pressure in the permeable lenses of sand and gravel in the lower aquifer. The known thickness of the lower water-bearing unit ranges from about 300 feet at the outer edges of the basin to as much as 2,000 feet along the axis of the valley. The more permeable water-bearing zones are in the sand and gravel lenses which are interbedded with less permeable zones of clay, sandstone, and conglomerate (table 2). The less permeable zones do not yield water readily to wells and seem to occur with increasing frequency below about 700 feet. However, data regarding the occurrence of water at depths below about 700 feet are sparse and dissimilar in several areas where deep wells have been drilled. The log for well (D–14–31)16dcc, drilled to a depth of 2,000 feet, indicates that no water was found below 928 feet—although several zones of cemented sand and gravel were present below that depth. The logs for wells (D–13–29)6cdb and (D–13–30)28acc indicate that water was found at depths of 1,275 and 1,350 feet, respectively.

Above the blue clay unit, ground water is under water-table conditions in the sand and gravel beds of the upper aquifer. The water in this aquifer moves generally northwestward at a gradient somewhat steeper than that of the land surface.

In the Bowie area no data are available to determine the extent of the water-bearing lenses of the upper aquifer, as only three wells are known to be finished in this zone and they are dry and abandoned. Schwennesen (1919, p. 11) stated: "In all the wells in the Bowie area of which records are available the water of the upper horizon was found in sand or in mixed clay and gravel commonly called wash." He further stated (1919, p. 28): "In the Bowie region the supply at the upper ground-water horizon is very scanty and it is generally necessary to sink to the lower horizon, even for small supplies." Apparently, these statements are based on the logs for the three railroad wells at Bowie, which may have been producing when Schwennesen made his investigation in 1915, but which are now dry. Subsequent records do not show any wells finished in the upper aquifer in the Bowie area. Logs of wells in the area indicate that extensive clay lenses are present in the upper aquifer that would act to limit the amount of water available. More data are necessary to determine the extent and the effect of these lenses or other factors affecting the occurrence of water in the upper aquifer in the Bowie area.

In 1946 the depth to the water table in the upper aquifer was least along the axis of the valley and increased toward the mountains (Cushman and Jones, 1947). Data were included only for the San Simon area of the basin. However, miscellaneous water-level measurements made since 1946 indicate that several cones of depression have developed in the irrigated area along San Simon Creek near San Simon in which the depth to water is greater than it is at the margins of the basin.

Ground water is under water-table conditions in the marginal zone where the upper and lower aquifers are continuous.

RECHARGE

The major source of recharge to both the lower and upper aquifers in the San Simon basin probably is seepage from runoff near the mountain fronts. Contours of the artesian-pressure surface (pl. 3) indicate that the lower artesian aquifer in the San Simon basin is recharged along the margins of the basin in the area between the clay pinchout and the mountain front where the upper and lower aquifers are continuous. The extent of this recharge zone is somewhat irregular, and its delineation is tentative owing to a lack of data. A part of the water that reaches the marginal zone percolates downward and moves laterally beneath the blue clay unit into the lower aquifer, and part moves laterally above the water table and into the upper aquifer above the blue clay unit. The proportion of the total water available that moves into each of the aquifers depends upon several factors: (1) the permeability of the material in the area of recharge; (2) the level of the water table and the artesian-pressure surface; and (3) the amount and rate of movement of the runoff, either streamflow or sheetflow, across the recharge area.

Some water moves into the upper and lower aquifers in the San Simon basin by underflow from the south end of the basin. The water moving through the cross-sectional area at the arbitrary southern boundary of the basin would be recharge to the basin as described, and may be a large part of the total recharge to the basin.

With regard to underflow into the artesian aquifer of the San Simon basin, Cushman and Jones (1947, p. 6) stated:

> A large part of the ground water moving into the San Simon Basin from the south is forced to the land surface about 14 miles north of Rodeo, New Mexico, by a ground-water barrier, forming a marshy area of about 1,600 acres, known as the San Simon Cienaga. The change in slope of the water table at the cienaga indicates the presence of a partial ground-water barrier * * * This barrier may be part of the clay beds of the lake-bed zone.

In discussing underflow into the upper aquifer Cushman and Jones (1947, p. 9) further stated:

> Underflow into the basin occurs in the vicinity of the San Simon Cienaga; however, a large quantity of this water is discharged by evaporation and plant use within the cienaga.

No further data are available to modify the statement. However, it seems logical that the total quantity of water that could move through the cross-sectional area and into the upper aquifer of the basin at the cienaga would be reduced only by the quantity of water that is lost to evapotranspiration from the cienaga. The cienaga averages less than half a mile in width, whereas the width of the basin here is at least 5 miles. Furthermore, depending upon the nature of the barrier, the quantity of water that could move through the cross-sectional area of the lower aquifer may not be affected at all. For instance, if the barrier is part of the blue clay unit occurring near the surface, thus causing the cienaga, the water moving through the cross-sectional area of the lower aquifer beneath the clay would not be affected. However, it is possible that the characteristics of the barrier could be such that they would affect the movement of water into the lower aquifer. Test holes in the area would aid in determining the nature and extent of the barrier.

The upper aquifer may be recharged by water moving upward from the lower aquifer through corroded well casings or casings perforated both in the upper and lower aquifers. Prior to extensive development of the lower aquifer, the artesian-pressure head was higher than the water table, allowing movement of water into the upper aquifer through artesian wells open in the upper zone. As of 1960, the artesian-pressure head in some places is lower than the water table, prohibiting recharge to the upper aquifer in this manner.

The upper aquifer of the San Simon basin is recharged also by seepage from irrigation water applied to the land. The amount of water that percolates to the ground-water reservoir from that source has been estimated as about 15 percent of the total applied to the land (Cushman and Jones, 1947). Seepage from direct precipitation on the valley floor is negligible in the area. The comparatively low precipitation rates and high evapotranspiration potential cause most of the water to be returned to the atmosphere before it can reach the ground-water reservoir.

DISCHARGE

Ground water is discharged from the upper and lower aquifers in the San Simon basin by natural and artificial means. As indicated by the slope of the artesian-pressure surface before extensive development (pl. 3), water in the lower aquifer moved northwestward, and some water probably discharged as underflow into the Safford Valley. The same probably was true for water in the upper aquifer. Although some water may be lost from the upper aquifer by evapotranspiration, for the most part, development has lowered the water table to a depth sufficient to prevent loss of water in this manner except near the San Simon Cienaga. White (1932) indicated that as the depth to water approaches 10 feet, evaporation becomes negligible. The depth to water in the upper aquifer of the San Simon basin ranges from about 60 to 100 feet. No water is discharged from the lower aquifer by evapotranspiration owing to its great depth below land surface and to its position below the upper aquifer and the blue clay. A small but undetermined amount of water is discharged from the lower aquifer through corroded well casings; this discharge of water from the lower aquifer is recharge to the upper aquifer, and therefore may not be discharge from the basin.

Ground water is discharged artificially from both aquifers by wells. All wells producing water from the upper aquifer are pumped; wells producing water from the lower aquifer may be pumped or flowing. A more detailed discussion of the discharge of water by artificial means is given in the following section.

QUANTITATIVE ANALYSIS

The methods of analyzing the ground-water resources of basins in southern Arizona include several standard techniques, and the results obtained from applying some of these to the data from the San Simon basin are discussed below.

LOWER AQUIFER

The extent and configuration of the lower aquifer in the San Simon basin are known in general from well logs and reconnaissance geologic mapping of the area by previous investigators. Well logs indicate that the lower aquifer is thicker in the San Simon area than it is in the Bowie area. The overlying clay unit that serves as the confining layer also is thicker in the San Simon area than it is in the Bowie area.

Prior to extensive development in the San Simon basin, the pressure head in the lower aquifer was sufficient to cause water to flow from wells in an area of about 70 square miles (pl. 3), extending southeast to northwest along San Simon Creek near San Simon. The pressure head was greatest in the southeastern part of the area. Outside this area, the artesian pressure was sufficient to cause water to rise above the confining layer but insufficient to cause the wells to flow at the surface.

When an artesian well is allowed to flow, the pressure head in the aquifer is reduced near the flowing well, thus allowing water to move into the well. This lowering of the artesian-pressure surface has been described as the cone of depression or cone of influence of the well. The amount of lowering decreases with the distance from the flowing well and increases with time of flow. Thus, time and distance are essential dimensions of the cone of depression. As more and more wells are drilled and allowed to flow, the cones of depression around the wells overlap, resulting in additional water-level decline at each well. This in turn results in less discharge from the wells. When pumps are installed on wells and discharges from the wells are increased, the rate of decline in the water level at the well and the spread of the cone of depression are increased.

Schwennesen (1919) measured the height of the artesian-pressure surface in many wells in the San Simon basin in 1913 and 1915, and his data for 1915 were used to construct a contour map depicting the artesian-pressure surface at that time (pl. 3). These contours show that the pressure surface sloped northwestward along San Simon Creek and generally in from the sides of the valley toward its axis. The gradient of the pressure surface in 1915 was about 12 feet per mile to the northwest along San Simon Creek; in the Bowie area the gradient was about 30 feet per mile from the mountain front toward San Simon Creek. On the northeast side of the basin, data are insufficient to determine the slope of the pressure surface.

Plate 4 shows contours of the artesian-pressure surface for December 1919. The water-level measurements were made and the contours were constructed by H. C. Schwalen, Agricultural Engineering Department, University of Arizona. The general configuration of these contours and of those for 1915 (pl. 3) is similar. For the most part, they differ only a few feet in altitude, owing to decline in the artesian pressure.

The contour maps of the altitude of the artesian-pressure surface for spring 1952 and spring 1960 show the changes in the pressure caused by progressively increasing development of ground water near San Simon and Bowie (pls. 5 and 6).

To determine the change in the artesian-pressure head in the San Simon basin, the artesian-pressure-surface contour maps for 1915, 1952, and 1960 were superimposed to indicate the amount of change for the periods 1915–60 and 1952–60 (pls. 7 and 8). Comparison of the amount of change between these two intervals indicates that a large part of the overall decline in artesian pressure since 1915 has taken place in the period 1952–60.

Figure 5 shows hydrographs of the water level in several artesian wells in the San Simon basin for the period 1915–60. The measurements for 1915 were taken from Schwennesen (1919), and those for 1919 were made by H. C. Schwalen, University of Arizona. Al-

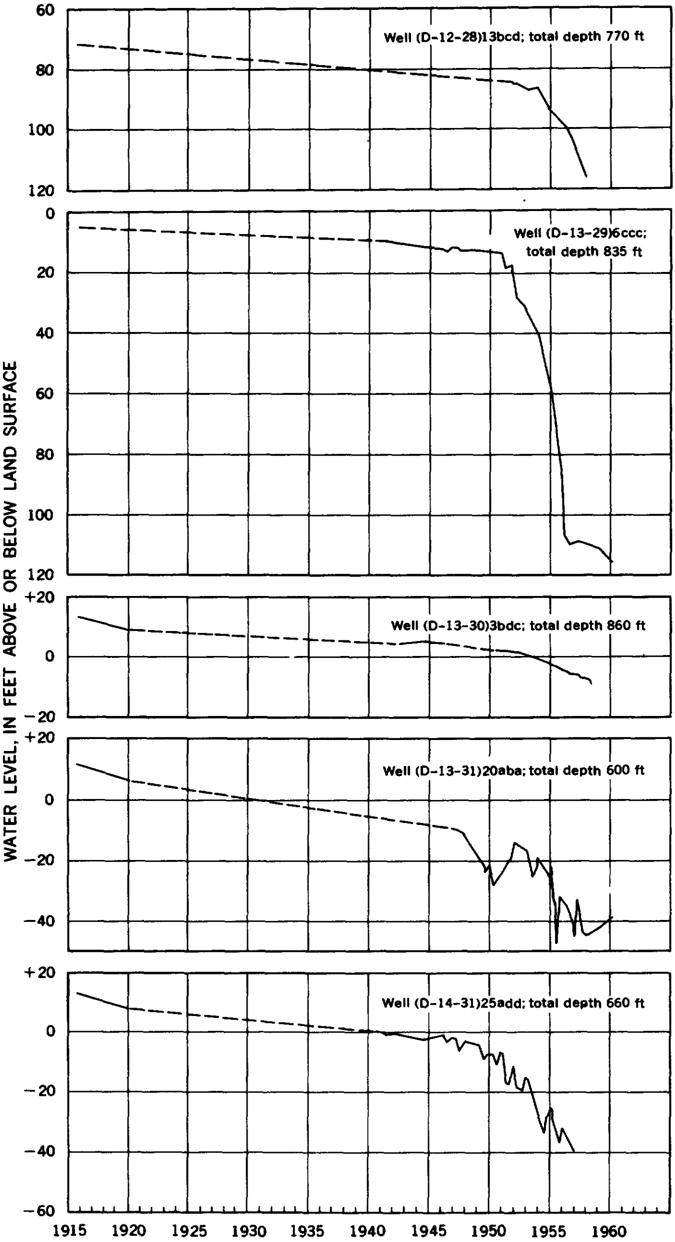

FIGURE 5.—Hydrographs of water levels in selected artesian wells in the San Simon basin, Cochise and Graham Counties, Ariz.

though no measurements are available for the years 1919 to the early 1940's, the pattern of decline for individual wells shows that accelerated decline began in about 1952. The accelerated decline probably resulted from an increase in cultivated acreage in 1952 and 1953 and a corresponding increase in use of water in the area (table 3).

TABLE 3.—*Amount of ground water discharged by wells in the San Simon basin, Cochise and Graham Counties, Ariz. (1940, 1946, 1951–56).*

Year	*Ground water (acre-ft)*
1940	3, 100
1946	5, 800
1951	6, 200
1952	15, 000
1953	25, 000
1954	32, 000
1955	40, 000
1956	40, 000

Decline in the artesian pressure in the basin has been greatest in the Bowie area. This may be because more water is pumped in the Bowie area than in the San Simon area or because the aquifer is thinner in the Bowie area. In the period 1952–60, the decline in artesian-pressure head in the Bowie area ranged from zero in the fringe areas to more than 80 feet in the center of the developed area; for the same period, decline in the San Simon area ranged from zero to about 40 feet (pl. 8). For the period 1915–60, the decline in artesian pressure in the Bowie area ranged from zero to more than 80 feet—about the same as that for the shorter period—but the area included within the 80-foot contour was much larger than that for the period 1952–60 (pl. 7). The water level in one well, (D–13–29)6ccc, declined about 110 feet in the period 1915–60 (fig. 5). In the San Simon area, the decline in artesian pressure for the period 1915–60 ranged from zero to about 60 feet. The artesian pressure in the area between Bowie and San Simon, an undeveloped area about 3 miles wide, did not decline during either period.

Figure 6 shows the hydrographs of two artesian wells—one in the Bowie area and one in the San Simon area. The rate of decline of the water levels in these two wells corroborates the evidence of the greater rate of decline in the Bowie area, as shown by the contour map of the change in the artesian pressure. Within the San Simon area, artesian pressure has declined most in the area described by Schwennesen (1919) and Cushman and Jones (1947) as the "flowing-well area." Cushman and Jones (1947) stated that the decline in artesian pressure as of 1946 was greater in the flowing-well area than elsewhere in the basin. However, at that time only a few wells were in operation in the Bowie area, and the water levels had not been affected by large withdrawals of water.

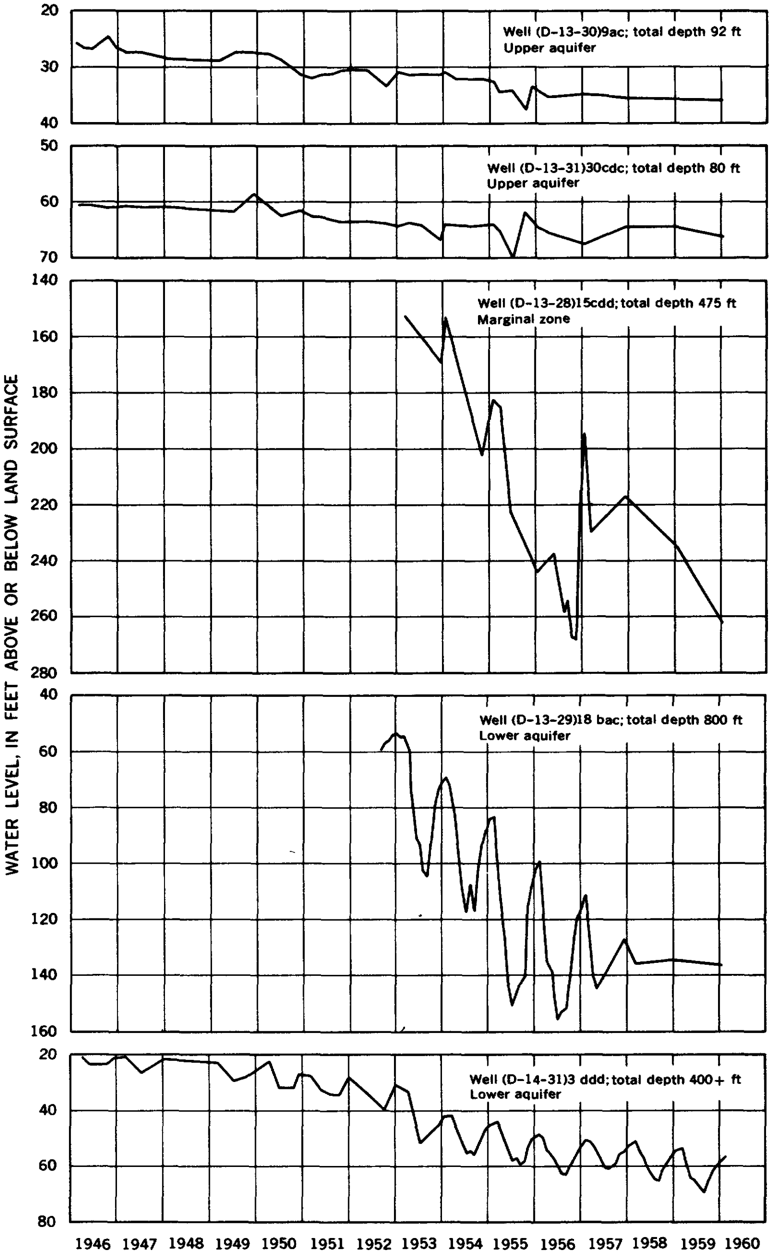

FIGURE 6.—Hydrographs of water levels in selected wells in the San Simon basin, Cochise and Graham Counties, Ariz.

Schwennesen (1919) stated that flows from 116 wells measured in 1913 and 1915 ranged from 1 to 300 gpm (gallons per minute) and averaged about 50 gpm. Few of the artesian wells were pumped at

TABLE 4.—*Specific capacities and related data for wells in San Simon basin, Cochise and Graham Counties, Ariz.*

[USGS: Field measurement made by personnel of U.S. Geological Survey. SLD: Owner's or driller's report to State Land Department]

Location	Total depth (ft)	Date drilled	Discharge (gpm)	Specific capacity (gpm per ft of draw-down)	Date measured	Source of data
Lower aquifer						
Bowie area:						
(D-12-28)						
22cdc	660	8/51	770	11	5/52	USGS
33abc	550	8/51	1,020	21	5/52	USGS
33abc	550	8/51	830	18	7/52	SLD
36ccc	715	4/53	1,600	12	4/53	SLD
(D-13-28)						
4cce	462	10/51	1,150	13	8/56	USGS
13bcc	800	4/55	2,500	17	4/55	SLD
(D-13-29)						
20acc	616	5/53	2,260	15	8/56	USGS
27dcc	608	1/53	1,200	8	2/54	SLD
28bcc	629	12/52	2,000	11	12/52	SLD
San Simon area:						
(D-13-31)						
29acc	794	1915	260	11	5/56	USGS
29dda	740	1947	140	13	8/56	USGS
34cda	760	3/57	350	8	4/57	SLD
(D-14-31)						
3aba	735	8/57	1,300	22	9/58	SLD
10aaa	750	3/59	1,500	11	3/59	SLD
10bbd	680	5/53	250	3	8/56	USGS
15cdd	800	6/51	550	15	5/52	USGS
21bcc	711	3/51	900	4	3/51	SLD
23cdc	744	5/52	475	11	5/52	USGS
25adc2	600	1953	565	8	6/53	USGS
25dbc	600	1920	275	6	5/52	USGS
26bbc	920	1915	265	6	5/52	USGS
28cad	915	1958	1,450	38	3/59	SLD
34acc	1,000	6/59	1,175	17	8/59	SLD
35bcc	800	12/58	1,350	15	12/58	SLD
Upper aquifer						
San Simon area:						
(D-13-30)						
22dbc	113	1956	370	19	8/56	USGS
23cdd	118	2/56	300	8	5/56	USGS
24cdc	120	1956	270	17	8/56	USGS
(D-13-31)						
31acb	111	1/58	300	33	5/59	SLD
Marginal zone						
Bowie area:						
(D-13-28)						
15ccc	455	7/52	1,210	9	8/52	SLD
16ccc	895	9/52	2,150	14	12/52	SLD
16dcc	671	1/53	2,100	21	1/53	SLD
22acc	465	3/53	900	10	5/53	SLD
22dcc	500	3/53	2,200	12	7/53	SLD
23dcc	530	1/53	3,000	14	5/53	SLD
San Simon area:						
(D-14-32)						
16cab	465	3/57	135	34	5/57	SLD

that time. In 1946 the rate of discharge in the flowing wells ranged from seeps to about 120 gpm; about 40 artesian wells were pumped intermittently at rates averaging about 180 gpm (Cushman and Jones, 1947). By 1952 nearly all the wells in the San Simon basin were pumped at least part of the time to obtain sufficient water for irrigation.

Analysis of about 40 well-discharge measurements made in the Bowie area for the period 1952–60 shows that the discharges ranged from about 500 to 2,400 gpm and averaged about 1,300 gpm. Similar calculations for about 80 well-discharge measurements made in the San Simon area show that the discharges ranged from about 60 to 1,500 gpm and averaged about 300 gpm. Drillers' reports of pumping rates on 6 new wells in the San Simon area show discharges from 1,000 to 1,500 gpm.

Table 4 shows discharges and specific capacities for several wells in the San Simon basin. In general, new wells have the highest discharges and specific capacities, probably owing to better well construction and development or the fact that the casing in many of the older wells have become corroded or silted up. Wells in the Bowie area have higher specific capacities than those in the San Simon area with the exception of the new wells in the San Simon area. However, the specific capacities given should be considered as approximations only because discharges and drawdowns reported by the driller or owner generally are obtained from short-term tests; the pumping levels may not have reached equilibrium, and the conditions necessary for computing specific capacity correctly may not have been met. Table 4 gives the source of the data from which the computations of specific capacities were made.

The total amount of water withdrawn from the lower aquifer was about 5,600 acre-feet in 1946 (Cushman and Jones, 1947) and about 6,000 acre-feet in 1951 (DeCook, 1952). Since 1951 the amount of water pumped from the lower aquifer has not been calculated separately from that pumped from the water-table aquifer. However, a large part of the total amount of ground water pumped for any particular year (table 3) is removed from the artesian aquifer.

The above analysis of the artesian aquifer for San Simon basin lacks quantitative information on the capacity of the aquifer to store and transmit water. These two characteristics for an aquifer are expressed as the coefficient of storage and the coefficient of transmissibility, respectively. Data on these characteristics can be obtained from aquifer tests. No aquifer tests have been made in the San Simon basin, but they would provide knowledge necessary for a more exact quantitative description of the aquifer.

UPPER AQUIFER

Quantitative analysis of the upper aquifer in the San Simon basin is hampered by lack of data. Nevertheless, it is clear that this aquifer is of minor importance as a source of irrigation water in the basin because it is only locally permeable enough and thick enough to support irrigation wells. The aquifer yields small to moderate quantities of water to domestic and stock wells and to a few irrigation wells. The total thickness of the upper unit is from 60 to 200 feet throughout most of the area, but it may be water bearing only in the San Simon area. In parts of the San Simon area, the depth to the water table is as much as 100 feet, and the saturated thickness ranges from about 5 to 60 feet. Many of the wells that formerly penetrated only the upper aquifer have been deepened into the lower or artesian aquifer and are now obtaining water from both. No data are available to determine the saturated thickness of the upper aquifer in the Bowie area.

In 1946 only 3 irrigation wells produced water from the upper aquifer in the basin, and the average yield of these wells was about 400 gpm (Cushman and Jones, 1947). In 1960 about 20 wells produced water from the upper aquifer for irrigation. These wells yield from about 200 to 375 gpm. The total number of stock and domestic wells producing water from the upper aquifer is unknown.

Data are insufficient to construct maps showing contours of the decline of the water table, but sporadic measurements indicate that the water table is declining in response to the withdrawal of water from the aquifer in excess of the rate of replenishment. Figure 6 shows hydrographs for two water-table wells in the San Simon area of the basin. Well (D–13–30)9ac is in an isolated area where there is little pumping; well (D–13–31)30cdc is in the irrigated area. The water level in well (D–13–31)30cdc declined less in the period 1946–60 than that in well (D–13–30)9ac. This apparent discrepancy probably is due to the fact that well (D–13–31)30cdc receives recharge by leakage from the artesian aquifer.

A short-term test was made to determine the effects, if any, on water levels in wells screened in the upper aquifer caused by pumping wells screened in the lower aquifer. The location of the wells is shown on plate 1, and hydrographs of three water-table wells measured during the test are shown on figure 7. Artesian wells A1, A2, and A3 were pumping before and throughout the measurement period, and well A4 began pumping at a specified time during the test. The three water-table wells are within half a mile of well A4. Hydrographs of water-table wells WT1 and WT3 (fig. 7) show that the water level declined for at least 12 hours during the pumping of artesian wells A1, A2, and A3, but began to rise several hours before A4 was turned on. Thus it appears that factors other than the pumping of the artesian wells were affecting water levels in the water-table wells. The results are inconclusive, but the sharp rises in WT2 and WT1 seem to be related to the starting of the pump on A4 and suggest that the casing in well A4 may be open to the water-table aquifer. Measurements made in another set of wells, shown as A5, WT4, and WT5

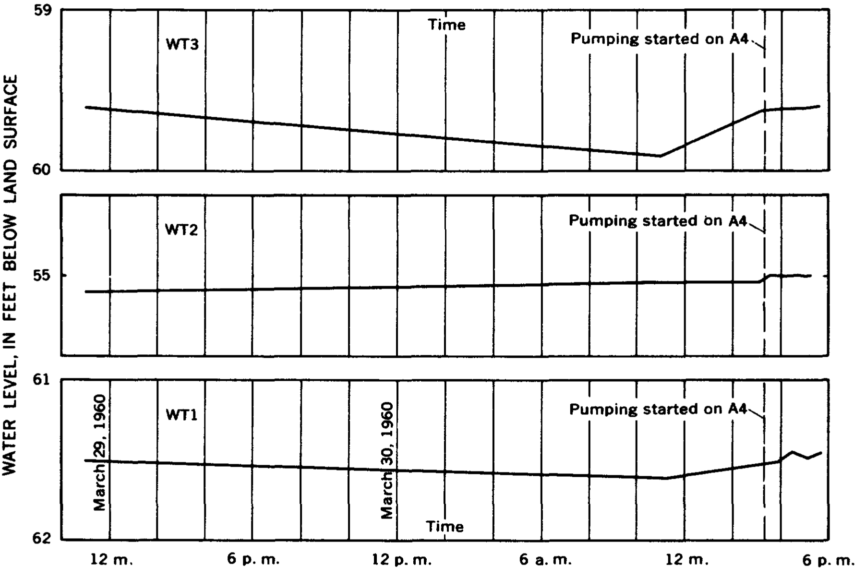

FIGURE 7.—Hydrographs for water-table wells measured during interference test.

on the map (pl. 1), indicate that the water level in water-table well WT4 declined about 0.6 foot in less than 2 hours after the start of pumping in an artesian well 0.1 mile away; the water level in water-table well WT5, 0.45 mile away from the pumped artesian well, showed no change during the same period.

These phenomena are unexplained, and further testing is necessary to obtain conclusive evidence. However, some interference between the two aquifers is indicated, although it may not have been caused by movement of water. The change in the water level in wells in the upper aquifer may be caused simply by transmission of pressure through the confining layer.

MARGINAL ZONE

The areal delineation of the marginal zone is tentative throughout most of the basin. However, the logs of several wells drilled in the area south of Bowie indicate the pinchout of the blue clay unit, and the marginal zone is well defined for about 6 miles. The wells in the marginal zone have characteristics different in some respects from those of either the upper or the lower aquifer.

At least 8 wells were drilled in this zone in late 1952 and early 1953, and drillers' records indicate that they produced from 1,200 to 3,000 gpm with specific capacities ranging from 9 to 21 gpm per foot of drawdown (table 4). Figure 6 shows the hydrograph of a well in this zone, and this and other measurements indicate that the water level in these wells declined 100 feet or more in the period 1953–60.

This decline is markedly greater than that in the nearby artesian wells but is comparable with that in artesian wells several miles away in the developed area which declined as much as 80 feet during the period 1952–60 (pl. 8).

It is possible that the blue clay unit abuts the hard rock southeast of the eight marginal-zone wells. If so, they would be in a small enclosed basin. No logs are available for the area to the southeast; therefore, this hypothesis cannot be tested. More data and further study of this area are necessary to estimate the extent of the aquifer in the vicinity of these wells.

A few wells have been drilled in the marginal zone in other parts of the basin, but no data for drawdown or discharge are available.

CONCLUSIONS

In the study of the San Simon basin an attempt has been made not only to analyze the available data within the scope of methods used at present but also to point out the shortcomings of both the data and the methods. Throughout the report, instances have been cited where more data are needed. These needs include: (1) logs of deep wells to determine the depth to bedrock; (2) logs of wells on the edges of the basin to more adequately delineate the marginal zone; (3) aquifer-test data to help determine the hydrologic characteristics of the aquifers; and (4) interference tests between the upper and lower aquifers to determine intermovement of water.

The quantitative analysis of the ground-water regimen of the basin is inadequate with the standard methods used herein. It is not possible, for instance, to predict the results of superimposing additional pumping in the presently developed areas or of adding new areas of development. For the most part, the hydrologic systems of arid basins are far too complicated for complete quantitative analysis by standard mathematical techniques. The electrical-analog method mentioned in the section "Methods of Analysis" is the most promising method for more detailed and comprehensive quantitative analysis of hydrologic data for arid-zone basins.

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