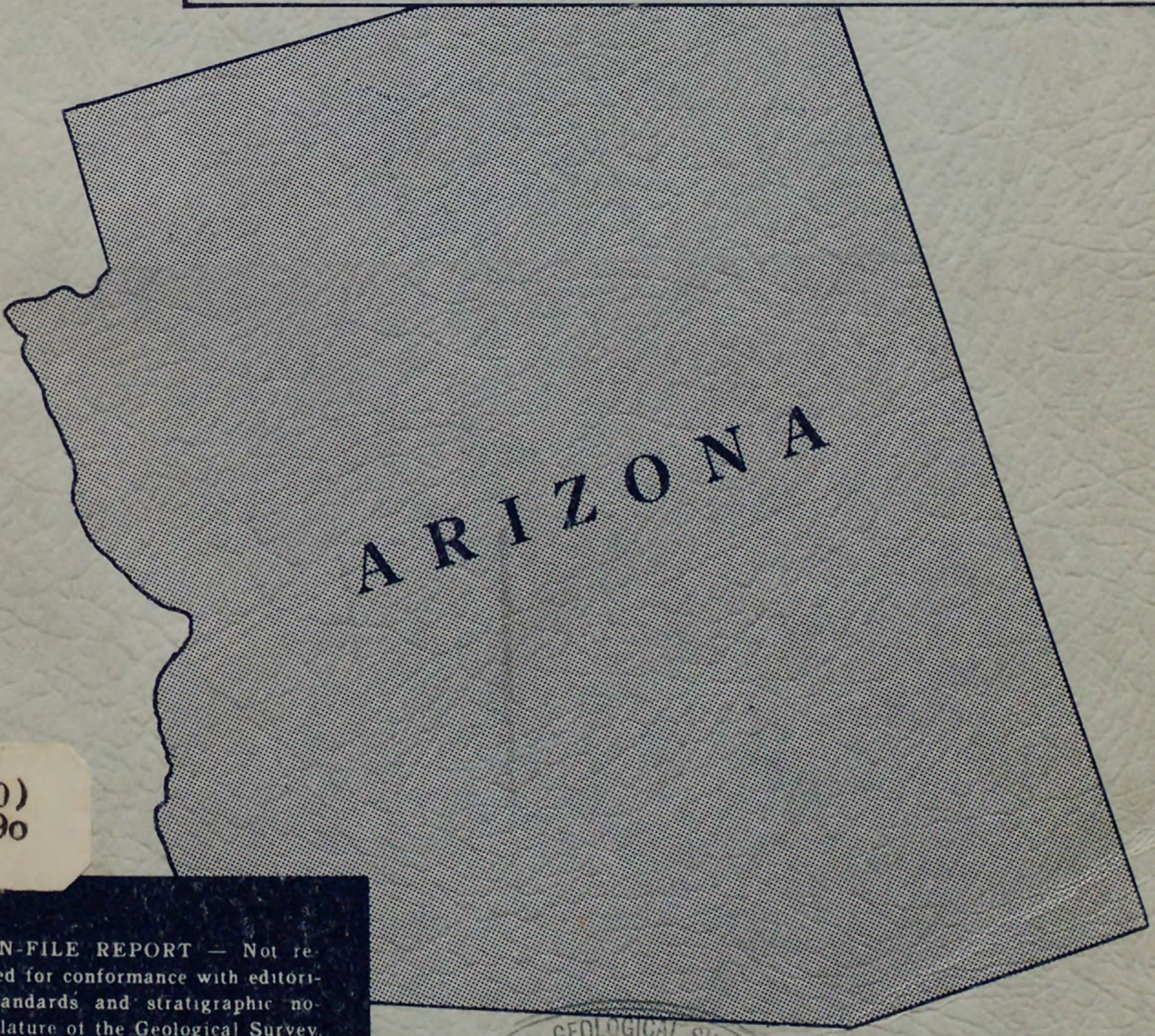
UNITED STATES DEPARTMENT OF THE INTERIOR — GEOLOGICAL SURVEY

GROUND WATER IN THE GILA RIVER BASIN AND ADJACENT AREAS, ARIZONA—A SUMMARY

PREPARED IN FINANCIAL COOPERATION WITH THE UNDERGROUND WATER COMMISSION OF ARIZONA BASED ON DATA COLLECTED IN COOPERATION WITH THE ARIZONA STATE LAND DEPARTMENT



OPEN-FILE REPORT — Not reviewed for conformance with editorial standards and stratigraphic nomenclature of the Geological Survey.

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United States
Department of the Interior
Geological Survey

GROUND WATER IN THE GILA RIVER BASIN AND ADJACENT AREAS, ARIZONA-A SUMMARY

By

L. C. Halpenny and others

Prepared in financial cooperation with the
Underground Water Commission of Arizona
Based on data collected in cooperation with
the Arizona State Land Department

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Tucson, Arizona
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ABSTRACT

This report is a resume' of the principal facts collected by the Geological Survey in the period 1890-1952 about the ground-water resources of the Gila River basin and certain other areas in Arizona. Since 1939 the Geological Survey has been making ground-water investigations on a continuing basis in cooperation with the State of Arizona. Since 1940 the cooperating agency has been the State Land Department.

The occurrence of ground water in fifteen areas that form a part of the Gila River drainage basin is described in this report. The areas are denoted by the name of a town or geographic feature, and are as follows: Duncan, Safford, San Simon, Upper San Pedro, Lower San Pedro, Aravaipa Creek, Upper Santa Cruz, Lower Santa Cruz, Salt River Valley, Rainbow Valley-Waterman Wash, McMullen Valley, Harquahala Plain, Gila Bend, Palomas Plain, and Wellton-Mohawk. Data also are presented for several areas not in the Gila River system, including Ranegras Plain and the Willcox and Douglas basins. A summary of the data is given following the ground-water discussion in each area.

A series of maps accompany the report, including an index map and maps of the principal areas of ground-water development. The maps show the geology, the location of most of the irrigation wells and irrigated lands, and, where data were available, contours of the water table, depth to the water table, and changes in its position over a period of years.

Ground water occurs in the region primarily in alluvial fill consisting of gravel, sand, silt, and clay which was deposited in structural troughs between mountain ranges. Ground water stored in these alluvial basins is derived from many sources. The principal sources are infiltration from runoff along the mountain fronts and seepage from irrigation water applied to cultivated lands.

Of great interest in Arizona at the present time is the rate of depletion of ground-water reserves by withdrawals from storage. Use of ground water in Arizona increased by more than 50 percent in the 6-year period 1946-51, from 2,400,000 acre-feet in 1946 to 3,750,000 acre-feet in 1951. The areas of greatest withdrawal are in Pinal and Maricopa Counties, in the south-central part of the State. Maps and hydrographs accompanying this report show that the water table is declining in the heavily pumped areas, indicating that ground water is being withdrawn in excess of replenishment. The rate of decline has been as much as 10 feet per year in the most intensively pumped areas, and has been greatest during the past few years.

In an effort to compensate for decreased well yields resulting from the decline of the water table in some areas, many deep wells have been drilled within the past few years. The deep aquifers do not represent a new source of water; their water is a part of the common supply of the structural basins in which they lie. The aquifers tapped by these deep wells generally yield less water per foot of drawdown than the shallower aquifers. The water in the deeper aquifers is variable in quality, ranging from water too high in dissolved solids to be usable for irrigation to water lower in concentration than that in the overlying aquifers.

The quality of the ground waters in most of the region is considered suit-

able for irrigation. In local areas, however, the ground waters are naturally unsuitable for irrigation and, in other areas, the concentration of dissolved solids has increased sufficiently to make the waters harmful to some crops. The problem of salt balance is becoming increasingly important, not only in the Salt River Valley area, but also in other parts of the Gila River Basin. A discussion of the salt-balance problem is given in Part II of this report.

It should be emphasized that ground waters in each of the individual areas in the Gila River drainage system are interrelated with ground waters in adjacent areas upstream and downstream. The connection is tenuous between some areas, but in central Arizona the ground waters in the different areas are closely related. Although subsurface barriers to ground-water movement exist in places, they are not everywhere fully effective.

The ground-water--surface-water interrelationship is important in some areas. Those basins occupied by perennial streams, or by streams having large influent seepage losses, have not shown large, perennial declines of water levels in wells. Effluent seepage of ground water contributes to stream flow in the lower reaches of several basins.

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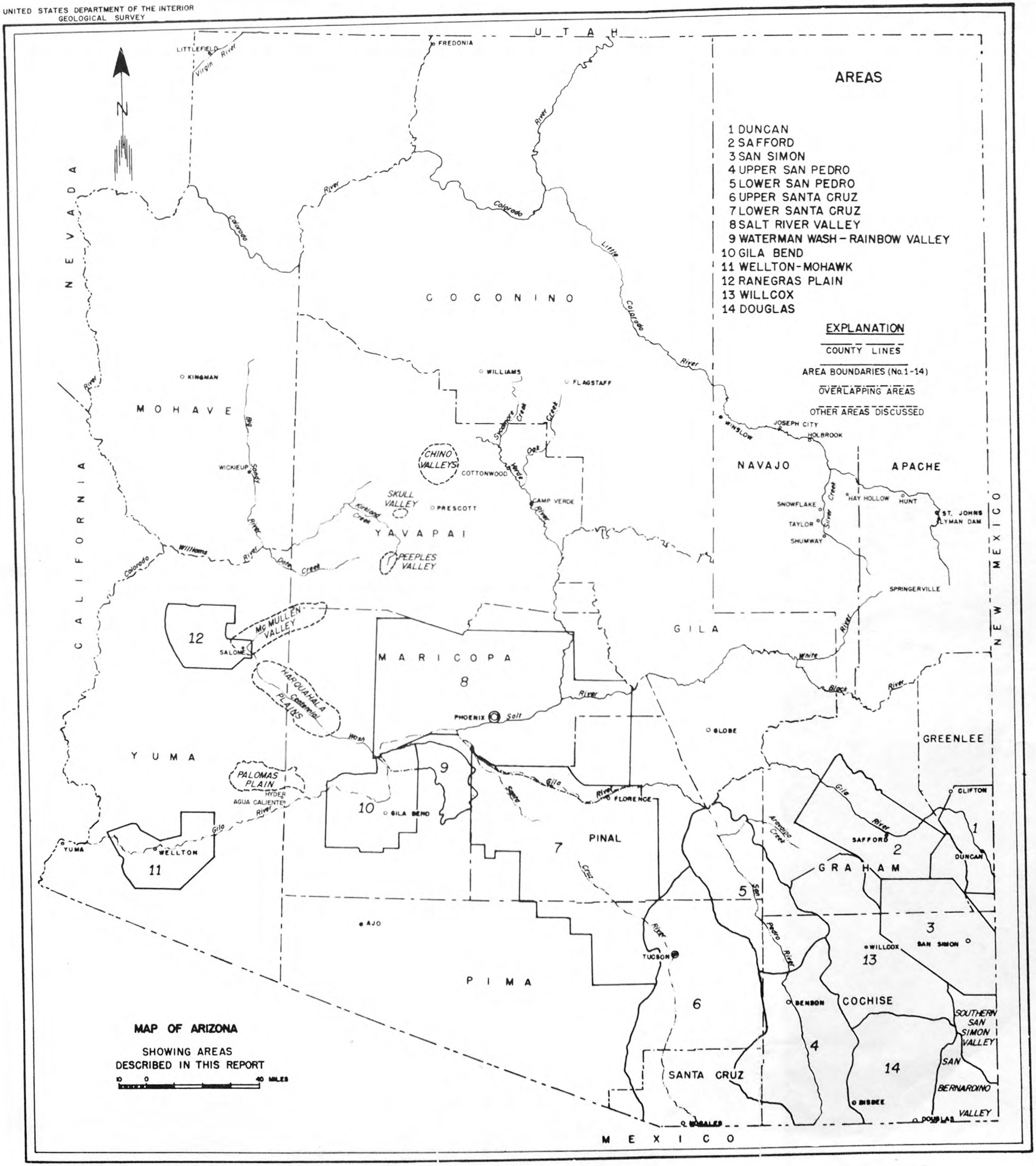


MAP OF ARIZONA

SHOWING AREAS
DESCRIBED IN THIS REPORT

10 0 40 MILES

Part I.

GENERAL DESCRIPTION

INTRODUCTION

By L. C. Halpenny

Scope and purpose of report

The 1952 session of the Arizona Legislature provided for the establishment of a State Underground Water Commission and charged the Commission to compile all available data on ground water in Arizona. A report to the Legislature is required by January 1, 1953.

The United States Geological Survey has made investigations of ground-water conditions in Arizona intermittently since the 1890's. Studies made prior to 1939 were on a comparatively small scale and were financed by Federal funds. In July of that year a cooperative agreement between the Geological Survey and the State Water Commissioner provided for equal financial participation in an expanded program of study. The Federal-State cooperation has continued to the present time; since 1940 the State has been represented by the State Land Department. The Ground Water Branch of the Geological Survey has established a district office at Tucson, sub-offices at Phoenix and Holbrook, and residencies at Casa Grande, Willcox, and Kingman.

In June 1952 the Underground Water Commission requested the District office of the Ground Water Branch to prepare a comprehensive report on all ground-water data available in its files at that time. Financial cooperation between the two agencies was arranged to provide for the preparation of the report. In order to allow time for compilation of the Commission's report by January 1, the Geological Survey was requested to provide its report to the Commission by September 1, 1952. It is obvious that the allotted time was insufficient to permit compiling and analyzing all the available data. Therefore the present report constitutes a summary, rather than a compilation, of the data.

Organization of report

The report is divided into three parts: (1) A general description of ground-water conditions; (2) a description of the occurrence of ground water in individual areas; and (3) a section on problems relating to use of ground water. Where sufficient data are available, the report is supplemented by maps, graphs, and tables. These include maps showing generalized geology, depth to water, water-table contours, and quality of water; graphs of water-level fluctuations; and tables of records of typical wells, well logs, and chemical analyses of water.

Personnel

The present report was prepared under the general supervision of A. N. Sayre, Chief, Ground Water Branch, and under the direct supervision of L. C. Halpenny, district engineer at Tucson. On October 1, 1951, Mr. Halpenny succeeded S. F. Turner, under whose direct supervision most of the data summarized herein were collected. The data on quality of water were prepared under the general supervision of S. K. Love, Chief, Quality of Water Branch, and under the direct supervision of J. D. Hem, district chemist, Albuquerque, N. Mex. J. L. Hatchett, chemist, assisted Mr. Hem in writing portions of this report. Data on stream flow are collected in Arizona by the Geological Survey, under the general supervision of J. V. B. Wells, Chief, Surface Water Branch, and under the direct supervision of J. H. Gardiner, district engineer.

Authors of sections of this report are individually credited. Other members of the district staff who contributed substantially to the preparation are: M. B. Booher, G. M. Babcock, J. M. Cahill, R. E. Cochrane, R. E. Geer, Mrs. G. M. Hoskins, Mrs. R. E. Johnson, Miss B. A. McMahon, J. E. Mernaugh, D. G. Metzger, E. K. Morse, R. T. O'Haire, Mrs. L. H. Stearns, J. I. Webster, N. P. Whaley, Mrs. S. M. White, and Miss D. B. Wolcott. C. T. Pynchon, administrative assistant, contributed substantially to preparation of the report.

Acknowledgments

The program of work in cooperation with the State Land Department had to be adjusted to permit preparation of this report. The cooperation of W. W. Lane, State Land Commissioner, in making these adjustments is gratefully acknowledged. Members of the Underground Water Commission assisted in many ways; and particular thanks are due Messrs. E. Ray Cowden, Chairman, and Elmer D. Hershey, Executive Secretary. Messrs. W. F. Guyton, N. A. Rose, and R. J. Tipton, consulting engineers retained by the Commission, were helpful in discussing technical problems.

UTILIZATION OF GROUND WATER IN ARIZONA

By L. C. Halpenny

In 1951, about 3,750,000 acre-feet of ground water was pumped from wells, mostly for irrigation. All but a small part of this amount was withdrawn in the southern part of the State, principally in Maricopa and Pinal Counties. Ten years ago, the total amount of ground water withdrawn annually for irrigation was not more than 1,000,000 acre-feet, and 20 years ago it was approximately 500,000 acre-feet.

In 1951, the value of agricultural crops produced in Arizona was $289,700,000, not including dairying, stock raising, or chicken raising (Barr and Seltzer, 1952, p. 1).1/ For comparison, in 1941 the value of crops raised was $46,600,000 (Barr, 1942, p. 370). This is a greater than sixfold increase in price of products in 10 years.

In addition to water for irrigation, the ground-water reservoirs in Arizona supply water for municipal, industrial, mining, domestic, and livestock use. With the exception of Phoenix, most of the larger cities and towns in central and southern Arizona depend entirely upon ground-water supplies.

1/See references at end of report.

Industry, with the exception of mining, is not as yet a dominant feature of the economy of Arizona, but the existing industrial plants use ground water almost entirely. The following data were compiled for a report requested by the President's Water Resources Policy Commission:

Water withdrawn for use in Arizona, 1949

	Annual withdrawal (acre-feet)		
	Ground Water	Surface Water	Total
Irrigation	3,195,000*	1,998,000	5,193,000
Municipal	43,400	37,600	81,000
Industrial	38,000	14,000	52,000
Other	34,000	6,000	40,000
Total	3,310,400	2,055,600	5,366,000

* Previously published figures include 4,000 acre-feet withdrawn in Virden Valley, N. Mex., and 20,000 acre-feet of municipal withdrawals.

These figures indicate the tremendous importance of agriculture in the utilization of ground water in Arizona.

DEVELOPMENT OF AGRICULTURE AS RELATED TO NATURAL FACTORS

By L. C. Halpenny

The development of agriculture in Arizona has been influenced by the natural factors of physiography, climate, and geology. These factors control the topography, precipitation, soil, and the occurrence of surface and ground water, and have localized the development of agriculture in areas where intensive irrigation is possible

Physiography

For the purposes of this report the State of Arizona is divided into three general physiographic regions: (1) The plateau region; (2) the mountain region; and (3) the desert region. These are outlined on the accompanying map (fig. 1). The plateau region is a portion of the Colorado Plateau province, and the mountain and desert regions are portions of the Basin and Range province (Fenneman, 1931, pl. 1).

The plateau region is a tableland ranging in altitude from approximately 4,000 to 7,000 feet. Mountains as high as 12,700 feet rise above the plateau, and canyons as deep as a mile have been cut into it. Agriculture, except for stock raising, is limited to small, widely scattered areas.

The mountain region lies south and west of the plateau (fig. 1) and consists mainly of rugged mountains cut by narrow stream valleys. Only small local areas are suitable for farming, and stock raising is the principal agricultural industry.

The southern and western parts of the State compose the desert region. In this region isolated northwest-trending mountain ranges are separated by broad, gently sloping alluvial valleys. These valleys contain much of the land in Arizona that is suitable for agriculture. Natural vegetal cover is sparse; large areas are free of boulders; and the gradient of the land surface is gentle. Consequently it is possible, at reasonable costs, to clear and level the land and construct water-distribution systems.

Arizona is drained principally from east to west by tributaries of the Colorado River (pl. 1). The plateau region of Arizona is drained chiefly by the Little Colorado River, and the Gila River drains most of the mountain and desert regions. Most of the streams of the mountain region, such as the San Francisco, Black, White, Salt, Verde, Agua Fria, and Hassayampa Rivers, are part of the Gila River drainage system.

Climate

The climate is different in each of the three physiographic regions of Arizona and has influenced the development of agriculture in each region. Table 1 provides climatological data for selected representative stations in each of the three regions.

On the plateau the growing season is short. The number of days averaging above 32° F. in 1951 (table 1) ranged from 93 at Flagstaff to 183 at Holbrook. Precipitation is substantial along the southern rim of the plateau and in the Flagstaff area but is insufficient for growing crops without irrigation in most places where farmlands are available. The mean temperature is considerably lower than in the other two physiographic regions.

In the mountain region the precipitation ranges from 10 to 30 inches per year, depending on altitude and the relation of individual areas to the general pattern of storm movement. Snow and rain in the higher altitudes provide spring runoff which can be collected in the catchment area of the headwater streams of the Gila River system. Precipitation in the mountain region supplies much of the water used for agriculture in the desert region.

In the desert region the climate, except for the small amount of rainfall, is highly favorable for farming. The growing season is long (table 1) and the temperature is mild. The long, hot summer days give many crops an

Figure 1– Map of Arizona showing physiographic subdivisions.

Table 1.--Climatological data for Arizona
(From annual summary, 1951, U. S. Weather Bureau)

Region and station	Altitude (feet above sea level)	Temperature				Precipitation		No. of days averaging above 32° F., 1951	Average evaporation(in.)
		Period of record (years)	Ave. (°F.)	Max. 1951 (°F.)	Min. 1951 (°F.)	Period of record (years)	Ave. (in.)		
PLATEAU									
Flagstaff	6,903	59	45	90	-8	59	21.2	93	-
Holbrook	5,069	59	55	104	0	61	8.0	183	-
Tuba City	4,936	46	55	104	8	49	6.7	166	-
MOUNTAIN									
Payson Ranger Station	4,900	39	57	100	-	49	20.6	108	-
Clifton	3,465	43	67	110	22	60	11.8	264	-
Roosevelt	2,200	46	68	112	25	47	15.6	279	79.87
DESERT									
Tucson, Univ. of Arizona	2.423	60	68	109	25	60	10.4	264	82.95
Mesa	1,245	54	68	112	22	54	7.2	276	80.54
Yuma	138	73	74	114	24	82	3.6	279	115.41

ideal environment. However, the rainfall is insufficient for raising crops without irrigation, and water must be imported from outside the region or pumped from underground reservoirs.

Geology

The character of the rocks exposed at the land surface in the three physiographic regions of Arizona has had an effect on the development of agriculture as important as the effects of physiography and climate.

In the plateau region three geologic features have been of importance in the development of agriculture: (1) In the vicinity of the Little Colorado River, along which limited irrigation with surface water is feasible, the formations exposed at the land surface are predominantly clay and silt. These formations provide an extremely fine-grained alluvial fill underlying the river-botton lands. Only small supplies of ground water can be developed from this alluvium. (2) In the southern, upland part of the plateau region the rocks exposed are sandstone and fractured limestone that absorb water readily. The permeable beds dip northward beneath the clay and silt along the river and contain ground water under artesian pressure, which provides a supplemental ground-water supply for farms in the river lowlands. (3) In some volcanic areas of the region the highly water-retentive soil, combined with higher precipitation, makes dry farming practicable on a limited scale.

The complex geologic structure and the comparatively recent uplift of the mountain region have resulted in a rugged terrain that has restricted the development of farming in this region. The rock types of the region, predominantly granite, gneiss, and schist absorb little water. This feature, combined with the high altitude and steep slope, results in the development of relatively large quantities of runoff. Thus, the region is the principal source of surface water for irrigating the lands of the desert region.

Geologically, the valleys of the desert region are highly suitable for agriculture. The alluvial fill in the valleys is composed of poorly consolidated gravel, sand, silt, and clay and some caliche. Large quantities of ground water are easily obtainable in most places, drainage is good, and sufficient lime is present to maintain the soil in good condition except in unusual circumstances.

DEVELOPMENT OF IRRIGATION IN ARIZONA

By L. C. Halpenny

Prehistoric agriculture

Indians have practiced agriculture in Arizona since prehistoric times. The present-day Hopis raise corn and some vegetables on sand dunes, depending on occasional scanty rains and following methods developed hundreds of years ago. In some localities Indians have raised crops by utilizing sheet runoff from floods. In others, crude diversions from surface streams provided water for irrigation. Only in the Salt River Valley and along the Gila River in Pinal County was large-scale farming by prehistoric Indians a success. Possibly as many as 200,000 Indians once lived in the Salt River Valley, and remains of their ancient canals can still be seen in some places.

Present-day agriculture

The westward migration of members of the Mormon Church provided the greatest stimulation to agriculture in the West since white men first saw the country. Prior to the arrival of the Mormons, the white man in Arizona was more interested in mining than in farming. Mormons began to settle in the northern part of Arizona after the Civil War, where they found level land, fairly good soil, and water supplies in limited quantities. Later, Mormons who had traveled across the southern part of the State migrated to the flat lands along the Salt and Gila Rivers. Settlements were made at Safford and Duncan on the Gila River, at St. David and Pomerene in the San Pedro Valley, and at Lehi in the Salt River Valley.

In those early days the only way to develop an irrigation supply was to dam the nearest stream and divert the water through canals. Hence, the first settlers in a valley would develop the lands at the upstream end, where runoff was less likely to fail in dry seasons. Gradually, as additional people settled in the valleys, settlements were made in downstream areas where crop failures often resulted from lack of water. Large volumes of water could not be utilized. Commonly the spring runoff was greater than the demand for irrigation. Summer rains would send floodwaters coursing through the streams, tearing out the diversion dams and filling the canals with silt. The early-day problem was not lack of water, but lack of means to control the water.

The necessity of conserving spring runoff and floodwaters for irrigation led to the construction of large storage reservoirs along the streams. The construction of Roosevelt Dam resulted in the more complete development of the lands of the Salt River Valley. An era of agricultural prosperity resulted. Other dams were constructed on the Salt, the Agua Fria, and the Gila Rivers. The most recent were Bartlett and Horseshoe Dams, on the Verde River. The usable storage capacity of the reservoirs on the Gila River and its tributaries in Arizona was 3,446,000 acre-feet in 1952.

By 1920 a new problem began to develop in the Salt River Valley. Continued application of irrigation waters began to raise the water table in the western part of the valley, and waterlogging of some farm lands resulted. The problem was solved by sinking wells and pumping ground water to lower the water table and drain the waterlogged lands. An irrigation district was formed to irrigate new lands west of the problem area, using the pumped water.

This pumping demonstrated the feasibility of using ground water on a large scale, and a new era of agricultural expansion was at hand. The development of ground water as a source of supply for irrigation was the key to the next forward step in the agricultural economy of Arizona.

Development of ground water for irrigation

Lee (1905, p.12) states that as early as 1900 ground water was being used for irrigation in areas where the depth to water was shallow. At that time, large, shallow dug or drilled wells provided water that was lifted by centrifugal pumps. As these pumps could lift water only a short distance by suction, they had to be lowered if the water table declined. The early-day sources of power were unreliable, and the pumps were inefficient. As a result, ground-water withdrawals generally were a last resort as a source of irrigation water.

The discovery at San Simon in 1910 of water under sufficient artesian pressure to cause wells to flow started the first ground-water boom in Arizona. Flowing wells had been discovered previously at St. David and at Artesia, but these earlier discoveries were in already developed areas having limited supplies of surface water and where only a small amount of land was available for expansion. At San Simon, expansion was rapid from 1910 to 1913, and it continued through World War I. The large number of wells drilled, the lack of adequate casing in the wells, and the lack of valves to shut the wells in when not in use caused the artesian pressure to decline and many wells ceased to flow. The diameter of the wells ranged from 2 to 8 inches, making it difficult or impossible to install irrigation pumps. The decline of prices for agricultural products after World War I, combined with the decline of artesian pressure, caused the abandonment of many farms. This failure of farming by irrigation with ground water was an early indication of the troubles facing Arizona today in overdevelopment of her ground-water supplies.

It has been noted that the first successful ground-water irrigation project in Arizona had developed early in the decade 1920-30 as an indirect result of the reclamation of waterlogged, alkali-laden lands. During the balance of the decade expansion of agriculture by irrigation with ground water was slow.

During the decade 1930-40, irrigation districts and individuals began to construct large wells for supplemental water supplies. In a few areas, generally on the fringes of irrigation districts, farms were developed using ground water only. Later, ground-water irrigation districts were formed and irrigation with ground water became a significant feature of the economy.

In the decade 1940-50, tremendous expansion of agriculture occurred. Several factors contributed to the boom--high prices for crops, increased efficiency of pumps, decreased cost of power, availability of better fertilizers, crop dusting by airplanes, introduction of cotton-picking machines, and removal of cotton quotas. Increased withdrawals of ground water caused corresponding declines of water levels in wells, and the question arose as to whether or not the ground-water supply would last indefinitely. In 1945 legislation to regulate the use of ground water was passed.

The 1945 law required that all wells having a yield of more than 100 gallons per minute must be registered with the State Land Commissioner. In 1948 a law was passed permitting the establishment of "critical ground-water areas," in which water levels had declined seriously and in which overdevelopment of the ground-water supplies was readily apparent. After an area had been declared critical, no new lands legally could be brought under irrigation with ground water. Four areas have been declared critical under the 1948 law, two are in the Salt River Valley and two are in the lower Santa Cruz area (pl.1).

PRINCIPLES OF GROUND-WATER OCCURRENCE

By L. A. Heindl and K. J. DeCook

The general principles of the occurrence of ground water in the region described in this part of the report are common to all the individual areas discussed in Part II. As the occurrence of ground water is fundamentally related to geology, the pages that follow provide a general description of the land forms of the region, its geologic history, and the principal rock types and their water-bearing properties.

Regional geology

It has been stated that Arizona is broadly divided into three physiographic regions: (1) The plateau region, a portion of the Colorado Plateau in the north and northeast parts of the State; (2) the mountain region, a comparatively narrow belt of mountains along the southwest margin of the plateau; and (3) the desert, or Basin and Range region, an area of broad valleys and mountain ranges in the southwestern half of Arizona. These three regions are an expression of differences in geologic structure and rock types. The divisions between the regions are not sharp and clear-cut at all points. In places the structural features and rock formations of one area merge with those of the adjoining area, and the selected boundaries (fig. 1) are necessarily arbitrary.

The following discussion of geologic features is limited to the Basin and Range region, the region of maximum ground-water development.

Geologic Structure

The Basin and Range country is composed of broad, gently sloping valleys and rugged mountain ranges that rise abruptly above them. These alternating mountains and valleys are the result of large-scale faulting along a predominantly northwest trend which resulted in the depression of some blocks and the relative uplift of adjacent blocks. The depressed areas were partly filled with sediments washed from the uplifted blocks and now form the valley floors.

Deep holes drilled at various places have encountered the bedrock of structural troughs at depths from 3,000 to 5,000 feet or more below the surface of the alluvial plains.

The present relations of mountains to valleys are the cumulative result of many separate events occurring over a geologically long period of time. The sequence of events was not necessarily the same in the various basins, nor was the deposition of the valley fill uniform. The apparent continuity from basin to basin in many cases exists only in the upper parts of the alluvial fill. Consequently several basins, particularly east of the Upper Santa Cruz basin, are structurally and hydrologically separate.

Land forms and drainage

With the exception of the Willcox and Douglas basins, the surface drainage of most of the individual basins in southern and western Arizona is to the Gila River. The Gila River, through a complicated and as yet incompletely understood history, has established its course westward along the valleys and through the mountains. The Willcox basin has no surface outlet, and the surface drainage in the Douglas basin flows southward to join the Yaqui River in Mexico. The altitude of the tributary channels of the Gila River is about 4,000 feet at the Mexican border and that of the Gila River at Wellton is about 300 feet.

The basins range in width from 5 to 30 miles or more, and in length from 20 to more than 80 miles. The valley floors slope from the mountains toward the drainage axes in a series of graded surfaces, and the streams commonly have incised inner valleys along their courses. The mountain areas are generally high and ruggedly dissected, with steep stream gradients. At the foot of the mountains the gradients flatten abruptly, the gently sloping surfaces being those of alluvial fans or, in some areas, rock-cut slopes known as pediments.

In general, the mountain summits are 3,000 to 5,000 feet above the adjoining valley floors. Mount Graham is more than 7,000 feet higher than the valley at Safford; the mountains in the Wellton-Mohawk area are less than 2,000 feet above the plain. The margins of the valley floors are from a few hundred to more than a thousand feet higher than the central stream channels.

Although the essential Basin and Range structures are probably similar throughout the region, there are important differences between the valleys of southeastern Arizona and those of central and western Arizona. In southeastern Arizona the valleys and mountains are approximately equal in area; the valley slopes are comparatively pronounced; and the dissection of the mountains is only moderately deep. In central and western Arizona the valleys have a much greater areal extent than the mountains; the valley slopes are comparatively gentle; and the dissection of the mountains is deep. The deeper dissection of the mountains and the greater extent of the alluvial fill suggests that the Basin and Range topography in the central and western parts of the State has been stable for a much longer period than it has in the southeast.

Along many of the mountain fronts, between the edge of the visible mountain mass and its structural boundary farther toward the valley, there are areas where the bedrock has been eroded approximately to the slope of the valley fill. This gently sloping eroded rock surface passes under the alluvial fill with a gradient slightly greater than that of the fill and becomes progressively deeper toward the structural boundary, where it plunges abruptly to still greater depth. These rock slopes are called pediments. They occur most commonly at the base of granitic hills but are known to be cut upon volcanic and older sedimentary rocks also.

Although the pediments are gently sloping they are not smooth surfaces, and small hills and bare rock areas protrude through the alluvial veneer in many places. Irregularities in the buried bedrock are usually reflected in the overlying sediments, and they result in a gently rolling topography that is markedly different from the flat surface of the alluvial fill.

Pediment areas are important in that they reduce, in proportion to their extent, the storage capacity of the ground-water reservoirs in the valleys adjacent to them. Alluvial surfaces that are underlain by pediments must be excluded in computing the area of sediments beneath which ground water is stored, because the bedrock surfaces of the pediments are almost everywhere far above the level of the water table in the valleys.

Geologic history

The occurrence of ground water in southern Arizona is closely related to the post-Cretaceous geologic history of the rock units of the region. Rock units of the earth have been grouped, according to age, into several rock systems, and these systems have been divided into several series. This grouping forms a scheme that is indispensable for the orderly description of the rock units of the earth. The grouping is shown here, with estimates for the time in millions of years since some of the rocks were laid down (Miller, 1941, p. 31):

Rock groups	Approximate date of beginning of time unit shown (millions of years ago)
Cenozoic rocks	
Quaternary system	1
Recent series	
Pleistocene series	
Tertiary system	50
Pliocene series	
Miocene series	
Eocene series	
Paleocene series	
Mesozoic rocks	200
Cretaceous system	
Jurassic system	
Triassic system	
Paleozoic rocks	500
Permian system	
Carboniferous system	
Pennsylvanian series	
Mississippian series	
Devonian system	
Silurian system	
Ordovician system	
Cambrian system	
Pre-Cambrian rocks	2,000

Geologic units discussed in this report may be made up of rocks of two or more ages. They are grouped together when they form a unit in terms of their relation to ground-water occurrence in the region.

The oldest rocks exposed in the region are schists of pre-Cambrian age. There is evidence that the schists were originally sedimentary and volcanic rocks. These rocks were intruded by granitic masses and mountains were formed. The earlier pre-Cambrian rocks were subsequently eroded to relatively level surfaces and covered by late pre-Cambrian sediments. In local areas volcanic flows were extruded at the end of pre-Cambrian sedimentation.

During the Paleozoic era seas encroached upon the land and marine sediments were deposited in places to thicknesses of several thousand feet. The sediments deposited during late pre-Cambrian and early Paleozoic time were predominantly detrital, and during late Paleozoic time, predominantly calcareous.

After the deposition of Paleozoic sediments, a period of regional uplift occurred, following which the rocks were deeply eroded. Later in the Mesozoic era, during early Cretaceous time, a thick series of marine sediments, consisting largely of sandstones, shales and some limestones, was deposited upon the pre-existing rocks. During late Cretaceous time continental and volcanic deposits were laid down over a large area. After the deposition of the Cretaceous rocks, the region was folded and faulted.

This deformation was followed at the end of Cretaceous or the beginning of Tertiary time by extensive volcanism which deposited lava, tuff, ash, and agglomerate. Large-scale movement along northwest-trending faults, during early and middle Tertiary time, is believed to have formed the general outlines of the Basin and Range structure. It is probable that movements have continued intermittently, and with moderated intensity, to the present time.

During and after the faulting, the intermontane basins began to receive detritus derived from erosion of the upfaulted mountain areas. In addition, during late Tertiary time and Quaternary time basaltic lavas were periodically and locally extruded, and fine-grained sediments were deposited in lakes and playas.

After the deposition of the valley fill, the Gila River established its present course through the region, marking the beginning of a period of dissection which has continued, with some interruptions, to the present. The interruptions are marked by the presence of prominent terraces.

The deposition of Recent alluvial fill in the inner valleys of some of the basins implies a change in conditions since the latest period of major downcutting. Within historic time, gullying of Recent alluvial fill has taken place in many of the basins.

Rock types and their hydrologic properties

Rock types, as shown on maps accompanying this report, consist of: (1) The crystalline and metamorphic complex; (2) pre-Tertiary sedimentary rocks; (3) sedimentary rocks of possible Cretaceous or Tertiary age; (4) Tertiary and Quaternary terrace deposits; (5) Tertiary and Quaternary alluvial fill; (6) Recent alluvial fill; (7) volcanic rocks of Cretaceous or Tertiary age; and

(8) Quaternary volcanic rocks.

Crystalline and metamorphic complex.--The complex is composed largely of granitic rock, schist, and gneiss of pre-Cambrian and younger ages. It forms a large proportion of the exposed bedrock areas, particularly in the mountain areas surrounding the Salt River basin and in the Santa Catalina, Rincon, and Pinaleno Mountains. These rocks range in texture from coarsely crystalline granite and gneiss to fine-grained schist and dikes. The rocks in places are highly fractured and are weathered to varying depths depending both upon the degree of fracture and upon their composition. The complex yields only a limited amount of ground water from weathered and jointed zones.

Pre-Tertiary sedimentary rocks.--The pre-Tertiary sedimentary rocks include conglomerate, quartzite, sandstone, shale, and limestone of pre-Cambrian Paleozoic, and Mesozoic ages. The total thickness locally may be greater than 10,000 feet, although in most places erosion has stripped away much of the thickness. Igneous sills up to a few hundred feet thick have been locally mapped with this unit. The older sedimentary rocks are folded and faulted and are highly fractured in many places. Ground water is found in only small quantities in the pre-Tertiary sedimentary rocks except locally where faulted or solution-channelled limestones carry large volumes of ground water.

Cretaceous (?) or Tertiary (?) sedimentary rocks.--Sedimentary rocks of possible Cretaceous or Tertiary age are exposed in small areas. These consist of conglomerate, sandstone, gypsiferous beds, and fresh-water limestone that are in fault contact with rocks of older or younger age. They may contain ground water in small quantities.

Tertiary or Quaternary terrace deposits.--Small exposures of Tertiary or Quaternary terrace deposits occur in the Salt River Valley area. These deposits are composed of river gravels that are now above the general valley floor and represent stages in the development of the present topography. They are not known to carry ground water.

Tertiary and Quaternary alluvial fill.--The sedimentary rocks of Tertiary and Quaternary age compose the older alluvial fill which occupies much of each structural basin. The older fill represents several ages and environments of deposition. The portion of it that is exposed at the surface is principally of Quaternary age. The age of the sediments increases with depth, and the deeper strata of the fill are of Tertiary age.

The materials of the older fill were eroded from the adjacent mountain masses by stream and sheet runoff originating in the mountains. As the slope flattened toward the valley and the carrying power of the water diminished, the boulders were dropped first, followed by gravel, sand, silt, and clay. Therefore, most deposits grade in texture from large boulders on the higher slopes near the mountains to fine-grained sediments toward the axes of the valleys. During large floods, coarse gravel and sand were deposited in channels farther down the slopes above finer materials. Shifting of the channels from time to time resulted in the irregular lens-like pattern typical of the alluvial fill. Because of these varying conditions, there is little continuity, either vertically or laterally, in the lenses of gravel, sand, and silt that constitute most of the valley fill. Closely adjacent drill holes are likely to penetrate entirely dissimilar materials at any given depth.

An exception to the irregular sequence is the common occurrence of considerable thicknesses of lake-bed clay in the upper part of the older valley fill. These clay beds are not altogether homogeneous but locally contain lenses of gravel, sand, and sandstone, and they are intercalated in many places with gypsiferous and calcareous beds.

Logs of deep drill holes show that in several basins the earliest deposits consist of conglomerate of volcanic and granitic material. These basal deposits are overlain by lake beds which in turn are overlain by deposits of younger, coarser material. Basaltic flows and beds of tuff are intercalated within the series. The total thickness of the alluvial fill and the included volcanic rocks varies from basin to basin. In individual basins it ranges from 3,000 to 5,000 feet or more near the axes to a feather edge toward the margins. Locally the lake beds within the sequence are known to be 1,500 feet thick.

Ground water contained in the coarser, more permeable beds of the older alluvial fill forms the principal supply used for irrigation in many basins. The ground water above the lake beds is generally nonartesian, whereas the water within or below the lake beds is, in some of the basins, under some artesian pressure. Commonly the deeper aquifers, because of their fine-grained texture, greater compaction, and tighter cementation, provide only small to moderate yields.

Recent alluvial fill.--The flood plains of the present streams are underlain by Recent alluvial fill consisting of unconsolidated gravel, sand, and silt up to 150 feet or more in thickness. These deposits occupy channels, often referred to as "inner valleys," incised into older rocks, generally the older alluvial fill. Many domestic and stock wells obtain their water from the Recent alluvial fill, and in many basins occupied by permanent streams the Recent alluvial fill supplies most of the ground water used for irrigation. Individual wells obtaining water from the alluvium have large yields because of its coarse texture and unconsolidated nature.

Cretaceous (?) and Tertiary (?) volcanic rocks.--Cretaceous (?) and Tertiary (?) volcanic rocks consist of rhyolite, latite, dacite, trachyte, andesite, and basalt in the form of flows, intrusive dikes and sills, and pyroclastic (explosively emitted) tuff, ash, and agglomerate. They are interbedded with sedimentary materials and in some places the pyroclastic materials form a large percentage of the detrital deposits. No volcanic rocks of pre-Cretaceous age have been reported in the areas mapped except as fragments in the clastic sediments of Cretaceous age. The Cretaceous (?) and Tertiary (?) volcanic rocks commonly are broken into fault blocks and in some places have been warped into shallow folds.

Water occurs in limited quantities in fissures and in porous pyroclastic materials. Some domestic and stock wells and small springs obtain ground water from these rocks. Basalt interbedded with alluvial sediments is the source of sufficient water for irrigation in a few places.

Quaternary volcanic rocks.--Quaternary volcanic rocks consist almost entirely of basalt flows and in many areas have not been mapped separately from the Cretaceous (?) and Tertiary (?) volcanic rocks. Locally the basalt is of considerable extent and is generally extensively jointed. However, it lies above the water table in most places and consequently is of minor importance in the storage and transmission of ground water.

Common misconceptions about geology in relation to ground water

It has been stated frequently that large quantities of ground water enter the Salt River Valley area, probably at considerable depths, from distant sources such as the State of Colorado, the Mississippi basin, and the Colorado River. These concepts are offered not as opinions but as unqualified statements of fact. The existence of underground rivers, lakes, and similar phenomena is claimed in support of these ideas and in explaining the supposed movement of vast quantities of ground water through hundreds of miles of practically impermeable rock, in many cases from lower to higher elevations.

Another misconception that has gained considerable credence is that of a tremendous fault that is supposed to extend from the vicinity of Camp Verde in Yavapai County to the Gila River just east of Wellton in Yuma County. This fault is supposed to continue without interruption for approximately 200 miles, to be the source of various hot springs in the region, and to be a conduit for the transmission of large quantities of ground water of undetermined origin.

A single fault or a fault series having such continuity would necessarily involve a throw or displacement of considerable magnitude. There is no visible displacement or topographic expression of such a structural feature between its supposed limits. Furthermore, the postulated northeast trend of the fault is perpendicular to the prevailing structural trend of the region.

These misconceptions have no basis in fact. They are opposed to the fundamental laws of physics and to long-established, thoroughly proved geologic concepts of the structure and character of the earth's crust as applied to this region. The only reason for mentioning the common misconceptions in the present discussion is that they have caused confusion in the minds of many people who are vitally concerned with the subject of the ground-water resources of the State.

Numerous accounts of unusual ground-water occurrences have been received in field offices of the Geological Survey. Most of these reports were made by thoroughly honest and sincere individuals. As an example, wells supposedly encountering underground rivers have been frequently reported. These usually have proved to be wells into which water was leaking through perforations from a local perched source above the water table. The sound of the falling water, combined with the agitation of the water-table surface in the well, has produced the very realistic illusion of a current moving rapidly across the well at the water line. In no case has it been possible to substantiate the reported conditions after careful investigation in the field.

Regional hydrology

Occurrence of ground water

The most important source of ground water in the desert region of southern Arizona is the alluvial fill. The preceding section contains brief statements regarding the occurrence of ground water in each of the principal rock types of the region. The following paragraphs describe in greater detail the occurrence of ground water in the older and Recent alluvial fills.

The principal aquifers of the alluvial fill are permeable lenses of sand and gravel interfingered with relatively impermeable lenses of silt and clay. Although silt and clay are highly porous, they yield little or no water to wells. The small particles of silt and clay provide a large surface area in proportion to volume, and therefore the water among the particles is retained by surface attraction. In contrast to that of the silt and clay, the large grain size of sand and gravel affords a relatively small proportion of surface area to volume, and therefore much of the water they contain moves freely in response to gravity.

Ground water in older alluvial fill.--Water-bearing beds of sand and gravel in the older alluvial fill occur at many different levels, and a single well may penetrate several water-bearing strata. The aquifers are generally interconnected and a single water table is common to an area. However, owing to the lens-like character of the aquifers, in some cases the interconnection among them is poor, so that pumping from one well does not always immediately affect water levels in nearby wells. Water-bearing beds at one or more levels in parts of some valleys are sealed off one from another, or at least separated over large areas, by impervious clay and silt beds. Consequently, two fairly distinct conditions of ground-water occurrence exist in the older alluvial fill: (1) Waters under little or no artesian pressure, and (2) waters under definite artesian pressure.

Water under considerable artesian pressure occurs both within and below the lake beds in some areas, and water under little or no pressure commonly occurs above the lake beds and along the margins of the valleys. Nonartesian aquifers lie at depths ranging from a few feet to many hundred feet below the surface. Artesian aquifers commonly yield water at depths ranging from about 700 feet to 1,500 feet and are known to yield water from depths as great as 3,500 feet. The yield from wells in artesian aquifers is generally less than from wells in the nonartesian aquifers, owing in part to the greater depth and compaction of the artesian aquifers.

Perched water may occur in the alluvium overlying a pediment along the sides of a valley, or locally above a lens of clay in the main body of alluvial fill. The term "perched water" is applied to ground water that occurs in local areas at altitudes above and separated from the main water table of the region. Perched water is the source of supply for some small domestic and stock wells but the supply is local and the amount is small. Wells of this type are likely to go dry during periods of drought.

Ground water in Recent alluvial fill.--Recent alluvial fill contains relatively large quantities of ground water in areas where it extends below the level of the water table. The water is not under artesian pressure. The Recent alluvial fill is 150 feet thick or more and in most places lies in channels incised in the older alluvium.

The Recent alluvial fill receives ground water discharged from the older fill in areas where water in the older fill is under greater hydrostatic pressure. The older fill receives water from the Recent fill along stream channels at the margins of the valleys and in some places along through-flowing streams where the water table in the older fill lies below the bottom of the Recent fill.

Source and recharge of ground water

Water is recharged to the ground-water reservoir in the individual basins from several sources. These are: (1) Precipitation; (2) surface runoff; (3) underflow from outside the basin; (4) seepage from irrigated lands and canals; and (5) seepage from springs.

Recharge from precipitation.-- It is generally accepted that the ultimate source of ground water is precipitation. Precipitation in the desert region of Arizona is only a fraction of the potential evaporation, because of the arid climate. The low ratio of precipitation to potential evaporation has a profound effect on the amount of water available for recharge. Little direct recharge occurs in the mountains and foothills from precipitation, owing to the steep slopes and the impermeable character of the rocks. Experiments have demonstrated that normally precipitation on the desert surface of the alluvial fill does not appreciably recharge the ground-water reservoirs, though considerable direct recharge may occur in exceptionally wet years. The water is lost mainly by evaporation and transpiration, and even after heavy rainfall the soil generally is dry a few inches below the surface. The water generally does not penetrate below the soil and root zone to the ground-water reservoir because the infrequent rainfall seldom saturates the soil and because in places impervious clay or caliche underlying the surface prevents the downward percolation of moisture.

Precipitation on irrigated lands may provide recharge at times when previously applied irrigation water has saturated the soil, and at places where no impermeable barriers to downward percolation exist. Furthermore, precipitation on irrigated lands conserves the water supply indirectly by reducing the need for additional applications.

Although precipitation on the desert area normally does not result in appreciable recharge, it is important in providing a part of the water for the runoff which is the major source of recharge in many areas of Arizona.

Recharge from surface runoff.-- Under natural conditions, the principal source of recharge to the alluvial fill of the desert region of Arizona is surface runoff. Recharge from runoff is greatest in washes issuing from the mountain fronts and in the centers of those valleys that contain a through-flowing stream underlain by Recent alluvium.

Recharge along the mountain fronts occurs where the runoff in stream channels crosses coarse permeable materials of the older alluvial fill. As the runoff proceeds to lower elevations it passes over progressively finer-grained materials and a decreasing proportion of the runoff is recharged. On the basis of long-range studies of rainfall and runoff, it is estimated that 8 to 15 percent of the total precipitation in the mountain areas becomes runoff (Cooperrider and Sykes, 1938, p.45; Peterson, 1945; Schwalen, 1942; Sondregger and others, 1929; Rich, 1951, p. 11); and that as much as 50 percent of this runoff may be recharged to the ground water in the pervious zone immediately adjacent to the mountain front (Babcock and Cushing, 1942, pp. 46-49) and through the Recent fill in the stream channels downstream from the pervious zone near the mountain.

Many of the basins in the desert region are drained by streams having well-developed channels. The Recent alluvium in these channels is permeable and much of the runoff seeps downward into the coarse sand and gravel. Studies indicate that under ideal conditions nearly all the flood runoff is recharged to the ground-water reservoirs in some valleys.

Underflow.--A source of recharge to some basins is movement of ground water from upstream areas through the permeable alluvium underlying stream channels. This movement is called "underflow." It constitutes a source of recharge to the lower basin and simultaneously a method of discharge from the upper basin. Underflow is not truly a source of recharge to the ground-water reservoirs of the region as a whole, but is recharge only when considered with respect to individual basins.

Seepage from canals and irrigated fields.--In irrigated areas, surface water brought to the lands and ground water pumped from wells are a source of recharge. Experiments at Safford showed that as much as a third of the flow in canals and a quarter of the water applied to fields for irrigation was recharged to the ground-water reservoir. The quantity of recharge depends on the permeability of the soil and on the amount and rate of application of irrigation water. In some areas recharge from irrigation is believed to be negligible.

Movement of ground water

Movement of ground water is controlled by three factors: (1) The permeability of the material; (2) the hydraulic gradient; and (3) the cross-sectional area of the saturated zone. In most places in the desert region, ground water establishes a gradient somewhat more gentle than the gradient of the land surface. Water moves under the force of gravity and, although its course is controlled to some extent by local cementation, clay barriers, buried hard-rock masses, fault zones, and the erratic shape of individual lenses, the movement of the water is down gradient toward the point of lower hydraulic head. The rate of movement of ground water in the alluvium ranges from a few feet to a few thousand feet per year. The most rapid movement is generally basinward from sources of recharge along the margins of the basin, where the gradient is greater and the permeability is higher.

The same forces that control the movement of ground water within a basin act to control movement between basins. Where there is contact between the ground-water reservoirs of adjoining basins, water will move in the direction of the hydraulic gradient, generally from the higher to the lower basin.

In some areas, separate structural troughs have been filled with alluvial material to a level above the hard-rock divides separating them. Where the water table in the alluvium is higher than the hard-rock divide, interbasin movement of ground water is possible. In some areas headward erosion of tributary streams from one structural basin have cut into the alluvial fill of an adjoining basin and have captured a part of the runoff and the ground water in storage.

Discharge of ground water

Ground water is discharged both through wells and by natural processes. Discharge through wells includes: (1) Pumpage; (2) flow from artesian wells; and (3) leakage from artesian aquifers lost through defective or corroded well casings. Natural discharge occurs by: (1) Evaporation; (2) transpiration by phreatophytes; (3) effluent seepage; (4) underflow; and (5) spring flow.

Discharge through wells.--Withdrawal of ground water by pumping, especially in the areas where irrigated farmlands have been widely developed, represents a major part of the discharge in many of the ground-water basins in Arizona. Pumping from wells upsets the balance between recharge and natural discharge. Discharge by pumping intercepts ground water that would otherwise be discharged by natural processes. Excessive pumping causes total discharge to exceed total recharge in a basin and thereby requires withdrawal of water from storage and results in a decline of the water table.

Flowing wells are a local source of water for irrigation in some parts of Arizona. Most flowing wells in Arizona are not equipped with shut-off valves, so that they flow all year long and are put to beneficial use only during the growing season. Many thousand acre-feet of water are wasted each year in this way; the losses could be substantially decreased by shutting off the flowing wells when there is no use for the water.

An undetermined amount of ground water is discharged from artesian aquifers to permeable beds in which the water is under lower hydrostatic pressure, by leakage through or around deteriorated casings or through partially cased wells. This leakage causes a decline of artesian head, and the water lost may not be as easily recoverable from the upper horizons. Such leakage can be decreased by casing wells to their entire depth and by perforating only below the confining stratum of the artesian system.

Natural discharge.--Locally, direct evaporation is an important method of discharge from areas where the water table is shallow. In these areas, water moves upward from the water table through capillary openings and evaporates. Depending upon the character of the rock materials, evaporation of ground water occurs from depths as great as 10 feet.

Large amounts of ground water are discharged in many areas through transpiration by phreatophytes. Transpiration is discharge of water by plants, and phreatophytes are growing plants that use ground water. It is estimated that approximately 1,375,000 acre-feet of ground water per year is used by phreatophytes in Arizona (Robinson, 1952, p. 60). Transpiration by phreatophytes not only reduces the amount of water available for recharge but also causes direct discharge of ground water. The annual quantity of ground water discharged by phreatophytes is different for each plant species and is affected by differences in altitude, length of growing season, character of soil, and depth to water. For example, mesquite trees transpire water withdrawn from the ground-water reservoir from depths down to 60 feet. Experiments in the Safford Valley (Gatewood and others, 1950, p. 195) indicate that, for the specific conditions there, the annual rates of water use, in acre-feet per acre, of several species are: Saltcedar, 7.2; cottonwood and willow, 6.0; baccharis, 4.7; and mesquite, 3.3. These data are for 1 year only, for average depths to the water table, and for 100 percent density of growth. They indicate the relative magnitude of water use by the different plants.

Discharge of ground water by seepage occurs where the water table is at or above the land surface. In recharge areas, where water enters highly permeable materials, seepage is almost entirely influent, or to the water table. As ground water moves to lower altitudes, the water table intersects the land surface and seepage becomes effluent. Discharge by evaporation and transpiration may depress the water table and reduce effluent seepage. A downstream constriction that reduces the cross-sectional area of a valley through which ground water is moving may cause the water table to rise and increase effluent seepage.

Ground water is discharged as underflow from individual basins by moving downstream through the permeable alluvium underlying stream channels.

Ground water is discharged through springs in places where the water table intersects the land surface or where water under artesian pressure finds an outlet. Water-table springs yield water whose temperature is approximately the mean annual temperature of the region. Their yield fluctuates widely in response to the position of the water table. Artesian springs discharge warm to hot water, in some places highly mineralized, and their yield fluctuates less than that of water-table springs. The average discharge of springs in the region ranges from 1 to 10 gallons per minute and exceptional springs yield as much as 1,000 gallons per minute. Springs are not an important source of water for irrigation in the region because their yield is relatively small and declines in dry seasons. In comparison with discharge of ground water by the other methods described in the foregoing paragraphs, the total discharge of ground water by springs is negligible.

Storage of ground water

Thousands of years were required to accumulate the ground water in storage in the alluvial-filled basins of Arizona. After the basins were filled, a natural balance between recharge and discharge developed. This balance has been disturbed by pumping for irrigation. During the last 15 years it has become evident that withdrawal of ground water by pumping has greatly exceeded the natural recharge in some areas and consequently the quantity of water in storage has decreased. Although this decrease is not large in proportion to the aggregate of water stored in the basins, it has occurred near the upper limits of the aquifers, where the materials are the most permeable and the proportional amount of water in storage is greatest. As the amount of water in storage continues to be depleted by pumping for irrigation, and as the water table continues to drop, withdrawal of ground water will become progressively more difficult and expensive.

In this report, estimates have been made of the amount of water in storage in a layer 300 feet thick below the water table in some of the individual basins. The availability of artesian water and the relation between ground water in older and in Recent alluvial fill are also considered in the estimates for some basins.

In computing the volume of water stored in this 300-foot layer, the large amount of water held by molecular attraction and surface tension (the specific retention) is not considered. In regard to the remaining ground water in storage (represented by the specific yield), a distinction must be made between the amount that is free to drain by gravity and the amount that can be withdrawn for irrigation. In this report, the total amount of water that is free to drain by gravity from the saturated rock within an entire alluvial-filled basin is called "latent storage," and that part of the latent storage that is theoretically available to wells (not necessarily feasibly) within the periphery of existing irrigated lands is called "underlying storage."

Latent storage is not a pertinent quantity in determining the amount of ground water available for irrigation, for it includes ground water throughout an alluvial-filled basin. Some of the water included as latent storage lies hundreds of feet below the land surface along the margins of the basins. To be utilized for irrigation, this ground water would have to be lifted from great depths and transported many miles in canals. Water withdrawn from latent storage outside irrigated areas is used for municipal, mining, and military supplies in some parts of Arizona. Estimates for latent storage in some basins were prepared to provide quantitative data for relating the rates of recharge and discharge to the whole regimen of the ground-water reservoirs.

For irrigation, the most important part of the stored ground-water supply is the "underlying storage." In computing underlying storage in the 300-foot layer below the water table it was assumed that a vertical boundary exists around the periphery of each of the irrigated areas. It is obvious that if this 300-foot layer could be unwatered, the bounding surface would slope inward toward the pumped area and would not be vertical. This factor may be considered to be a self-compensating error because the part of the ground-water reservoir outside the assumed vertical boundary that undoubtedly would be unwatered and would add to the underlying storage would, in general, tend to be balanced by the part of the ground-water reservoir inside the vertical boundary that could not be unwatered practicably. Therefore, for the purposes of this report, the assumption of the vertical boundary is considered valid.

It is believed by the authors that not all the water in a 300-foot layer below the 1952 stage of the water table in the irrigated areas of Arizona could feasibly be withdrawn for irrigation under 1952 conditions of withdrawal. The figures for underlying storage as given in this report are considered a maximum, possibly obtainable under ideal conditions of uniform aquifers, scientific well spacing, and rigorous control of exploitation. The figures for underlying storage cannot be construed to represent ground water available for irrigation under current conditions and must be revised downward in the light of local conditions and practices. The amount of downward revision necessary is beyond the scope of this report.

<u>Fluctuations of ground-water levels</u>.--Fluctuations of water levels indicate changes in the quantity of water stored and occur chiefly in reponse to changes in the rates of recharge or discharge of ground water. They may be broadly classified as seasonal or persistent. In areas where recharge is comparatively slow and where irrigation pumping is heavy, the water table has declined persistently and the amount of water in storage has decreased. Where the rate of recharge is high in proportion to the amount of water pumped for irrigation, water-table fluctuations are seasonal but no persistent decline is noted. Local fluctuations of the water table may occur also as the result of local changes of pumping from wells.

<u>Cones of influence and well interference</u>.--Pumping a well in a nonartesian aquifer unwaters part of the aquifer in the immediate vicinity of the well. This causes a temporary local depression of the water table, called a "cone of depression" because its shape resembles that of an inverted cone of which the well bore represents the axis. The surface of the cone is the surface of the temporarily depressed water table. As pumping continues, the cone becomes deeper and broader until it diverts an amount of water, formerly discharged elsewhere, equal to the amount pumped from the well. The shape of the cone and the time required for recovery of the water table after pumping is stopped are controlled by the hydrologic character of the materials comprising the aquifer.

A "cone of pressure relief" develops around a well producing water from an aquifer under artesian pressure, no matter whether the well is flowing or is being pumped. A cone of pressure relief differs from a cone of depression in that the confined aquifer is not temporarily unwatered around the producing well. The cone is imaginary and its shape represents a temporary reduction of artesian pressure, greatest at the well and becoming less progessively farther from the well. However, the behavior of the cone of pressure relief is completely analogous to that of the cone of depression in a water table.

The rate at which a cone of depression or a cone of pressure relief will develop and spread is related to the fundamental difference between water-table and artesian conditions. A cone of depression develops more slowly than a cone of pressure relief, because the amount of water drained by gravity from the pores of a water-table aquifer is much larger than that derived by the compaction of an artesian aquifer as its head is lowered; thus the water for a water-table well is derived from a much smaller volume of the aquifer than that for an artesian well.

An example of the rate of spread of a cone of depression surrounding a pumped well is seen in a study of a graph from a continuous water-stage recorder installed in an observation well by the Geological Survey. In August 1952, approximately 30 hours after an irrigation well began pumping at a distance of three quarters of a mile from the observation well, the graph showed a lowering of the water table progressing at the approximate rate of 1 foot of decline in 44 hours of pumping.

An example of the rate of spread of a cone of pressure relief in an artesian well is seen in data collected during a pumping test conducted by the Geological Survey near Snowflake, Ariz., in September, 1950. Approximately 15 hours after a well which partially penetrated an artesian aquifer began pumping, the water level in an observation well 4,800 feet from the pumped well was declining at the approximate rate of 1 foot in 12 hours.

Well interference occurs between two or more pumping wells when their respective cones of depression or of pressure relief spread sufficiently to overlap. The pumping lift in each of the wells thereby becomes greater than if only one of the wells were being pumped. Knowledge of the hydrologic character of an aquifer provides a basis for spacing wells so as to reduce or eliminatewell interference. Spacing of wells, no matter how done, obviously cannot make a basin yield perenially at a rate greater than the total recharge from all sources, though under some conditions scientific spacing may increase total recharge and reduce wasteful natural discharge.

QUALITY OF GROUND WATER

By J. D. Hem

An important feature of ground-water investigations is determination of the chemical quality of the ground water and its effect on the usefulness of the water. The types of mineral matter in the water and their concentration determine the suitability of the water for agicultural or industrial use, and for domestic or municipal supplies. Water analyses made by the Geological Survey determine only the chemical properties of the waters.

The ground water in Arizona is derived from rain and snow containing small amounts of dissolved mineral matter. When the water reaches the ground it begins at once to dissolve mineral matter from soil and rocks. The amounts and kinds of dissolved matter contained in the ground water depend upon the types of rocks through which the water moves and upon the length of time the water is in contact with them. Some rock formations contain readily soluble salts, and waters derived from these formations may contain so much mineral matter in solution that they cannot be used. Other rocks, particularly those of the crystalline complex in the mountain areas,contain comparatively few soluble materials and the water derived from them may contain only a little more dissolved matter than rain water.

The mineral content of waters analyzed is expressed in terms of parts by weight of dissolved matter, per million parts of water. The following chemical constituents and allied information are reported in most analyses: Silica; calcium; magnesium; sodium; potassium; bicarbonate; sulfate; chloride; fluoride; boron; nitrate; hardness; dissolved solids; percent sodium; and specific conductance. All except the last two of these are commonly reported in parts per million. Specific conductance is a measure of the ability of the water to conduct an electric current and, indirectly, of the concentration of mineral matter. It is reported in micromhos.

Significance of constituents in water analyses

Silica is found in all ground waters but is likely to be of higher concentration in water that has passed through areas of igneous rocks. Silica contributes to boiler scale and is especially undesirable in industrial water supplies.

Calcium is present in practically all ground waters. It is dissolved in large quantities from deposits of caliche, limestone, or gypsum. Magnesium, a common element, is found in nearly all ground waters. It is dissolved in small amounts from most limestones and in larger amounts from deposits of dolomite and other magnesium-bearing rocks. Most of the hardness, which makes water objectionable for use in washing and for other purposes, is caused by dissolved calcium and magnesium.

Sodium and potassium make up a large part of the dissolved matter in many ground waters of Arizona. Generally the potassium is less than 10 percent of the total content of sodium and potassium together, and often is not separately reported in the analyses. Sodium is dissolved in small amounts from many rocks and is dissolved in large amounts from salt beds and saline residues that may be found in the lake and playa deposits.

Bicarbonate is present in nearly all ground waters of the State. Its presence is generally due to the following chemical process: The water dissolves carbon dioxide from the air and from decaying vegetable matter in the soil and the resulting weak solution of carbonic acid may dissolve calcium from rocks. Bicarbonate may also be derived by dissolving deposits of sodium carbonate and sodium bicarbonate.

Sulfate is commonly found in ground waters of the State and may be present in large amounts in areas where gypsum deposits occur. Gypsum is composed of hydrated calcium sulfate.

Chloride is present in large amounts in many of the ground waters of Arizona. It is derived mainly from deposits or disseminated particles of common salt.

Fluoride is present in small quantities in many ground waters of the State. It is dissolved from hard rocks and valley-fill materials in much of southern Arizona.

Nitrate in water is generally believed to be the final oxidation product of organic material containing nitrogen. Usually nitrate is present in small quantities but some ground waters of the State contain exceptionally high concentrations of nitrate. The source of these high concentrations of nitrate is not definitely known but they may be derived from the solution of nitrogen-bearing caliche deposits.

Boron is normally present in very small quantities in most Arizona ground waters. It is sometimes found in larger quantities in water from hot springs and deep wells. It may be dissolved from certain types of igneous rocks or from saline residues in playa deposits.

The reported values for dissolved solids represent the sum of the determined constituents, the bicarbonate being computed as carbonate because the bicarbonate in water changes to carbonate as the water is evaporated.

Hardness is computed in parts per million as the quantity of calcium carbonate equivalent to the calcium and magnesium in the water.

The sodium percentage of a water is computed from the chemical equivalents. It is the proportion of sodium in the total sum of calcium, magnesium, sodium, and potassium.

The specific conductance is the reciprocal of the resistance of the water sample to an electric current measured under definite conditions. In general, the greater the dissolved-solids concentration of a water, the greater is its conductance, but the conductance determination does not indicate the chemical nature of the materials in solution. Specific conductance can be expressed in reciprocal ohms or mhos, but to avoid inconvenient decimals, micromhos or millionths of mhos are commonly used. Because conductance is affected by temperature all values are adjusted to 25° Centigrade.

Relation of the quality of water to its use

Irrigation use

In irrigation, the water applied is used mainly by evaporation from the soil and by transpiration from the growing plants. Most of the dissolved mineral matter in the water cannot be used by the plants and cannot be evaporated or transpired. It must be removed in some manner or eventually may accumulate in the soil to such an extent as to decrease the productiveness of the soil. Therefore, a satisfactory irrigation water should not contain excessive amounts of dissolved mineral matter. However, definite limits for concentration of dissolved matter are difficult to fix, because of the widely varying conditions under which a water may be used and because of the different characteristics of the various crops. Wilcox (1948, p. 26) has published a diagram for evaluation of irrigation waters based on sodium percentage and specific conductance. The diagram is reproduced in this report as fig. 2. By plotting the conductance of a water against its sodium percentage a point on the graph will be obtained indicating by its location which of five general classifications apply to that water. The following table, also from Wilcox (1948, p.27) shows limits of boron for various classes of water:

Classes of water	CROP GROUPS Sensitive	Semitolerant	Tolerant
	ppm	ppm	ppm
Excellent	<.33	<.67	<1.00
Good	0.33 to .67	0.67 to 1.33	1.00 to 2.00
Permissible	.67 to 1.00	1.33 to 2.00	2.00 to 3.00
Doubtful	1.00 to 1.25	2.00 to 2.50	3.00 to 3.75
Unsuitable	>1.25	>2.50	>3.75

Boron is an essential element in plant nutrition but only small amounts are needed and some plants are very sensitive to excess amounts. The crops in the sensitive group most likely to be damaged by excess boron include citrus and other fruit trees and a number of other deciduous trees. The semitolerant plants include small grains and cotton and certain vegetables. Tolerant plants include lettuce, root crops (except potatoes and sweet potatoes), alfalfa and date palms.

Boron in excessive concentrations in irrigation water is not common in Arizona and has not been recognized as an important problem in most places in the State.

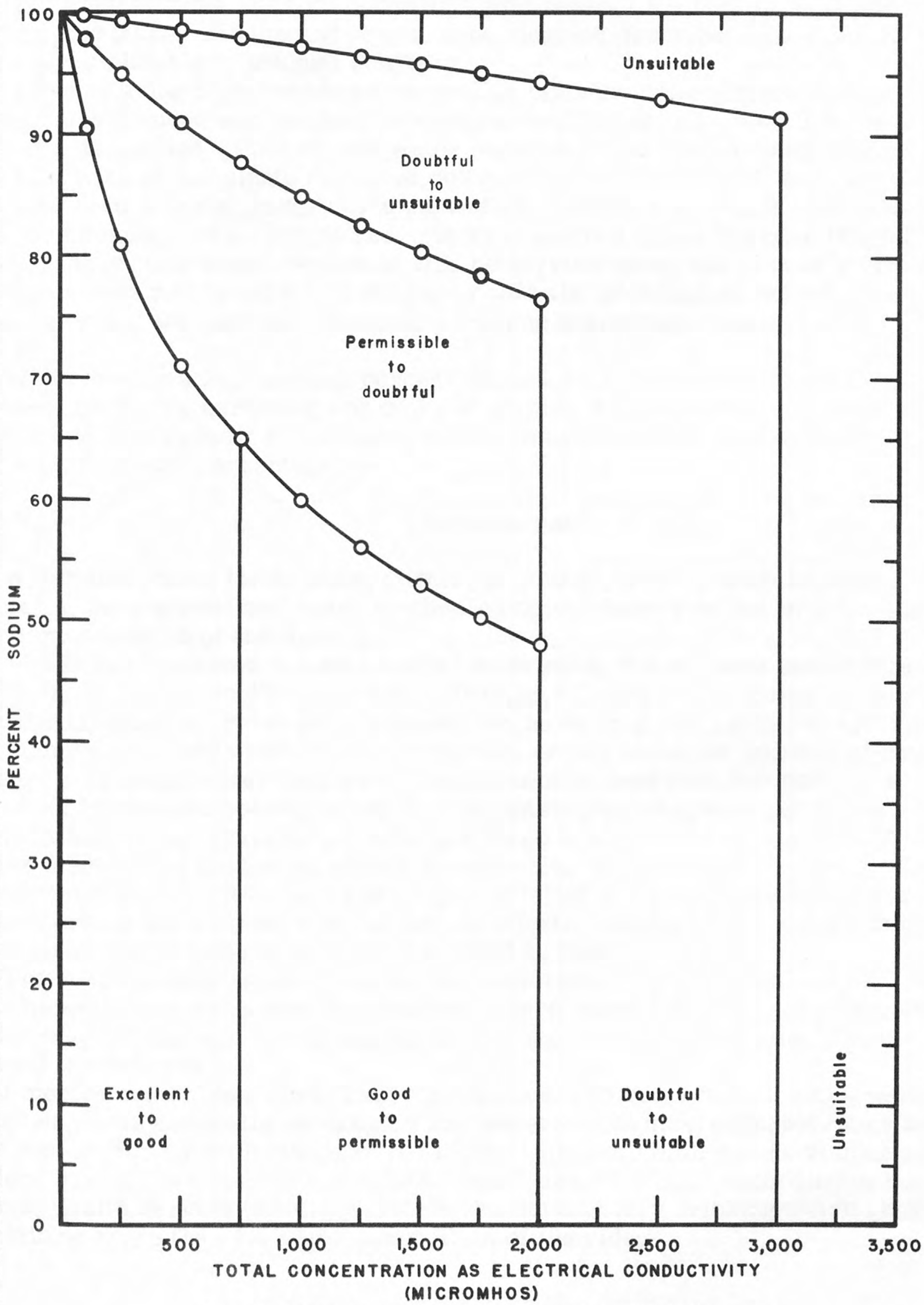


Figure 2. —Diagram for use in interpreting the analysis of irrigation water.

As pointed out by Wilcox (1948, p. 27) any system for evaluating irrigation waters must assume average conditions with respect to quantity, soil permeability, drainage, climate and crops. The diagram described above is not directly applicable to unusual conditions.

Waters having high conductances or high chloride concentrations may sometimes be used successfully in areas where drainage is good if an excess of water is applied. This excess water penetrates the soil to a depth below the root zone of the plants and in so doing leaches from the soil and carries into the ground-water reservoir a part of the soluble matter left from water that was evaporated or transpired. In well-drained areas the resulting addition to the ground-water reservoir will be carried away, but in poorly drained areas the water table will rise gradually with the additions of excess irrigation water and the land will eventually become waterlogged and saturated with alkali.

Water having a high sodium percentage reacts with the soil to which it is applied, gradually hardening the soil and making it less pervious to water. The addition of gypsum to the water or soil may permit the use of water having a high sodium percentage.

Domestic use

Water to be used for drinking should, of course, be free from harmful bacteria, but the analyses made by the Geological Survey do not indicate the sanitary condition of the waters.

Limits for dissolved mineral matter in drinking waters have been suggested by the U. S. Public Health Service (1946,pp.371-384). According to these standards, drinking water should contain no more than 250 parts per million of chloride, 250 parts per million of sulfate, or 125 parts per million of magnesium. Drinking water preferably should contain less than 500 parts per million of dissolved solids, but up to 1,000 parts per million is permissible if better water is not available. There are large areas in Arizona where no water meeting the quoted standards is available. Waters containing somewhat more than the suggested limits of dissolved mineral matter have been used by many persons for long periods without ill effects, although such waters might have a noticeable taste to one unaccustomed to them.

The soap-consuming effect of hardness in water is well known and is objectionable in waters used for washing. Hard water tends to leave deposits in hot-water tanks and piping and in cooking utensils, and may affect foods cooked in the water.

Fluoride content has particular significance with respect to drinking-water supplies. It is generally recognized that waters containing excessive amounts of fluoride may cause mottling of the tooth enamel of children who drink such waters during the time their permanent teeth are forming. According to the Public Health Service (1946, pp. 371-384) a satisfactory drinking water should contain no more than 1.5 parts per million of fluoride.

Application of water analyses in ground-water studies

The quality-of-water work is a vital part of the study of the ground-water resources of Arizona. The significance of the quality of water to the water user has been mentioned. It is helpful also in determining the source of the ground water and its direction of movement in a basin. Ground waters in a basin may show similarities of chemical character to surface or ground waters of a tributary basin, suggesting that ground water from the tributary basin is moving into the main basin. In some places these relations are so definite that the quantity of inflow may be estimated through the use of water analyses and other pertinent data regarding the ground water. Because the kinds of dissolved matter a water carries are dependent upon the type of rock with which it has been in contact, it is sometimes possible to determine the source of a water by a study of the analysis and of the geology of the surrounding area. In these and other ways the quality-of-water studies aid in determining the facts about a ground-water basin, including the sources of recharge and the safe yield.

Discharge of dissolved solids from basins

To be permanent any irrigation development should provide for removal by drainage from the irrigated area of an amount of dissolved mineral matter equal to the amount applied to the land in the water used for irrigation. If drainage is not adequate, soluble mineral matter left when water is evaporated or transpired by the crops accumulates in the soils or ground water of the irrigated area. This mineral matter gradually increases in amount until the land loses its productivity or until the ground water becomes too highly mineralized for further use.

In each basin studied consideration has been given to the amounts of dissolved mineral matter entering and leaving the basin. The relation between these two quantities is sometimes referred to as the "salt balance" of a basin. In order to determine the "salt balance" it is necessary to know (1) the quantities of water entering and leaving the basin both as surface flow and as ground-water flow, and (2) the concentration of dissolved mineral matter in all the waters entering and leaving the basin. Accurate measurements of all these factors require a large amount of work over a long period of time; hence, data for inflow and outflow of dissolved matter in most of the irrigated areas of the State are tentative at this time. More extensive studies than those yet made will be required in some areas.

Excessive pumping may interfere with the movement of ground water away from irrigated areas, thus leaving no effective means for removal of the excess soluble matter. Although a rather long period might be required before the accumulation of soluble mineral matter in the ground water and soils made farming unprofitable, excessive pumpage may thus eventually reduce the productivity of land in some areas of the State.

COLLECTION OF GROUND-WATER DATA

By

L. C. Halpenny

The program of collection of basic ground-water data in Arizona is outlined here in order that the reader can evaluate the scope of the work. A wide variety of techniques is employed, and geologists, hydraulic engineers, mathematicians, chemists, and geophysicists are required for the collection and interpretation of the data. Basically the work can be divided into two broad categories, geologic and hydrologic, but many problems overlap from one category to the other.

Geologic data

The occurrence of ground water in the alluvial-filled basins of Arizona is intimately related to the geology of the region. Geologic studies are necessary to determine the water-bearing character of the rocks, their relations one to another, and the structural features that affect the movement of ground water.

Rocks are exposed on the land surface as outcrops, and in mines and well bores. Geologic investigations that relate to the occurrence of ground water are therefore broadly grouped as surface mapping and subsurface studies.

Surface mapping

A geologic map provides many types of information. By color or distinctive symbol each of the various rock types cropping out in the mapped area is shown in its proper place. The geologic maps accompanying this report show the rock types, the positions of the mountain masses in relation to the alluvial valleys, and the pediment areas.

Subsurface studies

A map of the surface geology of an area is not of itself sufficient to describe all the pertinent geologic features. It is necessary to know what lies beneath the land surface--the thickness of the rock formations, their permeability, and the presence of soluble materials which might seriously affect the quality of the ground water. Several techniques are employed by ground-water geologists to learn what lies below the land surface. Among these are: (1) Well-cutting analysis; (2) geophysical probing; and (3) electrical or gamma-ray logging.

Samples of the materials encountered by the drill enable a geologist to identify the rock units through which the drill has passed. Examination of the samples under a microscope provides data on the character of the materials. Records from a series of wells may provide data for the plotting of geologic cross sections, which show the depth to bedrock, the position of potential water-bearing beds, and the structural relation of the mountain masses to the valleys.

Another tool available to the geologist for conducting subsurface studies is the science of geophysics. Four general methods in common use are electrical-resistivity, seismic, gravimetric, and magnetometric. Of these, only the first has been used by the Geological Survey for ground-water studies in Arizona. Geophysical prospecting provides data on the depth to bedrock and, combined with the drilling of a minimum number of test wells, is faster and cheaper, though less accurate, than prospecting by test drilling only.

Probing with an electric-logging instrument or a gamma-ray-logging instrument provides a graphic record of rock character from the top to the bottom of a well. These instruments provide data from which the relative permeability of the water-bearing materials and the quality of the water can be estimated. Electric-logging instruments are not adapted to collecting data in cased wells. Gamma-ray-logging instruments can be used in cased or uncased holes.

Hydrologic data

Collection of data

Well records.--Records are made for all wells visited by personnel of the Ground Water Branch and new data are continually being added to the original records. An attempt is made to compile a record for every irrigation well in the State, as well as for industrial, municipal, and railroad wells. Records of domestic and stock wells are made where wells of other types are scarce, where specific information about depth to water is needed, or where the well is ideally situated for periodic water-level measurements.

Figure 3 shows the types of well information collected by the Ground Water Branch and the form in which the information is recorded. The records shown are of hypothetical wells, although the figures given are typical of actual conditions. Illustration A in figure 3 is the front of a standard form used to catalog the information that normally can be obtained on the first visit to a well. The reverse side of this form, illustration B, is used to record additional information that does not lend itself to the check-list arrangement such as is recorded on the front of the standard form. Periodic observations of the water level in a well are recorded on another standard form, illustration C. A special form was developed for use in the Arizona district for recording each trajectory-type discharge measurement, illustration D. Illustrations A, B, and C in figure 3 are for a hypothetical stock well; illustration D is for a hypothetical nearby irrigation well.

The numbering system used for well identification embodies an abbreviated description of the well location. The system is based on division of land areas into successively smaller quadrants, and describes the well location to the nearest 10 acres. Using the intersection of the Gila and Salt River Base and Meridian as a central point, the state is divided into four quadrants and assigned the letters A, B, C, D, progressing counterclockwise from the northeast quadrant. Thus, all the townships north and east of the base point are in quadrant A, those north and west are in quadrant B, and so forth. The first figure following the quadrant letter signifies the township; for the well record

Sample

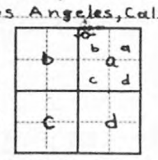
9-185
(October 1950)

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES DIVISION

WELL SCHEDULE

Date July 18, 1941 Field No. 81
Record by R.L. Coleman Office No.
Source of data Owner (D-10-8)8abb

1. *Location:* State Ariz. County Pinal
Map U.S.G.S. Base
NW¼ NW ¼ NE ¼ sec. 8 T 10 N (S) R 8 (E) W
2. *Owner:* John Doe Address Phoenix
Tenant Richard Rae Address Eloy
Driller Bill Jones Address Los Angeles, Calif.
3. *Topography* Flat
4. *Elevation* 1,695 ft. (above) below sea level
5. *Type:* Dug, (drilled) driven, bored, jetted 1932
6. *Depth:* Rept. 235 ft. Meas. 232 ft.
7. *Casing:* Diam. 8 in., to – in., Type steel
Depth 235 ft., Finish –



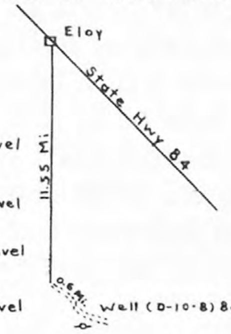
8. *Chief Aquifer* Sand and gravel From 175 ft. to 235 ft.
Others –
9. *Water level* 144.08 ft. rept. (meas.) July 18 1941 above (below)
top of casing which is 1.0 ft. (above) below surface
10. *Pump:* Type Cylinder Capacity G. M.
Power: Kind Windmill Horsepower
11. *Yield:* Flow G. M., Pump 2 G. M., Meas., Rept (Est)
Drawdown 1 ft. after 2 hours pumping 2 G. M.
12. *Use:* Dom., (Stock) PS., RR., Ind., Irr., (Obs)
Adequacy, permanence ?
13. *Quality* see Analysis Temp 66 °F.
Taste, odor, color O.K. Sample (Yes) No 7-18-41, 8-12-45, 6-8-52
Unfit for –
14. *Remarks:* (Log, Analyses, etc.)
Log on File

U. S. GOVERNMENT PRINTING OFFICE 16—63801-1

A

Sample

Reverse Side of Well Record



Drillers log

0-30	Soil
30-35	Caliche
35-60	Sand + gravel
60-90	Clay
90-93	Caliche
93-118	Sand + gravel
118-130	Clay
130-160	Sand + gravel
160-175	Clay
175-235	Sand + gravel

2-12-45 New irrigation well ½ mi. E. P.D.Q.
8-12-45 Resampled, reported getting saltier L.C.H.
2-12-50 Road fenced off; turn E. to well ½ mi. S. of old trail. H.A.B.
2-27-52 Tenant reports well may be deepened this spring – now dry. E.L.M.

B

Sample

9-195
May 1935

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES BRANCH

WATER LEVEL MEASUREMENTS (Office) Field No. 81
Owner John Doe Office No. (D-10-8)8abb
Location NW ¼ NW ¼ NE ¼ sec. 8, 10S., 8E. Project Santa Cruz
Measuring Point Top of casing, 1 ft. above land surf.
Elevation of Measuring Point 1,695.62

Date	Hour	Depth to Water	Elev. of Water Surface	Meas. by	Remarks (Nearby wells pumping, etc.)
7-18-41	2p	144.08	1,551.54	RLC	
2-8-42	10a	149.12	1,546.50	RLC	
5-4-43	10a	157.90	1,537.72	EMC	
2-10-44	5p	162.01	1,533.61	RAL	
2-12-45	9a	166.30	1,529.32	PDQ	
12-14-46	1p	170.18	1,525.44	LCH	
2-11-47	8a	173.80	1,521.82	EKM	
6-5-47	10a	177.13	1,518.49	SFT	
9-25-47	11a	183.20	1,512.42	ADH	
2-6-48	2p	181.36	1,514.26	HAB	No irr. pumps running
3-5-49	3p	–	–	HAB	Pumping
2-12-50	1p	193.88	1,501.74	HAB	
2-15-51	3p	202.79	1,492.83	ELM	
6-27-51	9a	206.01	1,489.61	ELM	
9-9-51	10a	229.90	1,465.72	ELM	
2-27-52	9a	–	–	ELM	Dry at 232 ft.

6—6194 U. S. GOVERNMENT PRINTING OFFICE

C

Sample

DISCHARGE DATA SHEET

State No. (D-10-8) 8aaa
Office No. (D-10-8) 8aaa
County Pinal
Owner John Doe
Observer Richard L. Coleman Date 7-20-49
Meter No. 276142 Type General Electric
K_h 2.4 K_r 4.0 K .96 :
rev. disc. 20 ~~cu. ft.~~ 44 sec.
Power used/ac.ft. pumped 410 kwh Motor H.P. 200
Pumping lift 280 ft. Input H. P.
D 12" F/D – 8.3 % EAF .960
F 1" Temp. °F. Est. GPM
T ¼"
Y 19"
H 14" - ¼" - 1" = 12¾"
Q 2,080 G. P. M.

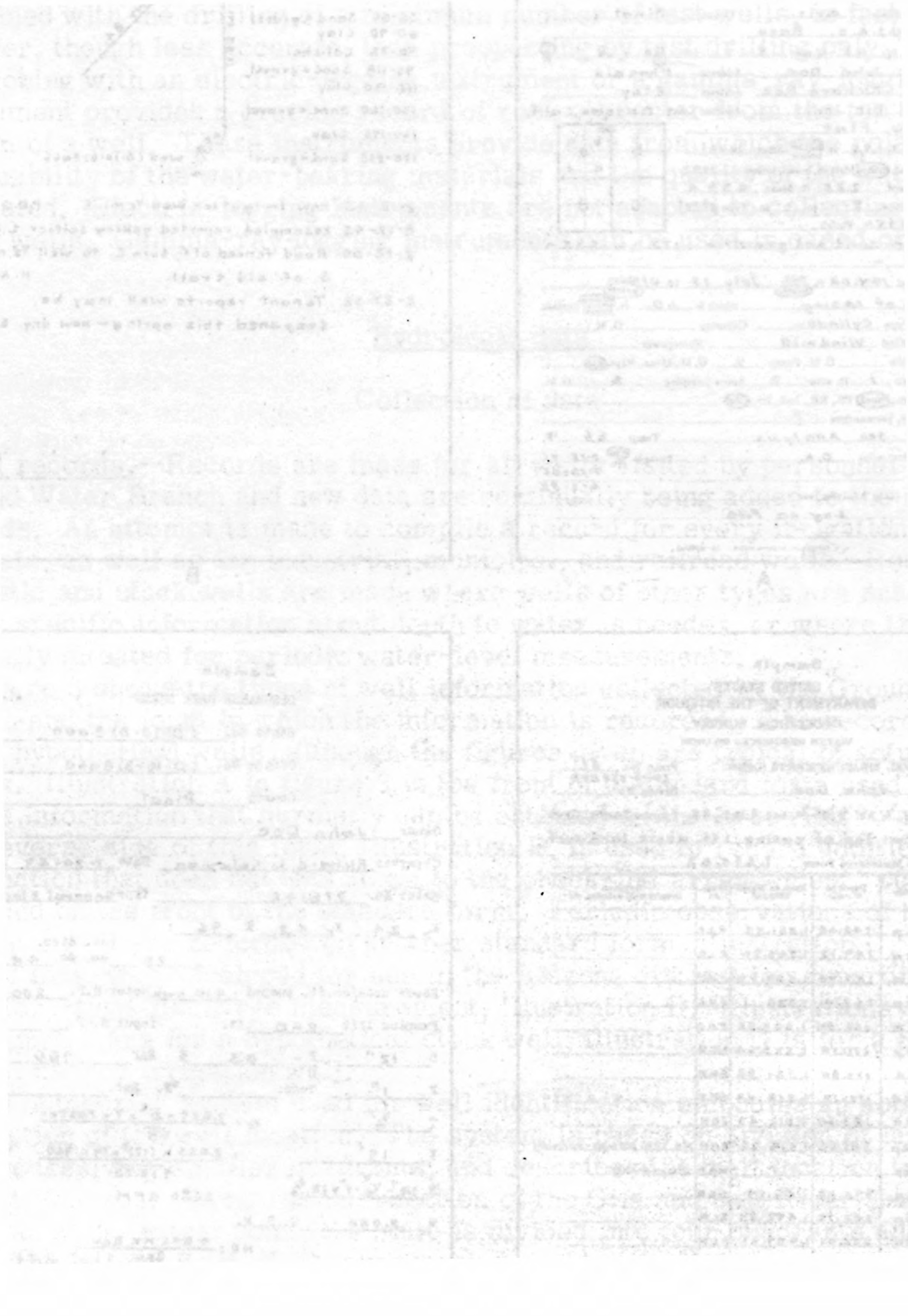
$$Q = \frac{2.835 \times D^2 \times Y \times \text{Factor}}{\sqrt{H}} = \frac{2.835 \times (12)^2 \times 19 \times .960}{\sqrt{12.75}} = 2080 \text{ GPM}$$

$$HP = \frac{4.83 \times K \times \text{Rev.}}{\text{Sec.}} = \frac{4.83 \times 96 \times 20}{44} = 211$$

$$\frac{\text{Kwh}}{\text{Ac. ft}} = \frac{HP \times 4050}{GPM} = \frac{211 \times 4050}{2080} = 410$$

D

Figure 3.- Typical well record, showing forms used and type of well data colleted.


B
A
Sample
UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

shown in figure 3 A the well is in T. 10 S. The second figure signifies the range; for the record shown it is R. 8 E. The third figure indicates the section number within the township, (D-10-8)8. The section is divided into 160-acre quadrants, to which lower-case letters a, b, c, and d are assigned, progressing counterclockwise from the northeast quadrant. The well in figure 3 A is in the (a) quadrant. Further subdivision into 40-acre quadrants and finally into 10-acre quadrants is designated by two additional lower-case letters, (bb) for the well shown. If more than one well is recorded in a given 10-acre plot, additional numbers are added, such as (D-10-8)8abb(1) and (D-10-8)8abb(2).

Water-level measurements.--By a program of periodic measurements of water levels in wells, the Geological Survey collects data indicating seasonal and long-term changes in the position of the water table. The program includes also measurements of changes in hydrostatic pressure in some of the artesian basins.

Water levels in the irrigated areas are most nearly stable during the months of January, February, and March, when the cones of depression caused by pumping during the preceding irrigation season have partially filled. For this reason most of the water-level measurements are made in the first 3 months of the year, particularly in February. Figure 3 C illustrates the form used by the Geological Survey to record water-level measurements, and shows data for a hypothetical well near an irrigated area. At the locality indicated the decline in 10 years was more than 85 feet, a figure in accord with actual measurements in that area.

Pumpage inventory.--One of the principal phases of the ground-water investigations in Arizona is the annual inventory of water withdrawn from wells. Pumpage data for some areas have been published annually since 1940, but only since 1946 have sufficient areas been inventoried to publish an annual figure for total withdrawals in the principal areas of ground-water development. Even the most recent figure published, 3,681,000 acre-feet in 1951 (table 2), does not represent all withdrawals of water from wells in Arizona. An estimate was made of pumpage in 1951 in each of the areas not inventoried, and the sum of these estimates was 75,000 acre-feet. Thus, the total withdrawal of ground water in Arizona in 1951 was approximately 3,750,000 acre-feet.

The inventory is based on two principal factors: (1) Power consumption per acre-foot of water withdrawn from each well; and (2) total power consumption per well per year.

Irrigation wells in Arizona are operated with different types of power in different areas, including electricity, natural gas, butane, gasoline, and diesel fuel. Wells powered with electricity and natural gas, and some wells powered with butane, are equipped with meters. Wells powered with gasoline or diesel fuel, and some wells powered with butane, are not equipped with meters, and the only available record of power consumption is monthly fuel bills. Fortunately power or fuel meters are installed on about 90 percent of the irrigation wells in the State. Without meters the inventory could not be accurately made.

The power or fuel consumption per acre-foot of water withdrawn is the product of two factors: (1) Power consumption per unit of time; and (2) discharge of the well per unit of time. Figure 3 D is a facsimile of the form used to record these data. The data shown are hypothetical but are typical of an electric-powered pump in the area indicated by the well number.

To determine power consumption per unit of time the following data are needed: Meter factor (Kh); transformer factor (Kr); and revolutions of the meter per unit of time. The calculations are shown (fig. 3 D) and indicate that for the well illustrated the power input was 211 horsepower.

The discharge of the well illustrated was measured by the trajectory method. For this method the water must fall freely, and the discharge pipe preferably should be horizontal. A carpenter's square and a level are used. The method consists of measuring the diameter (D) of the pipe and the horizontal and vertical components (Y, H) of the trajectory of the falling column of water. Corrections are made for pipe thickness (t) and, as needed, for a pipe only partly full (F) or not horizontal. Calculations made as shown on the form (fig. 3 D) indicate that for the date measured the discharge was 2,080 gallons per minute.

The product of the horsepower input and the discharge indicates a power consumption of 410 kilowatt-hours per acre-foot of water pumped. The total pumpage during the year is calculated by dividing total power input by power input per acre-foot.

Errors in the method are that the discharge of the well on the day it was measured may not be representative of the entire pumping season and that meters are not available for about 10 percent of the wells. The first error listed is considered to be the more important. Owing to limitations of personnel, the discharge of the average well cannot be measured oftener than once every 3 years. Statistical methods of representative sampling are applied to offset this deficiency, but the fact remains that many more well-discharge measurements are needed to improve the pumpage inventory. The second error listed is offset by applying average data for the area to the unmetered wells, by reviewing monthly fuel bills when possible, or by applying consumptive-use figures to the crops grown.

It has been suggested that a change be made in the method of making pumpage inventories, by basing all pumpage figures on crop inventories and consumptive-use figures. The crop inventory-consumptive use method also is subject to inaccuracies: (1) Climatic changes from one year to another affect the consumptive use; (2) available figures for consumptive use were developed at specific locations under ideal conditions; and (3) some farmers use more water, and some less, to raise the same crops. It is believed that the power input-well discharge method is far better adapted to conditions in Arizona, although its accuracy can be improved by making more discharge measurements.

Pumping tests.--Pumping tests are made for the purpose of collecting data on the rate of movement of ground water through an aquifer and on the quantity of stored water that will be yielded to wells. These tests are made sometimes on a single well and sometimes on two or more wells. Tests may require

Table 2.--Pumpage, in acre-feet, from wells in principal ground-water areas of Arizona

	1944	1945	1946	1947	1948	1949	1950	1951
Cochise County:								
San Simon Basin	(a)	(a)	5,800	(a)	(a)	(a)	(a)	(a)
Willcox Basin	(a)	9,000	15,500	20,000	23,000	28,000	35,000	38,000
Douglas Basin	(a)	8,000	12,500	17,000	22,000	30,000	35,000	38,000
Graham County:								
Cactus Flat-Artesia area	(a)	(a)	5,600	(a)	(a)	(a)	(a)	(a)
Safford Valley	52,000	35,000	115,000	100,000	110,000	40,000	90,000	125,000
Greenlee County:								
Duncan Valley[b]	8,000	6,500	17,000	21,000	21,000	11,000	23,000	33,000
Maricopa County:								
Salt River Valley area[c]	1,017,000	1,143,000	1,360,000	1,406,000	1,670,000	1,644,000	1,852,000	1,910,000
Gila Bend area	(a)	(a)	33,300	40,500	60,800	67,000	59,000	(110,000
Dendora area	(a)	(a)	6,700	6,700	1,900	5,000	6,000	(
Pima County:								
Part of Santa Cruz River Basin	106,000	111,000	108,000	145,000	145,000	150,000	180,000	240,000
Pinal County:								
Part of Santa Cruz and Gila River Basin	530,000	610,000	660,000	700,000	950,000	1,100,000	1,000,000	1,030,000
Santa Cruz County:								
Part of Santa Cruz River Basin	12,500	18,500	24,000	25,000	28,000	31,000	21,000	30,000
Yuma County:								
Dateland area	4,000	4,000	4,000	4,000	5,000	8,000	9,000	15,000
Wellton-Mohawk area	37,000	35,000	38,000	43,000	50,000	45,000	46,000	50,000
South Gila Valley	20,000	22,000	32,000	35,000	54,000	56,000	56,000	62,000
Total			2,437,000	2,563,200	3,140,000	3,215,000	3,412,000	3,681,000

a. Not determined; b. Does not include Virden Valley, N. Mex.; c. Includes Queen Creek area, Maricopa and Pinal Counties.

from several hours to 30 days to complete, and frequent water-level and discharge measurements are made.

In making a pumping test on a single well, the pump is shut off to allow recovery of the water table approximately to the static level of the area. The well is then pumped, preferably at a constant rate, or in steps of successively higher rate, until the rate of decline of the water table at the well becomes relatively small. If it is anticipated that changes in quality of the water might occur, samples of the water pumped are collected at intervals for analysis. The rates of drawdown and recovery of the water table after the period of pumping provide data that can be used in computing the rate of ground-water movement in the aquifer.

If more than one well is available for measurement during a pumping test, measurements of depth to water are made in the pumped well and in the nearby observation wells. Tests of this type provide data that can be used to calculate not only the rate of ground-water movement, but also the storage capacity of the aquifer.

Laboratory tests.--Data for transmissibility and for storage-capacity calculation can be obtained in the laboratory, as well as by making pumping tests. Samples of the aquifer to be tested are collected from outcrops or from wells and are placed in containers through which water is forced under controlled conditions to determine the permeability of the sample. After the permeability of a sample has been determined in the laboratory, water is drained from the sample under controlled conditions to determine the rate and relative amount of water that drains freely.

Electrical current-meter tests.--Knowledge of the rates at which water moves into pumped or flowing wells at various depths is sometimes desirable. Water may be moving into a well more readily from some strata than from others; the discharge of a well may be declining for no apparent reason; or leakage from an artesian aquifer into a nonartesian aquifer may be occurring. Problems of this type sometimes can be solved by testing a well with a deep-well current meter, or with a recording electrical current meter developed recently by H. E. Skibitzke, of the Geological Survey. The instrument indicates the velocity of water in the well bore. If no water is entering the well below a given depth, the upward velocity below that depth will be zero. This may mean that the formation is too impermeable to yield water, that the well casing has been improperly perforated, or that the perforations have become clogged with sediment or chemical precipitates. In a flowing well, if the upward velocity of water in the well bore decreases greatly at a given depth, leakage of water into an aquifer of lower head at that depth is indicated.

Seepage measurements.--Seepage measurements are used to determine losses or gains in stream flow due to recharge to or discharge of ground water. These measurements are made at permanent gaging stations or at intermediate points selected with reference to the geologic character of the rocks underlying the stream channel.

Interpretation of data

Calculations of ground-water movement.--Data from pumping and laboratory tests are used to compute the "coefficient of transmissibility"--the rate of movement of ground water in gallons per day per mile of width of aquifer per foot per mile of hydraulic gradient. The volume of movement of ground water can be calculated by multiplying this coefficient by the width of an aquifer in miles and the slope of the water table in feet per mile. Calculations of coefficients of transmissibility provide figures for estimating underflow into and out of basins, recharge and discharge, and the potential amount of water that may be pumped from a given well, or a given depth in a well.

Coefficients of transmissibility may also be obtained from laboratory tests. These provide data for the calculation of the "coefficient of permeability." This coefficient is a measure of the rate in gallons per day at which ground water will move through each 1-foot layer of a mile-wide segment of the aquifer under a hydraulic gradient of 1 foot per mile. The average field coefficient of permeability (permeability at the prevailing temperature of the ground water) multiplied by the thickness of the saturated portion of the aquifer gives the coefficient of transmissibility.

Calculations of ground-water storage.--When data are available from pumping tests involving two or more wells, or from laboratory tests, calculations can be made not only of the rate of movement of ground water, but of the storage capacity of the aquifer as well. The capacity of a material to store water is expressed as the "coefficient of storage" (Wenzel, 1942, p. 89) or, for water-table conditions "coefficient of drainage" (Gatewood and others, 1950, p. 81). For practical considerations, these two coefficients are approximately equivalent for water-table aquifers.

Coefficients of storage and drainage vary from basin to basin, and from aquifer to aquifer within each basin, because the hydrologic properties of the alluvial fill underlying the valleys are not uniform. Numerous determinations of the coefficients of storage at different depths and at different localities are needed to make accurate calculations of latent and underlying storage, and these are not everywhere available. Table 3 lists some of the available coefficients of storage and drainage used in this report. For basins in which specific determinations have not been made, coefficients of storage or drainage from table 3 were modified through knowledge of the geology of the basins. The figures of latent and underlying storage in individual basins could be improved if more test data were available. However, within the limits of the data on hand, the figures on latent and underlying storage that are presented are believed to be reasonable.

The latent or underlying storage in the 300-foot layers immediately below the water table in a given area is computed by multiplying the area, in acres, by the thickness in feet, and by the coefficient of storage or drainage in percent. Areas are corrected for the presence of pediments and bedrock hills. The quantity of ground water in latent or underlying storage is given in acre-feet.

Table 3.--Coefficients of storage; Arizona, California, Nebraska, and Utah

Area and reference	Type of material	Coefficient of storage (percent of total volume)
Eloy district, Ariz. (Smith, 1940)		9 - 13
Florence-Casa Grande area, Ariz. (White, 1935)	Sand and gravel	20 - 25
Bill Williams River, Ariz. (Unpublished data, U. S. Geol. Survey, Ground Water Branch, Tucson, Ariz.)	Sand and gravel	10 - 30
Escalante Valley, Utah (White, 1932)	Clay, clay loam, silt, and fine-grained sand	1 - 6
Grand Island, Nebr. (Wenzel, 1936)	Coarse sand	22 - 23
Mokelumne area, Calif. (Stearns, Robinson, and Taylor, 1930)	Hard sandy clay to medium-grained sand	1 - 20
Mokelumne area, Calif. (Piper, Gale, Thomas, and Robinson, 1939)	Very fine sand, silt, and clay	4
	Medium and fine sand	23
	Gravel and coarse sand	35
	All materials	13
Santa Clara Valley, Calif. (Estimate made by Clark, cited in Piper, Gale, Thomas, and Robinson, 1939)		12
Safford Valley, Ariz. (Gatewood and others, 1950)	Flood-plain materials	16
Phoenix area, Ariz. (Turner, McDonald, and Cushman, 1946)	Silt, sand, and gravel	15
Verde River Valley, Ariz. (McDonald and Padgett, 1945)	Sand and gravel	4 - 30
	(average)	16

Maps showing ground-water conditions.--Most ground-water conditions in an area can be presented in an understandable form by the use of maps. Maps are used to show, for a given date, the elevation of the water table, the depth to water, or the quality of the ground water. Maps also are used to show, for a period between two given dates, changes in the position of the water table or in the quality of water.

A map portraying lines of equal elevation of the water table is called a water-table contour map. It aids in determining the direction of movement of ground water, areas of recharge and discharge, and the position of subsurface barriers that impede or divert movement of ground water.

A map portraying lines of equal depth to the water table is called a depth-to-water map and aids in determining the approximate position of the water table below the land surface.

A map portraying lines of equal mineral content of the ground water aids in determining the quality of water available to wells, changes in the quality of the ground water as it moves through the area, sources of recharge, and sources of soluble mineral matter in the aquifer.

A map portraying lines that show changes in the position of the water table between two given dates aids in determining areas in which withdrawals exceed recharge, areas in which withdrawals are balanced by recharge, or areas in which recharge exceeds withdrawals.

Ground-water equations.--Evaluations of the ground-water supply of some areas have been made by the use of an inventory. Items of the inventory include water entering the area, water in storage, and water leaving the area. An inventory of this type is expressed by means of what is called a "ground-water equation." It is based on the premise that total recharge equals total discharge when no change occurs in the quantity of ground water contained in storage within the area. In applying ground-water equations to some of the components of recharge, the discharge and storage must be estimated owing to lack of complete data.

Quality-of-water data

Data regarding source and movement of ground waters and their suitability for different uses are obtained from determinations of chemical quality of water samples collected in the field. The samples are indentified as to point of collection and described as to use and readily apparent physical properties such as temperature, taste, color, and turbidity. The samples are shipped to the district office of the Quality of Water Branch.

The Quality of Water Branch of the Geological Survey is charged with the responsibility of determining the chemical quality of ground waters and surface waters in the United States. A district office is maintained at Albuquerque, N. Mex., under the supervision of J. D. Hem, district chemist. This office works closely with the Arizona district of the Ground Water Branch, analyzing water samples collected by ground-water field men and participating in the writing of those parts of the Arizona ground-water reports that discuss quality-of-water problems.

The significance of the chemical quality of ground water has been discussed earlier in this report.

SCOPE OF DATA AVAILABLE

By L. C. Halpenny

Reports on ground water in Arizona have been issued by the Geological Survey and other agencies since before 1900.

Data collected since the district office of the Ground Water Branch was opened at Tucson in 1939 have been compiled into reports of three general categories: (1) General reports on specific areas, mostly prepared in cooperation with the State Land Department; (2) annual reports, including the annual report on water-level measurements and inventory of pumpage, and annual reports to the State Land Commissioner; and (3) special reports on specific areas, mostly prepared at the request of the armed services, or of other Federal agencies, or in cooperation with municipalities. Some of the special reports prepared at the request of the armed services cannot be released because of security regulations. A list of all the released reports, prepared since the office was opened, is a part of the bibliography of this report.

In addition to the reports prepared by the district office, data are available for public inspection in the "open file." These data include well records, well logs, water analyses, and maps prepared at the request of the State Land Commissioner.

Data are continually being collected by the staff for general or special reports, for the annual water-level report, or for future use in later, more detailed investigations. Some of them are classed as "open file" information and the remainder are classed as "not available until released." The policy of the Geological Survey is to release factual data and interpretive reports without favor to special interests. Once released, the reports are available to anyone who is interested.

Part II.

GROUND WATER IN INDIVIDUAL AREAS

INTRODUCTION

Part II of this report describes ground-water occurrence in the intensively developed areas of Arizona, and includes a section for each of the areas. The individual areas are discussed in this report in progressive order downstream along the Gila River and its tributaries, and their locations are shown on plate 1.

The data for each area described differ considerably in the extent of detail of the information collected, the year in which detailed studies were made, and the period of years in which continuing measurements were made. For some areas a considerable amount of factual information had been collected and was available for analysis; for others, fewer data were available. There are areas where little work has been done subsequent to an intensive investigation that was made several years ago; there are areas where recent investigations have made available results that previously have not been published and are included herein for the first time. Throughout most of the areas the annual water-level measurement program and pumpage inventory have continued and all these data were studied in preparing the sections on individual areas.

DUNCAN BASIN, GREENLEE COUNTY

By J. H. Feth

The Duncan basin is a part of a structural trough that extends northwest from the vicinity of Lordsburg, N. Mex., to the vicinity of Guthrie, Ariz. The Gila River enters this trough about 10 miles east of the town of Duncan and flows northwest through the lower end of the trough. The eastern margin of the Duncan basin is set arbitrarily at the Arizona-New Mexico State line.

The Duncan basin terminates on the west about 1 mile upstream from the junction of the San Francisco and Gila Rivers. At that point the rocks of the Peloncillo Mountains are exposed continuously across the valley of the Gila River, and form both a topographic and a ground-water boundary. The basin is enclosed on the northeast by the Steeple Rock Mountains and on the southwest by the Peloncillo Mountains. The rocks of these mountain ranges are of low permeability and effectively confine ground water of the Duncan basin within the sedimentary materials partly filling the intermontane trough. The drainage area of the Duncan basin, as here defined is about 680 square miles; the area of the valley floor is about 270 square miles. The basin trends north-northwest, and is about 37 miles long. The alluvial valley ranges from 5 to 9 miles in width.

The present report on this basin summarizes data gathered mainly in 1939-40 and in 1943-44, when ground-water investigations in the Safford Valley included observations in the Duncan basin. Since 1944 few new data except annual pumpage inventories and periodic water-level measurements have been added.

Geology

Plate 2 shows the shape of the Duncan basin and presents a generalized view of the geology of the region. The northeast and southwest margins are irregular; spurs and ridges project from the main mountain masses far into the valley floor. On either side, the Peloncillo and Steeple Rock Mountains consist largely of volcanic rocks. In T. 6 S., R. 32 E., a fault block of older sedimentary formations occupies a few square miles. In T. 4 S., R. 30 E., two areas of crystalline rocks are exposed. The faults bounding the intermontane trough are concealed by alluvial fill.

The absence of deep wells in the basin precludes any possibility of defining the subsurface shape of the trough, the composition of materials composing the deeper parts of the alluvial fill, or the composition of the rock floor of the basin. The total depth of alluvial material in the Duncan basin can be estimated only by analogy with nearby basins where deep wells near the axes of the valleys have encountered approximately 3,000 feet of valley fill. The alluvial fill in the Duncan basin also may be a few thousand feet thick.

The upper part of the valley fill includes at least three facies (Halpenny and others, 1946, pp. 3-4), an older fill, lake or playa beds, and Recent alluvium. The lake or playa beds interfinger with or grade into the older alluvial fill. The Recent alluvium occurs in the inner valleys and in the channels of tributary washes. The character of these deposits is described in the section on general geology of the Gila River region.

Logs of representative wells in Duncan basin are shown in table 5. One of the deepest wells in the area, (D-9-32)4ca, is near the upstream end of the basin. The driller reported the total depth to be 301 feet, and noted that below 55 feet mostly clay was encountered. No water was produced below 200 feet. The well logs in the basin indicate that the Recent alluvium ranges in thickness from 50 to 125 feet and averages about 90 feet. The Recent alluvium is generally underlain by silt and clay beds of the older alluvium which provide a floor of low permeability beneath the Recent alluvium.

Wells in the Duncan basin obtain water almost exclusively from the Recent alluvium. Recent alluvium in the Duncan basin is comparable to the Recent alluvium in the Safford Valley because both were deposited under similar conditions at about the same time. Data from 300 field and laboratory tests of the Recent alluvium within the Safford Valley show the mean coefficient of drainage to be 16 percent (Gatewood and others, 1950, p. 92). This coefficient of drainage is considered applicable to the Recent alluvium of the Duncan basin because of the similarity of the deposits in the two basins. A few laboratory determinations and one pumping test in Duncan valley confirm this conclusion (Halpenny and others, 1946, p. 6). No data are available from which the permeability or coefficients of drainage of either the lake beds or the older alluvium in Duncan basin can be determined.

Ground-water hydrology

Occurrence, source, and movement

Ground water in the Duncan basin is obtained almost exclusively from the Recent alluvium of the inner valley. The character and permeability of the aquifers have been described. In general, water in the Recent alluvium is derived from several sources, moves through the alluvium toward the Gila River, and is discharged by the natural processes of evaporation, transpiration, or seepage into the river.

In some respects the Duncan basin is like many other valleys in the southwest through which perennial streams flow. Ground water and surface water in such valleys is intimately interrelated. In general, there is constant downstream movement of both ground water and surface water through the length of the basin from the head of the valley, where recharge of the ground-water aquifers occurs, to points of discharge near the downstream end.

In other respects, the Duncan basin offers problems somewhat different from those characteristic of southwestern valleys occupied by through-flowing streams. As defined in this report, the Duncan basin is only a part of a physiographic basin, the upper part of which lies in New Mexico. Thus interstate complications may arise in allocations of waters of the basin. Similarly, the existence of downstream rights to water of the Gila River must be considered.

Recharge

Gila River underflow.--Estimates of recharge to ground-water reservoirs in the Duncan basin have been made for the year October 1, 1939, to October 1, 1940. For that period, underflow of the Gila River at the Arizona-New Mexico State line was estimated (Halpenny and others, 1946, p. 6) to be about 7,000 acre-feet. Recharge from other sources includes: (1) Underflow from tributary washes; (2) direct recharge from infiltration of rainfall upon the valley floor; (3) infiltration from irrigation water, both from ditches and from irrigated lands; (4) seepage from the Gila River; and (5) recharge to the alluvium of the inner valley by seepage out of older alluvium.

Tributary underflow.--Recharge by underflow from washes tributary to the Gila River constitutes one of the more important contributions to the ground-water supply of the basin. Although present data do not permit an accurate estimate of the amount, the effect of recharge from side washes is evident in the changing pattern of the dissolved-solids content of well waters sampled in the valley. The effect is shown by graphical analyses of waters from wells near Sheldon, (D-8-31)11ac (pl. 4) and (D-7-32)33b a few miles downstream, near York. The wells near Sheldon are relatively high in dissolved solids, whereas those downstream and below several large washes are appreciably lower in mineral content.

Rainfall.--Direct infiltration of rainfall upon the valley floor to the water table is possible in parts of the Duncan basin, where depth to water ranges from a few feet to 30 feet and materials of the Recent alluvium are relatively coarse, uniform, and uncemented. The amount of such recharge is not known. Rainfall on the older alluvium is not believed to recharge the ground-water reservoir.

Canals and irrigated fields.--Recharge from canals and irrigated areas occurs in the Duncan basin, but no quantitative estimate of the volume of this recharge was made by the present author. Halpenny and others (1946, p. 7) estimated recharge from this source to be in the order of 10,000 acre-feet in 1940, based on data collected in the Safford area (Turner and others, 1941, pp. 36-37).

Seepage from the Gila River.--The slope of the water table at most times is toward the river, indicating movement of ground water in that direction. At times when pumpage is heavy, however, the slope is reversed and water recharges from the river into the Recent alluvium (Halpenny and others, 1946, pp. 7-8). Recharge by seepage from the Gila River also fluctuates in response to the changing stages of the river. During periods of heavy runoff, water from the river is recharged to shallow aquifers in the Recent alluvium. A falling stage of the river results in a lowering of the water table and discharge occurs. These fluctuations are so rapid that they may be considered as bank storage rather than as recharge.

Seepage from older alluvium.--Ground water that leaks under artesian pressure from the older alluvium into the Recent alluvium is considered as recharge to the Recent alluvium. Quantitatively, the average amount of such recharge is not known. Halpenny and others (1946, p. 6) estimated recharge from this source to be approximately 2,500 acre-feet for the 12-month period ending October 1, 1940.

Discharge

Discharge of water from the Duncan basin can be considered under two principal headings, pumpage and natural discharge.

Pumpage.--Annual pumpage from wells in the Duncan basin during the period 1942-51 is shown graphically in figure 4. Data compiled in 1950 at the request of the President's Water Resources Policy Commission showed that pumpage for irrigation in Duncan basin over a 10-year period averaged 10,000 acre-feet per year. During the same period, average annual pumpage for municipal use was about 80 acre-feet (unpublished data, U. S. Geol. Survey). Pumpage for domestic use, other than municipal, and for industry was not estimated. The Phelps-Dodge Corp. mining, milling, and smelting operations at Morenci require large volumes of water, but are supplied from sources outside Duncan basin.

Discharges of representative irrigation wells in the basin were measured in 1939-1946 and ranged from 170 to 2,250 gallons per minute. Discharge measurements of several irrigation wells were made in June and July, 1952, and ranged from 150 to 1,700 gallons per minute. Irrigation wells are drilled only in areas underlain by Recent alluvium (pl. 3). They range in depth from about 30 to about 300 feet, and casing diameters range from 6 to 20 inches. Pumping lifts, measured in 1952 (table 4), ranged from 30 to 60 feet. Specific capacities were determined for only a few wells and ranged from 5 to 70 gallons per minute per foot of drawdown. No appreciable decrease in yields of wells or persistent decline of the water table have as yet been detected.

Natural discharge.--Natural discharge of water from the Duncan basin is discussed under the following topics: (1) Surface flow; (2) underflow; and (3) evapotranspiration.

The Surface Water Branch has maintained a gaging station on the Gila River near Clifton, about $1\frac{1}{2}$ miles above the downstream boundary of the basin, (pl. 1) at intervals totalling 23 years from 1911 to the present. The last published record (Water-Supply Paper 1149, 1951, p. 365) reports an average annual discharge of 246 second-feet or about 175,000 acre-feet per year. Discharge from the ground-water reservoirs in the Duncan basin to the Gila River is estimated (Halpenny and others, 1946, p. 8) to range from 4 to 25 second-feet, or 2,800 to 17,500 acre-feet per year.

The amount of underflow out of the Duncan basin was estimated (Halpenny and others, 1946, p. 7) to be less than 400 acre-feet per year. The estimate is tentative because there is relatively little information for the northwestern part of the basin regarding the depth of the Recent alluvium or the slope of the water table. The narrowness of the gorge of the Gila River and the apparent near-surface occurrence of volcanic rocks suggest that the estimate of 400 acre-feet per year of underflow is in the correct order of magnitude.

Intensive investigations to determine the use of ground water by native, nonbeneficial vegetation in Safford Valley were made by the Geological Survey, in cooperation with the State of Arizona and the Corps of Engineers during 1939-40 (Halpenny and others, 1946), and with the Defense Plant Corporation and the Phelps-Dodge Corp. during 1943-44 (Gatewood and others, 1950). Loss of water through use by nonbeneficial vegetation in the bottom lands of the Duncan basin was estimated (Halpenny and others, 1946, p. 7) to be 9,300 acre-feet between October 1, 1939, and October 1, 1940. The range from year to year in transpiration by bottom-land vegetation has not been determined. It is believed to fluctuate with variations in precipitation, position of the water table, and stages of the river. The estimate of direct evaporation from wetted lands in the Duncan basin for the same period was about 1,200 acre-feet. This evaporative loss is somewhat dependent upon the same variables that influence discharge by nonbeneficial vegetation. Data do not exist that would lead to a more accurate estimate of evapotranspiration losses in the basin.

Storage

An estimate is made of underlying storage in the Duncan basin but no estimate of latent storage is presented. The estimate of underlying storage is based on the available data and certain assumptions. The area within the periphery of irrigated lands includes the inner valley and the lower parts of the large tributary washes underlain by Recent alluvium, and totals 25 square miles. The average thickness of saturated Recent alluvium is assumed to be 65 feet. This thickness was obtained by assuming an average depth of 25 feet to the water table and subtracting it from an average thickness of 90 feet for the Recent alluvium. The coefficient of drainage is estimated to be 16 percent.

Calculation of underlying storage from the data and assumptions cited is shown below:

25 $mi.^2$ x 640 $acres/mi.^2$ = 16,000 acres within the periphery of irrigated lands.

16,000 acres x 65 feet (thickness of saturated Recent alluvium) = 1,040,000 acre-feet of saturated material.

1,040,000 acre-feet x .16 (coefficient of drainage) = 166,400 acre-feet of underlying storage.

Underlying storage in the Duncan basin is therefore estimated to be about 165,000 acre-feet.

In the absence of deep wells in the basin, no data are available regarding storage within the older alluvium.

Changes in ground-water storage

Graphs showing fluctuations of water levels in observation wells and total

Table 4.--Specific capacities - Duncan basin

July 1952

Well no.	Static level (feet)	Pumping level (feet)	Draw-down (feet)	Dis-charge (gpm)	Specific capacity as gpm per foot of drawdown
(D-8-31)13abd	15	32	17	800	47
(D-8-32)33cdc	30	48	18	100	6
(D-9-32)4bac	54	58	4	275	69
(D-9-32)4cbd	43	51	8	150	19
(D-9-32)4cdd	40	48	8	275	34

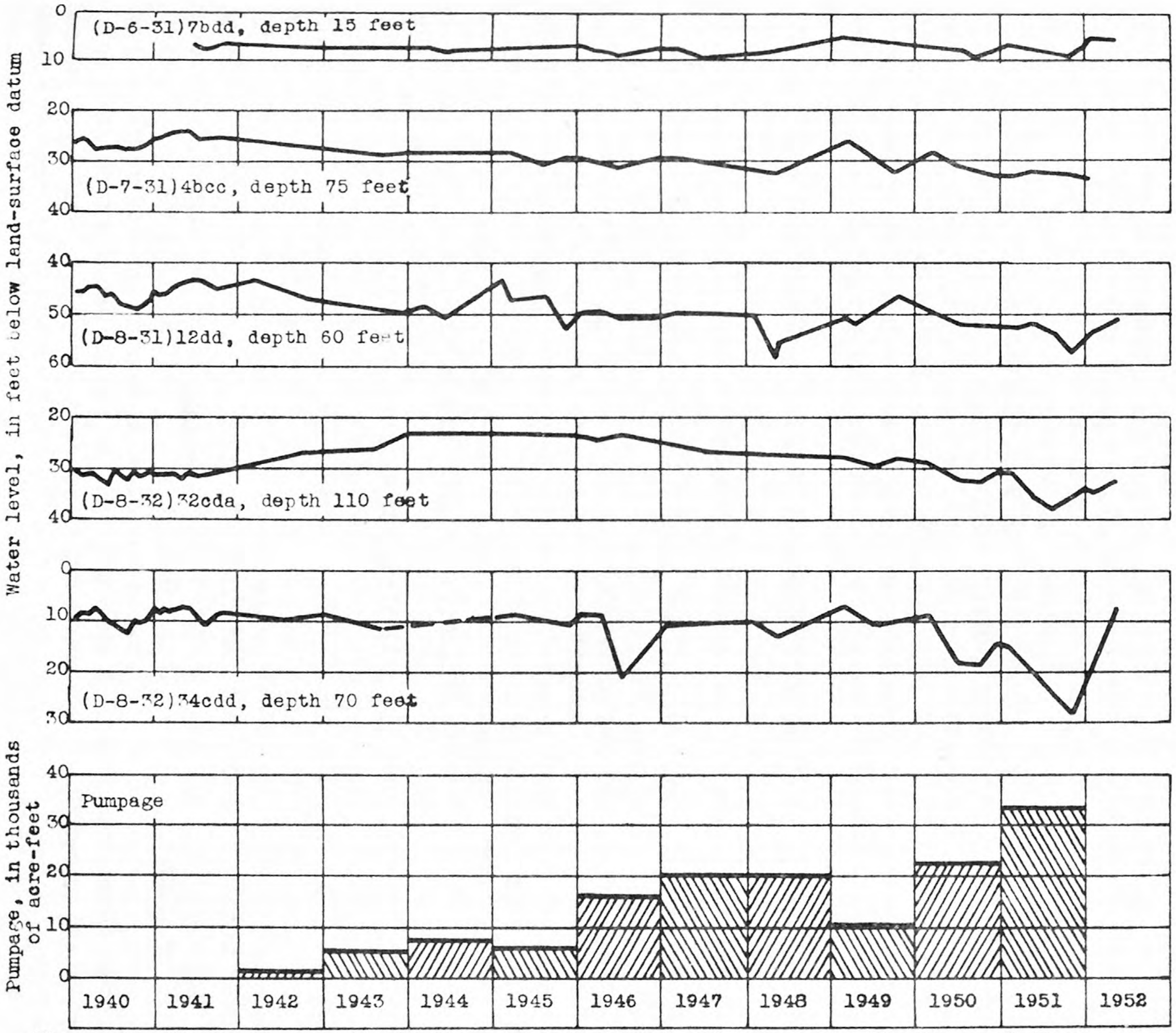


Figure 4.--Graphs showing fluctuations of water level and pumpage in the Duncan Valley, Greenlee County.

annual pumpage in the Duncan basin are presented in figure 4. During the period 1942 to 1951, pumpage increased from 2,000 acre-feet (1942) to 34,000 acre-feet (1951). The declines were least in wells near the river where the water table was only a few feet below land surface. The volume of water pumped for irrigation in any year is, at a maximum, about 20 percent of the volume estimated to be in underlying storage. Water levels in irrigation wells commonly are lowest at the conclusion of the pumping season. Following a season of reasonably heavy runoff, however, the curves show a tendency of the water table to return to the level at which it stood in 1942. The record to date does not indicate a persistent net decline.

Seasonal fluctuations in water levels reflect several factors: (1) Periods of heavy rainfall followed by rising water levels resulting partly from direct recharge and partly from cessation of irrigation pumping; (2) changes in the amounts of water used by nonbeneficial vegetation; (3) variations in the amount of surface water diverted, which result in variations in the amount of water pumped for irrigation and recharged through seepage from canals and ditches.

No data are available regarding well interference in the Duncan basin.

Quality of water

Analyses of ground-water samples from the Duncan basin show ranges in concentrations of total solids from 250 to 5,000 parts per million (Hem, 1950, pp. 86-87). Waters of higher concentration occur in wells at the upstream end of the basin near the State line. These variations are illustrated by 9 analyses presented graphically on plate 4. The graphs show specific conductance and percent of sodium. The selection of constituents for graphical presentation is based on their importance in determining the suitability of waters for irrigation. The bar graphs are arranged with reference to the position of wells in the basin.

In general the waters are suitable for irrigation. Exclusive use of more highly mineralized waters may result in damage to the land. Where such waters are used alternately with, or mixed with, surface water from the Gila River, permanent damage to the lands is not likely to result.

Areas of maximum mineralizaion of the water are associated with areas where faults permit upward seepage of water from the older alluvium. Concentrations of fluoride (Hem, 1950, pp. 76-77) range from 0.4 to 9.6 parts per million. In general, the higher concentrations of fluoride are associated with the higher concentrations of dissolved solids.

Few data on chemical quality of ground waters in the Duncan basin have been obtained since 1944, and changes in the chemical character of the waters therefore cannot be discussed.

Ground-water--surface-water interrelations

The relationships in the Duncan basin between the water of the Gila River and the water table have been discussed in the section on storage. The surface flow into the basin is known approximately from records obtained at a gaging station on the river 16 miles upstream from the State line. At that gaging station the average discharge over 22 years of record was 180 second-feet (Water-Supply Paper 1149, 1951, p. 362) or about 130,000 acre-feet per year. The maximum annual pumpage from the basin is 34,000 acre-feet per year. The lack of net decline in the water table, as shown by the hydrographs, clearly indicates that the relatively large volume of surface water, and the recharge from other sources, offset the seasonal discharge by pumpage.

Methods of increasing or conserving ground-water supply

Removal of nonbeneficial vegetation which uses ground water in the bottom lands of the Gila River constitutes a method by which ground-water supplies in the Duncan basin might be conserved. Experimental work in clearing the growth or in attempting to kill it with chemical sprays is so far inconclusive in terms of economic feasibility as well as of effectiveness (Bowser, 1952, pp. 72-74). A parallel problem involves replacement of nonbeneficial vegetation by other plant growth that uses little ground water, yet holds the soil in place without blocking flood flows in river channels.

Lining canals and ditches would result in more efficient use of surface water diverted for irrigation and consequently in reduced pumpage. It is not known whether the savings so effected would offset the effect of the resulting diminution in ground-water recharge from canal and ditch losses.

Problems for further investigation

(1) If ground-water pumpage continues to increase, its effect on surface flow will require a more detailed knowledge of the relation between stages of the Gila River and of the water table in the Recent alluvium. A program of frequent water-level measurements in numerous wells at varying distances from the river, and a simultaneous inventory of water pumped and water flowing in the channel would, if continued for a few years, clarify the relationships.

(2) The geology of the Duncan basin and the presence of clay beds along the axis of the valley suggest the possibility of artesian aquifers within or below the lake beds. Deep test holes, possibly to bedrock, in the center of the valley might reveal the presence of artesian water. The chemical quality of any artesian water obtained would determine whether it could be used for irrigation perennially, intermittently, or not at all.

(3) The occurrence of fluoride in waters of the basin should be more thoroughly investigated, especially with relation to public supplies. It should be possible to discover areas within the basin from which water with less than 1.5 parts per million of fluoride could be obtained in quantities sufficient for municipal use. The detrimental effects of large amounts of fluoride on the teeth of children make an investigation of this problem desirable.

Summary

The Duncan basin is part of a larger topographic valley on the main stem of the Gila River. It is arbitrarily separated from the rest of the valley at the Arizona-New Mexico State line. Ground water used at present in the basin is derived almost entirely from Recent alluvium of limited extent and relatively little thickness in the inner valley. The water table fluctuates in most places with stages of the Gila River. The entire ground-water supply utilized at present for irrigation is intimately interconnected with surface flow and underflow of the river.

Recharge occurs principally by seepage from canals and irrigated lands, and by underflow into the basin at the Arizona-New Mexico State line, and possibly as the result of direct precipitation on the valley floor. Recharge-discharge relationships between flow in the Gila River and ground water in the Recent alluvium appear to be in a state of dynamic equilibrium.

Discharge from the basin includes surface flow and underflow, pumpage, evaporation, and transpiration. The use of water by nonbeneficial vegetation was estimated to exceed 9,000 acre-feet in the water year 1940. It is estimated that as much as 165,000 acre-feet of water may at times be in underlying storage in the Recent alluvium.

Waters in the basin are generally of suitable quality for irrigation. Locally, seepage from lake beds or fault zones results in areas where ground water is highly mineralized. Fluoride concentrations exceed the safe limit for domestic use in many water supplies.

The principal ground-water problem of the basin involves the recharge-discharge relationship between flow in the Gila River and ground water in the Recent alluvium. Artesian aquifers in the older alluvium might be encountered by deeper drilling.

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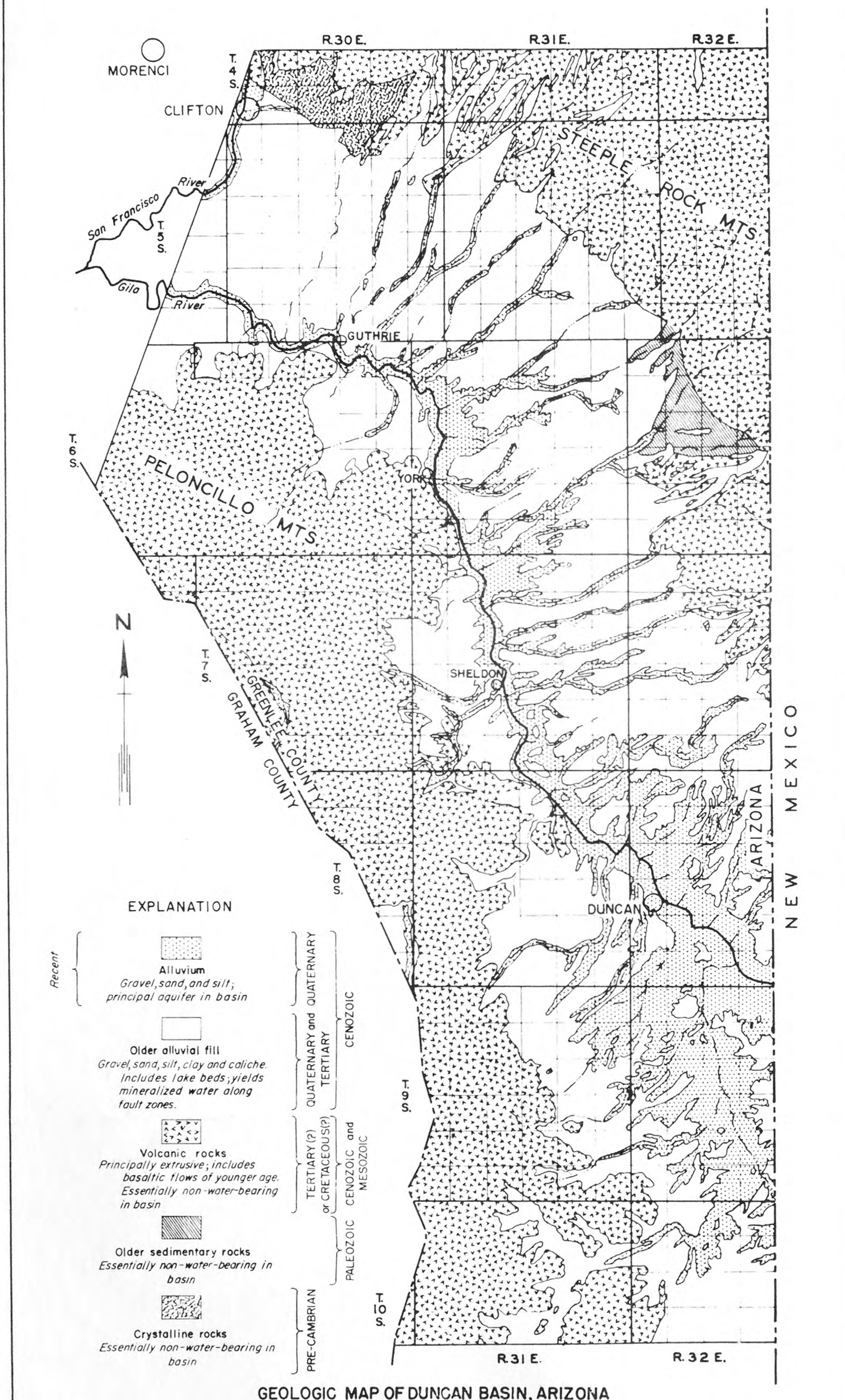
und water is ... Fluoride concentrations exceed the
limit for domestic use in many water supplies.
he principal ground-water problem of the basin involves the recharge-
harge relationship between flow in the Gila River and ground water in
nt alluvium. Artesian aquifers in the older alluvium might be developed
by deeper drilling.

Table 5.--Logs of representative wells in Duncan basin, Ariz.

	Thickness (feet)	Depth (feet)
(D-6-31)17bba		
Topsoil - - - - - - - -	13	13
Gravel-water first encountered at 13 ft.	22	35
TOTAL DEPTH		35
(D-6-31)32ddd		
Topsoil - - - - - - - -	8	8
Clay - - - - - - - - -	14	22
Sand - - - - - - - - -	3	25
Clay - - - - - - - - -	13	38
Sand and gravel - - -	14	52
Clay - - - - - - - - -	4	56
Sand - - - - - - - - -	16	72
Sandy clay - - - - - -	14	86
Sand and gravel - - -	30	116
Red clay - - - - - - -	4	120
TOTAL DEPTH		120
(D-7-31)4dba		
Topsoil - - - - - - - -	10	10
Dry sand - - - - - - -	30	40
Clay - - - - - - - - -	34	74
Sand, water - - - - - -	20	94
Water gravel - - - - -	32	126
Dry sand - - - - - - -	16	142
Sand and clay - - - - -	13	155
TOTAL DEPTH		155
(D-7-31)21abd		
Soil - - - - - - - - -	18	18
Sand and shale - - - -	12	30
Dry gravel - - - - - -	5	35
Shale - - - - - - - - -	5	40
Gravel, water - - - - -	46	86
TOTAL DEPTH		86
(D-7-31)28adb		
Earth - - - - - - - - -	25	25
Gravel - - - - - - - - -	40	65
TOTAL DEPTH		65
(D-8-31)13bbd		
Topsoil - - - - - - - - -	8	8
(no record) - - - - - - -	22	30
Gravel and small stone	20	50
TOTAL DEPTH		50
(D-8-32)34ddb		
Topsoil, sandy - - - - -	20	20
Gravel - - - - - - - - - -	50	70
Clay - - - - - - - - - - -	25	95
TOTAL DEPTH		95
(D-8-32)20ccb		
Topsoil - - - - - - - - - -	2	2
Sand and gravel - - - - -	18	20
Quick sand - - - - - - -	14	34
Sand and gravel - - - - -	31	65
Yellow clay - - - - - - -	5	70
TOTAL DEPTH		70
(D-8-32)19acc		
Soil - - - - - - - - - - -	13	13
Sand, gravel, water - -	61	74
Clay - - - - - - - - - - -	6	80
TOTAL DEPTH		80
(D-8-32)29aaa		
Clay - - - - - - - - - -	20	20
Clay and fine sand bearing some water - - -	6	26
Gravel, sand, rocks - -	44	70
Blue clay - - - - - - - -	1	71
TOTAL DEPTH		71
(D-8-32)32dad		
Adobe - - - - - - - - - -	63	63
Fine red sand, gravel -	11	74
Red clay - - - - - - - -	2	76
Coarse gravel - - - - - -	4	80
TOTAL DEPTH		80

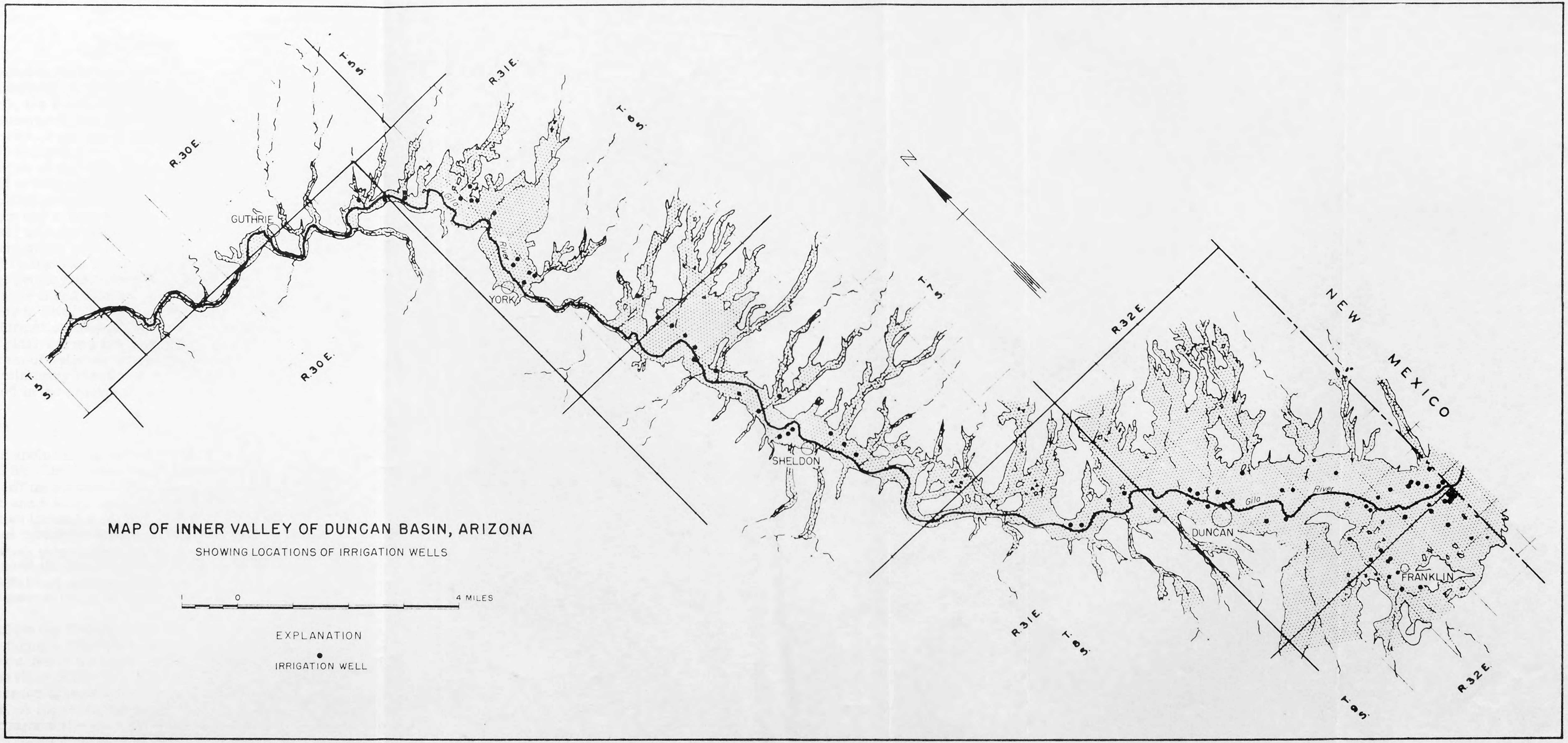
Table 5. Logs of representative wells in Duncan basin--continued

	Thickness (feet)	Depth (feet)
(D-9-31)2aab		
Fill, clay	50	50
Clay	60	110
Rock, hard	15	125
Hard, black rock	15	140
(More volcanics reported, some black, some color not specified)	198	338
Sand rock	19	357
Water sand	7	364
Sand rock	61	425
Sand, hard, carrying water	5	430
Sand rock	72	502
TOTAL DEPTH		502
(D-9-32)3bcc		
Clay	45	45
Water	5	50
Clay	25	75
Water	10	85
Clay	15	100
Water	10	110
Clay	40	150
TOTAL DEPTH		150
(D-9-32)4ca		
Silt	5	5
Clay	5	10
Gravel and clay	5	15
Gravel and clay, very little water	25	40
Gravel, very little water	15	55
Clay with a little sand	145	200
Clay	101	301
TOTAL DEPTH		301



GEOLOGIC MAP OF DUNCAN BASIN, ARIZONA

1952


MAP OF INNER VALLEY OF DUNCAN BASIN, ARIZONA
SHOWING LOCATIONS OF IRRIGATION WELLS
0
4 MILES
EXPLANATION
IRRIGATION WELL
GUTHRIE
YORK
SHELDON
DUNCAN
FRANKLIN
Gila River
NEW MEXICO
R.30E.
R.31E.
R.32E.
T.5S.
T.6S.
T.7S.
T.8S.
T.9S.
N

SAFFORD BASIN, GRAHAM COUNTY

By J. H. Feth

Introduction

The Safford basin lies entirely within Graham County (pl. 5). The report is largely concerned with the Safford Valley which is bounded by the Gila Mountains to the north, the Peloncillo Mountains to the east, and the Pinaleno and Santa Teresa Mountains to the southwest. An arbitrary line between Townships 9 and 10 South is the southern boundary and separates the Safford basin from the San Simon basin. At the northwest, the boundary is an arbitrary line at right angles to the Gila River, about 5 miles downstream from Geronimo. The basin is thus approximately 50 miles long and 15 to 20 miles wide. Most of the cultivated lands are within the inner valley, a strip along the river ranging from half a mile to about $3\frac{1}{2}$ miles in width. The Safford basin, as here defined, includes most of the Cactus Flat-Artesia area, an area of about 15 square miles in Tps. 8 and 9 S., Rs. 25 and 26 E. The Safford basin is drained by the Gila River and tributary washes.

Investigation of the geology and water resources of the Safford basin was made principally in 1939-41 and 1943-44. The Cactus Flat-Artesia basin received additional study in 1946. Reports of these investigations comprise the main body of information used in preparing the present discussion. Since 1940, the Geological Survey has maintained an annual inventory of pumpage and a program of water-level measurements in observation wells in Safford basin. Preliminary results of a re-inventory in 1952 of irrigation wells are incorporated in the present report.

Geology

Mountainous areas enclosing Safford basin on the north and east consist of volcanic rocks (pl. 5). The Pinaleno and Santa Teresa Mountains are composed of crystalline and metamorphic rocks, except for a small area of volcanic rocks in Tps. 5 and 6 S., R. 21 E., at the western corner of the region.

The Gila River flows through a northwest-trending structural trough depressed relative to the mountains on either side. That part of San Simon Creek and Stockton Wash in the southeastern part of the region lies at the extreme northwest end of the San Simon basin which is an extension of the structural trough. Details of geologic structure are imperfectly known because valley fill has masked the rock structures along the margins of the trough.

Logs of wells disclose the presence of a thick sequence of fine-grained sediments deposited during a time when lakes or playas existed in the Safford basin. The hard-rock sides of the basin, below present ground level, and the composition of the floor of the structural trough can only be inferred. The deepest well recorded in the Safford basin penetrated 3,767 feet without encountering bedrock. A log of the deep well and logs of other wells representative of those throughout the basin are reproduced in table 8. The logs show that in some parts of the basin there is not less than 3,500 feet of sediments, and that at least the upper 1,800 feet may be of lake or playa origin. The top of the lake-bed or playa sequence is found in most places along the inner valley at depths from 20 to 100 feet below the surface. The origin of the older alluvium and its relationship to the Recent alluvium is described in Part I of this volume under the title, "Regional geology." Water obtained by wells that penetrate aquifers in the older alluvium commonly is highly mineralized.

Data from all well logs that could be interpreted with reference to depth of Recent alluvium are shown in table 6. This table shows depth of Recent alluvium and the water level at the time the well was drilled. These tabulations indicate that the Recent alluvium ranges in thickness from 20 to 100 feet and that rapid variations in thickness occur from place to place within the inner valley. Comparison of the logs of wells (D-6-24)10bdc and (D-6-24)10cdb, less than a quarter of a mile apart, shows that in the one the water-bearing gravel is at least 52 feet thick and extends to a depth of 76 feet below land surface, and in the other, the gravel is 20 feet thick and is underlain by clay at a depth of only 52 feet.

Studies of the permeability of Recent alluvium in the Safford basin were made in 1939-41 (Turner and others, 1941) and 1943-44 (Gatewood and others, 1950). The mean of all determinations for coefficient of drainage--approximately equivalent to specific yield--made during the 1943-44 investigations, was 16 percent (Gatewood and others, 1950, p. 92).

Twenty-four determinations of coefficients of permeability of the Recent alluvium were made in connection with the study of the basin in 1939-41. The coefficients ranged from 15 to 12,000 gallons per day per square foot (Turner and others, 1941, table 22). The tabulations demonstrate a distinct zonation of permeability within the Recent alluvium. The low figures (15 to 644) were all determined for samples of surface soils to a depth of 7 feet below land surface. The high permeabilities (1,100 to12,000) were for samples taken at depths between 29 and 82 feet below land surface.

No determinations of permeability were made for materials of the older alluvium.

Ground-water hydrology

Source and movement

Source and movement of ground water are discussed in Part I of this report under the heading "Regional hydrology." Safford Valley differs from most other Arizona valleys because of the presence of a perennial stream, the Gila River, and because of the importance of mineralized springs and seepages in relation to the chemical quality of the water.

Recharge

The sources of ground-water recharge in the Safford basin include: (1) Seepage from the Gila River; (2) underflow; (3) seepage from canals and irrigated areas; (4) seepage from older alluvium; and (5) precipitation.

Table 6.--Depth from land surface to base of Recent alluvium and driller's report of depth to water at time of drilling, Safford basin, Graham County, Ariz.

Well no.	Depth of Recent alluvium	Depth to water	Well no.	Depth of Recent alluvium	Depth to water
(D-4-23)19bbb	64	38	(D-6-25)7aca	74	50
20bcb	42	26	7baa	78	55
33aaa	70	39	8caa	74	68
33abb	83	68	8cad	60	38
34ccb	103	62	8cbb	60	42
34cdd	121	65	8ddb	53	40
			16cca	47	27
(D-5-23)2dcb	60	25	18baa	60	Dry
12ac	50	16	18cab	51	16
13bcc	61	24	18dbc	42	10
19dcc	52	18	19bb	45	32
20bdc	52	31	19bbc	46	18
20ddb	56	41	19bbd#2	58	30
30acd	63	21	20bdE½	54	14
30cdc	64	45	20cac	40	17
31bdd	71	52	20cda	45	30
31bcd	77	46	20dcc	60	22
31dbd	70	54	20dcd	60	16
32aca	52	14	20ddc	55	18
36add	80	60	21a	56	36
			22bdd	70	30
(D-6-24)2abd	62	40	23ccb	77	62
2aca	62	40	25cda	43	22
2adc	60	30	25cdc	43	22
2bcc	46	17	25dcc	65	42
4ad	56	28	27ccd	60	17
4bbd	44	28	32cac	65	34
1bb	71	44	33aaa	72	20
4cca	58	30	33aad	40	26
5aac	62	40	33abd	50	32
9aba	50	18	33b	68	46
10bdc	76	11	35bcb	62	20
10cdb	38	22			
11ab	31	20	(D-7-25)1ccb	94	45
12a	40	21	1ccc	99	43
12adb	48	18	1cdc	85	44
12dab	40	7	2acb	81	62
13bac	33	21	2acc	75	48
13bda	42	27	2bdd	57	16
13bdd	53	33	2c	95	40
23 center NE	65	48	2cd	69	54
14bd	60	48	2dac	95	70
24dd	49	33	11aa	101	63

Table 6.--Depth from land surface to base of Recent alluvium and driller's report of depth to water at time of drilling.--continued

Well no.	Depth of Recent alluvium	Depth to water	Well no.	Depth of Recent alluvium	Depth to water
(D-7-25)11aa	111	52	17abc	92	32
11aab	110	41	17add	87	30
12adb	77	41	17bbc	79	36
12adb	72	39	18aac	75	45
12bad	88	50	18aab	87	34
12bbd	103	69	18abd	81	43
12bca	112	40	21baa	100	75
12cca	98	55	21daa	110	50
12cd	98	55	22cbb	103	36
12dcd	103	36	23aaa	82	48
			24aab	75	45
(D-7-26)6add	48	20	24aac	97	32
6add	38	10	25bad	80	25
7bdd	72	22			
7cad	80	44	(D-7-27)2aaa	52	10
7dbc	82	20	2cbb	70	7
7dbd	75	25	3add	54	16
8dcc	79	30	4dad	90	52
8ddd	75	23	7ddd	70	24
9cdc	83	70	8add	45	16
9cdd	84	36	16	94	47
13cdd	75	35	16aac	97	35
13dcd	75	35	16aac	70	44
13dda	71	35	16cab	97	58
14dcd	75	50	16ccd	72	61
14ddd	75	35	18	71	35
15bcc	80	53	18aad	69	18
15bcd	82	40	18cac	70	33
15caa	82	23	19cba	90	62
15daa	45	30	20	50	35
15dad	47	26	20aaa	104	76
15ddd	78	45	20aaa	109	70
16acc	82	34	20aac	100	76
16ccc	96	54	20aac	98	66
16ddc	99	53			

Gila River.--The generalization can be made that the river loses water in the upstream part of the valley and gains water in the downstream part. With the many variables involved, it is considered impossible to estimate quantitatively the recharge from the river. Infiltration from the river is a direct local source of recharge to aquifers in the Recent alluvium of the basin. Evidence of this recharge is the rapid rise of the water table in wells near the river following a rising stage of the river. The effect decreases progressively away from the river, and disappears at the margins of the inner valley (Turner and others, 1941, p. 14). This effect was not observed in wells outside the inner valley and it is therefore believed that recharge from the river does not directly reach aquifers in the older alluvium. It is well to emphasize that the valley fill contributes ground water to the surface flow of the Gila River. Conditions of recharge and discharge vary with such factors as changing stages of the river, the stage of the water table, the time of year, and the rate of pumping from wells.

Records (Water-Supply Paper 1149, 1951, p. 366) indicate that, for a period of 35 consecutive years, the average discharge of the Gila River near Solomon was about 360,000 acre-feet per year. This average includes water diverted in the Brown Canal above Safford, and represents surface water available at the head of Safford Valley. This inflow includes water from perennial streams such as San Francisco River and Eagle Creek, which join the Gila River above the gaging station.

Underflow.--Estimates of recharge by underflow have been made for a 12-month period ending October 1, 1940 (Turner and others, 1941, pp. 38-43). During that period it was estimated that about 9,000 acre-feet of water entered the valley as underflow.

Canals and irrigated areas.--Turner and others (1941, pp. 15,28,49) presented a tentative estimate that more than 50,000 acre-feet of water was returned to the aquifers by seepage from canals and irrigated lands in the 12-month period ending October 1, 1940. The estimate was based on measurements which indicated that about one-half of all surface water diverted and one-fourth of all ground water pumped for irrigation constituted recharge to the ground-water reservoir.

In recent years it is probable that more than one-fourth of the water pumped has been returned to the ground-water reservoir because of a change in manner of distributing the water from wells. In the period 1940-45 most of the water pumped passed a short distance through the farmers' ditches and onto the fields. In the periods 1946-48 and 1950-51 there was a shortage of surface water and, to reach the farms principally served by surface water, it became mecessary to pump water from wells into the canals and then divert the water at downstream points. Many wells were added to the small number that previously had pumped into canals, and consequently much more of the water from wells flowed for as much as several miles in canals. Therefore, a percentage of the original pump-water input that was lost in the canals must be added to the one-fourth of the pumped water that becomes recharge after reaching the farmers' ditches. Although no data are available to estimate this additional recharge, it could be assumed that between one-third and one-half of the pumped water carried in the canals, and then applied to lands, reaches the ground-water reservoir as recharge.

The pumped water and the surface water diverted in recent years had less sediment load than most of the surface water used in the period 1940-45. Consequently, it is possible that the infiltration and resultant recharge from these clearer waters is greater than formerly.

If the percentages given by Turner and others were used to compute the recharge from the ground and surface waters used for irrigation in 1951, the quantity would amount to about 45,000 acre-feet. However, with the increased recharge from pumped water and a probable increase from the clearer surface water, it is believed that the recharge from irrigation waters probably exceeded this quantity in 1951.

Older alluvium.--Discharge from springs and seeps from the older alluvium contribute recharge to the Recent alluvium. Areas of seepage from the older alluvium are concealed beneath the floor of the valley. Their existence is inferred because of observed changes in chemical quality of the water in the Recent alluvium where no other cause for the changes has been detected. The water emerging from the larger springs in the basin commonly is warm to hot and contains high concentrations of dissolved mineral content. It is believed that the water discharged from the springs and seeps rises to the surface along fractures in the older alluvium.

Precipitation.--Recharge from precipitation on older alluvium is probably negligible because the surface in many places is underlain by almost impermeable caliche. About one-third of the area of the valley consists of coarse materials of the Recent alluvium along the Gila River and its tributaries. Some recharge from direct precipitation occurs in this area, but the amount is believed to be small in the average year.

Discharge

Wells.--Hydrographs of wells and graphic representation of pumpage by years in the Safford basin are shown on figure 5. The total pumpage from deeper aquifers is not known quantitatively. The deeper aquifers--those lying below the Recent alluvium--are of little importance except in the Cactus Flat-Artesia area. The Recent alluvium in that area is very thin and provides sufficient water only for domestic or stock use. In most of the Safford Valley water from aquifers in the older alluvium or in the lake beds is normally so highly mineralized as to be injurious to farmlands (Hem, 1950, p. 54).

The gross annual pumpage is represented on the graph (fig. 5) for the years of record, 1942-51, inclusive. Data compiled for the President's Water Resources Policy Commission (U. S. Geological Survey, 1950, unpublished records) indicate that, in 1949, 47,000 acre-feet of ground water was pumped in the Safford basin for irrigation, 200 acre-feet for industrial use, and 100 acre-feet for municipal use. No data are available to indicate pumpage by seasons or for individual wells.

Table 7.--Specific capacities of wells in Safford basin, Graham County, Ariz., 1952.

Well no.	Static water level 1952* (feet)	Pumping level (feet)	Drawdown (feet)	Discharge (gallons per minute)	Specific capacity (gpm per foot of drawdown)
(D-4-23)29dbd	55	67	12	400	35
29db	55	65	10	250	25
(D-6-24)12dab	10	21	11	350	30
(D-7-25)2adc	45	60	15	1,000	65
(D-7-26)8daa	30	35	5	1,075	215
8dab	30	37	7	1,000	140
9cdc	30	37	7	850	120
13dcd	35	53	18	2,200	120
13dcd	35	49	14	2,050	145
15bcc	40	55	15	1,350	90
16cac	50	68	18	875	50
24baa	35	53	18	475	25
28acc	50	82	32	350	10
(D-7-27)1bba	20	74	54	1,050	20
1bbb	20	71	51	1,000	20
2add	20	110	91	1,025	10
4dad	15	49	34	925	25
11bbb	Flowing	85	85	1,850	20

* Adjusted from spring high measurements where June-July 1952 measurements were not made.

The Mack hot well, (D-6-24)13ab, is the largest of the flowing wells in the basin, and yields about 1,500 gallons per minute or about 2,500 acre-feet per year. Other flowing wells in the Safford Valley produce much less. In the Cactus Flat-Artesia area the flowing wells produce from less than 1 gallon per minute to about 90 gallons per minute. Most of the wells in the area discharge into surface tanks or reservoirs, and the discharge for a period of several days to several weeks is then used from the reservoir for irrigation.

A re-inventory of irrigation wells in the Safford basin was made in 1952, and 44 well-discharge measurements were made. These discharges ranged from about 250 to about 2,200 gallons per minute, with the mean in the order of 1,000 gallons per minute. In some wells both the static level and the pumping level were determined. For 18 wells, (table 7) the range in specific capacity was from 10 to 215 gallons per minute per foot of drawdown. The mean specific capacity was 65. Data are insufficient to determine whether yields of wells in the Safford basin have diminished over the period of record, 1940-52.

Natural discharge.--Natural discharge may conveniently be considered under the following topics: (1) Evapotranspiration; (2) surface flow; and (3) underflow.

One of the most extensive investigations of evapotranspirative use of water yet made in the United States was made in the Safford basin. In 1943-44 the Geological Survey, in cooperation with the Defense Plant Corporation and the Phelps-Dodge Corp., attempted to determine the amount of water used in the bottom lands of the Gila River by natural growth dependent upon shallow ground water. The data obtained were published (Gatewood and others, 1950) and constitute an important base upon which some of the estimates in the present report are founded.

Six methods were used in attempting to determine how much ground water was consumed annually by nonbeneficial vegetation growing on 9,300 acres in the bottom lands of the Gila River near Safford. The various methods employed in making determinations produced results that were consistent within a margin of 20 percent. The mean figures indicate (Gatewood and others, 1950, table 58, p. 194) that during the year ending September 30, 1944, in a 46-mile reach of the Gila River extending from Thatcher to Calva, 23,000 acre-feet of ground water was used by the bottom-land vegetation. An additional 5,000 acre-feet of direct precipitation was also utilized, to make a total of 28,000 acre-feet of water used by nonbeneficial vegetation. Saltcedar used more than 75 percent of the 23,000 acre-feet. These data apply to a reach of the Gila River that does not exactly coincide with the limits of the Safford basin as defined in this report. It is estimated that total evapotranspiration losses in the inner valley are of the order of 50,000-60,000 acre-feet per year. No important new methods of eradicating undesirable vegetation were developed during the study, nor were older methods evaluated.

No direct measurement of surface flow out of the Safford basin, as defined, has been made. The nearest gage is at Calva, Ariz., about 18 miles downstream from the northwest boundary. Records for the Calva gage for the

20-year period ending in 1949 (Water-Supply Paper 1149, 1951, p. 370) show an average discharge of 293 second-feet, or about 200,000 acre-feet per year. It is believed that this figure is in the order of magnitude of surface flow out of the Safford basin, as defined.

Underflow from the inner valley at Calva was reported (Turner and others, 1946, p.8) to be about 2 second-feet, or about 1,500 acre-feet, during the 12 months ending October 1, 1940. No recent data have been obtained. This figure probably represents the order of magnitude of underflow from the Safford basin, as defined.

Storage

As a basis for estimating underlying storage in the Recent alluvium in the irrigated parts of Safford basin, records of several hundred wells were examined. A total of 151 well records provided what was considered to be reliable data on thickness of saturated alluvium, and these data are given in table 6. The base of Recent alluvium was determined from the logs as the depth at which the driller reported encountering either clay at the bottom of the hole or an appreciable thickness of clay with no indication that materials below the clay could reasonably be considered part of the Recent alluvium. It was believed justifiable to use the water levels reported at the date of drilling, as water-level measurements in Safford basin from 1940 to 1952 show no large permanent declines. Unusually high or low individual water levels, caused by abnormal conditions at the time of drilling, are believed to be compensated for by data from nearby wells.

Data from table 6 were used to prepare a map (pl. 7) showing lines of equal thickness of saturated Recent alluvium. These lines are called "iso-sats" in this report.

The walls of the inner valley are believed to be steep because the 20-foot iso-sat closely parallels the edges of the inner valley. It is unlikely that much water is stored in Recent alluvium outside the 20-foot iso-sat. The areas included in each range of thickness were planimetered. Computations, based on these data and a coefficient of drainage of 16 percent (Gatewood and others, 1950, p. 92), are shown in tabular form on plate 7. These computations indicate that about 300,000 acre-feet of ground water is in underlying storage in the Recent alluvium in the Safford basin. This figure compares with an estimated 500,000 acre-feet in storage in 1940 (Turner and others, 1941, p. 92), at a time when ground-water levels were higher than normal.

Data do not exist that would permit estimating ground-water storage in the older alluvium.

Changes in ground-water storage.--Hydrographs of observation wells in the basin are presented in figure 5 with a graphic summary of water pumped in each of the years of record, 1942-51. The areas irrigated and locations of irrigation wells in the basin are shown on plate 6. A water-table map was not prepared for the present report because such a map would reflect only a transient condition. Hydrographs shown in figure 5 of this report show the rapidity with which the water table fluctuates in the Safford basin. The report by Gatewood and others (1950, pl. 4) also illustrates substantial changes in the position of the water table in a 6-month period.

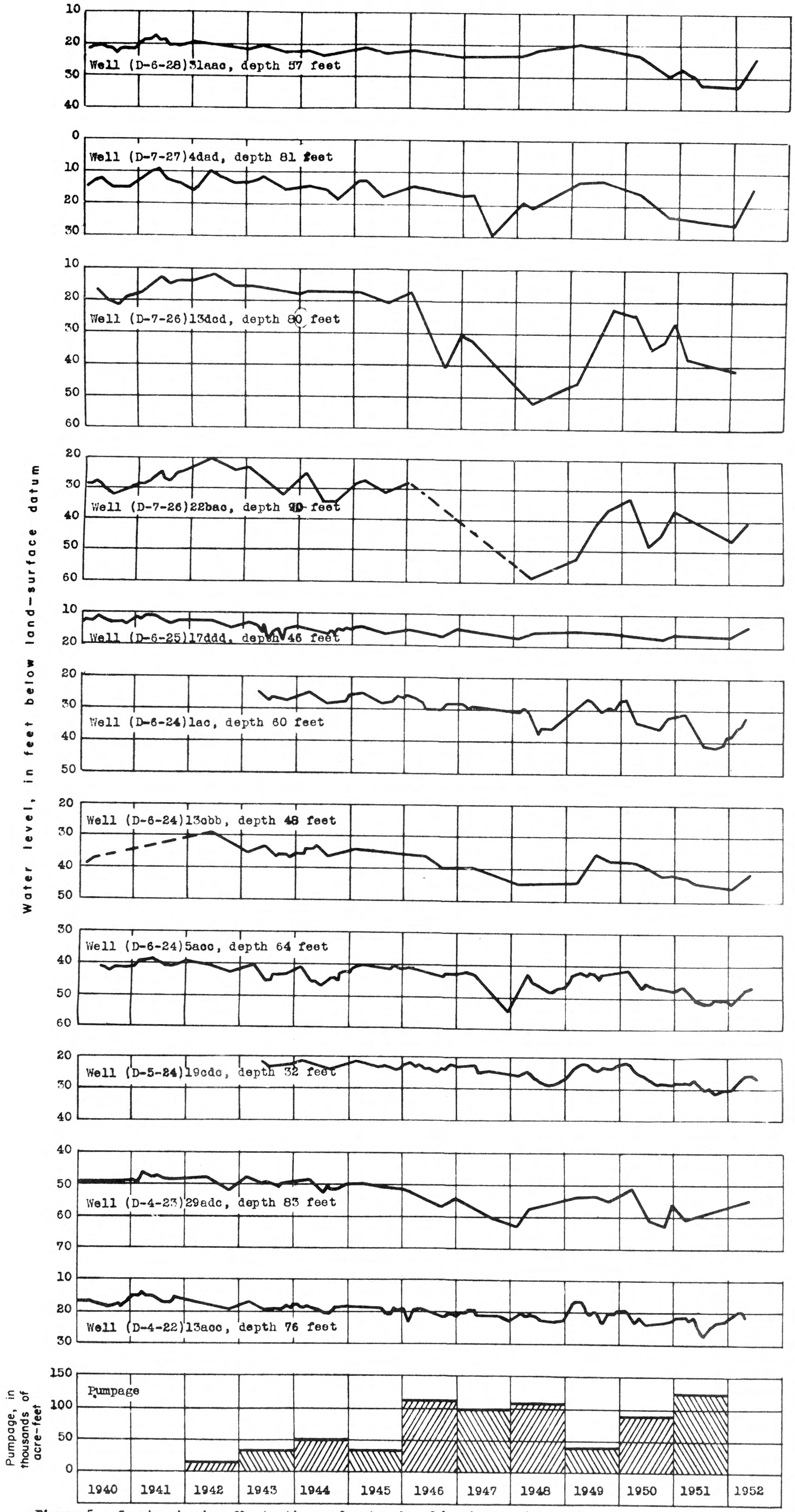


Figure 5.--Graphs showing fluctuations of water level in observation wells and pumpage in Safford Valley, Graham County.

Well interference

Information regarding well interference and the spread of cones of depression is available only in the Cactus Flat-Artesia area. In this area the influence of nearby pumping is reflected in diminished flow or cessation of flow in artesian wells. The maximum distance to which the reduction in pressure head extended is not known. Halpenny and Cushman (1947, p. 6) also report the case of a well that flowed until three others were drilled about 400 feet away. Orifices of the three newer wells were at a lower elevation than that of the older well. In time, flow from the three wells so reduced pressure head that the older well ceased to flow, and the water level in that well declined until it stood about at the elevation of the orifices of the wells 400 feet distant.

Relation between artesian and nonartesian water levels

The presence of artesian aquifers in the older alluvium and of nonartesian aquifers in the Recent alluvium creates a situation in which wells drilled to different depths, but at nearly the same surface location, may show marked differences in water levels. Comparison of two wells in the same quarter-section, (D-6-24)13ab and (D-6-24)13ac, shows that the deep well, penetrating the artesian aquifers, flows whereas the shallow well has a static water level about 25 feet below the land surface.

Quality of water

The chemical quality of waters in the Safford basin constitutes one of the major problems of water supply in the region. More than 4,000 water samples from the Safford Valley have been analyzed by the Quality of Water Branch. Interpretations of analyses and a tabulation of about 4,000 analyses are given in a paper by Hem (1950). Most of the waters analyzed were collected in the Safford basin, but the paper includes analyses of waters from the Duncan-Virden Valley and part of the San Simon basin. Individual wells have been sampled periodically in 1940, 1943, 1944, and 1952 (Hem, 1950, p. 176-77, and unpublished data, U. S. Geol. Survey files). Waters from the older alluvium show no appreciable changes in chemical quality between 1940 and 1952, but shallow wells obtaining water from the Recent alluvium show large and rapid changes in quality of water from time to time. Hem (1950, p. 49) reports one well in which the concentration of dissolved solids changed by 50 percent in a few months. Plate 4 indicates the wide range of chemical quality of ground waters in the basin.

Changes in chemical quality of water from aquifers near the river in the Recent alluvium occur mainly in response to fluctuations in the stages of the Gila River. A high stage in the river will, as earlier noted, provide rapid local recharge to the Recent alluvium. The surface flow of the river consists normally of water of relatively low mineralization; water of low mineral content is introduced into the Recent alluvium, mixes with the water already present, and thus serves to reduce the mineralization. When the river stage declines, recharge of the Recent alluvium occurs largely by infiltration from canals and irrigated fields, and seepage from the older alluvium. Water from these sources is higher in mineral content. Therefore, the water in the Recent alluvium near the river becomes more and more concentrated during low river stages.

Occurrence of areas of ground water of higher mineral content is thought to depend on several factors: (1) Localization of upward seepage from the older alluvium in zones of fracture, presumably along faults; (2) concentration of return flow from canals and irrigated lands; (3) inflow from mineralized springs; and (4) underflow from tributaries yielding mineralized water, notably, Stockton Wash.

The graphs of the chemical character of waters in Safford basin (pl. 4), indicate that the percentage of sodium, and the high total mineralization make the waters in some areas unsatisfactory for irrigation. Waters from the older alluvium are almost uniformly undesirable for irrigation as the percentage of sodium is sufficient to cause flocculation of soil particles if the waters are used without dilution on farmlands. Water high in sodium and bicarbonate tends to deposit "black alkali" on or under the land surface when the water evaporates or is transpired.

The quality of water in the Recent alluvium is affected by inflow from springs upstream from Safford basin. Two areas yielding water of high mineral content exist, one on the San Francisco River at Clifton, and the other, Gillard Hot Springs, in the channel of the Gila River downstream from its confluence with the San Francisco River. The flow from the hot springs at Clifton has been estimated as about 2.5 second-feet, about 1,900 acre-feet per year. Analyses show (Hem, 1950, pp. 82-83) that water from these springs contains more than 2,000 parts per million of sodium and potassium combined, and more than 5,000 parts per million of chloride. The Gillard Hot Springs produce an estimated 400 gallons per minute, or about 700 acre-feet per year. The dissolved-solids content is about 1,200 parts per million, of which sodium and chloride are the principal constituents. The high temperature, 181° F., indicates that the water ascends from considerable depth, probably along a fault zone.

In some localities, waters in the Safford Valley contain from 1 to 5 parts per million of boron. These concentrations might prove injurious to some plants if application of such waters were continued over a period of years. Although citrus, the crop most sensitive to boron, is not raised in the valley, there are pecan groves and peach orchards, and the fruits of these trees are affected by boron.

Analyses of waters used for public supplies in the Safford basin show (Hem, 1950, pp. 226-227) that, in general, the fluoride content is within the range of acceptability. One source of public supply, for the town of Pima, contained 2 parts per million fluoride when sampled in 1943--a concentration sufficient to cause slight mottling of tooth enamel in some children. One well sampled in Safford showed 47 parts per million of nitrate. There is some evidence to show that methemoglobinemia (a "blue-baby" disease) may be caused by nitrate (as NO_3) in concentrations higher than about 45 parts per million if the water is used in preparing formulas for infant feeding. (Comly, 1945, p. 112).

Hem (1950, pp. 67-68) points out that during the period, October 1, 1943, to September 30, 1944, Gila River in Safford Valley carried about 84,100 tons of dissolved salts into the basin past the Solomon gage, and about 105,000 tons out of the basin past the Calva gage. Hem states:

> The simplest interpretation of the gain in salt load of Gila River as it passes through Safford Valley would be that a favorable drainage condition exists, with excess soluble salts being removed from the soil and carried off in drainage waters. However, the significance of the observed gain in load of Gila River in Safford Valley cannot be interpreted so simply. Unknown and probably large quantities of soluble matter are added to the Calva load by surface flow entering the river.... Inflows of artesian water which occur in the lower part of the valley contribute large amounts of soluble salts to the area .... probably sufficient to equal or exceed the observed gain in load of the river from the head of the valley to Calva .... Although it is probable that drainage conditions are generally favorable in much of Safford Valley, the observed gain in load of soluble matter of the river should not be taken to indicate that soluble salts are not accumulating in any of the irrigated soils of the valley.
>
> .... In considering the 'salt balance' for the valley, the situation is further complicated because of the increasing use of ground water for irrigation. If the ground water pumped in 1944 had an average concentration of about 2 tons per acre-foot .... total pumpage of about 52,000 acre-feet in the valley that year would have contained 104,000 tons of dissolved salts, a quantity practically equal to the 105,000 tons of dissolved matter that left the valley in the river at Bylas during the year. If the productiveness of the lands of Safford Valley is to be maintained, the salt left by evaporation and transpiration of the irrigation water must be disposed of in some way.... unless the future annual gain in salt load of the Gila River between the Solomonsville and Calva gaging stations averages several times as much as that for the year ended September 30, 1944, it would seem that significant quantities of soluble salts are accumulating in the soil and shallow ground waters of the Safford Valley, particularly in the lower part of the valley.

Assuming a concentration of 2 tons of dissolved mineral matter per acre-foot of ground water, the 125,000 acre-feet withdrawn for irrigation in 1951 contained approximately 250,000 tons of salts.

Ground-water--surface-water interrelationships

In 1899, Safford basin had about 20,000 acres under cultivation, watered by diversion from 28 canals (Newell, 1901, pp. 341-347). Newell describes the use of water in the basin at that time:

> (The Gila River) passes alternately through narrow canyons and out upon valleys where its waters are diverted for irrigation. The development of agriculture by this means has been so extensive that all of the available summer flow is used, and there is need of additional water to bring extensive tracts of fertile land under cultivation.

By 1935, the area under cultivation had increased to 32,000 acres. Increased diversions upstream and increased demands downstream brought the problem of the allocation of surface water before the United States District Court. Since 1935, allocations of surface water of the Gila River, from the Virden Valley in New Mexico to the San Carlos Irrigation District near Florence, have been made annually by a water commissioner appointed by the Court.

Allocation of surface water under the Court decree has resulted in development of ground water as a supplemental supply. Pumping of wells for irrigation began on an appreciable scale about 1938. By the end of 1940 (Gatewood and others, 1950, p. 8) about 150 irrigation wells had been drilled, of which 120 were in use. By the fall of 1944, there were about 260 irrigation wells, of which 215 were being pumped. The re-inventory of irrigation wells in Safford basin, June and July 1952, located 680 wells of which 581 (pl. 6) were equipped for use. The increase in the number of wells in use is attributed to a deficiency of surface water during most of the years since 1944. Increased withdrawals from underlying storage resulted in a declining water table. This decline caused well yields to decrease which, in turn, led to drilling additional wells to supply the demand for water.

The following table shows that the quantity of ground water withdrawn each year is closely related to the quantity of surface water available, and that the total quantity used for irrigation does not change greatly from one year to another.

Year	Pumped Water (acre-feet)	Surface Water (acre-feet)	Total (acre-feet)
1940	24,600	99,693	124,293
1941	8,685	151,300	159,985
1942	18,900	172,005	190,905
1943	35,000	121,569	156,569
1944	52,000	128,027	180,027
1945	35,000	148,675	183,675
1946	115,000	69,909	184,909
1947	100,000	51,978	151,978
1948	110,000	39,848	149,848
1949	40,000	167,790	207,790
1950	90,000	68,504	158,504
1951	125,000	26,389	151,389

Other aspects of the interrelationship between ground water and surface water have been discussed under the topics of recharge and storage.

Problems

Hydrologic conditions in the Safford basin today are the result of the imposition of a sequence of developments upon a virgin valley. Where formerly a natural hydrologic balance existed, man imposed cultivation and irrigation by diverting surface water from the Gila River. By disturbing the natural vegetation and introducing new plants to the area, he contributed to the spread of phreatophytes. As the supply of river water became inadequate, men began to pump ground water, further disturbing the balance between surface and ground water. Climatic changes have also affected the hydrologic balance in the basin. All these modifications are magnified in their effect by such factors as the narrowness of the inner valley and the high permeability of the Recent alluvium. These developments have resulted in specific problems whose solution will require further study.

Need for additional studies

Problems of interrelationships of surface water and ground water.--In order fully to evaluate the effect of withdrawals of ground water on flow of the Gila River and the effect of river flow on the stage of the water table, continuing observations of water-level fluctuations should be made in greater detail than during the period 1944-52. These observations should be supplemented by additional stream-discharge measurements at intermediate points in the basin, and by additional quality-of-water studies.

Salt problems.--The "salt balance" problem has been mentioned in this chapter under "Quality of water". In addition, the Clifton Hot Springs, the Gillard Hot Springs, the Indian Hot Springs at Eden, and others of smaller discharge, combine to introduce a large, although undetermined, quantity of salt into the water supply of the basin. Water from the deeper aquifers is another large source of salt.

It is possible that methods could be developed to divert some or all of the spring waters at their sources and prevent this salt load from entering the basin. Hem calculated (1950, p. 34; letter, August 14, 1952) that under varying conditions of discharge the Clifton Hot Springs produce about 9,000 to 25,000 tons of salt per year. These calculations were based on 38 samples taken at intervals between 1940 and 1950. As the discharge of the springs is only about 2 second-feet, or about 1,500 acre-feet per year, the elimination of the salt by disposing of the water would far outweigh the loss of water involved.

Methods of increasing or conserving water

Eradication of nonbeneficial phreatophytes.--Gatewood and others (1950, p. 194) state that 9,300 acres of the phreatophytes in the basin use about 28,000 acre-feet of ground water per year. No satisfactory method of eradication has been found to date. A solution of this problem and of the corollary problem of replacement by vegetation of economic value is desireable. The effects of such changes on the discharge of the Gila River, the quality of the ground water, and the stages of the water table will require hydrologic investigations.

Summary

The Safford Valley lies along the main stem of the Gila River in Graham County. Mountains enclose the valley on the northeast and southwest. The southern and western boundaries are arbitrary. The valley, as defined, is about 50 miles long and 15 to 20 miles wide. Cultivated lands are confined to the inner valley and to Cactus Flat-Artesia area near Stockton Wash.

The principal aquifer of the basin is Recent alluvium which, in normal years, contains about 300,000 acre-feet of water in underlying storage. Recharge is derived from: (1) The Gila River; (2) underflow; (3) infiltration of irrigation water; (4) seepage from older alluvium; and (5) infiltration from precipitation.

Natural discharge of ground water from the basin occurs as: (1) Effluent seepage; (2) underflow; (3) evaporation from water surfaces and wetted lands; and (4) transpiration by natural vegetation. Investigations showed that 9,300 acres of bottom-land vegetation in a part of the valley caused nonbeneficial use of about 28,000 acre-feet of water per year. Based on this it is estimated that the total nonbeneficial use of water by all of the bottom-land vegetation in the valley may be between 50,000 - 60,000 acre-feet per year. The quantity of ground water withdrawn each year is closely related to the quantity of surface water available; the total quantity used for irrigation does not change greatly from one year to another. In 1951 about 125,000 acre-feet of ground water was pumped for irrigation.

Some deep wells obtain water from aquifers in older alluvium where the water is commonly highly mineralized and under artesian pressure. In the Cactus Flat-Artesia area, almost all ground water used for irrigation comes from the artesian aquifers in the older alluvium.

Water supplies of acceptable chemical character for domestic consumption can be obtained in the basin. Waters from the Recent alluvium are low in dissolved solids in some localities, and high in others. Waters from aquifers in the older alluvium are not of uniform chemical character, but are commonly so highly mineralized as to be undesireable for irrigation unless diluted. Assuming a concentration of 2 tons of dissolved mineral matter per acre-foot of ground water, the 125,000 acre-feet withdrawn for irrigation in 1951 contained approximately 250,000 tons of salts.

The ground-water reservoir of the inner valley is small in comparison with the quantity annually withdrawn for irrigation. Owing to the relatively high permeability of the Recent alluvium, effects of changes in recharge and discharge are rapid. Consequently, the water table fluctuates widely.

Turner and others (1946, p. 16) summarize ground-water—surface-water relationships in the basin as follows:

> Because of the intimate relation between the water in the ground in this basin and the water flowing in the Gila River, the regulation of withdrawal of ground water will be affected by the legal rights to the use of the river waters.

Therefore, in arriving at a determination of the principles that are to serve as a basis for regulation of ground-water withdrawals, careful consideration must be given to the interrelation of water from the two sources. To illustrate the intricacy of the problems involved, waters of the following four types or sources are cited:

1. Ground water derived by recharge from appropriated surface water, such as seepage from canals and from the irrigated lands. If this ground water is not intercepted by pumping, a part of it will be lost by evaporation and transpiration, but the remainder will eventually re-enter the river downstream and there become available for diversion. However, in many places it might be practicable to intercept this water partially by means of wells or to reduce the losses by lining the canals, thus in effect cutting off the source of some of the flow in the river channel downstream.

2. Ground water derived from recharge by tributary-wash inflow and from natural recharge on outcrop areas. If this ground water is intercepted before it reaches the river, the flow of the river will thereby be decreased even though such interception would tend to reduce losses by evaporation and transpiration. Diversion of such ground water might be made by wells near the source.

3. Ground water saved by destruction of natural river-bottom growth or by reduction of evaporation and transpiration through a lowering of the water table caused by pumping. Except for that in areas covered with river-bottom growth, there is only a small amount of additional cultivable land. The ground water saved by clearing such land would be available for use either by additional water-well developments on the land or by allowing it to return to the river for later diversion. Some ground water which would otherwise be lost by evaporation and transpiration could doubtless be saved through lowering the water table by pumping from wells.

4. Surface water that must now be allowed to move downstream in the Gila River to meet prior claims. Much of this water is used en route by phreatophytes or lost through evaporation. Removal of river-bottom growth would save some of this water for beneficial use.

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3. Ground water saved by destruction of natural river-bottom growth or by reduction of evaporation and transpiration through a lowering of the water table caused by pumping. Except for limited areas covered with river-bottom growth, there is only a small amount of additional cultivable land. The ground water saved by clearing such land would be available for use either by additional water-well developments on the land or by allowing it to return to the river for later diversion. Some ground water which would otherwise be lost by evaporation and transpiration would doubtless be saved through lowering the water table by pumping from wells.

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Table 8.--Logs of representative wells in Safford basin, Graham County, Ariz.

	Thickness (feet)	Depth (feet)
(D-4-22)12dbc		
Topsoil - - - - - - - - -	20	20
Rocks and sand - - - -	10	30
Water-bearing gravel -	20	50
Boulders and rocks - -	25	75
Clay - - - - - - - - -	5	80
TOTAL DEPTH		80
(D-4-22)25bcc		
Surface soil - - - - -	27	27
Sand and silt - - - - -	21	48
Water gravel and sand -	45	93
Solid rock - - - - - -	....	93
TOTAL DEPTH		93
(D-4-22)26add		
Dry sand, surface soil	11	11
Fill - - - - - - - - - -	16	27
Sand and fill with some water - - - - - - - -	21	48
Good water gravel and sand - - - - - - - - -	35	83
Bed rock - - - - - - - -	....	83
TOTAL DEPTH		83
(D-4-23)19bb		
Surface sand - - - - -	36	36
Sand - gravel, dry - -	2	38
Water sand and gravel -	26	64
Red clay - - - - - - - -	4	68
TOTAL DEPTH		68
(D-4-23)34ccb		
Gravel - - - - - - - - -	30	30
Clay - - - - - - - - - -	18	48
Gravel - - - - - - - - -	17	65
Clay - - - - - - - - - -	30	95
Sand - - - - - - - - - -	8	103
Clay - - - - - - - - - -	11	114
TOTAL DEPTH		114
(D-5-21)27		
Sandy loam - - - - - -	16	16
Dry gravel - - - - - -	8	24

	Thickness (feet)	Depth (feet)
Hard pan - - - - - - - - -	2	26
Gravel - - - - - - - - - -	35	61
Hard pan - - - - - - - - -	1	62
Gravel - - - - - - - - - -	6	68
Redrock - - - - - - - - - -	2	70
TOTAL DEPTH		70
(D-5-23)2dbb		
Topsoil - - - - - - - - - -	40	40
Gravel - - - - - - - - - -	10	50
TOTAL DEPTH		50
(D-5-23)13bcc		
Terrace material - - - -	40	40
Water gravel - - - - - -	6	46
Clay sand fill - - - - -	1	47
Water gravel (rocks) - -	11	58
Clay fill - - - - - - - -	1	59
Water gravel - - - - - -	2	61
Clay - - - - - - - - - - -	5	66
TOTAL DEPTH		66
(D-5-23)36add		
Topsoil and fill - - - -	56	56
White clay - - - - - - - -	9	65
Sand and pea-gravel - - -	15	80
Red clay - - - - - - - - -	8	88
TOTAL DEPTH		88
(D-5-24)19dcc		
Topsoil - - - - - - - - - -	18	18
Water gravel and sand - -	34	52
Red clay - - - - - - - - -	8	60
TOTAL DEPTH		60
(D-5-24)26d		
Conglomerate, brown, medium-hard - - - - - -	20	20
Clay, red, soft - - - - -	143	163
Sand and gravel, small water - - - - - - - - -	4	167
Clay, gray, soft - - - -	76	243
Sand, gravel, water - - -	14	257
TOTAL DEPTH		257

Table 8.--Logs of representative wells in Safford basin--continued

	Thickness (feet)	Depth (feet)
(D-5-24)30acd		
Topsoil	26	26
Sand	4	30
Rock and gravel	25	55
Clay	7	62
Trace of gravel bearing water	1	63
Clay	7	70
TOTAL DEPTH		70
(D-6-24)2abd		
Dry clay, sand, gravel	38	38
Water-bearing gravel	24	62
Clay	6	68
TOTAL DEPTH		68
(D-6-24)4bbd		
Clay soil	28	28
Sand and gravel	10	38
Water gravel	6	44
Clay	10	54
TOTAL DEPTH		54
(D-6-24)10bdc		
Unknown (old dug well)	24	24
Water gravel	52	76
Clay	2	78
TOTAL DEPTH		78
(D-6-24)10cdb		
Silt	18	18
Gravel	20	38
Clay	12	50
TOTAL DEPTH		50

	Thickness (feet)	Depth (feet)
(D-6-24)13ab		
(Mary Mack flowing well)		
Sandy loam	3	3
Sand	17	20
Gravel; water	160	180
Shale, sand, sandstone, gravel, vari-colored, streaks of gypsum; water encountered at 1,645 ft., 2,143 ft., 2,318 ft., 3,140 ft.	3,360	3,540
Red sandstone	180	3,720
Red sandy shale	14	3,734
Gypsum	4	3,738
Red sandstone	29	3,767
TOTAL DEPTH		3,767
(D-6-25)7aca		
Boulders	36	36
Sandy soil	10	46
Water gravel	14	60
Clay	10	70
Water gravel	4	74
Clay	41	115
TOTAL DEPTH		115
(D-6-25)18baa		
Topsoil	18	18
Sand and gravel	12	30
Sandy soil	12	42
Dry sand and gravel	4	46
Coarse gravel	2	48
Quicksand	2	50
Limestone (hard pan)	6	56
Clay soil and gravel	4	60
Clay	2	62
TOTAL DEPTH		62

Table 8.--Logs of representative wells in Safford basin--continued

	Thickness (feet)	Depth (feet)
(D-6-25)20cda		
Topsoil	5	5
Sand, dry	17	22
Gravel	23	45
Red clay	12	57
Blue clay	3	60
Red clay	40	100
TOTAL DEPTH		100
(D-6-25)22bdd		
Rocks and gravel	8	8
Sand and gravel	12	20
Sandy soil	8	28
Quicksand	12	40
Clay	6	46
Water, gravel	2	48
Hard pan	2	50
Quicksand	6	56
Sand and gravel	7	63
Water, gravel	7	70
Clay	10	80
TOTAL DEPTH		80
(D-6-25)33abd		
Sandy soil	29	29
Water gravel	21	50
Clay	4	54
TOTAL DEPTH		54
(D-6-27)35ddd		
Gravel	15	15
Gravel and caliche alternating in 3-foot layers	235	250
TOTAL DEPTH		250
(D-7-25)1		
Fill	26	26
Dry gravel	27	53
Gravel (water)	25	78
Clay	6	84
TOTAL DEPTH		84
(D-7-25)12adb		
Surface soil	28	28
Dry sand and gravel	25	53
Water gravel and sand	24	77
Red clay	14	91
TOTAL DEPTH		91
(D-7-26)6add		
Sandy soil	7	7
Sand, gravel, boulders (water-bearing)	31	38
Blue clay	10	48
TOTAL DEPTH		48
(D-7-26)16ba (Southern Pacific RR., Safford, Ariz.)		
Soil	8	8
Gravel and boulders	82	90
Clay, blue and yellow, streaks of gypsum and of hard rock	805	895
Yellow and brown clay with streaks of gypsum	105	1,000
Salty clay	820	1,820
TOTAL DEPTH		1,820
(D-7-26)16ccc		
Topsoil	28	28
Dry sand, gravel, boulders	29	57
Brown clay	21	78
Quicksand	7	85
Gravel and boulders	11	96
Blue clay	44	140
TOTAL DEPTH		140

Table 8.--Logs of representative wells in Safford basin--continued

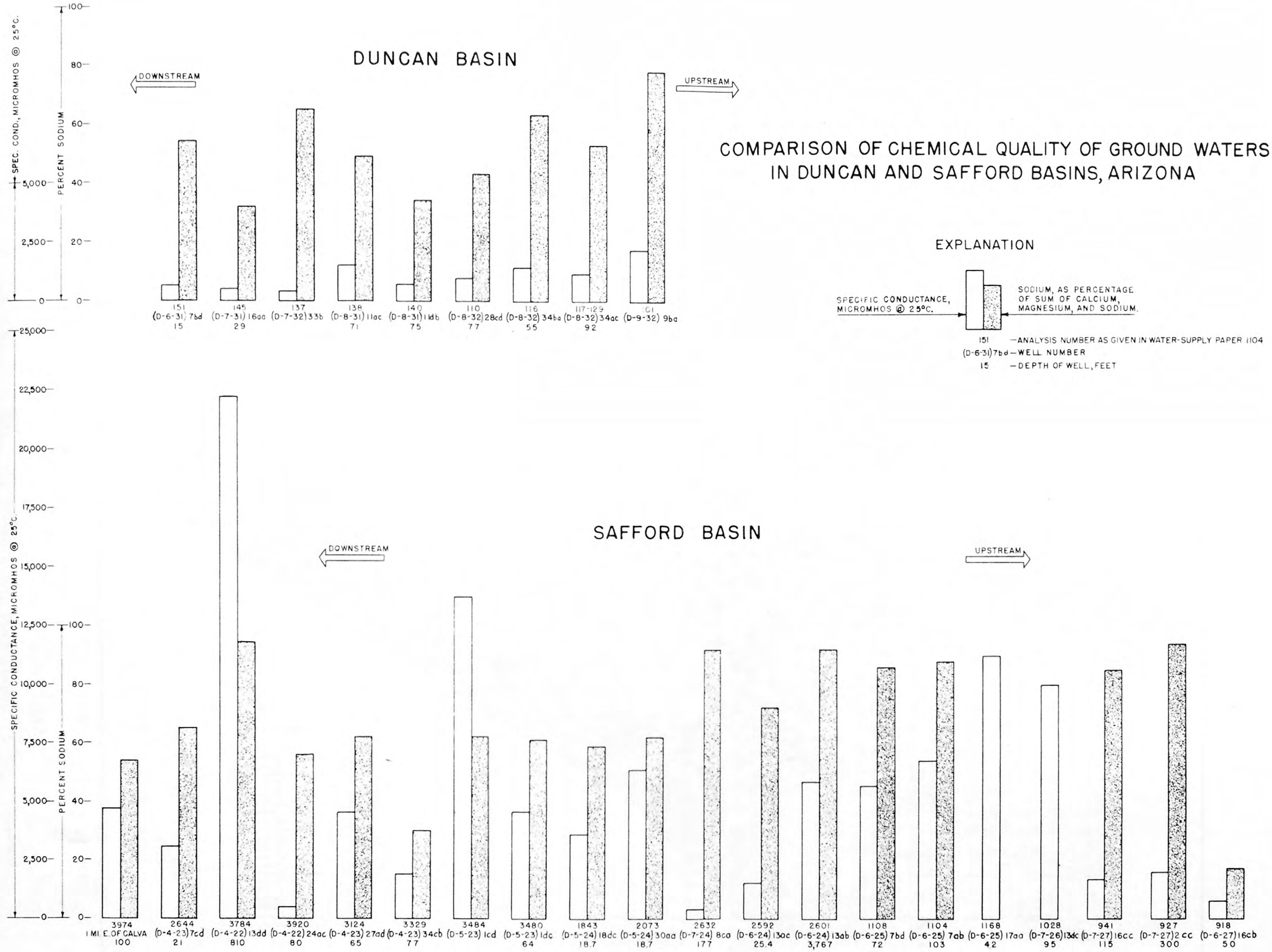
	Thickness (feet)	Depth (feet)
(D-7-26)24aac		
Clay	4	4
Dry boulders	26	30
Sand (water?)	8	38
Clay	2	40
Boulders and gravel	8	48
Clay	2	50
Sand and gravel (water)	20	70
Boulders	27	97
Blue clay	5	102
TOTAL DEPTH		102
(D-8-26)6abc		
Sandy loam	36	36
Sand	3	39
Sandy clay	51	90
Water gravel	5	95
Sandy clay	23	118
Water gravel	11	129
Sandy clay	4	133
Water gravel	5	138
Sandy clay	4	142
Water gravel	2	144
Sandy clay	26	170
Water sand	9	179
Sandy clay	9	188
Water sand	4	192
Sandy clay	14	206
Clay	4	210
Sand	4	214
Sandy clay	6	220
Clay	2	222
Clay	2	224
Sandy clay	10	234
Hard sand	1	235
Water sand and gravel	2	237
TOTAL DEPTH		237
(D-8-26)7ddb		
Topsoil	12	12
Quicksand	8	20
Blue clay with cavities	140	160
Gray clay	1	161
TOTAL DEPTH		161

	Thickness (feet)	Depth (feet)
(D-8-26)31ddc		
Sand	17	17
Sandstone	9	26
Sandy clay	3	29
Sandstone	7	36
Sandy clay	30	66
Water sand	2	68
Sandy clay	16	84
Red clay	24	108
Water gravel	2	110
Clay	5	115
Sandy clay	8	123
Sand	1	124
Clay	8	132
Sand	1	133
Clay	8	141
Sand	1	142
Clay	8	150
Sand	1	151
Clay	9	160
Sand	1	161
Sandy clay	14	175
Clay	34	209
Water sand	2	211
Clay	30	241
Hard sandy clay	9	250
TOTAL DEPTH		250
SUMMARY LOGS OF DEEP WELLS		
(Detailed logs in Knechtel, 1938, pp. 202-204)		
(D-9-27)36bd		
Southern Pacific RR, Tanque, Ariz.		
Hard pan	32	32
Gravel	6	38
Clay	52	90
Sand and gravel (water)	34	124
Clay, blue and yellow, thin beds sand and gravel	272	396
Sandstone	4	400
Blue clay	192	592
Gypsum and clay	143	735
Gypsum	30	765
TOTAL DEPTH		765

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PLATE 4

COMPARISON OF CHEMICAL QUALITY OF GROUND WATERS IN DUNCAN AND SAFFORD BASINS, ARIZONA



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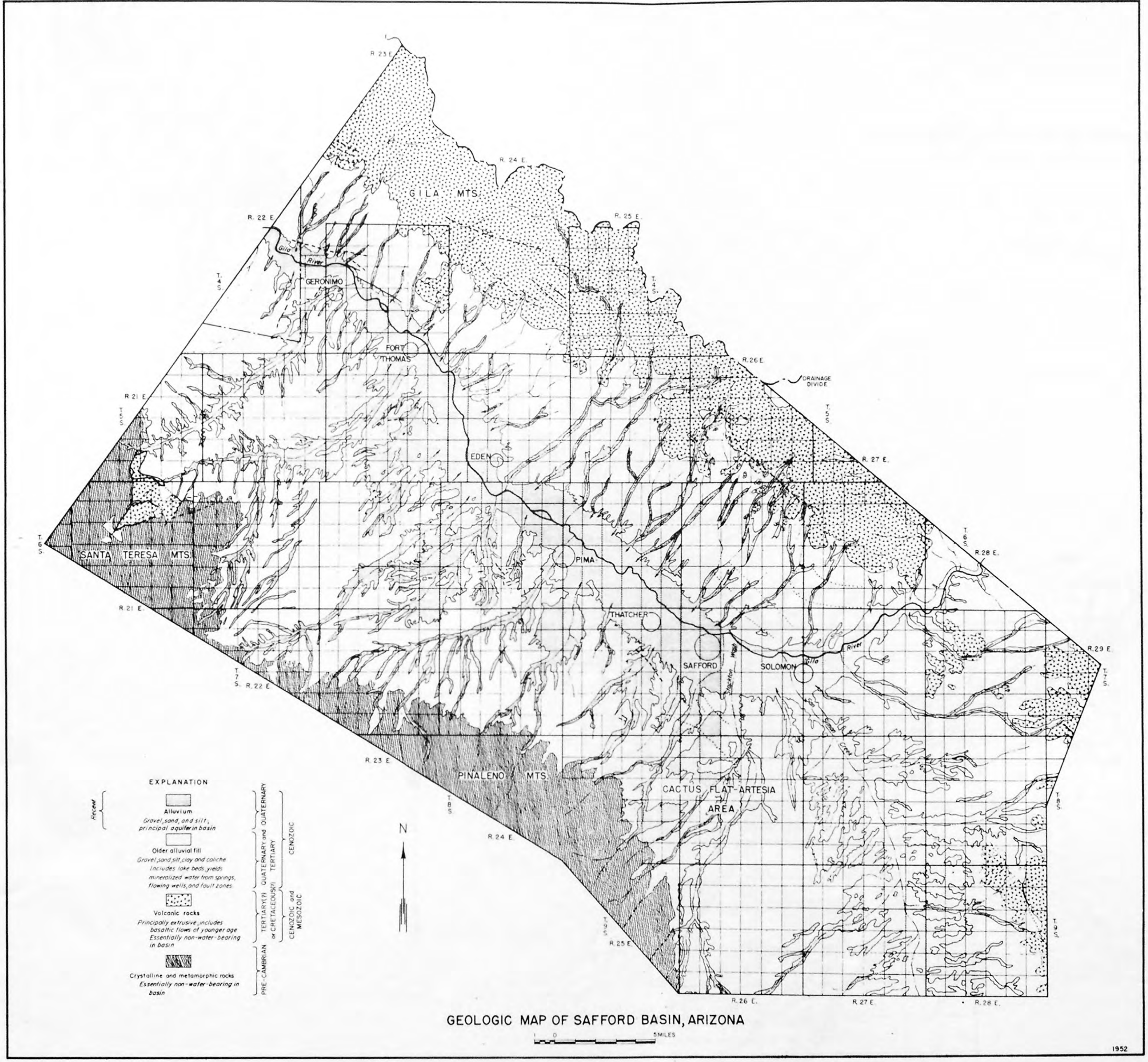
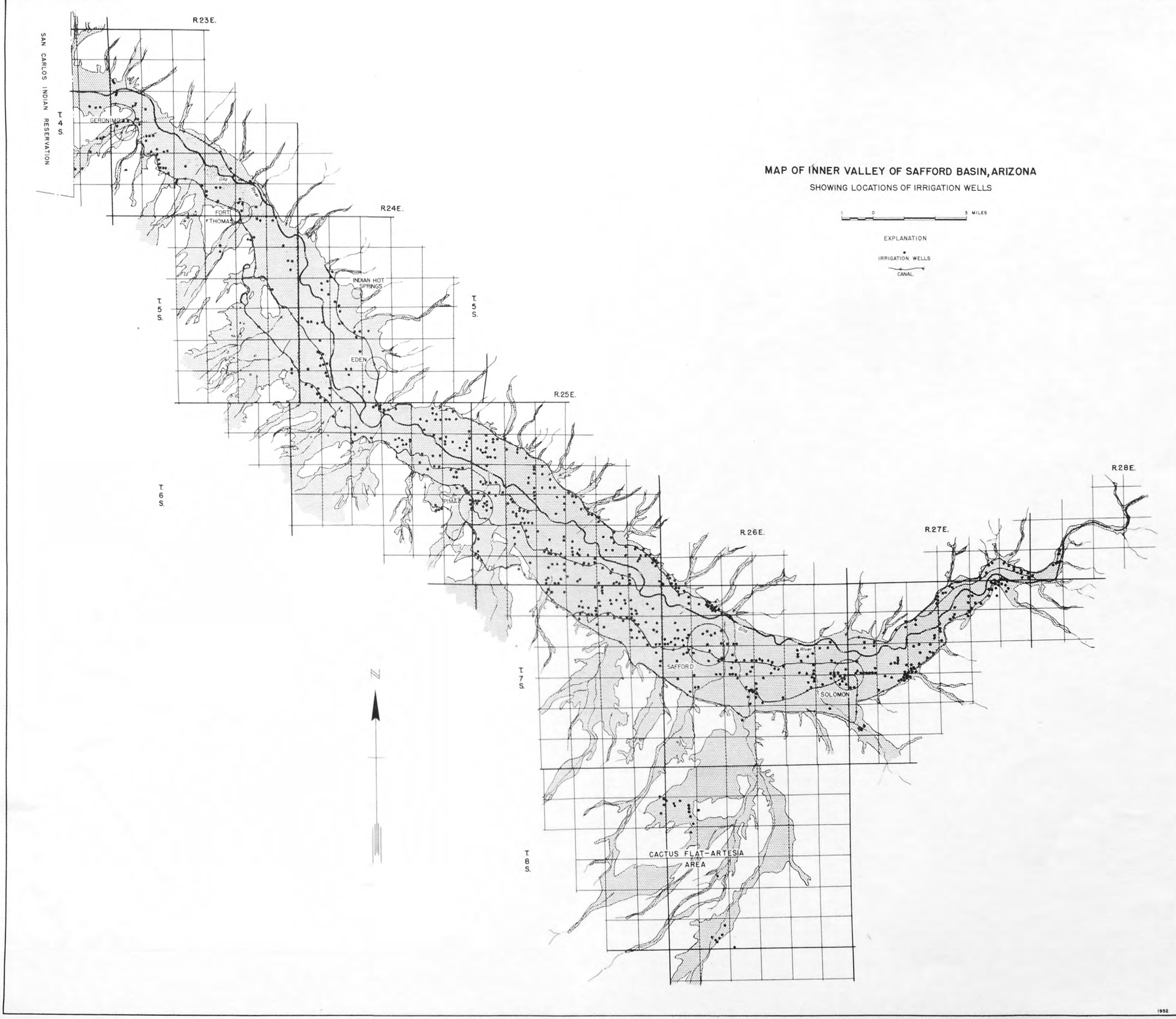


GEOLOGIC MAP OF SAFFORD BASIN, ARIZONA


MAP OF INNER VALLEY OF SAFFORD BASIN, ARIZONA
SHOWING LOCATIONS OF IRRIGATION WELLS
1 0 3 MILES
EXPLANATION
IRRIGATION WELLS
CANAL
SAN CARLOS INDIAN RESERVATION
R.23E.
R.24E.
R.25E.
R.26E.
R.27E.
R.28E.
T. 4 S.
T. 5 S.
T. 6 S.
T. 7 S.
T. 8 S.
GERONIMO
FORT THOMAS
INDIAN HOT SPRINGS
EDEN
PIMA
SAFFORD
SOLOMON
CACTUS FLAT-ARTESIA AREA
N
1952

MAP OF PART OF SAFFORD BASIN, ARIZONA

WITH ISOPACHS (CONTOUR LINES REPRESENTING EQUAL THICKNESSES) OF SATURATED RECENT ALLUVIUM AND COMPUTATIONS OF QUANTITY OF GROUND WATER IN STORAGE

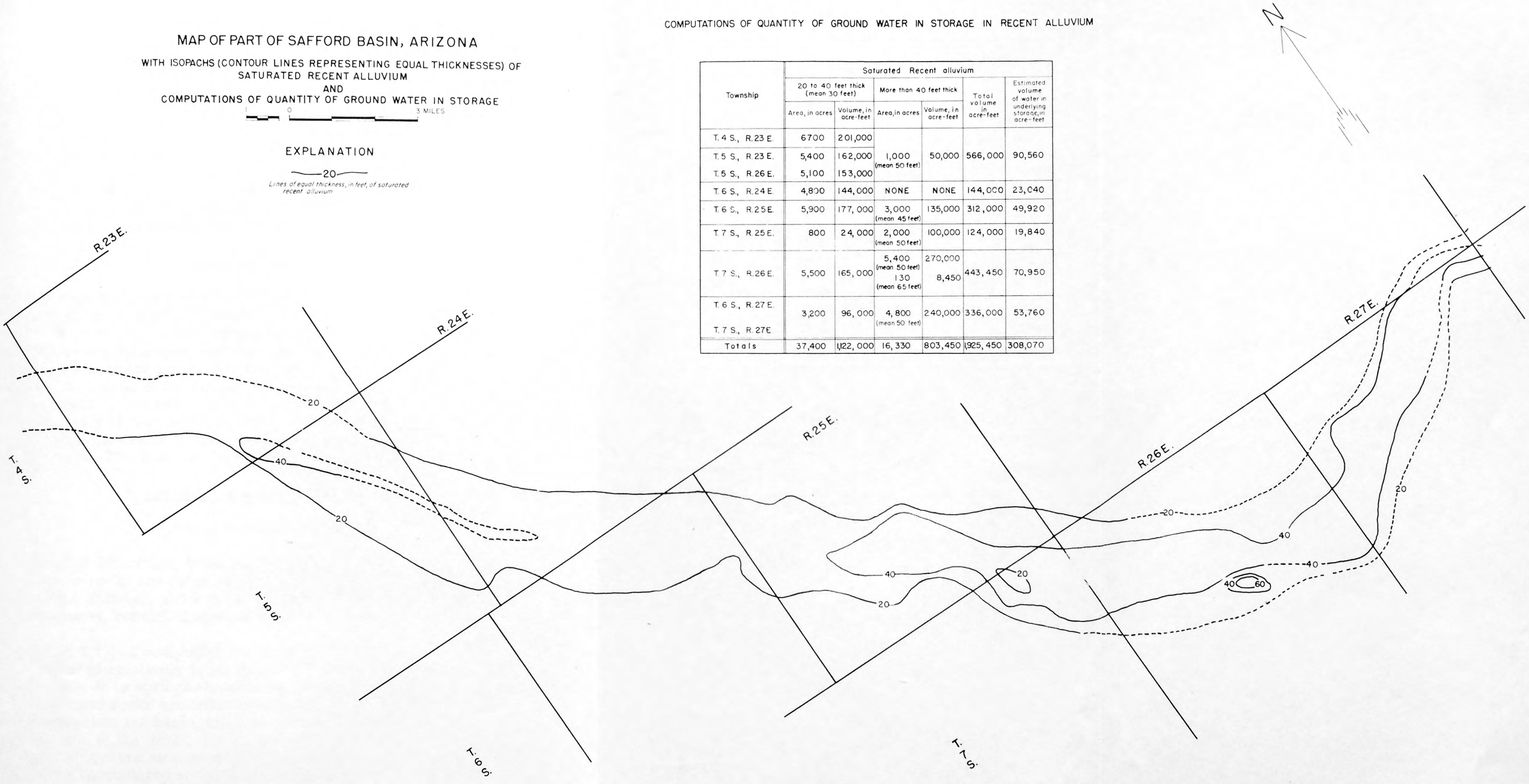
0 3 MILES

EXPLANATION

—20— *Lines of equal thickness, in feet, of saturated recent alluvium*

COMPUTATIONS OF QUANTITY OF GROUND WATER IN STORAGE IN RECENT ALLUVIUM

Township	Saturated Recent alluvium					
	20 to 40 feet thick (mean 30 feet)		More than 40 feet thick		Total volume in acre-feet	Estimated volume of water in underlying storage, in acre-feet
	Area, in acres	Volume, in acre-feet	Area, in acres	Volume, in acre-feet		
T. 4 S., R. 23 E.	6700	201,000				
T. 5 S., R. 23 E.	5,400	162,000	1,000 (mean 50 feet)	50,000	566,000	90,560
T. 5 S., R. 26 E.	5,100	153,000				
T. 6 S., R. 24 E.	4,800	144,000	NONE	NONE	144,000	23,040
T. 6 S., R. 25 E.	5,900	177,000	3,000 (mean 45 feet)	135,000	312,000	49,920
T. 7 S., R. 25 E.	800	24,000	2,000 (mean 50 feet)	100,000	124,000	19,840
T. 7 S., R. 26 E.	5,500	165,000	5,400 (mean 50 feet) 130 (mean 65 feet)	270,000 8,450	443,450	70,950
T. 6 S., R. 27 E. T. 7 S., R. 27 E.	3,200	96,000	4,800 (mean 50 feet)	240,000	336,000	53,760
Totals	37,400	1,122,000	16,330	803,450	1,925,450	308,070



SAN SIMON BASIN, COCHISE COUNTY

By K. J. DeCook

Introduction

Location and extent

The San Simon basin forms part of a structural trough, lying between two roughly parallel chains of mountains in the southeastern part of the desert region of Arizona. This trough trends northwest, and extends from the vicinity of Rodeo, N. Mex., to the vicinity of Globe, Ariz.

The southern part of the trough is known as the San Simon basin. For this report the San Simon basin is arbitrarily limited on the north by the line between T. 9 S. and T. 10 S., on the east by the Peloncillo Mountains, arbitrarily on the south by the line between T. 16 S. and T. 17 S., and on the west by the Chiricahua, Dos Cabezas, and Pinaleno Mountains (pl. 8).

Topography and drainage

The San Simon basin is drained by San Simon Creek and tributary washes. The drainage pattern trends northwest. The drainage area within the San Simon basin is approximately 1,250 square miles.

San Simon Creek enters the southern part of the area at an altitude of about 4,000 feet, and leaves the northern end of the area at an altitude of about 3,350 feet. Along the course of the creek, the area described in this report is about 42 miles in length. The gradient along the drainage axis of the valley is therefore approximately 15 feet per mile. The alluvial slopes extending from the bordering mountains are of steeper gradients, ranging generally from 20 to 100 feet per mile. The width of the alluvial basin ranges from 10 to 25 miles.

Geology related to ground water

Rocks bounding the basin

The Peloncillo Mountains, bounding the basin on the east, consist principally of volcanic rocks and older sedimentary and granitic rocks. The Chiricahua, Dos Cabezas, and Pinaleno Mountains, bounding the basin on the west and southwest, consist of similar types of rocks as well as some ancient schists.

All of the rock types composing the mountain ranges are hard and resistant and are considered relatively impermeable. These may yield small amounts of water to wells or to springs through fractures. The water-bearing characteristics of these hard rocks are indicated on plate 8.

Bedrock underlies the basin, and was reported at a depth of at least 3,000 feet near the axis of the basin. Rocks described as rhyolite and volcanic breccia reportedly were encountered near the base of the valley fill. The volcanic debris encountered at depth may correlate with volcanic rocks in the adjacent mountain ranges.

Alluvial fill

The valley fill consists of a thick series of sediments, most of which were derived from the rocks of the bordering mountains and were transported into the basin largely by stream runoff. The sediments are of Quaternary and late Tertiary age, and are almost entirely classified as older alluvial fill. Recent alluvial fill overlies a small part of the older fill, mostly along present stream channels.

Older alluvial fill.--Overlying the bedrock is the older alluvial fill, a series of beds and lenses of clay, silt, sand, gravel, and conglomerate, in places interbedded with sandstone and tuff. The older fill apparently is divided into three rather distinct zones (fig. 6): (1) Stream deposits, forming the lower part of the fill; (2) lake beds at intermediate depths; and (3) stream deposits, comprising approximately the upper 200 feet of the older fill.

The general conditions controlling deposition of stream deposits in the basin are discussed in Part I of this report under the title, "Regional geology." In the San Simon basin, the deposits grade in texture from clay to boulder conglomerate.

The stream deposits in the lower zone of the older alluvial fill overlie the bedrock and in places are interbedded with volcanic debris. It is expected that the porosity of these deposits has been reduced by compaction and cementation. The stream deposits that comprise the upper zone of the fill overlie the lake beds and merge with older stream deposits near the margins of the valley. The maximum thickness of this upper zone is about 200 feet.

At some time during the deposition of the older fill, a body of still water, probably without exterior drainage, occupied a large part of the San Simon basin and extended into the Safford basin. During this time a series of lake deposits was formed, consisting largely of clays. Regarding the composition of these deposits, now commonly referred to in the area as the "lake beds", Schwennesen (1917, p. 8) says: "They consist chiefly of gray, yellow, and greenish-blue clay and gray and reddish sand. The sands are commonly interbedded with thin beds of tuff and thin layers or partings of indurated coarse-grained sandstone." A layer of dense clay, predominantly blue in color and about 400 feet thick, occurs in the upper part of the lake beds (table 10). This blue clay is considered to be the layer that confines water under artesian pressure in the older stream deposits and in the lower sandy members of the lake beds. This artesian water is the principal source of ground water used for irrigation in the basin.

In figure 6 the profile of the lake beds is shown to be roughly parallel to the present topography of the valley. Near the boundaries of the former lake, the confining clay beds pinch out, and the older stream deposits below the clay and the younger stream deposits above it merge to form a common aquifer. The two principal aquifers in the basin are separated vertically by the confining clay layer throughout most of the valley, but are connected in places around the slightly elevated periphery of the valley.

Recent alluvial fill.--The Recent alluvial fill consists of unconsolidated silt, sand, and gravel which were laid down largely by the aggradational work of San Simon Creek and tributary streams and occupy parts of the present stream

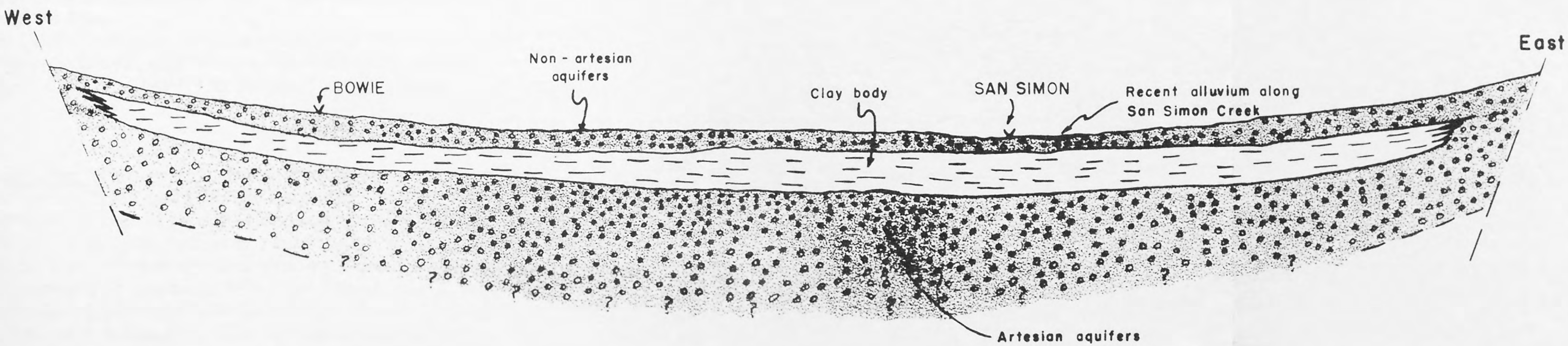


Fig. 6.- Generalized section across San Simon basin, showing relation of clay body to water-bearing materials.

1952

channels in the basin. The thickness of these deposits ranges from a few inches to a few feet. They have limited areal extent, and retain insufficient water to be considered important aquifers in the basin.

Ground water

Occurrence and movement

In the San Simon basin, ground water occurs principally in the older alluvial fill, as both artesian and nonartesian water. The artesian water occurs beneath the blue clay in the older lake-bed deposits and in the underlying stream deposits. This artesian water is encountered at depths ranging from about 350 feet to at least 2,500 feet. The nonartesian water occurs in the older alluvial fill overlying the blue clay. The water table is encountered generally below about 30 feet.

The general movement of ground water is similar in direction to the movement of surface water, and is from the bordering mountain ranges toward the axis of the valley, and down the valley from southeast to northwest.

Recharge

Nonartesian aquifers.--Water is recharged to the nonartesian aquifers as underflow, percolation from irrigation water, leakage from artesian aquifers, direct percolation from precipitation, and seepage from stream flow.

The mountain barriers prevent recharge by underflow from neighboring basins to the east and west of San Simon basin. Underflow approaching the southern boundary of the basin is forced nearly to the land surface by an underground barrier of undetermined nature and forms the San Simon Cienaga, an area of about 1,600 acres. The amount of ground water which moves northward from the cienaga to recharge the nonartesian system is not known.

Cushman and Jones (1947, p. 9) estimated that about 15 percent of the water applied to the land reached the water table as recharge. No additional data have been collected by the Geological Survey with which to revise this estimate. Based on the above estimate, the recharge from irrigation waters is less than 800 acre-feet annually.

An undetermined amount of ground water enters the nonartesian aquifers from the artesian aquifers by leakage through defective or corroded casings or outside the casings of artesian wells.

The discussion of recharge from precipitation in Part I of this report is, in general, applicable to the San Simon basin. Records of the U. S. Weather Bureau indicate that the annual precipitation on the valley floor ranges from less than 8 to more than 14 inches. Clay, silt, and caliche deposits, occurring extensively near the surface in this basin, effectively hold the soil moisture derived from precipitation at shallow depths within reach of evapotranspiration.

The major source of recharge to the nonartesian aquifers is probably seepage from runoff in stream channels. Seepage occurs in the permeable sandy or gravelly sediments in washes carrying runoff from the mountains to the alluvial slopes which form the valley floor. Most of this seepage is derived from winter precipitation.

San Simon Creek flows only after heavy storms or prolonged rains. Geological Survey (1947) records of surface waters show the amount of runoff in San Simon Creek for some years between 1919 and 1938, at gaging stations near Rodeo, N. Mex., near San Simon, and near Solomon, Ariz. These records show that most of the runoff occurs during the months of July and August. Recharge from this summer-storm runoff is probably decreased by the rapidity of runoff and consequent high content of suspended silt in the waters. Figures for runoff at the three stations are not accurately comparable because of the lack of synchronous records, the probable large flood inflow from tributary washes between gaging stations, and the extreme variations in amount of runoff in different years. Therefore, the amount of influent seepage and recharge between these stations has not been estimated.

Artesian aquifers.--The beds of sand and gravel forming the pervious strata of the artesian system receive practically all their recharge from runoff. The principal recharge areas are the gravel zones near the steep mountain fronts, outside the area underlain by the impervious clay stratum. The waters enter the permeable beds, and move downward and into the aquifers that extend beneath the confining lake-bed clays.

Discharge

Ground water is discharged from the aquifers in San Simon basin by natural and artificial means. Natural discharge occurs as evaporation, transpiration, and underflow. Artificial discharge occurs as pumpage and artesian flow.

Natural discharge.--Evaporation and transpiration from the nonartesian aquifers occur where the water table is relatively near the land surface, as in the San Simon Cienaga. It was estimated (Cushman and Jones, 1947, p. 9) that natural discharge in this 1,600-acre cienaga was about 8,000 acre-feet per year. Elsewhere in the basin the water table is at relatively great depths and the amount of ground water discharged by evaporation and transpiration is probably small.

Natural discharge from the artesian aquifers of the San Simon basin probably occurs as underflow to the Safford basin. Higher concentrations of dissolved minerals in the northwestern part of the basin are a probable indication of this movement. The quantity of water discharged from the basin by underflow is not known.

Artificial discharge.--Ground water is discharged from the nonartesian aquifers by pumping from wells for irrigation, domestic, and stock use. In 1946 there were three irrigation wells which pumped approximately 200 acre-feet per year from the nonartesian aquifers (Cushman and Jones, 1947, p. 9). Since then at least three more wells have been drilled for irrigation use. These irrigation wells are 12 inches in diameter, range from 100 to 190 feet in depth, and pump about 100 to 250 gallons per minute (table 10).

In 1952, about 80 irrigation wells discharged artesian waters of the San Simon basin in two general areas: (1) An area of earlier development in the vicinity of San Simon; and (2) an area of recent development in the vicinity of Bowie.

Most of the older wells of the San Simon area are 4 to 8 inches in diameter, and from 300 to 800 feet in depth. Newer wells in this area are between 12 and 18 inches in diameter, and range in depth from about 550 to about 1,300 feet. The natural flow from the wells in the San Simon area ranges from less than 1 to about 100 gallons per minute. Pumping from some of the wells has produced discharges greater than 500 gallons per minute, but the average is about 300 gallons per minute with an average pumping lift of about 80 feet.

The new irrigation wells in the Bowie area are 16 to 20 inches in diameter with depths ranging from 450 to 1,400 feet. The discharge from these wells, as measured by the Geological Survey, ranged from 650 to 2,100 gallons per minute. It is probable that some of these wells can be pumped at greater rates, because discharges of more than 3,000 gallons per minute have been reported. Drawdowns in these wells at the time discharge measurements were made ranged from 50 to 240 feet, with total lifts ranging from 150 to 290 feet. Water levels in artesian wells north and east of Bowie range from about 10 to 80 feet, and south and west of Bowie are as much as 220 feet below land surface.

Four wells, with diameters of 16 to 20 inches, were drilled west of San Simon in 1951-52 to depths ranging from 960 to 1,380 feet. It was reported that the discharge from these wells ranged from 300 to 500 gallons per minute with pumping lifts of 280 to 300 feet.

There are artesian wells in other parts of the basin, six of which are in T. 11 S., R. 29 E. These wells flow at rates of 15 to 75 gallons per minute, with an average discharge of about 25 gallons per minute. An oil test, known as the Whitlock No. 1, was drilled in sec. 31, T. 10 S., R. 29 E., to a depth of 1,925 feet. The flow of artesian water from this well was estimated to be 300 gallons per minute in 1943.

It was estimated by Cushman and Jones (1947, p. 7) that in 1946 about 1,400 acre-feet of artesian water was wasted through uncapped wells which were allowed to flow continuously. Some of these wells are abandoned and the flows are not used. Flows from the other wells are used only during the irrigation season. The decline in artesian head in the past few years has caused a decrease in the amount of water wasted.

The amount of water discharged from flowing and pumped artesian wells in 1951 was estimated to be 6,000 acre-feet. Approximately 1,800 additional acres of land have been put under irrigation in 1952. On the basis of this increase in irrigated acreage, it is estimated that the total amount of artesian water needed for irrigation in 1952 will be between 10,000 and 12,000 acre-feet.

An undetermined amount of artesian water has been discharged to nonartesian aquifers by leakage through deteriorated casings, through wells not cased into the upper part of the lake-bed clays, and outside of the casings in wells where the casing had not been properly sealed into the confining bed.

Storage

Amount of ground water in storage.--It was estimated (U. S. Geol. Survey, 1951, pp. 6-8) that the volume of "available" ground water in storage in the San Simon basin was 3,840,000 acre-feet, based upon a reservoir area of 1,000 square miles, an average coefficient of drainage of 6 percent, and an average reservoir depth of 100 feet. "Available water" refers to the water that would be withdrawn by wells if the wells were spaced sufficiently close together to remove the water from every cubic foot of saturated material in the area. It is recognized that such well spacing is not feasible. The figure for the amount of available water is in reality theoretical, and in actual practice can only be approximated.

Sufficient data are not available with which to revise this estimate. The data necessary for making storage estimates are discussed in Part I of this report under the title "Hydrologic data."

Changes in ground-water storage.--Water-level measurements made in wells in the period 1913-15 are listed by Schwennesen (1917, pp. 22-26). Since 1940 the Geological Survey has maintained a water-level measurement program in the San Simon basin. The water levels in about 20 wells are measured several times a year. In 1952, about 40 additional wells were selected for once-a-year measurements.

Figure 7 shows records of water-level fluctuations in four nonartesian wells near San Simon, and in four artesian wells in the vicinities of San Simon and Bowie. In these nonartesian wells, the average net decline in water levels was about 4 feet between December 1940 and December 1951 and the greatest decline was 8.2 feet in well (D-13-30)9acd during the same period.

The net decline in water levels in artesian wells (D-14-31)3bbd and (D-14-31)25add in the vicinity of San Simon averaged about 27 feet in the period 1915-52, of which $9\frac{1}{2}$ feet occurred in the period 1940-52. The decline in water levels in artesian wells (D-12-28)17ddd and (D-13-29)6ccc in the vicinity of Bowie averaged 13 feet in the period 1915-52, of which $6\frac{1}{2}$ feet occurred in the period 1940-52. The graphs of water-level fluctuation show a uniform rate of decline in each area. The decline in the vicinity of San Simon has been greater than that near Bowie because of the greater amount of water development.

Cones of influence and well interference.--Generally, the spread of cones of depression around nonartesian wells in the San Simon basin is insufficient to reach other nonartesian wells and cause mutual interference with well outputs.

An indication of the lateral extent and rate of radial expansion of cones of pressure relief in the artesian system is seen in the records of water-level fluctuations in observation well (D-13-28)10bbb. Charts from a continuous water-stage recorder maintained over the well showed a water-level decline starting about 1 hour after well (D-13-28)10bcc, half a mile south, began pumping at an estimated rate of 2,000 to 2,500 gallons per minute. The water level dropped approximately 13 feet in about 10 days.

Numerous flowing wells in the San Simon area cease to flow while nearby artesian wells are being pumped. Wells that formerly flowed throughout the year now flow only during the winter months when the pressure relief caused by pumping is at a minimum.

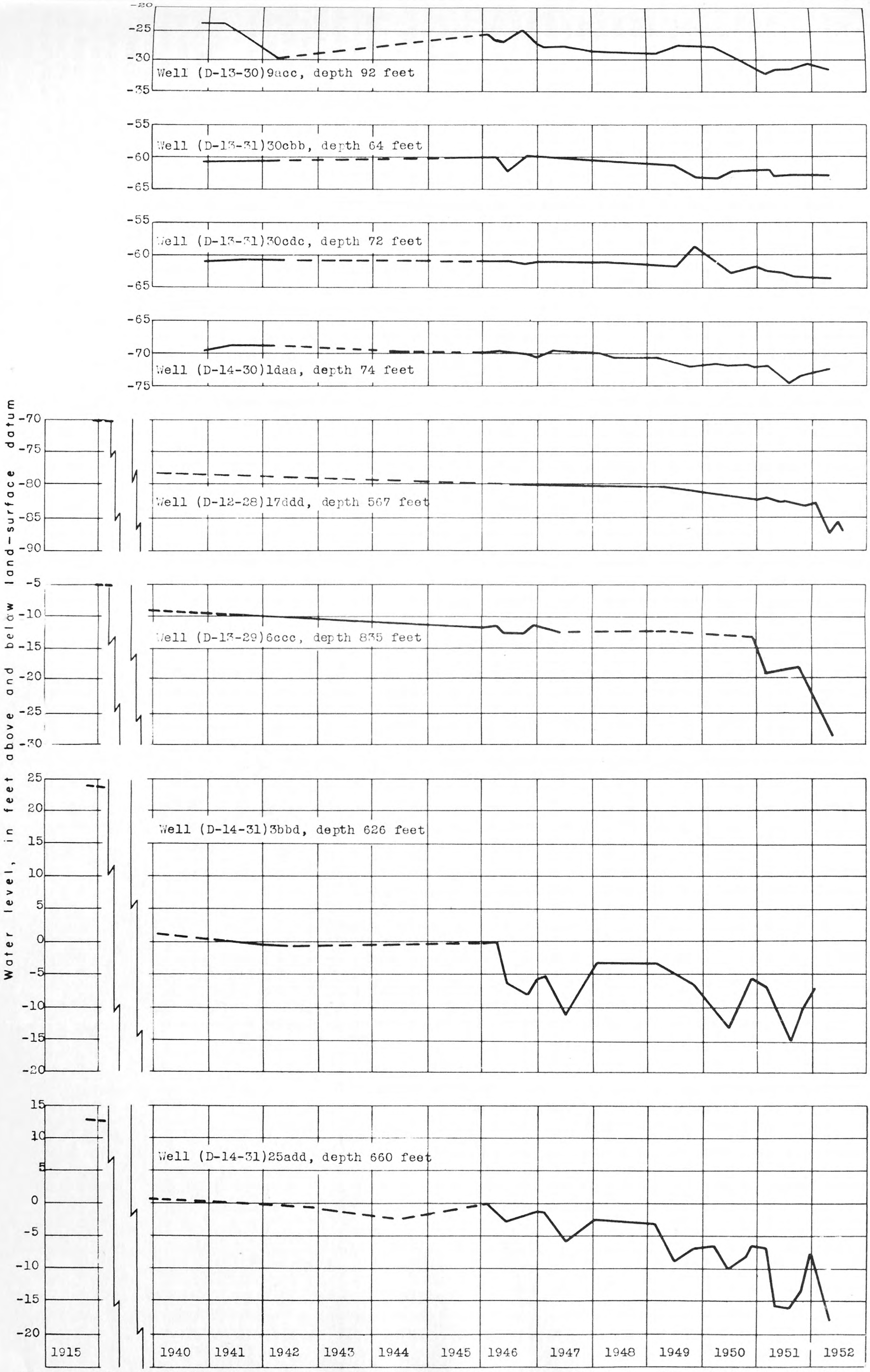


Figure 7.--Graphs showing fluctuations of water level in observation wells in San Simon Basin, Cochise County.

Quality of water

Chemical analyses of ground water

A study of the quality of ground water in San Simon basin was made by J. D. Hem (Cushman and Jones, 1947, pp. 10-13) based on analyses of about 100 water samples collected in 1940-41 and in 1946. Earlier, Schwennesen (1917, pp. 16-17) presented analyses of 25 samples in a discussion of quality of water. An insufficient number of water analyses are available to the Geological Survey to permit a general study of conditions later than 1946.

The results of the 1946 studies are briefly summarized below. From the analyses of water samples taken in 1951, it is considered unlikely that the chemical character of the ground water has changed appreciably since 1946. Table 11 shows 12 analyses of water samples taken from wells near San Simon and three from wells near Bowie.

Most of the water samples collected in the San Simon basin have been from the artesian aquifers. Samples obtained from the nonartesian aquifers show that the waters are generally more highly mineralized than artesian waters in the same area. There are too few analyses available for nonartesian waters to justify a separate discussion of their quality, and only the artesian waters will be discussed in the present report.

Relation of quality of water to use

The standards for quality of water with respect to use are set forth in Part I of this report, and form the basis for discussing waters of the San Simon basin.

Domestic use.--Waters in the vicinity of Bowie are relatively soft, while in the vicinity of San Simon waters are moderately hard. The hardest waters sampled were found east and southeast of San Simon. None of the analyses of waters from the basin show an excessive concentration of chloride or magnesium, or of total dissolved solids. Only three analyses show a sulfate content greater than 250 parts per million. About 70 percent of the waters sampled in the basin contained more than 1.5 parts per million of fluoride, and waters with more than 10 parts per million of fluoride are common.

Irrigation use.--Of the water samples from San Simon basin analyzed to date by the Geological Survey, none show a high chloride or boron content. About 8 percent of the samples showed a specific conductance greater than 1,000 micromhos, which may be considered moderately high. Of these, the most highly mineralized waters sampled were found along the course of San Simon Creek. The percent of sodium in the ground waters is highly variable in the basin. Sodium percentages greater than 75 were found in the northwestern part of the basin, in the immediate vicinity of San Simon, and in well (D-12-28)22cdc, near Bowie. However, the waters having high sodium percentages are not necessarily unsuitable for irrigation, because the dissolved-solids content is relatively low.

Problems

Need for additional studies

The following is a brief summary of the factors to be investigated in order to evaluate more completely and accurately the ground-water supply of San Simon basin:

1. Amount of ground water in storage and changes in storage in the artesian and nonartesian aquifers.
2. Amount of water recharged from precipitation, runoff, water applied to the land, and underflow to the basin.
3. Amount of water discharged by wells, evapotranspiration near the San Simon Cienaga, underflow from the basin, and leakage from artesian to nonartesian aquifers through defective wells.
4. Nature of the underground barrier near the cienaga.

Summary

The San Simon basin forms a part of a larger basin, probably of structural origin, lying between two parallel chains of mountains. The basin trends northwest, and extends from the vicinity of Rodeo, N. Mex., to the vicinity of Globe, Ariz.

Drainage of the basin trends in a general northwest direction, and empties into the Gila River near Safford. The drainage area of the basin is approximately 1,250 square miles.

The parallel mountain chains that border the basin are composed of igneous, metamorphic, and older sedimentary rocks, which are relatively impermeable. Hard rocks, possibly related to the mountain rocks, underlie the basin at depths ranging to at least 3,000 feet below the present land surface of the valley.

The valley fill, derived largely from erosion of the adjacent mountains, consists of a series of beds and lenses of clay, silt, sand, gravel, conglomerate, sandstone, and tuff. The valley fill is divided into two parts--the older alluvial fill, including the lake beds, and the Recent alluvial fill.

The older stream deposits and the lower part of the lake beds contain permeable members which form the confined strata of an artesian system. The upper member of the lake beds is a dense clay which forms the confining stratum.

The major source of water available for recharge to the artesian ground water of the basin is runoff from mountain areas. The major source of recharge to the nonartesian aquifers is seepage from stream flows.

Most of the ground water artificially discharged from the basin is pumped from the artesian system. In general the artesian wells are between 4 and 18 inches in diameter and between 300 and 1,400 feet in depth. The discharges by pumping of the wells range from about 80 to 2,100 gallons per minute. The amount of water discharged from flowing and pumped wells was about 6,000 acre-feet in 1951. About 1,100 acre-feet of water from flowing wells was not put to beneficial use in 1951.

The head of artesian water decreased about 10 feet between 1940 and 1951. The decline of nonartesian water level was about 4 feet between 1940 and 1951.

Chemical analyses of water samples show that the waters of the basin are moderately hard except in the vicinity of Bowie and contain excessive amounts of fluoride in many parts of the basin. Artesian waters are generally suitable for irrigation.

Additional data are needed in order to determine amounts of storage, recharge, and discharge of ground water in the basin.

Table 9.--Records of representative wells in San Simon basin, Cochise County, Ariz.

Well no.	Depth of well (feet)	Water level: Depth below land-surface datum (feet) a/	Water level: Date of measurement	Type of lift b/	Use of water c/	Log on file	Analysis on file	Discharge: Gallons per minute	Discharge: Date of measurement	Pumping level: Depth below measuring point (feet)	Pumping level: Date of measurement
(D-12-28)											
22cdc	660	49.34	10/51	T,Bu	I	X	X	935	5/52	143	5/52
35cdc2	620	54.26	10/51	T,G	I	X	-	665	5/52	150	5/52
(D-13-28)											
3c	830	-	-	-	P	X	X	-	-	-	-
9bcc	-	174.88	4/52	T,G	I	-	-	2,100	5/52	-	-
(D-13-29)											
18bac	860	46.27	1/52	-	N	-	X	-	-	-	-
27acc	1,040	-	-	D	I	X	-	1,490	5/52	141	5/52
(D-13-30)											
3cd	855	-	-	-	I	X	-	-	-	-	-
19ccc	980	-	-	-	-	X	-	-	-	-	-
36ccc	1,380	-	-	Artesian	I	-	-	500	5/52	295	5/52
(D-13-31)											
20dad	648	Flows	-	Cf,E	D,S,I	-	X	150	4/46	-	-
21caa	1,280	-	-	T,E	I	X	-	510	5/52	106	5/52
28baa	763	Flows	-	E	D,S,I	-	X	230	5/52	75.3	5/52
30cca	72	61.64	12/40	C,W	D	-	X	-	-	-	-
33aac	648	4.00	11/40	-	I	-	X	-	-	-	-
(D-14-31)											
3cda	700	-	-	T,E	S,I	-	-	105	4/46	-	-
15cdd	800	5.99	6/51	T,D	I	-	-	550	5/52	37.3	5/52
23cccl	650	-	-	T,E	I	-	-	245	5/52	93.8	5/52
25dbc	600	12.85	12/40	Bu	D,S,I	-	-	275	5/52	64.4	5/52
26bbc	800	-	-	T,E	D,I	-	-	265	5/52	65.8	5/52
(D-14-32)											
30bcd	560	Flows	-	Cf,E	D,S,I	-	-	115	5/52	-	-

a/ Depths were corrected to land-surface datum from measuring point.
b/ T, turbine; Cf, centrifugal; C, cylinder; Bu, butane; G, gasoline; D, diesel; E, electric; W, windmill.
c/ I, irrigation; P, public supply; D, domestic; S, stock; N, not used.

Table 10.--Logs of representative wells in San Simon basin, Cochise County, Ariz.

	Thickness (feet)	Depth (feet)
(D-12-28)35cdc2		
Topsoil, red	4	4
Caliche, light	4	8
Sandy clay, red	20	28
Clay, blue	7	35
Sand and gravel dry	15	50
Clay, yellow	20	70
Clay and boulders, yellow	5	75
Clay, yellow	40	115
Sand and gravel, yellow	5	120
Sand and rock, hard, yellow	15	135
Clay with sand, yellow	31	166
Blue shale, sticky	29	195
Blue clay	38	233
Sand and gravel, grey	22	255
Shale, sticky, blue	13	268
Gravel and boulders, (little water)	7	275
Shale, sticky, blue	30	305
Clay and shale, blue	60	365
Shale, sticky, blue	10	475
Sand and gravel, (water at 485'), grey	20	495
Gravel and sand with clay streaks, grey	10	505
Sand and gravel, grey	89	594
Sand and fine gravel, grey	6	600
Boulders, grey	15	615
Hard sand rock, grey	5	620
TOTAL DEPTH		620
(D-13-28)3c		
Sand	2	2
Soil	8	10
Clay	5	15
Sand and gravel	2	17
Clay	2	19
Sand and gravel	11	30
Clay	8	38
Sand and gravel	13	51
Light brown clay	57	108
Sand	2	110
Grey shale	25	135
Water sand	5	140
Blue clay	10	150
Brown clay	38	188
Grey shale	64	252
Sandstone	3	255
Grey shale	19	274
Brown sandy shale	41	315
Sand and gravel	5	320
Brown shale sand and gravel	5	325
Sand and gravel	126	451
Brown shale	41	492
Sand and gravel	50	542
Boulders	3	545
Blue shale	7	552
Sand and gravel	56	608
Water sand, big flow	4	612
Sand and gravel	113	725
Sand gravel, hard	40	765
Water sand	50	815
Blue shale, hard	15	830
TOTAL DEPTH		830
(D-13-29)24dcc		
Topsoil	3	3
Hard pan	3	6
Caliche	74	80
Sandy clay, grey	8	88
Brown clay, soft	7	95
Sandy clay (water)	17	112
Lime clay	28	140
Brownish shale	8	148
Blue shale	180	328
Sandy blue shale	7	335
Blue shale, hard	245	580
Black shale, tough	48	628
Blue shale, (trace of sand	7	635
Blue shale	43	678
Brown shale, hard limestone	107	785
Black fine sandy clay	23	808
Grey shale, hard	6	814
Black sandy clay	10	824
Black silty clay, (loose sand)	8	832
Sand and small gravel	8	840
Grey shale, hard	5	845
Gravel and sand	55	900
Gravel and sand with clay	30	930

Table 10.--Logs of representative wells in San Simon basin--continued

	Thickness (feet)	Depth (feet)
Gravel and shale, (hard)	15	945
Gravel and shale, (very hard)	19	964
TOTAL DEPTH		964
(D-13-30)28acc		
Surface soil, dark	4	4
Caliche, light	24	28
Caliche and boulders, light	44	72
Sand and small gravel (trace of H_2O), red	15	87
Clay and gypsum, light blue	113	200
Gypsum, light	40	240
Blue shale, blue	408	648
Grey shale, grey	113	761
Sand, hard, red	4	765
Congl. of soapstone, brown shale, little sandy, brownish	9	774
Congl. of sand, small gravel, and brown shale, brown	14	788
Sand, brown	2	790
Congl. of sand, quartz and shale streaks, light brown	50	840
Sand, soft, with quartz-water, grey	12	852
Sandy quartz, hard streaks, grey	13	865
Sand, soft with some boulders (water sand) grey	22	887
Sand, hard cemented with some large boulders, grey	4	891
Sand, soft streaks, some water, grey	39	930
Cemented sand, hard very light	68	998
Hard sand with blue shale streaks very thin, light blue	6	1004
Brown shale, sandy, brown	29	1033
Sand, gravel and granite wash water, light grey	35	1068
Brown shale	6	1074
Sand, gravel and boulders, light	34	1108
Rock with some broken sand (hard), brown	30	1138
Rhyolite (very hard), dark	82	1220
Rhyolite, boulders, quartz and some sand, (white), brown	8	1228
Granite boulders with some mica and brown shale, brown	9	1237
Shale, brown	28	1265
Conglomerate sand, boulders, quartz, brown	45	1310
Shale, red	7	1317
Red shale and sand, red	16	1333
Sand (water)	21	1354
TOTAL DEPTH		1354
(D-13-31)31cb		
Clay	78	78
Sand	4	82
Clay	4	86
Sand and gravel	57	143
Dense dark blue clay with foul odor	422	565
Fine sand	6	571
Grey, joint clay	86	657
Fine sand	5	662
Caliche and clay.	43	705
Coarse sand	5	710
Caliche, pebbles, clay	86	796
Coarse sand	4	800
Hard clay	50	850
TOTAL DEPTH		850
(D-14-31)16dc		
Surface soil	3	3
Light brown clay and silt, considerable lime	71	74
Light brown clay and silt, highly calcareous, water at 75 feet	46	120

Table 10.--Logs of representative wells in San Simon basin--continued

	Thickness (feet)	Depth (feet)
Light blue clay	203	323
Evenly graded water-worn particles of light blue shale or clay; first water stratum	2	325
Blue clay	45	370
Light brown clay	4	374
Blue clay	8	382
Fine clean sand	3	385
Blue clay	25	410
Light brown clay; lime	171	581
Sand; flowed 10 gallons a minute	11	592
Partly cemented sand and gravel	3	595
Brown clay mixed with lime	72	667
Sand and gravel; flowed about 1 gallon a minute	1	668
Sticky brown clay	14	682
Partially cemented sand and gravel	11	693
Brown clay	21	714
Partially cemented sand and gravel; water	2	716
Clay	5	721
Partially cemented sand and gravel; water	5	726
Fine cemented sand and clay	21	747
Partially cemented fine sand; water	5	752
Very fine cemented sand and clay	130	882
Fine sand; water	3	885
Fine cemented sand	41	926
Fine sand	2	928
Very fine sand, some cemented clay and fine sand	812	1740
Cemented sand and gravel	25	1765
Cemented sand and clay	10	1775
Cemented sand and gravel	5	1780
Cemented sand and clay	25	1805
Cemented sand, clay, and gravel	5	1810
Cemented sand and clay	20	1830
Cemented sand and gravel	5	1835
Cemented fine sand and clay	165	2000
TOTAL DEPTH		2000
No water was encountered below 928 feet.		

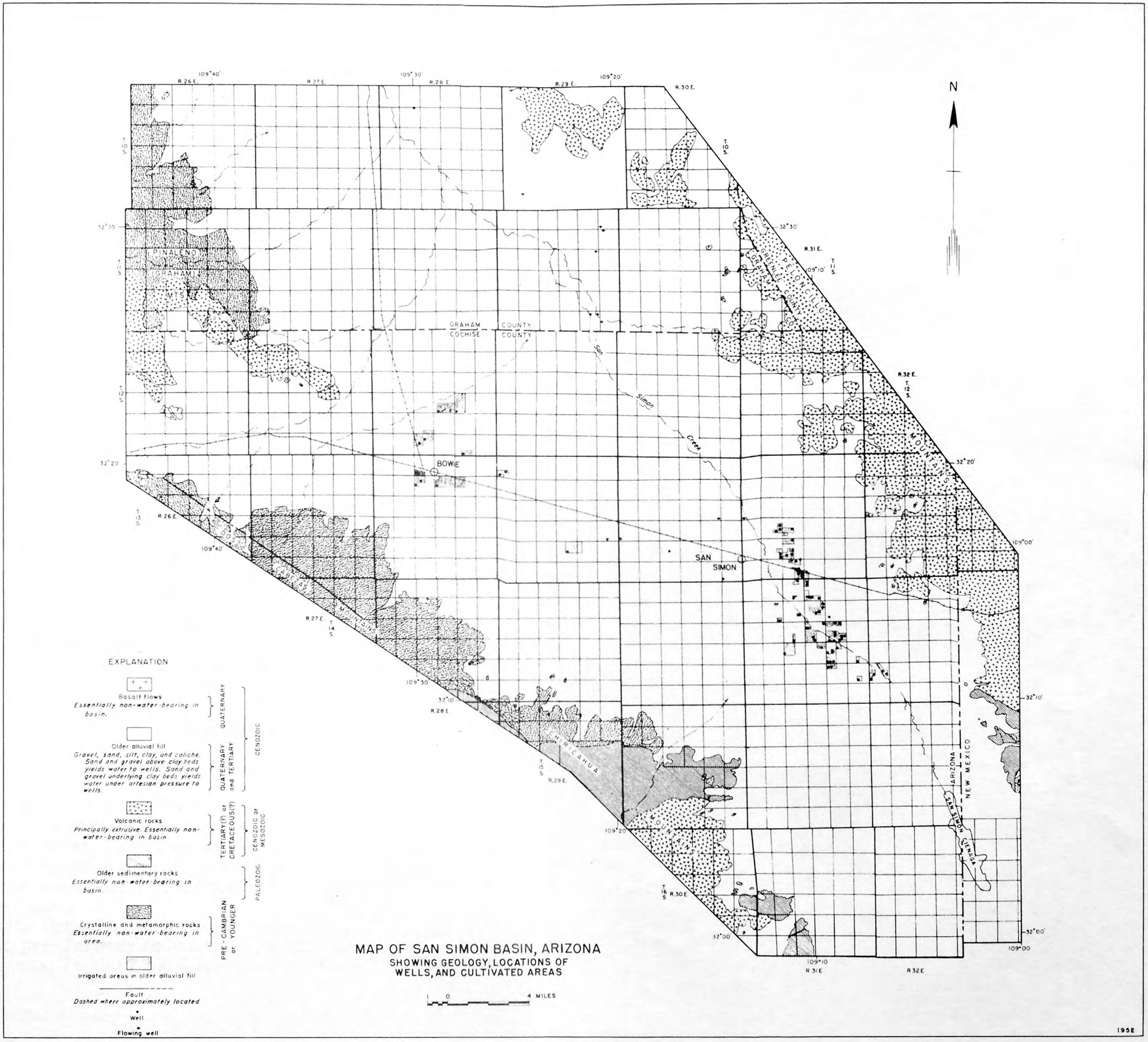
Table 11.--Analyses of water from wells in San Simon basin, Cochise County, Ariz.
(Parts per million except specific conductance and percent sodium)

Well no.	Date of collection	Depth of well (feet)	Temperature (°F.)	Specific conductance (micromhos at 25° C.)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Total hardness as $CaCO_3$	Percent sodium
(D-11-29)															
1cd	8-3-46	600+	84	1,060	4.0	0.5	223	a/263	189	50	14	.2	610	12	98
36cb	8-3-46	--	90	974	10	0.9	196	198	154	86	3.0	2.2	550	28	94
(D-12-28)															
22cdc	6-19-51	648	86	334	10	1.3	62	93	49	24	1.4	.5	b/216	30	82
(D-13-28)															
3c	6-19-51	800	99	343	16	3.2	57	126	34	24	.8	1.8	c/231	53	70
8	6-19-51	--	--	495	50	11	44	252	29	16	.6	6.7	d/329	170	36
(D-13-29)															
18bac	5-2-41	860	78	346	14	5.2	58	e/133	45	15	2.3	--	205	56	69
24dcc1	11-19-40	960	105	558	2.0	4.8	128	f/248	67	11	5.5	.2	340	25	92
(D-13-30)															
3bdc	11-19-40	860	85	510	4.5	6.6	114	136	94	17	20	1.0	324	38	87
24adb	4-29-41	880	65	660	5.5	4.4	157	g/281	42	10	32	--	389	32	91
(D-13-31)															
30cca	12-1-40	72	61	949	30	11	186	174	232	89	4.7	2.8	642	120	77
(D-14-31)															
4dcb1	4-30-41	825	76	367	22	4.8	58	127	72	7.0	4.8	--	232	75	63
7ccd	12-11-40	760	84	349	13	3.5	68	140	43	7.0	9.2	.8	214	47	76
16dcd	5-1-41	2,000	88	423	22	5.2	71	139	98	5.0	3.2	--	272	76	67
24dcc	5-2-41	630	77	405	46	7.9	32	148	79	5.0	2.4	--	245	147	32
(D-16-32)															
21dd	10-1-46	114	--	285	42	4.9	13	144	28	2.0	.8	.7	162	125	18

a/Contains equivalent of 34 parts per million carbonate (CO_3)
b/Contains 22 parts per million silica (SiO_2)
c/Contains 32 parts per million silica (SiO_2)
d/Contains 48 parts per million silica (SiO_2)
e/Contains equivalent of 10 parts per million carbonate (CO_3)
f/Contains equivalent of 57 parts per million carbonate (CO_3)
g/Contains equivalent of 58 parts per million carbonate (CO_3)

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PLATE 8



MAP OF SAN SIMON BASIN, ARIZONA
SHOWING GEOLOGY, LOCATIONS OF WELLS, AND CULTIVATED AREAS

UPPER SAN PEDRO BASIN, COCHISE COUNTY

By L. A. Heindl

Description

The Upper San Pedro basin is defined for this report as the drainage basin of the north-flowing San Pedro River between the International Border and The Narrows (pl. 9). As defined, it lies completely within Cochise County. The west boundary is the drainage divide between the San Pedro and Santa Cruz Rivers along the Rincon, Whetstone, and Huachuca Mountains. The east boundary is the drainage divide extending from the southern end of the Winchester Mountains southward through the Little Dragoon, Dragoon, and Mule Mountains. The southern boundary is the International Border and the northern boundary was selected as the drainage divide separating tributary streams entering the San Pedro above and below The Narrows at the Tres Alamos dam site.

The Upper San Pedro basin is 58 miles long and 15 to 35 miles wide and trends about N. 10° W. The San Pedro River above The Narrows drains an area of about 2,500 square miles, of which about 650 square miles is in Mexico and about 1,850 square miles is in the United States (Water-Supply Paper 1049, pp. 335-345).

Although the general trend of the basin is nearly north, the individual mountain ranges trend west of north. This relationship gives the valley an irregular outline which is accentuated by the Tombstone Hills. These hills jut into the valley from between the Dragoon and Mule Mountains and divide the Upper San Pedro basin, structurally and hydrologically, into two sub-basins. The division between the sub-basins was selected as the drainage divide separating tributary streams above Charleston from those below. The upper sub-basin is designated in this report as the Charleston sub-basin and includes the area between the International Border and Charleston; the lower is called the Benson sub-basin, and includes the area between Charleston and The Narrows.

Geology

General discussion

The geologic map of the Upper San Pedro basin (pl. 9) is compiled from the geologic map of the State of Arizona (Darton and others, 1924), published reports (Butler and others, 1938; Darton, 1925; Ransome, 1904), and unpublished data and reports in the files of the Geological Survey (Moore and others, 1941; Bryan and others, 1934; Cooper, J. R., unpublished data; Moore, B. N., unpublished data).

Rock types in the Upper San Pedro basin include the crystalline and metamorphic complex, pre-Tertiary sedimentary rocks, Cretaceous(?) and Tertiary(?) volcanic rocks, Tertiary and Quaternary or "older" alluvial fill, and

Recent alluvial fill. Schists, gneisses, and granites of the crystalline and metamorphic complex form large parts of all the mountains in the basin. Pre-Tertiary sedimentary rocks constitute the largest part of the Whetstone, Huachuca, and Mule Mountains and occur in limited areas in the Little Dragoon and Dragoon Mountains and in the Tombstone Hills. Small outcrops of volcanic rocks occur in the hills south of the Whetstone Mountains, the Canelo Hills, and at the south end of the Dragoon Mountains.

The trough of the Upper San Pedro basin contains a considerable thickness of alluvial material. The known thickness of the alluvial fill ranges from a few feet to at least 1,500 feet. In the Tombstone area hills of granitic material are surrounded by alluvium that attains a thickness of about 600 feet adjacent to the San Pedro River.

North and south of the Tombstone Hills, the river has developed a narrow flood plain which is locally cultivated. The flood plain is generally about a quarter of a mile to $1\frac{1}{2}$ miles wide. The Recent alluvium ranges from less than 10 to about 120 feet in thickness and averages about 60 feet. The alluvium is thickest in the central parts of the sub-basins and thins where the river cuts through crystalline rocks near Charleston and The Narrows.

Pediments are known to exist in some places below the alluvial fill along the mountain fronts, but their locations have not been mapped.

Alluvial fills

A general description of the older and Recent alluvial fills of the region appears in Part I, "Regional geology." The present discussion of these materials is based on interpretations of logs of wells in the Upper San Pedro basin. Only those wells discussed in this section are shown on plate 9. Their records are shown in table 12. A few selected logs are presented (table 13) to show the composition of both the shallow flood-plain deposits and the older alluvial fill.

Recent alluvium.--The following logs are considered representative of the flood-plain deposits along the upper San Pedro River: (D-16-20)34acd1 at Pomerene; (D-18-21)28db5 south of St. David; and (D-23-22)10acc in the Hereford area. These logs show that unconsolidated sands and gravels of the Recent alluvium supply shallow ground water to wells. They are generally underlain by clay.

Older alluvium.--Deep wells in and adjacent to the flood plain have penetrated artesian aquifers in two areas (pl. 9)—Palominas-Hereford in the Charleston sub-basin and St. David-Pomerene in the Benson sub-basin.

The limits of the Palominas-Hereford artesian area are not clearly defined. The area is estimated to be about 10 miles long and 1 mile wide but may be larger. A representative log from this area, (D-23-22)10acc, shows a thickness of 102 feet of gravel, sand, and silt, probably Recent alluvium, overlying gypsum. Below the Recent fill and within clay beds of the older alluvium there are at least seven sand or gravel members that yield small amounts of artesian water. Many wells are not cased below the shallow gravels, as the underlying material is consolidated and does not cave.

The St. David-Pomerene artesian area is much larger than the Palominas-Hereford area, and extends from about 6 miles south of St. David along the axis of the valley to the vicinity of Pomerene, a distance of about 12 miles. It has an average width of about 2 miles and is as wide as 4 miles near St. David. The total proved artesian area is about 25 square miles.

The water-bearing beds of sand and gravel in the St. David-Pomerene area range in thickness from 2 to 40 feet. Waters under artesian pressure apparently are present in two distinct zones. Flow has been reported from depths as shallow as 80 feet, but usually the first artesian zone is encountered at about 250 feet. The deeper artesian zone extends from 600 feet to a known depth of about 1,400 feet. The similarity of chemical quality of waters from aquifers in the deeper zone indicates that these aquifers are interconnected.

Logs of artesian wells in the St. David-Pomerene area are given in table 13. These logs demonstrate that the artesian aquifers occur at several depths below land surface in the different parts of the artesian area. Near St. David, water under artesian pressure is encountered between 250 and 400 feet and below 580 feet. Only the deeper zone is reported to be present 6 miles south of St. David. Near Benson, the first artesian aquifers are encountered at depths ranging from 500 to 915 feet and there is only one report of an artesian aquifer at a depth of less than 500 feet. Near Pomerene, artesian aquifers are reported from 300 to 800 feet and may be divided into aquifers above 600 feet and those below 600 feet on the basis of differences in water quality. Correlation of these data suggests that the artesian aquifers below 600 feet are interconnected, whereas the sand and gravel beds in the upper zone between 300 and 600 feet are lenticular and discontinuous.

No quantitative data are available regarding artesian pressure heads. In many cases the water does not rise to the land surface in a well, but this may be caused by leaks in the casing below ground or the relatively high position of the land surface at the well.

Wells drilled in the valley outside the artesian areas also penetrate older alluvium. In contrast to the predominance of clays and silts in the older alluvium along the axis of the valley, progressively coarser-textured but less sorted materials are encountered in wells that are located farther from the axis and nearer the mountains. The clay layers encountered in such wells tend to be relatively thin. The log of well (D-21-20)33ab is considered representative of wells drilled into older alluvium along the margins of the valley. The log of well (D-24-21)11 shows the rapid alternation of fine and coarse beds that is characteristic of the older alluvium in the zone between the predominantly coarse beds higher on the flanks and the predominantly finer beds along the axis of the valley. A coarser phase of the older alluvial fill near Naco is shown by the log of well (D-24-24)18.

Bedrock below older alluvium.--In a few places, wells drilled through the older alluvial fill have encountered bedrock. The log of a well at Fairbank shows granite at a depth of 617 feet. A well drilled in the alluvial fill between the Tombstone Hills and the Mule Mountains entered pre-Tertiary limestone at 250 feet. The log of a well between the Canelo Hills and the Huachuca

Mountains shows volcanic rocks were encountered at 210 feet with some interbedded sediments below. The log of well (D-21-18)6c suggests that about 600 feet of older alluvium overlies pre-Tertiary sedimentary rocks that extend at least to 1,115 feet.

Cross sections

Two diagrammetric cross sections of the Upper San Pedro basin are presented in figure 8 to illustrate the structural and depositional characteristics of the ground-water reservoir. The cross sections are not to scale and the gradients are exaggerated, but they are representative of available geologic and hydrologic data. The cross section in figure 8A shows transverse relations across the valley in the alluvial fill of the Benson sub-basin. Figure 8B shows the longitudinal relations of the Charleston and Benson sub-basins along the length of the San Pedro River from the International Border to The Narrows.

Transverse cross section.--The cross section of the alluvial fill of the Benson sub-basin (figure 8A) shows the broad relations of the older alluvial fill to the enclosing mountains and to the Recent alluvial fill and the general relations of the clay and silt to the sand and gravel within it. Four hypothetical wells are shown to demonstrate several of the known relations encountered by drilling. The wells are identified by letters and the rock types by numbers.

Alluvial material occupies the structural trough between steep-sided mountain masses (1). The alluvial material is in depositional contact with the hard rocks of the mountains in most places, but in some places the contact is formed by faults. Small pediment areas (8) are shown underlying the outer margins of the alluvial fill along the mountain fronts. The shape and material of the bedrock underlying the structural trough is not known in sufficient detail to be shown.

The older alluvial fill is composed of coarse materials along the margins (3) that grade toward the axis of the valley into clay and silt (4). During some periods, conditions were such that coarser materials, either sand or gravel, were deposited clear across the valley (6). Within the clay and silt there are local lenses of sand or gravel (7).

The sequence of deposits along the axis indicates that, in general, a series of coarser detrital materials (6) was deposited between a lower (5) and an upper (4) series of clay and silt. Ground water in sand and gravel lenses interfingering with, or lying within, the upper clay and silt series (4) is sometimes referred to as the "upper artesian zone" and ground water between the two clay and silt series is sometimes referred to as the "lower artesian zone."

A single fault within the older alluvium is shown beneath the Recent alluvium to illustrate one avenue by which ground water from the older alluvium may seep into the Recent alluvium. Such a fault may be inferred from the presence of springs or seepage areas along the San Pedro River. The diagrammed fault shows a small amount of displacement.

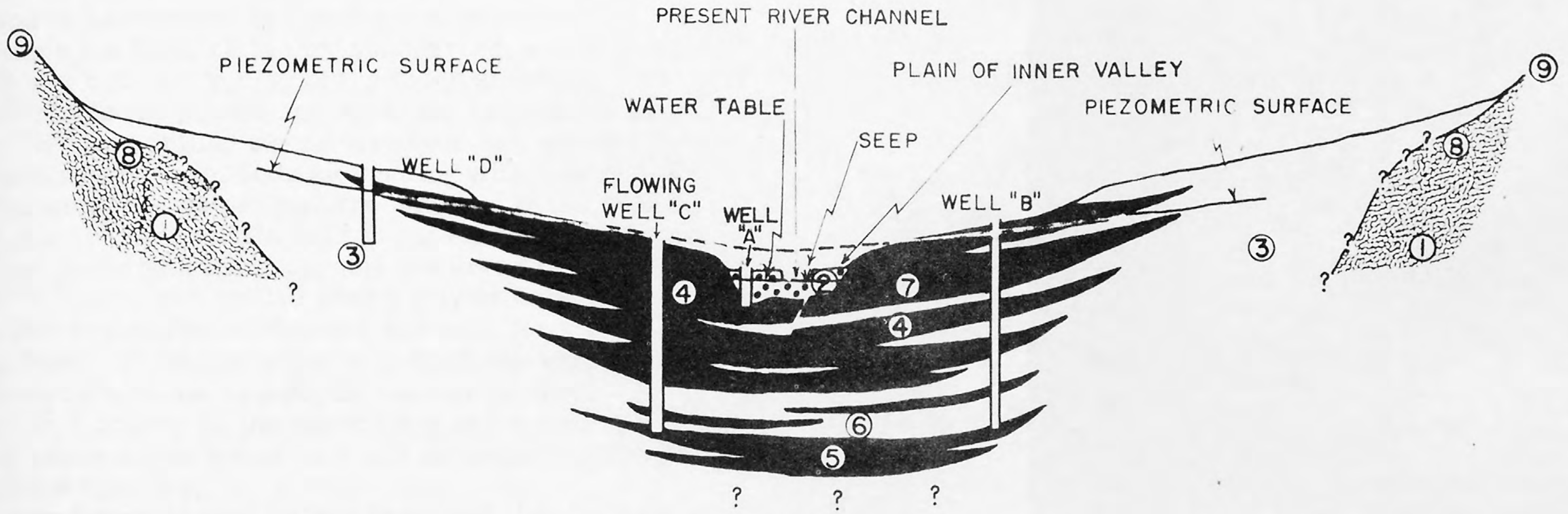


FIGURE 8A. —TRANSVERSE CROSS SECTION, BENSON SUB-BASIN

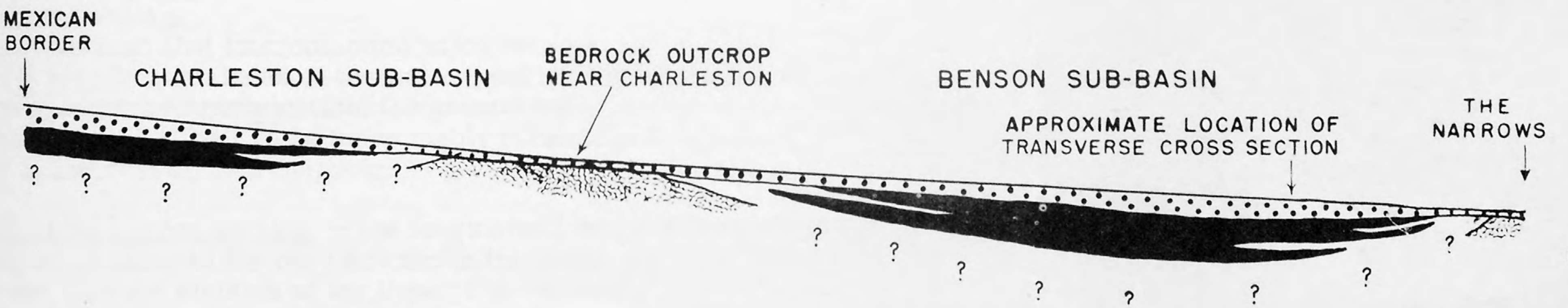


FIGURE 8B. —LONGITUDINAL CROSS SECTION, UPPER SAN PEDRO BASIN

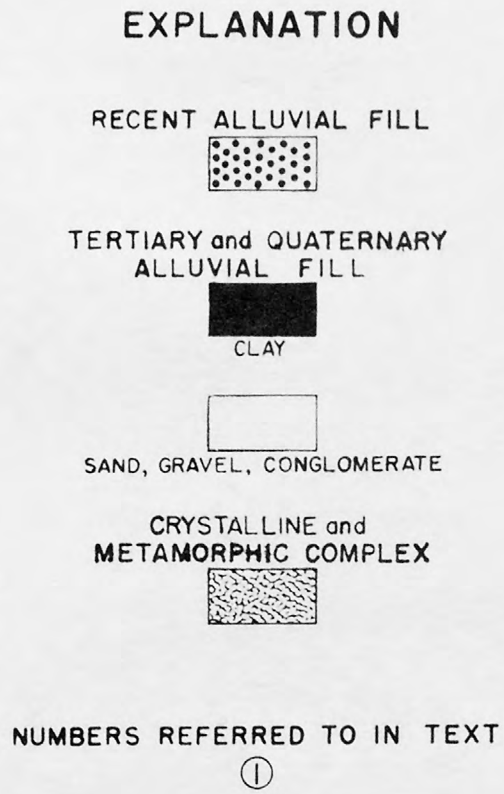


FIGURE 8. —DIAGRAMMATIC CROSS SECTIONS, UPPER SAN PEDRO BASIN, COCHISE COUNTY, ARIZONA

NOT TO SCALE

The older alluvium was incised by the channel of a through-flowing stream and then partly refilled by Recent alluvium (2) to form the flood plain of the inner valley. The coarser material of the Recent alluvium lies within the channel cut into the finer materials of the older alluvial fill. The Recent alluvium in turn has been incised by the present channel of the San Pedro River.

The artesian-pressure (piezometric) surface slopes toward the axis of the valley and is intersected by three hypothetical wells. A fourth well, "A," is drilled on the flood plain through coarser, variable materials of the Recent alluvium and bottoms in clay of the older alluvium. The water level in this well represents the position of the water table in the Recent alluvium.

Well "B" was drilled where clay beds are exposed and encounters six separate sand or gravel beds alternating with clay and silt. There is an artesian rise of the water from the aquifers to the level of the piezometric surface, but the hydrostatic head is not enough to make the well flow. Water is obtained from both the upper and the lower series of aquifers.

Well "C" also was drilled where clay and silt beds are exposed and is so located that it remains in clay and silt beds for a considerable proportion of its total depth. It obtains water only from the lower series of aquifers, and the land surface is low enough for the well to flow.

Well "D," drilled on the upper flank of the valley, penetrates coarse dry material above a thin bed of clay and encounters ground water in sand and gravel below the clay.

There is intercommunication throughout the ground-water reservoir in the alluvial fill, with the possible exception of some of the separated lenses shown within the upper series of clay and silt. Because of this intercommunication,. it is possible for the chemical quality of the water in artesian aquifers tapped by wells "B" and "C" to be similar to that of well "D," high on the flank of the valley.

It is assumed that intercommunication between the ground water in sand lens (7) and the remainder of the water-bearing beds is poor. Because of this lack of intercommunication, the ground water in lens (7) is not replenished readily and is likely to be more highly mineralized than most of the ground water in the rest of the reservoir.

Longitudinal cross section.--The longitudinal cross section (fig. 8B) illustrates the thinning of Recent alluvium in the lower end of the basin at The Narrows, and the division of the Upper San Pedro basin into the Charleston and Benson sub-basins. Crystalline and metamorphic rocks and pre-Tertiary sedimentary rocks crop out across the axis of the valley at The Narrows and west of Tombstone to form natural subdivisions of the drainage basin of the San Pedro River. These rocks are overlain depositionally by older alluvial fill adjacent to the areas of exposed bedrock. The relations at depth are not known.

The Recent alluvium is known to be thin where the San Pedro River scours through the exposed-bedrock areas and it thickens away from these exposures towards the middle parts of the sub-basins.

The gradation and interfingering of coarser to finer materials occur longitudinally as well as transversely (fig. 8B). The approximate location of the transverse cross section is indicated. The two sections are not to the same scale.

Ground-water hydrology

Source, occurrence, and movement

A discussion of the general aspects of ground-water hydrology is found in Part I of the report, under the heading "Regional hydrology."

The source of ground water in the Upper San Pedro basin is chiefly runoff from precipitation in the mountains and surface flow in the San Pedro River. Although ground water occurs in all the rocks shown on the geologic map (pl. 9), practically all of the ground water in the basin is in the alluvial fills. Domestic and stock wells obtain water from all rock types, but water for irrigation is obtained only from the older and Recent alluvial fills. Movement of ground water is toward the center of the valley from the flanks, and from south to north along the axis.

Recharge

Ground-water recharge to the Recent alluvial fill occurs from: (1) Precipitation and runoff; (2) surface flow in the river; (3) underflow; (4) seepage from irrigated areas; and (5) movement of ground water from older fill to Recent fill.

Precipitation and runoff.--Recharge from direct infiltration from precipitation on the valley floor is believed to be negligible. Most recharge is believed to occur from infiltration of runoff along the mountain fronts and in the central drainage channel of the valley. Only recharge from runoff along the mountain fronts is considered in this section; recharge from surface flow in the central drainage channel is considered separately.

In the Upper San Pedro basin, the mountain areas contain about 500 square miles of the total area of about 1,850 square miles. Mean annual precipitation in the Upper San Pedro basin ranges from about 11 inches at Benson to about 26 inches in the Huachuca Mountains. Estimates of recharge from runoff in the mountain areas are made separately for the Charleston and Benson sub-basins because conditions in the two sub-basins relating to this runoff are somewhat different.

The Charleston sub-basin is the smaller of the two and has a higher ratio of mountain area and a higher average rainfall in the mountains. About 185 square miles of mountain area in the Charleston sub-basin receive an estimated average annual rainfall of about 18 inches, or about 175,000 acre-feet of precipitation annually. Runoff from precipitation in the mountain areas is estimated to be between 8 and 15 percent of the precipitation in the mountain areas (Part I, this report). Using these percentages, the runoff at the mountain fronts in the Charleston sub-basin is estimated to be from 14,000 to 25,000 acre-feet per year. As much as 50 percent of the runoff at the mountain front is recharged to the alluvium in other places in the State.

Assuming the figure of 50 percent is applicable in the Charleston sub-basin, recharge from runoff originating in the mountains is estimated to be from 7,000 to 12,000 acre-feet per year. Because of the higher elevation of the mountains, the greater rainfall, and the greater length of time snow stays on the ground in the Charleston sub-basin, it is possible that the higher figure may more nearly approach the annual recharge.

In the Benson sub-basin, the mountain area of about 300 square miles receives and average annual rainfall of about 16 inches, making a total precipitation of about 250,000 acre-feet per year. Using the same assumptions that were applied to the Charleston sub-basin, recharge from precipitation in the Benson sub-basin is estimated to be in the order of 12,000 acre-feet per year.

Total recharge along the mountain fronts in the Upper San Pedro basin thus is estimated to be from 20,000 to 25,000 acre-feet per year.

Surface flow in the river.--The quantity of recharge to the Recent alluvial fill from surface flow of the San Pedro River in the basin could not be determined on the basis of available data. The data indicate the river gains in flow through the basin. It is possible that this gain is represented in part by effluent seepage from the Recent alluvium. However, if runoff originating within the basin were greater than the indicated gain, the river could recharge the ground-water reservoir.

The gaging station nearest the International Boundary is at Palominas, 4½ miles north of the boundary. For the present report the discharge of the San Pedro River at Palominas is assumed to represent surface flow into the Upper San Pedro basin. The 10-year period 1932-41 was chosen to conform with comparable data for the lower basin. During this period the average flow at Palominas was about 26,000 acre-feet per year (Water-Supply Papers 879, p. 233; 899, p. 248; 929, p. 267; and 1049, p. 336). At the gaging station at Charleston, the annual flow during the same period averaged about 45,000 acre-feet per year. The flow out of the basin, at The Narrows, was computed to average about 45,000 acre-feet per year during the same 10-year period, plus or minus an error of about 20 percent. This computation was based on data from existing gaging stations, none of which is at The Narrows.

Thus, insofar as the data are accurate, an estimated average net gain in surface flow of about 20,000 acre-feet per year occurred within the San Pedro basin during the 10-year period 1932-41. The data from the station at Charleston indicate that, on the basis of average flow, all of the gain occurred between Palominas and Charleston. The data also indicate that no average net gain occurred between Charleston and The Narrows, although in some years there were net gains or losses in the reach.

Underflow.--Underflow moves into the ground-water reservoir of the Upper San Pedro basin at the International Border. There, the saturated cross section of the Recent alluvium in the channel of the San Pedro River is about half a mile wide and 100 feet deep. Average coefficients of permeability for channel fill in the Safford basin range from 1,000 to 5,000 (Turner and others, 1941, p. 45). As the channel materials are similar, it is assumed that these permeability coefficients are applicable to the Upper San Pedro basin. The gradient of the water table is about 13 feet per mile. On the basis of these figures, underflow through the channel is calculated to be between 700 and 3,500 acre-feet per year. An intermediate figure, 2,000 acre-feet per year, is adopted as the best estimate possible at present. At Charleston the channel fill is probably less than 50 feet deep and the underflow is considered neglibible.

Underflow may be occurring into the San Pedro basin from the Sonoita basin, west of the head of the Babocomari River, but no data are available to confirm this movement.

Seepage from irrigated areas.--In 1952 there was a total of 5,600 acres of cultivated land in the Upper San Pedro basin; of this total, 4,000 acres was in the Benson sub-basin. If the data on infiltration rates in Safford basin were directly applicable to the Upper San Pedro basin, about 25 percent of the water applied to the land for irrigation is recharged. It was believed by the author that this figure should be revised downward for the Upper San Pedro basin and, therefore, a figure of 15 percent was assumed. About 17,000 acre-feet of ground water is used each year for irrigation, and recharge from this source was estimated to be about 2,500 acre-feet annually. Of this total, about 1,800 acre-feet is considered to have been recharged in the Benson sub-basin and 700 acre-feet in the Charleston sub-basin.

Movement from older fill to Recent fill.--According to calculations from present data, recharge to the Recent alluvial fill as upward seepage from the older alluvial fill is in the order of 8,000 acre-feet of water per year.

It is believed that similar ground-water movement from the older fill to the Recent fill occurs in the Benson sub-basin, but data are not available by which the quantity can be evaluated.

Discharge

Discharge in the Upper San Pedro basin is discussed under the following headings: (1) Wells; (2) evapotranspiration; (3) underflow; and (4) springs.

Wells.--Discharge from wells may be divided as follows: (1) Domestic and stock wells; (2) irrigation wells; (3) industrial wells; and (4) wells used by municipalities and military installations.

Domestic and stock wells.--Pumpage from domestic and stock wells in the Upper San Pedro basin is not accurately known, but is estimated to be in the order of 1,500 acre-feet per year. Of this total, about 1,200 acre-feet is considered to be withdrawn in the Benson sub-basin. These figures are derived from an estimate that 1,000 acre-feet is withdrawn for domestic and stock use per year in the Lower San Pedro basin, where more data are available. The Upper San Pedro basin is more densely populated than the Lower San Pedro basin, and has a larger area of range land. Therefore, pumpage for domestic and stock use in the Upper San Pedro basin is believed to be greater.

Irrigation wells.--No accurate data regarding annual withdrawals of ground water for irrigation are available for the Upper San Pedro basin. There are two irrigated areas: St. David-Pomerene and Palominas-Hereford (pl. 9). Ground water is withdrawn from both the artesian and the nonartesian aquifers.

As the crops raised in the Upper San Pedro basin generally are of a type that use less water than the type of crops raised in other parts of Arizona, the duty of water is estimated to be 3 acre-feet per acre. The 4,000 acres of land cultivated in the St. David-Pomerene area in 1952, therefore, used about 12,000 acre-feet, and the 1,600 cultivated acres in the Palominas-Hereford area used about 5,000 acre-feet.

Incomplete pumpage data from the areas suggest that in the St. David-Pomerene area about 4,000 acre-feet of the total is withdrawn from the artesian aquifers and 8,000 acre-feet from the nonartesian aquifers. In the Palominas-Hereford area about 4,000 acre-feet is estimated to be withdrawn from deeper aquifers and 1,000 acre-feet from the nonartesian aquifers.

Industrial wells.--Railroads pump about 600 acre-feet per year from artesian and shallow wells. Most of this pumpage, about 500 acre-feet, is from the artesian basin at Benson. No large-scale mining operations were withdrawing water in the Upper San Pedro basin at the time this report was prepared.

Wells used by municipalities and military installations.--Benson withdraws about 250 acre-feet annually from artesian wells for municipal use. The water used in other communities is not included in this section. Tombstone brings water by pipe line from springs in the Huachuca Mountains. Pomerene, St. David, and the other smaller communities are supplied by individual domestic wells.

In 1941, about 2,000 acre-feet was pumped from wells in the older alluvium at Fort Huachuca. During World War II, additional wells were drilled to supply increased demands. After the war the use of ground water at Fort Huachuca dropped to below the 1941 level, although for purposes of this report the 1941 consumption data are used.

Yields from wells.--Yields from irrigation wells in the Recent alluvium may be as high as 2,000 gallons per minute, but are commonly between 500 and 1,000 gallons per minute. Yields from wells in the older alluvial fill, including the artesian areas, are generally smaller than yields from Recent alluvium. Yields from the older alluvial fill may range up to 400 gallons per minute from wells located on the flanks of the valley and up to about 1,000 gallons per minute from artesian wells along the axis of the valley. The greater yields from wells along the axis may appear to contradict the concept that the coarsest materials are along the margins of the basin. However, this apparent discrepancy can be explained by considering that wells along the axis generally penetrate a greater total thickness of aquifer and consequently have a higher specific capacity. Furthermore, larger pumps generally are used in the wells along the axis than in the wells along the margins.

Within the St. David-Pomerene artesian area, the yields from flowing wells average about 6 gallons per minute. Original flows of as much as 200 gallons per minute have been reported, but no well in the area is now reported to flow more than 40 gallons per minute. Many of the flowing wells are pumped to increase their yield. The small yields may be due in part to the small diameter of the casing, in many wells as small as $1\frac{1}{2}$ inches. Other factors that have resulted in reduced yields include caving and sanding within the cased or uncased wells.

Artesian flow is seasonal and the greatest flow is during the winter.

Evapotranspiration.--Discharge of ground water by evapotranspiration is estimated only for the San Pedro River flood plain. The flood plain has an area of about 21,700 acres; in addition, 3,200 acres is occupied by the river channel. About 5,600 acres of the flood plain is cultivated and the remainder, about 16,000 acres, is overgrown by nonbeneficial vegetation. Of these 16,000 acres, 5,000 acres is in the Charleston sub-basin and 11,000 is in the Benson sub-basin.

Data presented in Part I under "Regional hydrology" are used to prepare an estimate of evapotranspiration of ground water in the Upper San Pedro basin. Annual consumptive use of water by phreatophytes of 100-percent density is estimated to be about 3.5 acre-feet per acre, of which 1 acre-foot per acre is from rainfall, and 2.5 acre-feet per acre is from ground water. The density of phreatophytes is estimated to be about 20 percent in the Charleston sub-basin and about 40 percent in the Benson sub-basin. Corrected to 100-percent density, the phreatophyte area in the Charleston sub-basin is about 1,000 acres and in the Benson sub-basin about 4,400 acres. The annual consumption of ground water by evapotranspiration in the Charleston sub-basin is therefore estimated to be about 2,500 acre-feet, and in the Benson sub-basin, about 11,000 acre-feet. Evaporation from the river surface and wetted sand bars was estimated to average about 0.5 acre-foot per acre, or about 1,500 acre-feet per year. The total is, therefore, about 15,000 acre-feet per year.

Underflow.--Underflow out of the Upper San Pedro basin at The Narrows is estimated to be between 40 and 200 acre-feet per year. The derivation of this quantity is given in the next section, on the Lower San Pedro basin.

The possibility of ground-water movement westward from the Upper San Pedro basin to the Upper Santa Cruz basin through the alluvial saddle between the Rincon and Whetstone Mountains is considered to be remote. Outcrops of crystalline rocks and pre-Tertiary sedimentary rocks across the saddle immediately west of the drainage divide suggest that a bedrock barrier exists.

Springs.--Incomplete data regarding springs indicates a total discharge of about 3,000 acre-feet per year. About 2,000 acre-feet of this discharge is estimated to occur in the Charleston sub-basin and 1,000 acre-feet in the Benson sub-basin. The total ground-water discharge from springs in the Charleston sub-basin includes about 200 acre-feet per year piped to Tombstone and about 400 acre-feet per year piped to Fort Huachuca.

Storage

The terms "latent storage" and "underlying storage" are explained in Part I of this report under "Regional hydrology." The concept of underlying storage is not applied to the Upper San Pedro basin because the water withdrawn from the Recent alluvial fill for irrigation purposes is not, strictly speaking, withdrawn from storage; it is withdrawn from a supply that currently is completely replenished each year by recharge.

A marked contrast exists between the Upper San Pedro basin and, for example, the Salt River Valley area and the Lower Santa Cruz area, where the concept of underlying storage applies. In those basins, the withdrawal of ground water is from alluvium beneath a large area, and the quantity in storage is high in proportion to the amount of recharge. Progressive declines in the water table in such basins indicate that ground water is being removed from storage. In contrast, in the Upper San Pedro basin, cultivated areas are relatively small and withdrawals are not high in proportion to the amount of recharge. There is generally enough recharge from surface flow to replace completely the amount of water withdrawn. So far, no persistent annual declines in the water table have been discovered.

A second complication in the application of underlying storage to the Upper San Pedro basin is that the water for irrigation is obtained from two distinct sources; nonartesian aquifers in the Recent alluvium, and artesian aquifers in the older alluvium. Artesian aquifers occur both within the upper 300 feet of the zone of saturation, and below.

The third complication in applying the concept of underlying storage to this basin is the fact that cultivated lands in the basin are widely separated and cannot readily be grouped into a unified area. Most of the cultivated land is in small discontinuous areas along the flood plain of the San Pedro River. In addition, a few scattered areas are farmed in the Palominas-Hereford area above the flood plain, and along some of the larger tributaries, such as the Babocomari River. In consideration of these difficulties, no estimate for underlying storage is made in this section.

Storage of ground water in the Upper San Pedro basin is discussed as latent storage, as outlined in Part I, "Regional hydrology," except that separate estimates are made for the older alluvium and for the Recent alluvial fill along the main channel of the San Pedro River. Estimates of storage in pre-Tertiary and crystalline rocks could not be made. Partial data are available for total quantities withdrawn in one area over a period of several years.

Latent storage in older alluvium.--The alluvium occupies about 860,000 acres, of which 25,000 acres is Recent alluvium, and the balance is older alluvium covered by a thin veneer of reworked material. It is assumed that in this area of older alluvium there are at least 300 feet of saturated sediments below the 1952 water table. The latent storage is computed only for this 300-foot section of saturated sediments. The older alluvium contains much silt, clay and cemented material, and therefore it is believed that the coefficient of drainage is much less than in many basins in southern Arizona, possibly as low as 2 percent. Some artesian aquifers occur within this 300-foot section, and the water stored in them is included in the computation for latent storage. The latent storage in this 300-foot section of older alluvial fill is estimated to be about 5,000,000 acre-feet. If the coefficient of drainage were as much as 6 percent, the quantity would be about 15,000,000 acre-feet.

Latent storage in Recent alluvium.--About 25,000 acres is underlain by the Recent alluvial fill along the San Pedro River. The saturated thickness of the Recent fill along the river is estimated to average about 40 feet, on the basis of well logs. The coefficient of drainage is estimated at 15 percent, on the basis of data given in table 3. Latent storage in Recent alluvium along tributary washes is small and has been included in the calculations of storage in older alluvium. The amount of ground water in latent storage in Recent alluvium along the San Pedro River is estimated to be about 150,000 acre-feet.

Storage within pre-Tertiary sedimentary rocks.--It has been reliably reported that 12 billion gallons was pumped out of the Tombstone mines during the period 1903-11, the time of greatest pumping. Average pumping was at a rate of about 3,000 gallons per minute, or 4,500 acre-feet per year. It is also reported that it required from 5 to 7 years for the withdrawn water to be replaced by recharge.

Water-level fluctuations

Water-level measurements have been made in only a few wells in the basin for periods long enough to show trends. An expanded program of well measurements was begun in 1950, but does not yet provide data adequate for a full discussion of fluctuations. Hydrographs of wells that have been measured for extended periods are shown on figure 9. These graphs and other well information provide the basis for a few generalities: (1) In most parts of the basin, fluctuations are seasonal and no persistent decline in the water table has been detected; (2) in the St. David-Pomerene area, recharge to the artesian aquifers may be slightly less than withdrawals; (3) recharge to aquifers in the Recent alluvium, especially in areas near the mountain fronts, follows very closely upon flood runoff; and (4) records are not complete enough to show the effect of recently increased pumping upon the water table in the Recent alluvium under the flood plain of the San Pedro River.

Hydrographs of wells (fig. 9) illustrate the tendency for water levels in wells in the basin to recover, after temporary declines, to about the level prevailing when measurements were begun. Rapid recharge of aquifers in Recent alluvium is shown by hydrographs of wells (D-23-21)6cc, (D-21-21)11aa, and (D-20-20)32cd. The latter well, located adjacent to the Babocomari

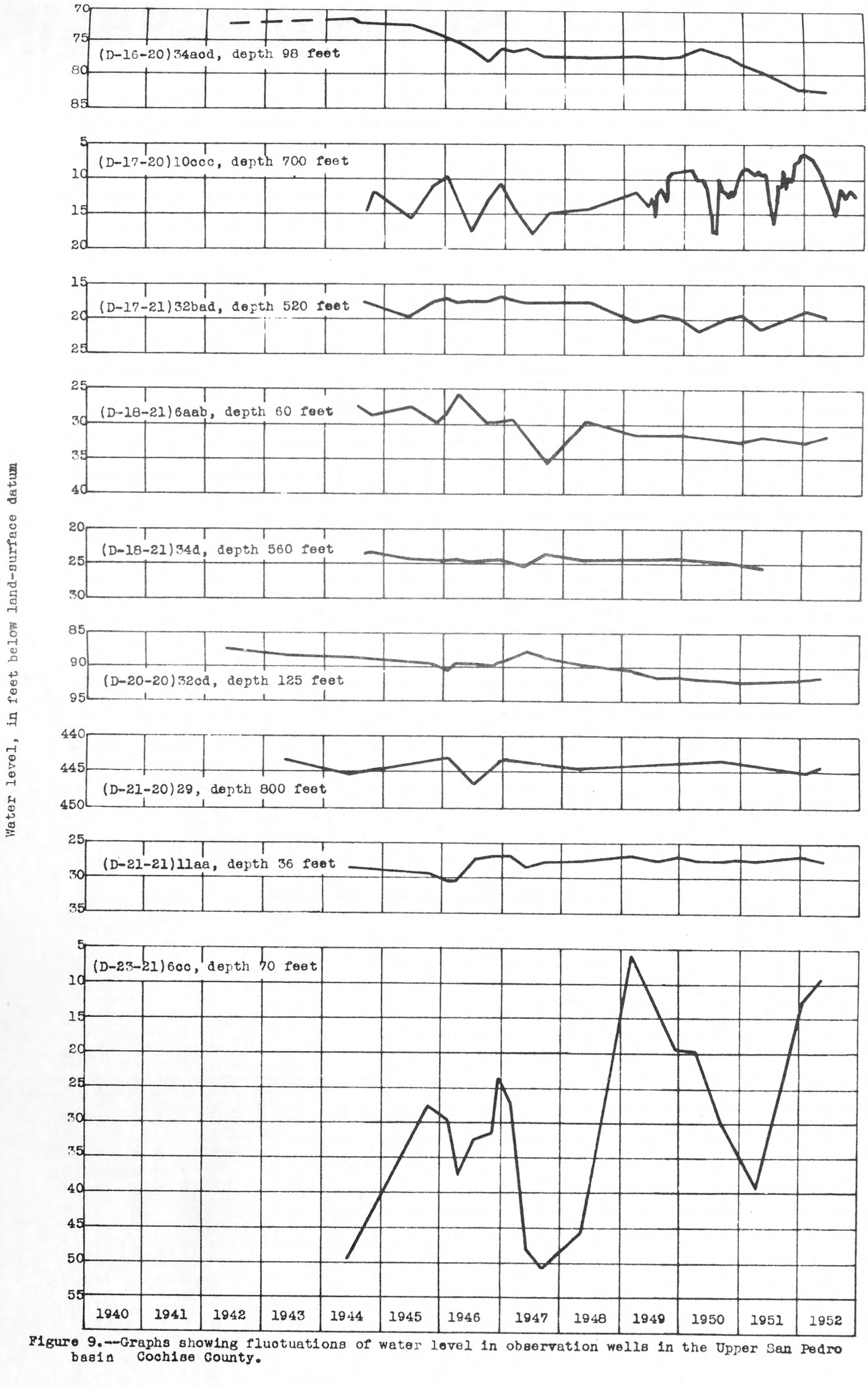


Figure 9.--Graphs showing fluctuations of water level in observation wells in the Upper San Pedro basin Cochise County.

River, is especially significant in that slight rises in water levels are indicated in 1951-52 in spite of the fact that during that period two small irrigation wells were in use nearby. The cones of depression caused by pumping from those irrigation wells either did not extend far enough to influence the water level in well (D-20-20)32cd, or the effect was more than compensated for by natural recharge.

The hydrograph of well (D-16-20)34acd2 shows a drop in water level during 1951-52 that may reflect either conditions of low runoff in the San Pedro River, or increased withdrawal from Recent alluvium of the flood plain near Pomerene, or both.

Declines in pressure head in artesian wells near St. David and Pomerene are illustrated by hydrographs of wells (D-18-21)34d and (D-17-21)32bad.

(D-17-20)10ccc is a recorder observation well located in Benson at an elevation of about 3,610 feet and about 110 feet above the level of the San Pedro River. The artesian water level stands at an average of 10 feet below the surface. When the well was drilled in 1908, it flowed 20 gallons per minute. The erratic fluctuations may be due to heavy local use of artesian water, to possible recharge from local sources, or to other causes not determined.

Well interference.--There are no quantitative data in the Upper San Pedro basin on well interference. However, decrease or cessation of flow is reported in many artesian wells at times when heavy withdrawals are made from nearby artesian wells.

Quality of water

About 100 analyses of surface and ground waters are available for the Upper San Pedro basin. Most of the analyses were made in 1921 and 1934, and it is not known to what extent these old analyses may represent present conditions. A few were made between 1941 and 1951, particularly from the Fort Huachuca area during World War II. Analyses characteristic of waters in the Upper San Pedro basin are given in table 14.

Most of the waters of the basin contain moderate amounts of dissolved mineral matter, ranging in concentration from 200 to 400 parts per million and composed mostly of calcium, sodium, and bicarbonate. The extremes in dissolved solids are 71 and 3,680 parts per million.

The ground water in the Upper San Pedro basin is generally satisfactory for most purposes except that some waters have a high sulfate content. Waters containing large amounts of sulfate generally are hard. The fluoride content in some artesian waters and in some spring waters from faulted crystalline and older sedimentary rocks is higher than the limit of 1.5 parts per million for domestic use.

No appreciable changes were detected in quality of waters from wells sampled in 1921 and in 1934. No samples have been collected since that time from wells previously sampled.

Quality of nonartesian water

Nonartesian waters are obtained from three sources: (1) Rocks of the mountains; (2) older alluvial fill; and (3) Recent alluvium.

Waters from crystalline and pre-Tertiary sedimentary rocks (table 14), are comparatively low in total mineral content, except where the waters, (D-17-23)18a, and (D-15-21)18dcb, issue from fractured zones which may be associated with faulting. Water from limestone, (D-22-20)31a, contains mostly calcium and bicarbonate.

Many nonartesian waters from the older alluvial fill are only moderately mineralized, the total dissolved-solids concentrations ranging from 150 to 350 parts per million. However, some of these waters, such as that from well (D-16-20)7c, contain large amounts of calcium and sulfate. Water in the Recent alluvial fill is of good quality and generally contains less than 300 parts per million of dissolved solids.

Quality of artesian water

The quality of water obtained from artesian aquifers in the basin is varied. Waters in the Palominas-Hereford area, (D-23-22)15b, and in the St. David vicinity, (D-17-21)31da2, are similar, except that the fluoride content is higher and the waters are softer near St. David. The total mineral content in samples from artesian sources in these two areas ranges from about 150 to 250 parts per million. In the vicinity of Benson and Pomerene, the quality of water from aquifers at depths less than 600 feet differs from that observed for water at greater depths. The water from aquifers above 600 feet have mineral contents of about 3,000 parts per million, principally calcium and sodium sulfates. These aquifers appear to be limited in yield as the water becomes rapidly diluted when mixed with water from below 600 feet when the well casing is perforated at both horizons. This dilution is illustrated by analyses (D-17-20)9cbc, (2), (3), (4), (5) which represent samples taken at progressively greater depths during the drilling of the well. Analyses (D-16-20)34dab, (1), (2) show a decrease from a dissolved-solids concentration of 3,680 to 251 parts per million when the well had been in use over a period of a few months and after pumping had flushed away the waters of higher concentration.

The high-sulfate and low-bicarbonate waters from the upper artesian aquifers are similar in composition to water from the spring, (D-16-20)7c, which issues from gypsiferous silt and clay. The deeper artesian aquifers, which contain the low-sulfate and high-bicarbonate waters, are composed of arkosic gravels. Some of the waters from the deeper artesian aquifers of the older alluvial fill are similar in composition to some waters from the upper margin of the older alluvial fill.

Ground-water--surface-water interrelations

The data on surface flow in the river unavoidably were based on the 10-year period 1932-41. These data are considered to be applicable currently in their relation to the hydrology of the basin, because comparatively little development of the ground-water supplies has occurred since 1941.

At the present time the Upper San Pedro basin is considered to be essentially in hydrologic balance. More water enters the basin than is used within it and the remainder leaves as surface flow. The close interrelationship between surface water and ground water in the basin is shown by the rapid recharge of aquifers in the Recent alluvium. Increased consumptive use of ground water would tend to decrease the total amount of surface flow to the Lower San Pedro basin. In those reaches where the San Pedro River has perennial flow, it appears probable that the ground water in the Recent alluvium will not be depleted unless withdrawals are increased to the point where the river ceases to flow.

Problems

Special problems and additional studies

A detailed understanding of hydrologic conditions and problems in the Upper San Pedro basin would require extensive geologic study and the collection of many basic hydrologic data. These studies would have to include areal geologic mapping, additional rainfall and runoff data, water-level measurements, determination of elevations at measuring points, water analyses, pumping tests, and related observations.

There are large areas for which there is little or no hydrologic information. One of the most important of these is the area near Tombstone; another is near Naco. There are insufficient data to determine the amount of possible underground movement from the Sonoita basin into the Upper San Pedro basin.

The constricted opening at The Narrows through which surface flow leaves the Upper San Pedro basin provides an opportunity to determine accurately those hydrologic conditions in both the Upper and Lower San Pedro basins that are related to surface flow and underground flow between the two basins.

In the artesian areas, the number of water-bearing beds, and their physical properties, occurrence, and areas of recharge should be carefully studied. From the information it should be possible to determine the amount of ground water that can be withdrawn annually.

One continuous recorder is in operation in Benson and the relation of water-level fluctuations in this well to precipitation and runoff should be determined. Marked differences in chemical quality of water in the upper and lower artesian aquifers have been determined. On the other hand, the quality of waters from the deeper artesian aquifers is remarkably similar to the average quality of nonartesian water from the older alluvial fill. These facts suggest two possibilities: (1) that recharge to both upper and lower artesian aquifers may take place in the same area, and differences in chemical quality have resulted by movement of the water through materials of different composition; or (2) that recharge to the two aquifers may be in separate areas. Investigation of this problem might make it possible to practice artificial recharge of the shallower aquifers in local areas.

Methods of increasing or conserving ground-water supplies

The possibility of a dam at Charleston for the purposes of flood control and storage of water for municipal use has been discussed by several agencies. Recharge in the Benson sub-basin and the Lower San Pedro basin is dependent in part on surface flow of the San Pedro River. Any depletion or regulation of this flow would result in changes in the hydrologic balance downstream. The suitability of the project must be evaluated in terms of the probable effect of these changes.

There is some waste of ground water in the St. David-Pomerene area through uncontrolled flow from artesian wells. New wells should be properly cased and equipped so as to control flow. It is questionable whether control of the old wells could be effective because of leakage at depth.

Locally, artificial recharge could be effected in the gravel-floored washes along the mountain front by retarding runoff. The possibility of artificial recharge to artesian aquifers in the Benson area has been mentioned.

Summary

The Upper San Pedro basin is bounded by drainage divides in the mountains on the east and west, by the International Border on the south, and by a hard-rock barrier at The Narrows on the north. It is drained by the north-flowing San Pedro River which continues past The Narrows into the Lower San Pedro basin. The Upper San Pedro basin is about 58 miles long and has an area of about 1,850 square miles; about 1,350 square miles is underlain by alluvial fill and about 500 square miles by bedrock. The area has been subdivided into the Charleston and Benson sub-basins in the vicinity of Charleston, along a line that separates tributary drainage areas, and where bedrock is near the surface.

The valley of the Upper San Pedro basin is a structural trough partly filled with alluvial material of at least two different periods of deposition. The older alluvial fill has been incised by stream channels which have been partly refilled with Recent alluvium. The flood plain thus formed averages about half a mile in width along the San Pedro River. A total of 5,600 acres on this flood plain was cultivated in 1952.

The average flow of the San Pedro River into the Charleston sub-basin at Palominas is about 26,000 acre-feet per year. Surface flow out of the sub-basin at Charleston is about 45,000 acre-feet per year. This increase indicates that the total gain of water to the river from all sources in the sub-basin exceeds the total amount used by about 20,000 acre-feet per year.

Surface flow out of the Benson sub-basin at The Narrows is about 45,000 acre-feet per year. The lack of net loss of surface flow in the Benson sub-basin indicates that recharge and runoff are essentially in equilibrium with all discharge, except surface flow, from the sub-basin.

Ground water in the Upper San Pedro basin is obtained from both the Recent and older alluvial fills. Along the axis of the valley, water in the older alluvium is under sufficient hydraulic head to flow or to rise to within a few feet of the land surface. Two artesian areas are designated; St. David-Pomerene, and Palominas-Hereford.

Recharge in the area occurs predominantly from runoff. Minor sources of recharge are underflow and seepage from irrigated fields. Discharge of ground water is predominantly by non-beneficial evapotranspiration. The second largest use of ground water is for irrigation, and small amounts are discharged by pumping for other purposes and by underflow out of the basin.

Latent storage in the Recent alluvial fill is estimated to be 150,000 acre-feet. Latent storage in the upper saturated 300 feet of the older alluvium is estimated to be about 5,000,000 acre-feet. In most parts of the basin, fluctuations of the water table are seasonal, and no persistent decline can be detected except in the St. David-Pomerene artesian area, where slight declines have occurred. Data are not available to evaluate the effect of increased pumping from the Recent alluvium during the past two years.

Ground waters in the Upper San Pedro basin are generally of good quality; dissolved solids average from 200 to 400 parts per million. A few waters are high in sulfate and sodium and many waters are relatively high in calcium and bicarbonate. Locally, the fluoride content is more than 1.5 parts per million, which makes the water unsatisfactory for drinking by children.

Geologic and hydrologic data for the Upper San Pedro basin are incomplete. Special problems include: (1) The relation of precipitation to runoff and recharge; (2) the relation of perennial and intermittent flow of the San Pedro River to recharge; (3) the possibility of artificial recharge to artesian aquifers; and (4) the control of waste and leakage from artesian aquifers.

Table 12.--Records of representative wells and springs in Upper San Pedro basin, Cochise County, Ariz.

Well or spring no.	Depth of well (feet)	Water level: Depth below land-surface datum (feet) a/	Water level: Date of measurement	Type of lift b/	Use of water c/	Analysis on file	Log on file	Remarks
(D-15-19)								
21c	g/	-	-	-	-	X	-	Spring; aquifer, schist.
(D-15-21)								
18dcb	100	d/ 98	7-51	J,G	S	X	-	Discharge, 2 gpm, 7-51.
(D-16-19)								
11d	g/	-	-	-	D,S,I	X	-	Spring; aquifer, sandstone within clay beds. Discharge, 1 gpm estimated.
17ab	75	69.27	5-51	J,W	S	X	-	Dug well, 4'x4'. Discharge, 1½gpm, 5-51.
(D-16-20)								
6dcc	700	Flows	10-50	-	N	-	-	Discharge, trickle.
7bdb	78	d/ 50	10-50	T,D	D,S,I	X	-	Discharge, 600 gpm.
7c	g/	-	-	-	D,S	X	-	Spring; aquifer, clay beds. Discharge ¼ gpm estimated.
27b	590	-	-	-	-	-	X	-
34acd1	117	d/ 87	-	T,G	I	-	X	-
34acd2	98	82.81	4-52	C,W	D	-	-	See hydrograph, Fig. 9.
34dab	1000	-	-	-	P	X(2)e/	X	-
34dba	750	d/ 16	1934	T,E;C,W	P	-	X	-
(D-16-22)								
15ac	g/	-	-	-	S	X	-	Spring; aquifer, granite. Discharge, 1 gpm estimated.
(D-16-23)								
19cb	565	d/400	3-50	-	RR	-	X	-
(D-17-19)								
17ab	1550	-	-	-	S	-	X	Oil test.
(D-17-20)								
9adc	1000	f/ 11.6	7-46	T,EandG	P	-	X	Flow, 35 gpm; pump, 450 gpm, 7-46.
9cbc	1088	d/ 49	10-46	-	D	X(5)e/	X	-
9dd	1505	d/ 13	1921	-	-	-	-	Lake beds; main water from 902-938 and 1337-1371.

a/ Depth was adjusted to land-surface datum from measuring point.
b/ J, jack; T, turbine; D, diesel; E, electric; G, gas; W, windmill.
c/ D, domestic; I, irrigation; Ind., industrial; N, not used; P, public supply; RR, railroad; S, stock.
d/ Reported water level.
e/ Number of depths from which water analyses are on file.
f/ Pressure level above land surface. g/ Spring.

Table 12.--Records of representative wells and springs in Upper San Pedro basin--continued.

Well or spring no.	Depth of well (feet)	Water level: Depth below land-surface datum (feet) a/	Water level: Date of measurement	Type of lift b/	Use of water c/	Analysis on file	Log on file	Remarks
(D-17-20)								
10cac	1068	f/ 5	1946	T,E	P	X	--	Flow, 35 gpm.
10ccc	700	15.55	6-49	--	--	--	--	See hydrograph, Fig. 9.
10dd	707	--	--	--	--	--	X	--
18da	627	d/520	1951	J,G	RR	X	X	Discharge, 400 gpm, 1951.
(D-17-21)								
15c	1000	325	1946	Airlift,D	RR	--	X	Discharge, 100 gpm, 1946.
31da2	380	Flows	1934	--	D,S,I	X	X	Discharge, 2 gpm, 2-34.
32bad	520	18.34	9-44	J,W	D,S	--	--	See hydrograph, Fig. 9.
32dcd	1012	Flows	10-48	T,E	P,I	--	X	Flow, 11 gpm; pump, 350 gpm, 10-48.
32dd	200	5.29	2-47	J,EandW	D	X	--	Discharge, 9 gpm, 9-44.
(D-17-23)								
18a	g/	--	--	--	D,S,I	X	--	Spring, aquifer limestone. Discharge, 3 gpm estimated.
(D-18-21)								
6aab	60	31.74	5-52	J,W	I	--	--	See hydrograph, Fig. 9.
7aa	760	d/ 16	1942	T,E	Ind.	--	X	--
28c	470	Flows	--	--	I	½	X	Discharge, 8 gpm, 6-47.
28db5	105	d/ 70	7-46	--	I	--	X	--
33cb	625	Flows	6-47	--	--	--	X	--
34d	560	25.62	5-52	--	N	--	--	See hydrograph, Fig. 9.
(D-20-20)								
32cd	125	91.07	5-52	--	N	--	--	See hydrography, Fig. 9.
(D-20-21)								
3cd	623	d/ 37	1909	--	RR	--	X	--
15a	--	d/ 12	1934	J,W	D	X	--	Dug well.
(D-21-18)								
6c	1115	--	--	--	--	--	X	Oil test.
7	774	d/ 29	11-51	--	I	--	X	--
(D-21-20)								
29-1	802	--	--	--	--	X	--	--
29-2	800	444.21	5-52	T,E	P	--	--	See hydrograph, Fig 9.
33ab	912	460	1-42	--	--	--	X	Test well.

Table 12.--Records of representative wells and springs in Upper San Pedro basin--continued.

Well or spring no.	Depth of well (feet)	Water level: Depth below land-surface datum(feet)a/	Water level: Date of measurement	Type of liftb/	Use of waterc/	Analysis on file	Log on file	Remarks
(D-21-21) 11aa	36	27.14	5-52	J,W	D	–	–	See hydrograph, Fig. 9; dug well, 48" diameter.
(D-21-22) 20d	g/	–	–	–	S	X	–	Spring; aquifer, Recent fill. Discharge 100 gpm estimated.
(D-21-23) 29bdb	973	d/400	12-49	–	D,S	–	X	Water rose from 955'.
(D-22-20) 31a	g/	–	–	–	P	X	–	Spring; aquifer, limestone faulted against quartzite. Discharge 100 gpm estimated.
(D-23-21) 6cc	70	9.41	5-52	J,W	S	–	–	See hydrograph, Fig. 9.
(D-23-22) 3a	114	d/110	1934	–	–	X	–	Dug well, 3 ft. diameter.
10acc	384	d/ 23	8-51	–	I	–	X	–
15b	350	d/ 10	1934	–	I	X	–	–
(D-24-21) 11	1015	d/180	10-48	–	–	–	X	–
(D-24-24) 18	200	d/121	–	–	–	–	X	–

Table 13.--Logs of representative wells in Upper San Pedro basin, Cochise County, Ariz.

	Thickness (feet)	Depth (feet)
(D-16-20)27b		
Soil	27	27
Red clay	403	430
Packed sand and clay	70	500
Clay and gravel strata	80	580
Very hard, streaks of caliche	9	589
White sand pumped out	1	590
TOTAL DEPTH		590
First water at 430'. Rose to 21' and later to 5'.		

	Thickness (feet)	Depth (feet)
(D-16-20)34acd1		
Top soil	5	5
Sandy soil	55	60
Sand, a little water	30	90
Sand, gravel and more water	25	115
Red clay	2	117
TOTAL DEPTH		117

	Thickness (feet)	Depth (feet)
(D-16-20)34dab		
Soil, dark	3	3
Sand, gravel, yellow	92	95
Clay, red	2	97
Sand, gravel	4	101
Clay, red	449	550
Sand, gray	10	560
Clay, sandy, red	16	576
Sand, gray	5	581
Clay, sandy, red	26	607
Sand, rock and clay, red	13	620
Rock, gray	45	665
Clay, red	3	668
Rock, gray	22	690
Rock, sandy, gray	29	719
Clay rock, light	21	740
Rock, light	60	800
Rock, light	178	978
Rock and clay, light	15	993
Rock, light	7	1000
TOTAL DEPTH		1000

	Thickness (feet)	Depth (feet)
(D-16-20)34dba		
Soil	20	20
Gravel	70	90
Sand and sandstone	60	150
Pink clay	300	450
Gravel (artesian water rises within 16 ft. of the surface	300	750
TOTAL DEPTH		750

	Thickness (feet)	Depth (feet)
(D-16-23)19cb		
Caliche	100	100
Cemented gravel	185	285
Sticky clay	115	400
Cemented gravel	10	410
Gravel	2	412
Cemented gravel	48	460
Sand streak, some water	1	461
Cemented gravel	104	565
TOTAL DEPTH		565
Water at 410 rose 10' to stand at 400'. The water at 460' did not materially change water level.		

	Thickness (feet)	Depth (feet)
(D-17-19)17ab		
Surface soil	20	20
Lime and gravel	40	60
Red bed	18	78
Clay and gravel	42	120
Gray lime	20	140
Sandy white lime	10	150
Red bed	75	225
Lime	10	235
Red bed	10	245
Hard conglomerate	10	255
Red bed	50	305
Blue lime	3	308
Red bed	7	315
Lime and shells	7	322
Gray lime, water test 3 bbls. per hour	13	335

Table 13.--Logs of representative wells in Upper San Pedro basin--continued.

	Thickness (feet)	Depth (feet)
Red bed	5	340
Gray lime	48	388
Lime, shells	17	405
Red bed	25	430
Blue lime, 20 bbls. per hr.	19	449
Red bed	33	482
White shale	13	495
Gray lime	15	510
Shale	10	520
Brown lime	10	530
Brown sand, dry	12	542
Sandy shale	12	554
Gray lime	11	565
Gray shale	15	580
Hard gray shale	115	695
Blue shale	100	795
Blue lime	5	800
Sandy shale	10	810
Blue lime	30	840
Gray green shale	5	845
Lime	10	855
Gray shale	10	865
Dark blue to black shale, hard	5	870
Lime	15	885
Blue shale	20	905
Gray lime	10	915
Gray lime	45	960
Blue shale	30	990
Lime	25	1015
Blue shale	25	1040
Lime	30	1070
Blue shale	50	1120
Lime	25	1145
Blue shale	80	1225
Sandy shale	30	1255
Blue shale	45	1300
Blue shale	250	1550
TOTAL DEPTH		1550

(D-17-20)9adc	Thickness (feet)	Depth (feet)
Red sand soil	3	3
Red clay	24	27
Sand	3	30
Red clay	20	50
Sand, water	18	68
Red sticky clay	592	660
Red clay, thin layers of cemented sand	23	683
Sand, water raised to 390 ft.	3	686
Red clay, little sand	14	700
Red clay	12	712
Red clay, layers of hard cemented sand at 720 ft. water raised to 310 ft.	28	740
Red clay, thin layers of sand; water raised to 215 ft.	10	750
Red clay, sticky	53	803
Packed sand and gravel	17	820
Cemented sand, thin layers of packed sand	40	860
Cemented sand	140	1000
TOTAL DEPTH		1000

(D-17-20)9cbc	Thickness (feet)	Depth (feet)
Red soil	10	10
Red clay	345	355
Red sandy clay, very small amount of water	2	357
Red clay	490	847
Coarse gravel and water sand	6	853
Sand and gravel	3	856
Sand	7	863
Red clay	7	870
Sand and gravel	16	886
Red clay broken with sand	11	897
Sand and red clay	18	915
Sand	5	920
Sand, hard and sharp	50	970
Sand, soft	16	986
Sand	102	1088
TOTAL DEPTH		1088

(D-17-20)10dd	Thickness (feet)	Depth (feet)
Clay	42	42
Sand and coarse gravel	82	124
Clay - artesian flow began here	376	500
Sandstone	199	699
Gravel	8	707
TOTAL DEPTH		707
Struck water at 15 ft. and cased it off.		

	Thickness (feet)	Depth (feet)
(D-17-20)18da		
Gravel	159	159
Clay and gravel	207	366
Clay	75	441
Clay and gravel	75	516
Sand and gravel	9	525
Gravel	20	545
Sand and gravel	15	560
Sand	8	568
Sand and gravel	12	580
Gravel	20	600
Sand and gravel	27	627
TOTAL DEPTH		627
(D-17-21)15c		
Sand	41	41
Clay	21	62
Sand	9	71
Clay	11	82
Cemented gravel and boulders	98	180
Sandstone	5	185
Cemented gravel and boulders	165	350
Water gravel	22	372
Cemented gravel and boulders	608	980
Yellow clay	20	1000
TOTAL DEPTH		1000
(D-17-21)31da2		
Soil, gravel	28	28
Quick sand, water	27	55
Clay	298	353
Sand, gravel	27	380
TOTAL DEPTH		380
(D-17-21)32dcd		
Red soil	10	10
Red and gray sand	15	25
Blue clay	79	104
Water sand and clay	76	180
Red clay	31	211
Sand, gravel, water	19	230
Red sandy clay - broken	11	241
Red clay	79	320
Sandy red clay	15	335
Clay	15	350
Red broken sand and shale	30	380
Yellow shale and broken rock	100	480
Lime shells and broken yellow shale	145	625
Gray sandstone - 5 gal. water	35	660
Broken sandstone - more water	15	675
Red clay	7	682
Red sand	33	715
Red clay	125	840
Red sand shale - little water	20	860
Light red clay	55	915
Red clay	97	1012
TOTAL DEPTH		1012
	From	To
Surface water	106	180
First artesian	211	330
Second artesian	350	388
Increase in water all along	388	840
(D-18-21)7aa		
Surface soil (adobe and rocks)	32	32
Adobe, with veins of gypsum	168	200
Hard, red clay	47	247
Soft, red clay	20	267
Sandstone	3	270
Hard, red clay	55	325
Water gravel, (first water strata)	3	328
Hard, red clay	22	350
Red clay, slightly sandy	50	400
Sandy, red clay, some gravel	50	450
Rocks, gravel and sand cemented together with red clay	100	550
Gravel and sand, second water strata	30	580
Rocks, gravel and sand, cemented together with red clay	70	650

Table 13.—Logs of representative wells in Upper San Pedro basin—continued

	Thickness (feet)	Depth (feet)
Gravel imbedded in sandy, red clay	6	656
Sand and small gravel cemented with hard sandy clay	28	684
Sand and small gravel cemented with clay	7	691
Sandstone and cemented quick sand, with layers of silty clay	69	760
TOTAL DEPTH		760
(D-18-21)28c		
Sandy clay	150	150
Cement	1	151
Quick sand	10	161
Cement, clay, sand	140	301
Clay	50	351
Gravel, water	5	356
Alternating sand and clay	110	466
Cement	1	467
Gravel, water main flow	3	470
TOTAL DEPTH		470
(D-18-21)28db		
Red sand and gravel	70	70
Water sand and gravel	32	102
Red clay	3	105
TOTAL DEPTH		105
(D-18-21)33cb		
Soil, some sandy streaks	100	100
Clay	400	500
Water strata, some streaks of hard pan	125	625
TOTAL DEPTH		625
(D-20-21)3cd		
Clay	6	6
Gravel	10	16
Clay	89	105
Hard clay	113	218
Clay and gravel	32	250
Gravel and water	12	262
Sand and gravel	8	270
Clay	6	276
Clay and gravel	40	316
Sandy clay	44	360
Clay and gravel	114	474
Cemented gravel	41	515
Boulders and gravel	15	530
Sand and gravel	14	544
Cemented gravel	19	563
Gravel and clay	10	573
Cemented gravel	39	612
Cemented rock	5	617
Solid granite	6	623
TOTAL DEPTH		623
(D-21-18)6c		
Red gravel	60	60
Red gravel	42	102
Limestone	46	148
Conglomerate	66	214
Conglomerate - very hard	122	336
Layers sandy shale and hard shell	75	411
Varying sand conglomerate with shale	189	600
Shale	5	605
Harder mixture of shale and sand	35	640
Sticky red clay	5	645
Red shale	35	680
Hard gray sandstone	50	730
Red shale	15	745
Gray sandstone	55	800
Red shale	20	820
Hard gray sandstone	60	880
Red shale	15	895
Sandstone and shale	15	910
Hard gray sandstone	20	930
Red clay and shale	30	960
Red shale	10	970
Gray sandstone - some lime	40	1010
Sandstone	10	1020
Gray sandstone	20	1040
Red shale	10	1050
Hard gray sandstone	50	1100
Shale - very muddy drilling	15	1115
TOTAL DEPTH		1115

Table 13.—Logs of representative wells in Upper San Pedro basin—continued.

	Thickness (feet)	Depth (feet)
(D-21-18)7		
Silt	20	20
Silt and gravel	10	30
Clay and gravel	5	35
Water gravel	7	42
Clay and gravel with water forming ooze	5	47
Light brown clay with spots of gypsum	163	210
Decomposed igneous material and clay	5	215
Light brown clay with small quantity fine gravel	100	315
Blue gray shale and clay	235	550
Sandy streak making some water -- 361 ft.		
Light brown sandy shale	53	603
Blue gray shale (some sand)	109	712
Light colored porphyry	43	755
Blue gray shale	19	774
TOTAL DEPTH		774
Static water level 28 ft.		
(D-21-20)33ab		
Gravel and adobe	67	67
Adobe and boulders	230	297
Sand gravel, boulders, and adobe	149	446
Clay	7	453
Gravel and clay	34	487
Sand and clay	95	582
Sand	35	617
Cemented sand	100	717
Sand with thin clay layers	45	762
Sand and gravel	15	777
Coarse sand	70	847
Cemented sand and gravel	65	912
TOTAL DEPTH		912
(D-21-23)29bdb		
Loose gravel, sand, clay, (dry)	250	250
Limestone, shale and sandy lime, stratified (Paleozoic limestone), (dry)	705	955
Fissure in limestone (water)	18	973
TOTAL DEPTH		973
(D-23-22)10acc		
Soil and gravel mixed	28	28
Gravel showing little water at 36 ft.	8	36
Sandy clay	60	96
Water sand	6	102
Gypsum	16	118
Sandy clay	26	144
Gypsum	10	154
Red clay	4	158
Water sand	8	166
Sandy clay	10	176
Water gravel and sand	14	190
Red clay	4	194
Water gravel	6	200
Sandy clay	14	214
Water gravel and sand, well mixed	8	222
Sandy clay	22	244
Water gravel and fine sand	4	248
Sandy clay	4	252
Sand and gravel heaves up from bottom two and three ft.	16	268
Sandy clay	6	274
Sand and gravel heaves up from bottom two and three ft.	10	284
Sandy clay	44	328
Gravel and sand mixed with heavy clay	12	340
Sand	8	348
Sandy clay	36	384
TOTAL DEPTH		384
(D-24-21)11		
Soil	7	7
Clay and gravel	133	140
Clay, gravel and sand streaks	70	210
Cement gravel and clay	20	230
Packed sand and gravel	26	256
Clay and fine gravel	26	282
Clay	16	298
Packed sand and gravel	17	315

Table 13.---Logs of representative wells in Upper San Pedro basin---continued.

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Clay and gravel - - - -	83	398	Clay - - - - - - - - - -	6	1015
Loose gravel and rock -	10	408	TOTAL DEPTH		1015
Clay and gravel (hard)	30	438			
Sandy clay - - - - - - -	24	462			
Clay - - - - - - - - - - -	24	486	(D-24-24)18		
Clay and gravel - - - -	12	498	Top soil - - - - - - - - -	$1\frac{1}{2}$	$1\frac{1}{2}$
Packed sand - - - - - - -	22	520	Red clay with scattered boulders - - - - - - -	$80\frac{1}{2}$	82
Tough clay - - - - - - -	15	535			
Gravely clay - - - - - -	15	550	Gravel and boulders with caliche - - - - -	39	121
Hard packed sand - - -	22	572			
Tough clay - - - - - - -	90	662	Gravel and boulders with caliche (with water)- - - - - - - - -	1	122
Cement gravel and sand	10	672			
Clay and hard shells -	76	748			
Hard packed sand - - -	32	780	Caliche - - - - - - - - - -	36	158
Sticky clay - - - - - - -	14	794	Sand, gravel (water) -	2	160
Packed sand - - - - - - -	21	815	Gravel, boulders, caliche - - - - - - - -	14	174
Clay and sand streaks -	39	854			
Packed sand - - - - - - -	41	895	Very hard solidified cemented boulders and gravel - - - - - - - -	12	186
Clay and sand streaks -	53	948			
Clay - - - - - - - - - - -	29	977			
Hard packed sand - - -	8	985	Gravel, sand (water) -	4	190
Clay - - - - - - - - - - -	21	1006	Red clay - - - - - - - - -	10	200
Packed sand - - - - - - -	3	1009	TOTAL DEPTH		200

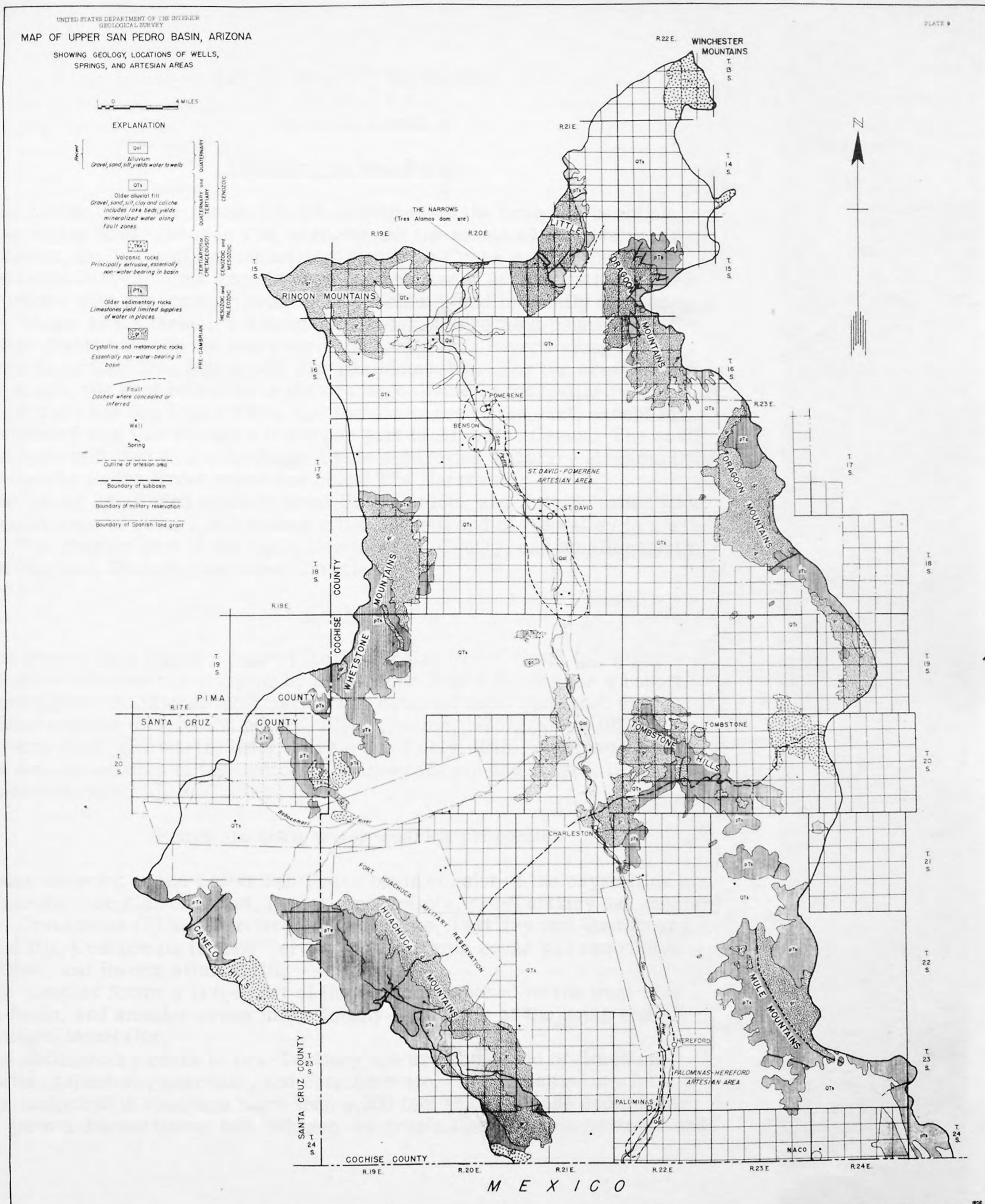
Table 14.--Analyses of water from representative wells and springs in Upper San Pedro basin, Cochise County, Ariz. (Parts per million except specific conductance and percent sodium)

Well or spring no.	Date of collection	Depth of well (feet)	Temperature (°F.)	Specific conductance (micromhos at 25° C.)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Total hardness as $CaCO_3$	Percent sodium
Recent alluvial fill															
(D-16-19) 17ab	5-51	75	69	152	12	3.2	18	73	5.1	11	0.2	1.8	128	43	48
(D-16-20) 7bdb	10-50	--	66	379	51	6.6	21	200	21	7	0.4	4.4	239	154	23
(D-17-21) 32dd	3-46	200	68	292	29	1.6	39	169	5.6	9	2.0	1.6	171	79	52
(D-20-21) 15a	2-34	-	-	-	45	12	27	246	15	2.0	0.1	.0	222	162	-
(D-21-22) 20d	2-34	a/	61	-	46	16	37	252	28	14	1.2	2.9	269	181	-
(D-23-22) 3a	2-34	114	-	-	42	28	8	200	14	3.0	0.2	66	260	220	-
Artesian water from older alluvial fill															
(D-16-20) 34dab(1) (2 analyses at different depths)	3-51	600	-	4000	576	4.9	554	54	2,500	8	1.5	0.2	3680	1460	45
(2)	6-51	1000	-	383	28	6.8	51	223	15	6	0.8	1.4	251	98	53
(D-17-20) 9cbc(1) (5 analyses at different depths)	10-46	355	-	3380	388	31	471	53	1950	26	3.4	0.4	2900	1100	48
(2)	10-46	856	-	1830	-	-	-	57	-	15	-	-	-	-	-

Table 14.--Analyses of water from representative wells and springs in Upper San Pedro basin--continued-

Well or spring no.	Date of collection	Depth of well (feet)	Temperature (°F.)	Specific conductance (micromhos at 25° C.)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Total hardness as $CaCO_3$	Percent sodium
(D-17-20)															
9cbc(3)	10-46	900	-	2230	-	-	-	137	-	48	-	-	-	-	-
(Cont.)(4)	10-46	926	-	2050	-	-	-	217	-	88	-	-	-	-	-
(5)	10-46	1087	-	2820	182	24	223	111	850	38	2.7	0.2	1370	552	47
9dd	5-21	1505	-	-	35	11	39	243	9.1	5.0	-	1.1	257	133	-
10cac	11-50	1068	82	384	37	12	31	235	9.9	2	0.6	1.3	252	142	32
(D-17-21) 31da2	2-34	340	69	-	13	-	49	133	10	4.0	5.8	2.0	146	36	-
(D-23-22) 15b	2-34	350	-	-	48	11	15	222	8	4.0	0.2	0.7	196	165	-
Nonartesian water from older alluvial fill															
(D-16-19) 11d	10-50	a/	65	382	46	10	22	216	5.8	12	0.4	3.2	240	156	23
(D-16-20) 7c	10-50	a/	78	1,590	307	25	51	140	819	4	2.4	1.9	1320	869	11
(D-21-20) 29-1	4-52	802	60	350	44	11	17	213	6.6	5.2	0.1	2.1	222	155	19
Crystalline and pre-Tertiary sedimentary rocks															
(D-15-21) 18dcb	7-51	100	-	936	64	36	89	419	9.9	102	0.8	0.8	526	308	39
(D-15-19) 21c	5-51	a/	73	382	38	5.9	39	202	11	14	1.6	5.2	258	120	42
(D-16-22) 15ac	2-34	a/	-	-	17	-	8.9	46	17	4.0	0.8	0.2	-	44	-
(D-17-23) 18a	2-34	a/	62	-	123	29	21	386	130	13	0.3	2.1	508	426	-
(D-22-20) 31a	2-46	a/	-	575	96	20	3.2	349	36	3.1	0.0	0.4	341	322	-

a/ - Spring


UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
PLATE 9
MAP OF UPPER SAN PEDRO BASIN, ARIZONA
SHOWING GEOLOGY, LOCATIONS OF WELLS, SPRINGS, AND ARTESIAN AREAS
4 MILES
EXPLANATION
Qal
Alluvium
Gravel, sand, silt; yields water to wells
Recent
QUATERNARY
QTs
Older alluvial fill
Gravel, sand, silt, clay and caliche includes lake beds; yields mineralized water along fault zones
QUATERNARY and TERTIARY
CENOZOIC
TKv
Volcanic rocks
Principally extrusive, essentially non-water-bearing in basin
TERTIARY(?) to CRETACEOUS(?)
CENOZOIC and MESOZOIC
PTs
Older sedimentary rocks
Limestones yield limited supplies of water in places
MESOZOIC and PALEOZOIC
Crystalline and metamorphic rocks
Essentially non-water-bearing in basin
PRE-CAMBRIAN
Fault
Dashed where concealed or inferred
Well
Spring
Outline of artesian area
Boundary of subbasin
Boundary of military reservation
Boundary of Spanish land grant
WINCHESTER MOUNTAINS
THE NARROWS
(Tres Alamos dam site)
LITTLE DRAGOON MOUNTAINS
RINCON MOUNTAINS
POMERENE
BENSON
ST. DAVID-POMERENE ARTESIAN AREA
ST. DAVID
DRAGOON MOUNTAINS
WHETSTONE MOUNTAINS
COCHISE COUNTY
PIMA COUNTY
SANTA CRUZ COUNTY
TOMBSTONE HILLS
TOMBSTONE
Babocomari River
CHARLESTON
FORT HUACHUCA MILITARY RESERVATION
HUACHUCA MOUNTAINS
CANELO HILLS
MULE MOUNTAINS
HEREFORD
PALOMINAS-HEREFORD ARTESIAN AREA
PALOMINAS
NACO
R.17E.
R.18E.
R.19E.
R.20E.
R.21E.
R.22E.
R.23E.
R.24E.
T.13S.
T.14S.
T.15S.
T.16S.
T.17S.
T.18S.
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1952

LOWER SAN PEDRO BASIN

By L. A. Heindl

Location and boundaries

The Lower San Pedro basin (pl. 10) is defined as the drainage basin of the San Pedro River between The Narrows and the mouth of the river near Winkelman, exclusive of the drainage of Aravaipa Creek east of the mouth of Aravaipa Canyon. This area is excluded because it is in a distinct structural trough with separate ground-water problems, and is briefly discussed under "Other areas irrigated with ground water." The west boundary is the drainage divide between the San Pedro and Santa Cruz Rivers along the Rincon, Santa Catalina, Black, and Tortilla Mountains. For the greater part of its length, the east boundary is the drainage divide in the Galiuro Mountains between the San Pedro River and the drainages to the east, except for the arbitrary line that excludes the upper part of Aravaipa Creek. The south boundary is selected as the drainage divide separating tributary streams that enter the San Pedro River above and below The Narrows.

The Lower San Pedro basin is about 65 miles long and 15 to 30 miles wide and has an area of about 1,550 square miles. The trend of the valley is northwest. The greater part of the basin lies in Pinal County, and smaller parts are in Cochise, Graham, and Pima Counties.

Geology

The generalized geologic map of the Lower San Pedro basin (pl. 10) is based on reconnaissance mapping by the Ground Water Branch for a report in preparation. Additional information was obtained from published and unpublished reports (Moore and others, 1941), (Darton, 1925), (Kuhn, 1938), (Peterson, 1938), (Schwartz, 1945), (Steele and Rubly, 1948), and from unpublished data in the files of the Geological Survey (Bryan and others, 1934), (B. N. Moore, 1935), (J. R. Cooper, 1952).

Rocks and their water-bearing properties

Rocks occuring in the Lower San Pedro basin consist of the crystalline and metamorphic complex of schist, gneiss, and granite, pre-Tertiary sedimentary rocks, Cretaceous (?) and Tertiary (?) sediments, Tertiary and Quaternary alluvial fill, Cretaceous (?) and Tertiary (?) volcanic rocks and associated intrusives, and Recent alluvial fill.

The complex forms a large part of the bedrock exposed on the west side of the basin, and smaller areas in the Johnny Lyon Hills at the south end of the Galiuro Mountains.

The sedimentary rocks of pre-Tertiary age are composed of limestone, mudstone, sandstone, quartzite, and conglomerate. In this basin they form a nearly conformable sequence more than 5,000 feet thick. These sedimentary rocks form a discontinuous belt between the crystalline or volcanic areas and the valley fill at the northeast and northwest boundaries of the valley. The rocks are folded and faulted and are inclined at slight to steep dips. Both detrital rocks and the limestones transmit small amounts of ground water. They are the source of many small springs in the higher parts of the mountains.

Alternating lake-bed mudstone, sandstone, conglomerate, and fresh-water limestone of probable Tertiary, but possible Cretaceous, age, occur in small masses. These sediments give some evidence of conditions just prior to the vast outpouring of volcanic rocks. They are not important aquifers.

Volcanic rocks and shallow intrusive bodies, of probable Cretaceous or Tertiary age, form the main mass of the Galiuro Mountains, small areas in the Black Hills, the southwest end of Black Mountain, and a few areas in the Santa Catalina and Rincon Mountains. Basalt flows of possible Quaternary age are included in this unit. Water occurs in fractures and along bedding planes, but it supplies only scattered domestic and stock wells and small springs.

Alluvial fills

The structural trough of the Lower San Pedro basin contains alluvial material of Tertiary and Quaternary age. The known thickness of alluvial material ranges from a thin veneer to at least 2,000 feet along the axis of the valley. Locally there are islands of granitic, sedimentary, or volcanic rock surrounded by alluvial fill. These islands may represent residual hills of an older topography about which the alluvial material was deposited, or they may represent fault blocks. The largest of these are the Black Hills. The San Manuel and St. Anthony mining districts, near Mammoth, are at the southern end of these hills.

After the older alluvial fill was deposited, the Lower San Pedro basin was more deeply dissected than most basins in the desert region because of the comparatively steep gradient of the San Pedro River. The average gradient between The Narrows and Redington is about 18 feet per mile and, between Redington and the mouth of the San Pedro River, it averages about 22 feet per mile. In some reaches it is as high as 30 feet per mile. The gradients of the tributary streams are correspondingly higher and the consequent dissection has exposed bedrock in many more areas than in most alluvial basins of the State.

The older alluvial fill has been described in Part I under the heading, "Regional geology." Sand and gravel lenses within silt and clay beds of the older alluvial fill contain water under artesian pressure south of Mammoth. Water supplies from the older alluvium on the higher slopes of the valley are small.

The present channel and flood plain of the San Pedro River and its tributaries are underlain by Recent alluvium consisting of unconsolidated gravel, sand, and more rarely silt and clay, from 50 to 150 feet thick. The width of the San Pedro River channel and flood plain averages about half a mile. Some of the large tributaries, such as Aravaipa and Hot Springs Creeks, have flood plains as much as a mile wide at their mouths. These deposits of Recent alluvium are the major sources from which water is withdrawn for irrigation along the lower San Pedro and its tributaries.

Records of wells of the Lower San Pedro basin referred to in this chapter are shown in table 15. Table 16 presents logs of representative wells.

Wells in Recent alluvium.--Logs of shallow wells along the flood plain show that the Recent alluvium is from 60 to 150 feet thick and is underlain by clay or tightly cemented conglomerate of the older alluvial fill.

Where some tributaries of the San Pedro River have cut through clay beds, ridges of clay may underlie the Recent alluvium at relatively shallow depths. Wells (D-8-17)18cda and (D-8-17)18cdd, (table 16), less than 300 feet apart, illustrate this condition.

Wells in older alluvial fill.--Wells in older alluvial fill may be classified as follows: (1) Artesian wells drilled along the San Pedro flood plain through Recent alluvial fill into older alluvium; and (2) wells drilled on the flanks of the valley.

Well (D-9-17)25bdd is representative of the artesian wells. Older alluvium was encountered in this well below 80 feet. Clay predominated from about 80 to 628 feet, where water under artesian pressure flowed from a coarse sand. Sand, interbedded with a little gravel and clay, was encountered between 628 and 860 feet and artesian flow increased steadily. Clay predominated from 860 to 967 feet and no further increase in flow was noted. Well (D-9-17)32daa, drilled to 1,485 feet, penetrates a deeper artesian zone.

Well (D-7-16)3ca is located on a clay terrace northwest of Aravaipa Creek, and was drilled to 825 feet entirely in clay. It is reported to be "completely dry." Well (D-12-19)32ddd was drilled to a reported depth of 900 feet in an attempt to obtain a flowing well south of Redington. Impervious silt, clay, or tight conglomerate was encountered the entire depth of the well and no water was obtained below the Recent gravels.

In the vicinity of Mammoth, warm water leaks around the casings in some wells and escapes into the Recent alluvial fill. The temperatures and mineral content of waters from shallow wells (D-9-17)10cca and (D-9-17)14cdb are closely comparable to temperatures and mineral content of waters from nearby artesian wells. Apparently two aquifers are present, one between 625 and 860 feet, the other between 1,275 and 1,370 feet. The temperatures and chemical quality of the two waters are different.

Deep wells have been drilled along the flanks of the valley in four general areas: (1) The west side of the valley; (2) the east side of the valley; (3) Camp Grant Wash area; and (4) Allen Flat area. The logs of wells drilled in the four areas show differences in the types of materials encountered and in the depths at which water was obtained.

On the west side of the valley, in well (D-8-16)25dcd, the driller reported "ordinary conglomerate" to 785 feet and "red material" from 785 to 2,144 feet. Laboratory examination showed the red material to be alluvium consisting almost entirely of water-worn particles of volcanic rocks. Other wells in this area are less than 750 feet deep and the logs show undifferentiated conglomerates throughout. Water levels in all these wells are reported to be below 250 feet.

On the east side of the valley, the materials encountered and the depths to water vary more than those on the west side. Well (D-9-17)2dcb was drilled through silts and clays to 1,025 feet, and the water level was reported to be 250 feet. This well is considered a "dry hole" by the owner. Well (D-9-19)32cab was drilled through conglomerate to a total depth of 800 feet. The water level is reported to be more than 500 feet below the surface and the well supplies only enough water for domestic and stock purposes. In well (D-11-19)10dc, 300 feet deep, the driller reported a small seep of water at the top of "volcanics" below 142 feet of conglomerate. Well (D-10-18)3b is reported to be 390 feet deep and to contain water with a temperature above 120° F. It is believed to tap water along a fault zone in the older alluvium.

In the Camp Grant Wash area, the alluvial fill is known to be at least 680 feet thick and water is obtained within the alluvium and from rocks below the alluvium. Well (D-9-15)15aad is reported to be 835 feet deep. Alluvial fill is reported underlain by "porphyry" at 680 feet and water is obtained only from the "porphyry" between 770 and 786 feet. Well (D-7-14)10dba is reported to be 398 feet deep and to obtain water between 388 and 398 feet in alluvial fill overlying granite. Water levels in other wells, drilled entirely within alluvial materials, are reported to be 100 to 500 feet below land surface.

The alluvial fill in the Allen Flat area is known to be more than 1,250 feet thick and water levels are reported at depths from 150 to 900 feet. Volcanic rocks have been reported in some well logs.

Wells in older rocks.--Some deep wells, in addition to those in the Camp Grant Wash area, obtain small amounts of water in rocks older than the alluvial fill. Well (D-13-21)20ddc, 400 feet deep, is reported to obtain water from within Tertiary (?) volcanic rocks at 314 feet. Well (D-8-14)15bbb, 550 feet deep, is reported to obtain water from alluvial sand between volcanic flows. Well (D-14-21)19cac was drilled into granite to 644 feet. Some water was reported at 270 to 275 feet and below a "fault zone" encountered between 460 and 480 feet. Well (D-6-15)8cb was begun in diabase intruding the older sedimentary rocks.

Cross sections

The diagrammatic cross sections in figure 10 illustrate some of the relations discussed in the preceding pages. Figures 10A and 10B are sections across the valley in the vicinities of Mammoth and Redington, respectively. Figure 10C is a section along the San Pedro River from The Narrows to the confluence of the San Pedro and Gila Rivers near Winkelman. Each is a composite of known structural features in the vicinity. They are included to show the complexity of the geology of the region, and are not to scale.

The transverse cross section in the vicinity of Mammoth (fig. 10A) shows that alluvial fill extends about two-thirds across the valley and attains maximum thickness in the center of the valley.

The thick sequence of clay and silt and the two artesian zones are shown along the axis of the valley. Recent alluvium partly fills the channel incised into the upper clay and silt beds. The series of fault blocks across the basin

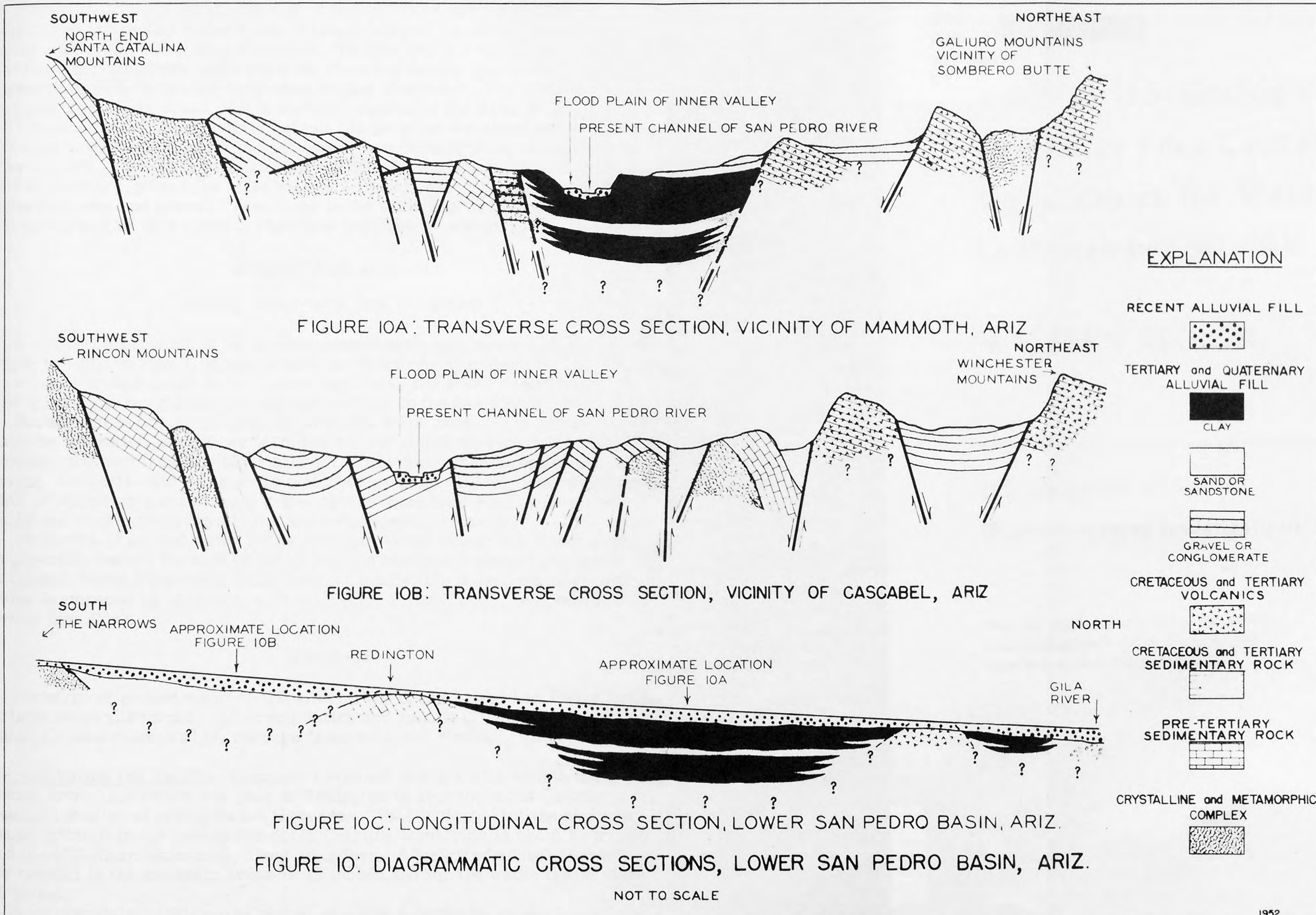


FIGURE 10: DIAGRAMMATIC CROSS SECTIONS, LOWER SAN PEDRO BASIN, ARIZ.

represents in general terms relationships observed in the field.

Figure 10B is a generalization of structural relations viewed transversely across the Lower San Pedro basin in the vicinity of Cascabel. In contrast to the part of the basin near Mammoth, the clay and silt series is missing and the older materials underlying the Recent alluvium are generally coarse, moderately well-indurated conglomerate and sandstone. The small alluvial basin at the northeast end of this section represents the Allen Flat area.

The longitudinal cross section shows the probable relationships between the area north of Redington, in which there are considerable thicknesses of clay and silt beds and known artesian aquifers, and the area from Redington to The Narrows, where the older alluvium is composed predominantly of indurated sand and gravel. Variations in the thickness of Recent alluvial fill in relation to hills close to the river are also illustrated.

Ground-water hydrology

Source, occurrence, and movement

A general discussion of the source, occurrence, and movement of ground water is found in Part I, in the section on "Regional hydrology." The chief sources of ground water in the Lower San Pedro basin are runoff from precipitation in the mountains and surface flow in the San Pedro River.

Ground water occurs in all types of rocks in the basin. The ground water used for irrigation is obtained from the Recent alluvium, except for small amounts obtained from the older alluvial fill by four artesian wells and one spring. Domestic and stock wells obtain water from all the rocks of the area. Most of the water pumped from mines comes from fault zones in volcanic rocks and rocks of the crystalline and metamorphic complex.

Movement of ground water in the alluvium of the Lower San Pedro basin is generally toward the axis of the valley and northward toward the mouth of the San Pedro River near Winkelman. Locally, the movement of ground water is impeded by barriers, such as blocks of older rock, and possibly buried lava flows.

Recharge

Recharge of ground water to the alluvial fill of the Lower San Pedro basin is from several sources: (1) Precipitation and runoff; (2) surface flow in the river; (3) underflow; and (4) seepage from irrigated fields.

Precipitation and runoff.--Average measured precipitation in this basin ranges from 10.5 inches per year at Redington to 19.5 inches at Oracle. Regional studies of precipitation (Peterson, 1945) indicate that the average annual rainfall in the Rincon and Santa Catalina Mountains is about 21 inches and in the Galiuro Mountains, about 16 inches. A weighted annual average for rainfall in the mountain areas is 18 inches and for the whole basin, about 16 inches.

Approximately 1,000 square miles, or about two-thirds, of the Lower

San Pedro basin is composed of desert flats and mesas. Direct recharge from precipitation on this area is believed to be negligible in an average year.

About 550 square miles, or 350,000 acres, is composed of mountain areas where the rainfall averages about 18 inches per year. Runoff from the mountain areas in this basin is estimated, on the basis of figures given in Part I of this report, to be about 10 percent of the precipitation, or about 50,000 acre-feet per year, and recharge to the alluvial fill is estimated to be about half of the runoff. On this basis, the recharge is estimated to be in the magnitude of about 25,000 acre-feet annually. The other 25,000 acre-feet of runoff is discharged by evaporation and as stream flow into the Gila River from the San Pedro River.

Surface flow.--Data on surface flow are based on the 10-year period 1932-41, as records for gaging stations in this area are most nearly complete during that period. Annual inflow from Aravaipa Creek for this period averaged about 23,000 acre-feet per year. Average annual inflow into the Lower San Pedro basin at The Narrows was calculated from available stream-flow records to be about 45,000 acre-feet per year. Runoff originating within the basin is estimated to add another 10,000 acre-feet per year on the average, and springs and seeps issuing from older rocks along the San Pedro River are estimated to add another small but negligible amount. The average total surface flow is estimated to average about 78,000 acre-feet per year and to range from about 35,000 to about 110,000 acre-feet per year. On the basis of data from the gaging stations on the Gila River above and below the mouth of the San Pedro River, surface flow at the mouth of the San Pedro River was calculated to average about 43,000 acre-feet per year.

Underflow.--Underflow into the alluvial fill of the Lower San Pedro basin comes from the Upper San Pedro basin and the upper Aravaipa Valley.

Underflow from the Upper San Pedro basin is restricted to alluvium in the channel through The Narrows. This alluvium has an average thickness of about 60 feet and a maximum width of 300 feet. The gradient at this point is approximately 15 feet per mile. Average permeability coefficients for unconsolidated alluvial material of this type range from 1,000 to 5,000 (Turner and others, 1941, p. 45). Calculations based on these figures indicate that underflow through this restricted channel is between 40 and 200 acre-feet per year.

Aravaipa Creek is intermittent in the lower 5 miles of its course. Where perennial flow ceases, the channel is about 400 feet wide, the alluvium is estimated to be 50 feet deep, and the gradient is 50 feet per mile. Using the same permeability coefficients as above, the underflow from Aravaipa Creek is estimated to be from 200 to 1,000 acre-feet per year.

Seepage from irrigated fields.--Recharge from irrigated fields in the Lower San Pedro basin is estimated to be about 15 percent of the 20,000 acre-feet applied, or about 3,000 acre-feet per year. The estimate was made on the same basis as was used for the Upper San Pedro basin.

Seepage from mine pumpage.--Between 5,000 and 10,000 acre-feet of water per year is pumped from the mines near Tiger. A small proportion is recirculated at the mill, and a small amount, possibly 500 acre-feet, is used for domestic purposes. Much of the balance is lost by evapotranspiration and the remainder is recharged to the Recent alluvium.

Discharge

Discharge of ground water from the alluvial fill of the Lower San Pedro basin occurs as follows: (1) Pumping; (2) evapotranspiration; (3) underflow out of the basin; and (4) springs.

Pumping.--Discharge by pumping may be divided as follows: (1) Discharge from domestic and stock wells; and (2) discharge from irrigation wells.

In 1951 there were approximately 300 wells in use in the Lower San Pedro basin. Of these, 50 were irrigation wells constructed in Recent alluvium, and six were artesian wells in the older alluvial fill. The remainder were domestic and stock wells.

The total pumpage from about 200 domestic and stock wells in the alluvium is estimated to be approximately 1,000 acre-feet per year, including water used in Mammoth.

Fifty wells were used to irrigate about 6,700 acres in 1951. Of this total, about 5,900 acres was in cultivation between Winkelman and 9 miles south of Mammoth, and about 800 acres was in cultivation between Redington and The Narrows. The amount of water applied to the land for irrigation was assumed to be 3 acre-feet per acre per year, as explained in the section on the Upper San Pedro basin. On this basis, the discharge from irrigation wells was about 20,000 acre-feet in 1951. The artesian wells are uncontrolled and continuously discharge about 1,100 gallons per minute, a total of about 2,000 acre-feet per year. The total discharge from wells in the alluvial fills in the Lower San Pedro basin was estimated, therefore, to be approximately 23,000 acre-feet in 1951.

Yields from most irrigation wells in the Lower San Pedro basin range from 400 to 1,200 gallons per minute. Pumping rates from nonartesian wells in older alluvium range from less than 1 to 12 gallons per minute. Flow of the artesian wells ranges from about 20 to about 500 gallons per minute.

Evapotranspiration.--Estimates of discharge of ground water by evapotranspiration were made for the flood plain of the lower San Pedro River and the lower 4 miles of Aravaipa Creek, and for areas of Recent alluvial fill in the main tributary washes. The Recent alluvial fill of the lower San Pedro River and lower Aravaipa Creek has an area of about 36 square miles or about 23,000 acres. About a quarter of this area consists of stream channels, and the remaining three-quarters, or about 17,000 acres, consists of flood plain. An additional 10,000 acres of Recent alluvial fill has been deposited in other tributary channels outside the main flood plain. It is covered with a scattered growth of phreatophytes.

The greatest discharge of ground water on the flood plain is through transpiration by phreatophytes, which cover the entire uncultivated part of the flood plain. The vegetative cover is predominantly mesquite, but includes some cottonwood and baccharis. Areal density of growth is almost 100 percent. In the tributary washes the phreatophyte growth is thinner. It is estimated that in areas of 100-percent density of mesquite in the Lower San Pedro basin, water consumption is 3.5 acre-feet per acre per year. This annual use includes an average of 1 acre-foot of rainfall on the flood plain, and a draft on ground water of 2.5 acre-feet. Of the 17,600 acres of flood plain along the river and lower Aravaipa Creek, approximately 6,700 acres is under cultivation and the balance of about 11,000 acres is overgrown with phreatophytes. Assuming a density of 100 percent, about 27,000 acre-feet of ground water per year is estimated to be lost by evapotranspiration in the 11,000-acre area. The average density of the 10,000 acres of phreatophytes in the tributaries was estimated to be 20 percent, and the total annual use by evapotranspiration in tributaries was estimated at 5,000 acre-feet.

Discharge of ground water from the stream-channel areas includes evaporation from wetted sands and from surface water. Assuming an average discharge of 0.5 acre-foot per acre per year, the discharge from the approximately 5,000 acres of stream channel was estimated to be about 3,000 acre-feet per year.

The sum of these estimated losses by evapotranspiration is 35,000 acre-feet per year.

Underflow out of the basin.--Underflow at the mouth of the San Pedro River occurs through a cross section of alluvium nearly 4,300 feet wide, and about 100 feet thick. The gradient is 10 feet per mile. On the basis of these data, and assuming a range of coefficients of permeability of between 500 and 2,500, underflow from the basin is estimated to be between 450 and 2,700 acre-feet per year.

Springs.--The total discharge from about 80 springs is approximately 4,000 acre-feet per year. Perhaps 20 percent of this quantity, or about 800 acre-feet per year, finds its way back into the alluvium as recharge. Yields from springs range from less than 1 to more than 1,000 gallons per minute.

Storage

The concepts of "latent storage" and "underlying storage" are explained in Part I, under "Regional hydrology." The concept of underlying storage is not applied to the Lower San Pedro basin for reasons similar to those outlined in the discussion of storage in the section on the Upper San Pedro basin.

Storage of ground water in the Lower San Pedro basin is calculated as latent storage in the older alluvial fill and latent storage in the Recent alluvium.

Latent storage in older alluvial fill.--The older alluvial fill occupies an area of about 640,000 acres. Storage is calculated for a saturated thickness of 300 feet, assuming a coefficient of drainage of 2 percent, the same percentage used in the Upper San Pedro basin. The volume of Recent alluvial fill along the San Pedro River, and enclosed within older alluvial fill, is deducted from the total volume of older alluvial fill. The Recent alluvial fill along the tributaries, however, is included with the older alluvium. The coefficient of drainage in older alluvium is estimated to be 2 percent and may be as high as 6 percent. Latent storage in the older alluvial fill therefore is estimated to be about 4,000,000 acre-feet and may be as high as 12,000,000 acre-feet.

Latent storage in Recent alluvial fill.--The Recent alluvial fill along the San Pedro River in this basin has an area of 23,000 acres. The thickness of saturated fill averages 60 feet, and the coefficient of drainage is estimated to be 15 percent. Latent storage in Recent alluvial fill thus is calculated to be in the order of about 200,000 acre-feet. Storage in Recent alluvial fill along tributaries is included with storage in older fill.

Water-table fluctuations

Continuous records of water-level fluctuations are available only for the period 1948-51 and are considered insufficient to show a definite trend. Some water-level measurements for the years 1921 and 1934 are available. In general, the water levels in the Recent alluvium along the San Pedro River in the period 1948-1951 appear to be lower than those in 1921 and 1934, but no direct comparisons can be made because it has proved impossible to identify the bottom-land wells measured in 1921 and 1934.

Quality of water

About 180 analyses of surface and ground waters from the Lower San Pedro basin are on record. Most of the analyses were made during 1948-51, but some represent samples taken in 1921 and 1934. Analyses of characteristic waters are presented in table 17 and are grouped by their rock-type association. Analyses show that most of the waters of the basin contain moderate amounts of mineral matter; the dissolved solids content usually does not exceed 600 parts per million. In local areas, concentrations are higher; the maximum for the basin is about 9,000 parts per million.

Waters obtained from all the upper artesian aquifers of the older alluvium, and from the Recent alluvium underlying the flood plain, are normally suitable for irrigation. Many waters obtained from the alluvial fill are acceptable for domestic and stock use. However, waters with a fluoride content exceeding 1.5 parts per million occur near Winkelman, along Aravaipa Creek, near Oracle, at the mining communities near Mammoth, and in the artesian area. In general, waters obtained from nonartesian sources in alluvial fill or from volcanic rocks are acceptably low in fluoride; those obtained from the crystalline and metamorphic rocks, from fault zones, or from the artesian aquifers tend to be high in fluoride.

Water moves through the basin, both as surface flow and as underflow, at a rate apparently sufficient to prevent excessive accumulation of dissolved solids in the ground waters. Near the mouth of the San Pedro River, however, and for a distance of nearly 2 miles upstream, more highly mineralized waters occur than are characteristic of waters either from wells in the Recent alluvium or from seeps and springs along the river. A comparison of analyses of waters sampled in the period 1921-34, and resampled between 1947 and 1951 shows that there has been a detectable, although slight, increase in mineralization in the last quarter-century. The cause of this change is unknown at present.

The quality of waters from the Recent alluvium along the San Pedro River between The Narrows and the mouth is represented by the first four analyses in table 17. The quality of underflow in Aravaipa Creek, shown by analysis (D-7-16)11a is comparable to the quality of water from spring (D-6-16)33c.

Waters from the older alluvial fill are variable in chemical character, but in general are suitable for domestic and irrigation use, except that artesian waters may be so high in fluoride as to be undesirable for domestic consumption. Some of the waters have excessively high sodium percentages, making their use for irrigation questionable.

Analysis (D-9-17)24dc is representative of waters from the upper artesian aquifers, and analysis (D-8-17)32daa is representative of waters from deeper artesian sources. The leakage of artesian water into aquifers in the Recent alluvium is illustrated by comparison of the analysis of water from well (D-9-17)14cdb with analyses characteristic of waters from Recent alluvium.

Several analyses are presented that are characteristic of waters from nonartesian wells and springs in the older alluvial fill. Water from well (D-8-17)36a is exceptional in that it contains about 30 parts per million of fluoride, the highest concentration of fluoride observed in waters in this basin. Well (D-10-18)3b produces what may be the hottest water in the basin, although no temperature measurement has been made. The proportions of sodium, sulfate, chloride, and fluoride are unusually high. It is possible that the water emerges from a fault zone. Spring (D-13-21)6a issues from a fault zone separating older alluvium from volcanic rocks. The water emerges at a temperature of 109°F. The analysis of water from this spring is comparable in dissolved solids concentration to analysis of water from the older alluvial fill nearby, (D-12-21)31a. The hot-spring water is slightly higher in fluoride and has a sodium content appreciably higher than calcium, thus reversing the condition normal to waters from older alluvial fill.

Water from the Cretaceous (?) and Tertiary (?) sediments, from well (D-13-20)23dc, has the highest reported mineral content in the basin, 9,160 parts per million. Fairly high silica and bicarbonate concentrations are features typical of waters from volcanic rocks, and appear in analysis (D-8-19)31a. Waters from older sedimentary rocks are generally low in mineral concentration. The analysis of water from spring (D-7-18)8a illustrates their chemical character. The chemical character of waters from rocks of the crystalline complex is illustrated by analyses of waters from diorite, granite, and schist. These waters show ranges in concentration of dissolved solids from 344 to 1,110 parts per million. The moderately high fluoride concentrations characteristic of waters from the crystalline rocks are apparent.

Ground-water--surface-water interrelationships

The San Pedro River is intermittent throughout the length of the basin. Locally the Recent alluvium gains recharge from stream flow and discharges ground water to the river. Detailed measurements of gains and losses in stream flow are required before a quantitative determination of ground-water--surface-water interrelationships can be made.

Problems

Additional studies

The Lower San Pedro basin has been more thoroughly dissected than other basins in southern Arizona, and consequently the geologic formations in the basin are comparatively well exposed. The flood plain along the river is narrow, and future agricultural development probably will be small. The area is easily accessible and is suitable for intensive geologic and hydrologic studies, and the basin might be useful as an area of reference from which to evaluate conditions in other basins. A reconnaissance of the geology and hydrology of the basin has been made and the following is suggested for further study:

1. Detailed studies of the stratigraphy, structure, and water-bearing qualities of rocks.
2. Investigation of artesian aquifers and their relation to the stratigraphy and structure of lake beds and fine-grained flood-plain materials. Exploration for deep aquifers could be carried on by test drilling and by geophysical methods, including the electrical-resistivity methods already used in a few localities.
3. Collection of detailed precipitation and runoff data and studies of variation in runoff with respect to varying rock types and hydraulic gradients.
4. Quantitative determinations of recharge and its relation to permeability and transmissibility in different rock materials.
5. Determination of use of water by phreatophytes, with particular attention to seasonal use, and to the proportions of ground water and precipitation comprising the total water used. If use of ground water by phreatophytes were found to be less than or approximately equal to consumptive use by farming, additional land could be cleared and irrigated without adverse effect on the hydrologic balance of the basin.
6. Relation of quality of water to rock types and geologic structures as an aid in studying the movement of ground water.
7. Flood control dams across the San Pedro River have been suggested at locations such as The Narrows and downstream from the mouth of Aravaipa Creek. The effect of such dams on ground-water conditions, in both the upstream and downstream areas, should be evaluated in advance of construction.

Methods of increasing or conserving ground-water supply

The following methods for increasing or conserving ground water are suggested:

1. Artesian flow from wells could be regulated by valves and utilized only when needed. Artesian wells should be adequately cased and properly set and perforated to eliminate loss of pressure head. Uncontrolled artesian flow could be put to beneficial use or artificially recharged.

2. The apparent heavy use of water by non-beneficial phreatophytes along the San Pedro River suggests that replacement of phreatophytes by crops may be desirable.

3. Storage and regulation of flood flow might allow greater use of surface water without materially decreasing recharge, outflow probably would be decreased, but not in direct proportion to the increased use of surface water.

Summary

The Lower San Pedro basin occupies the northwestern third of a structural trough that extends from south of the International Border to the vicinity of Winkelman, Ariz. Nearly continuous exposures of rock at The Narrows separate the Lower from the Upper San Pedro basin. The area is drained by the San Pedro River, which flows roughly northwest to the Gila River.

Debris from the mountains, which were elevated along the northwest-trending faults, accumulated as alluvial fill in the structural trough. During the later stages of the geologic history of the basin, one or more lakes were present, and thick deposits of clay, silt, and gypsum were formed. These sediments were subsequently dissected, and channels were incised into the older alluvium. The channels were later partly filled with Recent alluvium.

Surface flow into the basin is estimated to be about 45,000 acre-feet per year at The Narrows, about 23,000 acre-feet per year from upper Aravaipa Creek. Discharge at the mouth of the San Pedro River into the Gila River is estimated to be about 43,000 acre-feet per year. Thus there is a net loss of about 25,000 acre-feet per year of the surface water that flows into the basin.

The sedimentary, granitic, and volcanic rocks yield only small amounts of ground water. The older alluvial fill yields water to a few wells in an area of artesian flow in amounts sufficient for irrigation, and supplies domestic and stock wells in most of the basin. The principal sources of ground water used for irrigation are sand and gravel lenses in the Recent alluvial fill.

Recharge to Recent alluvium in the area is principally from surface flow originating outside the basin and from runoff from mountains within the drainage basin. Recharge to the older alluvial fill, including the artesian aquifers, is principally from runoff across the margins of the fill, where permeabilities probably are highest.

Ground-water discharge occurs principally by evapotranspiration and by pumping. Total discharge of ground water from the Recent alluvium is estimated to be more than 50,000 acre-feet per year. Discharge by evaporation and by phreatophytes is estimated to be about 35,000 acre-feet per year. In 1952, about 6,700 acres was under cultivation, and about 20,000 acre-feet of ground water was pumped from the Recent alluvial fill. About 2,000 acre-feet per year of ground water was estimated to flow from wells drilled into artesian aquifers in the older alluvial fill.

Latent storage in the Recent alluvial fill is estimated to be about 200,000 acre-feet.

Water analyses indicate that, except for local high percentages of sodium, most of the waters in the basin are suitable for irrigation. In many areas the ground water is undesireable for drinking by children because of excessive quantities of fluoride.

Data available do not indicate changes in storage are occurring, other than seasonal fluctuations and those related to climatic variations from year to year. Further development of both shallow ground water and deeper artesian supplies may be possible.

Table 15.--Records of representative wells and springs in Lower San Pedro basin, Ariz.

Well or spring no.	Depth of well (feet)	Water level: Depth below land-surface datum(feet)a/	Water level: Date of measurement	Type of liftb/	Use of waterc/	Analysis on file	Log on file	Remarks
(D-5-15)								
24cb	33	13.77	9-49	T,E	D	X	-	-
(D-5-16)								
31bcd	-	26.83	9-50	T,Bu	I	X	X	Discharge, 1000 gpm.
(D-6-15)								
8cb	285	48.9	9-50	J,W,G	S	-	X	-
(D-6-16)								
12d	d/	-	2-51	-	S	X	-	Spring in pre-Cambrian conglomerate. Discharge, $\frac{1}{4}$ gallon per minute.
33cc	d/	-	9-50	-	I,S	X	-	Spring in river gravels.
(D-6-17)								
13d	-	-	10-50	-	I,D,S	X	-	Aravaipa Creek. Discharge, 5000 gpm.
(D-7-14)								
10dda	398	388 rept.	-	J,W	D,S	X	X	Discharge, 10 gpm, estimated.
(D-7-16)								
3ca	825	Dry	-	-	-	-	-	In silt and clay, all the way.
10caa	84	40 apprx.	3-48	T,G	I	-	X	Discharge, 790 gpm, 10-50.
11a	87	-	-	T,Bu	I	X	-	Discharge, 1440 gpm.
(D-7-18)								
8a	d/	-	8-50	-	S	X	-	Spring in fault.
(D-8-14)								
5ccd	70	58.6	3-50	J,G,W	S	X	-	Dug well 4' x 4' diameter.
15bbb	550	145.1	3-50	J,G	D	X	X	Discharge, 2 gpm, estimated.
(D-8-15)								
3adb	137	115.1	3-50	J,G,W	D,S	X	X	-
3d	d/	-	2-50	-	D,S	X	-	Spring in Cenozoic conglomerate.
35ddd	850	520 rept.	10-47	J,G	S	X	-	Discharge, 6 gpm.
(D-8-16)								
25dcd	2144	375 rept.	7-48	None	-	-	X	

a/ Measuring point was usually top of casing, corrected to land-surface datum.
b/ C, cylinder; J, jack; T, turbine; G, gasoline; W, windmill; Bu, butane; D, diesel; E, electric.
c/ D, domestic; S, stock; I, irrigation; N, not used.
d/ Spring.

Table 15.--Records of representative wells and springs in Lower San Pedro basin--continued.

Well or spring no.	Depth of well (feet)	Water level: Depth below land-surface datum (feet) a/	Water level: Date of measurement	Type of lift b/	Use of water c/	Analysis on file	Log on file	Remarks
(D-8-17)								
18cda	70	–	–	J,E	D	–	X	Discharge, 10 gpm.
18cdd	144	98 rept.	1949	J,E	D	–	X	Discharge, 3 gpm.
19d	46	12.56	9-49	J,E	D	X	–	
29dda	100	13.45	9-49	T,D	I	X	X	Discharge, 1740 gpm.
32daa	1485	–	–	Artesian	–	X	X	Discharge, 20 gpm.
36aa	–	–	–	J,W,G	S	X	–	
(D-8-18)								
10c	d/	–	5-51	–	S	X	–	Spring in basalt; discharge, 1 pint per minute.
11b	d/	–	5-51	–	S	X	–	Spring in diorite. Discharge 4 gpm, est.
17a	d/	–	5-51	–	D,S	X	–	Spring in Cenozoic conglomerate. Discharge, 50 gpm, estimated.
(D-8-19)								
31a	d/	–	2-51	–	D,S	X	–	Spring in volcanic agglomerate. Discharge, 12 gpm.
(D-9-15)								
15aad	835	760 rept.	6-49	J,G	S	X	X	Discharge, 5 gpm.
36d	224	72	8-49	C,E	D	X	–	Discharge, 8 gpm.
(D-9-17)								
2dcb	1025	250 rept.	1935	none		–	X	
10caa	80	57.64	11-30	J,W	D,S	X	X	Discharge, 4 gpm.
14cdb	54	22.61	9-50	J,W	D	X	–	
24dcb	825	–	–	Artesian	D,S,I	X	–	Discharge, 200 gpm.
24ddc	870	–	–	Artesian	D,S,I	X	X	Discharge, 390 gpm.
25bdd	967	–	–	Artesian	D,S,I	X	X	Discharge, 600 gpm.
(D-9-19)								
32cab	800	503 rept.	1949	J,G,Burro	D,S	–	–	
(D-10-17)								
15bb	285	213.8	8-49	C,W,G	S	X	–	Discharge, 5 gpm.
(D-10-18)								
3b	390	225	3-50	T,G	S	X	–	Discharge, 3 gpm.

Table 15.--Records of representative wells and springs in Lower San Pedro basin--continued.

Well or spring no.	Depth of well (feet)	Water level: Depth below land-surface datum (feet) a/	Water level: Date of measurement	Type of lift b/	Use of water c/	Analysis on file	Log on file	Remarks
(D-11-17)								
4dc	736	286 rept.	4-49	J,G	S	-	-	In conglomerate to 736 feet.
(D-11-18)								
15a	19	6.0	9-50	C.G	I	X	-	
(D-11-19)								
10dc	300	-	-	J,G	D,S	X	X	Sealed.
(D-12-18)								
13caa	165	64.6	7-48	T,Bu	I	-	X	Discharge, 2000 gpm, estimated.
(D-12-19)								
32ddd	900	12.77	11-50	None	N	-	-	
(D-12-21)								
27cd	410	340 rept.	6-42	C&W; J&G	S	X	-	
31a	d/	-	11-50	-	S	X	-	Spring; conglomerate.
36ca	723	570 rept.	12-47	W,G	S	-	X	Discharge, 6 gpm.
(D-13-18)								
1aaa	180	57.91	1-51	C,W	S	X	-	Discharge, 6 gpm.
(D-13-20)								
23dc	-	-	-	J,W	S	X	-	
(D-13-21)								
6a	d/	-	11-50	-	D,S	X	-	Spring in conglomerate faulted against volcanics. Discharge $2\frac{1}{2}$ gpm.
20ddc	400	314 rept.	12-50	-	S	-	X	
21aba	250	187 rept.	1948	J,W,G	D,S	X	-	Discharge, 4 gpm.
(D-13-22)								
28bc	1104	900 rept.	-	J,G	S	X	X	Log of abandoned oil test 150 feet north.
(D-14-20)								
6daa	101	28 rept.	12-51	None	I	-	X	
34c	-	116.8	10-50	J,G	D,S	X	-	
(D-14-21)								
19cdc	644	270 rept.	1950	J,W	S	X	X	Discharge, 3 gpm.
(D-15-19)								
5c	d/	-	5-51	-	D,S	X	-	Spring in schist. Discharge, $\frac{1}{2}$ gpm.

Table 15.--Records of representative wells and springs in Lower San Pedro basin--continued.

Well or spring no.	Depth of well (feet)	Water level: Depth below land-surface datum (feet) a/	Water level: Date of measurement	Type of lift b/	Use of water c/	Analysis on file	Log on file	Remarks
(D-15-20) 8cb	515	300	-	J,G	S	X	-	Discharge 3 gpm, 1951. In conglomerate to 515 feet.

Table 16.--Logs of representative wells in Lower San Pedro basin, Ariz.

	Thickness (feet)	Depth (feet)
(D-5-16) 31bcd		
Clay - - - - - - - - - - -	20	20
Cgl. water begins here -	40	60
Sand and gravel-full of water - - - - - - - - - -	40	100
Hard clay - - - - - - - -	24	124
TOTAL DEPTH		124
(D-6-15)8cb		
Overburden - - - - - - - -	37	37
Hard granite - - - - - - -	128	165
Small crevice in granite	-	-
Hard granite - - - - - - -	120	285
Small crevices with yellow sandstone - - -	13	298
TOTAL DEPTH		298
(D-7-14)10dba		
"Broken formation" - - -	388	388
Water sand - - - - - - - -	10	398
Granite - - - - - - - - -	-	398
TOTAL DEPTH		398
(D-7-16)10caa		
Topsoil - - - - - - - - -	10	10
Clay and gravel - - - -	24	34
Water in boulders - - -	25	59
Clay - - - - - - - - - - -	21	80
Bed rock - - - - - - - - -	4	84
TOTAL DEPTH		84
(D-8-14)15bbb		
Wash fill - - - - - - - -	25	25
Volcanics (lava flows) -	90	115
Sand streak (water) - -	5	120
Volcanics (lava flows) -	430	550
Monzonite - - - - - - - -	-	550
TOTAL DEPTH		550
(D-8-16)25dcd		
"Ordinary conglomerate" - - - - - -	785	785
"Red material" - -	1359	2144
TOTAL DEPTH		2144
1st water at 475 ft.		
2nd water at 700 ft.		
Rose to 375 ft.		
(D-8-17)18cda		
Gravel - - - - - - -	30	30
Clay - - - - - - - -	20	50
Dry gravel - - - -	10	60
Water gravel - - -	10	70
TOTAL DEPTH		70
(D-8-17)18cdd		
Ground - - - - - - -	30	30
Clay - - - - - - - -	108	138
Water gravel-water rose to 98'- - - -	6	144
TOTAL DEPTH		144
(D-8-17)32daa		
Sand & gravel - - -	80	80
Sand - - - - - - - -	5	85
Sand & boulders - -	55	140
Sand - - - - - - - -	20	160
Gravel - - - - - - -	45	205
Hard sand - - - - - -	15	220
Gravel - - - - - - -	65	285
Sand - - - - - - - -	30	315
Sand & boulders - -	136	451
Sand - - - - - - - -	144	595
Sand & gravel - - -	10	605
Gravel - - - - - - -	20	625
Sand & gravel - - -	35	660
Running sand - - -	5	665
Sand - - - - - - - -	80	745
Clay & gravel - - -	10	755

Table 16.--Logs of representative wells in Lower San Pedro basin--continued.

	Thickness (feet)	Depth (feet)
Sand & clay	10	765
Red clay & gravel	240	1005
Brown shale with sand	10	1015
Red clay & gravel	15	1030
Sticky black clay (show oil)	5	1035
Sticky brown shale (show oil)	5	1040
Red clay & gravel	65	1105
Gypsum	5	1110
Red clay & gravel	25	1135
Brown lime	9	1144
Red clay & gravel	16	1160
Hard sand (small amount water)	35	1195
Red clay	2	1197
Hard brown sand	8	1205
Hard gray lime	15	1220
Conglomerate with lime	37	1257
Red clay	8	1265
Hard conglomerate	2	1267
Red clay	8	1275
Sandstone (artesian water flowing 20 gpm)	95	1370
Hard sandstone	70	1440
Red beds	45	1485
TOTAL DEPTH		1485
(D-9-15)15aad		
Dry conglomerate	680	680
Porphyry water-bearing (heavy water 770-786')	106	786
Hard rock	49	835
TOTAL DEPTH		835
(D-9-17)2dcb		
Lake beds with occasional sand stringers-water at 250'.	250	250
Lake beds, (light gravel at 600')	350	600
Lake beds with occasional sand stringers. Caved badly	425	1025
TOTAL DEPTH		1025

	Thickness (feet)	Depth (feet)
(D-9-17)24ddc		
River gravel	25	25
Coarse river gravel	20	45
River sand, mostly silica	26	71
Sandy gypsum	33	104
Solid gypsum beds	56	160
Gypsum beds and clay seams	160	320
Sandy gypsum. A little water in hole after 325'	40	360
Gypsum beds and clay seams	60	420
Gypsum beds	60	480
Sandy clay	60	540
Heavy clay	20	560
Sandy clay	60	620
Sand with clay nodules	40	660
Sand and gravel	20	680
Artesian water-bearing sand and fine gravel	120	800
Heavy clay with few boulders	70	870
TOTAL DEPTH		870
(D-9-17)25bdd		
River sand and silt	20	20
River gravel	40	60
River gravel & clay (24" csg. set)	20	80
Heavy clay with little gravel	40	120
Heavy clay	200	320
Sandy clay	140	460
Sandy gypsum	20	480
Gypsum sand (water in hole after 487')	60	540
Gypsum sand with clay nodules	60	600
Clay and sand	28	628
Coarse sand with artesian water	12	640
Fine sand	60	700

Table 16.--Logs of representative wells in Lower San Pedro basin--continued.

	Thickness (feet)	Depth (feet)
Coarse sand with clay seams - - - - - - - - -	120	820
Coarse sand and gravel	40	860
Sand & clay seams but no increase in water flow. Flow increased steadily from 628' to 864' - - - - - - - - -	95	955
Hard clay - - - - - - -	10	965
Running fine sand but no increase in water flow - - - - - - - - -	2	967
TOTAL DEPTH		967
(D-11-19)10dc		
Soil & boulders - - -	20	20
Cgl.-seep of water on top of volcanic - - -	122	142
Volcanics(?) like "Galiuro red rock" -	158	300
TOTAL DEPTH		300
(D-12-19)32ddd		
River gravels - - - - -	80	80
Silts - - - - - - - - -	170	250
"Rock" - - - - - - - - -	625	875
TOTAL DEPTH		875
(D-13-22)28bc		
Clay and boulders - -	27	27
Conglomerate - - - - - -	790	817
Water sand carrying 8 gpm - - - - - - - - -	5	822
Conglomerate - - - - - -	92	914
Dry sand - - - - - - - -	98	1012
Conglomerate - - - - - -	63	1175
Granite conglomerate -	5	1180
TOTAL DEPTH		1180

	Thickness (feet)	Depth (feet)
(D-12-18)13caa		
Clay boulders - - -	70	70
Sand gravel & water	25	95
Clay gravel - - - -	40	135
Possibly water - -	15	150
Conglomerate-tight	15	165
TOTAL DEPTH		165
(D-12-21)27cd		
Boulders and black dirt - - - - - - - -	55	55
Red conglomerate -	315	370
Sand and gravel water - - - - - - -	5	375
Yellow clay - - - -	5	380
Hard conglomerate -	10	390
Sand water - - - -	10	400
Conglomerate - - -	10	410
TOTAL DEPTH		410
(D-12-21)36ca		
Sand, gravel and lava boulders - -	200	200
Clay - - - - - - - -	365	565
Caving sand & clay	5	570
Clay - - - - - - - -	95	665
Hard lava - - - - - -	5	670
Sandstone - - - - - -	53	723
TOTAL DEPTH		723
(D-14-20)6daa		
Surface sand - - -	2	2
Clay - - - - - - - -	36	38
Sand (water) - - -	32	70
Clay - - - - - - - -	10	80
Very hard granite conglomerate. Pardee reports this to be very similar to granite cgl. up Teran Wash. More		

Table 16.--Logs of representative wells in Lower San Pedro basin--continued

	Thickness (feet)	Depth (feet)
likely it is a local granite boulder lens - - - -	21	101
TOTAL DEPTH		101
(D-14-21)19cac		
Decomposed granite - -	20	20
Medium hard granite -	180	200
Low granite (water 270 to 275 ft.) - - -	80	280
Soft granite - - - - -	45	325
Hard granite - - - - -	60	385
Soft granite - - - - -	25	410
Hard granite - - - - -	10	420
Soft granite - - - - -	5	425
Hard granite - - - - -	20	445
Soft granite (fault gouge) - - - - - - -	5	450
Hard granite (water at 460 ft.) - - - - - -	10	460
Soft granite - - - - -	10	470
Hard granite - - - - -	9	479
TOTAL DEPTH		479

Table 17.--Analyses of water from representative wells and springs in Lower San Pedro basin, Ariz.
(Parts per million except specific conductance and percent sodium)

Well or spring no.	Date of collection	Depth of well (feet)	Temperature (°F.)	Specific conductance (micromhos at 25° C.)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Total hardness as $CaCO_3$	Percent sodium
Waters from Lower San Pedro flood plain															
(D-5-15) 24cb	9-50	33	84	1540	79	28	234	355	378	92	2.3	0.3	1030	312	62
(D-8-17) 19d	9-50	46	-	665	51	12	81	248	109	18	3.0	2.2	432	176	50
(D-11-18) 15a	9-50	30	68	609	60	14	56	250	96	11	1.2	7.1	400	207	37
(D-14-20) 34c	10-50	-	78	387	33	16	29	204	20	12	0.8	4.6	243	148	29
Waters in vicinity of Aravaipa Creek															
(D-6-16) 12d	9-50	a/	67	981	86	18	112	300	228	28	2.8	3.4	666	288	46
33c	2-51	a/	70	571	74	13	33	251	82	10	1.0	2.6	378	238	23
(D-6-17) 13d	10-50	b/	60	438	54	8.3	33	253	17	8	1.2	0.4	287	168	30
(D-7-16) 11a	10-50	87	66	518	70	13	25	269	41	10	1.2	3.6	337	228	19
Artesian waters south of Mammoth															
(D-8-17) 32daa	10-50	1485	108	683	12	1.6	133	114	152	42	5.6	1.1	441	36	89
(D-9-17) 14cdb	10-50	54	88	877	48	4.9	140	176	212	44	6.0	1.2	590	140	68
24dc	10-50	-	87	516	12	1.6	101	127	93	27	6.0	1.2	341	36	86
Waters from older alluvial fill															
(D-8-15) 3d	4-51	a/	67	391	26	21	25	193	5.6	18	0.8	19	237	152	26

a/ Spring.
b/ Aravaipa Creek.
c/ Seep in tunnel.
d/ Reported.

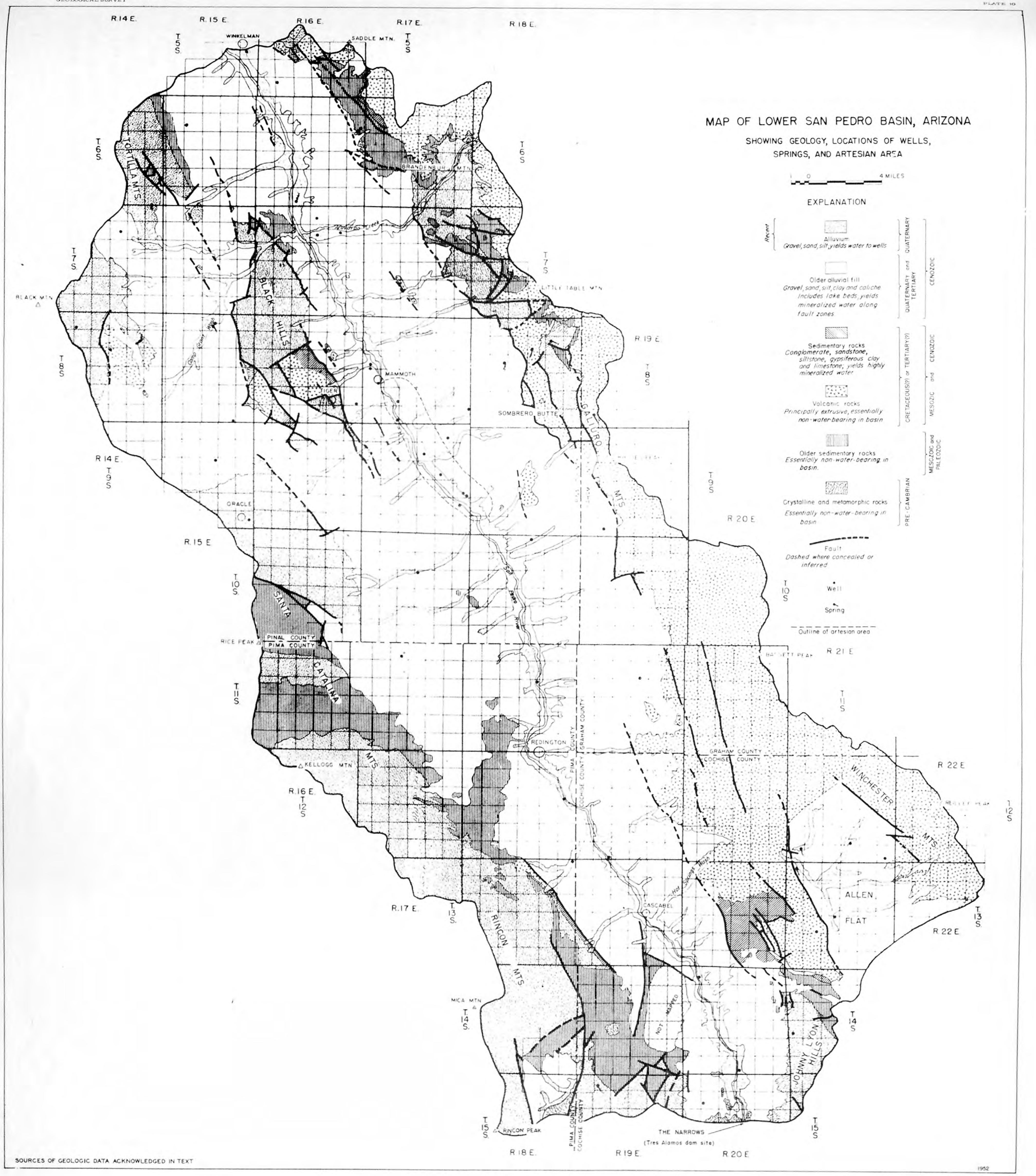
Table 17.--Analyses of water from representative wells and springs in Lower San Pedro basin--continued.

Well or spring no.	Date of collection	Depth of well (feet)	Temperature (°F.)	Specific conductance (micromhos at 25° C.)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Total hardness as $CaCO_3$	Percent sodium
(D-8-17) 36a	2-51	-	75	498	1.5	1.6	109	e/185	9.1	7.0	30	16	314	10	96
(D-8-18) 17a	5-51	a/	69	878	102	39	36	234	257	15	0.5	14	618	415	16
(D-10-17) 15bb	6-51	285	71	396	42	16	21	235	6.0	10	0.4	3.2	243	171	21
(D-10-18) 3b	6-51	390	d/hot	819	38	2.4	141	172	167	51	9.0	0.7	541	105	74
(D-12-21) 31a	11-50	a/	67	384	36	12	32	231	5.8	8	0.8	0.6	265	140	33
(D-13-18) 1aaa	1-51	140	65	428	66	9.4	13	234	23	6	0.2	8.2	260	203	12
(D-13-21) 6a	11-50	a/	109	287	4.0	0.4	68	f/173	4.9	4	2.0	1.3	218	12	93
21aba	7-51	250	67	296	33	12	14	172	4.3	8	0.6	4.0	197	132	18
Water from Cretaceous (?) - Tertiary (?) sedimentary rocks															
(D-13-20) 23dc	5-52	-	84	11700	168	74	2830	263	4600	1330	1.6	1.9	9160	724	89
Waters from volcanics															
(D-8-18) 10c	5-51	c/	78	1200	119	72	45	66	579	20	2.1	0.2	902	593	14
(D-8-19) 31a	2-51	a/	64	426	48	16	24	275	3.3	6.0	0.2	0.2	299	186	22
Water from pre-Cambrian and Paleozoic sedimentary rocks															
(D-7-18) 8a	5-51	a/	62	417	50	19	12	250	7.2	10	0.2	3.3	261	203	12
Water from diorite															
(D-8-18) 11b	5-51	a/	71	1100	124	57	47	643	79	25	0.3	1.4	700	544	16

e/ Includes equivalent of 22 parts per million carbonate (CO_3).
f/ Includes equivalent of 8 parts per million carbonate (CO_3).

Table 17.--Analyses of water from representative wells and springs in Lower San Pedro basin--continued.

Well or spring no.	Date of collection	Depth of well (feet)	Temperature (°F.)	Specific conductance (micromhos at 25° C.)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Total hardness as $CaCO_3$	Percent sodium
Waters from granitic rocks															
(D-8-14) 5ccd	4-51	70	-	1700	110	43	218	371	386	150	2.9	0.2	1110	452	51
(D-9-15) 36d	8-49	224	-	594	55	19	51	322	13	30	2.0	0.3	344	215	34
(D-14-21) 19cac	11-50	644	-	923	33	33	132	373	80	73	4.4	0.7	562	218	57
Water from schist															
(D-15-19) 5c	5-51	a/	60	698	93	22	35	414	28	19	1.2	1.0	425	322	19


MAP OF LOWER SAN PEDRO BASIN, ARIZONA
SHOWING GEOLOGY, LOCATIONS OF WELLS, SPRINGS, AND ARTESIAN AREA
0
4 MILES
EXPLANATION
Recent
Alluvium
Gravel, sand, silt, yields water to wells
QUATERNARY
Older alluvial fill
Gravel, sand, silt, clay and caliche includes lake beds, yields mineralized water along fault zones
QUATERNARY and TERTIARY
CENOZOIC
Sedimentary rocks
Conglomerate, sandstone, siltstone, gypsiferous clay and limestone; yields highly mineralized water
Volcanic rocks
Principally extrusive, essentially non-water-bearing in basin
CRETACEOUS(?) or TERTIARY(?)
MESOZOIC and CENOZOIC
Older sedimentary rocks
Essentially non-water-bearing in basin.
MESOZOIC and PALEOZOIC
Crystalline and metamorphic rocks
Essentially non-water-bearing in basin
PRE-CAMBRIAN
Fault
Dashed where concealed or inferred
Well
Spring
Outline of artesian area
R.14 E.
R.15 E.
R.16 E.
R.17 E.
R.18 E.
R.19 E.
R.20 E.
R.21 E.
R.22 E.
T.5 S.
T.6 S.
T.7 S.
T.8 S.
T.9 S.
T.10 S.
T.11 S.
T.12 S.
T.13 S.
T.14 S.
T.15 S.
WINKELMAN
SADDLE MTN.
TORTILLA MTS
BRANDENBURG MTN
LITTLE TABLE MTN
BLACK MTN
BLACK HILLS
MAMMOTH
TIGER
SOMBRERO BUTTE
GALIURO MTS
ORACLE
SANTA CATALINA MTS
RICE PEAK
PINAL COUNTY
PIMA COUNTY
KELLOGG MTN
REDINGTON
PIMA COUNTY
GRAHAM COUNTY
COCHISE COUNTY
BASSETT PEAK
WINCHESTER MTS
ALLEN FLAT
CASCABEL
RINCON MTS
MICA MTN
NOT MAPPED
JOHNNY LYON HILLS
RINCON PEAK
THE NARROWS
(Tres Alamos dam site)
San Pedro River
SOURCES OF GEOLOGIC DATA ACKNOWLEDGED IN TEXT
1952

UPPER SANTA CRUZ BASIN, PIMA AND SANTA CRUZ COUNTIES

By P. W. Johnson

Introduction

Location and extent

The Upper Santa Cruz basin described in this report is the Arizona portion of a larger basin that extends from within Mexico northward about 90 miles into Arizona. This basin is bounded (pl. 11) on the north by the drainage divide between streams that enter this basin and streams that enter the Lower Santa Cruz and Lower San Pedro basins; on the east by the Santa Catalina, Tanque Verde, Rincon, Whetstone, and Huachuca Mountains and the Canelo Hills; on the south by the International Boundary; and on the west by the Atascosa, Tumacacori, Cerro Colorado, Sierrita, Tucson, and Tortolita Mountains. The alluvial basin is about 45 miles wide at the widest part and includes an area of about 1,700 square miles.

Land forms and drainage

The Santa Cruz River, the principal stream of the basin, is an intermittent stream that heads in the San Rafael Valley in Arizona. The river flows southward into Mexico for about 20 to 30 miles, turns west and then north, and enters Arizona at an altitude of about 3,700 feet, 6 miles east of the City of Nogales. The river continues to flow northward in a long, serpentine arc, with gradients ranging from 15 to 40 feet to the mile. The greatest gradient is in the southern part of the basin. The Santa Cruz River, when first seen by white men, was reported to have been a "live" stream, but since then, except for flood flows, it has been dry owing to the lowering of the water table. As the Santa Cruz River flows northward, it receives inflow from five major tributaries; Sonoita Creek, Nogales Wash, Sopori Creek, Rillito Creek, and Cañada del Oro Wash.

The mountains forming the boundary on the east side are much higher than those on the west. Altitudes range from 4,000 to 9,000 feet, and it is in these mountains that heaviest precipitation falls. The total area of hard rock within the natural drainage divide of the basin is approximately 1,300 square miles. The bottom-land portion of the basin along the stream channels is roughly 12 to 18 miles wide at the widest part, about 80 miles long, and includes about 600,000 acres. Most of the cultivated land and most of the irrigation wells are within this area.

Bryan (1923, pp. 74-76) describes some of the physiographic features of the Upper Santa Cruz basin as follows:

> The lowland is composed of long ridges and flat-topped spurs extending from the bordering mountains toward Santa Cruz River and its tributaries.... Between the ridges are sharp walled, terraced canyons, which lead to the flat inner valleys along Santa Cruz River and its two main tributaries. The flat floor of Nogales Wash is from an

> eighth to half a mile wide, a moist and fertile meadowland which narrows in places but grows wider downstream until it merges into the similar floors of the inner valleys of Santa Cruz River and Sonoita Creek. In these flat meadows the streams have cut narrow, steep-sided gullies from 10 to 30 feet deep.
>
> The bluffs bordering these flood plains show a double terrace, the upper one coincident with the sloping ridges and the lower about 50 feet above the flood plains. The upper terrace is in places covered with thin alluvium. The lower terrace is everywhere capped with 10 to 20 feet of gravel. From Calabasas to the mouth of Sopori Creek, Santa Cruz Valley is from 8 to 12 miles wide. Long-dissected slopes lead down to an inner valley bounded by bluffs. Near the mountains, the side streams flow in deep gorges through narrow pediments, and lower down they occupy flat-bottomed valleys bounded by bluffs of alluvium. The floors of the tributaries join and merge with the flood plain of Santa Cruz River. This flood plain is 1 to 2 miles wide, and through it the stream flows in a steep-walled channel from 10 to 20 feet deep .... Forty miles to the north, near Tucson, the inner valley, with its flood plain and the narrow trench in which the river runs, is bounded by ragged bluffs about 25 feet high. From the tops of these bluffs, the alluvial slopes sweep upward to the mountains....
>
> From Tucson northward the bluffs bounding the inner valley of the river decrease in height and near the north end of the Tucson Mountains disappear. Similarly, the trench in the flood plain becomes shallower, and the Santa Cruz in flood spreads widely over great adobe flats in which the main channel is so obscure that its mapping is arbitrary.

It is to be noted also that the Santa Cruz River does not follow the axis of the basin. Heavy deposition of alluvial sediments from the east, related to the greater height of, and greater precipitation on, the mountains on this side, has pushed the stream channel in places almost to the base of the mountains on the west. This is evident particularly in the reach of the river from about 10 miles south of Tucson to the Rillito narrows.

The Santa Cruz River leaves the Upper Santa Cruz basin through a "narrows" between the Tucson and Tortolita Mountains. This narrows is referred to in this report as the "Rillito narrows." There is a natural subsurface structure here which forms a partial barrier to the downstream movement of ground water.

The tributaries of the Santa Cruz River are mostly ephemeral streams throughout their courses. Cañada del Oro Wash drains the western slope of the Santa Catalina Mountains and the eastern slope of the Tortolita Mountains. These higher slopes receive considerable snow and rain. The runoff from these sources usually causes Cañada del Oro to have a small flow in its upper course during the early months of the year.

Big Wash, the principal tributary of Cañada del Oro, extends northward and drains a wide upland area which lies north of the Santa Catalina Mountains. The wash has a sandy channel which is more than 100 feet wide along the eastern base of the Tortolita Mountains.

Rillito Creek is the largest contributor of water to the Santa Cruz River, which it joins about 6 miles north of Tucson. Although the creek name is applied to only the lower part of the stream, its main channel and tributaries drain an area of 934 square miles, including some of the most mountainous areas bordering the basin.

In a few places along the channel of Rillito Creek, notably in secs. 30 and 32, T. 13 S., R. 15 E., the underflow comes close to the surface, probably because of an underground constriction.

Pantano Wash is the largest tributary of Rillito Creek; it drains the northern slopes of the Santa Rita Mountains and the western slopes of the Empire Mountains.

Sopori Creek drains the northwest slopes of the Tumacacori, the eastern slopes of the Cerro Colorado, and the southern slopes of the Sierrita Mountains. The lower two-thirds of the stream course is in a narrow alluvial valley and contains two or three constrictions which bring the underflow near the surface.

The southern part of the Santa Rita Mountains is drained chiefly by Sonoita Creek, whose headwaters are separated from those of Cienaga Creek, a tributary of Rillito Creek, by a gentle divide near the town of Sonoita. The upper part of Sonoita Creek is in a narrow alluvial valley bordered by terraces of outwash gravel. Below Patagonia the narrow valley ends, and the stream channel is in a rock-walled canyon for several miles; thence it emerges into a narrow valley tributary to the Santa Cruz River Valley.

Nogales Wash is the uppermost western tributary of the Santa Cruz River in Arizona. The stream heads in Mexico, flows through the two Cities of Nogales on the International Boundary, and through a narrow alluvial valley to its junction with the Santa Cruz River about 8 miles north of Nogales, Ariz.

Between the Patagonia Mountains on the west and the Huachuca Mountains on the east, is the wide upland area of the San Rafael Valley. Here the Santa Cruz River has its headwaters. Numerous nearly parallel washes come from the east and west to join the main channel, which extends southward through the center of the valley and enters Mexico at an altitude of about 4,600 feet.

Geology

The descriptions of general rock types as given in Part I, "Regional geology," of this report are applicable to the rocks composing the mountain masses and the valley fill in the Upper Santa Cruz basin. The distribution of the rocks, together with their water-bearing properties, are shown on plate 11.

The generalized geology presented in plate 11 was taken from the geologic map of the State of Arizona (Darton and others, 1924), and from open-file data from the Geological Survey (Moore and others, 1941).

Hard rocks and their relation to ground water

The mountains which rim the lower part of the basin are predominantly composed of rocks of the crystalline and metamorphic complex. These rocks occur in the Santa Catalina, Tanque Verde, Rincon, and Santa Rita Mountains on the east, and the Tortolita and Sierrita Mountains on the west. Pre-Tertiary sedimentary rocks form the main body of the Empire and Whetstone Mountains, the Canelo Hills, and the west side of the Huachuca Mountains. Cretaceous (?) or Tertiary (?) volcanic rocks are present in most of the mountains and seem to comprise a greater portion of the ranges toward the southern end of the basin. Associated with these rocks are numerous dikes, sills, and necks which range in composition from rhyolite to diabase. Younger volcanic rocks of Quaternary age are present in the Tucson and Sierrita Mountains and, perhaps in small amounts, in some of the other mountains that rim the basin.

Joints and other fractures, as well as composition, texture, and depth of weathering in the hard rocks of these mountains, control the possible small yields of water to wells and springs. Some limestones in the Rincon, Empire, and Whetstone Mountains contain springs temporarily yielding as much as 200 gallons per minute during periods following heavy rains. Two springs in limestone in the Canelo Hills have sustained flows of 150 and 750 gallons per minute. In places, water issues from springs close to outcrops of fractured schist along the fronts of the Santa Catalina and Rincon Mountains. The largest of these springs yield about 150 gallons per minute; however, the average discharge is less than 25 gallons per minute. Lavas and tuffs absorb water from precipitation and runoff, and discharge this water from fractured zones into the stream channels cut into these rocks.

Pediments are well developed in the Upper Santa Cruz basin. Pediments of sufficient extent to influence local runoff and ground-water movement occur at the north end of the Empire Mountains, in the southern part of the Cerro Colorado Mountains, on the northeast slope of the Sierrita Mountains (pl. 11), and on the southeast slope of the Tortolita Mountains.

Valley fill

The valley fill in the Upper Santa Cruz basin consists of both older and Recent alluvial fill. It is difficult in many places to distinguish these two types of fill from a study of well logs.

The greatest depth to which the older alluvial fill has been penetrated in this basin, according to logs on file in the Geological Survey, was in well (D-15-15)25caa which was drilled to a depth of 1,480 feet (table 20). The well log indicates that the older fill is cemented at depth, and no thick clay series was encountered. Well (D-16-17)35bd, near the railroad station at Pantano, was drilled to a depth of 1,380 feet, and encountered materials which were so tightly cemented that the well did not produce enough water for use by the railroad. Known depths of other deep wells in this basin are less than 1,000 feet.

The greatest depth of older fill is probably between Tps. 12 and 20 S., Rs. 12 and 16 E. South of T. 19 S., the valley along the Santa Cruz River is relatively narrow, and the thickness of valley fill is probably much less than in the area to the north. Bedrock crops out in the channel of the Santa Cruz River in T. 23 S., R. 14 E.

From these logs there is no evidence to show that a lake covered this valley at one time in the history of deposition, as in many of the other basins in southern Arizona. The absence in the well logs of a uniform thickness of clay bears this out, although these materials are noted in a few logs. However, lake beds may have been deposited in this basin at depths below that of present deepest penetration. Locally, small lakes or playa flats may have existed in which silt and clay were deposited.

On the basis of logs of deep wells and geological reconnaissance of the basin, it is believed that the older alluvial fill in most areas of the basin will yield water in quantities sufficient for domestic and stock wells. In some places there are yields of about 500 gallons per minute, in properly constructed and developed wells.

Recent fill overlies the older alluvial fill in the stream channels and flood plains of the basin, to depths of from a few inches to as much as 300 feet. In general, the thickest deposits are in the channels of the Santa Cruz River, Rillito Creek, and Pantano Wash. Logs of most wells in these areas show thickness of Recent fill generally ranging between 75 and 150 feet. Most of the irrigation wells in the valley develop all their water from the Recent fill. A few wells yield as much as 3,000 gallons per minute. Infiltration galleries constructed in the channels of Sonoita Creek, Sopori Wash, Santa Cruz River, Rillito Creek, and Pantano Wash develop water from the Recent fill.

Ground-water hydrology

Source and movement

General statements regarding ground-water hydrology are presented in Part I, "Regional hydrology." The principal source of water is precipitation in the mountainous areas. A small percentage of the precipitation finds its way into the ground-water reservoir by penetration of the coarse sediments along the mountain fronts and by percolation from surface flow in the stream channels. Ground water moves downhill along the hydraulic gradient from areas of recharge to areas of discharge. The slope of the water table varies but in general conforms to the topography of the area. The ground-water movement is perpendicular to the water-table contours and the general direction of movement is northwest (pl. 12).

Recharge

Recharge to the Upper Santa Cruz basin is by infiltration from runoff along the mountain fronts, seepage from surface flow in the main stream channels, direct infiltration from precipitation, seepage from canals and irrigated lands, and underflow.

Infiltration along mountain fronts.--Recharge along the mountain fronts occurs as infiltration from runoff from about 1,280 square miles, or about 820,000 acres, of mountain areas. Precipitation in the mountain areas averages about 18 inches per year. Runoff from the mountain areas is assumed to be

10 percent of the precipitation. If recharge is assumed to be about 50 percent of the runoff, recharge from this source in the Upper Santa Cruz basin, is of the order of 65,000 acre-feet per year.

Seepage from main stream channels.--Estimation of recharge by seepage from surface flow along the main stream channels is based on calculations and experiments conducted in the Upper Santa Cruz basin in 1940-41 (Turner and others, 1943, pp. 45-47) and gaging-station measurements in the basin for the period 1940-51. The 1940-41 data collected in the basin showed that essentially all the loss from stream flow was recharged. During the period 1940-41, loss from surface flow along the Santa Cruz River was estimated by Turner and others to be 61,000 acre-feet. Comparison of stream-flow losses for the period 1940-41 with those for the period 1940-51 shows that the average loss of stream flow for the 12-year period was slightly more than two-thirds of that for the period 1940-41. Using these data, the average recharge from stream flow along the Santa Cruz River in this basin was estimated to be approximately 45,000 acre-feet per year during the 12-year period.

Direct infiltration from precipitation.--Recharge from precipitation in the mountain areas has been discussed above. Direct infiltration from precipitation on the desert floor is believed to be negligible in the average year. Some recharge may occur by direct infiltration from precipitation on permeable Recent alluvial fill, but no quantitative data are available.

Seepage from irrigated fields and canals.--Recharge by seepage from irrigated fields and canals in other parts of southern Arizona has been estimated on the basis of field experiments to be between 10 and 33 percent of the water diverted. On the basis of soil conditions within the Upper Santa Cruz basin, it is assumed by the author that from 10 to 20 percent of the water diverted and used for irrigation is recharged. During the period 1947-51, about 105,000 acre-feet was used for irrigation annually, based on an average of about 30,000 acres under cultivation, and a duty of water estimated from Department of Agriculture data to be about 3.5 acre-feet per acre per year. Assuming that 105,000 acre-feet per year was used for irrigation in the period 1947-51, and assuming that 10 percent of this constituted ground-water recharge, the amount recharged each year would be about 10,000 acre-feet. If the proportion recharged was 20 percent, the quantity would be about 20,000 acre-feet per year.

Underflow.--Underflow into the Upper Santa Cruz basin at the International Border was estimated to be about 1,000 acre-feet in the year 1940-41 by Turner and others, (1943, p. 53). Calculations based on data collected since 1941 indicate that this estimate is of the correct order of magnitude.

Discharge

Discharge from the ground-water reservoir takes place by both natural and artificial means. The natural discharge is through evaporation, transpiration, springs, and underflow, and artificial discharge is from pumped wells.

Evaporation.--Losses by evaporation from the ground-water reservoir are considered negligible. Losses by evaporation prior to recharge from runoff were considered in making the computations of recharge from runoff.

Transpiration.--Discharge from the ground-water reservoir through transpiration or evapotranspiration by native vegetation and phreatophytes decreases as the water table is lowered. With the increase in the amount of land which has come under cultivation since 1941 and the organization of local interests to foster the systematic eradication of phreatophyte areas, it is believed that the loss has decreased about 20 percent from previous estimates (Turner and others, 1943, p. 83), and currently is assumed to be about 12,000 acre-feet per year.

Springs.--Water from springs in the basin is used for domestic and stock purposes and to irrigate small areas. These springs are not only a means of discharge from older rocks but also a source of recharge to the alluvial fill. It is believed that the discharge tends to balance the recharge and they have been omitted from the calculations. No estimates of total discharge by springs can be made because of a lack of quantitative data.

Underflow from the basin.--The underflow out of the basin at Rillito narrows was estimated to be about 3,000 acre-feet in the year 1941, (Turner and others, 1943, p. 56). On the basis of a decrease of about 20 percent in the saturated thickness of the alluvium caused by lowering of the water table at the Rillito narrows, the average underflow out of the basin during the period 1947-51 is assumed to have been about 2,500 acre-feet per year. Calculations based on coefficients of permeability determined since 1941 corroborate this estimate.

Underflow out of the San Rafael Valley into Mexico was roughly estimated to be about 2,000 acre-feet per year.

Irrigation wells.--The pumping of water from irrigation wells accounts for most of the discharge from the ground-water reservoir in the Upper Santa Cruz basin. A total of about 35,000 acres was irrigated in 1952 by water pumped from about 1,000 irrigation wells. Many of these wells are used to irrigate only a few acres each. Most of these wells are 40 to 500 feet deep, yield from 150 to 3,000 gallons per minute, and have an average pumping lift ranging from 80 to 100 feet (table 19). In certain heavily pumped areas the maximum lift is 235 to 250 feet. Most of the wells are equipped with turbine pumps and electric motors or natural gas or diesel engines, with horsepower ratings ranging from 30 to 250. The wells and the irrigated areas are concentrated along the Santa Cruz River and Rillito Creek (pl. 11).

The depth to ground water ranges from a very few feet to more than 500 feet and averages about 150 feet in the valley as a whole. The depths to water are shown on plate 13.

The total amount of discharge from the ground-water reservoir was about

140,000 acre-feet in 1951, of which about 20,000 acre-feet was exported to the Lower Santa Cruz basin. The figures for ground-water withdrawals published annually by the Geological Survey are tabulated by counties, and those figures therefore do not correspond with figures given in this part of the report. During the period 1947-51, it is estimated that an annual average of about 105,000 acre-feet was used to irrigate about 30,000 acres in the Upper Santa Cruz basin. During the same period the average annual amount exported to the Lower Santa Cruz basin was about 18,000 acre-feet.

Other types of wells.--Other types of wells that account for the remainder of the pumpage in the Upper Santa Cruz basin are listed in order of decreasing amounts of ground water pumped--public-supply, industrial, domestic, and stock wells.

There are a total of about 115 public-supply wells which serve a population of 163,000 in Tucson and vicinity. The 40 City of Tucson wells range in depth from 118 to 510 feet and discharge about 250 to 1,250 gallons per minute. Wells belonging to private water companies vary greatly in size, depth, and capacity. Total pumpage in Tucson and vicinity was about 28,000 acre-feet in 1951. The City of Nogales wells and infiltration gallery are about 6 miles northeast of Nogales and serve a population of about 6,600. The total pumpage from this system was about 9,000 acre-feet in 1951.

A collective estimate of 14,000 acre-feet was made in evaluating the quantity of ground water pumped for industrial, military, domestic, and stock purposes in 1951. Most of the industrial wells are located in the Tucson area. None of the industries require extremely large supplies of ground water and most of the water is used for personnel and in cooling systems. Ground water used at Davis-Monthan Air Force Base is included in this estimate.

Pumpage from wells, 1947-51.--Pumpage from wells in the basin during 1951 totalled about 191,000 acre-feet, and is summarized as follows:

Type of wells		Acre-feet
Irrigation		140,000
Public-supply:		
Tucson	28,000	
Nogales	9,000	
	37,000	37,000
Industrial, Domestic, Stock		14,000
		191,000

Total annual pumpages for the period 1947-51 are given below:

1947	156,000
1948	155,000
1949	154,000
1950	176,000
1951	191,000

On the basis of these quantities, the average annual discharge from wells in the Upper Santa Cruz basin during the period 1947-51 was about 166,000 acre-feet.

Recapitulation of ground-water resources in the Upper Santa Cruz basin.--The following summary of estimated gains and losses to the ground-water reservoir in the entire basin during the 5-year period 1947-51 is given for convenience and to evaluate the order of magnitude of the difference between gains and losses.

Estimated Annual Gains to Reservior	Acre-feet	Estimated Annual Losses from Reservoir		Acre-feet
Infiltration at mountain fronts	65,000	Discharge by pumping:		
		Irrigation	105,000	
		Exported	18,000	
		Public supply, Industrial, all others	43,000	166,000
Seepage from surface channel runoff	45,000	Underflow out of the basin:		
		Rillito narrows	2,500	
		San Rafael Valley	2,000	4,500
Underflow into basin	1,000	Evapotranspiration		12,000
Springs	---	Springs		---
Seepage from irrigation	20,000 - 10,000			
Total gains	131,000 - 121,000	Total losses		182,500
or approximately	125,000	Rounded to		182,000
		Total gains		131,000 - 121,000
		Net annual loss from storage		51,000 - 61,000
		or approximately		55,000

This recapitulation shows that there was not enough ground water recharged annually to meet the demands of discharge, and that the difference was made up by the removal of ground water from storage.

Storage

The concepts of "latent storage" and "underlying storage" discussed in Part I, "Regional hydrology," are not applied to the Upper Santa Cruz basin.

No estimate for latent storage is made because of inadequate data in certain parts of the basin, and no estimate for total underlying storage is made because of the large amount of water pumped for purposes other than irrigation in the vicinity of Tucson. However, an estimate of underlying storage is made for the effective area pumped for irrigation and other purposes, as outlined on plate 14.

The coefficient of drainage in the ground-water reservoir in this area has been estimated to be 10 percent (U. S. Geol. Survey, 1951, p. 8). Using the approximate totals of losses and gains from the recapitulation of ground-water resources, the amount of water removed from storage during the period 1947-51 amounts to approximately 275,000 acre-feet; total discharge of approximately 900,000 acre-feet less total recharge of approximately 625,000 acre-feet. The volume of sediments from which this water was removed was calculated, on the basis of water-table decline data (pl. 14), to be about 2,500,000 acre-feet. These approximations result in an estimate of 11 percent for the coefficient of drainage which bears out the previous estimate of 10 percent.

The amount of ground water in storage as calculated for this report, is the product of the effective area of pumping for irrigation and other purposes, the average thickness of saturated sediment within 300 feet of the surface, and the coefficient of drainage. This effective area pumped contains about 400,000 acres; the average thickness of saturated sediments is about 150 feet; and the coefficient of drainage used was the approximate 11 percent. On this basis, the amount of ground water in storage below the water table and within 300 feet of the surface is estimated to be about 6,600,000 acre-feet.

Fluctuations of the water table.--The over-all ground-water picture in the Upper Santa Cruz basin is one of decline. A large part of the information on water-level decline in Pima County was obtained by the Agricultural Engineering Department, University of Arizona, Tucson, Ariz. The amount of decline for the years 1947-52 is shown on the water-table-decline map (pl. 14). The areas of greatest decline are along the Santa Cruz River and are centered in the heavily pumped and irrigated areas about 5 miles north of Tucson, about 6 miles south of Tucson, and near Sahuarita. Some areas of small declines are located along the mountain fronts near the areas of heaviest pumpage, and there are local areas where the water table rose slightly (pl. 14).

The general decline in water levels is also illustrated by hydrographs of nine wells for the period 1940-52 (figs. 11 and 12). The hydrographs for wells (D-13-13)28add, (D-15-13)2cc, (D-17-14)18ca, and (D-19-13)3baa are representative of the areas of maximum decline. The maximum decline over the 11-year period 1941-51 was about 30 feet; the maximum decline during the 5-year period 1947-51 was about 20 feet, as illustrated on plate 14.

Well (D-12-12)16bad, located near the structural barrier that forms the Rillito narrows, illustrates fluctuations from periods of heaviest pumpage during the summer months to periods of greatest recharge during the winter and spring months. Most of the recharge is from waters of the Santa Cruz River. In general, successive water-level seasonal highs are progressively lower each year.

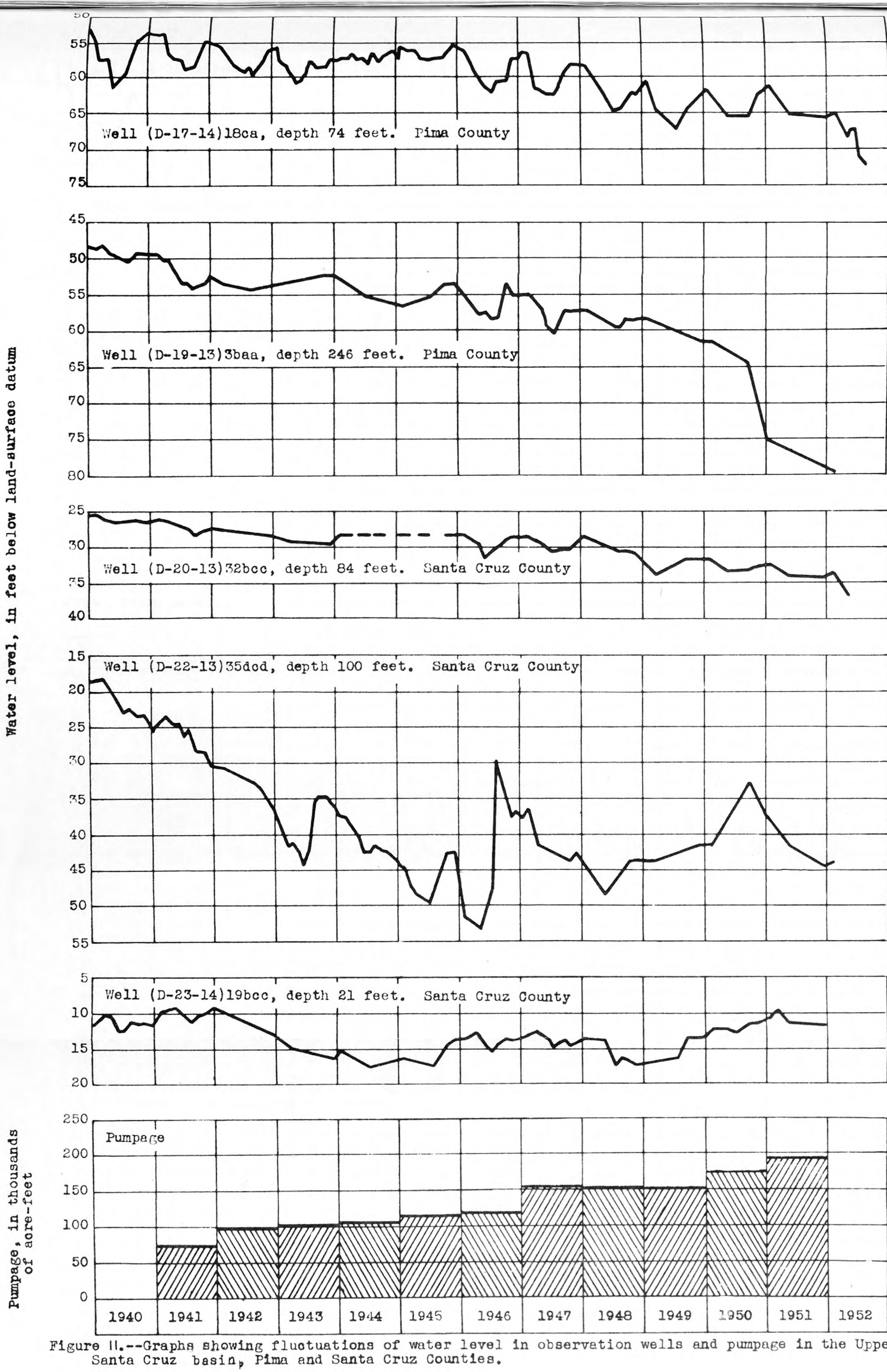


Figure 11.--Graphs showing fluctuations of water level in observation wells and pumpage in the Upper Santa Cruz basin, Pima and Santa Cruz Counties.

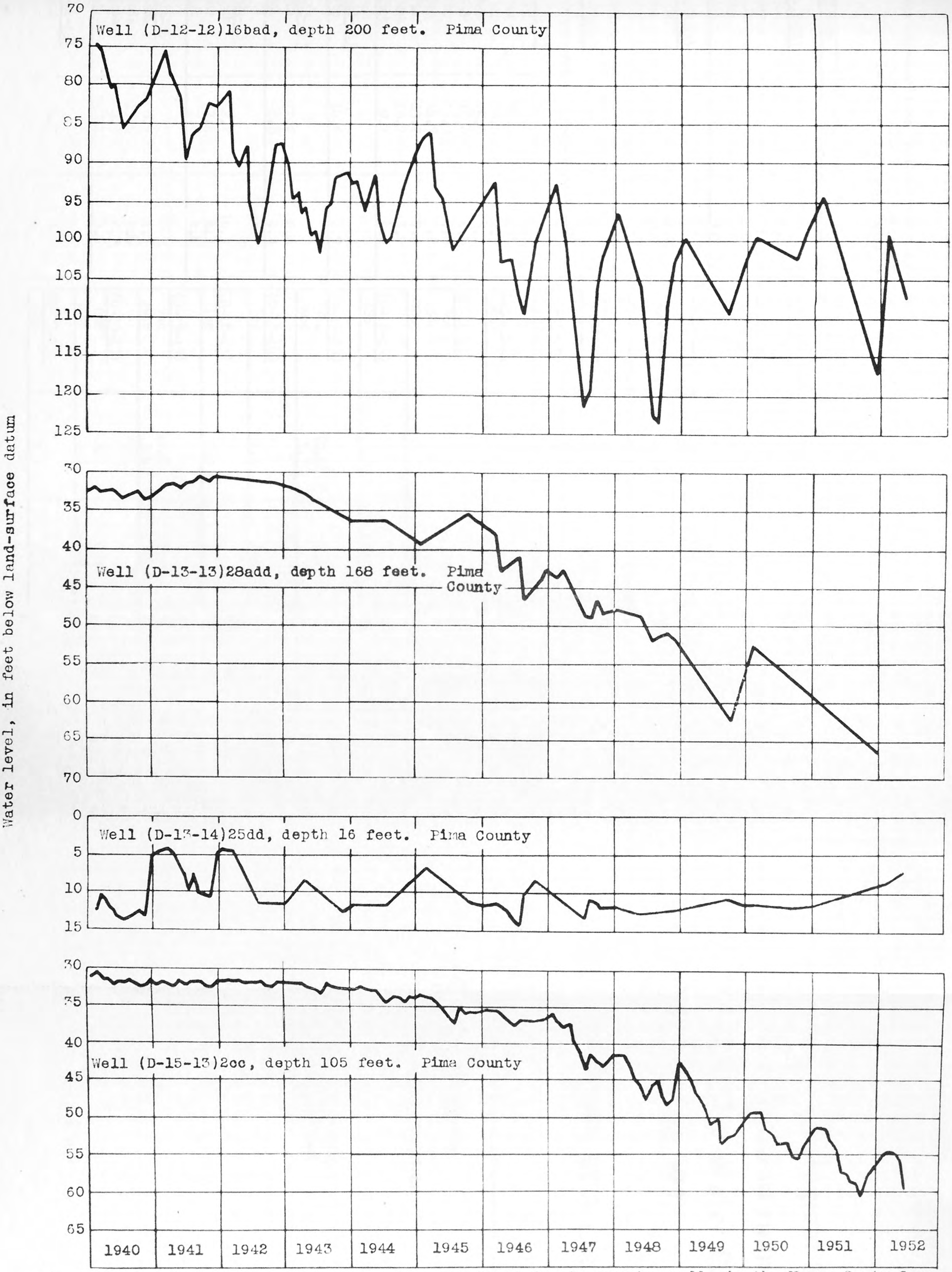


Figure 12.--Graphs showing fluctuations of water level in observation wells in the Upper Santa Cruz basin, Pima County.

Table 18.--Declines in the water table for 4 years, 1947-51, compared with 1 year, 1951-52, in representative wells in most of the irrigated areas of the Upper Santa Cruz basin, Pima and Santa Cruz Counties, Ariz.

Location	1947-51	1951-52	Location	1947-51	1951-52
(D-12-12)			17ad	4.3	1.9
5bd	7.4	15.6			
8ab	3.9	5.9	(D-15-13)		
15db	7.5	4.7	3ad	11.3	3.1
33ac	6.4	8.4	10db	3.4	6.2
33ad	37.3	1.8	21cd	2.4	0.7
			27dd	3.3	0.7
(D-12-13)					
14da	6.2	2.2	(D-15-14)		
18aa	5.8	3.7	5ab	1.9	0.4
29bc	8.7	3.0	30cc	1.1	1.0
32bd	8.7	3.9			
			(D-15-15)		
(D-12-14)			20bc	1.3	0.3
7cb	12.6	2.5			
			(D-15-16)		
(D-13-13)			7aa	8.5	1.1
2bd	7.6	2.6			
7ad	11.7	0.4	(D-16-13)		
13dd	18.5	3.9	36d	6.1	2.7
14cb	15.8	5.2			
19dd	15.6	5.6	(D-16-14)		
21bb	15.3	7.4	6bb	3.1	0.8
25ab	14.7	3.8	18dc	2.9	0.8
27ac	13.2	7.3	32bd	7.5	2.3
33dab	16.7	5.9			
36bcb	0.7	4.8	(D-16-15)		
			36b	1.6	13.2
(D-13-14)					
31bd	14.6	2.9	(D-17-13)		
			13ba	10.0	4.2
(D-13-15)			26bd	5.8	1.4
27ba	2.2	2.6			
31db	8.8	0.2	(D-17-14)		
			7cd	1.8	2.0
(D-14-13)					
3cab	2.7	10.3	(D-18-13)		
23ac	7.4	1.1	1bc	6.0	3.2
34da	7.6	1.4			
			(D-19-13)		
(D-14-14)			9ac	12.5	0.8
1dda	6.7	1.7	29cb	3.4	1.4
7bda	15.5	4.4			
22abb	8.3	2.7	(D-20-13)		
35a	3.4	3.5	6dc	3.7	0.1
			32bc	4.8	0.6
(D-14-15)					
9cd	4.7	1.8	(D-22-13)		
			35dc	2.9	5.0

Little or no decline is shown by the hydrograph for well (D-23-14)19bcc, in an area of small withdrawals at the upper end of the basin. The decline in this well during the years 1941-45 is attributed to drought. Well (D-22-13) 35dcd is a heavily pumped well that shows a similar pattern.

A small rise in the water table is shown by well (D-13-14)25dd. This well is located in the narrow area of water-level rise along Rillito and Tanque Verde Creeks (pl. 14). This area is recharged by flood waters originating in the Santa Catalina Mountains and by runoff from Pantano Wash.

Acceleration in decline of the water table in most of the irrigated areas is apparent when water-table declines for the year 1951 are compared with declines for the period 1947-50 (table 18). Declines during 1951 were greater than the average declines for the preceding 4 years, an increase not fully attributable to the increased withdrawals of ground water from storage in 1951 (figs. 11 and 12). This acceleration of the rate of lowering of the water table may possibly be due to decreased permeability and a decreased coefficient of drainage, with depth.

Quality of water

Chemical character of the ground water

The ground water of the Upper Santa Cruz basin contains moderate amounts of dissolved solids consisting largely of calcium and bicarbonate (table 21). Concentrations of total dissolved solids range from about 100 to about 950 parts per million, and of hardness range from 75 to about 350 parts per million. Analyses of water sampled for public-supply use in the Tucson area range in total dissolved solids from 177 to 484 parts per million and in total hardness from 94 to 220 parts per million. An analysis of a sample of water supplied to Nogales in 1951 showed 333 parts per million of total dissolved solids and a total hardness of 214.

Concentrations of dissolved solids do not appear to increase consistently downstream, though a local increase exists in the vicinity of Rillito narrows. In some places, concentrations of dissolved solids decrease at the confluence of the Santa Cruz River with some of its major tributaries and appear to increase again downstream from the confluence.

Relation of quality of water to its use

The ground waters in the Upper Santa Cruz basin are rated as excellent to good for irrigation purposes and are satisfactory for domestic use except for moderate hardness. The fluoride content of the ground water is generally within the limits of safe domestic use, although two springs along the front of Agua Caliente Hill have a fluoride content of 6.5 and 9.6 parts per million (table 21).

Problems

Extensive ground-water investigations in the Upper Santa Cruz basin have not been carried on by the Geological Survey. The Agricultural Engineering Department of the University of Arizona has been collecting ground-water data in the Pima County portion of the basin for several years. To avoid duplication of effort the Federal Survey makes only an annual pumpage inventory and periodic water-level measurements in selected observation wells.

Better information is needed about the total quantity of ground water in storage and the total annual discharge and recharge. Some of the factors about which more data are needed, and the type of data required, are as follows:

1. Extent and character of the alluvial fill, particularly at depth. Geologic mapping of the basin is required in order to delineate pediment areas, areas of greatest potential recharge, and the structural character of the basin.
2. Deep test holes are needed to determine if thick clay beds are present, if deep aquifers exist, and the quality of ground waters at depth. Samples of drill cuttings should be collected and examined.
3. Pumping tests and laboratory tests are required to determine more exactly the coefficients of drainage and transmissibility of the alluvial fill.
4. A complete inventory of all wells and springs should be made, to bring the records up to date. Electrical-conductivity or gamma-ray well logging should be done in the deeper holes, and all available drillers' logs should be collected.
5. The feasibility of artificial recharge of the ground-water reservoirs should be determined.
6. Additional well-discharge measurements are needed to improve the accuracy of the annual pumpage inventory.

Summary

The Upper Santa Cruz basin is a north-trending basin about 90 miles long and from 20 to 45 miles wide. It is bordered by mountains that rise abruptly to altitudes of 4,000 to 9,000 feet. The mountains on the east are much greater in elevation than those on the west, receive more precipitation, and furnish most of the recharge to the area.

The valley was formed by block faulting, and later filling of the downfaulted trough by detrital material eroded from the uplifted blocks. The Santa Cruz River and its five major tributaries drain the valley.

Ground water is obtained from unconsolidated sands and gravels in the valley fill.

Recharge to the ground-water reservoirs of the basin is supplied by infiltration from runoff and springs along the mountain fronts, seepage from surface flow in main stream channels, direct infiltration by precipitation, seepage from canals and irrigated lands, and underflow. The average recharge for the 5-year period 1947-51 was estimated to be in the order of 125,000 acre-feet per year.

Water is discharged from the ground-water reservoirs by both natural and artificial means. Natural discharge is by evaporation, transpiration, springs,

and underflow. Artificial discharge is by pumping for irrigation, public supply, and industrial, domestic, and stock use. It is estimated that the total average discharge was 180,000 acre-feet per year for the period 1947-51.

The water table has declined steadily in most of the basin since 1939. The most heavily pumped area is north of Tucson, where declines of more than 30 feet have been measured. The declines in the water table indicate that ground water is being removed from storage. The average amount of ground water taken from storage in the period 1947-51 was estimated to be about 55,000 acre-feet per year.

Analyses of ground water in the basin show moderate concentrations of dissolved solids. The water is considered excellent to good for irrigation, and is satisfactory for domestic use except for moderate hardness and objectionable fluoride content in local areas.

Table 19.--Records of representative wells in Upper Santa Cruz basin, Pima and Santa Cruz Counties, Ariz.

Well No.	Depth of well (feet)	Water level: Depth below land-surface datum (feet) a/	Water level: Date of measurement	Type of lift b/	Use of water c/	Log on file	Analysis on file	Discharge: Gallons per minute	Discharge: Date of measurement	Remarks
(D-12-12)										
5cb	333	d/140	-	-	RR	X	-	d/100	-	
14bcb	311	d/200	6/48	C,E	D	-	X	-	-	
16bad	200	99.45	2-20-52	None	N	-	-	-	-	Hydrograph, fig. 12
33aa	153	141.02	2-20-52	None	N	-	-	-	-	
(D-12-13)										
28aaa	296	166.72	1-24-52	T,E	I	X	-	-	-	
(D-13-13)										
17da	96	40.29	2-19-40	T,E	I	-	X	-	-	
21dcc	251	69.77	3-3-52	T,E	?	X	-	-	-	
28add	168	66.38	12-17-51	C,E	D	-	-	-	-	Hydrograph, fig. 12
35bca	228	86.29	3-3-52	T,E	I	X	-	-	-	
(D-13-14)										
22cd	60	-	-	T,E	D,S,I	-	X	487	5/41	
25ddd	16	8.59	2-20-52	None	N	-	-	-	-	Hydrograph, fig. 12
27cdc	190	45.35	2-25-52	T,E	I	-	-	306	6-13-52	
35bac	240	33.19	2-26-52	T,E	I	X	-	-	-	
(D-13-15)										
31aa	60	11.39	5-9-41	C,E	D,I	-	X	384	5-9-41	
32abd	85	12.05	2-26-52	T,E	I	-	-	-	-	
(D-14-12)										
17bb	113	78.68	3-15-40	C,G	D	-	X	-	-	
(D-14-13)										
3dda	400	41.05	3-3-52	T,E	I	-	-	-	-	
26bbb	130	37.37	1-21-52	T,E	I	-	X	775	8-4-49	
35bd	114	48.74	9-26-47	None	N	-	X	-	-	

a/ Depth was adjusted to land-surface datum from measuring point.
b/ T, turbine; Cf, centrifugal; C, cylinder; Bu, butane; G, gasoline; D, diesel; E, electric; W, windmill.
c/ I, irrigation; P, public supply; D, domestic; S, stock; RR, railroad; N, not used.
d/ Reported.

Table 19.--Records of representative wells in Upper Santa Cruz basin--continued.

Well No.	Depth of well (feet)	Water level: Depth below land-surface datum (feet) a/	Water level: Date of measurement	Type of lift b/	Use of water c/	Log on file	Analysis on file	Discharge: Gallons per minute	Discharge: Date of measurement	Remarks
(D-14-14)										
5ddc	200	d/105	9/51	T,E	P	–	X	–	–	
9dc	502	–	–	–	–	X	–	–	–	
16baa	323	d/128	9/50	T,E	P	X	–	d/540	9/50	
25cb	–	211.9	3-25-52	T,E	P	–	–	–	–	
(D-14-15)										
6aac	280	97.80	2-26-52	T,E	D	X	–	–	–	
26aaa	422	311.20	3-4-52	C,E	D	–	–	–	–	
(D-14-16)										
31bbc	500	266.18	3-4-52	C,W	S	–	–	–	–	
(D-15-13)										
2cc	105	54.88	2-26-52	None	N	–	–	–	–	Hydrograph, fig.12
3adc	142	57.70	1-21-52	T,E	I	X	–	–	–	
10dbb	141	51.95	3-11-52	T,E	I	X	–	420	6-6-52	
15dcc	200	52.27	1-21-52	T,E	I	X	–	219	3-26-52	
(D-15-15)										
8db	318	257.90	3-25-52	None	N	X	–	–	–	
25caa	1,480	401.02	3-6-52	C,G	RR	X	–	–	–	
(D-15-16)										
21aab	500	177.87	3-5-52	?,D	I	–	–	–	–	
(D-16-14)										
19bba	250	55.46	1-15-52	T,E	I	–	–	1214	5-21-52	P.L. 70.1,7-1-52
30ccc	200	58.24	10-5-39	T,E	I	–	X	632	7-14-41	
31adc	–	60.65	1-15-52	T,E	I	–	–	810	4-7-52	
(D-16-17)										
35bd	1,380	–	–	?	RR	X	–	–	–	Dry
(D-17-13)										
24acc	–	66.88	1-15-52	T,G	I	–	X	1090	4-26-46	

Table 19.--Records of representative wells in Upper Santa Cruz basin--continued.

Well no.	Depth of well (feet)	Water level: Depth below land-surface datum(feet) a/	Water level: Date of measurement	Type of lift b/	Use of water c/	Log on file	Analysis on file	Discharge: Gallons per minute	Discharge: Date of measurement	Remarks
(D-17-14)										
6ddd	200	78.89	1-15-52	T,E	I	X	-	1660	4-7-52	
18acc	182	68.14	1-16-52	T,E	I	X	X	615	4-7-52	
18ca	74	68.31	5-1-52	None	N	-	-	-	-	Hydrograph, fig. 11
(D-18-13)										
14cda	302	79.98	1-17-52	T,E	I	X	X	-	-	
24bbb	215	71.13	1-17-52	T,E	I	X	-	1130	6-25-41	
(D-19-13)										
3baa	246	79.83	2-19-52	None	N	X	-	-	-	Hydrograph, fig. 11
9acd	189	45.69	2-21-52	?,E	S	X	-	-	-	
(D-20-12)										
2cbb	270	139.11	1-28-52	None	S	-	-	-	-	
(D-20-13)										
19cda	150	31.20	1-22-52	T,E	I	X	-	1105	6-19-52	
32bcc	84	36.89	5-19-52	T,E	I	-	X	-	-	Hydrograph, fig. 11
(D-21-13)										
7abb	-	-	-	T,D	I	-	X	705	8/41	
32cc	-	36.02	1-25-52	T,E	I	-	X	-	-	
(D-22-13)										
9bc	88	31.27	10-24-39	Cf,E	D	-	X	-	-	
34acd	200	37.22	1-28-52	T,E	I	X	-	-	-	
35dcd	90	43.70	2-19-52	T,E	I	-	-	-	-	Hydrograph, fig. 11
(D-23-14)										
19bcc	21	11.8	12-18-51	Cf,G	I	-	-	-	-	Hydrograph, fig. 11
31acb	48	-	-	T,G	I	-	X	-	-	

Table 20.--Logs of representative wells in Upper Santa Cruz basin, Pima and Santa Cruz Counties, Ariz.

	Thickness (feet)	Depth (feet)
(D-12-12)5cb		
Sand boulders and cement gravel	25	25
Sand	15	40
Cement gravel	15	55
Boulders	10	65
Boulders and sand	20	85
Sand and gravel (first water)	15	100
Gravel and boulders	15	115
Boulders	5	120
Rock	11	131
Sand	100	231
Cement gravel	35	266
Clay	59	325
Gravel	8	333
TOTAL DEPTH		333
(D-13-13)21dcc		
Soil	8	8
Sandy brown clay	7	15
Gravel and sand, boulders	15	30
Coarse gravel	9	39
Brown clay and gravel	16	55
Sticky brown clay, gravel struck water at 56'	35	90
Brown clay, large boulders, some gravel, tight	35	125
Clay and boulders, little gravel	25	150
Red clay, gravel, some boulders	37	187
Red clay and gravel, loose	7	194
Red clay and gravel, very tight	57	251
TOTAL DEPTH		251
(D-13-14)35bac		
Red soil	5	5
Grey clay	12	17
Rocky sandy yellow clay	25	42
Sand and gravel (water)	8	50
Sandy brown conglomerate	10	60
Muddy sand and gravel (water)	10	70
Brown conglomerate with layers of sand 1' to 2' thick (water)	45	115
Cemented clay conglomerate	10	125
Hard cemented conglomerate	40	165
Sandy red clay, conglomerate	10	175
Sand and gravel (water)	5	180
Grey clay conglomerate	20	200
Rocky conglomerate may carry stringers of water	40	240
TOTAL DEPTH		240
(D-14-14)9dc		
Caliche	8	8
Cemented red sand	77	85
Red sand and clay	35	120
Sand and clay (struck water at 126')	15	135
Red sand and clay	7	142
White sand and clay	23	165
Little sand and clay (water)	13	178
Loose white sand (water)	12	190
Red clay and sand	20	210
Hard sand shell	5	215
White sand and clay	16	231
Red sand and clay	17	248
Loose sand (water)	6	254
White sand and clay	13	267
Hard sand shell	3	270
Red clay and sand	16	286
Hard sand shell	4	290
Little sand and clay (water)	20	310
Red sand and clay	15	325
Sticky clay and white sand	5	330
Hard sand shell	5	335
Loose water sand, white	12	347
Red sand and clay	12	359
White sand and clay	14	373
Loose water sand, white	16	389
Red sand and clay	11	400
Hard sand and shell	5	405
White sand and clay	13	418

Table 20.--Logs of representative wells in Upper Santa Cruz basin-continued

	Thickness (feet)	Depth (feet)
Hard sand shell	3	421
Clay, sand and boulders (little clay and water)	18	439
Red sand and clay	2	441
Hard sand shell	3	444
White sand and clay (water)	13	457
Red sand and clay	7	464
Hard sand shell	4	468
Sand and clay	17	485
Loose clay and sand streaks (water)	13	498
Clay and boulders	4	502
TOTAL DEPTH		502
(D-14-14)16ba		
Soil	2	2
Caliche	22	24
Sound clay	26	50
Boulders, clay	10	60
Sand	5	65
Boulders	5	70
Caliche	10	80
Sand, little clay	5	85
Boulders	2	87
Sand, clay	26	113
Cement shell	2	115
Sand water	3	118
Dirty sand	4	122
Clean sand	3	125
Red clay - sand	4	129
Coarse sand - boulders clay	7	136
Cemented coarse sand	2	138
Sand clay	7	145
Sand shell	5	150
Red clay	3	153
Sand gravel	7	160
Gravel, clay, boulders	5	165
Cemented rock	1	166
Sand, clay, boulders	2	168.
Sand shell	3.5	171.5
Sand packed - boulders	22.5	194
Sand shell	1	195
Sand - little clay	5	200
Sand shell	2	202
Sandy clay - gravel	16	218

	Thickness (feet)	Depth (feet)
Sand shell	2	220
Fine shell	5	225
Sand shell	15	240
Shell	6	246
Packed sand	4	250
Sand, boulders, clay	2	252
Sticky sand, clay	3	255
Sand shell	5	260
Boulders, sand, clay	10	270
Sand shell	6	276
Sand and gravel	2	278
Boulders - clay	17	295
Red clay - sand	5	300
Sand, gravel, clay	5	305
Sand shell	1	306
Sand, clay	2	308
Packed sand	15	323
TOTAL DEPTH		323
(D-15-13)3adc		
Black soil	18	18
Pack sand	6	24
Boulders and gravel	10	34
Gravel	12	46
Clay and gravel	84	130
Boulders and gravel	8	138
Red clay	4	142
TOTAL DEPTH		142
(D-15-13)15dcc		
Topsoil	10	10
Fine sand	2	12
Dry gravel and sand	30	42
Brown sandy clay	20	62
Gravel (water)	1	63
Red sandy clay(gravelly)	72	135
Light grey conglomerate	30	165
Yellow clay packed	13	178
Gravel (water)	1	179
Light yellow conglomerate (hard)	21	200
TOTAL DEPTH		200
(D-15-15)8db		
Soil	2	2
Clay conglomerate	8	10

Table 20.--Logs of representative wells in Upper Santa Cruz basin--continued

	Thickness (feet)	Depth (feet)
Sandy conglomerate -	70	80
Yellow clay conglomerate - - - - - - -	40	120
Muddy, sandy, conglomerate - - - - - - -	65	185
Hard clay conglomerate - - - - - - - -	10	195
Sandy clay conglomerate - - - - - - -	65	260
Fine water sand - - -	10	270
Sandy conglomerate, carrying water - -	30	300
Clay hardpan - - - - -	12	312
Water sand (water) -	2	314
Hardpan - - - - - - - -	4	318
TOTAL DEPTH		318
(D-15-15)25caa		
Caliche and boulders	13	13
Yellow clay - - - - - -	6	19
Caliche and sand - -	6	25
Yellow clay - - - - - -	4	29
Caliche and sand - -	16	45
Yellow clay - - - - - -	35	80
Gravel - - - - - - - -	6	86
Yellow clay - - - - - -	10	96
Gravel - - - - - - - -	4	100
Yellow clay - - - - - -	19	119
Gravel - - - - - - - -	8	127
Yellow clay - - - - - -	18	145
Gravel and boulders -	5	150
Yellow clay - - - - - -	10	160
Gravel - - - - - - - -	4	164
Yellow clay - - - - - -	20	184
Cemented gravel - - -	4	188
Yellow clay - - - - - -	32	220
Cemented gravel - - -	4	224
Yellow clay - - - - - -	12	236
Cemented gravel and boulders - - - - - -	4	240
Yellow clay - - - - - -	15	255
Cemented gravel - - -	3	258
Yellow clay - - - - - -	22	280
Cemented gravel and boulders - - - - - -	34	314
Yellow clay - - - - - -	16	330
Cemented gravel and boulders - - - - - -	55	385

	Thickness (feet)	Depth (feet)
Yellow clay - - - - - - -	15	400
Cemented gravel - - - - -	10	410
Yellow clay - - - - - - -	3	413
Cemented clay - - - - - -	5	418
Gravel - - - - - - - - -	6	424
Yellow clay - - - - - - -	6	430
Cemented gravel - - - - -	10	440
Clay - - - - - - - - - -	30	470
Cemented gravel - - - - -	8	478
Clay - - - - - - - - - -	28	506
Cemented gravel - - - - -	20	526
Clay - - - - - - - - - -	4	530
Cemented gravel - - - - -	5	535
Clay - - - - - - - - - -	20	555
Cemented gravel - - - - -	8	563
Clay - - - - - - - - - -	22	585
Cemented gravel - - - - -	5	590
Clay - - - - - - - - - -	70	660
Cemented gravel - - - - -	10	670
Clay - - - - - - - - - -	10	680
Cemented gravel and boulders - - - - - - -	45	725
Water gravel (water rises to 432' level)	143	868
Cemented gravel - - - - -	3	871
Cemented clay - - - - - -	33	904
Cemented gravel - - - - -	46	950
Clay - - - - - - - - - -	15	965
Cemented gravel - - - - -	10	975
Cemented clay - - - - - -	37	1012
Cemented gravel and boulders - - - - - - -	44	1056
Clay - - - - - - - - - -	19	1075
Coarse gravel - - - - - -	9	1084
Yellow cemented clay - - - - - - - -	396	1480
TOTAL DEPTH		1480
(D-16-17)35bd		
Gravel - - - - - - - - -	60	60
Clay - - - - - - - - - -	140	200
Clay and sand rock - -	465	665
Shale - - - - - - - - - -	590	1255
Grey sand - - - - - - - -	20	1275
Gravel - - - - - - - - -	10	1285
Sand - - - - - - - - - -	10	1295

Table 20.--Logs of representative wells in Upper Santa Cruz basin--continued

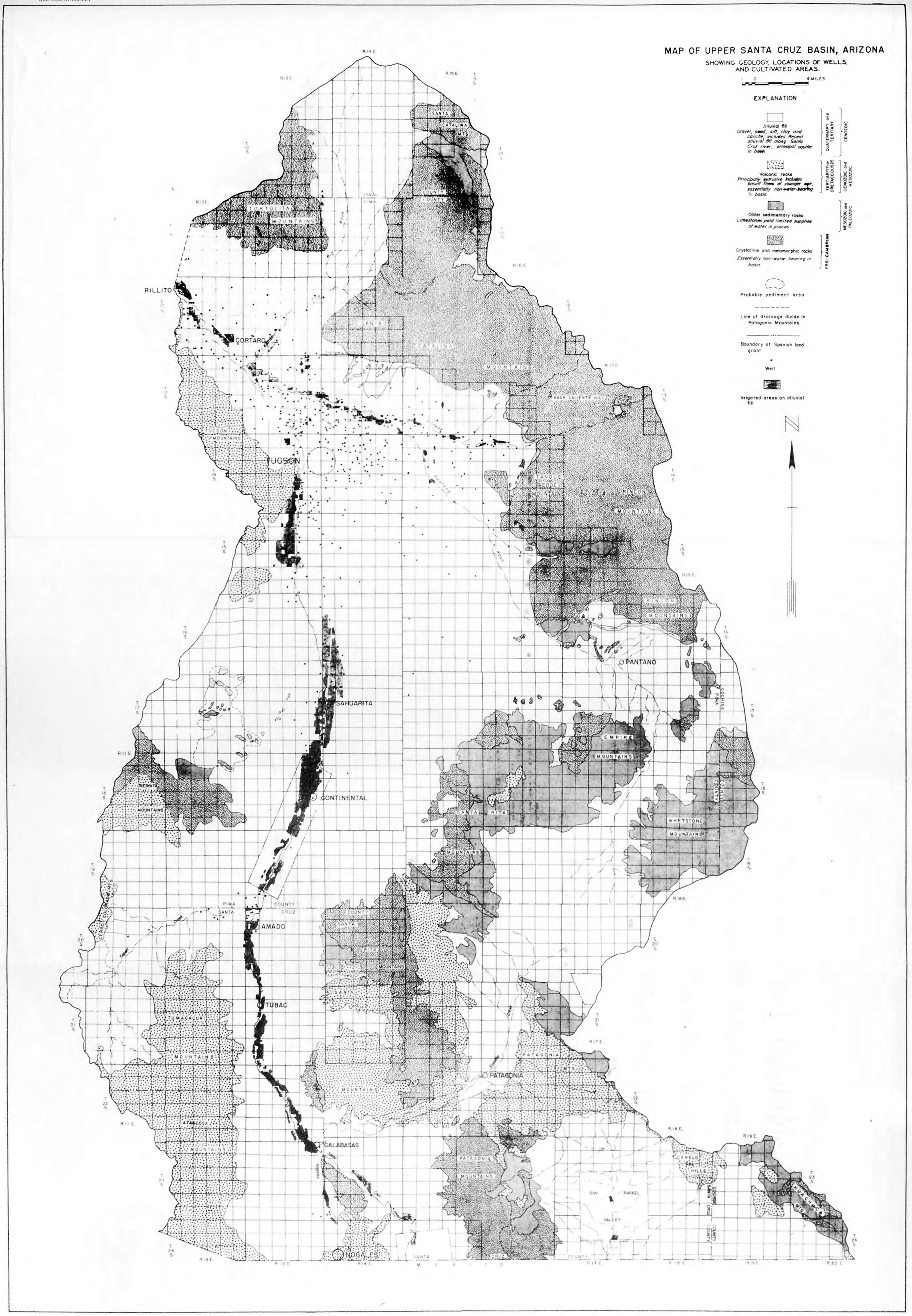
	Thickness (feet)	Depth (feet)
Gravel - - - - - - - - -	45	1340
Sand - - - - - - - - - -	20	1360
Gravel, dry - - - - - - -	20	1380
TOTAL DEPTH		1380
(D-19-13)9acd		
Black soil - - - - - - -	6	6
Sandy clay - - - - - - -	4	10
Sand, boulders, struck water 40' - -	30	40
Red clay, gravel - - -	45	85
Sandy clay - - - - - - -	20	105
Clay and gravel - - - -	35	140
Cemented sand with streaks of sticky clay - - - - - - - -	40	180
Cemented sand - - - - -	9	189
TOTAL DEPTH		189
(D-20-13)19cda		
Topsoil - - - - - - - - -	1	1
Sand gravel dry - - - -	35	36
Water (gravel) - - - -	14	50
Hard red conglomerate -	21	71
Soft clay, red (water)	3	74
Grey conglomerate - - -	24	98
Clay, soft (water) - -	3	101
Light conglomerate, grey	49	150
TOTAL DEPTH		150
(D-22-13)34acd		
Topsoil - - - - - - - - -	14	14
Dry sand and gravel - -	16	30
First water - - - - - - -	1	31
Hard light grey congl.	67	98
Second water (2 feet of gravel) - - - - - - -	?	100
Yellow conglomerate - -	8	108
Hard light conglomerate	92	200
TOTAL DEPTH		200

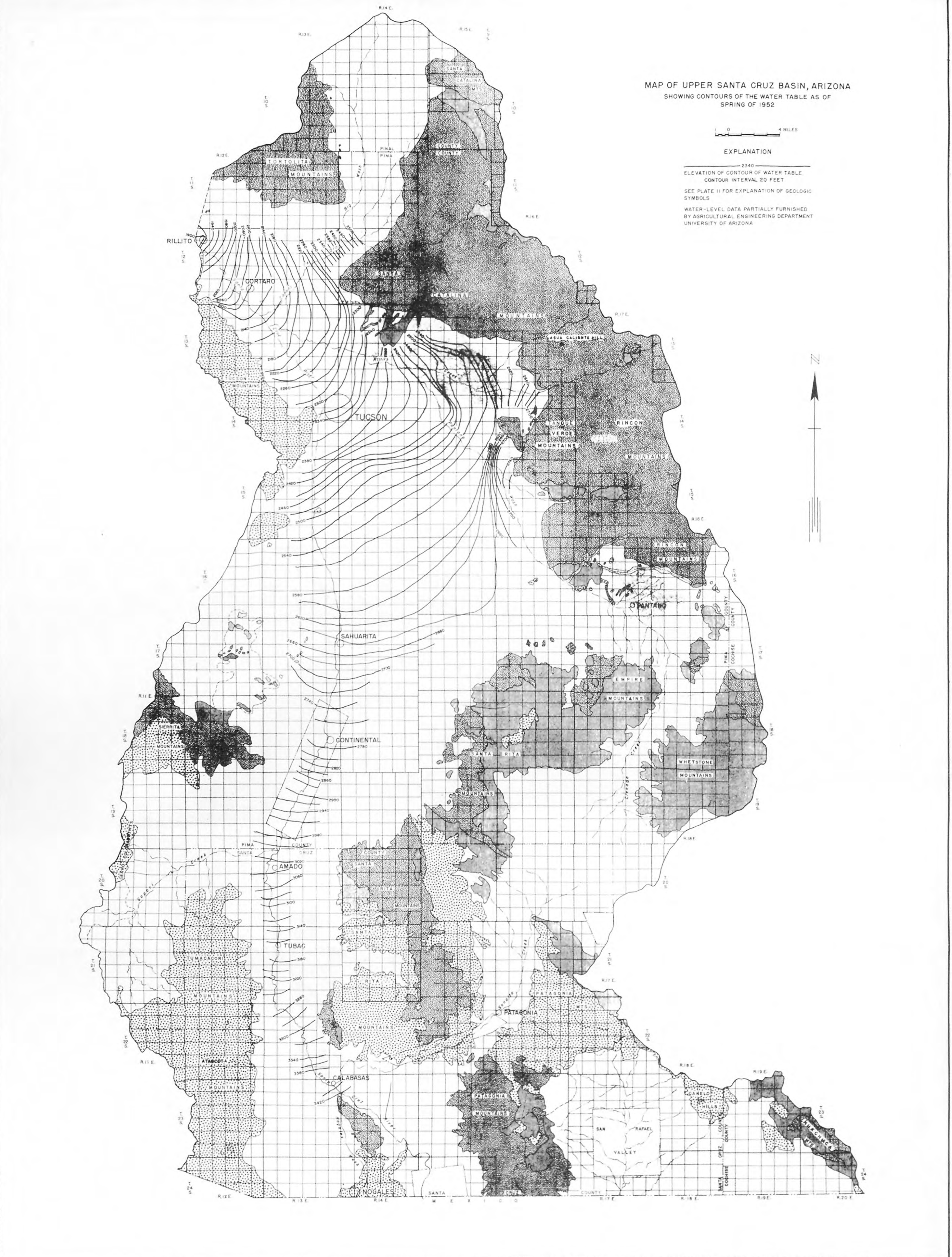
Table 21.--Analyses of water from representative wells and springs in Upper Santa Cruz basin, Pima and Santa Cruz Counties, Ariz. (Parts per million except specific conductance and percent sodium)

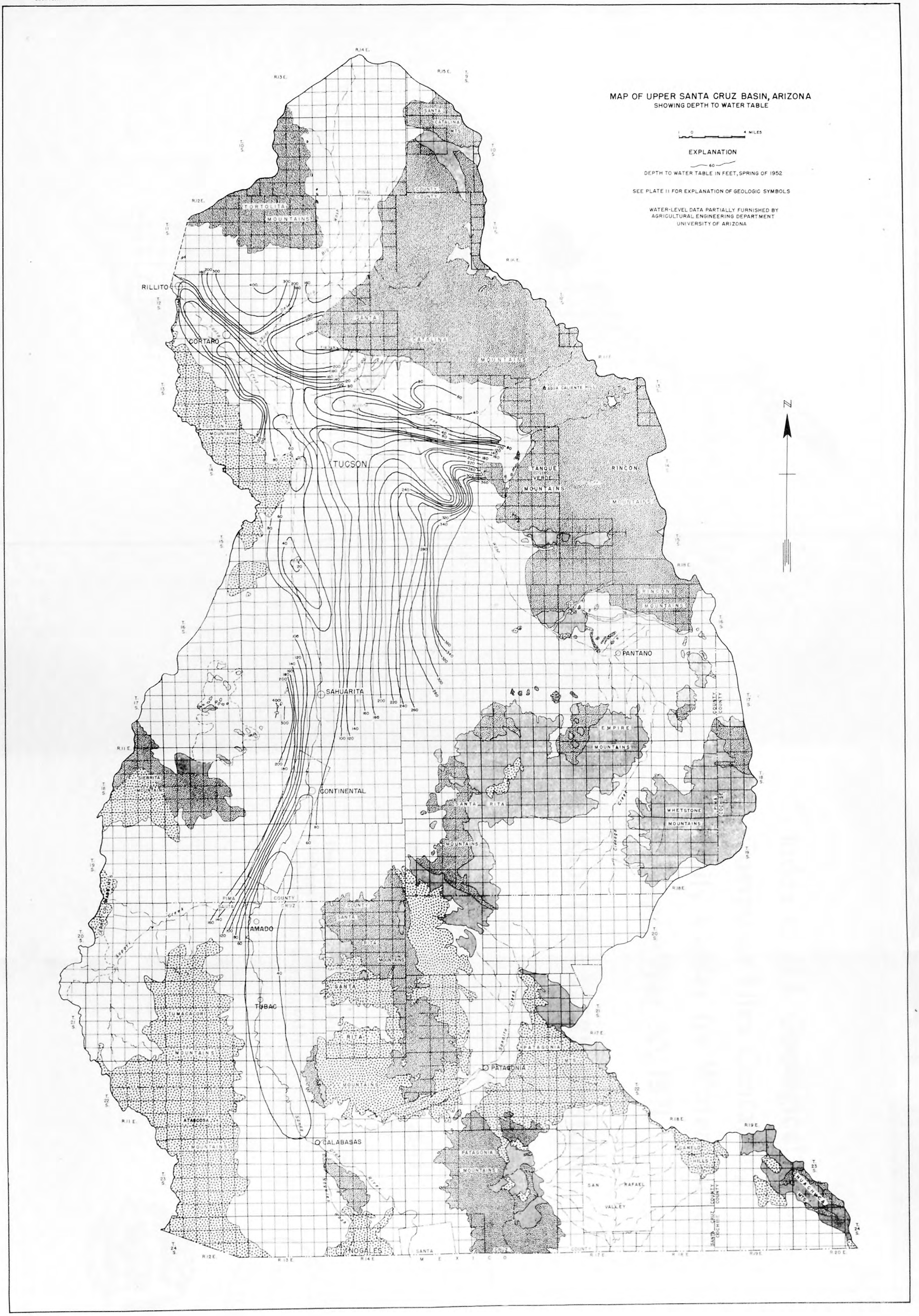
Well no.	Date of collection	Depth of well (feet)	Temperature (°F)	Specific conductance (micromhos at 25° C.)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Total hardness as $CaCO_3$	Percent sodium
(D-12-12) 14bcb	6-23-48	311	-	322	28	9.6	33	175	16	8	0.8	0.9	208	110	40
(D-13-13) 17da	5-8-41	96	74	1170	98	25	125	175	340	79	0.4	12	766	347	44
(D-13-14) 22cd	5-8-41	60	68	237	33	7.4	11	114	26	6.0	0.9	5.5	146	113	17
(D-13-15) 31aa	5-9-41	60	68	222	18	7.4	23	84	25	8.0	1.5	2.0	134	75	40
(D-14-12) 17bb	3-15-40	113	-	750	45	29	76	316	67	45	1.5	-	420	231	42
(D-14-13) 35bd	5-24-41	114	-	628	72	22	39	247	119	13	1.0	2.4	390	270	24
(D-14-14) 5ddc	9-14-51	200	80	320	34	6.0	26	157	17	8.5	0.3	10	210	110	34
(D-16-14) 30ccc	7-14-41	200	74	464	54	11	35	210	63	11	-	2.5	280	180	30
(D-17-13) 24acc	6-20-41	-	73	416	30	17	33	82	105	15	0.4	3.8	254	145	33
(D-17-14) 18acc	6-24-41	182	-	603	86	17	29	245	106	15	1.2	14	389	285	18
(D-18-13) 14cda	8-25-41	302	-	373	-	-	-	141	-	9.0	-	-	-	-	-
(D-20-13) 32bc	10-12-39	84	-	670	94	19	31	248	152	13	-	-	431	313	18
32bc	7-9-46	84	68	759	103	19	39	264	170	14	0.5	6.1	482	335	20
(D-21-13) 7abb	8-27-41	-	70	470	52	8.7	40	197	74	10	-	1.0	283	166	35
32cc	8-26-41	-	-	628	-	-	-	234	-	10	-	-	-	-	-

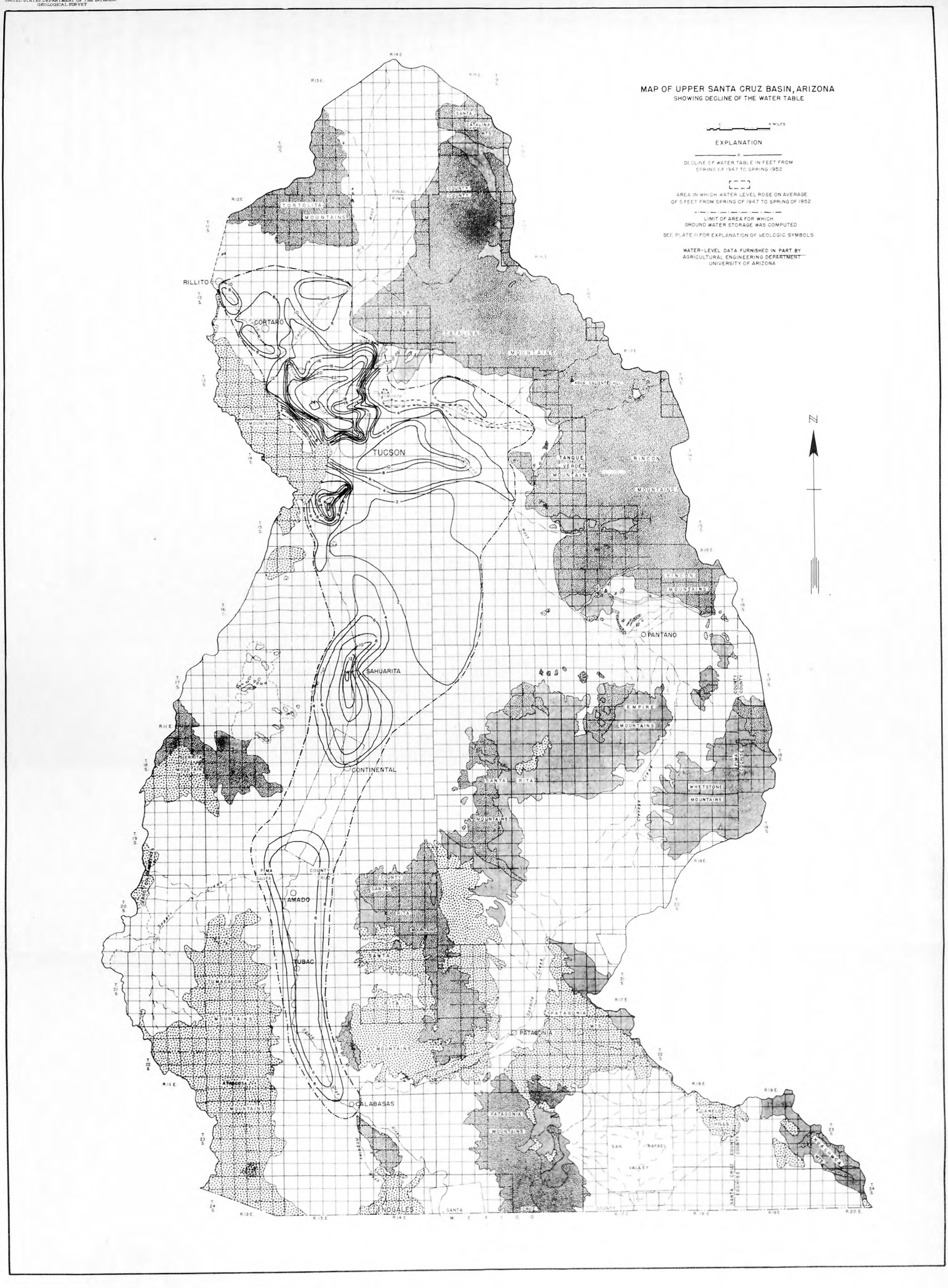
Table 21.--Analyses of water from representative wells and springs in Upper Santa Cruz basin--continued.

Well no.	Date of collection	Depth of well (feet)	Temperature (°F.)	Specific conductance (micromhos at 25° C.)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Total hardness as $CaCO_3$	Per cent sodium
(D-22-13) 9bc	10-24-39	88	-	380	46	11	20	180	41	10	-	-	217	160	22
(D-23-14) 31acb	8-26-41	48	-	678	85	16	33	226	36	45	-	80	406	278	21
Spring no.															
Agua Caliente (D-13-16) 20dc	2-5-42	Flow 150gpm	86	801	32	6.1	141	205	176	30	6.5	-	493	105	75
Cebodillo (D-14-16) 3ad	2-5-42	Flow 40gpm	81	1160	34	5.5	223	183	339	45	9.6	-	746	108	82


MAP OF UPPER SANTA CRUZ BASIN, ARIZONA
SHOWING GEOLOGY, LOCATIONS OF WELLS, AND CULTIVATED AREAS.
1 0 4 MILES
EXPLANATION
Alluvial fill
Gravel, sand, silt, clay and caliche; includes Recent alluvial fill along Santa Cruz river, principal aquifer in basin
QUATERNARY and TERTIARY
CENOZOIC
Volcanic rocks
Principally extrusive includes basalt flows of younger age; essentially non-water-bearing in basin
TERTIARY(?) or CRETACEOUS(?)
CENOZOIC and MESOZOIC
Older sedimentary rocks
Limestones yield limited supplies of water in places.
MESOZOIC and PALEOZOIC
Crystalline and metamorphic rocks
Essentially non-water-bearing in basin
PRE-CAMBRIAN
Probable pediment area
Line of drainage divide in Patagonia Mountains
Boundary of Spanish land grant
Well
Irrigated areas on alluvial fill
N
SANTA CATALINA MTS
TORTOLITA MOUNTAINS
RILLITO
CORTARO
SANTA CATALINA MOUNTAINS
AGUA CALIENTE HILL
TUCSON
TUCSON MOUNTAINS
TANQUE VERDE MOUNTAINS
RINCON MOUNTAINS
PANTANO
SAHUARITA
EMPIRE MOUNTAINS
SIERRITA MOUNTAINS
CONTINENTAL
SANTA RITA MOUNTAINS
WHETSTONE MOUNTAINS
PIMA COUNTY
SANTA CRUZ COUNTY
COCHISE COUNTY
AMADO
TUBAC
TUMACACORI MOUNTAINS
PATAGONIA
ATASCOSA MOUNTAINS
CALABASAS
PATAGONIA MOUNTAINS
CANELO HILLS
SAN RAFAEL VALLEY
HUACHUCA MTS
NOGALES
MEXICO
R.11 E.
R.12 E.
R.13 E.
R.14 E.
R.15 E.
R.16 E.
R.17 E.
R.18 E.
R.19 E.
R.20 E.


MAP OF UPPER SANTA CRUZ BASIN, ARIZONA
SHOWING CONTOURS OF THE WATER TABLE AS OF SPRING OF 1952
0 4 MILES
EXPLANATION
2340
ELEVATION OF CONTOUR OF WATER TABLE
CONTOUR INTERVAL 20 FEET
SEE PLATE II FOR EXPLANATION OF GEOLOGIC SYMBOLS
WATER-LEVEL DATA PARTIALLY FURNISHED BY AGRICULTURAL ENGINEERING DEPARTMENT UNIVERSITY OF ARIZONA
N
RILLITO
CORTARO
TUCSON
SAHUARITA
CONTINENTAL
AMADO
TUBAC
CALABASAS
NOGALES
PATAGONIA
PANTANO
TORTOLITA MOUNTAINS
SANTA CATALINA MOUNTAINS
RINCON MOUNTAINS
TANQUE VERDE MOUNTAINS
EMPIRE MOUNTAINS
SANTA RITA MOUNTAINS
WHETSTONE MOUNTAINS
SIERRITA MOUNTAINS
PATAGONIA MOUNTAINS
CANELO HILLS
SAN RAFAEL VALLEY
PIMA COUNTY
SANTA CRUZ COUNTY
COCHISE COUNTY
PINAL COUNTY
M E X I C O


MAP OF UPPER SANTA CRUZ BASIN, ARIZONA
SHOWING DEPTH TO WATER TABLE
EXPLANATION
DEPTH TO WATER TABLE IN FEET, SPRING OF 1952
SEE PLATE 11 FOR EXPLANATION OF GEOLOGIC SYMBOLS
WATER-LEVEL DATA PARTIALLY FURNISHED BY
AGRICULTURAL ENGINEERING DEPARTMENT
UNIVERSITY OF ARIZONA
TORTOLITA MOUNTAINS
SANTA CATALINA MOUNTAINS
RILLITO
CORTARO
TUCSON
TUCSON MOUNTAINS
TANQUE VERDE MOUNTAINS
RINCON MOUNTAINS
PANTANO
SAHUARITA
EMPIRE MOUNTAINS
SIERRITA MOUNTAINS
CONTINENTAL
SANTA RITA MOUNTAINS
WHETSTONE MOUNTAINS
AMADO
TUBAC
TUMACACORI MOUNTAINS
PATAGONIA
PATAGONIA MTS.
PATAGONIA MOUNTAINS
CALABASAS
NOGALES
SAN RAFAEL VALLEY
CANELO HILLS
HUACHUCA MTS.
M E X I C O


MAP OF UPPER SANTA CRUZ BASIN, ARIZONA
SHOWING DECLINE OF THE WATER TABLE
0
4 MILES
EXPLANATION
6
DECLINE OF WATER TABLE IN FEET FROM SPRING OF 1947 TO SPRING 1952
AREA IN WHICH WATER LEVEL ROSE ON AVERAGE OF 5 FEET FROM SPRING OF 1947 TO SPRING OF 1952
LIMIT OF AREA FOR WHICH GROUND WATER STORAGE WAS COMPUTED
SEE PLATE 11 FOR EXPLANATION OF GEOLOGIC SYMBOLS
WATER-LEVEL DATA FURNISHED IN PART BY AGRICULTURAL ENGINEERING DEPARTMENT UNIVERSITY OF ARIZONA
N
TORTOLITA
MOUNTAINS
SANTA
CATALINA
MOUNTAINS
PINAL
PIMA
RILLITO
CORTARO
TUCSON
TANQUE
VERDE
MOUNTAINS
RINCON
MOUNTAINS
PANTANO
SAHUARITA
EMPIRE
MOUNTAINS
CONTINENTAL
SANTA
RITA
MOUNTAINS
WHETSTONE
MOUNTAINS
PIMA
COCHISE
AMADO
TUBAC
TUMACACORI
MOUNTAINS
PATAGONIA
CALABASAS
PATAGONIA
MOUNTAINS
SAN
RAFAEL
VALLEY
NOGALES
M E X I C O
R.11 E.
R.12 E.
R.13 E.
R.14 E.
R.15 E.
R.16 E.
R.17 E.
R.18 E.
R.19 E.
R.20 E.

LOWER SANTA CRUZ AREA, PIMA AND PINAL COUNTIES

By R. L. Cushman

Introduction

Location and extent

The Lower Santa Cruz area is part of a large drainage basin. About seven-eighths of the Lower Santa Cruz area is within Pinal County, and the remainder is within Pima County. The area is roughly triangular (pl. 15). It is bounded on the east by the Tucson and Tortolita Mountains and by a large unnamed hard-rock area. The north boundary follows an arbitrary line westward from Ashurst-Hayden Dam to the Santan Mountains, thence northward to the Pinal-Maricopa County line, thence westward along the county line to the Gila River, and thence northwestward along the river to the line between Rs. 1 and 2 E. The western boundary is formed by the Sierra Estrella, Palo Verde, Table Top, Tat Momoli, Silver Reef, Sawtooth, Silver Bell, Waterman, and Roskruge Mountains. The southern boundary is an arbitrary line between Tps. 15 and 16 S. The Lower Santa Cruz area and the Upper Santa Cruz basin meet in a common boundary in the narrows between the Tucson and Tortolita Mountains. The valley floor of the area covers approximately 2,200 square miles and ranges in altitude from about 2,500 feet at the southern boundary to about 1,000 feet at the northwest corner. The principal towns in the area are Florence, Coolidge, Casa Grande, and Eloy.

Irrigation in the Lower Santa Cruz area was started in four separate localities. The irrigated acreages expanding from these centers have coalesced or are joined by slender links of irrigated land. In order to discuss local conditions the four centers of development are denoted by name. The broad valley south of the Pima-Pinal County line will be referred to in this report as the Avra-Marana district. The valley northwest from the county line to the Silver Reef and Casa Grande Mountains and the Florence-Casa Grande canal will be referred to as the Eloy district. The valley from the Florence-Casa Grande canal northward to the Santan Mountains and westward from Ashurst-Hayden Dam to Pima Butte, will be called the Casa Grande-Florence-Sacaton district. The area west and northwest of the Eloy and Casa Grande-Florence-Sacaton districts will be called the Maricopa-Stanfield district.

Topography and drainage

The broad alluvial valleys of the Lower Santa Cruz area are almost surrounded by mountains, the highest of which are the Table Top Mountains, with an altitude of 4,375 feet. The valley floors have low relief and are pierced by isolated mountain masses, the highest being the Picacho Mountains with an altitude of 4,500 feet. The slope of the alluvial surface is from the mountain fronts to the axis of the valleys and from southeast to northwest.

The valley is drained by the Gila and Santa Cruz Rivers and by small washes emerging from the mountains. The small washes and most of the major streams such as the Santa Cruz River, Brawly Wash, Santa Rosa Wash, and Vekol Wash, fail to maintain well-defined channels throughout their courses in the area.

The Santa Cruz River, an intermittent stream, enters the area from the southeast and trends northwestward at a gradient of about 15 feet per mile for about 30 miles, where the channel becomes almost indefinable. Clearing and cultivation of the land in this vicinity have practically erased what formerly were shallow braided channels. Flows in the Santa Cruz that reach this land are diverted into irrigation ditches. Occasionally, flows are too big to handle in that manner and some flood damage results. Brawly Wash, which drains the southern part of the area, likewise almost loses its identity in many places. Santa Rosa Wash enters the area between the Tat Momoli Mountains and the Vaiva Hills and fans out into numerous small channels that soon are too small to distinguish. Cultivation has erased many of these small channels. Occasional flows in Santa Rosa Wash are used for irrigation, but at times the volume of flow is too great and some damage occurs. Vekol Wash enters the area south of the Palo Verde Mountains. Flows in this wash seldom reach as far north as Maricopa. McClellan Wash enters the area from the east and flows around the north end of the Picacho Mountains, losing its identity near the Florence-Casa Grande canal.

The Gila River flows westward for about 65 miles across the extreme northern part of the area. The altitude of the river at the eastern side of the area is about 1,600 feet and, where it leaves the area, about 1,000 feet. It approaches the area as a perennial stream but all the normal flow is diverted into canals at Ashurst-Hayden Dam. The river is intermittent through the area except in the extreme western part, where the stream channel intersects the water table.

Geology

Many generalizations about the geology of the desert region, as discussed in Part I of this report, are applicable to the Lower Santa Cruz area. Unlike some of the other major basins and most of the minor basins in the desert region of Arizona, however, the Lower Santa Cruz area is not considered as occupying a single structural trough. The area includes several interconnected structural depressions.

With the exception of the alluvial fill, the rocks exposed in the mountains are predominantly volcanic rocks of Cretaceous, Tertiary, and Quaternary age, and crystalline and metamorphic rocks of pre-Cambrian and later age. Cretaceous (?) or Tertiary (?) sedimentary rocks are exposed in small areas, the largest being in the Tucson Mountains. With the possible exception of some of the sedimentary rocks, the hard rocks of the mountains are too impermeable to yield more than extremely small amounts of water to wells. These rocks will not be discussed further in this report. Plate 15 depicts the character and location of the various rock types in the area, and provides a brief statement of their water-bearing properties.

Pediments

Several areas bordering mountain bases have been outlined on plate 15 as pediments or probable pediments. The outlines of these pediment areas are only approximate because data are not available to delineate their outer limits. These outlines indicate areas where it is probable that only limited water supplies are available. The outlines also show areas that, from surficial inspection, might be considered avenues of ground-water movement to or from adjacent valleys, as for example, the narrow passes among the Roskruge, Waterman, and Silver Bell Mountains. Pediment areas are underlain by hard rock at shallow depths and therefore reduce the apparent volume of valley fill. This is particularly evident in the vicinity of the Sacaton Mountains. It is probable that additional pediment areas will be discovered by drilling or other methods of subsurface exploration.

Alluvial fill

The generalized discussion in Part I of this report contains much that is applicable to the alluvial fill of the Lower Santa Cruz area. The following discussion describes the occurrence of the valley fill in the area and points out some of the features of the fill that affect the storage and transmission of ground water. The description of the alluvial fill is based largely on well logs, a selection of which are given in table 23 at the end of this section.

The alluvium that partially fills the rock troughs between the mountains ranges from a few feet to several thousand feet in thickness in the area. Except for Recent alluvium in the channels of washes, the valley fill is classed as older alluvial fill of undifferentiated Tertiary and Quaternary age. The Recent alluvium along stream channels is not an important aquifer except in the mountain canyons and, therefore, will not be discussed further in this section.

Avra-Marana district.--Of the wells in the Avra-Marana district, the deepest for which a record was obtained by the Geological Survey, (D-12-10)18bcc, was drilled to a depth of 904 feet without encountering bedrock. An oil test, (D-12-11)6, reportedly reached a depth of 4,850 feet, but information is not available to show whether bedrock was encountered.

Examination of logs of wells in this district, (D-11-11)20ddd, (D-11-11)21aaa, (D-12-10)21ddc, (D-12-11)29add, (D-13-10)26ccd, and others, shows that beds of unconsolidated sand and gravel interbedded with silt, clay, and caliche are generally present to depths of 500 to 700 feet. Below these depths the few data available indicate the presence of cemented sand and gravel or partially cemented finer-grained sediments.

The alluvial fill is thin in the pediment areas along the fronts of the Roskruge, Waterman, and Silver Bell Mountains and in the small valleys among these mountains. The alluvial fill in these areas generally is above the water table of the main ground-water body of the district. Local areas of perched water may be present.

Eloy district.--The deepest water well in the Eloy district, (D-8-7)12bdd, was drilled to a depth of 2,700 feet without encountering bedrock. The driller's log of this well indicates the presence of sand and gravel lenses to depths greater than 1,100 feet. However, an electric log of the well suggests that those lenses below 1,100 feet contain predominantly finer-grained sediments. These materials are more compact and have less porosity than the fill at shallower depths. Logs of other deep wells in the Eloy district indicate that, in general, numerous relatively permeable lenses of sand and gravel are present to depths of about 500 to 700 feet. From those depths to about 1,100 feet the silt and clay layers increase in thickness and number and the sand and gravel lenses are thinner. From 1,100 feet to about 1,500 feet, fine-grained, poorly sorted, and more consolidated sediments predominate. Data on the character of the valley fill below 1,500 feet are insufficient to warrant general conclusions. It is probable that some wells may encounter relatively permeable sediments below a depth of 1,500 feet.

In the southeastern part of the Eloy district, well (D-9-10)20aaa was drilled to a depth of 1,090 feet without encountering bedrock. Examination of the drill cuttings indicated that sand and gravel lenses were present to a depth of about 650 feet. Below this depth the materials were fine-grained and poorly sorted.

The following compilation lists the wells whose depth exceeds 1,000 feet, based on data in the files of the Geological Survey in August 1952:

Location	Depth drilled (feet)	Location	Depth drilled (feet)
T. 7 S., R. 7 E.		T. 8 S., R. 8 E.	
Sec. 31	1,200	Sec. 20	1,302
32	1,432	29	1,685
32	1,285	T. 9 S., R. 6 E.	
T. 7 S., R. 8 E.		Sec. 24	1,200
Sec. 22	1,011	T. 9 S., R. 7 E.	
T. 8 S., R. 7 E.		Sec. 4	1,240
Sec. 2	1,002	7	1,000
11	1,500	11	1,095
11	1,000	13	1,041
12	2,700	17	1,243
20	1,049	19	1,148
21	1,697	19	1,410
29	1,000	23	1,050
29	1,109	25	1,260
33	1,120	26	1,285
T. 8 S., R. 8 E.		28	1,257
Sec. 11	1,075	29	1,242
12	1,010	T. 9 S., R. 8 E.	
12	1,000	Sec. 20	1,124
13	1,170	21	1,300
14	1,022	T. 9 S., R. 10 E.	
17	1,328	Sec. 20	1,090

There are local areas in the Eloy district in which wells have reportedly encountered bedrock at comparatively shallow depths. All these wells in the Eloy district are listed in the following tabulation. The list was compiled from data on file August 1952.

Location	Depth drilled (feet)	Depth to rock (feet)	Driller's description of rock
T. 7 S., R. 6 E.			
Sec. 3	81	47	Granite, hole abandoned
11	465	452	Rock
11	297	297	Granite
17	86	78	Rock, hole abandoned
17	105	100	Rock
17	145	140	Rock
20	450	449	Hard granite
20	108	108	Bedrock
28	468	464	Solid rock
31	522	285	Alternating red and gray rock
31	180	165	Rock
31	186	184	Granite rock
31	176	172	Granite rock
31	190	183	Granite
33	487	487	Solid rock, (warm water)
34	606	606	Solid rock, (warm water)
34	611	611	Solid rock, (warm water)
T. 7 S., R. 7 E.			
Sec. 8	255	222	Granite
T. 8 S., R. 5 E.			
Sec. 1	228	228	Granite
T. 8 S., R. 6 E.			
Sec. 29	282	272	Black rock
29	358	340	Rock
30	296	290	Black rock
30	440	285	Red rock
31	280	266	Black rock
32	306	302	Black rock
32	600	415	Rock, red bed, and malapai
32	400	323	Black rock
33	425	420	Red rock, black rock on bottom of hole
33	653	250	Red rock, black rock, etc.
34	380	377	Rock, last 8 inches very hard
T. 9 S., R. 6 E.			
Sec. 13	930	885	Hilltop

Location	Depth drilled (feet)	Depth to rock (feet)	Driller's description of rock
T. 9 S., R. 9 E.			
Sec. 34	527	517	Rock
T. 9 S., R. 10 E.			
Sec. 19	566	566	Bedrock
T. 10 S., R. 7 E.			
Sec. 33	340	335	Mountain rock
T. 10 S., R. 9 E.			
Sec. 5	600	590	Granite rock
21	405	270	Rock
		280	Granite and malpais

It is unlikely that there is a great thickness of alluvial fill between Picacho Peak and the Picacho Mountains. A domestic well (D-9-9)10acd, drilled to a depth of about 220 feet, reportedly encountered lava at less than 210 feet. No information is available to indicate the depth or composition of valley fill east of the Picacho Mountains. In the comparatively narrow valley of the Santa Cruz River between the Silver Bell Mountains and Picacho Peak, bedrock was reported at 270 feet in well (D-10-9)21aad, and at 590 feet in well (D-10-9)5ccb. The greatest thickness of fill apparently is closer to Picacho Peak than to the Silver Bell Mountains. In the southwestern part of T. 8 S., R. 6 E., wells encountered rock at depths of about 300 feet. Logs of wells (D-10-6)11ccd and (D-10-6)11ddd indicate that bedrock may be present between the Sawtooth and Silver Bell Mountains at depths as shallow as 360 feet. South and west of the Casa Grande Mountains, wells (D-7-6)21aad2 and (D-7-6)28ddd reportedly encountered bedrock at depths of 285 and 464 feet, respectively. Northeast of the Silver Reef Mountains a well on unsurveyed land, approximately in sec. 1, T. 8 S., R. 5 E., encountered bedrock at a depth of about 230 feet. Between these two localities the depth to bedrock is at least 600 feet in places. In the vicinity of the small hills in secs. 7 and 9, T. 7 S., R. 7 E., well (D-7-7)8add is reported to have encountered bedrock at a depth of 222 feet. On the northeast side of the Casa Grande Mountains, wells (D-7-6)11aaa and (D-7-6)11acd reportedly encountered bedrock at depths of 452 and 297 feet, respectively.

Casa Grande-Florence-Sacaton district.--A large part of the Casa Grande-Florence-Sacaton district is underlain by a thick series of clays generally encountered at depths of from 250 to 450 feet. Table 22 was compiled from data available as of August 1952 and shows depth to the top of the clay for all wells 300 feet or deeper in Tps. 5 and 6 S., Rs. 7, 8, and part of 9 E., the area principally underlain by the clay series.

Table 22.--Wells with total depths of 300 feet or more that encountered clay in Tps. 5 and 6 S., Rs. 7, 8, and 9 E., Lower Santa Cruz area, Ariz.

Well	Depth drilled (feet)	Depth to top of clay series (feet)
T. 5 S., R. 7 E.		
Sec. 13	308	275
13	350	148
13	670	274
13	352	280
14	446	258
25	368	157
25	470	270
33	300	248
34	355	275
34	308	264
T. 5 S., R. 8 E.		
Sec. 1	308	300
10	515	338
12	420	390
17	421	280
19	318	260
19	300	185
25	396	201
25	406	390
29	355	315
30	420	305
30	360	304
30	414	318
31	345	331
31	338	318
32	442	198
33	400	272
34	600	290
35	400	344
T. 5 S., R. 9 E.		
Sec. 4	341	260
5	355	260
6	504	197
8	621	293
18	396	160
30	500	418
31	556	435
32	600	484
32	550	436
T. 6 S., R. 7 E.		
Sec. 1	418	331
1	450	402
2	380	337
3	300	206
4	330	266
4	400	264
4	402	392
8	700	295
10	500	414
10	400	274
10	414	321
11	416	376
12	400	344
12	492	348
12	512	475
12	412	350
14	700	300
14	400	290
16	560	428
18	370	360
21	300	192
21	310	278
22	498	380
22	601	350
22	634	250
25	380	252
28	350	265
32	580	270
32	498	288
33	350	302
33	400	256
34	400	250
34	338	320
34	430	240
34	497	356
34	300	254
35	420	355
36	452	410
36	360	340
36	550	505
T. 6 S., R. 8 E.		
Sec. 1	300	268
2	490	295
2	365	354
2	700	350
3	400	206

Table 22.--Wells with total depths of 300 feet or more that encountered clay in Tps. 5 and 6 S., Rs. 7, 8, and 9 E., Lower Santa Cruz area--continued.

Well	Depth drilled (feet)	Depth to top of clay series (feet)	Well	Depth drilled (feet)	Depth to top of clay series (feet)
T. 6 S., R. 8 E.			T. 6 S., R. 8 E.		
Sec. 3	388	382	Sec. 17	410	390
3	316	296	18	540	359
3	380	300	18	440	376
3	474	384	18	355	331
4	297	375	18	394	350
5	312	295	21	300	226
5	312	292	23	320	286
5	360	298	23	409	339
6	515	275	25	510	402
6	396	342	27	604	502
6	402	351	28	416	328
7	508	470	29	300	212
9	468	380	29	352	340
9	504	385	29	304	294
10	300	249	29	400	368
11	365	300	31	406	294
11	300	252	32	320	310
13	300	182	33	500	472
16	400	397	T. 6 S., R. 9 E.		
16	395	350	Sec. 6	584	200
			30	390	358

The total thickness of the clay series is unknown, but wells have been drilled to depths of 700 feet without reaching the bottom of the series. The log of an oil test, (D-6-7)25ddd shows a clay and shale series from 445 to 2,619 feet, interrupted only at 1,022 feet by a 1-foot lens of sand.

The clay series does not appear consistently at shallow depths in logs of wells south of the Florence-Casa Grande canal. Logs also show that wells along the eastern side of the district have encountered sandier clays than are present in the interior of the district. Well (D-6-9)33bad, depth 1,100 feet, reportedly did not encounter clay but did encounter much fine sand. In the vicinity of Casa Grande the clay apparently grades westward into conglomerates.

The deepest well on record in the Gila River Indian Reservation, (D-4-5)7bcb, is in the vicinity of Sacaton. The well is 446 feet deep and did not pass out of valley fill, nor did it encounter a clay series. Logs of this and other wells indicate that the valley fill in this area is partially consolidated by cementation below depths of about 250 feet. Bedrock is probably present at comparatively shallow depths in the narrows between the Santan and Sacaton Mountains.

There are other local areas in the Casa Grande-Florence-Sacaton district in which wells are reported to have encountered bedrock at comparatively shallow depths, as shown by the following tabulation:

Location	Depth drilled (feet)	Depth to rock (feet)	Driller's description of rock
T. 3 S., R. 5 E.			
Sec. 32	106	100	Granite
T. 4 S., R. 5 E.			
Sec. 4	285	272	Brown rock
6	385	370	Granite
T. 4 S., R. 7 E.			
Sec. 18	185	166	Granite
T. 4 S., R. 9 E.			
Sec. 4	434	430	Lava flow
5	403	400	Black rock
27	290	270	Hill formation
31	382	368	Granite
34	270	264	Hill formation
34	184	180	Solid rock
T. 4 S., R. 10 E.			
Sec. 12	309	308	Granite
14	50		Solid rock, hole abandoned
21	304	296	Bedrock

Location	Depth drilled (feet)	Depth to rock (feet)	Driller's description of rock
T. 4 S., R. 11 E.			
Sec. 7	136	135	Bedrock
T. 5 S., R. 7 E.			
Sec. 4	135	126	Solid rock, hole abandoned
T. 5 S., R. 8 E.			
Sec. 1	360	332	Granite
T. 6 S., R. 5 E.			
Sec. 12	150	82	Red rock
		135	Brown rock
		142	Sandstone
		147	Granite
12	70	70	Bedrock
12	80	80	Bedrock
22	115	112	Granite
22	195	185	Hill top
23	90	73	Red malpais
25	115	110	Granite
27	103	100	Granite
36	114	109	Purple malpais and granite mixture
T. 6S., R. 6 E.			
Sec. 7	218	138	Rock
14	510	507	Hard rock
16	730	705	Hard abrasive rock (granite basement)
18	325	150	Rock, red, white, black, granite
20	280	248	Hill formation
29	625	580	Granite

Maricopa-Stanfield district.--The deepest irrigation well in the Maricopa-Stanfield district, (D-6-4)17ddc, was drilled to a depth of 1,294 feet, reportedly without encountering bedrock. From available records, wells over 1,000 feet deep that did not encounter bedrock are listed as follows:

Location	Depth drilled, in feet
(D-5-3)36	1,212
(D-6-3)3	1,203
3	1,114
(D-6-4)4	1,120
17	1,294

An oil test, (D-4-3)36ca, reportedly passed out of valley fill at a depth of about 2,000 feet and continued to a depth of 3,642 feet in rock. Logs of wells in the interior of the district indicate alluvial-fill conditions similar to those described for the Eloy district.

There are local areas in the Maricopa-Stanfield district where bedrock is reported to have been encountered at comparatively shallow depths, as follows:

Location	Depth drilled (feet)	Depth to rock (feet)	Driller's description of rock
T. 4 S., R. 2 E.			
Sec. 15	372	332	Granite, hard
22	305	301	Granite
23	386	335	Granite, hard
26	309	300	Hard granite
T. 4 S., R. 4 E.			
Sec. 20	506	488	Granite rock
22	415	405	Granite
27	600	598	Hard rock
27	550	432	Rock and crevices
34	425	420	Blue granite
34	337	320	Blue granite
T. 5 S., R. 2 E.			
Sec. 2	427	385	Base of mountain
26	600	536	Hard granite
33	540	520	Granite
36	261	253	Granite, hole abandoned
T. 5 S., R. 4 E.			
Sec. 10	430	425	Mountain granite
10	450	445	Mountain granite
T. 6 S., R. 2 E.			
Sec. 1	551	545	Granite
T. 6 S., R. 3 E.			
Sec. 5	650	640	Rock
17	592	570	Hill formation
19	400	385	Solid granite
25	380	380	Bedrock
T. 6 S., R. 5 E.			
Sec. 16	200	198	Hill top
16	280	280	Mountain
18	340	340	Hard rock surface
18	430	430	Granite
32	414	412	Granite
T. 7 S., R. 4 E.			
Sec. 17	500	485	Solid rock
T. 7 S., R. 5 E.			
Sec. 16	200	195	Rock
21	415	405	Rock

Location	Depth drilled (feet)	Depth to rock (feet)	Driller's description of rock
T. 7 S., R. 5 E.			
Sec. 23	250	200	Rock
23	200	180	Rock
24	475	260	Hard rock malapai

Thirteen wells in Tps. 4, 5, and 6 S., R. 2 E., and T. 6 S., R. 3 E., reportedly encountered hard rock at depths ranging from 253 to 680 feet, with an average thickness of alluvium of about 400 feet. Several wells in T. 4 S., R. 4 E., reportedly encountered hard rock at depths ranging from 320 to 598 feet. Drillers' logs of wells in much of the eastern half of Tps. 6 and 7 S., R. 5 E., indicate the presence of hard materials at relatively shallow depths. Terms such as "solid rock", "bedrock", and "granite" appear in the logs of 20 wells in the area. These logs suggest that the top of the hard material is at an average depth of about 200 feet. This surface could be the top of a buried mountain, the top of lava flows, or possibily, the top of cemented valley-fill sediments.

Ground water

Occurrence

Avra-Marana district.--Depth-to-water measurements in wells in the Avra-Marana district show that the water table is at depths as shallow as 110 feet near Rillito, where the Santa Cruz River enters the area, and deeper than 300 feet in the southern part of the district and along the eastern and western margins of the valley fill. Plate 15 shows the depth to the water table for most of the district. The average depth to water in the district is about 200 feet.

Near the community of Rillito, where underflow from the Upper Santa Cruz basin enters the Avra-Marana district, the depth to water increases from about 100 feet to over 200 feet in a distance of less than 1½ miles. A partial ground-water barrier of undetermined composition and extent holds the ground water south of the barrier at a higher elevation than north of the barrier.

The water that has been pumped from wells in the district was withdrawn from the fill at depths generally less than 800 feet. Deeper wells may encounter aquifers at greater depth, but the permeability and yield from these deeper aquifers probably will be less than from the shallower aquifers.

Eloy district.--The depth to water in March 1952 in the Eloy district ranged from about 100 feet in the northeastern part to about 300 feet southeast of the Picacho Mountains. The average depth to water was about 175 feet.

In the southeastern part of the Eloy district the depth to the water table ranges from about 150 feet near the Santa Cruz River to over 300 feet southeast of the Picacho Mountains. Well (D-9-10)20aaa reportedly had only a small increase in water production below 650 feet. The depth to water in this well was about 200 feet in March 1952. The record for a domestic well in the pass between Picacho Peak and the Picacho Mountains indicates a thickness of saturated alluvium of about 10 feet. The depth to water between Picacho Peak and the Silver Bell Mountains averaged about 175 feet in March 1952. Logs of wells indicate that the maximum thickness of saturated sediments in this area probably is not greater than 425 feet.

In general, the water-bearing materials from which wells in the Eloy district have withdrawn water in past years are at depths less than 700 feet. In recent years, deeper drilling has tapped water in permeable materials at depths greater than 700 feet. These deeper wells do not represent new sources of supply, but are merely tapping a common reservoir at a lower level. The deeper aquifers are interconnected with those at shallower depths, although the connections may be circuitous. Initial water levels higher than the prevailing water levels in the vicinity have been noted in wells that tap these deeper aquifers, and in which the shallow aquifers have been sealed off. This does not indicate that an extensive artesian system is present. It has been noted that this apparent artesian head is only temporary and disappears with pumping. A possible cause for the anomaly is that the connection between the shallow aquifers and the deeper aquifers may be relatively remote, and the hydrostatic pressure on the deeper waters may in effect reflect pressure conditions at the remote point of connection, where there may not have been as much decline in head as in the vicinity of the well.

The Geological Survey has not yet had the opportunity to obtain sufficient data to justify any general conclusions about the rate of yield from these deeper aquifers. Preliminary conclusions, based on data collected from the relatively few deep wells that have been drilled, are that the sediments in the deeper aquifers are more compacted and cemented and are less productive than those at shallower depths. For this reason a unit volume of the deeper sediments probably will yield less water and at a slower rate than will a unit volume of the shallower sediments. In terms of pumping from wells, larger drawdowns will be required to obtain a given rate of pump discharge.

In a few small local areas along the margins of the Eloy district the thickness of saturated alluvium is considerably less than in most of the district. Logs of irrigation wells show that the thickness of the saturated alluvium in the southwestern part of T. 8 S., R. 6 E., averaged about 180 feet in March 1952. In sec. 11, T. 10 S., R. 6 E., the minimum known thickness was about 210 feet. Between the Silver Reef and Casa Grande Mountains the thickness ranged from 150 to 500 feet.

Casa Grande-Florence-Sacaton district.--In the Casa Grande-Florence-Sacaton district the depth to the water table ranges from about 30 feet near the Ashurst-Hayden Dam to over 140 feet along the Florence-Casa Grande canal east and southeast of Coolidge. The average depth to water in the district is about 75 feet. The top of the extensive clay layer marks the lower limit of about 200 feet of permeable and saturated sediments from which the present irrigation wells are withdrawing water. Although the clays contain much water in their upper layers, they yield comparatively little to wells. It is not definitely known whether the clays rest on bedrock or on permeable sediments.

The logs of wells in the Gila River Indian Reservation near Sacaton indicate that below 200 to 250 feet the sediments may be cemented and have but limited storage capacity.

Maricopa-Stanfield district.--In March 1952 the depth to water in wells in the irrigated parts of the Maricopa-Stanfield district ranged from about 30 feet near Maricopa to over 300 feet in the southwestern part of T. 7 S., R. 4 E. The average depth to water in the irrigated part of the district is about 145 feet. The depth to water decreases northward from Maricopa and, in the extreme northwestern part of the district, the Gila River channel intersects the water table.

The thickness of saturated fill overlying the relatively impermeable hard materials in Tps. 6 and 7 S., R. 5 E., averaged about 125 feet in March 1952. No wells are known to have been drilled through the hard materials and consequently it is not known if they are underlain by water-bearing sediments.

Among the buttes and ridges along the western margin of the Maricopa-Stanfield district, 15 wells reportedly encountered saturated alluvium averaging about 270 feet in thickness. In T. 4 S., R. 4 E., several wells reportedly passed through 200 to 450 feet of saturated fill before encountering hard rock.

Source

Possible sources of recharge to the ground-water reservoir of the Lower Santa Cruz area are as follows: (1) Underflow to the area; (2) seepage from surface-water flows within the region; (3) precipitation on the valley floor; (4) water rising from depth as fault springs; and (5) seepage from water diverted for irrigation.

Underflow.--Underflow enters the Lower Santa Cruz area from the Gila and Santa Cruz Rivers, and from Brawly, Santa Rosa, and Vekol Washes. It has been estimated (Turner and others, 1943, pp. 83-84) that the total average annual amount of underflow at that time from these sources was about 28,000 acre-feet. With the exception of underflow from the Upper Santa Cruz basin at Rillito, there has been little or no change in conditions that would raise or lower this estimate. In the vicinity of Rillito, the water table has lowered about 30 feet since 1941. This lowering has reduced by about 20 percent the cross-sectional area of saturated sediments through which underflow occurs.

Seepage from surface flows.--It is concluded generally that the larger river and wash channels offer the best possibilities for recharge from surface flows. The principal areas where seepage from surface flows reaches the ground-water reservoir are the channels of the Santa Cruz and Gila Rivers and Brawly, Santa Rosa, Vekol, and McClellan Washes.

The total recharge from these sources has been estimated to be over 20,000 acre-feet per year (Turner and others, 1943, pp. 82-84). No measurements of seepage losses from stream flows have been made in the area in recent years. Farms and ranches along these rivers and washes have diverted and used all waters that formerly were permitted to flow downstream. These diversions reduce the recharge in the river and wash channels.

Precipitation.--Tests made in this area and in other parts of southern Arizona indicate that, in most years at least, little recharge to ground-water reservoirs is derived from direct precipitation on the valley floor. Most of the precipitation runs off, evaporates, or is transpired by vegetation. The areas most favorable for receiving recharge from direct precipitation are those with 5 feet or more of coarse uncemented material underlying the surface. Such areas occur in the channels of the Gila and Santa Cruz Rivers and the larger washes. The gross area is small and the amount of recharge is correspondingly small.

Water rising from depth.--The principal locality in the Lower Santa Cruz area where it is suspected that water is rising from depth and discharging into the valley fill is immediately west of Casa Grande, mostly in T. 6 S., R. 5 E. Chemical analyses of the ground waters in this locality show a maximum mineral content of about 5,000 parts per million, or over 10 times the mineral content of ground waters in surrounding areas. The highly mineralized water in this locality could be rising along a fault zone, a possibility that is supported by geologic evidence.

Seepage from water diverted for irrigation.--Recharge from irrigation water may occur as seepage from water applied to the land, or as seepage in canals and ditches. The amount of recharge by seepage from irrigation water probably ranges from almost zero to as much as 25 percent in different parts of the Lower Santa Cruz area. Values in the low range most likely apply to all except the Casa Grande-Florence-Sacaton district.

The over-all average figure for recharge from this source is believed to be between 5 and 15 percent. This estimate is based on data collected by (Turner and others, 1941, p.30), modified by the author of the present report on the basis of conditions in the Lower Santa Cruz area. In 1951, the total amount of ground water and surface water used for irrigation in the Santa Cruz area was about 1,150,000 acre-feet, of which it is estimated that 50,000 to 175,000 acre-feet will eventually reach the water table.

Movement

The movement of ground water in the Lower Santa Cruz area is illustrated in plate 16 by contours showing the position of the water table in March 1952. Ground-water contours for the Avra-Marana district are not shown because sea-level datum elevations are, at present, not available for these wells.

In the Avra-Marana district the direction of ground-water movement is from south to north, and from the sides of the valley toward the axis. In 1952 the slope of the water table averaged about 12 feet to the mile from T. 14 S. to the Pima-Pinal County line. In the vicinity of Rillito, where inflow from the Upper Santa Cruz basin enters the area, the gradient was about 50 to 75 feet per mile but, about 5 miles northwest of Rillito, reduced to between 10 and 12 feet per mile.

North of the Pima-Pinal County line the water table slopes northwest, indicating that the general movement of ground water is toward the central part of the Eloy district through the pass between the Silver Bell Mountains and Picacho Peak. There are strong indications that little or no ground water moves from the Avra-Marana district into the area east of the Picacho Mountains. Ground water in that vicinity moves westward from recharge areas farther east.

In the central part of the Eloy district the ground-water movement is predominantly northward. The configuration of the water table has changed since 1942. At that time most of the ground water moved northwest toward the Maricopa-Stanfield district, but some moved northward into the Casa Grande-Florence-Sacaton district. This pattern was altered by heavy withdrawals of water from wells in the Eloy district. The present trough-like form of the water table in the Eloy district indicates that less water is now moving toward the Casa Grande-Florence-Sacaton district.

Less water is moving toward the Maricopa-Stanfield district between the Casa Grande and Silver Reef Mountains than moved in 1942. The water table here has been lowered about 30 feet in the period 1942-52, with the result that a gradient of 10 feet per mile was reduced to less than 5 feet per mile. The decline of the water table has reduced the cross section of saturated material, and the rate of ground-water movement has become less with a decrease in gradient.

Ground water moves to the Casa Grande-Florence-Sacaton district from the Eloy district, from the area north and east of the Picacho Mountains, and from underflow of the Gila River. In 1942 water moved westward out of the district between the Casa Grande and Sacaton Mountains. In 1952 there was virtually no movement through that avenue, because pumping from wells in the Casa Grande-Florence-Sacaton district intercepted this water for use within the district. Ground water also moved to the Gila River Indian Reservation near Sacaton between the Sacaton and Santan Mountains. The amount of water moving through here was less in 1952 than in 1942 because of a 20-foot decline of the water table. It is possible that some ground water moves northward from the area between Florence and Ashurst-Hayden Dam to the Queen Creek area of the Salt River Valley.

Ground-water movement into the Maricopa-Stanfield district was estimated in 1943 as 18,000 acre-feet, most of which entered the district between the Casa Grande and Sacaton Mountains (Turner and others, 1943, p. 83). The balance of the inflow was largely through the avenue between the Casa Grande and Silver Reef Mountains. Since 1942, heavy pumping in the Eloy district and in the Casa Grande-Florence-Sacaton district has virtually stopped movement of ground water between the Casa Grande and Sacaton Mountains (pl. 16). Pumping has also reduced the movement of ground water between the Casa Grande and Silver Reef Mountains.

At the eastern edge of the Maricopa-Stanfield district the ground-water movement is partially blocked by hard materials that form a subsurface barrier previously discussed. The presence of the barrier is shown by the ground-water contours on plate 16. From a gradient of 20 feet per mile, the water-table slope abruptly steepens to more than 50 feet per mile. The ground water moves westward from the barrier toward Maricopa. Beyond Maricopa the ground water moves northward and joins with underflow of the Gila River from the vicinity of Sacaton. One of the striking developments in the movement of ground water through the Maricopa-Stanfield district since 1942 is the large decrease in gradient of the water table in the vicinity of Maricopa. In 1942 the gradient in the locality was about 5 feet per mile; in 1952 the gradient was 1 1/4 feet per mile. This decrease in gradient has reduced the outflow from the Maricopa area.

Discharge

The discharge of water from the ground-water reservoir of the Lower Santa Cruz area occurs as underflow, effluent surface flow, evapotranspiration, and withdrawals by pumping. The first three are considered natural discharge, and the fourth as artificial discharge.

Natural discharge.--Data available are insufficient to revise estimates of natural discharge made by Turner and others (1943, p. 84). Their estimates for the year 1941 were 10,000 to 25,000 acre-feet of underflow, 3,000 acre-feet of surface flow, and about 100,000 acre-feet of evapotranspiration from the lowlands of the Gila River.

Artificial discharge.--Pumpage from wells in the Lower Santa Cruz area has increased greatly in the period of record 1940-51. The following tabulation lists the amount of water pumped each year in each district in the area.

	District				
Year	Avra-Marana	Eloy	Maricopa-Stanfield	Casa Grande-Florence-Sacaton	Total
			Acre-feet		
1940	------	140,000	70,000	162,000	--------
1941	7,000	150,000	72,000	115,000	344,000
1942	4,000	200,000	100,000	200,000	504,000
1943	11,000	190,000	110,000	215,000	526,000
1944	10,000	180,000	115,000	235,000	540,000
1945	13,000	200,000	140,000	270,000	623,000

Year	District				
	Avra-Marana	Eloy	Maricopa-Stanfield	Casa Grande-Florence-Sacaton	Total
	Acre-feet				
1946	12,000	220,000	150,000	290,000	672,000
1947	14,000	260,000	150,000	290,000	714,000
1948	18,000	360,000	260,000	330,000	968,000
1949	27,000	420,000	360,000	320,000	1,127,000
1950	25,000	370,000	340,000	290,000	1,025,000
1951	80,000	380,000	370,000	280,000	1,110,000

Wells.--The rates of discharge from irrigation wells range widely in the Lower Santa Cruz area. The Geological Survey makes numerous well-discharge measurements during each pumping season to aid in preparing a pumpage inventory. A discharge measurement made by the Geological Survey represents operating conditions at the time of the measurement. It does not represent the maximum discharge from the well, because no attempt is made to regulate the speed of the motor. During the period from May to September 1952, approximately 200 well-discharge measurements were made in in the Pinal County portion of the Lower Santa Cruz area. In the Eloy district the discharge from 85 wells averaged 1,160 gallons per minute; in the Maricopa-Stanfield district the discharge from 74 wells averaged 1,490 gallons per minute; and in the Casa Grande-Florence-Sacaton district the discharge from 30 wells averaged 880 gallons per minute. The discharges ranged from about 300 to about 3,000 gallons per minute. The following list shows the range of well discharges with respect to the number of wells measured:

Number of wells	Discharge (gallons per minute)
4	Greater than 2,500
14	2,000 - 2,500
36	1,500 - 2,000
63	1,000 - 1,500
60	500 - 1,000
12	Less than 500

There were about 1,550 irrigation wells in use in the Pinal County portion of the Lower Santa Cruz area during the 1952 pumping season.

Twenty-five well-discharge measurements made in the Avra-Marana area ranged from 500 to 3,500 gallons per minute, an average of 1,650 gallons per minute. Approximately 90 irrigation wells were in use at the start of the 1952 irrigation season.

Storage

Fluctuations of water levels.--In the Lower Santa Cruz area water levels are measured in widely spaced wells at least four times a year, approximately in March, June, September, and December. Late in February or early in March water levels are measured in a much larger number of wells. The following list shows the number of wells measured and the frequency of measurement in each of the districts:

District	Number of wells measured	
	Once a year	Four times a year
Avra-Marana	33	29
Eloy	183	25
Casa Grande-Florence-Sacaton	106	23
Maricopa-Stanfield	175	11

Hydrographs of water-level fluctuations were drawn for a few selected wells, as shown in figures 13, 14, 15, and 16. Figure 13 shows fluctuations of water levels in wells in the Avra-Marana district. In the southern part of the district, where pumping for irrigation is small, the water levels in wells (D-15-10)35aaa and (D-14-10)25caa show negligible seasonal fluctuations, and the long-term trend indicates little change in ground-water storage in their vicinity. The other hydrographs (fig. 13) are for wells in the more heavily pumped areas in the central and northern part of the district. The decline of the water table becomes progressively greater as the center of the oldest pump irrigation development is approached. The area of oldest pump irrigation is northeast of the Santa Cruz River and, therefore, it is natural that the maximum water-table decline is in that area. The water table beneath the cultivated lands in that area declined an average of about 22 feet in the period 1940-52, and the hydrographs for wells (D-11-11)17baa and (D-11-11)34add show a decline of as much as 26 feet in the same period. The graphs show that the rate of water-table decline has increased in recent years.

In the southeastern part of the Eloy district, water levels in wells lowered a net average of about 25 feet in the period 1940-52. The water-level fluctuations in well (D-10-9)10dba, shown graphically in figure 14, are representative of fluctuations in that locality. Graphs of water-level fluctuations in other selected wells are shown to illustrate local trends in ground-water levels. The maximum water-table decline in the Lower Santa Cruz

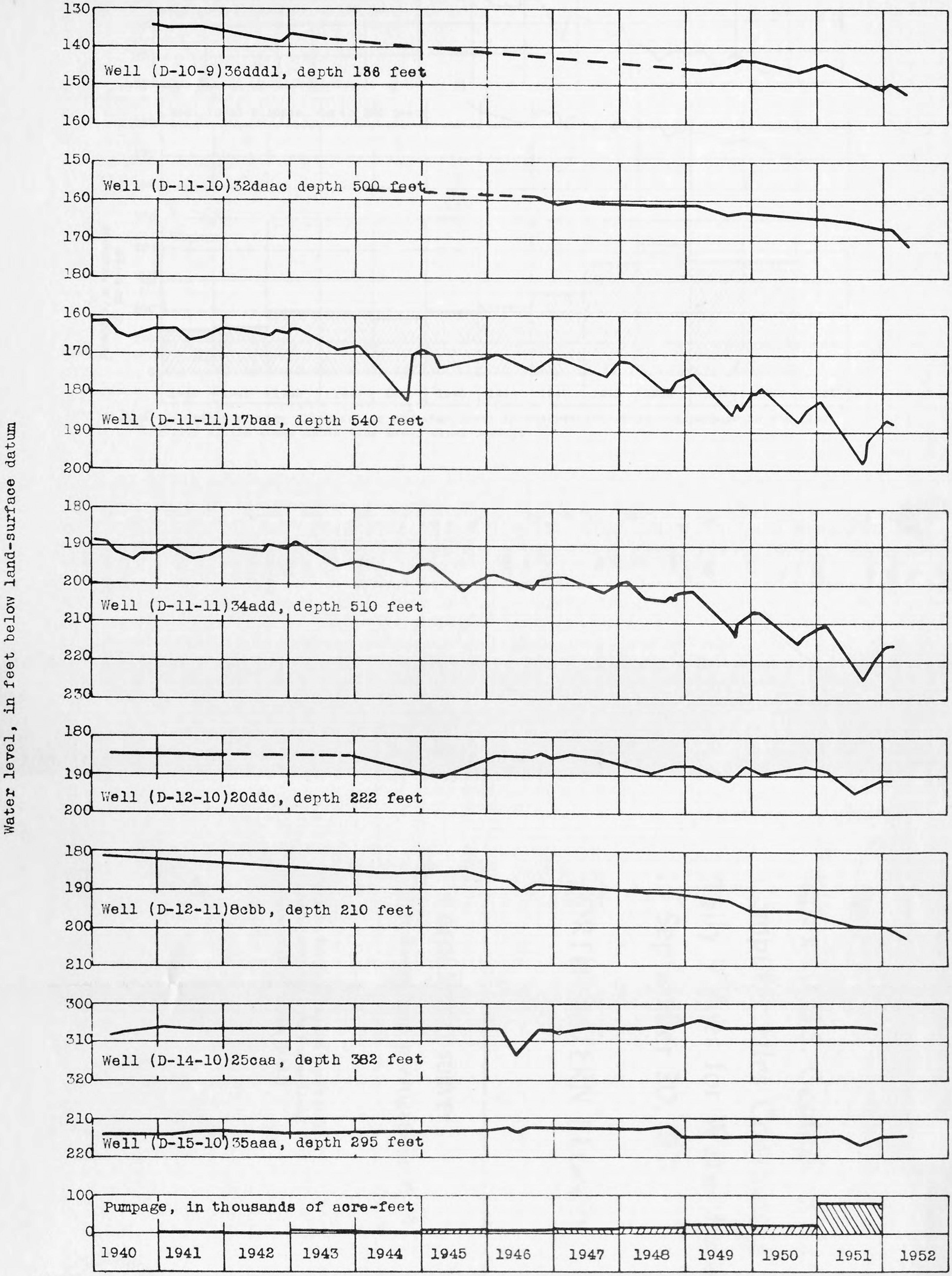


Figure 13.--Graphs showing fluctuations of water level in observation wells and pumpage in the Avra-Marana district of the Lower Santa Cruz area, Pima County.

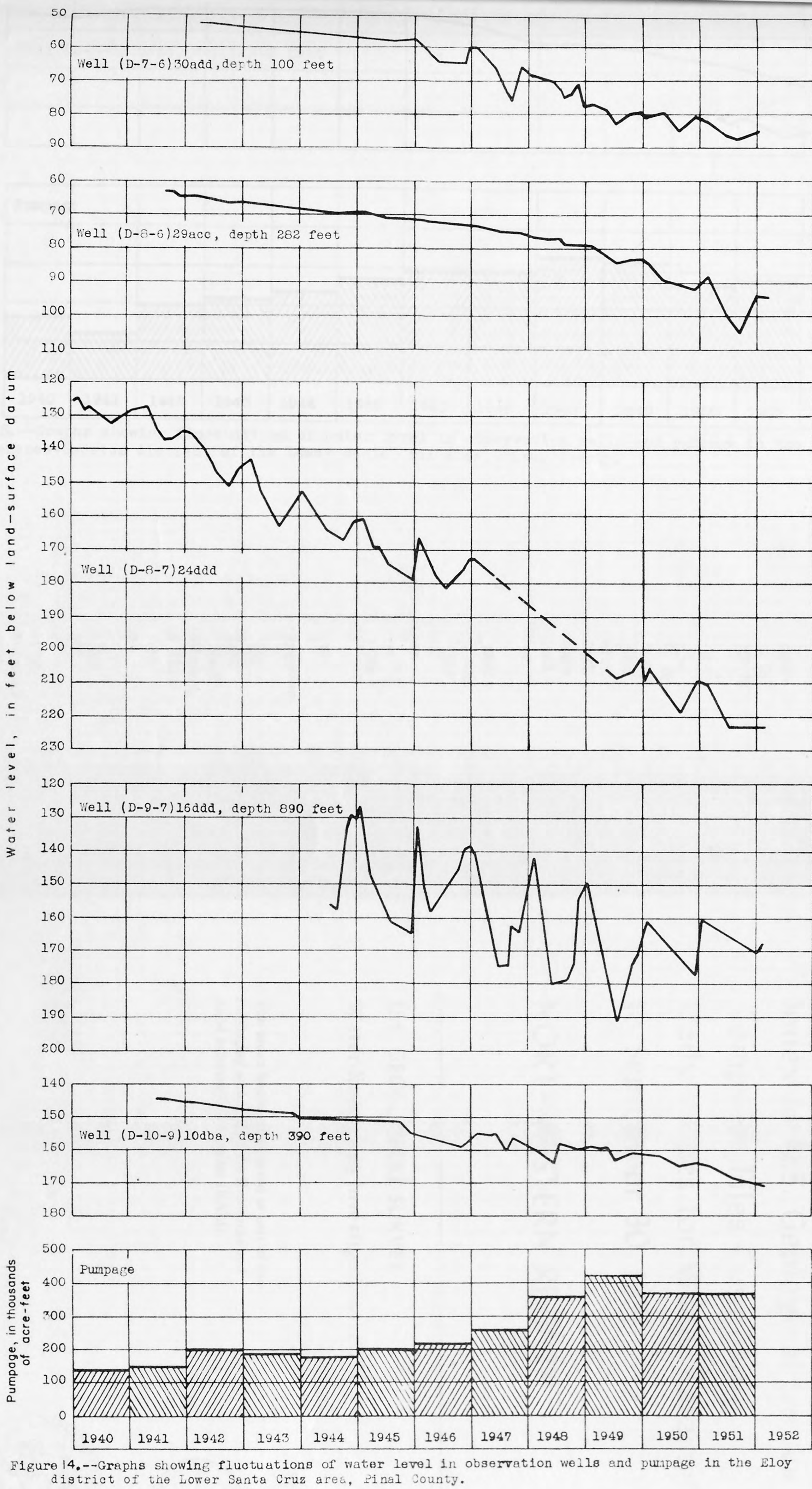


Figure 14.--Graphs showing fluctuations of water level in observation wells and pumpage in the Eloy district of the Lower Santa Cruz area, Pinal County.

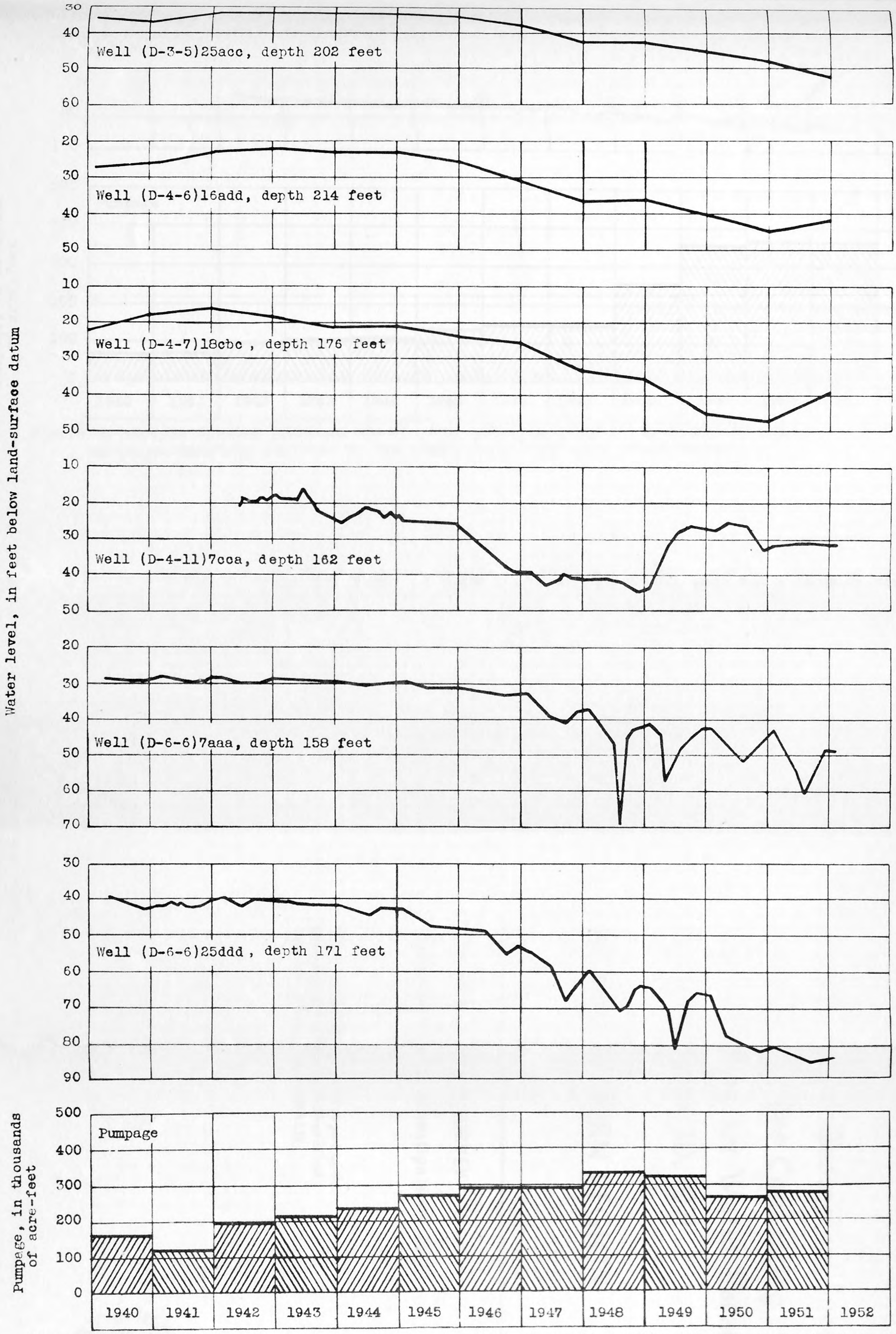


Figure 15.--Graphs showing fluctuations of water level in observation wells and pumpage in the Casa Grande-Florence-Sacaton district of the Lower Santa Cruz area, Pinal County.

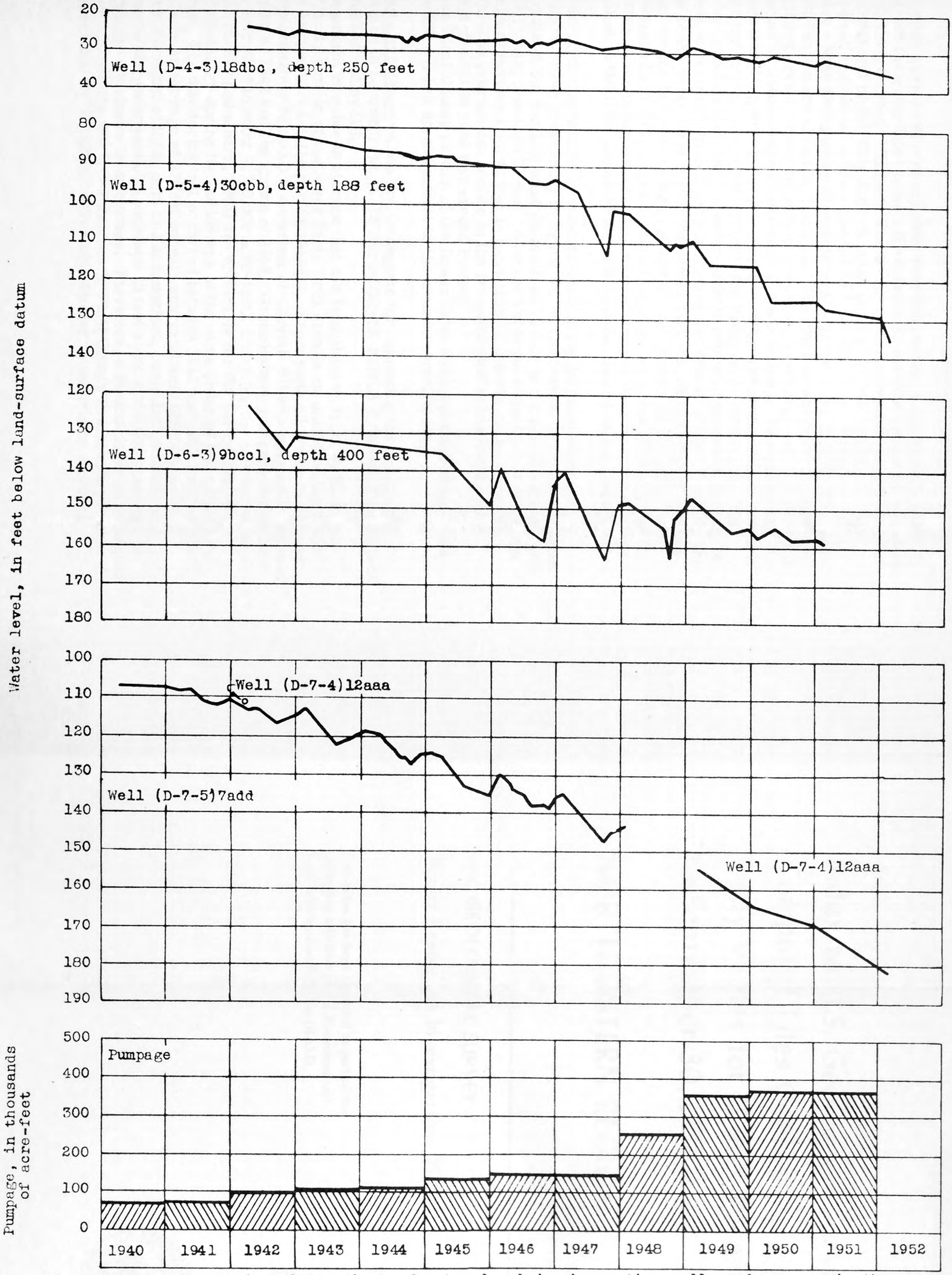


Figure 16.--Graphs showing fluctuations of water level in observation wells and pumpage in the Maricopa-Stanfield district of the Lower Santa Cruz area, Pinal County.

area for the period 1940-52 occurred near the center of the Eloy district. In this period the water level in well (D-8-7)24ddd, near the center of maximum decline, lowered about 100 feet. The water table declined at least 60 feet in over 50 percent of the Eloy district in the period 1942-52 (pl. 17). The average net decline in the Eloy district in 1951 was about 7½ feet.

Water - level fluctuations in selected wells in the Casa Grande-Florence-Sacaton district are shown in figure 15. The rises in water levels shown in the first four graphs were caused by increases in recharge and reductions in the amount of water pumped from wells in their vicinity. The additional recharge was derived from above-average amounts of surface water available for irrigation. Well (D-4-11)7cca, for example, is between the Gila River and a main canal, and the water level in this well fluctuates quickly in response to recharge from nearby surface-water flows. Plate 17 shows the decline of the water table during the period 1942-52. It is apparent that the average decline has been between 30 and 40 feet in over 50 percent of the area between Casa Grande and Florence, and not more than 20 feet in most of the Gila River Indian Reservation in the vicinity of Sacaton. The average net decline in the Casa Grande-Florence-Sacaton district in 1951 was about 6 feet.

Water-level fluctuations in selected wells in the Maricopa-Stanfield district are shown graphically in figure 16. In the central and southern parts of the district the declines were as much as 70 feet in the period 1942-52 and, near Maricopa, less than 20 feet. Average water-level declines in the same period were greater than 40 feet in more than 50 percent of the district (pl. 17). The average net decline in the irrigated part of the Maricopa-Stanfield district in 1951 was around 8½ feet.

In the Pinal County portion of the Lower Santa Cruz area the water-table decline (pl. 17) has spread almost to the mountain boundaries.

Quantity in storage.--Data are inadequate for computing the amount of water that can be withdrawn in the Avra-Marana district by unwatering a given increment of valley fill.

The amount of water in storage that can be withdrawn from wells in the Pinal County portion of the lower Santa Cruz area is estimated on the basis of what has occurred in the period 1942-52. From plate 17 it was calculated that approximately 33,000,000 acre-feet of alluvial fill was unwatered between the spring of 1942 and the spring of 1952. Ground-water pumpage during this period amounted to about 7,600,000 acre-feet. Assuming the data collected in 1941 (Turner and others, 1943) are applicable for the period 1942-52, natural discharge during the period was of the same order of magnitude as recharge. The unwatering that occurred between 1942 and 1952 lowered the water table an average of 37 feet beneath approximately 925,000 acres of land. On the basis of these data and assumptions, computations show that by lowering the water table an additional 13 feet about 2,700,000 acre-feet of water will be withdrawn from storage. Therefore, a 50-foot layer of saturated alluvium beneath the 925,000-acre area in Pinal County is estimated to contain approximately 10,000,000 acre-feet of water in underlying storage.

No attempt has been made to estimate the storage capacity of the alluvium in deeper 50-foot increments because too many variables are involved. In some parts of the area it will doubtless be feasible to unwater completely the alluvial fill to depths considerably below the present level of the water table. Elsewhere there are localities where clay, cemented sediments, or bedrock are not far below the water table, and in these localities the process of unwatering would necessitate many closely spaced wells. The character of the valley-fill materials is too variable to warrant the application of a single drainage coefficient to such a large area, as the drainage coefficient apparently decreases with depth.

Problems

Additional data are needed for the Lower Santa Cruz area to determine more accurately the ground-water resources of the area. Further data on the following are needed:

1. Recharge, particularly by infiltration from irrigation water.
2. Natural discharge, particularly by evapotranspiration along the Gila River.
3. Position, extent, and water-bearing character of deep aquifers, particularly with respect to their permeability and coefficients of drainage.
4. Chemical quality of ground water in both shallow and deep aquifers.
5. Changes in chemical quality of ground waters with respect to time.
6. Extent of pediment areas.
7. Additional well-discharge measurements in order to increase accuracy of pumpage inventory.

Summary

The Lower Santa Cruz area occupies about 2,200 square miles. The area is mostly within Pinal County, but a small part lies in Pima County. The area is drained principally by the Gila and Santa Cruz Rivers. Unlike most other basins of the desert region, the area is not within one structural depression but includes several. The principal aquifers of the area are in the older alluvial fill, which generally is several hundred feet thick. In the past, most of the irrigation wells have withdrawn water from aquifers generally less than 800 feet deep. In recent years, wells have been drilled deeper and have encountered water-bearing beds at greater depths. The deep aquifers are interconnected with those above and form a common ground-water reservoir.

The depth to water ranges from a few inches in the northwest part of the area, near Gila River, to more than 300 feet in the southwestern and southern parts of the area. The depth to water in the irrigated parts of the area ranges from about 30 feet, near Maricopa, to about 300 feet, in the southwestern part of the Maricopa-Stanfield district.

Annual withdrawals from wells generally have increased; from 344,000 acre-feet in 1941 to 1,127,000 in 1949, 1,025,000 in 1950, and 1,110,000 in 1951.

Pumping from wells has lowered the water table as much as 100 feet in some parts of the area during the period 1940-52. In the Pinal County portion of the area the water table has been lowered an average of 37 feet in the period 1942-52, during which time 7,600,000 acre-feet of ground water was withdrawn. It is estimated that by the time the average decline becomes 50 feet, 10,000,000 acre-feet of water will have been withdrawn. It is believed that this amount of water cannot be obtained for succeeding 50-foot increments of decline.

QUALITY OF WATER IN LOWER SANTA CRUZ AREA

By. J. D. Hem

The quality of ground waters in the Lower Santa Cruz area is discussed in a report by Turner and others (1943, pp. 72-81). As noted in that report, the quality of ground waters in the Avra-Marana, Eloy, and Maricopa-Stanfield districts is in general suitable for irrigation and domestic use. In the Casa Grande-Florence-Sacaton district some of the ground water is too highly mineralized to be satisfactory for domestic use and may be "doubtful to unsuitable" for irrigation. In several parts of this district fairly well-defined areas occur where the ground water is highly mineralized. One of the most notable is west of Casa Grande. Selected analyses of samples of water from the four districts are given in table 24.

A number of wells in the area have been resampled periodically since 1943 (table 24). The analyses of these samples indicate in a general way the changes that have occurred in quality of ground water. In those parts of the area where the ground water contains less than 500 parts per million of dissolved solids, few changes in chemical quality have occurred since 1943.

No large areas of highly mineralized water have developed since preparation of the 1943 report, although some of the areas noted previously have increased in size since that time. The cause of the increase in size is attributed in large part to the lowering of the regional water table. In local areas, particularly in the Casa Grande-Florence-Sacaton district, where the sand and gravel aquifers are collectively rather thin, the unwatering is causing wells in those areas to draw a greater proportion of their supply of water from the underlying, less permeable materials. The waters in these beds are more highly mineralized than the waters in the sand and gravel aquifers. Therefore, as the water table lowers, wells in adjacent areas withdraw more and more water from the less permeable materials, and the area in which highly mineralized water is withdrawn from wells grows larger. In areas where deep-seated highly mineralized water leaks into the valley fill, the lowering of the water table has decreased the head near the avenue of leakage, and greater quantities of this mineralized water enter and spread into adjacent areas. In the area south and southeast of Coolidge the concentration of dissolved solids has increased considerably. In the area west of Coolidge the highly mineralized waters apparently have spread southward. In the area west of Casa Grande the highly mineralized waters apparently are spreading eastward.

The decline of the water table in this area and the decrease in well yields have resulted in drilling some wells deeper. The quality of water encountered at depths of 1,000 feet or more seems to differ from that of water at shallower depths. Available data indicate that the sodium percentage increases with depth. No consistent change in dissolved-solids concentration is associated with the change in sodium percentage in the areas where samples were collected. The following tabulation lists a few shallow wells and deep wells sampled for quality-of-water comparison:

Well	Year sampled	Depth (feet)	Specific conductance (micromhos at 25° C.)	Percent sodium
T. 5 S., R. 3 E.				
Sec. 35	1941	350	600	41
36	1952	1,212	562	56
T. 6 S., R. 4 E.				
Sec. 16	1941	525	493	50
17	1952	1,294	501	58
T. 6 S., R. 5 E.				
Sec. 22	1941	130	4,950	58
21	1952	400	4,800	67
T. 7 S., R. 7 E.				
Sec. 31	1941	352	430	49
32	1952	1,432	498	70
T. 8 S., R. 7 E.				
Sec. 15	1941	297	534	37
21	1952	1,697	481	55
T. 8 S., R. 8 E.				
Sec. 17	1941	500	539	32
17	1952	1,328	469	63
T. 9 S., R. 6 E.				
Sec. 24	1941	382	432	40
24	1948	1,110	372	82
24	1952	1,110	421	84
T. 9 S., R. 8 E.				
Sec. 20	1941	500	498	42
21	1952	1,300	540	69

The higher sodium percentage of the deeper waters makes them somewhat less desirable for irrigation use than the shallower waters. As stated in Part I of this report, waters having a high sodium percentage tend to enter into base-exchange reactions that harden the irrigated soil and make it progressively less permeable.

Table 23.--Logs of representative wells in Lower Santa Cruz area, Pinal County, Ariz.

	Thickness (feet)	Depth (feet)
(D-4-5)6bcc		
Soil- - - - - - - - - - - - -	2	2
Clay and caliche- - - - -	10	12
Sand and gravel 6"- - - -	52	64
Clay and gravel - - - - -	96	160
Clay- - - - - - - - - - - -	100	260
Clay and gravel - - - - -	70	330
Sand and gravel ½"- - - -	10	340
Cemented sand and gravel	30	370
Granite - - - - - - - - - - -	15	385
TOTAL DEPTH		385
(D-4-6)24baa		
Soil- - - - - - - - - - - - -	16	16
Fine sand - - - - - - - - -	14	30
Loose gravel boulders - - - - - - - -	23	53
Clay- - - - - - - - - - - - -	1	54
Loose gravel and clay -	18	72
Cemented gravel and boulders - - - - - - - - -	56	128
Gravel with streaks of clay - - - - - - - - - - -	41	169
Cemented material - - -	10	179
TOTAL DEPTH		179
(D-4-11)7adb		
Topsoil - - - - - - - - -	12	12
Sand- - - - - - - - - - - - -	16	28
Sand and gravel to 1½"	8	36
Coarse gravel to 1½"- -	44	80
Cemented gravel - - - - -	41	121
Granite boulders- - - - -	3	124
Cemented boulders - - - -	11	135
Bed rock- - - - - - - - - -	1	136
TOTAL DEPTH		136
(D-5-3)36cdd		
Sandy soil- - - - - - - - -	20	20
Clay- - - - - - - - - - - - -	40	60
Dry gravel- - - - - - - - -	30	90
Clay- - - - - - - - - - - - -	25	115
Sand- - - - - - - - - - - - -	15	130
Clay- - - - - - - - - - - - -	28	158
Water gravel- - - - - - - -	8	166
Clay- - - - - - - - - - - - -	24	190
Gravel- - - - - - - - - - - -	6	196
Clay- - - - - - - - - - - - -	10	206
Sand- - - - - - - - - - - - -	6	212

	Thickness (feet)	Depth (feet)
Clay- - - - - - - - - - -	34	246
Clay and sand - - - - -	6	252
Clay- - - - - - - - - - -	24	276
Clay and gravel - - - -	6	282
Clay- - - - - - - - - - -	18	300
Sand and gravel - - - -	5	305
Clay- - - - - - - - - - -	23	328
Sand and gravel - - - -	4	332
Clay- - - - - - - - - - -	13	345
Sand- - - - - - - - - - -	5	350
Clay and gravel - - - -	18	368
Clay- - - - - - - - - - -	36	404
Sand- - - - - - - - - - -	6	410
Gravel- - - - - - - - - -	10	420
Clay- - - - - - - - - - -	38	458
Clay- - - - - - - - - - -	12	470
Sand and gravel - - - -	30	500
Gravel and sand - - - -	10	510
Sandy clay- - - - - - -	18	528
Clay- - - - - - - - - - -	6	534
*	*	*
Sticky red clay - - - -	185	800
Brown shale - - - - - -	30	830
Red clay- - - - - - - -	10	840
Brown clay- - - - - - -	70	910
Hard shale- - - - - - -	5	915
Clay- - - - - - - - - - -	55	970
Sandy clay- - - - - - -	10	980
Clay- - - - - - - - - - -	50	1030
Sandy gravel 3/4" - - -	20	1050
Clay and gravel - - - -	8	1058
Clay- - - - - - - - - - -	22	1180
Fine sand - - - - - - -	5	1185
Clay- - - - - - - - - - -	27	1212
TOTAL DEPTH		1212
(D-5-7)13caa		
Topsoil - - - - - - - -	2	2
Caliche - - - - - - - - -	3	5
Sand, gravel, boulders to 8" - - - - - - - -	65	70
Clay- - - - - - - - - - -	3	73
Gravel to 2"- - - - - -	13	86
Clay- - - - - - - - - - -	28	114
Gravel to 2"- - - - - -	6	120
Sand and gravel, tight	22	142
Clay- - - - - - - - - - -	123	265
Tight sand and gravel	9	274
Shale - - - - - - - - - -	6	280

Table 23.--Logs of representative wells in Lower Santa Cruz area --Continued.

	Thickness (feet)	Depth (feet)
Blue clay	4	284
Shale	18	302
Clay	3	305
Clay and shale streaks	365	670
TOTAL DEPTH		670
(D-6-5)12cca		
Topsoil	20	20
Caliche	10	30
Sand	10	40
Sand and gravel	30	70
Quick sand	12	82
Red rock	53	135
Brown rock	7	142
Sandstone	5	147
Granite	3	150
TOTAL DEPTH		150
(D-6-8)2dad		
Sandy loam	12	12
Sand	18	30
Soft sandy clay	140	170
Hard caliche	40	210
Caliche and clay	134	344
Sand and gravel	6	350
Hard and soft clay	60	410
Blue clay very hard	15	425
Hard and soft clay	135	560
Hard clay	140	700
TOTAL DEPTH		700
(D-7-5)19cdd		
Surface soil	8	8
Sandy clay	47	55
Sand and boulders	30	85
Hard caliche	5	90
Clay	60	150
Sand some water	2	152
Clay	20	172
Sand and gravel, good	16	188
Clay	17	205
Sand and gravel, good	15	220
Clay	36	256
Gravel	3	259
Clay and gravel	27	286
Sand and gravel	7	293
Cemented sand	10	303
Sand and gravel	9	312
Cemented sand	7	319
Sand and gravel, good	13	332
Cemented sand	8	340
Sand and gravel	8	348
Cemented sand	8	356
Clay and gravel	8	364
Sand and gravel	7	371
Cemented sand	9	380
Sand and gravel	9	389
Clay	33	422
Cemented sand	6	428
Conglomerate	128	556
Gravel	9	565
Hard clay	51	616
Conglomerated rock	16	632
TOTAL DEPTH		632
(D-6-7)25ddd		
Coarse sand, streaks hard sand	60	60
Sand and gravel, streaks of clay	163	223
Sand, clay, streaks of gravel	168	391
Hard coarse water sand and gravel	7	398
Sand and clay	47	445
Blue clay	46	491
Tough brown shale	7	498
Clay	92	590
Tough brown shale	32	622
Hard brown shale	31	653
Soft brown shale	52	705
Hard brown shale	11	716
Hard shale, streaks of sandy shale	20	736
Hard shale, streaks of limestone shell	25	761
Hard shale, streaks of conglomerate and lime	93	854
Hard brown shale	86	940
Shale and limestone	5	945
Sandy shale	24	969
Hard brown shale, streaks of lime	32	1001
Tough reddish brown shale	21	1022
Sand	1	1023

Table 23.--Logs of representative wells in Lower Santa Cruz area -- continued.

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Hard brown shale	10	1033	Hard sand	30	2737
Tough reddish brown shale	59	1092	Coarse grey shale, streaks of sand and gravel	33	2770
Sandy shale	10	1102	Sand	9	2779
Reddish brown shale	16	1118	Sand and gravel	21	2800
Sandy shale	7	1125	Brown limey shale with streaks of sand	8	2808
Tough brown shale	12	1137	Shale	6	2814
Sandy shale	30	1167	Sand and gravel	44	2858
Reddish brown shale, streaks of lime	31	1198	Limey shale	8	2866
Reddish brown shale	32	1230	Shale with gravel streaks	47	2913
Sandy brown shale	37	1267	Sand with streaks of lime and gravel	20	2933
Sandy shale, with sticky streaks	38	1305	No record	244	3177
Hard shale	30	1335	Sharp fine sand	26	3203
Sandy shale, streaks of hard shale	115	1450	Fine hard sand	25	3228
Shale	80	1530	No record	19	3247
Hard sandy lime	3	1533	Conglomerate	30	3277
Shale	169	1702	Sandy clay, streaks of sand and gravel	40	3317
Shale with hard shells	187	1889	Sandy clay, streaks of rocks and conglomerate	31	3348
Shale with hard shells, lime streaks	33	1922	Shale	2	3350
Hard lime shale	142	2064	No record	23	3373
Shale - conglomerate	16	2080	Rocks	2	3375
Shale	38	2118	Soft sandy clay	54	3429
Hard shell shale	38	2156	Sand and shale	31	3460
Shale	127	2283	Hard sandy clay	29	3489
Shale and conglomerate	38	2321	Hard sand	6	3495
Shale and gypsum - lime silt	36	2357	Hard lime and sea shells	12	3507
Shale with streaks of gravel	35	2392	Hard sandy lime	17	3524
Shale with fine sand	33	2425	Hard shale and lime	43	3567
Soft shale and lime	4	2429	Hard shale with streaks of lime and sand	121	3688
Shale with sand and gravel streaks	33	2462	Hard sandy lime	17	3705
Hard grey and brown sandstone, lime streaks	31	2493	Quartzite	22	3727
Hard sandstone	7	2500	Quartzite with streaks of bentonite	15	3742
Sandstone and shale	4	2504	Lime and sand	9	3751
Hard, grey and brown sandstone	44	2548	Quartzite with streaks of tufa	23	3774
Hard shale and sandstone	49	2597	Andesite	3	3777
Shale and hard shells	22	2619	Andesite with streaks hard sandy lime	6	3783
Hard grey sand, streaks of lime and shale	71	2690	Andesite with streaks of bentonite and tufa	15	3798
Hard grey sand, wash gravel, streaks of lime	17	2707			

Table 23.--Logs of representative wells in Lower Santa Cruz area--Continued

	Thickness (feet)	Depth (feet)
Andesite with streaks lime and sand	9	3807
Hard lime with streaks sand	92	3899
Hard lime with streaks andesite	9	3908
Hard lime with streaks sand	38	3946
Hard lime with streaks dolomite	5	3951
Hard lime with streaks sand	31	3982
Hard lime with streaks quartzite and sand	19	4001
Hard lime with streaks of andesite	11	4012
Hard sand lime	34	4046
Hard sand	31	4077
No record	38	4115
Andesite	9	4124
Hard shells	23	4147
Shells of lime and shale	14	4161
Lime and hard shells, streaks of andesite	14	4175
Andesite with streaks of lime	74	4249
Andesite	22	4271
Sandy lime	206	4477
Hard sand	48	4525
Hard sandy lime	11	4536
Quartzite	3	4539
Sandy lime, streaks of andesite	53	4592
Hard sand and lime	26	4618
Hard fine grain sandstone	5	4623
Hard sand	14	4637
Sandstone with streaks of lime	51	4688
Quartzite and sandstone	3	4691
Sandy lime	5	4696
Sand with streaks of lime and sandstone	18	4714
Hard sand	15	4729
Sandstone	2	4731
Sandy lime	11	4742
TOTAL DEPTH		4742

	Thickness (feet)	Depth (feet)
(D-8-6)30ddd		
Silt	24	24
Clay and gravel	23	47
Cemented caliche	23	70
Clay	159	229
Broken black rock	56	285
Red rock	60	345
Gray shale	15	360
Brown rock	11	371
Gray shale	12	383
Red rock	42	425
Black rock	15	440
TOTAL DEPTH		440
(D-8-7)12bdd		
Sand	50	50
Fine sand	84	134
Sand and clay	58	192
Sand, streaks of clay	148	340
Sand and clay	150	490
Sand and heavy clay	60	550
Clay and gravel	20	570
Sand and streaks of clay	155	725
Sand and clay	35	760
Fine sand and clay	163	923
Sand, streaks of clay	357	1280
Sand and clay	20	1300
Sand, clay and gravel	116	1416
Brown shale	4	1420
Sand and clay	20	1440
Brown shale	37	1477
Brown shale and clay	23	1500
Sand and clay	32	1532
Brown shale	28	1560
Clay, sand and gravel	14	1574
Brown shale	105	1679
Brown shale and clay	11	1690
Shale, clay and sand	20	1710
Brown shale	33	1743
Brown shale and clay	42	1785
Shale and clay	125	1910
Sand and clay	52	1962
Shale and clay	15	1977
Clay and shale	23	2000
Clay, shale and gravel	17	2017
Sand and gravel	8	2025
Shale and gravel	55	2080

Table 23.--Logs of representative wells in Lower Santa Cruz area--continued.

	Thickness (feet)	Depth (feet)
Clay - - - - - - - - - -	5	2085
Clay and shale - - - -	24	2109
Clay, shale and sand -	7	2116
Shale and gravel - - -	19	2135
Gravel and sand - - -	73	2208
Gravel and clay - - -	39	2247
Clay and sand - - - -	13	2260
Black shale - - - - - -	13	2273
Clay - - - - - - - - - -	10	2283
Clay and sand - - - -	42	2325
Sand, clay and gravel	42	2367
Sand and clay - - - -	81	2448
Heavy clay, sand - - -	13	2461
Clay - - - - - - - - - -	14	2475
Clay and sand - - - -	93	2568
Sand - - - - - - - - - -	28	2596
Clay - - - - - - - - - -	20	2616
Sand and clay - - - -	11	2627
Clay - - - - - - - - - -	12	2639
Sand, clay - - - - - -	61	2700
TOTAL DEPTH		2700
(D-9-7)13cad		
Topsoil - - - - - - - -	12	12
Sandy clay - - - - - -	16	28
Cemented sand - - - -	13	41
Caliche - - - - - - - -	55	96
Clay - - - - - - - - - -	72	168
Sand and gravel - - -	69	237
Cemented sand - - - -	27	264
Clay - - - - - - - - - -	29	293
Cemented sand - - - -	31	324
Clay and gravel - - -	18	342
Cemented sand - - - -	149	491
Clay and gravel - - -	9	500
Sand and gravel - - -	8	508
Clay and gravel - - -	29	537
Cemented sand - - - -	11	548
Clay - - - - - - - - - -	124	672
Cemented sand, clay streak - - - - - - - -	36	708
Sticky clay - - - - -	60	768
Sandstone - - - - - -	16	784
Brown clay - - - - - -	16	800
Sandstone - - - - - -	6	806
Brown clay - - - - - -	98	904
Cemented gravel - - -	12	916
Clay and gravel - - -	26	942
Sticky clay - - - - -	99	1041
TOTAL DEPTH		1041

	Thickness (feet)	Depth (feet)
(D-9-10)20aaa		
No log - - - - - - - - - -	350	350
Clayey gravel - - - - -	50	400
Clayey gravel and caliche - - - - - - - - -	70	470
Clayey sand - - - - - -	10	480
Gravel, some clay - - -	30	510
Silt sand, some granules and pebbles - - -	60	570
Sand - - - - - - - - - - -	40	610
Pebbley clay - - - - - -	15	625
Clayey gravel - - - - - -	15	640
Clay - - - - - - - - - - -	60	700
Clay, sandy - - - - - - -	50	750
Clay - - - - - - - - - - -	295	1045
Clayey silt - - - - - - -	45	1090
TOTAL DEPTH		1090
(D-10-6)11ddd		
Fine sand - - - - - - -	160	160
Gravel - - - - - - - - - -	157	317
Coarse gravel - - - - -	119	436
Cemented sand and boulders - - - - - - -	94	530
Cemented sand and red rock - - - - - - - - -	115	645
TOTAL DEPTH		645
(D-10-9)5bda		
Sandy soil - - - - - - -	6	6
Caliche - - - - - - - - -	4	10
Gravel - - - - - - - - - -	7	17
Silt and clay - - - - - -	13	30
Sand and gravel - - - - -	5	35
Sand and gravel - - - - -	30	65
Boulders and gravel 8" -	57	122
Clay and gravel 2" - - -	23	145
Coarse gravel 4" - - - -	13	158
Clay - - - - - - - - - - -	17	175
Cemented sand - - - - - -	10	185
Coarse gravel 4" - - - -	41	226
Clay and caliche - - - -	44	270
Tight gravel $1\frac{1}{2}$" - - - -	16	286
Hard clay - - - - - - - -	18	304
Clay and gravel $1\frac{1}{2}$" - -	10	314
Clay and caliche - - - -	30	344
Clay and gravel 1" - - -	6	350
Clay - - - - - - - - - - -	25	375
Clay and gravel 2" - - -	12	387
Hard clay - - - - - - - -	21	408

Table 23.--Logs of representative wells in Lower Santa Cruz area--Continued.

	Thickness (feet)	Depth (feet)
Tight clay and gravel 2"	50	458
Hard clay	22	480
Clay and little gravel 1"	50	530
Hill top decomposed granite	32	562
TOTAL DEPTH		562
(D-11-11)20ddd		
Soil	6	6
Sandy clay	7	13
Boulders	127	140
Clay	10	150
Sand and gravel ½"	10	160
Clay	30	190
Gravel 3"	37	227
Clay and gravel	13	240
Gravel 4"	40	280
Clay	9	289
Gravel 3"	35	324
Clay	10	334
Gravel 8"	13	347
Clay and gravel	11	358
Clay	2	360
Clay and gravel	10	370
Gravel 2"	13	383
Clay	4	387
Gravel	43	430
Boulders	20	450
Gravel 3"	30	480
Boulders	20	500
Sandstone	6	506
Clay and gravel	16	522
Sandstone	6	528
Clay and gravel	8	536
Sandstone	3	539
Clay and gravel	28	567
Clay	73	640
Clay and gravel	32	672
Gravel 1"	11	683
Sandstone, some gravel	144	827
Hard sandstone	13	840
TOTAL DEPTH		840

	Thickness (feet)	Dep (fe
(D-12-10)21ddc		
Soil	7	[illegible]
Clay	23	[illegible]
Loose sand	12	[illegible]
Clay and gravel	48	[illegible]
Packed sand	17	[illegible]
Clay and gravel	101	[illegible]
Clay	34	[illegible]
Clay and gravel	48	[illegible]
Packed sand	42	[illegible]
Loose gravel	12	[illegible]
Clay and gravel	16	[illegible]
Clay	36	[illegible]
Packed sand	12	[illegible]
Clay and gravel	28	[illegible]
Packed sand and gravel	38	[illegible]
Clay	32	[illegible]
Packed sand	12	[illegible]
Clay and gravel	8	[illegible]
Clay	58	[illegible]
Clay and gravel	8	[illegible]
Sandy clay	48	[illegible]
Clay	30	[illegible]
TOTAL DEPTH		[illegible]
(D-12-11)29add		
Topsoil	7	[illegible]
Clay and gravel	43	[illegible]
Caliche, clay	28	[illegible]
Clay and gravel	82	[illegible]
Sandy clay	55	[illegible]
Clay	20	[illegible]
Gravel, sand, and clay	21	[illegible]
Gravel and sand	4	[illegible]
Sandy clay	30	[illegible]
Clay and gravel	30	[illegible]
Clay	190	[illegible]
Hard packed sand	12	[illegible]
Mountain gravel and hard rock	28	[illegible]
TOTAL DEPTH		[illegible]

Table 23.--Logs of representative wells in Lower Santa Cruz area --continued.

	Thickness (feet)	Depth (feet)
(D-12-12)6bad		
Sandy soil	8	8
Loose dry gravel	14	22
Coarse gravel and little clay	8	30
Boulders and clay	65	95
Sandy and little clay	30	125
Coarse gravel and clay	9	134
Dark clay and gravel	16	150
Yellow clay	7	157
Fine white sand	1	158
Clay and gravel	5	163
Yellow clay and gravel	7	170
Gravel and little clay	10	180
Yellow clay-gravel, little sand	38	218
Cement sand-gravel	18	236
Yellow clay-gravel	63	299
Yellow sticky clay	65	364
Cement sand	1	365
Yellow sticky clay	2	367
Cement sand-gravel	2	369
Yellow sticky clay	5	374
Yellow sandy clay	1	375
Yellow sticky clay	2	377
Cement gravel	2	379
Yellow sticky clay, little gravel	21	400
Cemented sand	2	402
Yellow sticky clay	54	456
Yellow clay - gravel	3	459
Yellow sticky clay	6	465
Yellow clay with gravel	8	473
Yellow sticky clay	16	489
Cemented sand	2	491
Yellow sticky clay	119	610
Red sticky clay	13	623
TOTAL DEPTH		623

	Thickness (feet)	Depth (feet)
(D-13-10)26ccd		
Topsoil	10	10
Clay and gravel	40	50
Packed sand	18	68
Clay	36	104
Packed sand	54	158
Clay and gravel	136	294
Packed sand	20	314
Loose gravel and sand	18	332
Gravel and clay	32	364
Loose gravel and sand	8	372
Packed sand	24	396
Loose gravel and sand	8	404
Clay	60	464
Packed sand	26	490
Clay	95	585
Packed sand	19	604
Sandy clay	36	640
Packed sand	8	648
Loose gravel and sand	20	668
Cement gravel and sand	29	697
Tough clay	3	700
TOTAL DEPTH		700

Table 24.--Analyses of water from representative wells in Lower Santa Cruz area, Pima and Pinal Counties, Ariz.
(Parts per million except specific conductance and percent sodium)

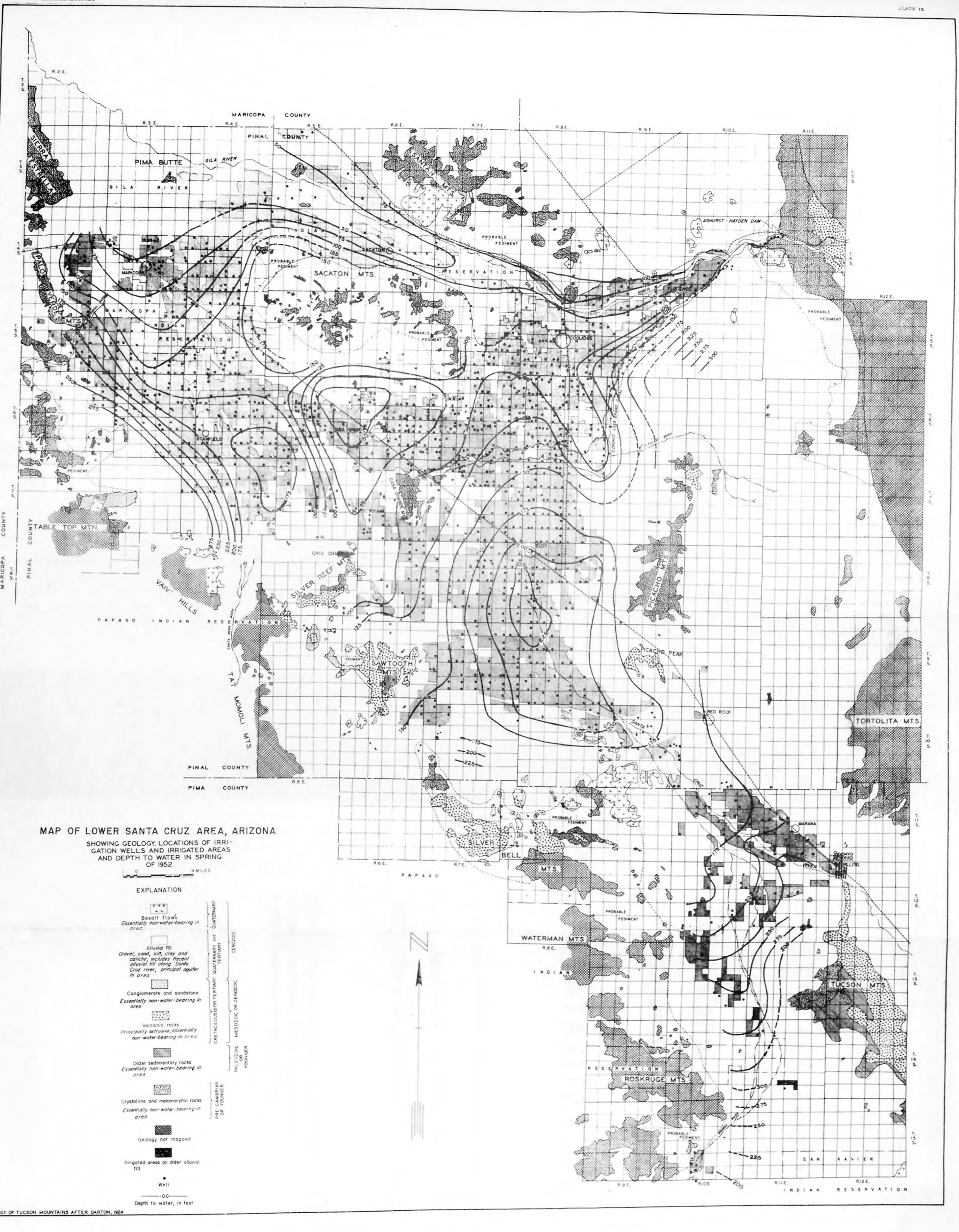
Well no.	Date of collection	Depth of well (feet)	Temperature (°F.)	Specific conductance (micromhos at 25° C.)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Total hardness as $CaCO_3$	Percent sodium
(D-4-3)															
36bcd	9-17-41	280	78	837	56	16	103	154	146	96	0.8	16	510	206	52
Do.	9-13-49	280	77½	1010	76	17	117	221	177	93	0.7	18	652	260	49
(D-4-4)															
16ddd	9-17-41	576	84	704	38	9.2	104	164	106	72	2.9	5.5	418	133	63
Do.	9-13-49	600	84½	807	35	6.0	134	151	144	84	3.1	3.5	514	112	72
Do.	8-23-50	600	85	779	–	–	–	150	–	81	–	–	–	–	–
(D-4-10)															
32bad	9-24-41	212	70	1350	92	23	160	236	136	228	1.0	17	773	324	–
Do.	8-16-50	392	71	1780	–	–	–	237	–	290	–	–	–	–	–
(D-5-8)															
31bdd	9-3-41	207	79	987	70	13	119	173	116	150	3.0	6.1	562	228	53
Do.	6-21-49	207	78	2050	196	32	190	216	279	384	1.5	24	1,260	620	40
Do.	8-17-50	207	78½	2330	–	–	–	218	–	448	–	–	–	–	–
(D-5-9)															
6caa	9-17-41	320	70	1810	136	31	205	297	180	342	–	–	1,040	467	49
(D-6-3)															
23dcc	9-16-41	501	78	507	22	10	83	146	60	30	1.6	8.1	311	96	65
Do.	9-14-49	501	79½	555	–	–	–	186	–	35	–	–	–	–	–
Do.	8-23-50	501	79½	545	–	–	–	187	–	33	–	–	–	–	–
(D-6-4)															
13add	9-15-41	356	77	868	64	13	99	139	129	123	0.7	6.3	504	213	50
Do.	9-14-49	356	77	1610	156	28	132	164	226	278	0.9	34	980	504	36
Do.	8-23-50	356	77½	1550	–	–	–	163	–	264	–	–	–	–	–
(D-6-5)															
25bbb	6-19-41	100	74	4120	304	96	511	81	1,131	700	1.3	23	2,810	1,153	49
Do.	6-21-49	100	75	3990	263	61	587	363	970	600	1.6	33	2,760	907	58
Do.	8-23-50	100	74	3400	–	–	–	411	–	485	–	30	–	–	–
Do.	3-20-51	100	74	3070	–	–	–	406	–	425	–	–	–	–	–

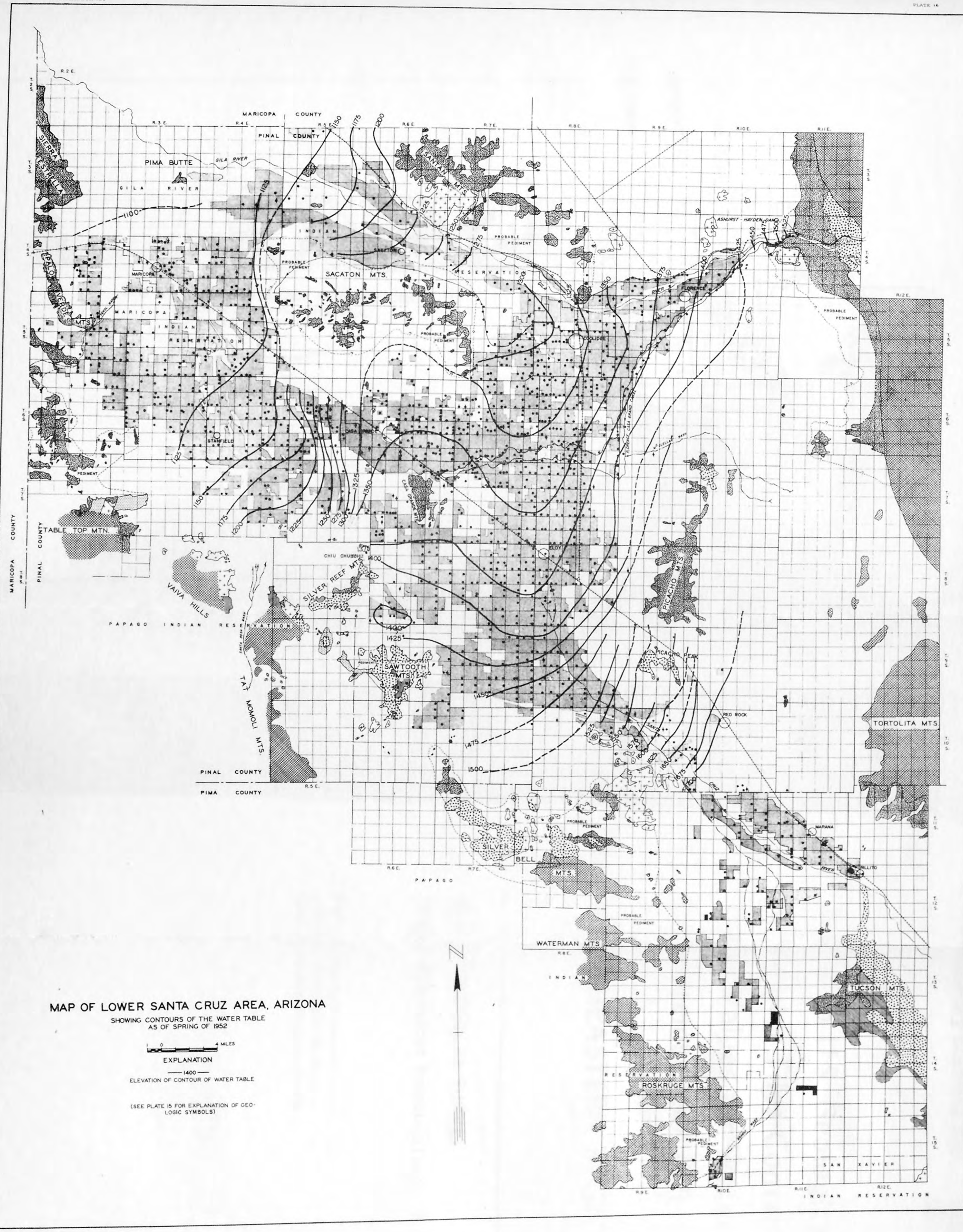
Table 24.--Analyses of water from representative wells in Lower Santa Cruz area-continued.

Well no.	Date of collection	Depth of well (feet)	Temperature (°F)	Specific conductance (micromhos at 25° C.)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Total hardness as $CaCO_3$	Percent sodium
(D-6-5)															
25bbb	4-9-51	100	74	3080	-	-	-	399	-	440	-	-	-	-	-
Do.	5-3-51	100	75	3160	-	-	-	390	-	455	-	-	-	-	-
Do.	6-8-51	100	74	3180	-	-	-	398	-	466	-	-	-	-	-
Do.	7-16-51	100	74	3230	-	-	-	397	-	476	-	-	-	-	-
(D-6-7)															
19bdd	8-25-41	220	78	1770	200	43	105	143	292	330	0.9	23	1,064	676	25
Do.	6-21-49	378	77	2060	240	48	127	146	396	365	0.5	32	1,350	796	26
Do.	8-17-50	378	78½	739	62	13	70	128	105	97	0.4	9.0	456	208	42
(D-7-7)															
12ccd	9-9-41	450	78	436	45	9.8	39	184	53	19	0.8	2.0	259	153	35
Do.	8-12-48	450	82	450	40	6.0	48	168	52	24	0.4	3.9	257	124	46
Do.	8-18-50	460	82	449	-	-	-	160	-	25	-	-	-	-	-
(D-7-8)															
33cdd	9-8-41	515	78	391	39	7.9	42	186	51	10	-	1.9	243	130	41
Do.	8-3-48	515	78	484	-	-	-	183	-	24	-	-	-	-	-
Do.	8-18-50	515	80	484	-	-	-	177	-	27	-	-	-	-	-
(D-8-5)															
1	11-6-41	228	80	501	26	9.8	72	174	65	36	-	-	294	105	60
Do.	9-15-48	228	80	546	33	7.4	77	193	67	33	1.0	5.5	355	113	60
(D-8-6)															
32ccb	9-12-41	400	80	567	23	7.4	94	177	78	44	-	4.9	338	88	70
Do.	7-28-48	400	80	625	23	6.2	105	181	81	50	1.6	4.2	399	83	73
(D-8-8)															
29bcc1	9-15-41	350	77	493	-	-	-	197	-	17	-	-	-	-	-
Do.	9-10-48	350	79	541	54	10	47	198	67	26	0.8	8.8	311	176	37
29bcc2	9-10-48	1386	90	342	8.5	2.6	64	104	35	19	2.0	2.7	194	26	82

Table 24.--Analyses of water from representative wells in Lower Santa Cruz area-continued.

Well no.	Date of collection	Depth of well (feet)	Temperature (°F.)	Specific conductance (micromhos at 25° C.)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Total hardness as $CaCO_3$	Per cent sodium
(D-9-8)															
20add	7-29-41	500	77	498	56	10	61	220	90	24	0.9	3.5	354	181	42
Do.	7-21-48	730	81	522	-	-	-	201	-	23	-	-	-	-	-
Do.	8-21-50	730	80	550	-	-	-	195	-	27	-	-	-	-	-
(D-10-9)															
8dd	7-3-41	404	78	446	46	8.3	57	208	63	22	0.3	5.0	304	149	45
(D-11-10)															
9ddd	9-1-48	600	78	539	43	6.6	62	198	76	19	0.2	2.0	337	134	50
(D-12-11)															
18ccc	3-27-40	218	-	430	30	10	53	167	31	22	-	-	247	116	50
(D-14-10)															
24cdd	4-16-40	382	90	1080	118	8.3	113	139	317	90	0.9	-	715	329	43
(D-15-10)															
33dbb	3-4-40	186	-	330	26	5.7	36	124	16	19	0.2	-	177	88	47


MAP OF LOWER SANTA CRUZ AREA, ARIZONA
SHOWING GEOLOGY, LOCATIONS OF IRRIGATION WELLS AND IRRIGATED AREAS AND DEPTH TO WATER IN SPRING OF 1952
4 MILES
EXPLANATION
Basalt flows
Essentially non-water-bearing in area
Alluvial fill
Gravel, sand, silt, clay and caliche; includes Recent alluvial fill along Santa Cruz river, principal aquifer in area
Conglomerate and sandstone
Essentially non-water-bearing in area
Volcanic rocks
Principally extrusive, essentially non-water-bearing in area
Older sedimentary rocks
Essentially non-water-bearing in area
Crystalline and metamorphic rocks
Essentially non-water-bearing in area
Geology not mapped
Irrigated areas on older alluvial fill
Well
100
Depth to water, in feet
QUATERNARY
QUATERNARY and TERTIARY
CRETACEOUS(?) OR TERTIARY
CENOZOIC
MESOZOIC OR CENOZOIC
PALEOZOIC OR YOUNGER
PRE-CAMBRIAN OR YOUNGER
MARICOPA COUNTY
PINAL COUNTY
PIMA COUNTY
SIERRA ESTRELLA
PIMA BUTTE
GILA RIVER
SACATON MTS.
SACATON
COOLIDGE
SAN TAN MTS.
ASHURST - HAYDEN DAM
PROBABLE PEDIMENT
PALO VERDE MTS.
MARICOPA
MARICOPA INDIAN RESERVATION
STANFIELD
TABLE TOP MTN.
VAIVA HILLS
PAPAGO INDIAN RESERVATION
SILVER REEF MTS.
CHIU CHUF
SAWTOOTH MTS.
TAT MOMOLI MTS.
PICACHO MTS.
PICACHO PEAK
ELOY
RED ROCK
TORTOLITA MTS.
SILVER BELL MTS.
MARANA
RILLITO
WATERMAN MTS.
TUCSON MTS.
ROSKRUGE MTS.
SAN XAVIER INDIAN RESERVATION
GEOLOGY OF TUCSON MOUNTAINS AFTER DARTON, 1924



MAP OF LOWER SANTA CRUZ AREA, ARIZONA

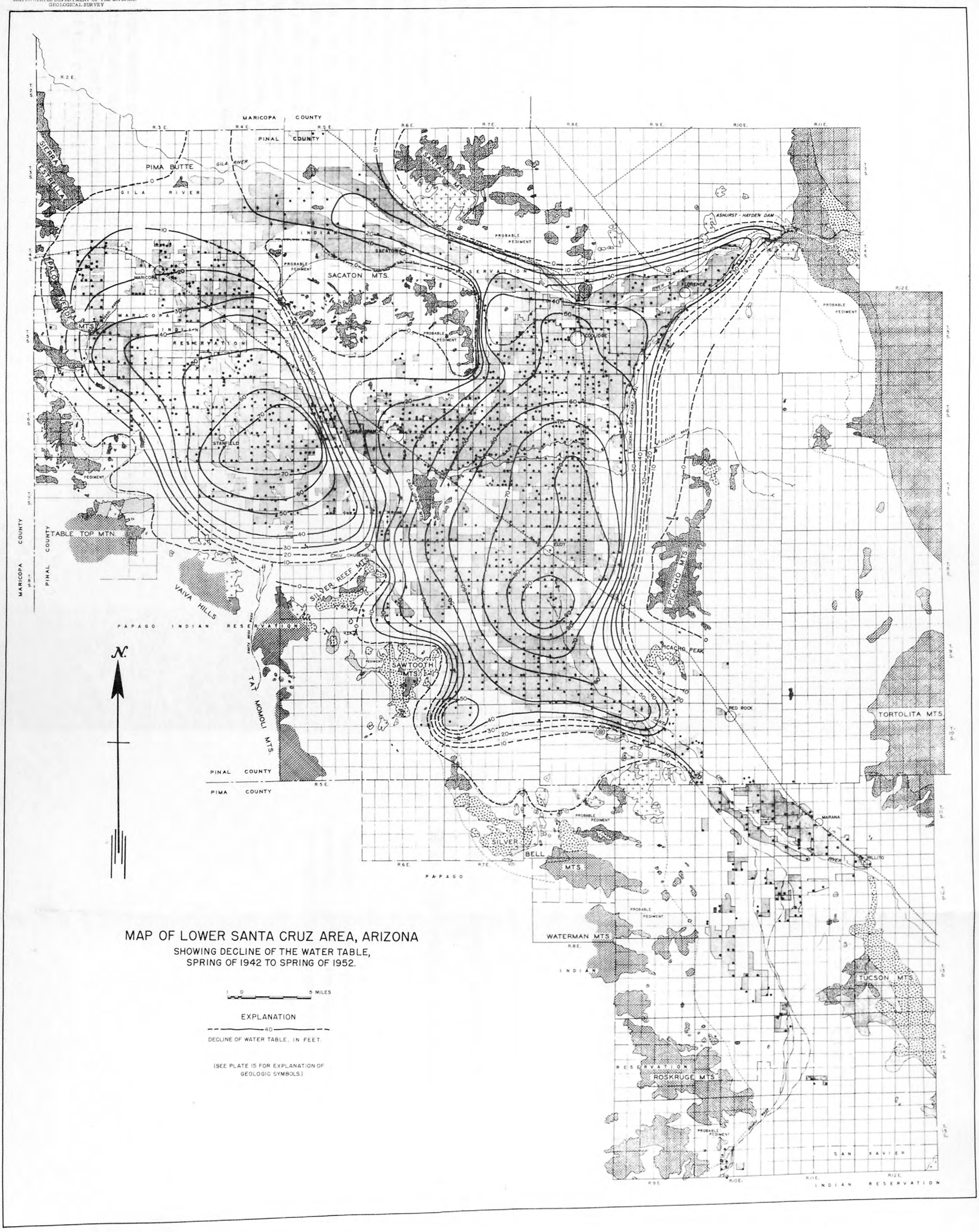
SHOWING CONTOURS OF THE WATER TABLE AS OF SPRING OF 1952

4 MILES

EXPLANATION

—1400— ELEVATION OF CONTOUR OF WATER TABLE

(SEE PLATE 15 FOR EXPLANATION OF GEOLOGIC SYMBOLS)



MAP OF LOWER SANTA CRUZ AREA, ARIZONA
SHOWING DECLINE OF THE WATER TABLE, SPRING OF 1942 TO SPRING OF 1952.

SALT RIVER VALLEY AREA, MARICOPA AND PINAL COUNTIES

By H. N. Wolcott

Introduction

A general geologic and hydrologic study of the Salt River Valley area was made in 1946 by the U. S. Geological Survey in cooperation with the Arizona State Land Department (McDonald, Wolcott, and Hem, 1947). Since 1946, other studies have been made and reports have been compiled on Paradise Valley (McDonald, Wolcott, and Bluhm, 1947) and Deer Valley (Bluhm and Wolcott, 1949), subdivisions of the Salt River Valley area. The present report is intended to bring up to date the information contained in the earlier report, and to include revisions and modifications that have been made possible by collection of additional data during the past 5 years.

Location and boundaries of area

The area included in this report is known as the Salt River Valley although some land is included that drains into the Gila River by way of other tributaries (pl. 18). The boundaries, though arbitrary, include all the area that is of substantial hydrologic significance to the main part of the area. In general, the boundaries include the bordering portions of the mountains that form the edges of the Salt River Valley. In one locality the limit of the area was arbitrarily established as along the course of the Gila River, and in other places the boundary has been selected arbitrarily along township and range lines.

The boundaries chosen conform with local usage that has considered the Salt River Valley as an entity distinct from other parts of Maricopa and Pinal Counties. In those localities where arbitrary boundaries were of necessity selected, the body of ground water is common to both sides of the boundaries. It is impossible, for example, to differentiate between ground water in the southeast part of the Queen Creek area and ground water across the Gila River in the vicinity of Florence. Likewise, no distinction can be made between ground water north of the Gila River and south of the river southwest of Chandler. Ground water underlying the valley of the Hassayampa River, downstream from Morristown to the Gila River, cannot be separated from ground water in the main Salt River Valley on the basis of present evidence.

Geology

The ground-water reservoir that lies beneath the Salt River Valley area occupies structural troughs of the Basin and Range type described in Part I of this report. Deep holes drilled at various places in the area have encountered the rock floors of the troughs at depths ranging from 3,000 to almost 5,000 feet below the surface of the alluvial plains. The probable character of the valley-fill deposits and the configuration of the bedrock floors of the structural troughs are shown in a hypothetical section (fig. 17).

Clay layers

A massive and relatively extensive deposit of clay has been penetrated by numerous wells between Phoenix and Litchfield Park. Within recent years several wells in this part of the valley have been drilled sufficiently deep to pass through the clay into underlying sand and gravel. Other wells have been drilled into the clay, but have been stopped short of complete penetration. The continuity of the body of clay over the distance of almost 20 miles between Phoenix and Litchfield Park has not yet been definitely established. The proved thickness of the deposit - more than 700 feet - suggests a relatively large areal extent.

A few conclusions can be drawn from the logs of wells in the area, most of which are of shallow to medium depth. The top of the clay deposit lies at depths between 300 and 700 feet below the valley surface. Irregularities in the upper surface of the clay suggest that it was eroded prior to the deposition of the overlying alluvium. Meager data from the deeper wells suggest similar irregularities on the lower surface of the deposit, and it is probable that the clay accumulated upon an eroded surface of older alluvium or possibly, in some places, upon bedrock. Apparently the clay layer interfingers with more permeable materials northward and westward from Litchfield Park. Wells in those vicinities have encountered clay layers of considerable thickness at various depths, although there is no direct evidence that these layers are extensions of the large deposit. From data thus far available, it is believed that the thick clay was deposited in a lake impounded when the valley drainage was blocked by lava flows. Remnants of these flows are visible in many places between Buckeye and Gillespie Dam.

Deep aquifers

It is possible to advance certain tentative conclusions regarding the water-bearing character of the deeper sediments in the Salt River Valley. In general, the aquifers below depths of 700 to 1,000 feet are less permeable and, therefore, less productive than those at shallower levels. Drill cuttings from some of the deeper holes include well-rounded cobbles, gravel, and coarse sand particles with little or no evidence of cementation. Materials of this character penetrated at shallower depths generally are highly permeable. In most of the deep wells drilled thus far the permeability of the coarse materials is impaired to such an extent by cement, clay, and compaction that they do not yield water to wells at the rate that might be anticipated. It is not intended to imply that deep drilling in the Salt River Valley area will not result in wells with satisfactory yields. Although the deep aquifers are proportionately less productive than those at shallower depths, deep wells provide a means of withdrawing additional

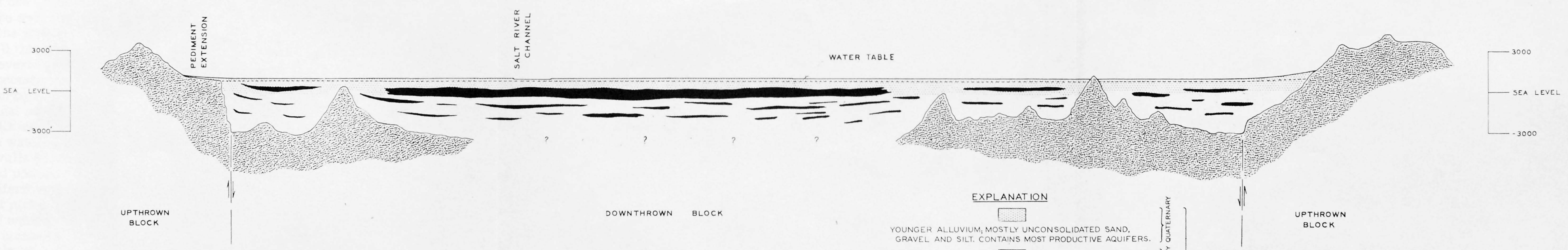


FIG.17: HYPOTHETICAL SECTION ACROSS SALT RIVER VALLEY SHOWING PROBABLE CHARACTERISTICS OF ALLUVIAL DEPOSITION AND UNDERLYING HARD—ROCK FLOOR

1 0 1 MILE

EXPLANATION

YOUNGER ALLUVIUM, MOSTLY UNCONSOLIDATED SAND, GRAVEL AND SILT. CONTAINS MOST PRODUCTIVE AQUIFERS. — QUATERNARY

CLAY, RELATIVELY IMPERMEABLE. LOCALLY INCLUDES THIN LAYERS OF SAND OR GRAVEL. YIELDS LITTLE WATER TO WELLS.

OLDER ALLUVIUM. USUALLY FIRMLY CONSOLIDATED AND PARTIALLY CEMENTED. YIELDS FAIR QUANTITY OF WATER TO WELLS. CONTAINS LOCAL AREAS OF HIGHLY SALINE WATER. — TERTIARY & QUATERNARY

CENEZOIC

BASEMENT ROCK OF STRUCTURAL TROUGH. MOSTLY CRYSTALLINE AND METAMORPHIC ROCK. ESSENTIALLY NON-WATER-BEARING IN AREA. — PRE-CAMBRIAN water from a common storage reservoir. In areas where the shallower, more permeable aquifers have been partially unwatered, deep wells may constitute the most feasible method of temporarily increasing withdrawals of ground water. Production from deep wells eventually will decrease by a proportionate amount the yields from the shallower aquifers because all the aquifers, deep and shallow, are interconnected. Deep wells in which the shallow aquifers are completely cased off show a static water level that corresponds to the general water-table level in the immediately surrounding area. In some wells water in the deep aquifers has been under an initial artesian head that temporarily forced the water considerably higher than the prevailing water level in the vicinity. This condition, however, generally has been of short duration and the water levels in the deep wells have declined to conform to the general water-table elevation.

The log of one of three deep wells in sec. 9, T. 1 N., R. 2 E., is shown in table 27 . The well was drilled to obtain water of better quality than was available in the shallower aquifers in the locality. The shallow aquifers were cased off. All three wells went through the massive clay deposit and penetrated several hundred feet of coarser alluvium. It was reported that, when first encountered, the water from the deep aquifers rose to within 3 feet of the land surface. Within a few days, however, the water subsided to a static level that corresponded to levels in shallow wells in the same area. The deep wells were drilled to obtain water for industrial use, therefore the quality of the water was of more vital importance than the yield. In that respect the wells were successful. It is apparent, therefore, that for industrial purposes, and possibly for municipal use if future development should demand, the deep aquifers hold considerable promise. It should be emphasized, however, that mere depth does not necessarily assure desirable quality. Highly saline aquifers have been encountered in places at depths below 1,000 feet and this condition constitutes one of the inescapable hazards of deep-well drilling in the area.

With measured discharges of 1,500 gallons per minute, the drawdowns in the three deep wells ranged from 273 feet to 350 feet, a specific capacity of from 4.3 to 5.5 gallons per minute per foot of drawdown. Logs of the wells indicate that cementation is probably largely responsible for the relatively low yields of the deeper aquifers in this locality. Present production (1952) from each of the three wells ranges from 1,460 to 1,740 gallons per minute. Although these wells do not yield as much water as most irrigation wells in the Salt River Valley, their yield and the quality of the water produced indicates that these deep aquifers are not locally connected with shallower aquifers. Eventually, the effects of deep withdrawals will be reflected in depletion of the shallower aquifers, as all ground water in the valley, with the exception of local zones of perched water, belongs to a common reservoir.

Relatively small quantities of warm water are obtained from wells in several localities in the Salt River Valley area. The temperature of the waters is considerably higher than average for the region, indicating a local source, possibly along a deep fault zone.

Subsurface constrictions of the valley

There is no geologic or hydrologic evidence to suggest that the ground-water reservoir in the Salt River Valley area is completely divided by subsurface barriers. There are places in the valley, notably in the vicinity of Tempe and near Buckeye, where the bedrock of the valley trough forms constricted passages that impede the movement of ground water sufficiently to force it to the land surface. There are no data available from which to determine the actual width or depth of these bedrock channels. It is certain, however, that in neither locality does the constriction constitute a complete barrier to the movement of ground water.

Pediments

It has been stated that there are certain localities along the borders of the Salt River Valley where bedrock is present at comparatively shallow depths beneath the alluvial surface. These pediment areas or areas of probable pediments (pl. 18) occur almost invariably at the base of hills or mountains of granite or granitic-type rocks. All the mountains in the area have been subjected to identical conditions of climate, weathering and erosion, and therefore, it seems logical to attribute the pediment-forming tendency to petrological and mineralogical characteristics of the granitic rocks.

The relation of pediment areas to the occurrence of ground water has been discussed in Part I of this report.

Ground-water hydrology

Since the publication of the 1947 report on the Salt River Valley there has been a substantial expansion of cultivated lands, most of which has been irrigated with water pumped from wells. This has entailed the drilling of hundreds of new wells and has correspondingly increased the withdrawal of ground water from storage. Ground-water levels in most parts of the valley have declined, extensively affecting the rate and direction of ground-water movement. These changes are shown in various illustrations that accompany this report (pls. 18, 19, 20, and 21). This section of the report describes the conditions now affecting the ground-water resources in the area.

Occurrence and movement

Ground water moves down the slope of the water table—in other words, at right angles to the contour lines (see pl. 19). The natural direction of ground-water movement conforms in general to the slope of the land surface, but the pattern has been disrupted in several areas by heavy pumping. In extreme cases the natural direction of movement has been reversed and ground water is now moving toward cones of depression that have resulted from heavy withdrawal. This condition is shown on plate 19, being particularly noticeable in the Deer Valley area and the Queen Creek area.

Recharge

Recharge to the ground-water reservoir in the Salt River Valley area is derived from the following four sources, listed in the order of their importance: (1) Seepage from canals and from irrigated lands; (2) surface flow in streams and washes; (3) underflow along major streams in the area; and (4) rainfall.

Irrigation and canal seepage.--The Geological Survey has made no experiments in the area to determine the amount of recharge that is derived from seepage from canals and irrigated fields. An estimate for recharge in the Deer Valley subarea was made by Bluhm and Wolcott (1949, p. 7) on the basis of experimental work done in the Safford Valley (Turner and others, 1941, p. 30). With allowance for differences in soil character and in climatological enviroment, it was estimated that 15 to 20 percent of the water applied to land for irrigation in Deer Valley is returned to the ground-water reservoir. This estimate was based only upon analogy with factual data obtained in a distant area, and the figures given cannot be substantiated without actual experimental work in the Salt River Valley. If the factors of 15 and 20 percent are applied to the area as a whole, the estimated amount of recharge from water applied to land for irrigation in the Salt River Valley area during 1951 would range from 360,000 acre-feet to 480,000 acre-feet. The amount thus estimated includes recharge from canal seepage. These figures are based upon 1951 pumpage of 1,910,000 acre-feet plus surface-water diversions of 510,000 acre-feet during the same period.

Stream flow.--Recharge from stream flow, once an important source in the area, is now of minor consequence except during brief periods of heavy rainfall. Because of the large storage capacity of dams on the Salt, Verde, and Agua Fria Rivers, surface flow in the channels downstream from these dams is a rarity, and occurs only during or following heavy local rainfall. Stream flow is slightly more frequent in Centennial Wash, Hassayampa River, New River, Skunk Creek, Cave Creek, and Queen Creek, but even in these streams the flows are generally of short duration, and the aggregate recharge is not large. The same is true of other minor tributaries that enter the valley. Even during the wet winter of 1940-41, Queen Creek contributed only about 32,000 acre-feet of recharge (Babcock and Cushing, 1942, pp. 49-56), an amount probably much higher than average. Without many more data, no reliable estimate can be made of the average annual recharge from stream flow in the Salt River Valley area.

Underflow.--Recharge derived from underflow of streams entering the valley is impossible to evaluate because of lack of data. There has been no opportunity since the preparation of the 1947 report to do any experimental work that would supply the necessary data. No conditions have arisen that seem to require revision of the statement: "The underflow of other washes that enter the area is not known, but it is probable that the total underflow from all sources into the Salt River Valley is little more than 5,000 acre-feet per year'' (McDonald, Wolcott, and Hem, 1947, p. 18).

Rainfall.--Precipitation, occurring as rainfall upon either the cultivated lands or upon desert areas within the valley, contributes little recharge to ground-water storage (Turner and others, 1943, pp. 53-61). The rise in water levels in wells sometimes observed following heavy local rainfall does not represent a regional increase in the amount of ground water in storage. The rise results from temporary cessation of pumping for irrigation, which allows partial filling of the cones of depression caused by previous pumping.

Discharge

Ground water is discharged from the Salt River Valley area both by pumping and by natural means. Natural discharge indludes surface flow and underflow leaving the valley, as well as water lost by evaporation and by transpiration from plants.

Pumping.--Mention has already been made of the substantial increase since 1946 of cultivated acreage in the valley and the attendant necessity for drilling new wells to supply the required water for irrigation. In the latter part of 1946, about 850 irrigation wells were in use in the area; by the fall of 1951 there were approximately 1,500. Records of typical wells in the area are shown in table 26. During the same period, the total area of irrigated land increased from 436,000 acres to approximately 590,000 acres. From the foregoing it is apparent that the ratio of increase in number of wells, 76 percent, is much greater than that of cultivated acreage, 35 percent. This disparity is explained by the diminishing yield of many of the older wells in the valley as the water table declined and the shallow, more productive aquifers were unwatered. As well yields diminished, it became necessary either to deepen existing wells or to drill new ones where deepening failed to attain the desired yield. Thus, many new wells were needed to maintain a water supply for land already in cultivation. Additonal acreage brought into cultivation each year since 1946 also has required the drilling of many new wells.

The increased withdrawal of ground water from storage (table 25) as a result of irrigation of new lands has been aggravated by a dangerously low supply of stored surface water in the Salt and Verde River reservoirs, caused by successive years of subnormal precipitation. The measure of the increase in the use of ground water is shown by a comparison of pumpage figures for the Salt River Valley area for 1946 and for 1951. Total pumpage for 1946 amounted to 1,360,000 acre-feet; for 1951, 1,910,000 acre-feet, an increase of 40 percent. Annual pumpage for each year from 1933 through 1951 is shown graphically in figure 18.

Natural discharge.--Natural discharge from the Salt River Valley area occurs by: (1) Evaporation from the land surface and transpiration by plants; (2) surface flow in the Gila River; and (3) underflow.

Of the three means of natural discharge, evapotranspiration is by far the largest. Detailed work was done by the Geological Survey in 1950 in

Table 25.--Quantity of surface water diverted and quantity of water pumped from wells, 1946-51, Salt River Valley area, Maricopa and Pinal Counties, Ariz.
(Acre-feet)

Year	Diverted at Granite Reef Dam	Diverted by Buckeye Irr. Canal	Diverted at Carl Pleasant Dam	Total surface water diverted	Total water pumped from wells	Percentage ratio, water pumped to total surface water diverted
1946	875,500	65,473	10,388	951,361	1,360,000	142.9
1947	663,600	51,558	5,580	720,738	1,406,000	195.1
1948	682,500	40,922	4,122	727,544	1,670,000	229.5
1949	732,200	38,676	29,425	800,301	1,644,000	205.4
1950	659,900	30,787	6,049	696,736	1,852,000	265.8
1951	476,000	35,058	453	511,511	1,910,000	373.4

cooperation with the Corps of Engineers (Turner and Skibitzke, 1952, pp. 66-72) in determining the use of water by phreatophytes along a 2,000-foot-wide channel on the Gila and Salt Rivers between Gillespie Dam and Granite Reef Dam. Observations made on the ground and from an airplane at low altitude were combined with data from large-scale aerial photo-mosaics to determine growth, frondage, and areal densities. It was found that under conditions at the time of the survey, the annual use of water by phreatophytes within the limits of the channel amounted to about 29,000 acre-feet. For the present report the data were extrapolated to include the entire flood plain between the two dams, and it is estimated that the total water use within that reach in 1950 was approximately 70,000 acre-feet. The largest discharge of water from the Salt River Valley area is by transpiration by cultivated crops and evaporation from the surface of irrigated lands. It is impossible to place a quantitative value upon such use with data now available.

Effluent seepage from the ground-water reservoir enters the Gila River channel at numerous places between its junction with the Salt River and Gillespie Dam. This water, combined with normal surface flow in the Gila River upstream from the junction leaves the Salt River Valley area at Gillespie Dam. Average annual surface flow at the dam for the period 1946-1949 inclusive was about 77,000 acre-feet. Effluent seepage from the ground-water reservoir probably furnished the greater part of this flow; the remainder was derived from floods.

It has been established by Jakosky (1940, pp. 373-374) that ground water is discharged from the Salt River Valley area as underflow beneath Gillespie Dam. He determined the existence of aquifers under the lavas upon which the foundations of the dam rest, but the amount of underflow transmitted through the aquifers has never been determined and cannot be estimated from data presently available, however, it is much less than that discharged by evapotranspiration. There is also a possibility that a small amount of ground water is discharged as underflow either through or beneath the lavas at the north end of the Gila Bend Mountains along old channels of the Gila River (McDonald, Wolcott, and Hem, 1947, p. 20).

Storage

The determination of the amount of ground water in storage in the alluvial materials in the Salt River Valley area is a problem that cannot be solved accurately without more data than are at present available. For an area as large and as variable in the characteristics of the materials by which it is underlain as is the Salt River Valley, any figure for the coefficient of drainage must be recognized as an estimate only and computations that involve such a figure should be interpreted with due allowance for a considerable margin of error.

Upon this premise, the Geological Survey (1951, pp. 13-14) made an estimate of the volume of water in storage in 1950 in a thickness of 100 feet of allumium in the Salt River Valley based upon an area of 1,600,000 acres. It was roughly estimated that the volume of water in storage was 19,200,000 acre-feet. The upper limit of the aquifer was defined as the water table in 1950.

For the present report the area of the valley has been measured as 1,370,000 acres, excluding the Verde River Valley, which is set apart by Granite Reef Dam, and excluding areas in the main valley where the depth to the water table is known to be in excess of 300 feet. Using the area of 1,370,000 acres and assuming a coefficient of drainage of 12 percent for the materials in the upper part of the valley fill, the latent storage of ground water in the uppermost increment of 50 feet between the water table and a depth of 300 feet is 8,200,000 acre-feet. The coefficient of drainage decreases with depth and therefore figures for the succeeding 50-foot increments are not given.

In estimating underlying storage beneath the irrigated area of the valley a coefficient of drainage of 12 percent was used, and the quantity of water stored in a 50-foot layer underlying 590,000 acres was computed to be 3,500,000 acre-feet. It is not considered advisable to apply the coefficient of 12 percent for successive 50-foot increments to a depth of 300 feet below the water table because the coefficient of drainage is known to decrease with depth. The amount of decrease is not known. It should be noted that if all water pumped in the valley were withdrawn from storage in aquifers underlying the irrigated area of 590,000 acres, the 50-foot layer would be unwatered in 2 years at the 1951 rate of withdrawal.

It is emphasized that the above figures are estimates and that the results are based upon two factors, one of which is unknown. Future work may show that the value of 12 percent for coefficient of drainage is too low or too high, requiring upward or downward revision of the figures for storage. Also, it would be impossible to unwater a thickness of 50 feet of aquifer over the entire Salt River Valley area without a well system so closely spaced that it would be utterly impracticable and uneconomical. Currently there are numerous localities in the valley where well interference is resulting from overlapping cones of depression, and the irregularities in the process of unwatering are shown by the water table contours (pl. 19).

Fluctuations of ground-water levels

The average level of the water table in the Salt River Valley area for each year from 1930 through 1951 is shown graphically in figure 18. Graphs of water levels in individual wells throughout the area are shown in figures 19 to 21. Although there are numerous fluctuations of the water levels in individual wells the long-term downward trend of water levels is obvious for the area as a whole. The declines range from a few feet to more than 100 feet. As shown by figure 18, the decline has persistently increased owing to the increased withdrawal of ground water from storage. In the vicinity of Buckeye, where the effects of recharge from surface-water irrigation are reflected and where the ground-water reservoir is constricted into a relatively narrow rock channel, the decline of the water table has been least.

Quality of water

During the investigation that preceded the 1947 report, more than 150 water samples were taken from wells in various locations throughout the area, and some 500 analyses, some from other agencies, were used in pre-

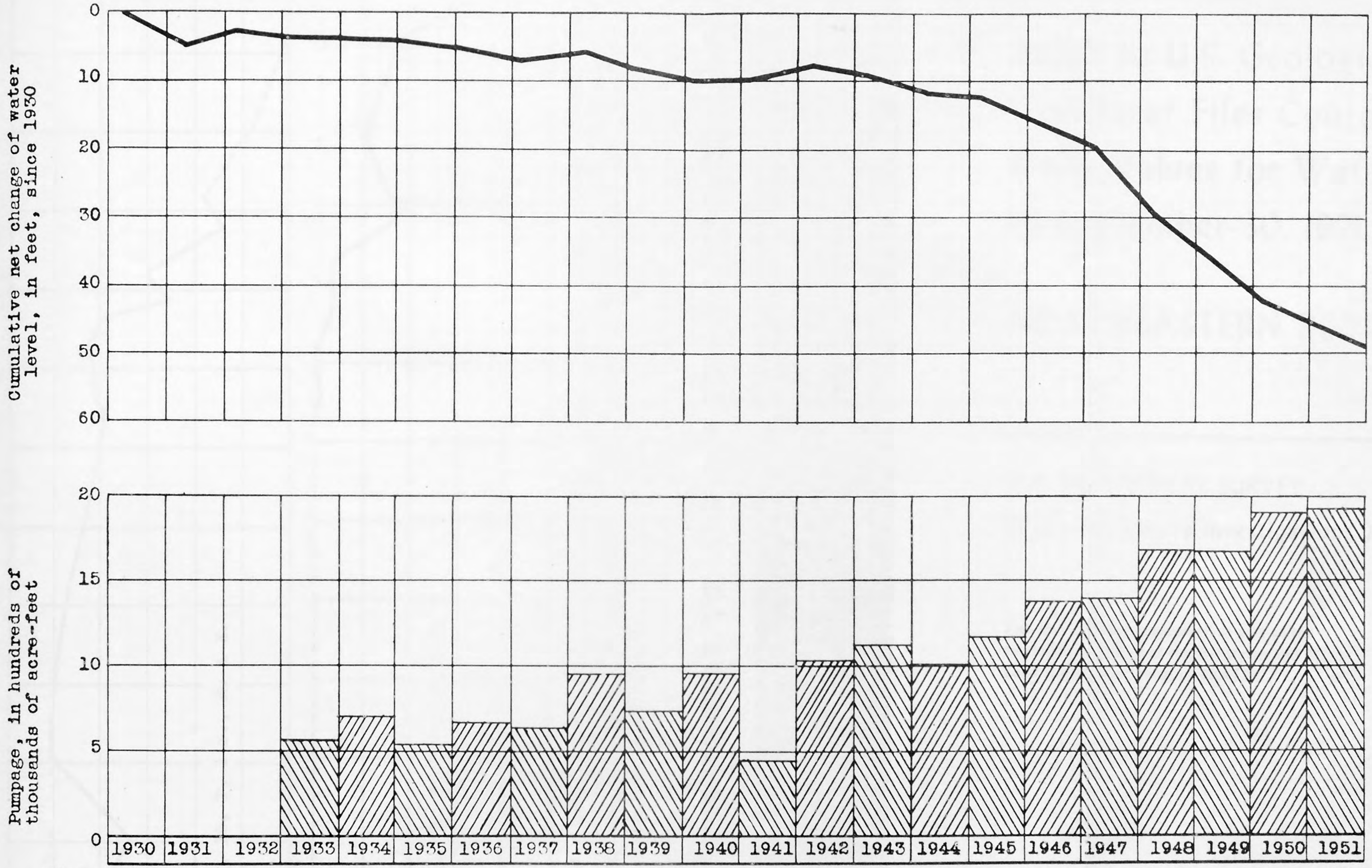


Figure 18.--Graph showing cumulative net change in water levels and water pumped for irrigation in the Salt River Valley area, Maricopa County.

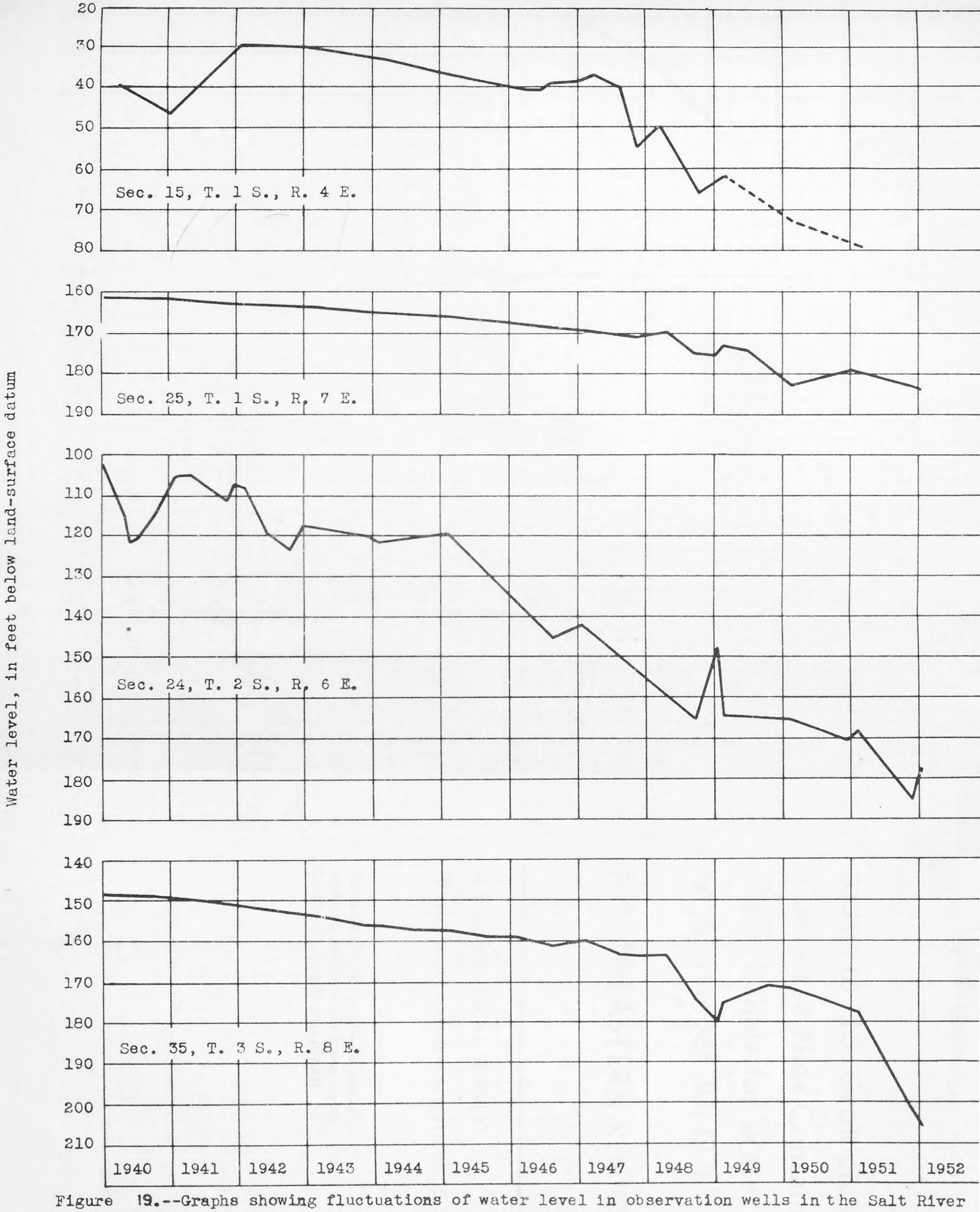


Figure 19.--Graphs showing fluctuations of water level in observation wells in the Salt River Valley area, Maricopa County.

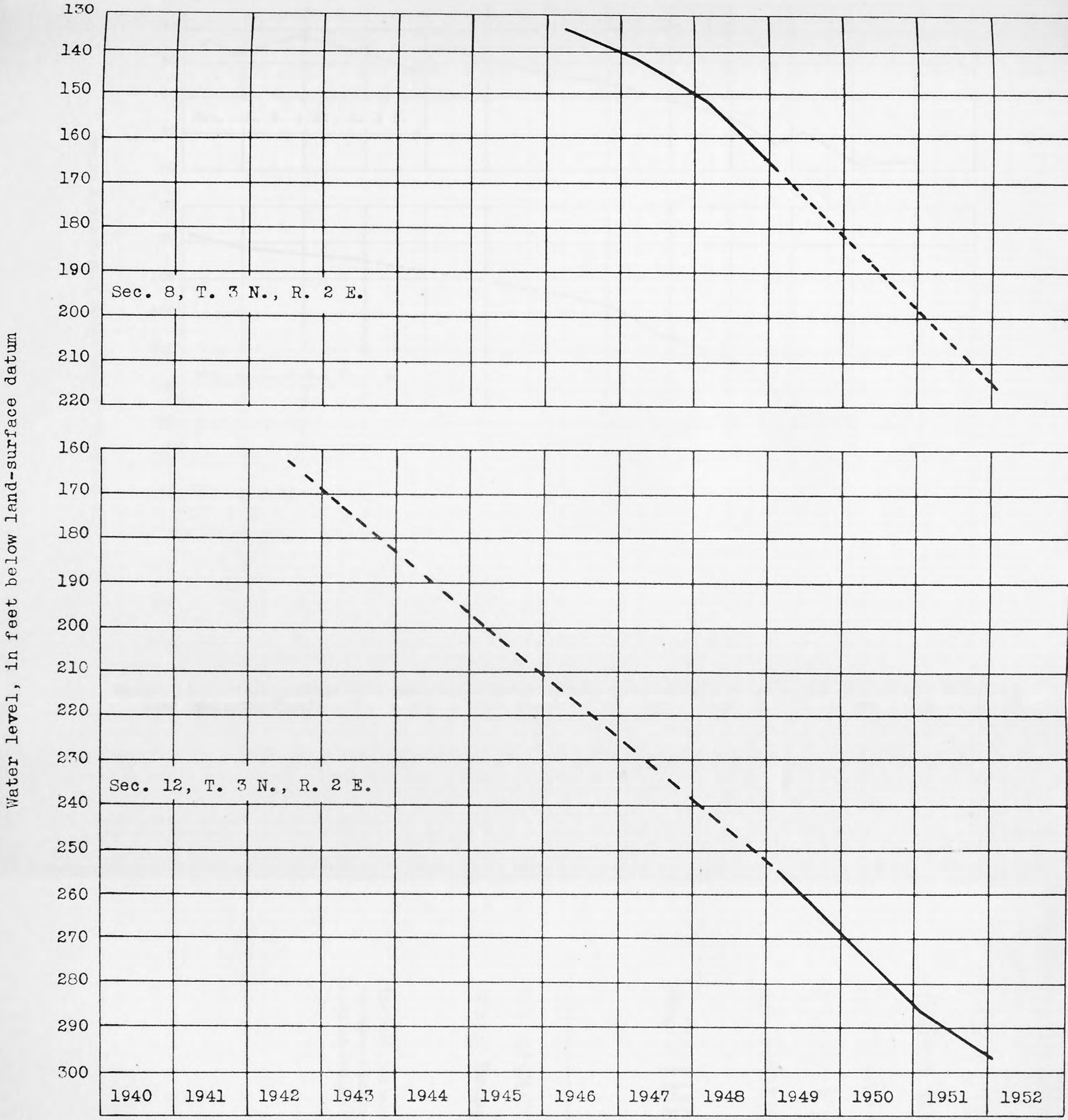


Figure 20.--Graphs showing fluctuations of water level in observation wells in the Salt River Vall area, Maricopa County.

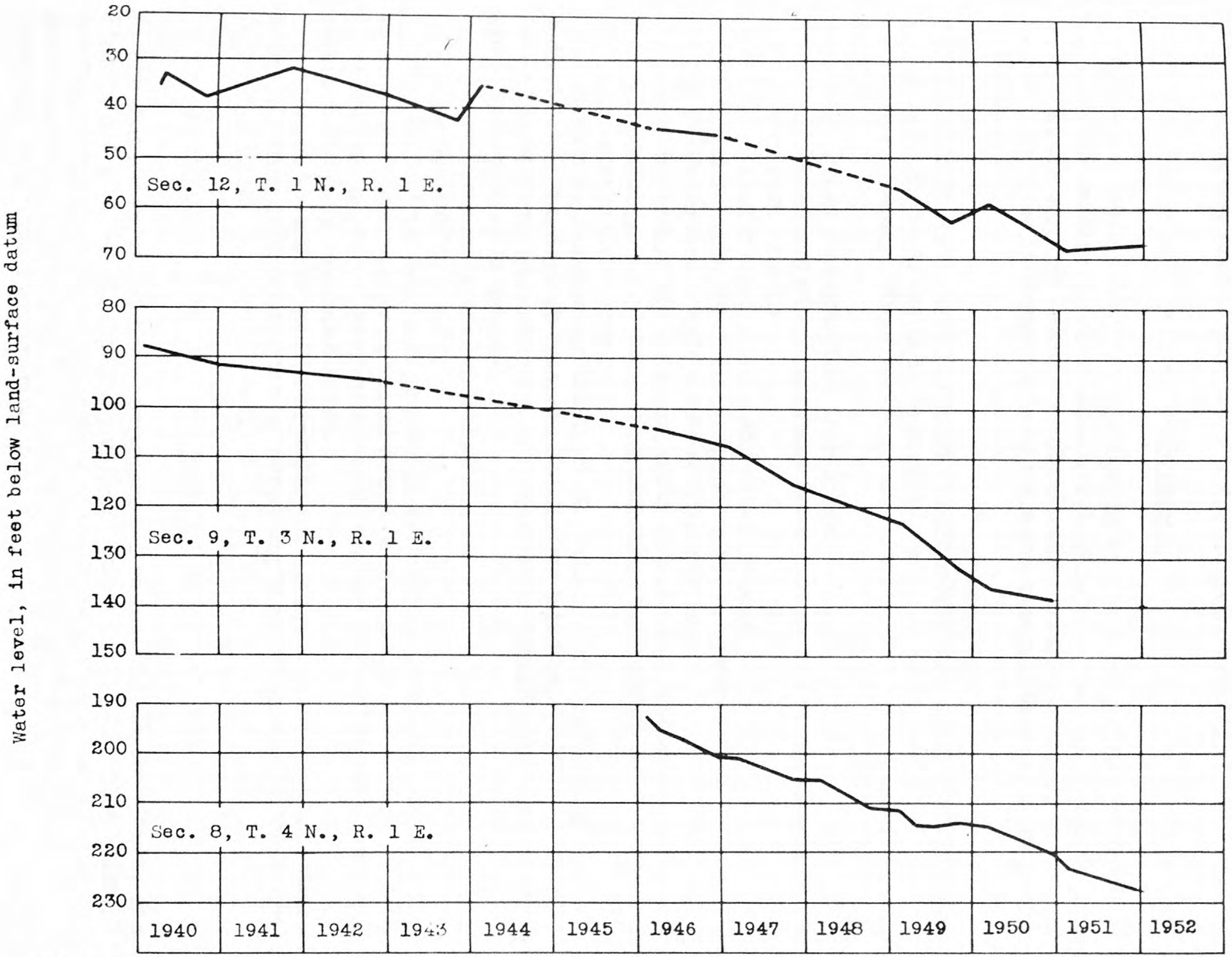


Figure 21.--Graphs showing fluctuations of water level in observation wells in the Salt River Valley area, Maricopa County.

preparing a section on quality of water. Since preparation of that report, few data on quality of the ground water have been collected and therefore no additional discussion is presented here. The subject of salt balance in the Salt River Valley area is discussed in the following chapter.

Problems

Various problems involved in obtaining adequate information about the ground-water resources of Arizona are discussed in Part III of this report. The problems outlined below are considered to apply specifically to the Salt River Valley area, although some of them are common to many other areas in the State.

1.--Determine location and attitude of subsurface structural boundaries of valley by geophysical methods—resistivity and magnetometer.

2.--Determine quantity of recharge entering the area from various sources such as:

(a).--From streams other than Queen Creek.

(b).--Movement of ground water from Florence area into Magma area.

(c).--From rainfall.

(d).--From irrigated lands and canal seepage.

3.--Determine quantity of discharge from the area by:

(a).--Underflow of Gila River at Gillespie Dam.

(b).--Underflow of Gila River north of Gila Bend Mountains.

4.--Determine yields to wells from individual aquifers by means of current-meter and conductivity logging.

5.--Determine reasons for lower yields, both specific yield and yield to wells, of deep aquifers as compared to shallow aquifers.

6.--Collect more adequate data on transmissibility and coefficient of drainage of the aquifers in the area by:

(a).--Pumping tests.

(b).--Laboratory tests.

7.--Increase frequency and number of well-discharge measurements to provide greater accuracy in annual pumpage inventory.

8.--Broaden scope of observation-well program to provide more complete coverage of newly developed areas.

9.--Collect additional quality-of-water data in areas where concentration of mineral matter in ground water is increasing to assist in solving the salt-balance problem.

Summary

The Salt River Valley area comprises the valley lands in the vicinity of Phoenix and includes the tributary valleys, Queen Creek, Paradise Valley, and Deer Valley, as well as lands west of the Hassayampa River and the lower reaches of Centennial Wash. The boundaries of the area are, of necessity, established arbitrarily.

The present report is intended to supplement an earlier report describing the ground-water situation through 1946, and therefore the present report describes only conditions as they may have changed between 1946 and 1952.

The presence of an extensive clay deposit between Phoenix and Litchfield Park, the top of which lies at a depth of 300 to 700 feet below the land surface, has been determined on the basis of logs of deep wells. The clay, in some places, is at least 700 feet thick.

Since 1946, and particularly in 1950 and 1951, many deep wells have been drilled and many shallow wells have been deepened. The deep aquifers apparently have a lower coefficient of drainage than the shallower aquifers, and yields from deep wells are generally less than those from the shallower aquifers.

The principal source of recharge to the ground-water reservoir of the area is considered to be from infiltration of water from irrigated fields and canals. Other sources of recharge are stream flow, underflow into the area, and precipitation.

The principal method by which ground water is discharged is by pumping for irrigation. In 1951, 1,910,000 acre-feet was withdrawn by pumping, an increase of 40 percent since 1946. Natural discharge occurs by evapotranspiration, surface flow of the Gila River at Gillespie Dam, and underflow. Discharge by phreatophytes is roughly comparable to average annual surface flow.

The amount of ground water stored in a 50-foot layer below the water table, underlying the irrigated lands in the area was estimated to be 3,500,000 acre-feet. It has been obvious for several years, as shown by the continuous decline of the water table, that a large part of the water pumped for irrigation has been withdrawn from storage. Each annual increase in pumpage has been reflected in an increased decline of the water table.

Table 26.--Records of representative wells in Salt River Valley area, Pinal and Maricopa Counties, Ariz.

Well location	Depth of well (feet)	Water level: Depth below measuring point(feet)a/	Water level: Date of measurement	Water level: Depth below measuring point(feet)a/	Water level: Date of measurement	Pump and power b/	Use of water c/	Discharge (gallons per minute)
Sec. 10, T. 1 N., R. 1 E.	650	d/ 48.	8-7-40	d/ 98	2-20-51	T,E	I	2,200
Sec. 36, T. 1 N., R. 3 E.	-	32.9	10-31-46	53.4	1-24-52	C,E	D	-
Sec. 24, T. 1 N., R. 4 E.	-	d/ 25.6	8-24-42	82.2	1-21-52	C,E	D	-
Sec. 3, T. 1 N., R. 5 E.	500	d/110	8-4-50	120.3	11-13-50	T,E	I	4,000
Sec. 8, T. 1 N., R. 6 E.	705	-	-	-	-	T,E	I	1,100
Sec. 23, T. 1 N., R. 7 E.	-	301.8	11-4-39	317.2	1-15-52	C,E	D	-
Sec. 5, T. 2 N., R. 1 E.	354	-	-	-	-	-	-	1,800
Sec. 8, T. 2 N., R. 2 E.	-	62.5	2-12-43	117.7	1-23-52	None	N	-
Sec. 19, T. 2 N., R. 4 E.	-	12.4	12-18-46	16.9	1-23-52	None	N	-
Sec. 31, T. 2 N., R 6 E.	135	90.5	10-4-46	104.3	2-14-49	C,E	D	-
Sec. 7, T. 3 N., R. 1 E.	285	115.0	3-10-42	150.4	1-28-52	T,E	I	-
Sec. 17, T. 3 N., R. 2 E.	622	d/138	1-22-46	218.0	3-52	T,E	I	-
Sec. 14, T. 4 N., R. 1 E.	440	d/250	10-25-51	257.2	3-52	-	I	-
Sec. 27, T. 4 N., R. 2 E.	620	-	-	d/292	10-14-50	T,E	I	3,000
Sec. 10, T. 1 N., R. 1 W.	210	d/ 40	1-14-45	62.4	1-30-52	T,E	I	1,900
Sec. 16, T. 1 N., R. 2 W.	200	73.2	3-5-46	89.2	1-30-52	T,E	I	-
Sec. 34, T. 1 N., R. 3 W.	200	56.7	10-25-46	63.1	1-30-52	T,E	I	-
Sec. 31, T. 1 N., R. 4 W.	250	-	-	70.2	1-30-52	T,E	I	-
Sec. 2, T. 2 N., R. 1 W.	181	87.8	1-17-46	136.0	1-29-52	None	N	-
Sec. 20, T. 3 N., R. 1 W.	-	-	-	294.3	1-29-52	T,E	I	2,100
Sec. 8, T. 4 N., R. 1 W.	500	196.0	2-6-46	232.0	1-28-52	None	N	-
Sec. 18, T. 1 S., R. 4 W.	-	-	-	d/ 25	9-26-51	T,E	I	3,200

a/ Measuring point was usually top of casing, top of pump base, or top of well curb.
b/ T, turbine; C, cylinder; E, electric motor; G, gasoline or natural gas; W, wind; H, hand; D, diesel.
c/ I, irrigation; S, stock; D, domestic; P, public supply; N, none.
d/ Water level reported.

Table 26.--Records of representative wells in Salt River Valley area.--continued.

Well location	Depth of well (feet)	Water level		Water level		Pump and power b/	Use of water c/	Discharge (gallons per minute)
		Depth below measuring point(feet)a/	Date of measurement	Depth below measuring point(feet)a/	Date of measurement			
Sec. 8, T. 1 S., R. 2 E.	-	10.9	10-30-46	18.9	1-24-52	T,E	D	-
Sec. 36, T. 1 S., R. 3 E.	-	98.6	10-8-48	110.9	1-21-52	None	N	-
Sec. 22, T. 1 S., R. 6 E.	762	d/108.0	1-23-47	-	-	T,E	I	1,800
Sec. 25, T. 1 S., R. 7 E.	-	169.2	1-31-47	182.9	1-17-52	C,E	S	-
Sec. 24, T. 2 S., R. 6 E.	900	164.2	2-15-49	169.5	1-17-52	T,E	I	1,500
Sec. 3, T. 2 S., R. 7 E.	596	-	-	221.9	5-9-51	T,E	I	2,700
Sec. 32, T. 2 S., R. 8 E.	700	195	1-19-49	-	-	T,E	I	2,500
Sec. 22, T. 3 S., R. 8 E.	600	-	-	d/205	1-15-51	T,E	I	2,800

Table 27.--Logs of representative wells in Salt River Valley, Maricopa County, Ariz.

	Thickness (feet)	Depth (feet)
Sec. 10, T. 1 N., R. 1 E.		
Soil	3	3
Caliche	17	20
Sand	9	29
Coarse gravel, boulders and some sand	31	60
Packsand and small gravel	30	90
Hard packsand or sandstone	10	100
Cemented gravel	15	115
River silt	10	125
Soft sandstone	12	137
Cemented sandstone	4	141
Caliche and gravel	12	153
Hard sandstone	5	158
Sand and gravel	7	165
Sand rock	4	169
Good sand, gravel and boulders	26	195
Hard sandstone	15	210
TOTAL DEPTH		210
Sec. 9, T. 1 N., R. 2 E.		
Topsoil and clay	0	35
Sand, gravel and boulders	85	120
Tight sand, gravel and boulders, water-seepage	30	150
Gravelly clay, water-seepage	1	151
Loose sand, gravel, small river boulders	24	175
Clay, gravel, small boulders	10	185
Tough gravelly clay, light seepage nearly shut off	10	195
Gravel and small amount of clay, seepage	21	216
Sand, gravel, small boulders, some water	33	249
Fine sand, gravel and boulders, water-seepage	37	286
Sand, gravel and boulders, seepage	12	298
Hard conglomerate of gravel and sand cemented	4	302
Gravelly clay, water	8	310
Packed silt, water	3	313
Gravel, shells, small boulders, less water	27	340
Clay with some gravel and sand, very light seepage	10	350
Packed sand and gravel, light seepage	14	364
Caliche clay, near shut off	2	366
Packed sand and gravel, seepage increasing	2	368
Gravel, clay and small boulders, seepage	7	375
Coarse sand and gravel, strong seepage	8	383
Clay, makes some water	5	388
Soft packed sand, packed silt and sandy-lime rock	8	396
Sticky, tough clay, water shut off at 408'	12	408
Clay with some gravel and sand	7	415
Clay, light seepage	22	437
Blue clay with brown streaks and small gravel	5	442
Packed silt and gravel	3	445
Gravelly clay	5	450
Sandy clay	10	460
Sand and gravel, water increasing	1	461
Sandy clay and small gravel	11	472
Hard sand and small gravel	2	474
Silt and clay	4	478
Sand and gravel	2	480
Silt and clay, small rock	18	498
Sandy clay	2	500
Tight, fine sand	5	505
Kaolin	1	506
Packed sand, water decreasing	4	510

Table 27.--Logs of representative wells in Salt River Valley--continued.

	Thickness (feet)	Depth (feet)
Tough silty clay, some gravel, light seepage	40	550
Sticky clay, water near shut off - - - - - - - -	10	560
Sand, makes some water	3	563
Clay, all water shut off	609	1172
Mountain wash, first flow of water below clay bank - - - - - - -	9	1181
Sandy clay - - - - - - -	19	1200
Sticky clay - - - - - - -	7	1207
Mountain canyon conglomerate, increasing from fairly hard to tough -	96	1303
Very tough conglomerate	8	1311
Soft decomposed granite, coarse and fine sand harder conglomerate towards 1330, good flow of water - - - - - - - -	19	1330
Very hard conglomerate softening towards 1355	25	1355
Mountain wash, sand, then finer sand, water seepage - - - - - - - -	8	1363
Fine sand going into mountain wash; water seepage - - - - - - - -	11	1374
Soft conglomerate; seepage - - - - - - - -	14	1388
Conglomerate becoming harder, seepage - - -	8	1396
Conglomerate, mountain wash, grey and red stratified formation, seepage - - - - - - -	12	1408
Very red conglomerate, some water at 1408, very little at 1428 -	20	1428
Soft grey conglomerate some seepage - - - - -	4	1432
Stratified areas, hard mountain canyon conglomerate and mountain wash - - - - - - - - - -	18	1450
Mountain wash strata and hard conglomerate, seepage - - - - - - - -	12	1462
Hard conglomerate, seepage nearly shut off -	32	1494
Conglomerate breaks into sandy mountain wash, possible flow of water	7	1501
Waterbearing sand, mountain wash - - - -	6	1507
Mountain wash going into soft conglomerate, possible water flow -	26	1533
Soft mountain canyon conglomerate, strong seepage - - - - - - - -	7	1540
Clay - - - - - - - - - -	10	1550
Soft red clay and mountain wash going to tight sand and mountain wash - - - - - - -	15	1565
Tight sand and mountain, strong seepage -	10	1575
Red clay, fine sand, coarse and medium mountain wash gravel; light seepage - - - -	4	1579
Mountain wash with less clay, light seepage -	10	1589
Light clay, gravel, light flow of water -	6	1595
Conglomerate, light flow of water - - - -	25	1620
Fairly clean tight mountain wash, water seepage very light to 1630, none 1630 to 1641, fair 1641 to 1651, strong 1651 to 1673 - - - - - - - - - -	53	1673
Same formation, sticky in spots, strong seepage - - - - - - - -	17	1690
Very tight mountain wash, light flow - - -	9	1699
Same formation going into red decomposed granite, light flow -	9	1708
Red decomposed granite, light seepage - - - - -	10	1718
Red decomposed granite, going into coarse, tight sand, strong seepage - - - - - - - -	6	1724

Table 27.--Logs of representative wells in Salt River Valley--continued.

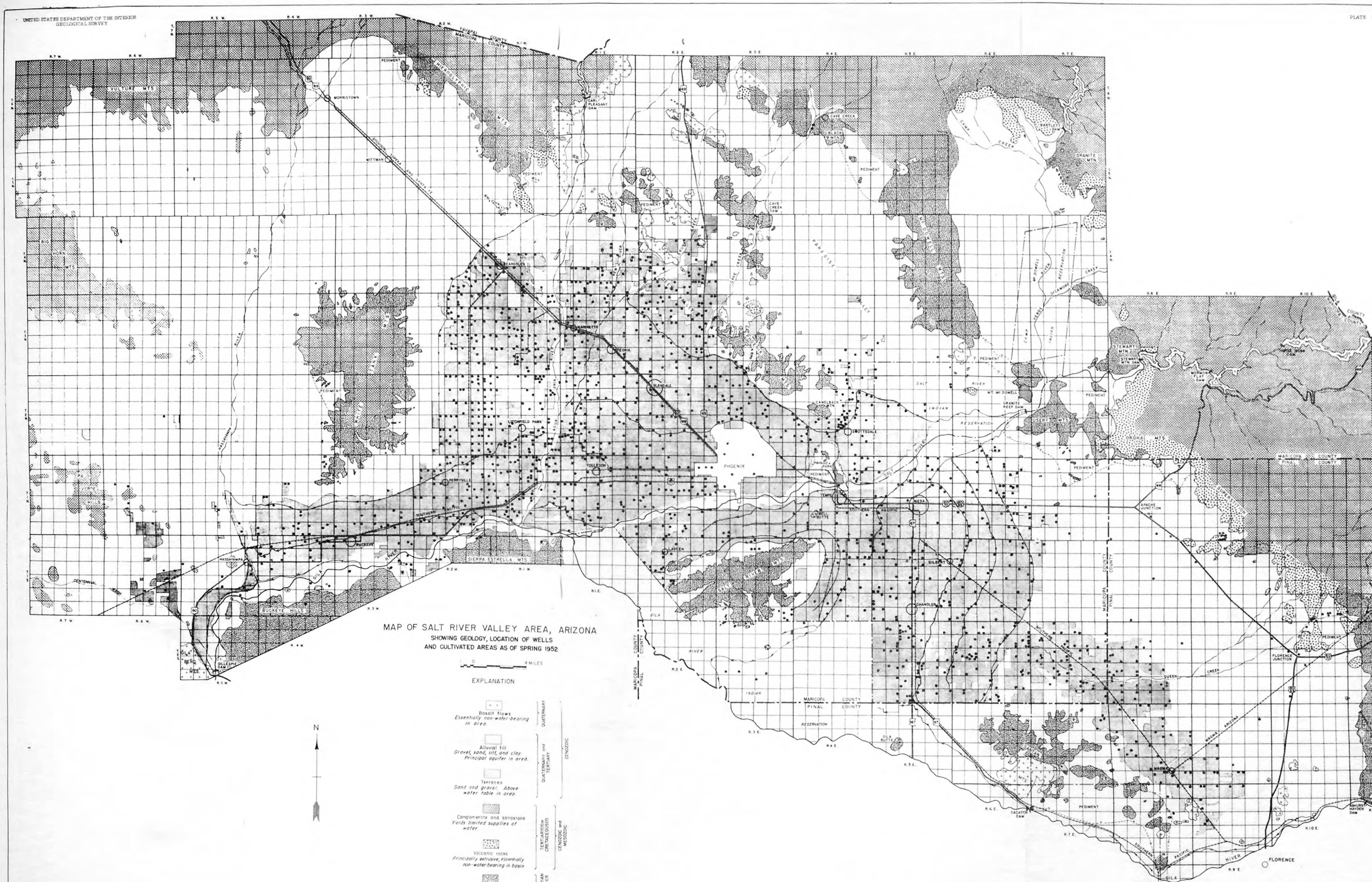
	Thickness (feet)	Depth (feet)
Coarse tight sand changing into muddy sand, strong seepage -	6	1730
Soft muddy mountain wash, gravel and sand, light flow - - - - - -	11	1741
Tight muddy mountain wash, gravel and sand; strong seepage - - - -	13	1754
Very tightly packed fine mountain wash, light flow - - - - - -	10	1764
Same formation or possibly mountain canyon conglomerate; light flow - - - - - - - - - - -	7	1771
Very tight mountain wash, light seepage -	9	1780
Hard packed mountain wash; light seepage -	9	1789
Hard packed mountain wash, light flow - - -	4	1793
TOTAL DEPTH		1793
Sec. 23, T. 1 N., R. 6 E.		
Topsoil - - - - - - - - -	8	8
Caliche clay - - - - -	64	72
Tight gravel and boulders - - - - - - - - -	84	156
Loose sand and gravel -	32	188
Caliche - - - - - - - - -	13	201
Loose sand and gravel -	18	219
Caliche - - - - - - - - -	5	224
Loose sand and gravel -	4	228
Cement - - - - - - - - -	4	232
Loose sand and gravel -	6	238
Alternate loose strata and cemented loose gravel - - - - - - - - -	18	256
Cement - - - - - - - - -	23	279
Very loose gravel - - -	73	352
Very hard cemented gravel - - - - - - - - -	12	364
Caliche - - - - - - - - -	131	495
Very hard cemented gravel - - - - - - - - -	11	506
Caliche - - - - - - - - -	6	512
Very coarse gravel mixed with hard streaks - -	183	695
Loose sand and gravel	9	704
Gravel and cemented streaks - - - - - - - -	10	714
Very hard cemented gravel - - - - - - -	12	726
Gravel and cemented streaks - - - - - - - -	35	761
Cemented sand and gravel - - - - - - - -	23	784
Gravel with clay streaks - - - - - - - -	6	790
Hard clay - - - - - - -	20	810
TOTAL DEPTH		810
Sec. 19, T. 2 N., R. 1 W.		
No log - - - - - - - - -	180	180
Sandstone - - - - - - -	33	213
Silt - - - - - - - - - - -	17	230
Sandstone and gravel -	18	248
Cemented gravel - - -	6	254
Tight gravel - - - - - -	4	258
Loose sand and gravel	4	262
Loose sand and gravel	6	268
Tight gravel - - - - - -	20	288
Tight gravel - - - - - -	7	295
Loose gravel - - - - - -	11	306
Tight gravel - - - - - -	2	308
Loose gravel - - - - - -	18	326
Loose silt, sand, gravel - - - - - - - - - -	14	340
Silt tight - - - - - - -	14	354
Loose gravel - - - - - -	8	362
Clay, gravel and sand	12	374
Tight gravel - - - - - -	20	394
Clay, some gravel - -	12	406
Loose sand - - - - - - -	8	414
Tight clay and gravel	26	440
Tight clay and gravel	50	490
Hard clay - - - - - - -	14	504
Sand and gravel - - -	41	545
Clay - - - - - - - - - -	10	555
Sandstone and small gravel, water - - - -	25	580
Clay - - - - - - - - - -	10	590
Clay and sand - - - -	30	620
Hard clay - - - - - - -	10	630
Clay and some gravel -	185	815
Clay and silt with water - - - - - - - - -	40	855

Table 27.--Logs of representative wells in Salt River Valley--continued.

	Thickness (feet)	Depth (feet)
Dry silt	26	881
Joint clay and silt	54	935
Silt	35	970
Clay and silt with little streaks of sand	208	1178
Soft sandstone	14	1192
Clay, trace of sand	2	1194
Hard sandstone	1	1195
Clay and fine sand	11	1206
Clay and silt	40	1246
Soft clay and silt	8	1254
Soft sandstone	6	1260
Sticky clay and silt	36	1296
Heavy clay	22	1318
Clay and silt	19	1337
Sand and silt very fine (with water)	3	1340
Clay and silt	20	1360
Clay very sticky, some silt	130	1490
Silt with clay binder	26	1516
Fine grain rock ledge, very hard	4	1520
Silt	8	1528
Silt and sand	42	1570
Fine sand (salt water)	16	1586
Clay and silt	11	1597
Mountain rock and sand	4	1601
Clay, silt and sand	4	1605
Fine sandstone and clay	10	1615
Clay and silt	15	1630
Sandstone inlaid in silt	30	1660
White mt. gravel in clay and silt	29	1689
White spar rock in boulder form	11	1700
White rock in hard clay	20	1720
White rock in silt and sand	9	1729
Clay and silt more clay	11	1740
Clay	3	1743
Hard clay	4	1747
Clay and silt	63	1810
Soft sandstone with a white lime	27	1837
Hard sandstone	3	1840
Clay dry	28	1868
Fine sand and silt	3	1871
Hard silt stone and clay	27	1898
Sand, some gravel and clay	12	1910
Clay and silt	18	1928
Fine sand and water hot	8	1936
Hard clay	32	1968
Soft clay and silt with very hot water	56	2024
Sand and gravel	16	2040
Granite boulders embedded in hard cemented sand	8	2048
Granite gravel, loose	6	2054
Granite gravel, tighter	16	2070
Hard granite ledge	3	2073
Fine sand and granite gravel	11	2084
Granite sand, gravel boulders	22	2106
Loose sand		2106
Still drilling at 2130'		

<u>Sec. 8, T. 4 N., R. 1 W.</u>

	Thickness (feet)	Depth (feet)
Hard red clay	12	12
Caliche	5	17
Sandy red clay	13	30
Caliche	5	35
Brown clay	19	54
Gravel and clay	2	56
Sandy brown clay	62	118
Clay and caliche	18	136
Gravel and caliche	4	140
Caliche	14	154
Brown sandy clay	30	184
Gravel and caliche	14	198
Sandy brown clay	50	248
Caliche and gravel	12	260
Hard brown clay	10	270
Cemented gravel	10	280
Brown clay and gravel	15	295
Cemented gravel	9	304
Hard cemented sand, gravel	18	322
Sandy brown clay	2	324
Conglomerate	40	364
Sandy brown clay, cemented streaks	36	400
TOTAL DEPTH		400



MAP OF SALT RIVER VALLEY AREA, ARIZONA

SHOWING GEOLOGY, LOCATION OF WELLS AND CULTIVATED AREAS AS OF SPRING 1952

1 0 4 MILES

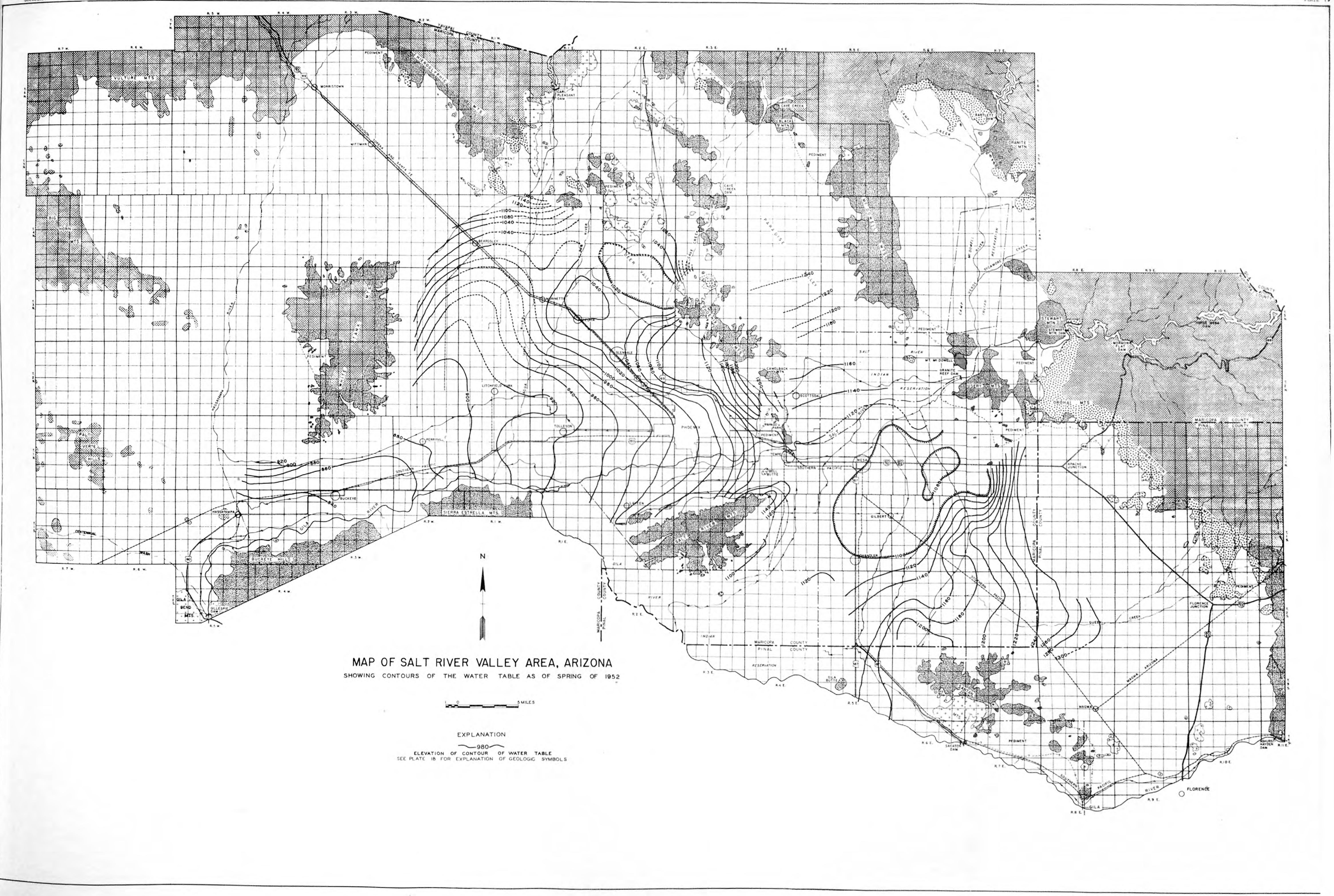
EXPLANATION

Unit	Description	Age	Era
Basalt flows	*Essentially non-water-bearing in area.*	QUATERNARY	CENOZOIC
Alluvial fill	*Gravel, sand, silt, and clay. Principal aquifer in area.*	QUATERNARY and TERTIARY	CENOZOIC
Terraces	*Sand and gravel. Above water table in area.*	QUATERNARY and TERTIARY	CENOZOIC
Conglomerate and sandstone	*Yields limited supplies of water.*	TERTIARY(?) or CRETACEOUS(?)	CENOZOIC and MESOZOIC
Volcanic rocks	*Principally extrusive, essentially non-water-bearing in basin*	TERTIARY(?) or CRETACEOUS(?)	CENOZOIC and MESOZOIC
Crystalline and metamorphic rocks	*Essentially non-water-bearing in basin*	PRE-CAMBRIAN or YOUNGER	

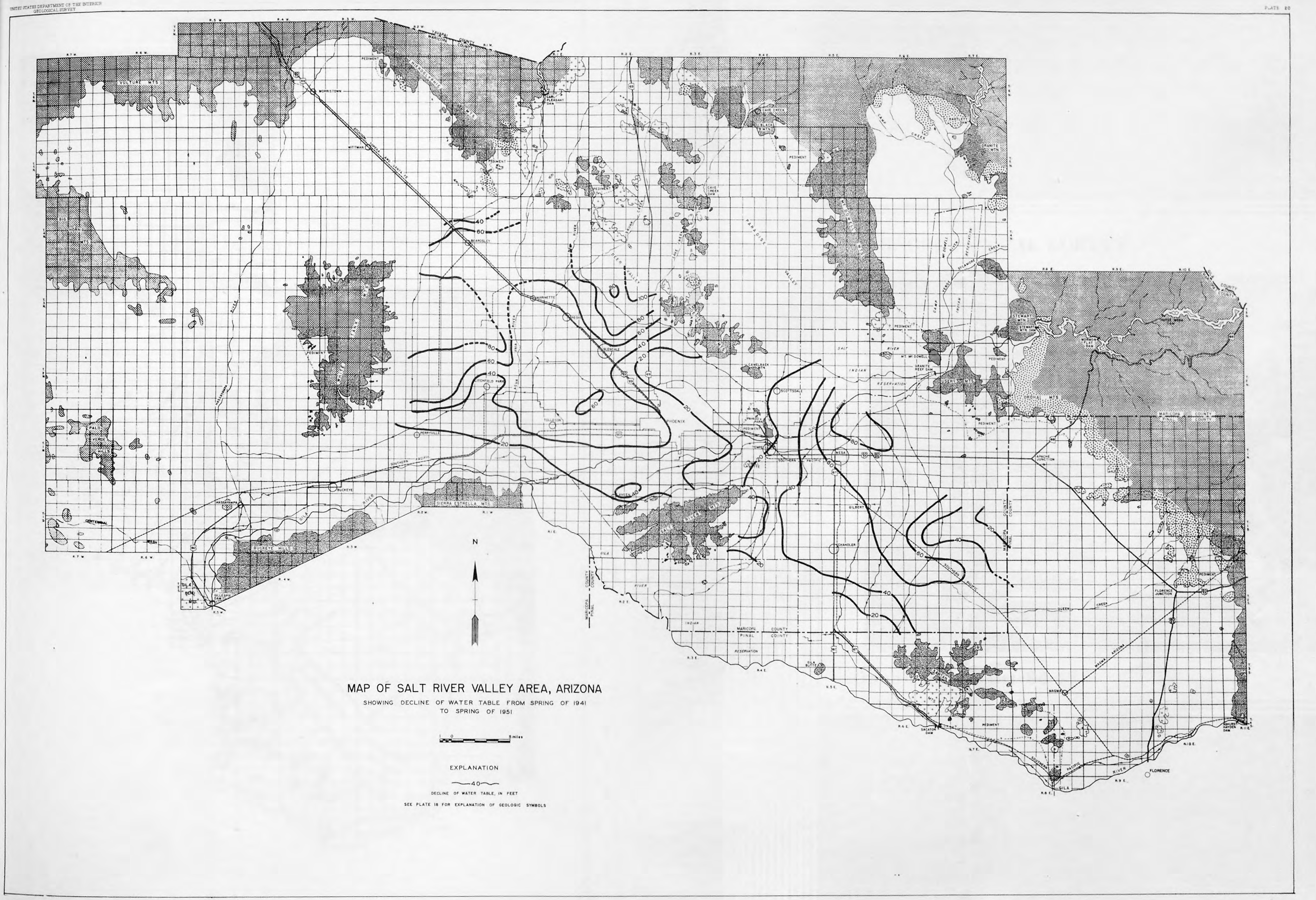
Geology not mapped

Irrigated areas on older alluvial fill.

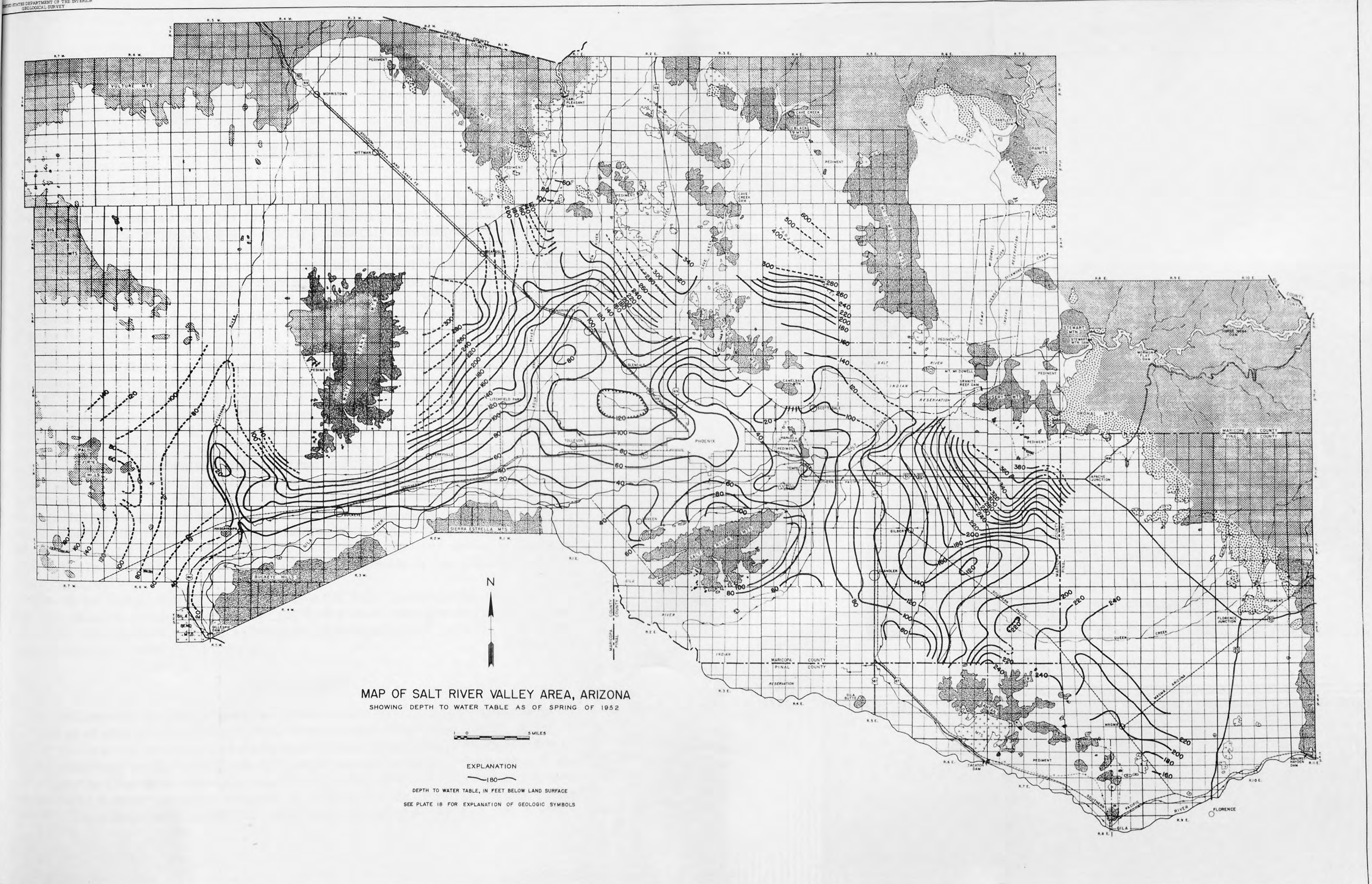
Wells



MAP OF SALT RIVER VALLEY AREA, ARIZONA
SHOWING CONTOURS OF THE WATER TABLE AS OF SPRING OF 1952



MAP OF SALT RIVER VALLEY AREA, ARIZONA
SHOWING DECLINE OF WATER TABLE FROM SPRING OF 1941 TO SPRING OF 1951



MAP OF SALT RIVER VALLEY AREA, ARIZONA

SHOWING DEPTH TO WATER TABLE AS OF SPRING OF 1952

1 0 5 MILES

EXPLANATION

180

DEPTH TO WATER TABLE, IN FEET BELOW LAND SURFACE

SEE PLATE 18 FOR EXPLANATION OF GEOLOGIC SYMBOLS

THE "SALT BALANCE" CONCEPT AND ITS APPLICATION TO THE SALT RIVER VALLEY AREA, ARIZONA

By J. D. Hem

Problem

The problem of disposal of dissolved mineral matter in irrigation water must be met and solved in order for any irrigation project to continue to exist and prosper. The irrigation water supply ordinarily contains dissolved mineral matter in considerable amounts. However, the water transpired by plants and evaporated from the soil is essentially free from dissolved mineral matter. The use of water for irrigation tends, therefore, to have a concentrating effect on the dissolved solids. Ultimately, in most areas, some provision has to be made for disposal of excess dissolved solids to avoid damage to soils and crops.

Where excellent drainage conditions exist, the individual farmer can prevent accumulation of soluble salts in the soil by adding an excess of irrigation water that passes downward unused through the root zone of his crops. The excess water leaches salt from the soil and carries it downward to the ground-water reservoir. This practice tends to raise the water table beneath irrigated lands. In areas where ground water lies close to the land surface it may be necessary to depress the water table by artifical drainage to prevent direct evaporation and a destructive accumulation of salts.

It has long been recognized that if an irrigation project is to be permanently successful, it must be so designed and operated that the drainage leaving the area of irrigation carries off the accumulating soluble salt from the whole area. Ideally, the amount of soluble mineral matter that must be removed should at least be equivalent to the amount entering the area in the irrigation water supply and from other sources. This is essentially the principle of "salt balance."

Not all the dissolved solids brought into the area are harmful. Possibly the salt-balance concept need apply only to the salts that are definitely harmful. This interpretation of the salt-balance problem needs further study and may be somewhat difficult to apply.

Data required

A considerable volume of detailed information is required to determine the status of salt balance in any area. The amount of dissolved salts in all inflow to the area, both surface water and ground water, must be known for a sufficiently long period to provide a reliable annual average. To do this it is necessary to determine the total quantity of inflow of water and, by analysis of an adequate number of water samples, to determine the mineral content of the inflow. The components of outflow, both surface and underground, must also be evaluated. In addition, areas of localized salt accumulation within the project may require collection of special data. These data would necessarily include much information on ground-water hydrology.

Data available

Present data are inadequate for more than general evaluation of the salt-balance condition of the Salt River Valley area. About all that can be stated with certainty is that the amount of dissolved solids entering the area in surface flow is far greater than the amount leaving the area in surface flow. An earlier evaluation (McDonald, Wolcott, and Hem, 1947), based on incomplete data, showed that during the period October 1, 1944, to September 30, 1945, 600,000 tons of dissolved mineral matter entered the area in surface flow of Salt River at Granite Reef Dam and that 460,000 tons left the area in surface flow at Gillespie Dam. No data for inflow of salt from the Gila River and other sources, or for outflow other than in the river at Gillespie Dam, were available for the 1944-45 water year. However, the difference between outflow and inflow indicates that a substantial amount of salt was left in the area during the year.

More complete data on amounts of dissolved matter in the surface inflow and outflow are available for the period October 1, 1950, to September 30, 1951, (U. S. Geol. Survey, Water-Supply Paper 1200, in preparation). These data show amounts of inflow during the year, as follows:

Gila River at Kelvin	81,000 tons
Verde River below Bartlett Dam	82,000
Salt River below Stewart Mountain Dam	565,000
Total	728,000

During the period a gaging station was operated on the Agua Fria Canal below Lake Pleasant, but there was practically no discharge. Analyses are not available for the first 2 months of the period, because sampling began on December 1, 1950. Loads of dissolved solids for the 2-month period were estimated on the basis of gaging-station records and on periods of similar conditions when samples were collected. No data are yet available on which to base estimates of amounts of soluble salts entering the area in ground-water inflow. However, these amounts probably are small compared to the amounts from surface-water sources.

The data for outflow for the 1951 water year also cover a period of only 10 months. Dissolved-solids loads for the 2 months before sampling was started were estimated by a process similar to that used for estimating inflow. The computations show an outflow of about 350,000 tons during the year in the river and canals below Gillespie Dam. No data are available for amounts of dissolved solids leaving the area in underground flow. To some extent the missing data for underground inflow and outflow counterbalance each other. Because sampling in 1951 was more frequent, the 1951 data for dissolved-solids load at Gillespie are considerably more accurate than those for 1945. Regardless of the missing data, it is evident that a greater amount of dissolved mineral matter enters the area in surface inflow than is removed in surface outflow. During the 1951 water year the excess of dissolved solids was at least 350,000 tons of dissolved matter.

Accumulation of salts in area

It is not known where the excess dissolved salts were left, but there are several areas where the concentration of dissolved solids, particularly sodium salts, in the ground water is known to be increasing from year to year. The largest area is between Tolleson and Gillespie Dam.

Many factors complicate the study of salt balance in this area. One of the more important is the extensive pumping of ground water for drainage and the re-use of the water for irrigation. This re-use, which may go through several cycles, eventually results in a concentration of dissolved solids that makes the water unfit for irrigation. Part of this highly mineralized residual water may reach the surface by natural drainage and leave the area as flow past Gillespie Dam. The deterioriation of the quality of water in some areas may eventually require discontinuance of use of the water for irrigation, but it may be necessary to continue withdrawal, by pumping or other means, to provide drainage.

In areas where the shallow ground water has become saline, deepening wells and casing off the upper water may allow continued pumping and use of the water for irrigation. Several factors might limit this possibility. The deeper ground water, even though it may be lower in dissolved solids than the shallower water, may have a high sodium percentage. If the percentage of sodium in the deep waters were higher than in the shallower waters or in the surface-water supply, the deeper waters would be less desirable for irrigation. Pumping from the deeper aquifers probably would induce vertical circulation of the ground water, which would eventually carry saline waters to the deeper aquifers.

Summary

To summarize, the available data indicate that a serious salt-balance problem exists within the Salt River Valley area. A more complete understanding of the problem is desirable in several respects. Investigations should be intensified to obtain more data on the amounts of dissolved salts entering and leaving the area. Data now available are sufficient only for rather crude estimates. At present the accumulation of dissolved salts in ground water appears to be a problem only in parts of the whole area. In future studies an attempt should be made to obtain more comprehensive data on these specific local areas. If the cause of accumulation of salts in local areas could be determined, remedial measures could be undertaken with greater hope for success. Otherwise remedial measures are likely to be wastefully expensive and may not achieve their purpose.

RAINBOW VALLEY - WATERMAN WASH AREA

MARICOPA COUNTY

By H. N. Wolcott

Introduction

This section of Part II provides data on the ground-water resources of an area in which work by the Geological Survey was begun in 1949 and completed in August 1952. The results of the work will later be issued as a separate report and are included in the present report because they relate to the ground-water supply of the Gila River basin as a whole. The work was done by the Geological Survey in cooperation with the Arizona State Land Department at the request of W. W. Lane, State Land Commissioner.

Purpose

The study was made for the purpose of determining:
(1) The sources and movement of ground water in each valley;
(2) Whether or not a subsurface channel or passage exists through which ground water might move from one valley into the other, and the effects of pumping in either valley in relation to the ground-water supply of both valleys;
(3) The approximate average annual recharge to the ground-water supply in the Waterman Wash Valley;
(4) The probable effects of pumping for irrigation in the Waterman Wash Valley upon water levels in shallow stock wells in the valley;
(5) The probable effects of continued expansion of irrigation development in Rainbow Valley.

Geography and physiography

The Rainbow Valley-Waterman Wash area includes two distinct bodies of ground water that lie a few miles south of the towns of Hassayampa, Buckeye, and Liberty. The area forms a broad arc extending eastward from Gillespie Dam on the Gila River to the Sierra Estrella Mountains, then southward to a low drainage divide between the Maricopa Mountains and the Palo Verde Mountains (pl.22). The area is bounded on the northwest and north by the Buckeye Hills and outliers of the Sierra Estrella Mountains, on the northeast and east by the Sierra Estrella and the Palo Verde Mountains, on the southeast and south by the Haley Hills and the low drainage divide already mentioned, and on the southwest and west by the Maricopa Mountains and the Gila River.

To avoid confusion in the descriptions of the two valleys, the small valley that drains into the Gila River immediately downstream from Gillespie Dam is designated in this report as Rainbow Valley (pl. 22) and is a part of a larger ground-water area known as the Gila Bend basin. The area drained by Waterman Wash is designated the Waterman Wash area. The total drainage area of Rainbow Valley is approximately 80 square miles; of Waterman Wash, approximately 400 square miles. The physiographic line of division between the valleys is a low alluvial ridge that extends northward from the Maricopa Mountains to the Buckeye Hills.

Geology

The Waterman Wash basin probably was formed by downfaulting of a block between the Sierra Estrella Mountains and the Maricopa Mountains. The deepest well in the area, in sec. 23, T. 2 S., R. 2 W., was drilled to a depth of 1,263 feet without encountering bedrock (table 28). There is nothing to indicate how much deeper the basin may be, but the depth already proved is sufficient to justify the hypothesis of structural origin. Rainbow Valley is a re-entrant of the Gila River Valley, and it is probable that, except along the extreme western border, near the Gila River, bedrock lies at much shallower depths than in the Waterman Wash basin.

On the map (pl. 22) some of the areas underlain by shallow bedrock are outlined and designated as "pediment." Within these areas small quantities of water may be encountered in shallow wells. These wells may produce enough water for stock or domestic use, but the supply is not dependable and the wells are liable to go dry during periods of prolonged drought. Owing to the presence of the pediments, the ground-water storage capacity in each valley is less than would be suggested by the large alluvial areas.

Granitic and metamorphic rocks, probably pre-Cambrian in age, compose the mountain borders of both valleys and, in all probability, rocks of the same types form the hard-rock basin floors. Granite and granite-gneiss are predominant in the mountains on the northern and western sides of the area. Schist and gneiss predominate in the mountains and hills on the eastern and southern border.

The logs of various wells in the Waterman Wash basin (table 29) indicate that the alluvial fill is similar in character to that in other basins of the desert region. Gravel, sand, silt, and clay are encountered at various depths and in varying thicknesses. The basin appears not to have been in the course of any major drainage, and therefore the alluvial-fill materials probably have been derived from the nearby hills and mountains.

Clay deposits thus far encountered appear to be lenticular and none is of any great lateral extent, suggesting that there was no protracted interruption of drainage from the basin, and, hence, no deposition of extensive lake sediments, during the period of alluvial deposition. It is, therefore, probable that the closure of the basin outlet was the result of geologically recent uplift along the line of the Buckeye Hills, after deposition of most of the alluvium.

Ground-water resources

Sources and movement

Recharge to the ground-water reservoir underlying Rainbow Valley is received from four sources: (1) Underflow along the Gila River; (2) runoff of rainfall in portions of the Buckeye Hills and the Maricopa Mountains; (3) seepage from canals and irrigated lands; and (4) seepage from floods or other occasional surface flows in the Gila River channel.

The principal sources of recharge to the Waterman Wash Valley are runoff from rainfall within the drainage basin and seepage from irrigation of approximately 3,500 acres of land near the center of the valley. There is no entry of water into the basin from the Santa Cruz River or its tributaries. Vekol Wash may have discharged at one time into Waterman Wash, but its present course is deflected eastward into the Santa Cruz River in the vicinity of the Palo Verde Mountains. The slight underflow along Vekol Wash probably parallels the surface channel.

Ground water in Rainbow Valley moves westward toward the Gila River. In the vicinity of the river, movement is from north to south.

In the Waterman Wash Valley there appears to be no definite trend of ground-water movement except as indicated by a slight downward gradient of the water table from the hard-rock borders toward the center of the valley. The water-table gradient at present is slightly downward toward the south in the area where outflow might be expected northward through the narrows (secs. 29, 30, 31, and 32, T. 1 S., R. 2 W.). Therefore, no discharge occurs by underflow in this locality. The moderately heavy plant growth along this part of the wash probably is supplied from a zone of shallow water, and evapotranspiration from the plants constitutes the only natural dischage at present.

Possibility of movement of ground water from Waterman Wash into Rainbow Valley

The two basins are separated on the surface by only a low alluvial divide, and there has been some question as to whether ground water might move out of the Waterman Wash area beneath the surface of the divide and enter the Rainbow Valley. In the geologic study of the area, considerable time was spent along the divide. Electrical resistivity probes were made for the purpose of checking and verifying conclusions drawn from the geologic work.

The results of the work all indicate that, about 2 miles west of the alluvial divide, there is a continuous rock ridge at shallow depths below the surface, extending northward from the Maricopa Mountains to the Buckeye Hills. Low, inconspicuous outcrops of granitic and metamorphic rocks occur at several places along the line of the ridge, and geophysical probes were run at intermediate points between the outcrops. The probes indicated the presence of bedrock at shallow depths beneath the alluvial surface. There is, therefore, no possibility of any substantial ground-water movement from Waterman Wash basin into Rainbow Valley, and pumping in either valley should have no effect upon the water resources of the other valley.

Estimated average annual recharge to the ground-water supply in Waterman Wash Valley

As far as could be determined, there is no way in which ground water escapes at present from Waterman Wash Valley as underflow from the basin. Evaporation of ground water and transpiration by phreatophytes is small, and the only important discharge of ground water from the valley is by pumping for irrigation. A prolonged wet cycle probably would cause the water table to rise sufficiently to bring about the discharge of ground water as underflow through the narrow gap in the hills at the north end of the valley.

Recharge.--As already stated, the principal source of recharge to the area is runoff from rainfall within the drainage limits of the basin. The average annual recharge to the ground-water reservoir is, therefore, approximately the amount of rainfall runoff that infiltrates from the sandy washes to the ground-water reservoir.

Experimental work in other parts of Arizona has shown that in the average year there is little or no direct recharge from rain that falls upon the flat valley floors (Turner and others, 1943, p. 42). Some of the rain runs off and some penetrates a few inches into the soil and is lost through transpiration by desert plants and by evaporation. Of the rain that falls upon the hard-rock mountain surfaces, part is evaporated and part becomes runoff that percolates into the porous sands and gravels along washes and eventually reaches the ground-water reservoir.

Average annual rainfall at Phoenix is 7.80 inches and at Gila Bend, approximately 6 inches. As Waterman Wash Valley lies between the two cities, an average annual rainfall of 7 inches on the Waterman Wash area was assumed for the purpose of estimating the quantity of recharge from runoff of rainfall.

Neither aerial photographs nor topographic maps were available for all the mountains surrounding the basin, and the total hard-rock area within the drainage limits of the basin could be only approximated. A maximum of 50,000 acres might be thus classified.

Experimental work in 1943 on Queen Creek, in the eastern part of the Salt River Valley area, showed that 6 to 10 percent of the total rainfall on terrain of this type finds its way into washes as runoff (Turner, S. F., personal communication, 1950). Of this amount, as much as 50 percent percolates as recharge to the ground-water reservoir (Babcock and Cushing, 1942, pp. 49-56). The balance is lost by evaporation and transpiration.

Assuming a maximum hard-rock area of 50,000 acres, an average annual rainfall of 7 inches, a maximum factor of 10 percent for rainfall runoff into sand washes, and a factor of 50 percent for runoff contributing recharge to ground water, it is estimated that a maximum of 1,500 acre-feet might be recharged annually to the ground-water reservoir from rainfall upon the hard-rock areas. If the runoff factor used were 6 percent instead of 10 percent, the annual recharge would amount to less than 1,000 acre-feet.

In addition, there will be some recharge from rainfall that reaches sand washes as runoff after falling upon the flat valley surfaces. During heavy storms, rain sometimes falls more rapidly than it can be absorbed by the soil, and the excess water follows small branches that lead into the major washes. The average amount of recharge from this source probably does not exceed 1,000 acre-feet per annum, and might be as little as 500 acre-feet. On the basis of these estimates, it is estimated that the total average annual recharge from rainfall to the Waterman Wash ground-water reservoir does not exceed 2,500 acre-feet, and may be as little as 1,500 acre-feet.

Recharge from water applied to the land for irrigation is estimated on the basis of experimental work in Safford Valley (Turner and others, 1941, p. 30). In 1952 there was a total of about 3,500 acres under cultivation in Waterman Wash Valley. Assuming an annual consumptive use of 5 acre-feet of water per acre and a factor of 15 percent of water returned as recharge from irrigation, the total annual recharge from this source would amount to approximately 2,600 acre-feet.

Adding the estimated quantities of recharge received from precipitation, and from irrigation of lands under cultivation in 1952, the approximate total recharge is believed to be between 4,000 and 5,000 acre-feet per year.

Pumpage.--Withdrawal of ground water for irrigation in the valley in 1952 is estimated to be about 17,000 acre-feet on the basis of duty of water of 5 acre-feet per acre and a total irrigated area of 3,500 acres. If this factor for use were as low as 4 acre-feet per acre, total pumpage in 1952 would be 14,000 acre-feet. The amount of ground water withdrawn in 1952, therefore, will exceed recharge by approximately 10,000 to 12,000 acre-feet. This difference between recharge and pumpage will be withdrawn from storage.

Storage.--Agricultural development in the valley has been so recent that data are not yet available regarding the rate of decline of the water table in response to withdrawals from storage, nor are data available upon which to base an estimate of the quantity of ground water stored in the valley. Continued pumping, even from deep aquifers near the center of the valley, will result in an accelerated movement of ground water toward the points of withdrawal and a lowering of water levels throughout the area. Water levels in comparatively shallow stock or domestic wells will be affected, and some wells that are now producing water are likely to become dry.

Quality of water

Although a few analyses available indicate that the quality of the ground water in Waterman Wash Valley is suitable for irrigation, no account has been taken of the increase in mineral content that will result from continued use and re-use of the ground water in the basin. With no ground-water discharge to areas outside the valley to flush out accumulated salts, the water may eventually become so highly mineralized that it will be unfit for use. It is impossible to estimate how long it may take for such a condition to be brought about because the length of time depends upon two unknown factors--the quantity of water in storage and the rate at which it may be used for irrigation.

Effect of continued expansion of agricultural development in Rainbow Valley

No quantitative estimate of the recharge to or discharge from Rainbow Valley was attempted, because of the complexity of the problem and lack of necessary data. Recharge to the area is from several different sources, some of which would be difficult or impossible to evaluate. As there is no surface or subsurface division between Rainbow Valley and the Gila Bend basin, the ground-water reservoir is common to both. It is possible, however, to anticipate certain results that probably will follow a continued expansion of agricultural development in Rainbow Valley.

Chemical analyses of water from wells in this area (see table 30) show a high mineral content in the ground water paralleling the Gila River channel. Dissolved solids are highest in the wells nearest Gillespie Dam, where the water is derived principally from the river underflow. Downstream, the water improves somewhat in quality as a result of dilution by ground water of better quality moving westward in Rainbow Valley.

Increasing irrigation development in Rainbow Valley will eventually lower the water table sufficiently to cause movement of highly mineralized water eastward, away from the river, toward the area where pumping is heaviest. Evapotranspiration in the irrigated area will cause an increase in content of undesirable minerals in the root zone. If the quantities of salts in the soil and in the ground water that is used for irrigation becomes too high, some land will be forced out of cultivation.

The irrigable area in Rainbow Valley is not large and, from the standpoint of quantity alone, overdevelopment probably is not imminent, but the deterioration in quality of the ground water in this area may eventually become a factor limiting withdrawals. Pumpage figures for Rainbow Valley are included in the section on the Gila Bend basin.

Summary and conclusions

The Rainbow Valley-Waterman Wash area includes two distinct ground-water reservoirs.

The lower part of Waterman Wash Valley is enclosed by hard-rock boundaries and there can be no underflow out of the basin as long as the water table remains at or near its present level. Rainbow Valley is a re-entrant of the Gila River Valley and therefore is a part of the Gila Bend basin.

The alluvial fill in Waterman Wash basin is composed of gravel, sand, silt, and clay, and it has a proved depth, in places, of more than 1,200 feet. Deposition of the alluvium has been characteristically irregular, and there is no great continuity of individual beds or lenses, either vertically or laterally. The total thickness of alluvium in Waterman Wash is probably greater than in

Rainbow Valley.

Recharge to the ground-water reservoir in Rainbow Valley is from various sources, but the recharge in Waterman Wash basin is derived principally from runoff of rainfall and by seepage from irrigated lands.

The ground-water reservoirs of the two valleys are separated by a hard-rock barrier, and there is no appreciable movement of ground water from either valley to the other. Pumping in either valley will have no effect upon the ground-water supply of the other valley.

The recharge to Waterman Wash Valley in 1952 is estimated to be not more than 5,000 acre-feet, and it may be as little as 4,000 acre-feet. Continued use of ground water for irrigation in the valley will lower water levels and may result in some of the shallow stock or domestic wells becoming dry.

Continued expansion of irrigation development in Rainbow Valley will result in increasing mineralization of the ground water in that area, and the deterioration in quality of the water may ultimately force some land out of cultivation.

Table 28.--Records of representative wells in Rainbow Valley-Waterman Wash area, Maricopa County, Ariz.

Well no.	Depth of well (feet)	Water level: Depth below measuring point (feet) a/	Water level: Date of measurement	Pump and power b/	Use of water c/	Remarks
T. 1 S., R. 2 W.						
Sec. 22	-	84.15	4-18-49	None	N	
24	67	57.82	8-16-49	C,W	D,S	
30	75	61.65	6-30-49	None	N	
31	33	24.00	5--5-52	C,G	D,S	
36	208	-	-	None	N	Dry.
T. 2 S., R. 1 W.						
Sec. 15	-	312.61	2--6-51	None	N	Uncased below 2 feet.
16	-	316.10	6--3-52	C,G	S	
19	-	177.00	6-11-52	None	N	Recently drilled irrigation well.
20	-	195.00	6-11-52	None	N	Recently drilled irrigation well.
33	1030	266.70	6--2-52	H	D	Uses bailer to get water.
T. 2 S., R. 2 W.						
Sec. 1	585	188.50	4--2-52	None	N	Well abandoned.
3	136	108.38	2--1-51	None	N	
5	1122	95.25	2--7-51	None	N	
9	515	132.98	4--2-52	T,G	D,I	
12	188	185.36	2--1-51	None	N	
13	680	181.32	4--2-52	None	N	
14	-	144.00	6--1-49	C,G	S	
21	150	-	-	None	N	Well dry at 86 feet 2-7-51.
22	161	-	-	None	N	Dry.
22	1250	195.00	12-16-50	T,D	I	Estimated discharge 2500 - 3000 gpm.
23	-	142.85	2--1-51	T,G	I,D	Reported discharge 1000 gpm.
23	1263	180.00	11----50	T,G	I,D	Reported discharge 3476 gpm.

a/ Measuring point was usually top of casing, top of pump base, or top of well curb.
b/ T, turbine; C, cylinder; E, electric motor; G, gasoline or natural gas; W, wind; H, hand; D, diesel.
c/ I, irrigation; S, stock; D, domestic; P, public supply; N, none.

Table 28.--Records of representative wells in Rainbow Valley-Waterman Wash area --continued.

Well no.	Depth of well (feet)	Water level: Depth below measuring point (feet) a/	Water level: Date of measurement	Pump and power b/	Use of water c/	Remarks
T. 2 S., R. 2 W.						
Sec. 23	175	168.70	4--2-52	None	N	
24	155	-	-	None	N	Dry.
26	1031	-	-	T,G	I	
27	1055	200.00	1-12-51	T,G	I	
34	112	-	-	None	N	Dry.
35	1037	213.61	4--3-52	T,G	I	
T. 2 S., R. 4 W.						
Sec. 32	450	188.15	4--1-52	T,E	I,S	
32	-	-	-	None	N	Recently drilled.
32	-	-	-	None	N	Recently drilled.
33	168	-	-	None	N	Dry.
T. 2 S., R. 5 W.						
Sec. 35	400	-	-	T,E	I	
35	386	-	-	T,E	I	
36	-	-	-	T,E	I	
36	65	-	-	None	N	Dry.
36	345	-	-	T,E	I	
T. 3 S., R. 1 W.						
Sec. 1	350	330.17	6--2-49	C,G	S	
9	-	211.30	6--3-49	C,G	S,D	
36	-	294.68	6-11-52	C,G	S	
T. 3 S., R. 2 W.						
Sec. 1	237	-	-	None	N	
T. 3 S., R. 4 W.						
Sec. 4	250	159.68	2-13-51	T,E	I	
4	492	-	-	T,E	I,D	2984 gpm 8-16-51.
6	530	-	-	T,E	I	
7	176	100.25	4--1-52	None	N	

Table 28.--Records of representative wells in Rainbow Valley-Waterman Wash area.--continued.

Well no.	Depth of well (feet)	Water level: Depth below measuring point (feet) a/	Water level: Date of measurement	Pump and power b/	Use of water c/	Remarks
T. 3 S., R. 4 W.						
Sec. 7	332	-	-	T,E	I	
8	406	105.10	4--1-52	T,E	I	
8	370	113.13	2-15-51	T,E	I	
8	780	-	-	T,E	I	
9	474	185.00	4--6-52	T,E	I	
9	490	155.15	2-13-51	T,E	I	Discharge 1816 gpm 8-16-51.
9	500	-	-	T,E	I	Discharge 2280 gpm 8-16-51.
15	420	-	-	T,E	I	Discharge 3175 gpm 8-16-51.
15	465	-	-	T,E	I	Discharge 3180 gpm 8-16-51.
16	-	159.30	4--1-52	T,E	I	
17	-	-	-	T,E	I	
17	302	-	-	T,E	I	Discharge 2028 gpm 8-30-50.
20	228	-	-	-	-	
21	300	105.80	1-28-52	T,E	I	Discharge 2042 gpm 8-30-50.
21	-	-	-	T,E	I	Discharge 2160 gpm 8-30-50.
21	550	-	-	T,E	I	Discharge 2820 gpm 8-30-50.
21	812	-	-	T,E	I	Discharge 2815 gpm 8-30-50.
22	465	-	-	T,E	I,D	Discharge 3415 gpm 8-17-51.
23	372	-	-	T,E	I	
27	-	191.50	4--1-52	T,E	I	
28	918	-	-	T,E	I	Discharge 3000 gpm 8-30-50.
28	1000	-	-	T,E	I	
29	-	-	-	None	N	Well being drilled.
T. 4 S., R. 1 E.						
Sec. 21	-	-	-	-	-	Rig over well 4-3-52.
26	370	-	-	C,G	D	
28	504	-	-	T,G	D	
28	750	400.02	4--3-52	None	N	
29	-	401.60	4--3-52	None	N	

Table 29.--Logs of representative wells in Rainbow Valley - Waterman Wash area, Maricopa County, Ariz.

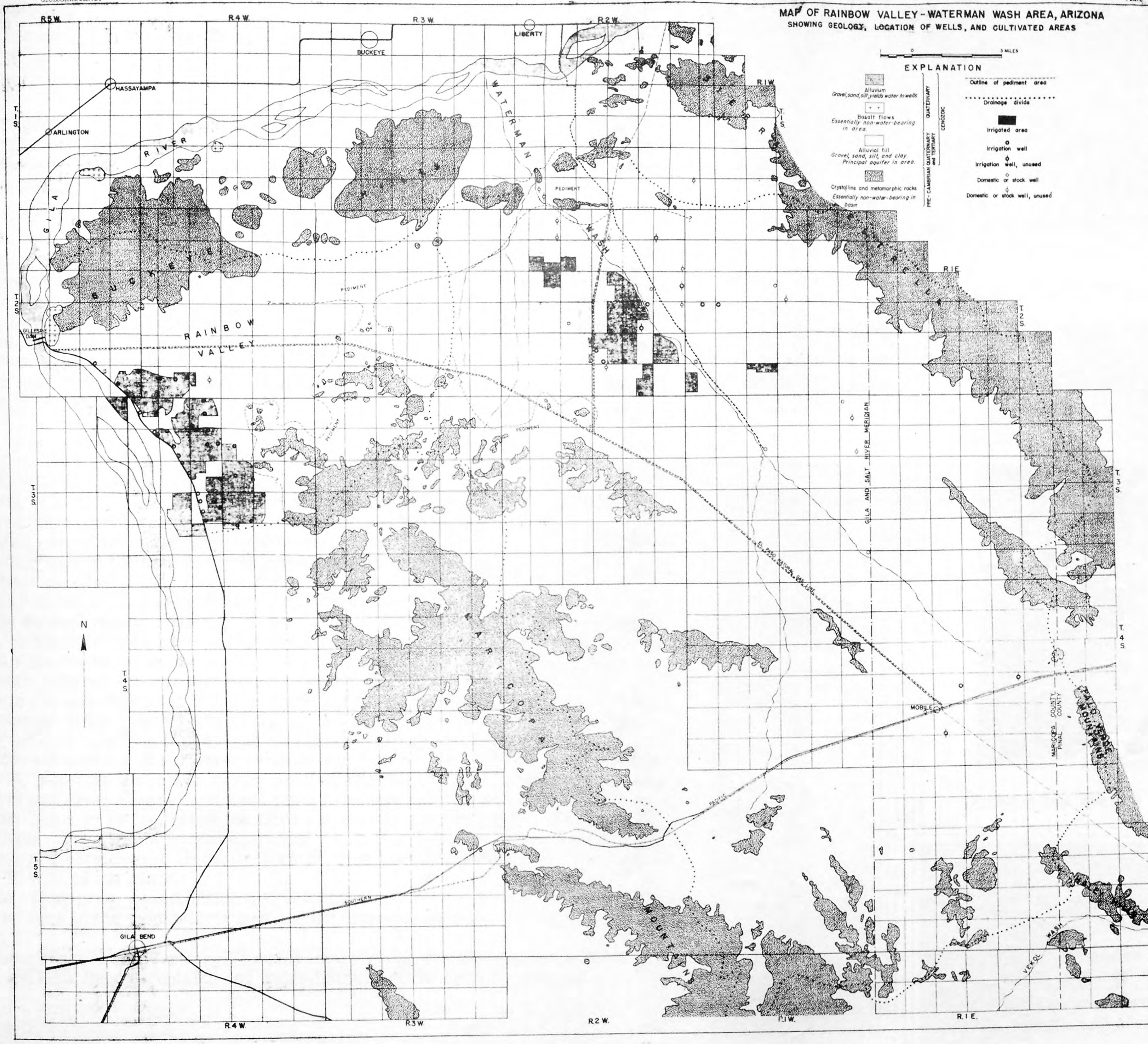
	Thickness (feet)	Depth (feet)
Sec. 33, T. 2 S., R. 1 W.		
Surface sand	80	80
Clay	121	201
Clay with streaks of sand	294	495
Sand	90	585
Tight, grey sand	91	676
Grey sand	51	727
Grey sand with streaks of blue clay	43	770
Soft grey sand	51	821
Medium grey sand	30	851
Hard streaks of grey sand	3	854
Medium grey sand	15	869
Tight sand	17	886
Sand	99	985
Tight sand	45	1030
TOTAL DEPTH		1030
Sec. 5, T. 2 S., R. 2 W.		
Surface sand and clay	120	120
Clay	20	140
Sand	70	210
Clay	5	215
Clay with streaks of sand	50	265
Sand	95	360
Clay	30	390
White sand	20	410
Clay	50	460
Sand	125	585
Silt and sand	537	1122
TOTAL DEPTH		1122
Sec. 22, T. 2 S., R. 2 W.		
Surface sand, clay, caliche	200	200
Sand, gravel, and clay	70	270
Sand, streaks of gravel	100	370
Sand, gravel, thin streaks sandy clay	190	560
Gravel, streaks sand	290	850
Gravel sand, thin streaks clay	100	950
Gravel and sand	50	1000
Gravel, sand with hard cemented streaks of sand	250	1250
TOTAL DEPTH		1250
Sec. 35, T. 2 S., R. 2 W.		
Surface sand	100	100
Brown clay	40	140
Sand, gravel, some boulders	60	200
Sand, gravel some streaks of light colored clay	600	800
Light grey sand mixed with blue clay	180	980
Hard light sand	57	1037
TOTAL DEPTH		1037
Sec. 28, T. 4 S., R. 1 E.		
Surface soil	4	4
Caliche - hard streaks	166	170
Fine sand	8	178
Clay and sand streaks	32	210
Sand and hard streaks	50	260
Sand	30	290
Cemented sand and boulders	11	301
Sand and boulders	69	370
Sand and boulder streaks	30	400
Sand & boulders & clay streaks	60	460
Clay	6	466
Sandy clay	54	520
Sand & clay streaks	43	563
Hard clay	57	620
Clay & sand streaks	83	703
Clay & boulder streaks	47	750
TOTAL DEPTH		750

Table 30.--Analyses of water from representative wells in Rainbow Valley-Waterman Wash area, Maricopa County, Ariz. (Parts per million except specific conductance and percent sodium)

Well or spring no.	Date of collection	Depth of well (feet)	Temperature (°F.)	Specific conductance (micromhos at 25° C.)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Total hardness as $CaCO_3$	Percent sodium
T1S., R4W.															
Sec. 9	12-15-50	250	76	5180	202	47	871	229	870	1040	3.5	86	3250	698	73
9	7-18-51	250	76	5210	–	–	–	241	–	1060	–	–	–	–	–
18	7-18-51	–	74	5210	–	–	–	267	–	1250	–	–	–	–	–
18	1-1-51	–	72	6520	298	100	1040	327	884	1530	2.6	77	4130	1150	66
T2S., R2W.															
Sec. 14	6-1-49	–	–	3030	–	–	–	160	–	760	–	–	–	–	–
23	4-7-52	1263	87	1370	17	3.4	264	101	116	282	2.6	28	783	56	91
27	4-7-52	–	89	1460	–	–	–	109	–	301	–	–	–	–	–
T2S., R5W.															
Sec. 35	4-19-46	386	–	2850	–	–	–	235	–	700	–	–	–	–	–
36	4-9-46	345	–	3580	–	–	–	270	–	920	–	–	–	–	–
36	4-9-46	400	–	3770	202	71	503	257	327	945	0.7	5.7	2180	796	58
T3S., R1W.															
Sec. 9	8-25-49	–	–	493	51	14	41	321	3.7	3	0.2	3.2	302	184	33
T3S., R4W.															
Sec. 6	5-27-46	530	–	2680	–	–	–	233	–	645	–	–	–	–	–
6	4-9-46	545	–	3390	194	63	428	247	274	835	1.1	6.7	1920	743	56
6	2-13-51	–	74	2940	152	57	384	251	231	705	1.2	6.6	1690	614	58
7	5-27-46	332	–	3100	–	–	–	259	–	772	–	–	–	–	–
8	5-27-46	370	–	2860	–	–	–	256	–	690	–	–	–	–	–
8	4-10-46	780	–	2460	–	–	–	234	–	585	–	–	–	–	–
9	2-15-51	490	70	2880	104	16	477	126	190	735	8.0	4.2	1620	326	76
9	4-1-52	500	85	2210	–	–	–	201	–	495	–	–	–	–	–
10	4-1-52	400+	–	3030	99	8.3	530	117	191	795	4.8	6.7	1720	281	80
17	4-10-46	302	–	3160	–	–	–	242	–	795	–	–	–	–	–
21	4-10-46	300	–	2690	134	46	361	186	205	660	1.1	11	1510	524	60
21	4-10-46	550	–	2610	–	–	–	254	–	620	–	–	–	–	–
22	4-1-52	400+	83	2500	76	6.3	444	128	179	615	4.4	14	1430	216	82
23	4-2-52	400	84	2090	–	–	–	114	–	480	–	–	–	–	–
28	5-27-46	1000	–	2660	–	–	–	246	–	620	–	–	–	–	–

Table 30.--Analyses of water from representative wells in Rainbow Valley-Waterman Wash area-continued.

Well or spring no.	Date of collection	Depth of well (feet)	Temperature (°F.)	Specific conductance (micromhos at 25° C.)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Total hardness as $CaCO_3$	Percent sodium
T4S., R1W.															
Sec. 21	8-12-49	504	-	923	48	13	131	209	109	111	0.5	20	568	174	62
26	8-12-49	370	-	1420	55	16	227	195	223	206	1.2	13	876	203	71
Gila River near Gillespie Dam	3-7-46	Surface flow	-	6920	300	136	1090	375	891	1710	1.6	32	4350	1310	64
Do.	3/1-10/46	do.	-	8880	418	177	1420	426	1170	2360	2.2	22	5810	1770	63


MAP OF RAINBOW VALLEY - WATERMAN WASH AREA, ARIZONA
SHOWING GEOLOGY, LOCATION OF WELLS, AND CULTIVATED AREAS
0
3 MILES
EXPLANATION
Alluvium
Gravel, sand, silt, yields water to wells
Basalt flows
Essentially non-water-bearing in area.
Alluvial fill
Gravel, sand, silt, and clay. Principal aquifer in area.
Crystalline and metamorphic rocks
Essentially non-water-bearing in basin
QUATERNARY
QUATERNARY and TERTIARY
CENOZOIC
PRE-CAMBRIAN
Outline of pediment area
Drainage divide
Irrigated area
Irrigation well
Irrigation well, unused
Domestic or stock well
Domestic or stock well, unused
R5W.
R4W.
R3W.
R2W.
R1W.
R1E.
T.1S.
T.2S.
T.3S.
T.4S.
T.5S.
BUCKEYE
LIBERTY
HASSAYAMPA
ARLINGTON
GILA RIVER
WATERMAN WASH
PEDIMENT
BUCKEYE
RAINBOW VALLEY
GILA AND SALT RIVER MERIDIAN
EL PASO NATURAL GAS LINE
MOBILE
MARICOPA COUNTY
PINAL COUNTY
PALO VERDE MOUNTAINS
MARICOPA
MOUNTAIN
SOUTHERN
PACIFIC
VEKOL WASH
GILA BEND
N
R4W.
R3W.
R2W.
R1W.
R1E.

GILA BEND BASIN, MARICOPA COUNTY

By D. R. Coates

The geology and ground-water resources of the Gila Bend basin have been described in a mimeographed report issued by the Geological Survey (Babcock and Kendall, 1948). This section is based on that report, supplemented by more recent pumpage and water-level data.

Location and extent

The Gila Bend basin is a wide, gently sloping, desert plain in southwestern Arizona. The basin extends over an irregular area from Gillespie Dam on the Gila River to a point 36 miles downstream, and is bounded by the Gila Bend Mountains and the Buckeye Hills on the north, the Maricopa and the Sand Tank Mountains on the east, the Sauceda Mountains on the south, and the Painted Rock Mountains on the west. The northeastern portion of the basin is known locally as Rainbow Valley. The basin covers an area of about 800 square miles in Maricopa County.

Geology

The Gila Bend basin occupies parts of at least two structural troughs (pl. 23). The alluvial valley is partially enclosed by mountains of crystalline, metamorphic or volcanic rocks which have been extensively eroded. The northern part of the valley averages about 5 miles in width, and rock pediments, extending toward the axis from the mountains, materially reduce the areas underlain by alluvial fill. The southern and western parts of the valley are about 12 miles wide, and pediments are less extensively developed.

The general geologic history of the region is discussed in Part I of this report. In the Gila Bend basin, much of the older alluvial fill was deposited at times when the basin had no outlet. After the Gila River had established through drainage, basaltic cinders and basalt flows of Quaternary age were erupted. Some of the lava flows dammed the river, forcing it to cut new channels, as may be observed at the present site of Gillespie Dam. Three terraces were formed by the Gila River as it deepened its channel through the alluvial fill.

After the surface of the lower terrace was formed, the Gila River cut a gorge about 80 feet deep which was partly refilled with Recent unconsolidated alluvium. The present river channel and flood plain have been cut into this material. The channel lies 5 to 15 feet below the flood plain in an inner valley about half a mile wide. The stream is now aggrading within this inner valley. A few irrigation wells obtain large amounts of water from the Recent alluvium in the western part of the basin.

The crystalline, metamorphic and volcanic rocks that comprise much of the outcrop area in the mountain ranges are not known to be water bearing in this basin.

Cretaceous(?) and Tertiary(?) sedimentary rocks are exposed in the Sand Tank and Gila Bend Mountains and underlie much of the area covered by

Quaternary volcanic rocks and later alluvium. These rocks are composed of interbedded lava flows, tuffs, fanglomerates, and porous sandstones. Material similar to these rocks was encountered at a depth of 1,100 feet in well (C-5-4)31db (table 32). No water has been obtained from the fanglomerate, but small amounts have been found at depth in porous sandstones interbedded with the fanglomerate.

In the western part of the basin, basal materials of the older alluvial fill rest on the fanglomerate and consist of about 800 feet of lake-bed clays, with some sand lenses. About 300 feet of sand and gravel with some clay overlies the lake beds. In the east part, wells have not encountered lake beds. Most of the irrigation wells in the eastern part of the Gila Bend basin are drilled into the older alluvial fill.

Ground-water hydrology

Occurrence and movement

The alluvial fills are the principal water-bearing formations in the Gila Bend basin and supply all the ground water used for irrigation. Aquifers in the older and younger valley fills are interconnected and form a continuous ground-water reservoir in the basin.

Depths to water in wells in the valley in general range from about 25 feet near the Gila River to more than 400 feet near the Sauceda Mountains. The depth to the water table in irrigation wells in the trough between the Gila Bend Mountains and the Maricopa Mountains ranges from about 70 to 100 feet (table 3[illegible] The depth to water along the Gila River in the western part of the area generally ranges from about 25 to 40 feet, but near the Painted Rock Mountains the water table is almost at the surface. The depth to water in the irrigated area around Theba is commonly more than 125 feet.

The slope of the water table in the valley fill is toward the Gila River and downstream, and approximates the land surface but with gentler gradients.

Recharge

Recharge into the ground-water reservoir of the Gila Bend basin occurs from four sources: (1) Flow in the Gila River; (2) canals and irrigation water applied to the land; (3) runoff in washes near the mountains; and (4) precipitation.

Flow in the Gila River.--Infiltration from the Gila River in some years is an important source of recharge to the ground-water reservoir of the basin. Quantitative data are not available, however, to determine the amount of this recharge. At infrequent periods, surface flow occurs in the river, and water percolates down to the water table through sands and gravels of the river channel. During the period 1945-51, flow past Gillespie Dam ranged from about 1,000 to 100,000 acre-feet per year and averaged about 13,000 acre-feet per year (Water-Supply Paper 1149, pp. 378-79, and unpublished records, Geol. Survey). The amount of water entering the basin as underflow in the channel of the Gila River at Gillespie Dam is probably small. Additional seepage may occur through volcanic rocks underlying the alluvial fill in the vicinity of Gillespie Dam.

Canals and irrigation water.--The recharge from irrigation water was not studied in the Gila Bend basin. Studies in Safford basin, Salt River Valley area, and other areas are probably applicable to the Gila Bend basin. Those studies show that about 15 to 20 percent of the water applied to the land and about 25 percent of water carried in canals is recharged to the ground-water reservoir. During the period 1946-51, it is estimated that approximately 40,000 to 50,000 acre-feet was recharged annually from these sources.

Runoff in washes near the mountains.--The recharge from runoff in washes passing over the materials near the mountain front was not studied in the Gila Bend basin. Studies in other basins suggest that in the Gila Bend basin perhaps less than 5 percent of the total rainfall occurring in the mountains is recharged to the ground-water reservoir. Precipitation data are not sufficiently detailed to permit making a quantitative estimate of such recharge, but it may be in the order of a few thousand acre-feet.

Precipitation.--Recharge to the ground-water reservoir by direct infiltration of rainfall in an average year is believed to be negligible. The average annual rainfall of about 6 inches is so small that most of it is returned to the atmosphere by evaporation and transpiration. Some recharge may occur from precipitation that falls on coarse materials in the various washes.

Discharge

Ground water is discharged from the Gila Bend basin by natural means and by pumping. Natural discharge includes underflow, surface flow, evaporation, and transpiration.

Natural discharge.--Underflow occurs at the western end of the basin where the Gila River passes through a gap between the Painted Rock and Gila Bend Mountains (pl. 23). The channels of the Gila River total about 1,200 feet in width, but the thickness of the alluvium is not known. The amount of underflow leaving the basin has not been estimated.

Some ground water leaves the basin as surface flow because the trough is constricted at the west end. It was estimated (Babcock and Kendall, 1948, p. 13) that this ground-water discharge averages less than 4,500 acre-feet per year.

The greater part of the natural discharge occurs by evaporation and transpiration in the river bottom. Such use of ground water is variable. The discharge of ground water by evapotranspiration in 1946 was stated to be from 50,000 to 100,000 acre-feet (Babcock and Kendall, 1948, p. 14). It is believed by the author of the present report that use by phreatophytes currently is less because of the decline in the water table.

Pumpage.--The principal development of ground water has occurred since 1937. In 1946, there were 17 irrigation wells discharging water into the Gila Bend Canal between the Gila Bend and Maricopa Mountains, and 7 irrigation wells near the Gila River discharged on to the irrigated fields in the western part of the basin. The wells in the western part of the basin develop most of their water in Recent alluvium. . Since 1946 about 20 new irrigation wells have been drilled in the older alluvium in the Rainbow Valley portion of the basin.

In 1946, about 21,000 acres was irrigated from ground-water and surface-water sources. The irrigated acreage has increased since 1946 to an estimated total of 30,000 acres in 1952. Most of the increase in irrigated acreage took place in Rainbow Valley since 1949. The following table summarizes, for the period 1946-51, the quantities of water used for irrigation from ground- and surface-water sources. The information on surface water was taken from published and unpublished gaging-station records of the Surface Water Branch of the Geological Survey.

Year	Ground water (acre-feet)	Surface water (acre-feet)	Rounded Total (acre-feet)
1946	33,300	88,660	122,000
1947	40,500	69,780	110,000
1948	60,800	49,070	110,000
1949	67,000	47,700	115,000
1950	59,000	36,810	96,000
1951	104,000	43,990	148,000

Well yields.--Most of the irrigation wells are 20 inches in diameter and are drilled to depths of about 500 feet in the older alluvial fill. The wells along the Gila Bend Canal had an average discharge in 1946 of 2,400 gallons per minute and an average discharge of 50 to 60 gallons per minute per foot of drawdown. Irrigation wells in the western part of the basin discharge 2,000 to 3,000 gallons per minute. The wells in that area are about 350 feet deep.

Quantities of water sufficient for domestic and stock use have been developed from the older valley fill on the higher slopes of the valley.

Water-level fluctuations

The withdrawal of ground water by irrigation wells in the northeastern part of the basin along the Gila Bend Canal has caused a net decline of the water table in their vicinity of 1 to 2 feet a year in the period 1945-51, with local water-level declines of as much as 4 feet in the years 1950-51. Water-level declines have been much less in the vicinity of the irrigation wells northwest of Gila Bend. Elsewhere in the basin, changes in water levels have been almost negligible.

Quality of water

The quality of water in the Gila Bend basin was discussed by J. D. Hem in an earlier report (Babcock and Kendall, 1948, pp. 14-17). No data have been obtained since that time, and the following paragraphs are a resume' of Mr. Hem's discussion. Analyses of waters from 11 wells are reproduced in table 33.

Ground water in the Gila Bend basin ranged from about 450 to 2,200 parts per million in total mineral content, and the surface flow diverted into canals at Gillespie Dam averaged about 4,000 parts per million. Sodium amd chloride predominate, but large concentrations of calcium and sulfate are also present. According to standards discussed in Part I of this report, the surface water would be considered "injurious to unsatisfactory" for irrigation. The amount of surface flow and underflow that leaves the basin is much less than the total flow that enters the basin. Concentrations of mineral matter in waters leaving the basin are about equal to concentrations of dissolved solids of waters entering the basin. Therefore, dissolved matter must be accumulating in the basin.

In general, ground waters are hard, salty, and contain fluoride concentrations in excess of 1.5 parts per million.

Problems for additional study in the Gila Bend basin

1. Quality-of-water studies are necessary in order to determine the rate of salt accumulation in the basin.
2. Discharge of ground water from the basin by underflow and by bottom-land vegetation should be studied.
3. Tests are needed to determine permeability and storage coefficients of the Recent alluvium and older alluvial fill.
4. Recharge from irrigation water in canals and on fields should be determined.

Summary

The Gila Bend basin lies entirely within Maricopa County, along the Gila River, between Gillespie Dam and the Painted Rock Mountains. The basin is about 36 miles long and covers an area of about 800 square miles.

The basin occupies parts of at least two structural troughs. The mountains are composed mostly of crystalline and volcanic rocks. Fanglomerates and interbedded volcanic rocks are overlain by the older alluvial fill. About 80 feet of Recent alluvial fill was deposited in a channel cut into older alluvial fill.

In 1946, about 21,000 acres was irrigated by both surface and ground water. Irrigated acreage has increased since 1946 to about 30,000 acres in 1952. Much of the increase has occurred in the Rainbow Valley area.

Ground water is obtained in small amounts from sandstones within the fanglomerate unit, and in larger quantities from the older and the Recent valley fills. The average discharge of wells in older alluvium was about 2,400 gallons a minute in 1946. Depths to water range from 25 to 400 feet in most parts of the basin. In the Recent alluvium well yields are slightly larger than from the older alluvium. Aquifers in the older alluvial fill and in Recent alluvium are interconnected.

The principal sources of recharge are flow of the Gila River below Gillespie Dam, and seepage from canals and fields.

Ground water is discharged from the basin mainly by evapotranspiration and by pumping. The total amount of ground water pumped by irrigation wells in 1951 was about 104,000 acre-feet.

The water table has shown persistent declines in the area of heavy pumping.

Water from most of the wells in the Gila Bend basin is high in dissolved mineral content, and most of it contains more than 1.5 parts per million of fluoride. Soluble salts are accumulating in the valley and are causing increased concentrations of dissolved matter in the ground water.

Table 31.--Records of representative wells in Gila Bend basin, Maricopa County, Ariz.

Well no.	Depth of well (feet)	Water Level: Depth below measuring point (feet) a/	Water Level: Date of measurement	Pump and power b/	Use of water c/	Remarks
(C-2-5)						
35ac	400	50.45	12-18-45	T,E	I	Measured discharge 2,150 gpm, 4-46. Log on file.
36cd	65	63.49	3-7-49	None	N	-
(C-3-4)						
6db	530	63.02	5-27-46	T,E	I	Measured discharge 3,020 gpm, 5-46. Log on file.
8bd	370	68.81	12-18-45	T,E	I	Measured discharge 2,080 gpm, 5-46. Log on file.
21bb	300	69.67	12-18-45	T,E	I	Measured discharge 2,600 gpm, 4-46. Log on file.
(C-3-5)						
2cb	256	25d/	-	T,E	I	Log on file.
(C-4-4)						
4aa	640	76.90	5-2-46	T,E	I	Measured discharge 2,350 gpm, 5-27-46. Log on file.
(C-4-6)						
29aa	340	31.50	1-15-46	None	N	Log on file.
(C-5-4)						
31db	1,746	-	-	T,E	Ind.	Reported discharge 150 gpm. Log on file

a/ Measuring point was usually top of casing, top of pump base, or top of well curb.
b/ T, turbine; C, cylinder; E, electric motor; G, gasoline or natural gas; W, windmill; D, diesel.
c/ I, irrigation; Ind., industrial; S, stock; D, domestic; N, not used.
d/ Water level reported.

Table 31.--Records of representative wells in Gila Bend basin--continued.

Well no.	Depth of well (feet)	Water level: Depth below measuring point (feet)[a]	Water level: Date of measurement	Pump and power[b]	Use of water[c]	Remarks
(C-5-5)						
13dc	-	32.78	1-1-52	C,W	D	-
(C-5-6)						
2db	418	19.93	1-15-46	T,D	I	Measured discharge 1,900 gpm, 4-29-45.
13ac	280	30[d]	-	T,D	I	Measured discharge 2,780 gpm, 4-46.
(C-6-6)						
4aa	244	124.22	1-1-52	C,G	D	Log on file.

Table 32.--Logs of representative wells in Gila Bend basin, Maricopa County, Ariz.

	Thickness (feet)	Depth (feet)
(C-2-5)35ac		
Silt	30	30
Gravel	28	58
Coarse sand	3	61
Caliche	9	70
Caliche and clay	8	78
Clay and gravel	18	96
Caliche	6	102
Sandy clay	48	150
Clay and gravel	6	156
Sandy clay	47	203
Gravel	22	225
Loose gravel	20	245
Clay and gravel	15	260
Gravel	20	280
Clay and gravel	28	308
Sand and gravel	6	314
Clay and gravel	16	330
Gravel	10	340
Sand and gravel	12	352
Clay and gravel	48	400
TOTAL DEPTH		400
(C-3-4)6db		
Sandy silt	39	39
Gravel	31	70
Clay, sand, and gravel	20	90
Clay and small gravel	130	220
Hard clay and gravel	276	496
Cemented gravel	34	530
TOTAL DEPTH		530
(C-3-4)8bc		
Clay	18	18
Hard packed clay	4	22
Gravel to 6 inche-	4	26
Clay and gravel	12	38
Clay sand	19	57
Gravel	22	79
Clay and caliche	7	86
Clay and gravel	50	136
Gravel, clay, and streaks of conglomerate	38	174
Gravel	5	179
Gravel, clay, and streaks of conglomerate	25	204
Cemented gravel	5	209
Gravel, clay, and cemented gravel	17	226
Coarse sand and gravel	48	274
Cemented gravel	2	276
Coarse sand and gravel	94	370
TOTAL DEPTH		370
(C-3-4)21bb		
Soil	2	2
Clay	4	6
Sand and clay	9	15
Clay and small gravel	15	30
Sand	11	41
Clay	29	70
Sand (water)	10	80
Small gravel	9	89
Clay and gravel	21	110
Small gravel	39	149
Shell, hard	2	151
Gravel	15	166
Shell	7	173
Gravel and shell	53	226
Loose gravel	74	300
TOTAL DEPTH		300
(C-3-5)2cb		
Sandy soil	6	6
Clay	3	9
Sandy clay	1	10
Clay	2	12
Coarse gravel (first water at 25 feet)	20	32
Decomposed granite gravel	150	182
Granite gravel in clay	38	220
Decomposed granite gravel	25	245
Granite gravel in clay	3	248
Decomposed granite gravel	8	256
TOTAL DEPTH		256

Table 32.--Logs of representative wells in Gila Bend basin--continued.

	Thickness (feet)	Depth (feet)
(C-4-4)4aa		
Loose gravel	40	40
Caliche	68	108
Gravel	16	124
Clay and gravel	56	180
Caliche, clay and gravel	75	255
Sand and gravel	15	270
Clay and gravel	40	310
Soft clay and gravel	90	400
Decomposed granite	220	620
Granite	20	640
TOTAL DEPTH		640

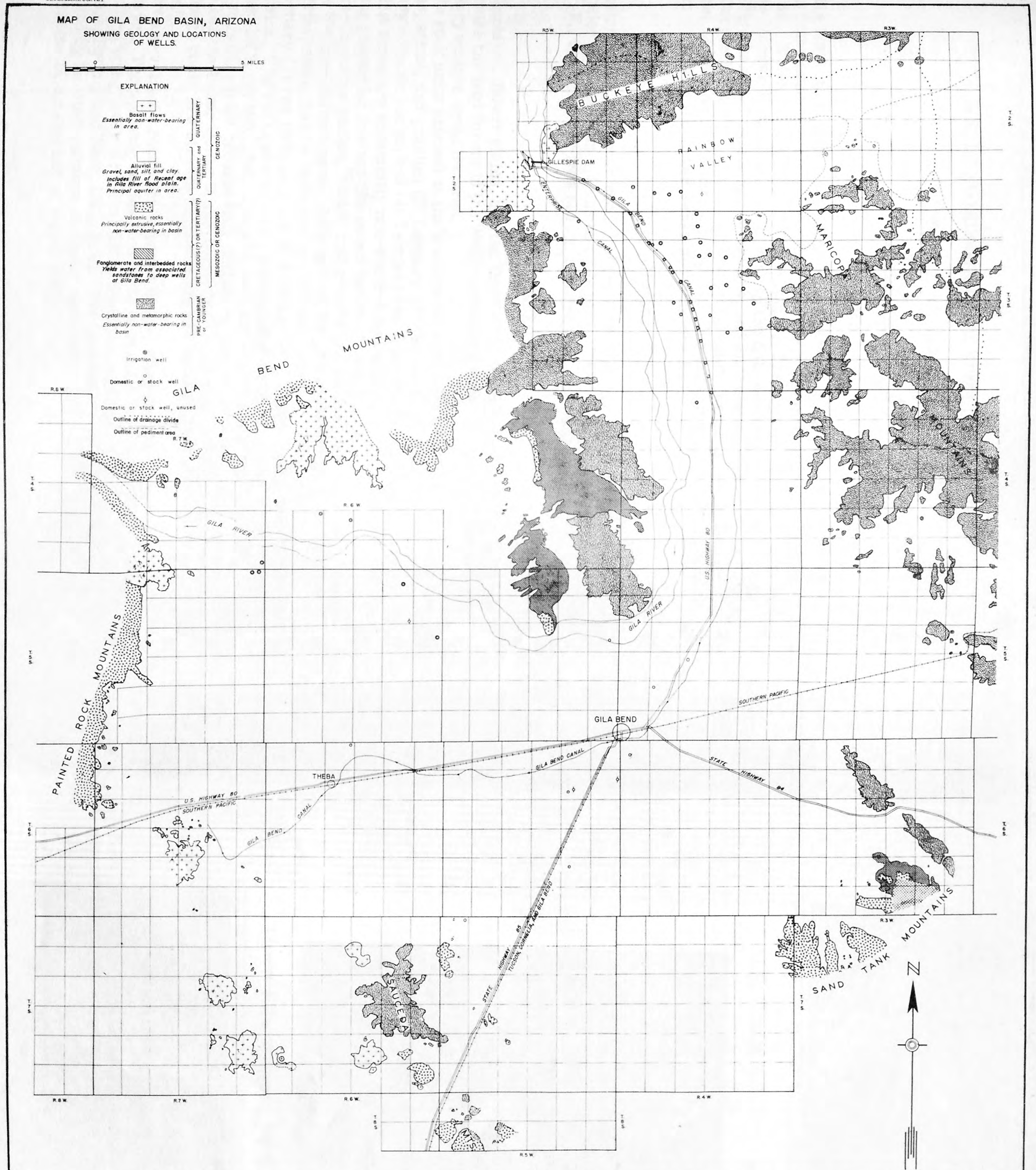
	Thickness (feet)	Depth (feet)
(C-4-6)29aa		
Soil	5	5
Gravel in clay	7	12
Clay	24	36
Gravel	4	40
Shells and gravel in clay	196	236
Gravel	6	242
Shells and gravel in clay	44	286
Gravel	16	302
Shell	8	310
Gravel in clay	14	324
Hard clay	6	330
Gravel in clay	10	340
TOTAL DEPTH		340

	Thickness (feet)	Depth (feet)
(C-5-4)31db		
Sand and gravel	25	25
Clay and boulders	20	45
Fine sand	20	65
Fine gravel	15	80
Coarse gravel	12	92
Clay	53	145
Fine sand (water-bearing)	30	175
Sandy clay	50	225
Fine sand	10	235
Sandy clay	235	470
Clay (hot mud)	410	880
Cemented clay	20	900
Coarse sand	5	905
Hard clay	215	1120
Hard clay and rock	50	1170
Sand	15	1185
Sand and rock	25	1210
Rock	49	1259
Clay with gravel	12	1271
Rock	13	1284
Clay and gravel	23	1307
Rock	5	1312
Clay and gravel	10	1322
Red rock	9	1331
Clay and gravel	24	1355
Light rock	6	1361
Clay and gravel	32	1393
Quartz rock	5	1398
Cemented gravel	18	1416
Clay	11	1427
Cemented gravel	18	1445
Clay	20	1465
Boulders in clay	9	1474
Clay and gravel	21	1495
Boulders in clay	15	1510
Clay and gravel	20	1530
Rock	25	1555
Clay	13	1568
Hard rock	33	1601
Clay	11	1612
Rock	9	1621
Clay	19	1640
Rock	7	1647
Clay	17	1664
Rock	9	1673
Clay	8	1681
Rock	13	1694
Clay	14	1708
Rock	6	1714
Sand	18	1732
Clay	8	1740
Rock	6	1746
TOTAL DEPTH		1746

	Thickness (feet)	Depth (feet)
(C-6-6)4aa		
Soil	4	4
Caliche	20	24
Fine dry sand and packed gravel	50	74
Caliche	15	89
Conglomerate	64	153
Red clay	15	168
Quicksand	5	173
Red clay	19	192
Fine sand	27	219
Red clay and sand	25	244
TOTAL DEPTH		244

Table 33.--Analyses of water from representative wells in Gila Bend basin, Maricopa County, Ariz.
(Parts per million except specific conductance and percent sodium)

Well no.	Date of collection	Depth (feet)	Specific conductance (micromhos @25° C.)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Total hardness as $CaCO_3$	Percent sodium
(C-2-5) 35ac	4-9-46	400	3,770	202	71	503	257	327	945	0.7	5.7	2,180	796	58
(C-3-4) 6db	5-27-46	530	2,680	–	–	–	233	–	645	–	–	–	–	–
8bd	5-27-46	370	2,860	–	–	–	256	–	690	–	–	–	–	–
21bb	4-10-46	300	2,690	134	46	361	186	205	660	1.1	11	1,510	524	60
(C-4-4) 4aa	5-27-46	640	2,780	–	–	–	240	–	660	–	–	–	–	–
(C-4-6) 29aa	4-12-46	340	3,720	135	62	580	230	280	965	2.7	5.4	2,140	592	68
(C-5-4) 31db	2-5-46	1,746	1,850	22	1.6	365	47	130	465	6.9	8.8	1,060	62	93
(C-5-6) 2db	4-10-46	418	1,680	50	9.4	293	191	92	382	2.6	2.9	926	164	80
(C-6-6) 4aa	4-10-46	280	3,460	118	39	565	236	181	915	2.3	5.9	1,940	455	73
(C-7-5) 6aa	1-31-46	290	1,200	23	4.4	227	107	124	236	6.9	2.0	676	76	87
(C-8-5) 2bd	1-31-46	495	724	36	18	102	303	34	32	0.4	68	440	164	57


MAP OF GILA BEND BASIN, ARIZONA
SHOWING GEOLOGY AND LOCATIONS OF WELLS.
0
5 MILES
EXPLANATION
Basalt flows
Essentially non-water-bearing in area.
QUATERNARY
Alluvial fill
Gravel, sand, silt, and clay.
Includes fill of Recent age in Gila River flood plain.
Principal aquifer in area.
QUATERNARY and TERTIARY
CENOZOIC
Volcanic rocks
Principally extrusive, essentially non-water-bearing in basin
Fanglomerate and interbedded rocks
Yields water from associated sandstones to deep wells at Gila Bend.
CRETACEOUS(?) OR TERTIARY(?)
MESOZOIC OR CENOZOIC
Crystalline and metamorphic rocks
Essentially non-water-bearing in basin
PRE-CAMBRIAN or YOUNGER
Irrigation well
Domestic or stock well
Domestic or stock well, unused
Outline of drainage divide
Outline of pediment area
BUCKEYE HILLS
RAINBOW VALLEY
GILLESPIE DAM
ENTERPRISE CANAL
GILA BEND CANAL
MARICOPA MOUNTAINS
GILA BEND MOUNTAINS
GILA RIVER
US HIGHWAY 80
PAINTED ROCK MOUNTAINS
GILA BEND
SOUTHERN PACIFIC
THEBA
GILA BEND CANAL
STATE HIGHWAY 84
US HIGHWAY 80
SAUCEDA MTS
STATE HIGHWAY 85
TUCSON, CORNELIA, AND GILA BEND
SAND TANK MOUNTAINS
N
R.5W.
R.4W.
R.3W.
R.8W.
R.7W.
R.6W.
R.5W.
T.2S.
T.3S.
T.4S.
T.5S.
T.6S.
T.7S.
T.8S.

WELLTON-MOHAWK AREA, YUMA COUNTY

By D. G. Metzger

Introduction

Location

The Wellton-Mohawk area occupies about 700 square miles and extends from Dome upstream along the Gila River for a distance of about 40 miles (pl. 24). It lies entirely within Yuma County. The area is bounded on the east by the Mohawk Mountains; on the west by the Gila Mountains; on the north by the Muggins and Castle Dome Mountains; and on the south by the Wellton Hills, the Copper Mountains, and an arbitrary line extending northeast from the Copper Mountains to the town of Mohawk. The area is partially separated into two valleys by the Baker Peaks and Antelope Hill.

Climate

According to a 43-year record of the U. S. Weather Bureau, the average precipitation at Mohawk is 4.43 inches per year. The mean annual temperature is 74.2° F., and the frost-free season is more than 11 months.

Geology

Mountains, desert plains, and the flood plain and terraces of the Gila River constitute the land forms in the Wellton-Mohawk area. The Gila River and its tributary washes drain the area.

The rock units exposed in the Wellton-Mohawk area are: (1) Pre-Cambrian gneiss, schist, and granite; (2) Tertiary (?) red beds; (3) Tertiary and Quaternary volcanic rocks; and (4) Tertiary and Quaternary alluvium. Of these, the first three are essentially non-water-bearing in the area, and their water-bearing properties are not discussed further in this report.

Pre-Cambrian gneiss, schist, and granite are exposed in all mountain ranges in the Wellton-Mohawk area. Although all the granite is assigned to the pre-Cambrian, some may be Mesozoic or Tertiary in age (Wilson, 1933, p. 185).

Tertiary (?) red beds crop out in Antelope Hill, Baker Peaks, and the Mohawk Mountains. The rocks are arkosic, consolidated sandstones and conglomerates (Wilson, 1933, pp. 150, 169). The red beds are regarded as older than the Tertiary volcanic series because they contain no lava fragments. Bryan (1925, p. 62) describes the Baker Tanks in the Tertiary (?) red beds as "a group of potholes and plunge pools in a stream channel along the southwestern flank of Baker Peaks."

Tertiary volcanic rocks are exposed in the Muggins and Castle Dome Mountains. The volcanic series "consists of several hundred feet of flat-lying to gently-dipping, well-stratified tuffs, breccias, agglomerates, and lava flows" (Babcock, Brown, and Hem, 1947, p. 4). The Quaternary volcanic rocks are represented by isolated outcrops of highly vesicular, dark-colored basalt in the Castle Dome Mountains and at Signal Butte.

The sediments exposed near Dome and in the Muggins Mountains, between the two outcrops of volcanic rocks, occur as a thick series of light-colored, locally stratified clay and silt. These sediments are part of the older alluvial fill. They may be related in age to the marine sediments of Miocene or Pliocene age exposed along the Colorado River (Wilson, 1933, pp. 31-32).

The alluvial fill in the area includes materials of Tertiary and Quaternary age. The older part of this series has been designated as "older alluvium," the younger part as "Recent alluvium." Well logs show that the older alluvium is composed of two general lithologic units. The upper unit is about 200 feet thick and is composed of lenses of silt, sand, and gravel. The lower unit is of much greater thickness and is predominantly clay. The Recent alluvium underlies the flood plain of the Gila River, and contains the principal aquifers in the area. It is about 100 feet thick, 2 to 4 miles wide, and is composed of unconsolidated gravel, sand, and silt.

Wellton-Mohawk Project

Public Law 272 limits the lands in the area to be supplied with Colorado River water to 75,000 acres. The area being developed by the U. S. Bureau of Reclamation extends from the vicinity of Dome upstream to Texas Hill, 3 miles east of the eastern boundary shown on plate 24. By September 1952 part of the canal system had been completed and some Colorado River water was being brought into the area. More acreage will be supplied as the canals and pumping stations are completed, and it is planned that a total of 75,000 acres will be irrigated by 1960. Assuming a duty of water of 5 to 6 acre-feet per acre per year, about 400,000 acre-feet of water will be applied to the lands annually after the project is completed. This will have a marked effect on the ground-water resources of the area, as explained in the following sections.

Ground-water resources

Occurrence and movement

Wells in the older alluvium are reported to yield 500 to 1,000 gallons per minute from the sand and gravel of the upper 200 feet. Wells in the Recent alluvium yield from 600 to 4,000 gallons per minute. In 1946 all irrigation water was derived from wells in the Recent alluvium.

The movement of ground water in 1946 (Babcock, Brown, and Hem, 1947, pl. 1) was generally westward, down the valley of the Gila River. There were variations in this trend near Roll and Wellton, where pumping had altered the gradients. Sufficient water-level measurements were not made in 1952 to provide a basis for plotting contours of the water table.

Recharge

Recharge to the alluvial fill is from the following sources: (1) Runoff in the Gila River and its tributaries; (2) irrigation; and (3) underflow of the Gila River into the area.

Percolation to the ground-water reservoir by runoff from rainfall is one of the principal sources of recharge in the Wellton-Mohawk area. Babcock, Brown, and Hem (1947, p. 8) state that most of the runoff in the smaller washes disappears by seepage into the stream-bed materials, and that surface flows seldom reach the Gila River. Data on runoff in washes are not available and therefore no figure for recharge from this source can be provided. Surface flow in the Gila River occurs at infrequent intervals. Seepage losses from surface flow percolate readily down through the coarse sand and gravel of the river channel to the water table. There is believed to be little recharge to the ground-water reservoir directly from rainfall on the valley floor (Turner and others, 1943, p. 35).

Recharge to the ground-water reservoir from irrigation seepage in 1944-45 was estimated to be about 25 percent of the water applied to cultivated areas (Babcock, Brown, and Hem, 1947, p. 8). Applying this estimate to 1951 pumpage, the recharge from this source in 1951 was more than 10,000 acre-feet. The amount of recharge from irrigation seepage will increase as more land is supplied with water from the Wellton-Mohawk canal. It is anticipated that by 1960, about 400,000 acre-feet of water will be applied annually to the land. If 25 percent of this water is recharged, the amount from this source will be about 100,000 acre-feet per year.

Underflow of the Gila River into the Wellton-Mohawk area was estimated to be 5,000 acre-feet per year in 1947 (Babcock, Brown, and Hem, 1947, p. 8).

Discharge

Ground water is discharged from the area by pumping for irrigation and by natural means.

The amount of water pumped from irrigation wells in the area in the period 1945-51 is shown in figure 22. The land now under cultivation is within the Wellton-Mohawk Project, and therefore pumping for irrigation will decrease as more land is supplied with project water. It is expected that the water table will rise owing to seepage from irrigation, and that ground water will have to be pumped for drainage purposes.

Natural discharge includes transpiration and evaporation of ground water in areas of dense growth of natural vegetation along the river channel, and an estimated 1,000 acre-feet per year of underflow out of the area through the narrows near Dome. There was practically no natural discharge of ground water by surface flow out of the area during the period 1941 to September 1, 1951.

Provisional stream-flow records for the period September 1, 1951, to September 1, 1952, are as follows:

Month	Discharge, in acre-feet
1951	
September	6,040
October	245
November	37
December	25

Month	Discharge, in acre-feet
1952	
January	45
February	15
March	19
April	145
May	909
June	0
July	0
August	0

Natural discharge from the area will increase as construction of the Wellton-Mohawk Project advances. When this increase will reach a maximum is not known.

On the assumption that the water table will rise, the following generalizations can be drawn. Transpiration by phreatophytes and evaporation will increase. Annual underflow out of the area, estimated to be 1,000 acre-feet (Babcock, Brown, and Hem, 1947, p. 10), will increase as the water table rises. Eventually the ground-water reservoir will supply perennial surface flow from the area. Drainage wells are planned, and if these wells are successful, part of the natural discharge by evapotranspiration will be minimized.

Fluctuations of the water table

There has been a slight downward trend of the water table in the area due to pumping during the period 1945-52 (fig. 22). The greatest decline was in the Roll area where about 10 feet was observed, an average of only 1.4 feet per year Now that water from the Wellton-Mohawk Project is reaching the area, it is expected that the water table will rise.

Storage

The amount of ground water in storage in the area is not known. Data are not available with which to determine the coefficient of drainage. The introduction of surface water to the area will eliminate withdrawals of ground water for irrigation. Therefore, the need for a knowledge of the quantity of ground water in storage is less than in other parts of Arizona.

Quality of water

No samples of ground water have been collected in the area since 1946. The following is quoted from Babcock, Brown, and Hem (1947, p. 14):

> The ground water in the younger alluvial fill of the area is highly mineralized, and most of it is "injurious to unsatisfactory" for irrigation. One well in the area yielded water containing 22.4 tons of dissolved matter per acre-foot. Generally, wells in the older alluvial fill yield water that is less highly mineralized than water from the younger fill. The most highly mineralized ground waters occur in the

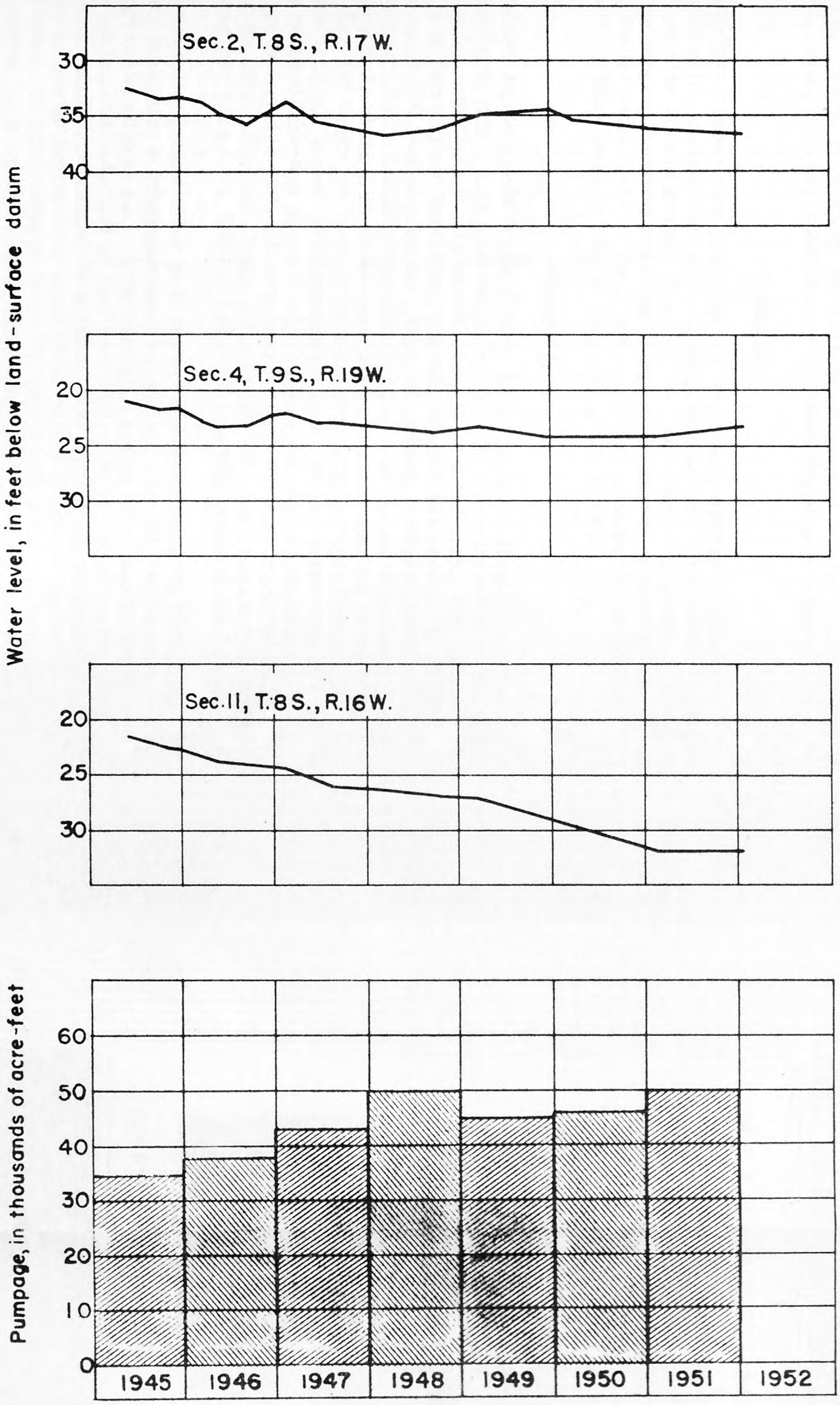


Figure 22.--Graphs showing fluctuations of water level in observation wells and pumpage in Wellton-Mohawk area, Yuma County.

irrigated district. Because only a small amount of dissolved salts can leave the basin, the concentration of dissolved matter in ground waters of the area is increasing. In one well, for example, the dissolved mineral content has increased 10 times since 1927.

A list of analyses of water from wells is contained in a report by Babcock and Sourdry (1948, pp. 37-39).

The introduction of surface water to the area will cause changes in the quality of the ground water. Initially there will be a dilution of the highly mineralized ground water, caused by recharge from irrigation seepage. Later, as the water table rises, evaporation and transpiration by phreatophytes will increase.

Problems

The principal ground-water problems that previously existed in the area were related to the undesirable quality of the ground water. After surface water is brought into the area to irrigate 75,000 acres, the principal problem is expected to be keeping the water table sufficiently depressed to prevent waterlogging of the irrigated lands. This problem has been anticipated, and the installation of drainage wells is planned as a part of the project.

Summary

The Wellton-Mohawk area, Yuma County, Ariz., occupies about 700 square miles and extends from Dome upstream along the Gila River for about 40 miles.

The alluvium contains the only important aquifers in the area. The older alluvium is of Tertiary and Quaternary age and includes two general lithologic units--the upper 200 feet contains silt, sand, and gravel; the lower unit is of much greater thickness and is predominantly clay. The Recent alluvium underlies the flood plain of the Gila River and contains the best aquifers in the area.

Public Law 272 limits the lands in the area to be supplied with Colorado River water to 75,000 acres. Upon completion of the project authorized by that law, about 400,000 acre-feet of water will be applied to the land annually.

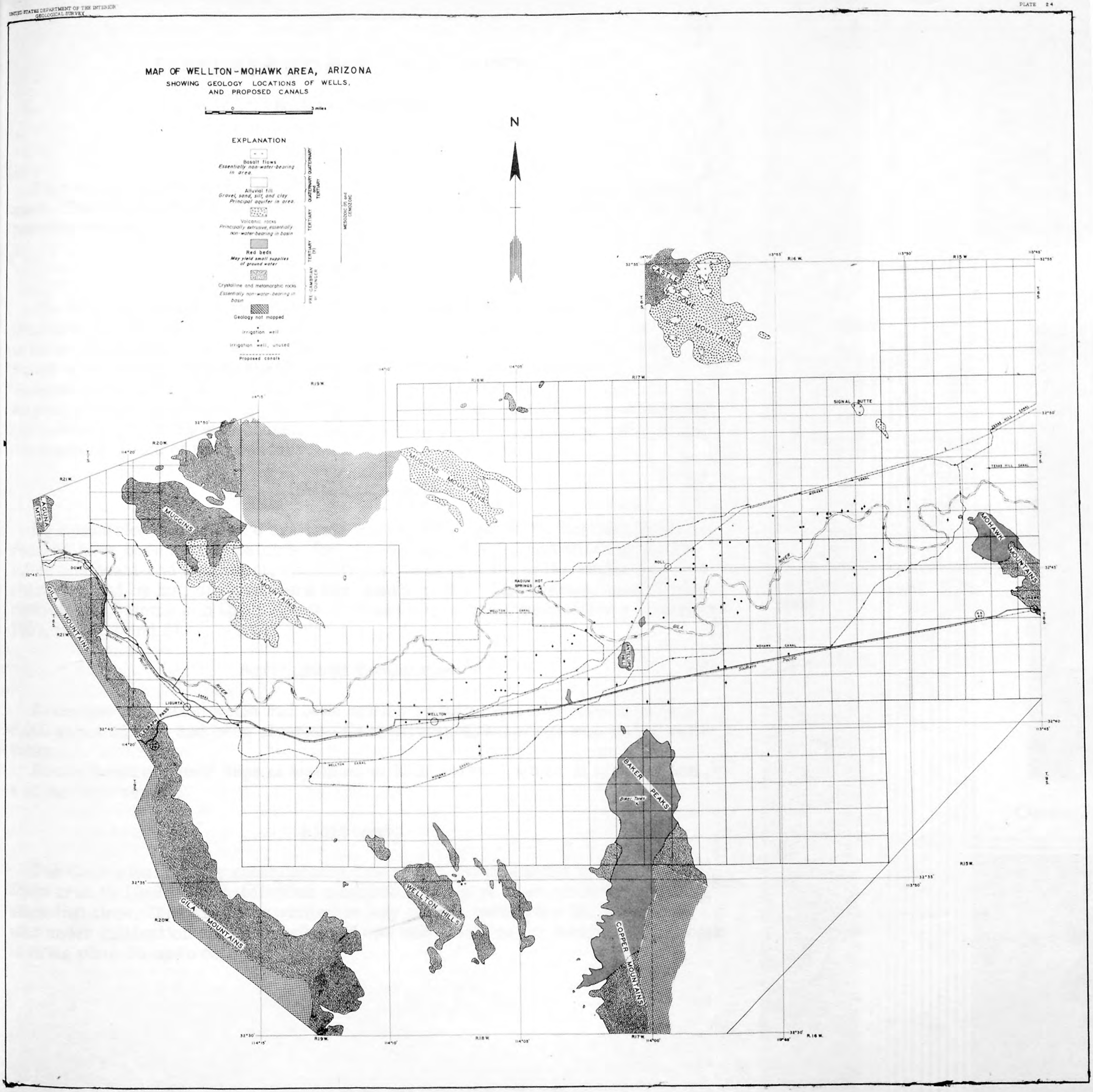
Wells are reported to yield 500 to 1,000 gallons per minute from the upper 200 feet of the older alluvium. Wells in the Recent alluvium produce from 600 to 4,000 gallons per minute. In 1946 all irrigation was from wells in the Recent alluvium.

The movement of ground water is in general westward, down the Gila River Valley, with variations in gradient caused by pumping near Roll and Wellton.

Recharge to the alluvial fill is from runoff in the Gila River and its tributaries, irrigation, and underflow of the Gila River. The amount of recharge by percolation of runoff from rainfall is unknown. Recharge from irrigation seepage in 1944-45 was estimated to be about 25 percent of the water applied to cultivated areas. In 1951 recharge from this source was estimated to exceed 10,000 acre-feet. It is estimated that, upon completion of the Wellton-Mohawk Project, recharge from irrigation seepage may be about 100,000 acre-feet annually. In 1947 underflow of the Gila River into the Wellton-Mohawk area was estimated to be 5,000 acre-feet per year.

Ground water is discharged from the area by pumping for irrigation and by natural means. Pumpage in 1951 was 50,000 acre-feet. Pumpage for irrigation will decrease as more land is brought under the project. It is expected that the water table will rise owing to seepage from irrigation, and that ground water will have to be pumped for drainage. Natural discharge includes transpiration and evaporation of ground water in the areas of dense growth of natural vegetation along the river channel. It also includes underflow out of the area through the narrows near Dome, which was estimated in 1947 to be 1,000 acre-feet per year. Natural discharge will increase as the water table rises.

The ground water in the Tertiary and Quaternary alluvium is highly mineralized. After completion of the project, there is expected to be an improvement in the quality of the ground water because the water brought in will be of better quality. Later, as the water table rises, there may be an increase in mineral content caused by increased evaporation and transpiration.


MAP OF WELLTON-MOHAWK AREA, ARIZONA
SHOWING GEOLOGY LOCATIONS OF WELLS, AND PROPOSED CANALS
3 miles
N
EXPLANATION
Basalt flows
Essentially non-water-bearing in area
Alluvial fill
Gravel, sand, silt, and clay
Principal aquifer in area
Volcanic rocks
Principally extrusive, essentially non-water-bearing in basin
Red beds
May yield small supplies of ground water
Crystalline and metamorphic rocks
Essentially non-water-bearing in basin
Geology not mapped
Irrigation well
Irrigation well, unused
Proposed canals
QUATERNARY
QUATERNARY AND TERTIARY
TERTIARY
TERTIARY (?)
PRE-CAMBRIAN OR YOUNGER
MESOZOIC (?) and CENOZOIC
CASTLE DOME MOUNTAINS
MUGGINS MOUNTAINS
MOHAWK MOUNTAINS
GILA MOUNTAINS
LAGUNA MTS
WELLTON HILLS
BAKER PEAKS
COPPER MOUNTAINS
SIGNAL BUTTE
RADIUM HOT SPRINGS
ROLL
WELLTON
LIGURTA
DOME
GILA RIVER
WELLTON CANAL
MOHAWK CANAL
TEXAS HILL CANAL
Southern Pacific
R.21W.
R.20W.
R.19W.
R.18W.
R.17W.
R.16W.
R.15W.
32°50'
32°45'
32°40'
32°35'
32°30'
114°20'
114°15'
114°10'
114°05'
114°00'
113°55'
113°50'
113°45'

RANEGRAS PLAIN AREA, YUMA COUNTY

By D. G. Metzger

Introduction

This report is, for the most part, a condensation of a report previously issued. The accompanying map (pl. 25) is a revision of the map prepared for the previous report.

Location

The area discussed in this report is in northern Yuma County, Ariz., and is limited to the northern part of a valley known as the Ranegras Plain. The area is known locally as "the Bouse country." It is bounded on the north by the Bouse Hills, on the east by the Granite Wash Mountains, on the west by the Plomosa Mountains, and on the south by a line along latitude 33°40′ (pl. 25). Although the plain extends approximately 25 miles southeast of the area mapped, the southern boundary was chosen arbitrarily because there was no agricultural development south of the boundary.

Climatological data

No climatological data are available for the area, but U. S. Weather Bureau records have been kept at Salome (pl. 1) and Quartzite, communities about 25 miles southeast and southwest, respectively. The climate of the region is characterized by hot, dry summers and mild winters. The average annual precipitation at Salome and Quartzite is 8.56 and 6.04 inches, respectively (Metzger, 1951, tables 1 and 2).

Agricultural development

Seventeen irrigation wells had been drilled by July 1952, and approximately 6,000 acres of land had been cleared. Of this total, 4,000 acres was under cultivation.

Records and drillers' logs of wells as of June 1949 are given in tables 3 and 4 of the 1951 report.

Field work

The Geological Survey established a line of observation wells in the Ranegras Plain area in 1949. Depth-to-water measurements have been made annually since that time. The area was visited in July 1952 to determine the amount of land under cultivation and the number of new wells drilled for irrigation, in order to bring plate 25 up to date.

Geology

The land surface of Ranegras Plain slopes gently northwest and is drained by Bouse Wash and its tributaries. The Granite Wash Mountains and the Plomosa Mountains have less relief on their eastern slopes than on their western slopes. The Bouse Hills are lower and less rugged than the other mountains in the area.

Faulting has been important in forming the mountains in the region. This faulting probably started with the earliest granitic intrusions and has continued until Recent time. Much of the recognizable faulting undoubtedly occurred during Cretaceous and Tertiary time. The structural trend of the region is predominantly northwest and Ranegras Plain is elongated in the same direction.

Rocks ranging in age from pre-Cambrian to Recent occur in the Ranegras Plain area. The rock units were discussed in the 1951 report. Only the alluvial fill, which yields water to wells for irrigation, is considered in this report.

The older alluvium of Tertiary (?) age is represented by clay and small amounts of sand and gravel encountered in drilling the deeper irrigation wells. The upper part of these sediments possibly may be of Pleistocene age but no fossils have been discovered in the alluvium. Lakes and playas are known to have existed in the Basin and Range Province during Pliocene (Knechtel, 1938, pp. 196-200) and Pleistocene (Meinzer, 1922, pp. 541-552) time, and it is probable that this concept applies to the older alluvium in Ranegras Plain. It is possible, however, that the sediments were deposited in an estuary. Marine sediments of Miocene or Pliocene age have been reported from various places along the Colorado River (Wilson, 1933, pp. 31-32).

The Quaternary alluvium in the Ranegras Plain area generally does not exceed a few hundred feet in thickness. The sand and gravel of this alluvium constitute the best aquifers in the area. It is probable that the Quaternary materials were deposited either as alluvial fans or in erosion channels cut into Tertiary(?) alluvium. However, there is no topographic or geologic expression on the surface of the plain that indicates the presence of buried alluvial-fan deposits or channels.

There is no indication that the Ranegras Plain ever was occupied by a major stream, and the alluvium probably was deposited by side washes that flowed only during periods of heavy rainfall. Where these streams emerged from the mountains and spread out upon the plain the velocity decreased, resulting in deposition of coarse materials in alluvial fans that were gradually extended some distance out from the mountains. The finer materials --clay and silt -- were carried farther out and deposited near the center of the valley.

The youngest Quaternary alluvium is Recent fill along Bouse Wash and Cunningham Wash and in the beds of the many washes extending from the mountain fronts. The Recent alluvium is coarse and unconsolidated. It is through these deposits that the ground-water reservoir receives the largest recharge.

Ground-water resources

Occurrence and movement

Ground water occurs in both the Tertiary (?) and Quaternary alluvium that forms the valley fill of Ranegras Plain. The best aquifers are sand and gravel lenses of the Quaternary alluvium. The rock units of the mountain masses are considered of little value for the storage or transmission of ground water because the rocks are relatively impermeable and the units are discontinuous owing to faulting. Wells sunk along fracture zones may yield limited quantities of ground water.

The water table in the alluvium forms a comparatively uniform surface. In most of the valley the slope of the water table is less than that of land surface, and the depth to water becomes progressively greater upstream and from Bouse Wash toward the mountains.

The movement of ground water in the area is predominantly northwest. Some ground water enters the area from the northeast as underflow from Butler Valley. A ground-water barrier underlies Bouse Wash about 1 1/2 miles northwest of Bouse, and its presence is shown by an abrupt change in depth to water. The depth to water is 30 feet near Bouse and for 1 mile downstream. In the next mile the depth to water increases to more than 100 feet.

Lines of equal depth to water in 1949 are shown on plate 25. Measurements in observation wells since 1949 show that cones of depression are forming beneath some of the cultivated areas. The cones have not yet spread sufficiently to affect water levels in wells outside the irrigated areas.

Recharge

Recharge to the aquifers of Ranegras Plain is derived from the following sources: (1) Runoff from rainfall; (2) underflow from Butler Valley; and (3) seepage from irrigation.

Bouse Wash, Cunningham Wash, and tributary washes from the mountains are ephemeral and flow only after a heavy rain or cloudburst. It is probable that the largest quantity of recharge to the ground-water reservoir is derived from stream flow following these heavy rains. Babcock and Cushing (1942, pp. 49-56) made a study of recharge to the ground-water reservoir from a typical desert wash. They state: "about half of the flow of Queen Creek at the mouth of its canyon was recharged to the ground water." Little or no recharge is derived from rainfall on desert areas. The greater part of the rainfall absorbed by the soil is probably lost by evaporation and transpiration (Turner, 1943, p. 42).

It is not known how much underflow moves from Butler Valley into Ranegras Plain, but the quantity is believed to be small in comparison with the total recharge.

The amount of recharge from irrigation is probably small at present because the soil is silty and only a relatively small amount of land is under cultivation.

The estimated average annual recharge in Ranegras Plain is given in the 1951 report as follows: "It may be as little as 5,000 acre-feet....and it probably does not exceed 20,000 acre-feet per annum."

Discharge of ground water

Discharge of ground water from Ranegras Plain is by pumping and by the natural processes of underflow and transpiration.

The amount of ground water pumped for irrigation has not been determined but it probably will not exceed 20,000 acre-feet in 1952.

Ground water is discharged by underflow over the ground-water barrier northwest of Bouse. The amount of ground water discharged due to transpiration by mesquite is small because only near Bouse is the water table sufficiently near the surface to support phreatophytes.

Storage

Data are not available for making an estimate of the quantity of ground water stored in the area. The first large irrigation wells were drilled in 1948. There has been no opportunity to determine coefficients of drainage by pumping tests or by laboratory tests.

Quality of water

Data about the chemical quality of the ground waters in the area indicate that the dissolved solids range from about 400 to about 3,700 parts per million. The more highly mineralized waters are near the center of the basin, and the less mineralized waters are near the recharge areas. On the basis of specific conductance and percent sodium, the waters near the center of the basin range from permissible to unsuitable for irrigation use. Most of the ground waters analyzed were high in fluoride, ranging from 3.8 to 8.9 parts per million. Dissolved solids are discharged from the basin in the surface flow and underflow of Bouse Wash. A more detailed discussion of the chemical analyses of water from wells in Ranegras Plain was given in the 1951 report. A list of the analyses is contained in table 5 of that report. No additional water samples have been collected for analysis since that time.

Summary

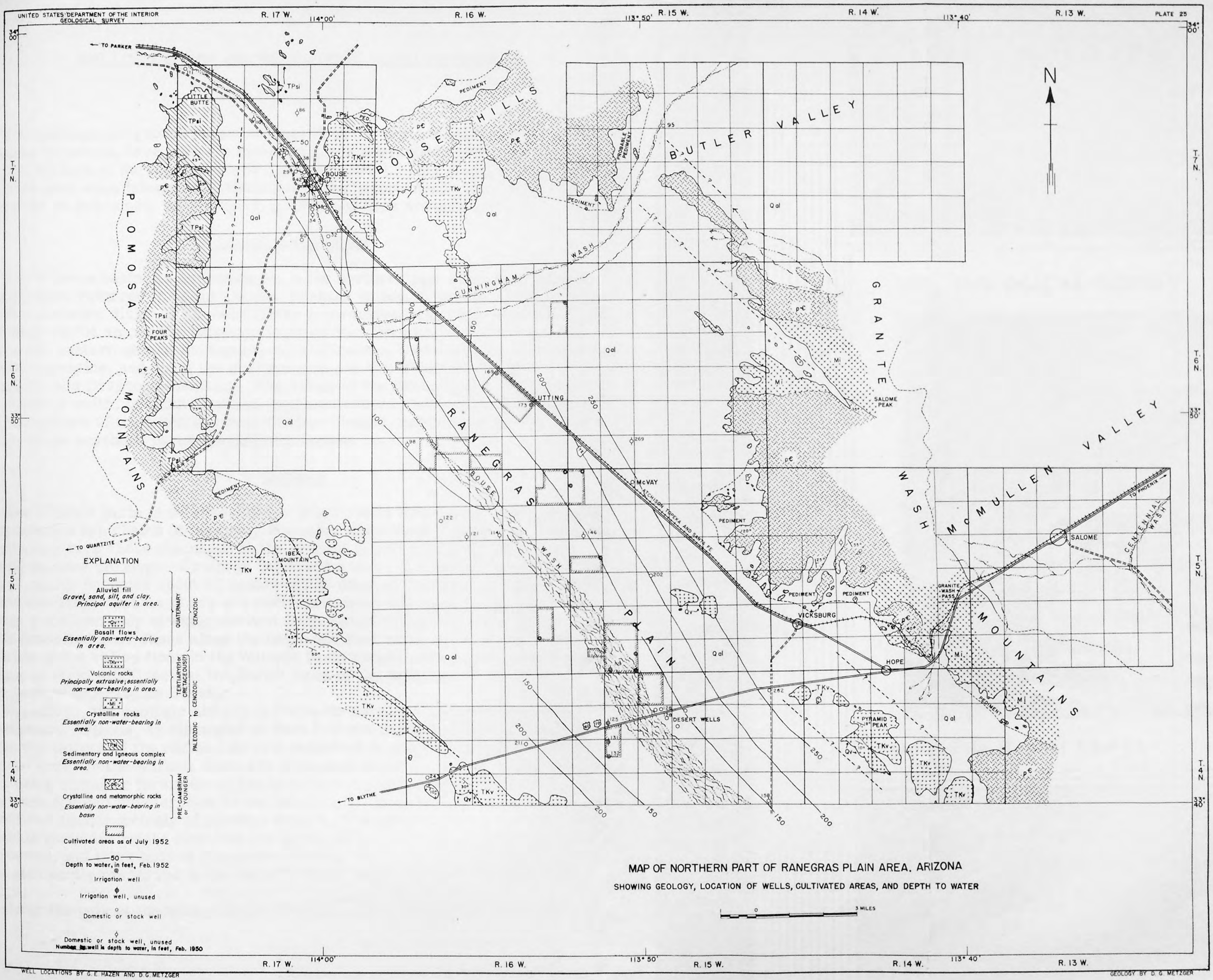
This report is, for the most part, a condensation of a report issued in 1951. The area included in this investigation is the northern part of Ranegras Plain, known locally as "the Bouse country." It is in northern Yuma County, Ariz.

Ground water occurs in the Tertiary (?) and Quaternary alluvium that forms the valley fill. The best aquifers are in the sand and gravel lenses of the Quaternary alluvium. The Tertiary (?) alluvium consists mostly of clay and other fine-grained materials. The movement of ground water is predominantly northwest. Some ground water, estimated to be small compared with the total recharge, enters the area from the northeast as underflow from Butler Valley.

Recharge to the aquifers of Ranegras Plain is derived principally from runoff of rainfall. Discharge of ground water is principally by pumping and by underflow out of the basin. The average annual recharge to the ground-water reservoir may be as little as 5,000 acre-feet and it probably does not exceed 20,000 acre-feet per year.

The following is quoted from the summary of the 1951 report:

> The waters from wells in the flat lands near the center of the basin may be considered "permissible to doubtful" for irrigation use. The ground waters generally contain enough dissolved mineral matter to have a noticeable taste. Most of the samples showed an excessive amount of fluoride which would cause mottling of tooth enamel in small children.


UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
PLATE 25
R. 17 W.
R. 16 W.
R. 15 W.
R. 14 W.
R. 13 W.
114°00'
113°50'
113°40'
34°00'
33°50'
33°40'
T. 7 N.
T. 6 N.
T. 5 N.
T. 4 N.
TO PARKER
TO QUARTZITE
TO BLYTHE
TO PHOENIX
PLOMOSA MOUNTAINS
BOUSE HILLS
BUTLER VALLEY
GRANITE WASH
RANEGRAS PLAIN
BOUSE WASH
CUNNINGHAM WASH
McMULLEN VALLEY
GRANITE WASH MOUNTAINS
CENTENNIAL WASH
LITTLE BUTTE
FOUR PEAKS
IBEX MOUNTAIN
SALOME PEAK
PYRAMID PEAK
GRANITE WASH PASS
PEDIMENT
PROBABLE PEDIMENT
BOUSE
UTTING
McVAY
VICKSBURG
HOPE
SALOME
DESERT WELLS
ATCHISON TOPEKA AND SANTA FE
Qal
TKv
TPsi
p€
Mi
Qv
EXPLANATION
Alluvial fill
Gravel, sand, silt, and clay. Principal aquifer in area.
Basalt flows
Essentially non-water-bearing in area.
QUATERNARY
CENOZOIC
Volcanic rocks
Principally extrusive; essentially non-water-bearing in area.
TERTIARY(?) or CRETACEOUS(?)
Crystalline rocks
Essentially non-water-bearing in area.
Sedimentary and igneous complex
Essentially non-water-bearing in area.
PALEOZOIC to CENOZOIC
Crystalline and metamorphic rocks
Essentially non-water-bearing in basin
PRE-CAMBRIAN or YOUNGER
Cultivated areas as of July 1952
50
Depth to water, in feet, Feb. 1952
Irrigation well
Irrigation well, unused
Domestic or stock well
Domestic or stock well, unused
Number by well is depth to water, in feet, Feb. 1950
MAP OF NORTHERN PART OF RANEGRAS PLAIN AREA, ARIZONA
SHOWING GEOLOGY, LOCATION OF WELLS, CULTIVATED AREAS, AND DEPTH TO WATER
0
3 MILES
WELL LOCATIONS BY G. E. HAZEN AND D. G. METZGER
GEOLOGY BY D. G. METZGER

WILLCOX BASIN, COCHISE AND GRAHAM COUNTIES

By D. R. Coates

The geology and ground-water resources of the Willcox basin, Cochise and Graham Counties, have been discussed in a mimeographed report published by the Geological Survey (Jones and Cushman, 1947). This discussion draws in large part upon information contained in the report of 1947, although many new data on hydrologic conditions in the Willcox area are incorporated.

Location and extent

The Willcox basin, as here defined, is the northern part of an intermontane trough often referred to as the Sulphur Springs Valley. The basin extends from a drainage divide at the headwaters of Aravaipa Creek southward to a drainage divide among the buttes and ridges near the town of Pearce (pl. 26). Along the eastern side of the basin are the Pinaleno, Dos Cabezas, and Chiricahua Mountains, and along the western side are the Winchester, Little Dragoon, and Dragoon Mountains. The valley of the basin ranges from 15 to 35 miles in width, is about 50 miles long, and covers about 1,600 square miles. Although most of the basin is within Cochise County, approximately 300 square miles in the northern part is in Graham County.

Geology

The Willcox basin is a broad, debris-filled valley that trends northwest and lies between two chains of maturely dissected fault-block mountains. The basin is unique among those discussed in the present report because it has no external surface drainage. Drainage is toward a large flat, known as the Willcox Playa, which occupies about 50 square miles south of the town of Willcox. At times the playa surface is dry and partly incrusted with white salts; at other times a shallow body of water derived from runoff covers the flat. Winds have deposited sand dunes along the north and east sides of the playa. The altitude of the valley floor in the Willcox basin ranges from 4,135 feet, on the playa, to about 4,500 feet, at the lowest point of the drainage divide at the headwaters of Aravaipa Creek.

In general, the geologic history of the basin parallels that of other basins in southern Arizona, as discussed in Part I of this report. Those departures from the pattern of the region that are important in relation to occurrence of ground water in the Willcox basin are discussed below.

During and after formation of the structural trough, thick deposits of alluvium were derived from erosion of the mountains. The earliest fill in the trough consisted almost entirely of volcanic debris. One or more lakes occupied the Willcox basin during the time that the upper parts of the valley fill were being deposited, and thick beds of clay were formed. Shore lines of the ancient lakes are still partly preserved in the form of beach ridges near the present-day playa.

After the bulk of the valley fill had accumulated, probably by early Quaternary time, basaltic lavas were extruded near the base of the mountains. These lavas are interbedded with the fill or lie on its surface.

Rock types

The oldest rocks exposed in the mountains surrounding the valley consist of schists and granites and are shown on the geologic map (pl. 26) as the crystalline and metamorphic complex. The water-bearing characteristics of the crystalline rocks are dependent upon weathering and jointing. Small amounts of water from jointed granitic rocks have been obtained from wells in the village of Dos Cabezas.

Conglomerate, quartzite, sandstone, shale, and limestone of Paleozoic and Mesozoic age constitute the older sedimentary rocks of the basin. These rocks occur in less than 5 percent of the total outcrop area of the mountains, dip in many directions, and are highly fractured. Water has been encountered in caves and in mine workings. Springs occur in the older sedimentary rocks in some localities.

The areas shown on plate 26 as older volcanic rocks contain both explosively extruded materials and lava flows. Andesitic and rhyolitic tuffs and agglomerates are the principal pyroclastic rocks of the basin. The flow rocks range from basalts to rhyolites, although the basalts constitute only a minor part of the total. Small amounts of water occur along fractures and other openings in the volcanic rocks. Several springs issue from the pyroclastic rocks in the basin and supply water for stock use.

Alluvial fills

The Willcox basin has apparently been without exterior drainage during most or all of the time since the structural trough was formed, and lakes occupied the lower parts of the basin. Clay and silt were deposited in these lakes, although exceptionally large floods deposited some gravel and sand lenses. These deposits of clay, silt, sand, and gravel comprise much of the older alluvial fill. The alternation of beds is shown in logs of characteristic wells (table 35).

Well (D-14-24)14b was reported to have penetrated clay from about 150 feet to 720 feet. The well was abandoned at 720 feet without penetrating the full thickness of clay. Ground water under artesian pressure has been encountered in a few wells that have penetrated sand and gravel lenses in the clay layers, particularly southeast of the Willcox Playa. Some of these wells have a flow of about 50 gallons per minute.

The washes that enter the basin from the mountains are underlain by deposits of sand and gravel of Recent age, but their areal extent is small. Some domestic and stock wells obtain water from these deposits.

Ground-water hydrology

In this report it is convenient to discuss ground-water conditions separately in the following three areas because of important inherent differences among the areas: (1) The Stewart district, northwest of Willcox and generally restricted to Tps. 12 and 13 S., R. 24 E.; (2) the Kansas Settlement area, about 8 miles south of Willcox and included in the eastern half of Tps. 15 and 16 S., R. 25 E.; and (3) the Willcox Playa.

Occurrence

All the ground water that is pumped for irrigation and most of the ground water that is pumped for domestic and stock uses is derived from older alluvial fill, generally from depths of less than 150 feet below the land surface (pl. 28). The aquifers are permeable lenses of sand and gravel, irregular but interconnected, and are interbedded with relatively impermeable layers of clay, silt, sandstone, and conglomerate.

The depth to the water table in the Stewart district ranges from 30 to 100 feet, and averages about 70 feet. In the Kansas Settlement area the depth to the water table averages about 40 feet. Water under artesian pressure is encountered in this area at a depth of about 400 feet. The pressure raises the water in wells about to the land surface, and some wells flow. Many of the irrigation wells in that area tap this artesian system.

The shallowest depth to water is in the Willcox Playa, where the water table is within a few feet of the land surface. The fine-grained materials beneath the playa have low permeability and yield water to wells slowly. The lake beds near the Willcox Playa are largely clay and silt, but locally they include fingers of sand and gravel containing water under artesian pressure. The maximum depth at which water-bearing beds occur in the older fill is not known. Water in gravel was encountered at a depth of 3,215 feet below the land surface in well (D-15-26)19db, drilled as an oil test.

Source and movement

Recharge.--Water recharges the ground-water reservoir of the valley fill by seepage from the following sources: (1) Runoff at mountain fronts; (2) irrigation water; (3) precipitation on the valley floor.

A generalized discussion of sources of ground water in southern Arizona is presented in Part I, "Regional hydrology." In the Willcox basin the ground water moves generally from the recharge areas toward the playa. However, near the surface drainage divides in the vicinity of Bonita and Pearce, some ground water moves out of the Willcox basin.

Recharge occurs as seepage from runoff principally in the areas of coarse materials near the mountain fronts and is probably largest on the eastern side of the basin. Rainfall in the mountain areas on the eastern side of the basin averages about 22 inches and, on the west side, the average is less than 16 inches. It is estimated that the amount of recharge from stream flow near the mountain fronts may be in the magnitude of 20,000 acre-feet annually.

Studies in some areas of Arizona indicate that as much as 25 percent of the irrigation water applied to the land may recharge the ground-water reservoir, but it is believed that the percentage of such recharge in the Willcox basin may be much less. It is reported that moisture penetration tests made in the

Douglas basin, immediately to the south, indicated maximum penetration of about 5 feet, even after excessive irrigation. In the Willcox basin the recharge occurring as seepage from irrigation water probably is less than 10 percent of the amount applied to the land, or in the order of 4,000 acre-feet in 1951.

The surface of the Willcox Valley is made up in large part of relatively impermeable clay or of partly cemented older alluvium. Areas underlain by highly permeable Recent alluvium are small. It is concluded, therefore, that recharge by direct infiltration of rainfall is negligible.

Discharge

Ground water is discharged from the valley fill of the Willcox basin by natural means and by pumping from wells. Natural discharge occurs through evapotranspiration, springs, and movement out of the basin. Ground water is discharged from artesian and nonartesian aquifers through flowing and pumped wells.

Natural discharge.--Evaporation of ground water occurs in areas where the depth to water is shallow. Approximately 30,000 acres is underlain by shallow ground water in the vicinity of the Willcox Playa. In an earlier report (Jones and Cushman, 1947, pp. 13-14) it was estimated that the average depth to water beneath the playa was 5 feet, and that more than 10,000 acre-feet of ground water was evaporated annually from the area. Recent measurements in observation wells on the playa show that the water table is now 8 to 10 feet below land surface. Evaporation of ground water from the area under present conditions is therefore probably reduced to a range of 5,000 to 10,000 acre-feet per year. Some ground water may be evaporated from a shallow-water tract in the extreme northern part of the basin, T. 10 S., R. 22 E.

A few of the springs in the basin are probably caused by artesian leakage. More springs, however, issue at places where the water table intersects the land surface. Most of the water-table springs issue on the margin of the playa, and in the shallow-water tract in the northern part of the basin. Croton Spring, adjacent to the playa, in sec. 6, T. 15 S., R. 24 E., is the largest water-table spring in the basin.

In the Willcox basin, grasses, brush, and mesquite may all be users of ground water. Mesquite is the principal plant that uses ground water in the basin, and calculations of evapotranspiration are restricted to areas of mesquite growth. Transpiration by phreatophytes was estimated to be about 85,000 acre-feet per year in 1946 (Jones and Cushman, 1947, p. 14) based on an acreage survey by Meinzer (1913, pl. 1) and on rates of use determined in Safford Valley (Turner and others, 1941, p. 11). Field checks made in 1951 by the author of this report indicate that about 30,000 acres contain mesquite with areal density of 30-40 percent, in areas where the water table is less than 60 feet, which was assumed to be the maximum limit of root penetration. The amount of ground water used by mesquite in the basin is therefore assumed to be in the order of 10,000 to 15,000 acre-feet a year.

The following localities appear from surficial inspection to be avenues through which ground water might move out of the basin: (1) Northward through the alluvial divide near Bonita; (2) eastward between the Pinaleno and Dos Cabezas Mountains; (3) southward among the buttes and ridges near Pearce; and (4) westward between the Winchester and Dragoon Mountains.

The ground-water contours (pl. 27) show, however, that there is no movement from the main ground-water body of the basin to areas outside the basin. Each of the avenues of movement crosses a surface drainage divide, and in each avenue it has been determined that the ground-water drainage divide is basinward from the surface-water drainage divide. Therefore, only the recharge occurring between the ground-water drainage divides and the surface-water drainage divides passes out of the basin through the previously mentioned avenues. The quantity of water recharged in the zones between the ground-water divides and the surface-water divides, and that leaves the Willcox basin as underground leakage, is estimated to be of the order of 4,000 acre-feet per year.

Discharge by wells.--Most of the water discharged from wells in the Willcox basin is used for irrigation (table 34). Lesser amounts of ground water are withdrawn for municipal, industrial, domestic, and stock use.

Wells for irrigation are located in three areas in the Willcox basin. In 1951 about 1,000 acres was irrigated in the area southwest of Bonita, 11,000 acres in the Stewart district northwest of Willcox, and 2,000 acres in the Kansas Settlement area southeast of Willcox. Rates of discharge from wells ranged from 130 to 1,300 gallons a minute, and the average discharge from 31 wells measured in the spring of 1952 was 450 gallons per minute. Pumping lifts range from about 80 to 145 feet. The irrigation wells yield an average of about 20 gallons per minute per foot of drawdown.

The artesian wells in the Kansas Settlement area range in maximum rate of flow from 10 to 60 gallons a minute, but the flow diminishes during the season of heavy pumping. Many of the artesian wells are pumped to obtain a supply of water sufficient for irrigation. These wells range in rate of discharge from 150 to 2,400 gallons a minute. The average discharge of six wells measured in the spring of 1952 was 1,060 gallons a minute. The wells yield as much as 80 gallons per minute per foot of drawdown.

In 1951 a total of about 14,000 acres was irrigated by 38,000 acre-feet of ground water pumped from 170 wells. It is estimated that the total amount of ground water pumped from other wells throughout the Willcox basin aggregates about 1,000 acre-feet annually. This pumpage is distributed as follows:

	Acre-feet
Municipal	100
Industrial	400
Stock and domestic	500

Storage

The discussion of storage in Part I, "Regional hydrology" is not entirely applicable to the Willcox basin. No attempt was made to estimate the latent storage, because of insufficient quantitative data.

Underlying storage was estimated only for the Stewart district. The area that was used in preparing this estimate is enclosed by an arbitrary line 1 mile outside the perimeter of the area irrigated. The area is estimated to be about 38,000 acres. Between land surface and a depth of 300 feet, there is in the district an average thickness of saturated aquifer of about 230 feet. An average coefficient of drainage of 5 percent is assumed. On the basis of these estimates and assumptions, about 440,000 acre-feet of water may be in underlying storage in the Stewart district.

The amount of ground water in storage in the zone between the water table and a depth of 300 feet in the Kansas Settlement area is considered negligible because of the great thicknesses of clay and silt known to be present. The area obtains most of its ground water from deep artesian aquifers, the extent and characteristics of which are unknown. No estimate of storage has been made for the playa area because the thick clays of this area yield little water to wells.

Fluctuations of the water table

A comparison of depths to water in 1910 (Meinzer and Kelton, 1913, pp. 117-121), 1946, and 1951, shows that the water table has declined in most parts of the Willcox basin. The largest declines in the water table have occurred in the Stewart district. The water level in well (D-12-24)28bbb (fig. 23) near the center of this district, lowered about 18 feet in the period 1946-51, and the average decline in the district was about 10 feet. In the Kansas Settlement area, the water table has declined from 1 to 3 feet since 1946. Declines throughout much of the remainder of the basin were less than 2 feet in the 5-year period. Data are inadequate to determine the trend in pressure changes in the artesian wells in the basin.

Water levels in some areas apparently have not yet been affected by the pumping. Wells (D-15-25)14ccd and (D-16-24)26ab (fig. 23) have maintained a nearly constant water level from year to year.

Seasonal fluctuations of the water table caused by heavy pumping amount to as much as 12 feet, as is illustrated by the hydrograph for well (D-13-24) 2abb (fig. 23). Data from water-stage recorders on the playa indicate seasonal fluctuations of the water table of 1 to 2 feet. These fluctuations reflect seasonal changes in rates of evaporation, the maximum evaporation occurring during the summer. Local fluctuations of water levels in wells are caused by cones of influence spreading from discharging wells. The water level in well (D-16-25)14dda was drawn down 1.7 feet after a well half a mile away was pumped for 2 days at a rate of 2,000 gallons per minute.

Changes in storage

Changes in ground-water storage at different places in the basin are shown by the graphs of water-level fluctuations (fig. 23). The total volume of sediments that have been unwatered in the period 1946-51 was computed as about 1,150,000 acre-feet. Assuming a coefficient of drainage of 10 percent in the portion of the aquifer unwatered, some 115,000 acre-feet of water has been

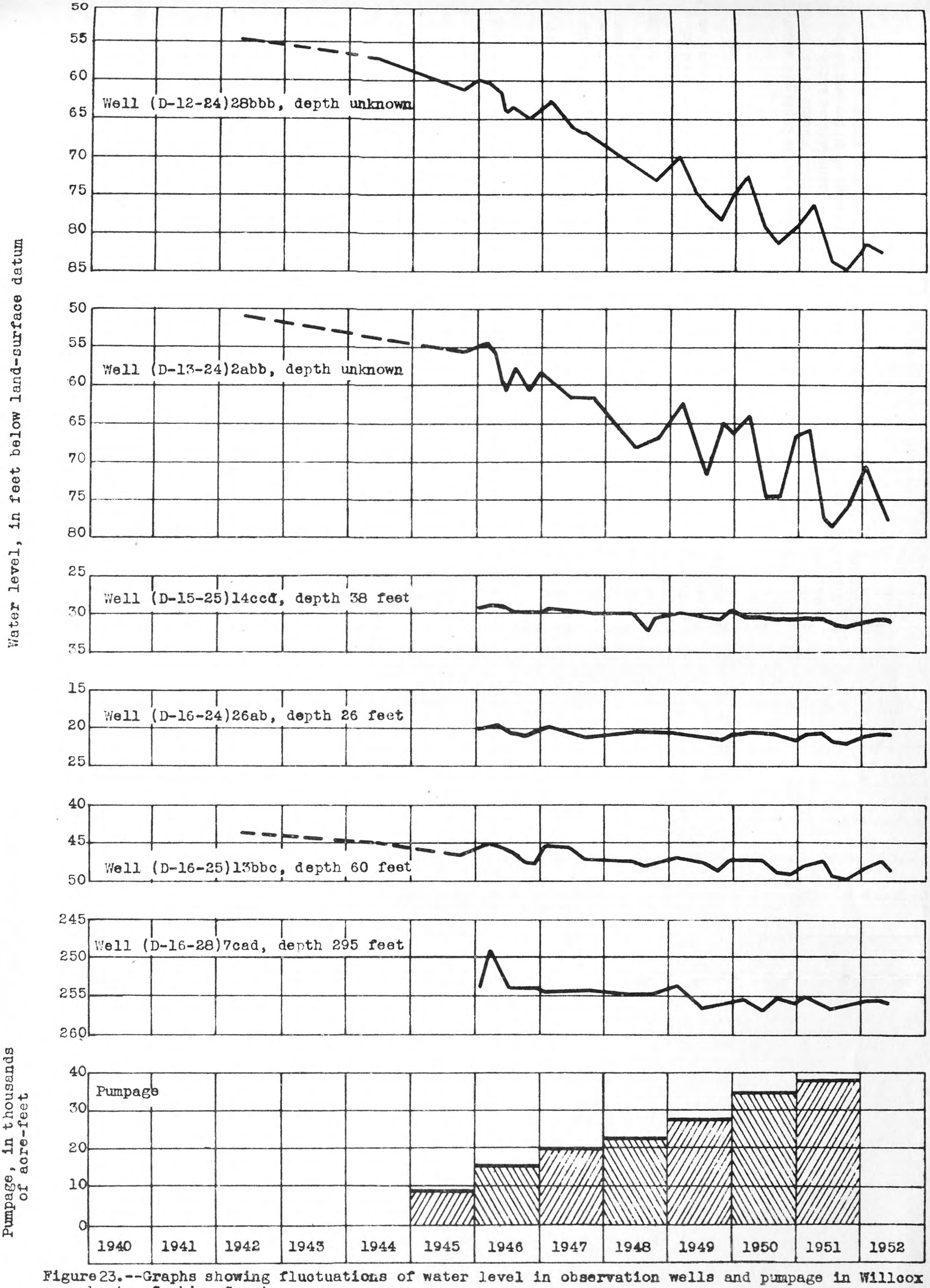


Figure 23.--Graphs showing fluctuations of water level in observation wells and pumpage in Willcox basin, Cochise County.

withdrawn from storage in 5 years, or about 23,000 acre-feet annually. In the Stewart district the change in storage has been sufficiently great to reverse the ground-water gradient and to start ground water moving northward from beneath the playa toward the large composite cone of depression underlying the district. Comparison of yields from individual wells in 1946 and in 1952 indicates a decrease of almost one-third. Changes in storage in the Kansas Settlement area are very slight. However, this area draws most of its ground water from artesian sources, and the effect of withdrawals upon storage in the artesian system may not be apparent for some time.

It is concluded that pumpage and natural discharge in the Willcox basin during the years 1946-51 have exceeded the annual increment of recharge to the basin, because the water levels in wells in some areas have shown net annual declines. Most of the declines have been the result of pumping for irrigation. Prior to irrigation from wells, the average annual recharge and discharge were in equilibrium. Pumping now exceeds natural withdrawals in discharging ground water. Not all of the pumpage comes from storage, as a part is the salvage of natural discharge. Pumpage in the period 1946-51 averaged about 28,000 acre-feet annually, and therefore the draft on storage by pumping was less, probably in the order of 20,000 acre-feet per year.

Quality of water

Table 36 lists characteristic analyses of ground waters in the Willcox basin. Analyses indicate that most of the waters of the basin contain dissolved solids ranging from 150 to 300 parts per million. These dissolved solids consist mostly of calcium, sodium, and bicarbonate.

In a few localities, principally near the northern end of the basin, waters contain less than 100 parts per million of dissolved solids. The more highly mineralized waters in the basin are found near the playa. Water from Croton Spring (table 36) contains the maximum mineralization observed in the basin; the mineral content totals 2,940 parts per million and consists mostly of sodium and sulfate.

Most of the ground water used for irrigation in the basin may be considered "excellent to good" for this purpose. Waters from a few local areas are sufficiently mineralized to be classified as "unsuitable" for irrigation. Criteria on which these classifications are based are explained in Part I of this report.

Most of the ground waters of the basin are rather hard, but only a few waters contain enough dissolved matter to be unpleasant to the taste. Ground waters in the vicinity of the Willcox Playa are too highly mineralized to be satisfactory for domestic use. Many ground waters in the basin contain too much fluoride to be used by young children without risk of mottling of tooth enamel. The area of high fluoride concentration centers near the playa, and extends southward. Along the southern margin of the basin, east of Pearce, along the mountains on either side of the valley, and in the northern part of the basin, fluoride concentrations are generally within the limits considered acceptable for domestic use.

Discharge of dissolved solids from the basin

The Willcox basin is without exterior surface drainage. Dissolved matter is accumulating in the ground water and valley fill in the lower parts of the basin. The accumulation has been slow, probably because dissolved matter is only slowly being added to the ground water of the basin. The water table in the heavily pumped areas has been lowered sufficiently that some of the more highly mineralized water near the playa is moving toward the areas of water-table decline. This movement, if continued, will cause wells in those areas to yield progressively saltier water.

A comparison of the analyses made during 1946 with those made in 1910 indicates that changes in quality of water took place in the 36-year period. In most parts of the basin, changes were slight. A few wells in the areas of dilute water show slight decreases in concentration. On the other hand, waters from wells southeast of Willcox Playa showed some increase in mineral content.

Problems and methods of conserving or increasing ground-water supplies

The principal ground-water problem in the Willcox basin is related to the abundance of phreatophytes, mostly mesquite, in the playa area. Elsewhere in this report it is estimated that about 30,000 acres near the playa is occupied by mesquite that is drawing upon the ground-water reservoir.

The fact that the basin has no external drainage makes it exceptionally useful as a type area for phreatophyte study. It should be possible to establish experiments under carefully controlled conditions, uncomplicated with problems related to through drainage, that would clarify such questions as: (1) The amount of water used annually by phreatophytes and evaporated from the playa; (2) the relative dependence of phreatophytes on ground water, precipitation and flood runoff; (3) seasonal variations in use of water; and (4) the effect of evapotranspiration on increasing concentrations of dissolved mineral matter in ground water.

Corollary studies by other agencies might develop suitable methods of eliminating the phreatophytes. The combination of investigations thus might result in development of methods that would salvage a large part of the ground water now used annually by phreatophytes.

It is thought that results of such investigations conducted in the Willcox basin would be applicable in most or all of the other basins in southern Arizona, as well as in basins outside the State where conditions are comparable.

Summary

The Willcox basin is part of a broad alluvium-filled northwest-trending valley that lies between two chains of mountains in southeastern Arizona. The basin has no through-flowing stream, but instead has interior drainage toward a large flat known as the Willcox Playa.

The basin has received large thicknesses of alluvium from the adjacent mountains. The earliest fill consisted almost entirely of volcanic debris. Later sediments show that lakes or playas existed during long periods of time, and silts and clays were the principal sediments deposited during those periods.

The principal aquifers in the basin are lenses of sand and gravel in the valley fill. Water in shallow aquifers in the valley fill generally is not under artesian pressure. However, the lake beds near the Willcox Playa include fingers of sand and gravel that contain water under artesian pressure.

The ground-water reservoirs of the valley fill are recharged mostly by runoff across the coarse materials near the mountain fronts. Small recharge increments occur by direct precipitation on Recent alluvium, and from excess irrigation water that percolates into the saturated zone. Recharge is estimated as roughly 25,000 acre-feet per year.

Ground water is discharged from the valley fill by natural processes and by pumping from wells. Natural discharge is principally by evapotranspiration, estimated to be 15,000 to 25,000 acre-feet in 1951. Ground-water withdrawal by pumping is mostly for irrigation. The total pumpage in 1951 was about 39,000 acre-feet.

Since 1946, the water table has generally declined throughout the basin. The largest declines occurred in the Stewart district, northwest of Willcox, where the maximum 5-year decline was 18.4 feet. The average yearly decline in the heavily pumped areas is about 2 feet. The average amount of ground water withdrawn from storage in the 5-year period, 1946-51, was about 20,000 acre-feet per year.

Chemical analyses indicate that most of the waters in the basin, except those in the vicinity of the playa, contain only moderate amounts of dissolved matter. Ground waters pumped for irrigation generally are suitable for the crops grown in the basin. Most of the waters in the basin are hard. Waters north of Willcox do not contain harmful fluoride concentration, but waters in some other parts of the basin contain fluoride in objectionable amounts.

Table 34.--Records of representative wells in Willcox basin, Cochise and Graham Counties, Ariz.

Well no.	Depth of well (feet)	Diameter of well (in.)	Water level: Depth below land-surface datum (feet) a/	Water level: Date of measurement	Type of lift b/	Use of water c/	Remarks
(D-11-23)							
6ba	1985	-	-	-	-	-	Log, table 35.
(D-12-24)							
20bbb	233	16	-	-	T,E	I	Discharge, 615 gpm, 1951.
28bbb	-	6	81.27	1-29-52	C,W	S	Hydrograph, fig. 23.
29baa	166	16	-	-	T,E	I	Discharge, 1280 gpm, 1951.
29cbd	94	16	-	-	T,D	I	Analysis, table 36.
33bbb	207	16	-	-	T,E	I	Discharge, 430 gpm, 1951.
34cd	107	16	-	-	T,E	I	Log, table 35.
(D-13-24)							
2abb	-	8	70.26	1-15-52	C,W	D,S	Hydrograph, fig. 23.
5cdb	160	-	-	-	T,E	D,I	Discharge, 250 gpm, 1951.
16bb	1356	16	-	-	-	-	Log, table 35.
18adb	-	-	-	-	T,E	I	Discharge, 340 gpm, 1951.
23bbb	62	10	-	-	T,E	I	Discharge, 300 gpm, 1951.
25cc	-	12	-	-	C,W	S	Analysis, table 36.
(D-13-25)							
3dc	118	6	-	-	C,W	S	Analysis, table 36.
(D-14-25)							
9dd	2360	-	-	-	-	-	Oil test. Log, table 35.
(D-15-24)							
6ac	-	-	-	-	-	-	Analysis, table 36.
(D-15-25)							
14ccd	38	8	30.90	1-29-52	-	-	Hydrograph, fig. 23.
36cdd	-	-	-	-	T,Bu	I	Discharge, 1055 gpm, 1951.
(D-15-26)							
19db	3285	-	-	-	-	-	Oil test. Log, table 35.
(D-16-24)							
26ab	26	-	22.97	1-31-52	C,W	S	Hydrograph, fig. 23.

a/Depth was corrected to land-surface datum from measuring point.
b/T, turbine; C, cylinder; Bu, butane; G, gasoline; D, diesel; E, electric; W, windmill.
c/I, irrigation; D, domestic; S, stock.

Table 34.--Records of representative wells in Willcox basin--continued.

Well no.	Depth of well (feet)	Diameter of well (in.)	Water level: Depth below land-surface datum (feet) a/	Water level: Date of measurement	Type of lift b/	Use of water c/	Remarks
(D-16-25)							
9ba	380	6	Flows	-	-	I	Analysis, table 36.
11add	-	-	-	-	Bu	I	Discharge, 570 gpm, 1951.
13bbc	60	8	48.20	1-29-52	C,W	D,S	Hydrograph, fig. 23.
14dda	500	-	d/36	-	D	I	Discharge, 250 gpm, 1951.
(D-16-28)							
7cad	295	6	255.11	1-30-52	C,W,G	S	Hydrograph, fig. 23.
(D-17-25)							
19dc	190	-	-	-	C,W	S	Analysis, table 36.

d/ Reported.

Table 35.--Logs of representative wells in Willcox basin, Cochise County, Ariz.

	Thickness (feet)	Depth (feet)
(D-11-23)6ba		
Soil and clay - - - -	40	40
Water gravel- - - - -	20	60
Red clay- - - - - - -	100	160
Water gravel- - - - -	20	180
Red clay- - - - - - -	60	240
Water gravel- - - - -	20	260
Red mud - - - - - - -	30	290
Sand and gravel - - -	10	300
Red mud - - - - - - -	30	330
Water gravel- - - - -	90	420
Red clay with some water- - - - - - - -	180	600
Quick sand (160 ft. to water) -	30	630
Red rock- - - - - - -	20	650
Cavey sand- - - - - -	15	665
Red rock- - - - - - -	10	675
Cavey sand- - - - - -	15	690
Red rock- - - - - - -	320	1010
Yellow clay - - - - -	80	1090
Red rock- - - - - - -	10	1100
Yellow clay - - - - -	20	1120
Red rock- - - - - - -	60	1180
Yellow clay - - - - -	20	1200
Red rock- - - - - - -	85	1285
Brown sand- - - - - -	50	1335
Gray sandy shale and clay - - - - - - - -	45	1380
Red sand- - - - - - -	40	1420
Hard red rock - - - -	50	1470
Sand, yellow clay - -	20	1490
Gray shale- - - - - -	20	1510
Brown sandy shale - -	100	1610
Brown sand- - - - - -	375	1985
TOTAL DEPTH		1985
(D-12-24)28db		
Topsoil - - - - - - -	2	2
Caliche - - - - - - -	1	3
Sand and clay - - - -	6	9
Clay- - - - - - - - -	49	58
Gravel and fine sand-	6	64
Gravel- - - - - - - -	4	68
Clay- - - - - - - - -	4	72
Gravel- - - - - - - -	4	76

	Thickness (feet)	Depth (feet)
Clay- - - - - - - - -	4	80
Gravel- - - - - - - -	4	84
Clay- - - - - - - - -	4	88
Gravel- - - - - - - -	4	92
Clay- - - - - - - - -	4	96
Gravel- - - - - - - -	4	100
Clay- - - - - - - - -	16	116
Fine sand - - - - - -	4	120
Clay- - - - - - - - -	12	132
TOTAL DEPTH		132
(D-12-24)32dd		
Clay- - - - - - - - -	10	10
Sand- - - - - - - - -	10	20
Clay- - - - - - - - -	15	35
Sand- - - - - - - - -	21	56
Clay- - - - - - - - -	19	75
Sand- - - - - - - - -	4	79
Clay- - - - - - - - -	3	82
Sand- - - - - - - - -	4	86
Clay and sand - - - -	38	124
TOTAL DEPTH		124
(D-12-24)34cd		
Sand and clay - - - -	10	10
Sand and gravel - - -	6	16
Clay- - - - - - - - -	36	52
Sand, water - - - - -	5	57
Gray sandy clay - - -	12	69
Sand and gravel - - -	9	78
Clay, yellow- - - - -	11	89
Sand and gravel, water	8	97
Clay, yellow- - - - -	10	107
TOTAL DEPTH		107
(D-13-24)3bb		
Clay and caliche- - -	44	44
Gravel and sand, some clots of clay- - -	16	60
Clay, heavy - - - - -	2	62
Creek gravel and sand	14	76
Small gravel and water sand - - - - -	12	88
Heavy clay- - - - - -	1	89

Table 35.--Logs of representative wells in Willcox basin-continued.

	Thickness (feet)	Depth (feet)
Small gravel and water sand	7	96
TOTAL DEPTH		96
(D-13-24)5bb		
Topsoil	4	4
Clay	20	24
Gravel and sand, dry	15	39
Clay	15	54
Fine sand	10	64
Coarse gravel	20	84
Clay	20	104
Sand and gravel	6	110
TOTAL DEPTH		110
(D-13-24)16bb		
Topsoil	3	3
Caliche	2	5
Yellow clay	13	18
Red clay	17	35
Sand and gravel, water	5	40
Sandy clay	40	80
Clay	3	83
Sandy clay	35	118
Sand, water	3	121
Packed sand	13	134
Sticky yellow clay	6	140
Sand, gravel, and clay, water	4	144
Fine gravel and sand	6	150
Yellow clay	2	152
Sandy clay	15	167
Sticky blue clay	13	180
Brown clay with sand	8	188
Sticky blue clay	24	212
Brown sandy clay	6	218
Sand and gravel, water	4	222
Sandy clay	21	243
Sticky yellow clay	18	261
Sand, water	4	265
Gray shale	2	267
Brown sandy clay	5	272
Sand and gravel, water	7	279
Blue sandy clay	23	302
Fine gravel, water	8	310
Blue sandy clay	6	316
Large gravel, water	3	319
Fine sand and clay, water	1	320
Gravel, water	4	324
Blue sandy clay	8	332
Sand, water	1	333
Blue sandy clay	7	340
Sand with little clay, water	3	343
Dark brown sandy clay	7	350
Fine sandy gravel, water	11	361
Blue sandy shale	10	371
Blue shale, hard	21	392
Gray shale	6	398
Light gray shale	5	403
Gray shale	9	412
Blue shale	10	422
Gray shale	20	442
Blue shale, sticky	18	460
Gray sandstone, hard	6	466
Gray shale	14	480
Blue clay	50	530
Brown clay	65	595
Hard gray sand	3	598
Brown clay	138	736
Gypsum	3	739
Brown clay	156	895
Brown clay and gypsum	23	918
Gray clay	2	920
Brown clay and gypsum	2	922
Dark brown clay	228	1150
Brown clay and crystallized gypsum	4	1154
Brown clay	126	1280
Sandy brown clay	10	1290
Brown clay	20	1310
Dark brown clay	46	1356
TOTAL DEPTH		1356
(D-14-25)9dd		
Yellow clay and sand	55	55
Salt water sand	13	68
Yellow clay	17	85
Water sand	5	90
Blue clay	260	350
Sticky shale	100	450
Lime shell	4	454
Sticky shale	31	485

Table 35.--Logs of representative wells in Willcox basin-continued.

	Thickness (feet)	Depth (feet)
Conglomerate	25	510
Yellow shale	5	515
Lime shell	4	519
Red bed and gravel	41	560
Sandy lime	8	568
Red mud	8	576
Lime shell	4	580
Red bed	33	613
Sandy shale	5	618
Lime shell	3	621
Sandy shale	9	630
Hard sand	5	635
Red bed and gravel	10	645
Conglomerate	100	745
Fresh water sand	15	760
Cemented gravel	100	860
Red bed	10	870
Cemented gravel	26	896
Red bed	10	906
Sandy gravel	10	916
Conglomerate	109	1025
Red chalk	37	1062
Sand and gravel	53	1115
Water sand	10	1125
Lime shell	5	1130
Sandstone	15	1145
Conglomerate	55	1200
Yellow clay	10	1210
Sandstone	10	1220
Sandy lime	11	1231
Sandstone	7	1238
Conglomerate	35	1273
Sandstone	9	1282
Sandy lime	8	1290
Sandstone	5	1295
Water sand	15	1310
Conglomerate	25	1335
Yellow clay and gravel	5	1340
Lime shell	10	1350
Yellow clay and gravel	10	1360
Red sandstone and clay	30	1390
Hard coarse sand	20	1410
Conglomerate	35	1445
Quicksand and gravel, flowing hot water	15	1460
Brown sand rock	15	1475
Yellow clay and gravel	45	1520
Hard, sharp sandstone	10	1530
Yellow clay and gravel	30	1560
Hard brown sand	15	1575
Yellow conglomerate	55	1630
Pink sand	15	1645
Yellow clay and gravel	5	1650
Hard red sand	10	1660
Yellow clay and gravel	5	1665
Pink sandstone	15	1680
Red sand rock	105	1785
Brown shale and sand	25	1810
Red sand	20	1830
Blue and brown shale	10	1840
Blood-red sandstone	45	1885
Red water sand	20	1905
Brown sand	105	2010
Yellow sand	55	2065
Red sand	5	2070
Brown sandstone	100	2170
Water seepage	3	2173
Brown sandstone	62	2235
Sand and gravel, water	15	2250
Red and brown sandstone	50	2300
Sand and shale	40	2340
Red sand and gravel	20	2360
TOTAL DEPTH		2360
(D-15-26)19db		
Yellow clay	40	40
White shale	43	83
Water sand	20	103
Yellow clay	2	105
Clay	5	110
Gravel	15	125
White and yellow clay	25	150
Red shale, sandy	15	165
Soft red shale	15	180
Red shale and gypsum	70	250
Red shale	5	255
Hard shells	5	260
Red shale	5	265
Hard shells and gypsum	18	283
Red shale	4	287
Gypsum	8	295
Red shale and sand	10	305
Gypsum shells and red shale	50	355
Gravel (water)	5	360

Table 35.--Logs of representative wells in Willcox basin-continued.

	Thickness (feet)	Depth (feet)
Red sand and gravel (water)	38	398
Gravel (water)	2	400
Red sand and gravel (water)	8	408
Hard shell, very sharp (water)	4	412
Gravel and boulders	7	419
Sand and gravel, very hard	166	585
Sandy shale, very sticky	5	590
Pink sandy shale	25	615
Red sandy shale	20	635
Pink sandy shale and gravel	30	665
Red and pink sandy shale with streaks of gravel	30	695
Pink sandy shale and gravel	5	700
Sandy gravel with pink shale bricks	15	715
Pink shale and sandy gravel	40	755
Pink shale and gravel	50	805
Pink shale very sticky	35	840
Pink shale	16	856
Pink shale, sand and gravel, soft	24	880
Pink shale and sand	60	940
Pink shale	15	955
Pink shale very sticky	60	1015
Pink shale	30	1045
Pink shale, sticky	20	1065
Pink shale, sandy	35	1100
Red sand	25	1125
Very hard brown gravel	15	1140
Brown sand and gravel	90	1230
Shale, sand and gravel	15	1245
Hard brown gravel	5	1250
Sand and gravel	10	1260
Brown sand and gravel	40	1300
Brown sand, water	10	1310
Brown sand	15	1325
Brown sand, hard	15	1340
Brown sand with hard shells	25	1365
Brown sand and shale	20	1385
Sand, gravel, and shale	10	1395
Shale, red	13	1408
Sticky red shale	2	1410
Red shale	5	1415
Sand and shale	15	1430
Red shale	5	1435
Gypsum	25	1460
Red shale	5	1465
Gypsum	75	1540
Gypsum with gray shale	48	1588
Quicksand, dark brown, water	4	1592
Gypsum and gray shale	6	1598
Red sand	22	1620
White shale	60	1680
Conglomerate	10	1690
Yellow conglomerate	60	1750
Red conglomerate	25	1775
Gray conglomerate, sandy	13	1788
Red conglomerate	10	1798
Gray conglomerate, hard	45	1843
Dark gray water sand	32	1875
Dark gray grit with small particles of bentonite	30	1905
Gray grit with gray shale streaks	70	1975
Gray sand, hole full of water	5	1980
Gray shale with streaks of sand	15	1995
Dark gray sand	5	2000
Gray sand	10	2010
Gray shale with sand	8	2018
Gray sand	42	2060
Sand, water	20	2080
Gray sand, very fine	20	2100
Water sand gray, hard and very fine	15	2115
Gray sand, soft	35	2150
Dark gray sand	40	2190
Gray sand	10	2200
Pink shale and sand	15	2215
Shale streaks in gray sand	10	2225
Gray sand, hard	60	2285
Hard gray sand, water	5	2290
Gray sand	30	2320
Gray sand and red shale	5	2325
Gray sand	23	2348
Dark brown sand, very hard	12	2360

Table 35.--Logs of representative wells in Willcox basin--continued.

	Thickness (feet)	Depth (feet)
Dark brown sand with brown shale streaks -	20	2380
Dark brown sand, very hard - - - - - - - - -	15	2395
Brown sand - - - - - - -	20	2415
Red sandy lime - - - - -	10	2425
Brown sandy lime, very hard at bottom - - -	25	2450
Brown sandy lime - - -	25	2475
Red volcanic mud and cinders - - - - - - - -	45	2520
Red volcanic mud - - -	25	2545
Red sand and shale - -	23	2568
Grey sand with small showing of lime - - -	52	2620
Brown sand - - - - - - -	20	2640
Grey sand - - - - - - -	15	2655
Red shale with sand shells - - - - - - - -	25	2680
Red sandy shale and shells - - - - - - - -	20	2700
Red sandy lime, hard -	20	2720
Red sandy lime, very hard - - - - - - - - -	15	2735
Red sandy lime, hard -	20	2755
Brown shale and very hard shells - - - - - -	15	2770
Red shale and shells -	10	2780
Red mud with very thin hard shells - - - - -	30	2810
Red mud with brown hard shells - - - - -	20	2830
Red mud with thin hard shells - - - - - - - -	25	2855
Red mud with hard brown shells - - - -	90	2945
Water in brown grit -	10	2955
Brown grit - - - - - - -	10	2965
Brown sand and shells	20	2985
Brown shale and shells	5	2990
Brown sandy lime, hard shells - - - - - - - -	25	3015
Brown shale - - - - - -	15	3030
Hard brown sand - - -	5	3035
Brown shale - - - - - -	10	3045
Brown sandy lime - - -	30	3075
Brown shale with thin hard shells - - - - - -	25	3100
Brown sandy lime - - -	25	3125
Brown shale and thin hard shells - - - - - -	25	3150
Brown sandy lime - - -	15	3165
Red limey shale - - - - -	15	3180
Red shale with lime-covered brown boulders -	35	3215
Red gravel, water 110° F.	15	3230
Red shale - - - - - - - - -	20	3250
Red shale and gravel -	5	3255
Red shale and gravel mixed with brown gravel	15	3270
Red shale and gravel -	5	3275
Red lime - - - - - - - - -	10	3285
TOTAL DEPTH - - -		3285

(D-16-25)1cd

	Thickness (feet)	Depth (feet)
Soil - - - - - - - - - - -	3	3
Clay and caliche - - -	11	14
Clay - - - - - - - - - - -	39	53
Sand - - - - - - - - - - -	0.5	53.5
Clay - - - - - - - - - - -	4.5	58
Gravel - - - - - - - - - -	6	64
Clay - - - - - - - - - - -	26	90
Conglomerate - - - - - -	10	100
Clay - - - - - - - - - - -	33	133
Sand and gravel - - - -	3	136
TOTAL DEPTH		136

(D-16-25)9ba

	Thickness (feet)	Depth (feet)
Soil - - - - - - - - - - -	5	5
White caliche - - - - - -	15	20
Brown clay - - - - - - -	45	65
Red sand - - - - - - - - -	4	69
Brown clay, some gravel	34	103
Sand and gravel - - - -	6	109
Hard sand rock - - - - -	1	110
Brown sticky clay, no sand or gravel - - - -	8	118
Sand - - - - - - - - - - -	3	121
Sticky brown clay - - -	14	135
Sand - - - - - - - - - - -	6	141
Brown sticky clay - - -	75	216
Hard sand - - - - - - - -	4	220
Brown sticky clay - - -	18	238
Hard sandstone or shale	1	239

Table 35.--Logs of representative wells in Willcox basin-continued.

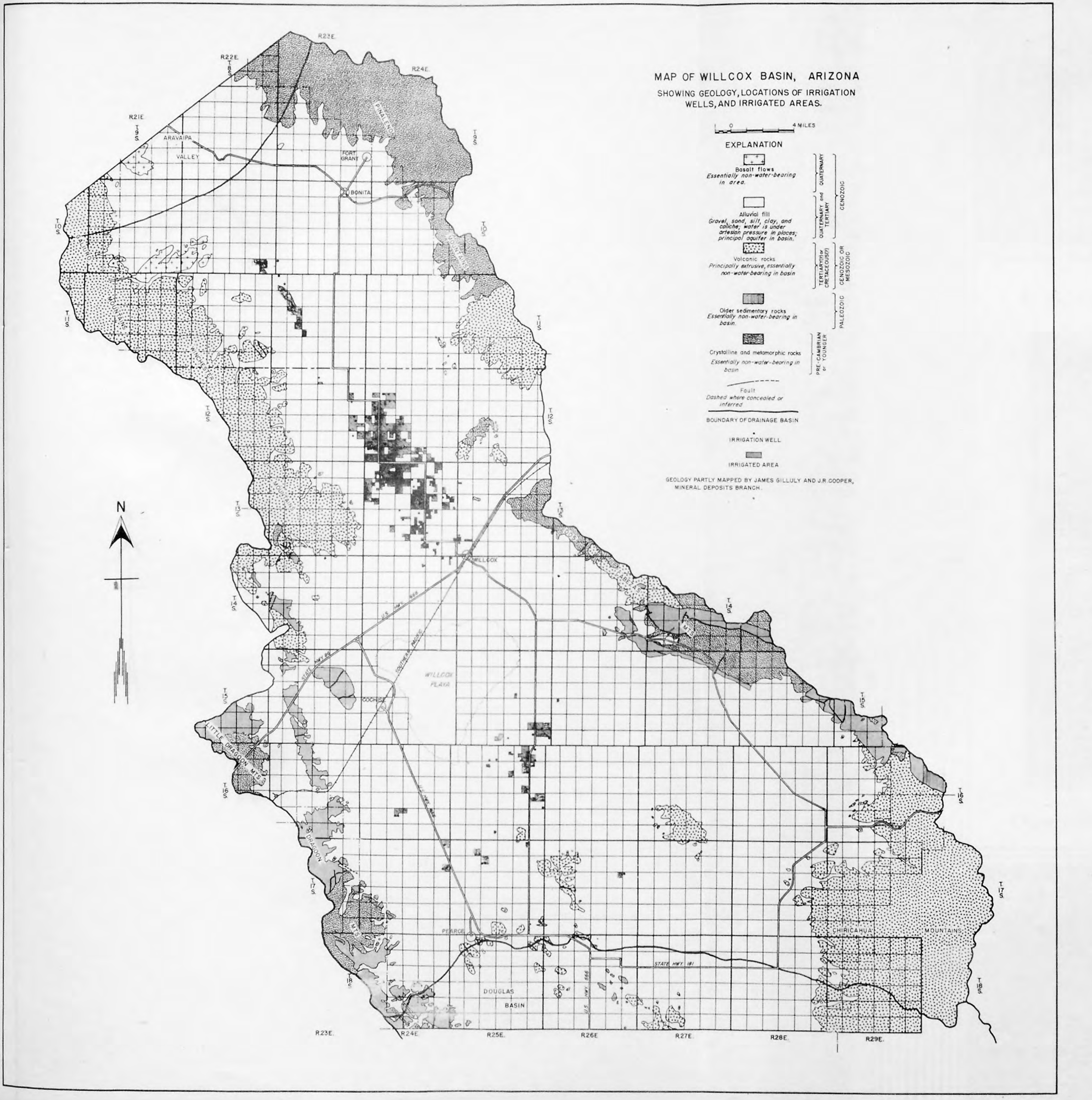
	Thickness (feet)	Depth (feet)
Brown clay - - - - - - - -	19	258
White caliche, lots of gravel - - - - - - - - - -	19	277
White and brown clay - -	30	307
Sandy brown clay - - - - -	11	318
Gray sand, water rose to within 5' of ground surface - - - - - - - - -	5	323
Red sand. Flowed 35 gpm 5 ft. hard brown clay, then water-bearing gray sand - - - - - - - - - -	27	350
	30	380
TOTAL DEPTH		380
(D-16-25)10dd		
Clay - - - - - - - - - - - -	55	55
Fine sand - - - - - - - -	10	65
Clay - - - - - - - - - - - -	3	68
Sand - - - - - - - - - - - -	9	77
Clay - - - - - - - - - - - -	25	102
Sand and gravel - - - - -	4	106
Clay - - - - - - - - - - - -	24	130
Clay and gravel mixture	10	140
Clay - - - - - - - - - - - -	25	165
Sand - - - - - - - - - - - -	4	169
Clay - - - - - - - - - - - -	17	186
Sandy silt - - - - - - - - -	2	188
Clay - - - - - - - - - - - -	38	226
Sand - - - - - - - - - - - -	8	234
Clay - - - - - - - - - - - -	2	236
TOTAL DEPTH		236
(D-16-25)23ad		
Topsoil - - - - - - - - - -	4	4
Gravel - - - - - - - - - - -	8	12
Clay - - - - - - - - - - - -	15	27
Clay, gravel - - - - - - - -	10	37
Sand with little water -	3	40
Clay - - - - - - - - - - - -	15	55
Gravel - - - - - - - - - - -	4	59
Clay - - - - - - - - - - - -	11	70
Gravel and sand - - - - -	3	73
Clay - - - - - - - - - - - -	35	108
TOTAL DEPTH		108

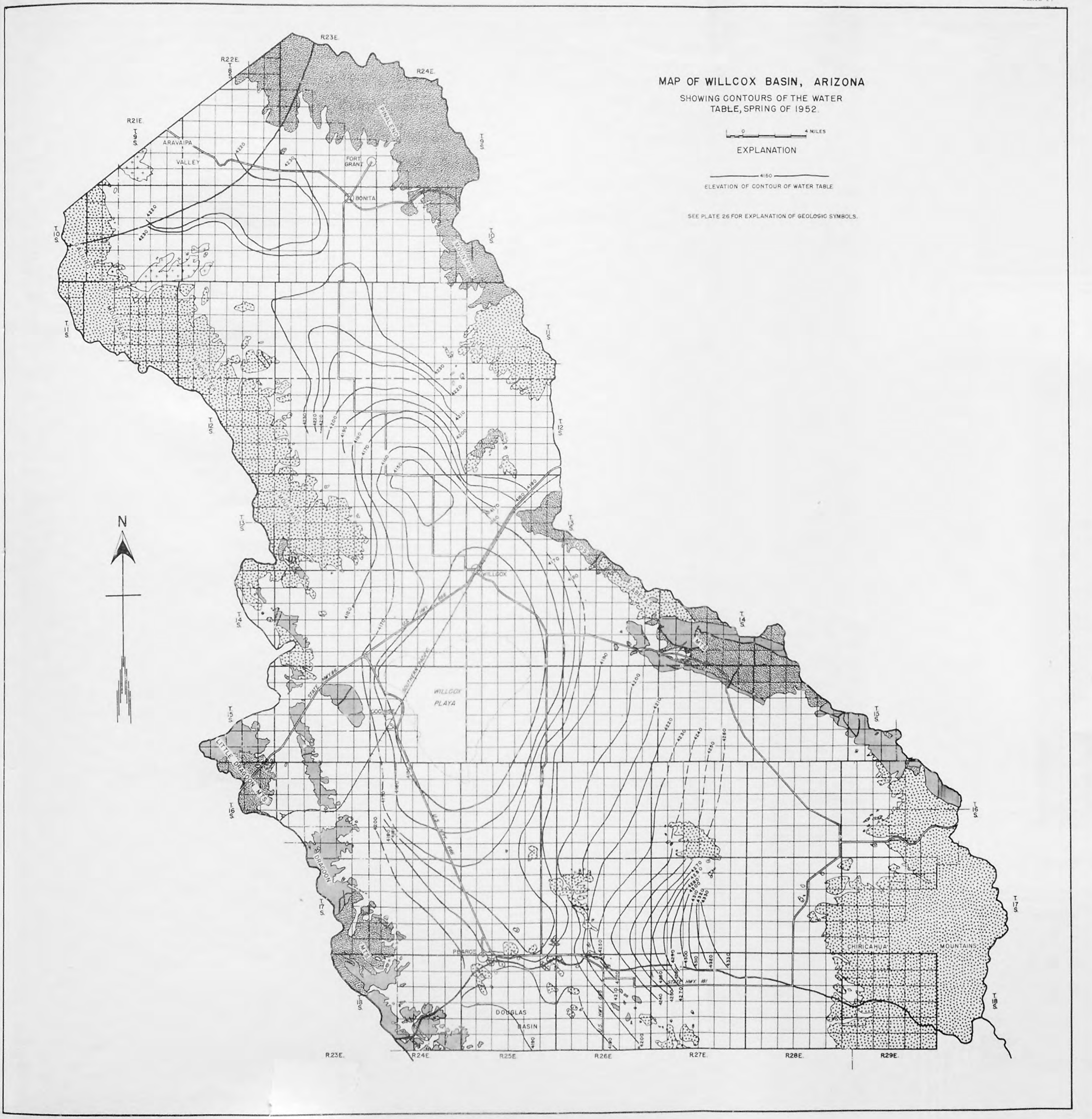
	Thickness (feet)	Depth (feet)
(D-17-25)9bc		
Clay - - - - - - - - - - - - -	54	54
Sand and gravel - - - - - - -	26	80
Clay - - - - - - - - - - - - -	16	96
Sand - - - - - - - - - - - - -	2	98
Clay - - - - - - - - - - - - -	14	112
Sand - - - - - - - - - - - - -	3	115
Clay - - - - - - - - - - - - -	15	130
TOTAL DEPTH		130

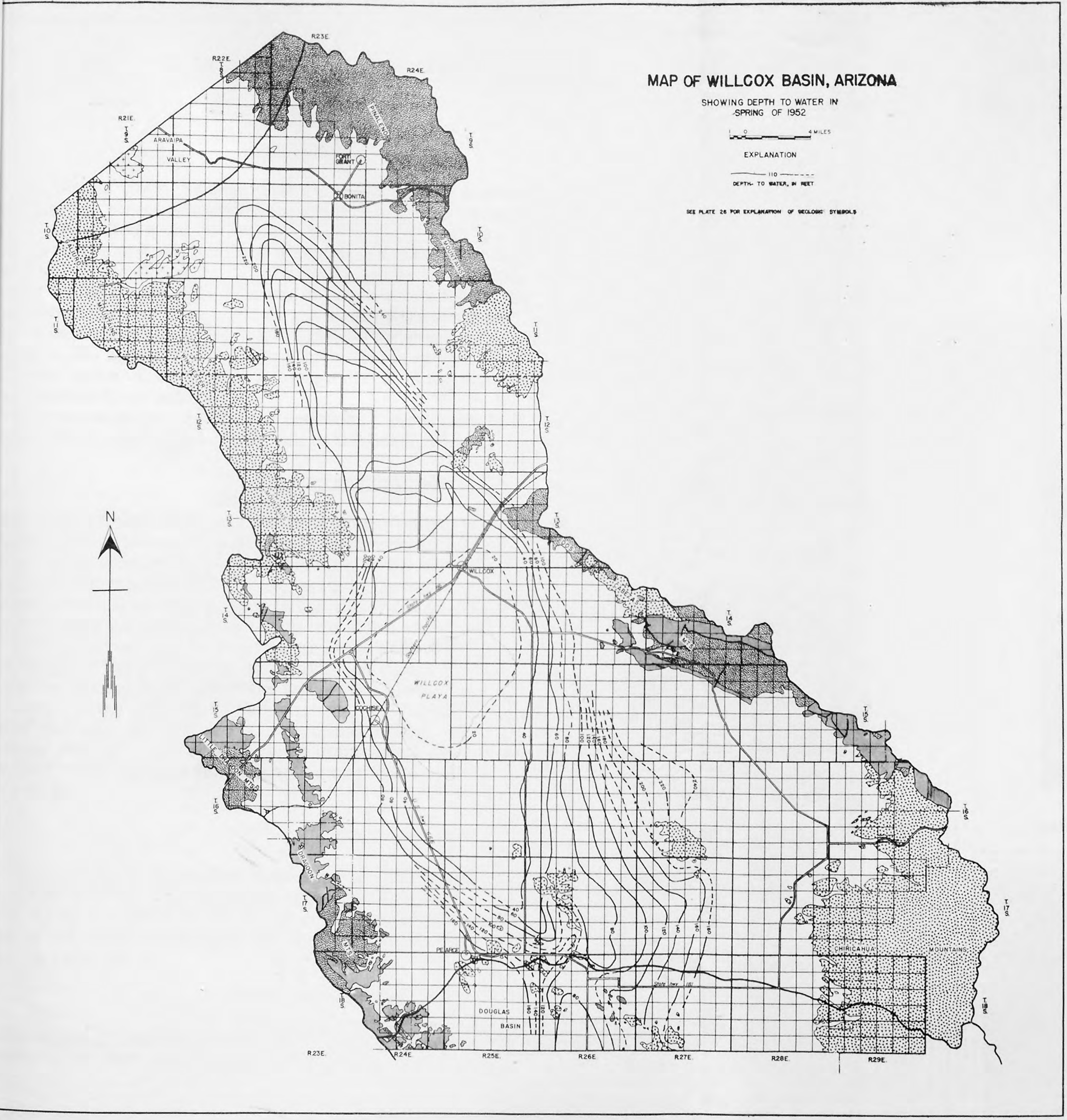
Table 36.--Analyses of water from representative wells and springs in Willcox basin, Cochise County, Ariz. (Parts per million except specific conductance and percent sodium)

Well no.	Date of collection (1946)	Depth (feet)	Specific conductance (micromhos at 25°C.)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Total hardness as $CaCO_3$	Percent sodium
(D-12-24)														
28db	4-5	132	212	24	4.0	19	120	6.2	6.0	0.8	2.2	121	76	35
29cd	6-11	94	362	42	6.9	17	112	7.0	46	0.4	5.8	180	134	21
32dd	4-5	124	319	34	8.0	25	136	15	24	0.4	13	186	118	32
(D-13-24)														
23bb	3-27	50	476	47	6.4	48	204	31	30	0.8	4.8	268	144	42
35ca	2-28	54	897	44	10	144	274	63	117	2.2	3.7	519	151	67
(D-13-25)														
3da	2-20	118	470	37	14	42	190	18	28	0.6	32	265	150	38
(D-15-24)														
6ac	2-14	a/	2550	12	3.7	553	367	251	455	16	1.6	1510	45	96
31dd	do.	a/	4260	66	38	904	378	1250	460	9.3	1.8	2940	320	86
(D-16-25)														
9ba	5-14	380	301	32	3.1	27	85	60	11	0.8	1.0	177	93	39
16ad	5-21	–	667	–	–	–	264	–	20	2.7	–	–	–	–
(D-17-25)														
19dc	2-28	190	415	53	8.0	27	198	22	23	0.6	4.8	236	165	26

a/ Spring.


MAP OF WILLCOX BASIN, ARIZONA
SHOWING GEOLOGY, LOCATIONS OF IRRIGATION WELLS, AND IRRIGATED AREAS.
0
4 MILES
EXPLANATION
Basalt flows
Essentially non-water-bearing in area.
QUATERNARY
Alluvial fill
Gravel, sand, silt, clay, and caliche; water is under artesian pressure in places; principal aquifer in basin.
QUATERNARY and TERTIARY
CENOZOIC
Volcanic rocks
Principally extrusive, essentially non-water-bearing in basin
TERTIARY(?) or CRETACEOUS(?)
CENOZOIC OR MESOZOIC
Older sedimentary rocks
Essentially non-water-bearing in basin.
PALEOZOIC
Crystalline and metamorphic rocks
Essentially non-water-bearing in basin
PRE-CAMBRIAN or YOUNGER
Fault
Dashed where concealed or inferred
BOUNDARY OF DRAINAGE BASIN
IRRIGATION WELL
IRRIGATED AREA
GEOLOGY PARTLY MAPPED BY JAMES GILLULY AND J.R. COOPER, MINERAL DEPOSITS BRANCH.
N
R21E.
R22E.
R23E.
R24E.
R25E.
R26E.
R27E.
R28E.
R29E.
T.8S.
T.9S.
T.10S.
T.11S.
T.12S.
T.13S.
T.14S.
T.15S.
T.16S.
T.17S.
T.18S.
ARAVAIPA VALLEY
FORT GRANT
BONITA
WILLCOX
WILLCOX PLAYA
COCHISE
LITTLE DRAGOON MTS.
PEARCE
DOUGLAS BASIN
CHIRICAHUA
MOUNTAINS
STATE HWY 181
U.S. HWY 666
SOUTHERN PACIFIC


MAP OF WILLCOX BASIN, ARIZONA
SHOWING CONTOURS OF THE WATER TABLE, SPRING OF 1952
0
4 MILES
EXPLANATION
4160
ELEVATION OF CONTOUR OF WATER TABLE
SEE PLATE 26 FOR EXPLANATION OF GEOLOGIC SYMBOLS.
N
ARAVAIPA
VALLEY
FORT GRANT
BONITA
WILLCOX
WILLCOX PLAYA
COCHISE
PEARCE
DOUGLAS
BASIN
LITTLE DRAGOON MTS.
DRAGOON
CHIRICAHUA
MOUNTAINS
PINALENO
R21E.
R22E.
R23E.
R24E.
R25E.
R26E.
R27E.
R28E.
R29E.
STATE HWY. 181


MAP OF WILLCOX BASIN, ARIZONA
SHOWING DEPTH TO WATER IN SPRING OF 1952
0
4 MILES
EXPLANATION
110
DEPTH TO WATER, IN FEET
SEE PLATE 28 FOR EXPLANATION OF GEOLOGIC SYMBOLS
N
ARAVAIPA
VALLEY
FORT GRANT
BONITA
WILLCOX
WILLCOX
PLAYA
COCHISE
PEARCE
DOUGLAS
BASIN
CHIRICAHUA
MOUNTAINS
R21E.
R22E.
R23E.
R24E.
R25E.
R26E.
R27E.
R28E.
R29E.
T9S.
T10S.
T11S.
T12S.
T13S.
T14S.
T15S.
T16S.
T17S.
T18S.

DOUGLAS BASIN, COCHISE COUNTY

By D. R. Coates

Location and extent

The Douglas basin, as described in this report, is a part of a large northwest-trending structural valley known as the Sulphur Springs Valley. The basin is separated from the Willcox basin on the north (pl. 29) by the surface-water drainage divide formed by a series of buttes and ridges, the most prominent of which are Six-mile Hill, Township Butte, and Turkey Creek Ridge; on the east by the Chiricahua, Pedregosa, and Perilla Mountains; on the south by the International Boundary; and on the west by the Mule and Dragoon Mountains. The basin is about 40 miles long, 30 miles wide, and includes an area of about 1,200 square miles. The alluvial basin ranges in altitude from about 4,400 feet in the vicinity of the drainage divide in the north to about 3,900 feet at the International Boundary.

The discussion presented here precedes a more complete report on the geology and ground-water resources of the basin, which will be released later.

Land forms and drainage

The valley floor slopes basinward from the mountains on the east and west and from the northern drainage divide southward into Mexico. Low ridges project into the valley from the mountains on the east side of the basin. In places these projecting ridges are partially buried by alluvium, leaving the exposed portions as rock islands in the valley floor. The Swisshelm and Perilla Mountains partially separate two small valleys from the main basin.

The basin is drained by Whitewater Draw and its tributaries. Whitewater Draw heads in the Chiricahua Mountains and enters the main part of the valley around the northern end of the Swisshelm Mountains. The channel loses its identity in the cultivated lands northeast of Elfrida, but reappears southwest of the town, and trends southward into Mexico. Whitewater Draw is a perennial stream in the 2-mile reach immediately north of the International Boundary. This surface flow is caused by the stream channel intersecting the water table.

Geology

The generalized discussion of geology as given in Part I, ''Regional geology,'' is applicable to the Douglas basin. The geology of the Douglas basin will be discussed as it relates to the storage and transmission of ground water. The extent of the rocks in the area and their general water-bearing character are shown on plate 29.

Hard rocks of the area

Crystalline and metamorphic rocks.--Crystalline and metamorphic rocks are exposed in the Mule and Swisshelm Mountains, and in some of the small hills at the northern end of the basin, and they compose much of the rocks exposed in the Dragoon Mountains. These rocks are predominantly schist and granite of various compositions, and supply limited amounts of water to wells in the basin. The town of Courtland is reported to have pumped about 15,000 gallons per day for several years from weathered zones in granite.

Older sedimentary rocks.--Older sedimentary rocks are present in all the mountain areas. Along the mountain front on the eastern side of the valley, they yield water in sufficient quantity for domestic and stock wells. These older sedimentary rocks not only are present in the mountains but also underlie some of the valley fill. An oil test (D-22-27)5b penetrated 1,600 feet of valley fill and entered a shaly limestone in the older sedimentary rocks. At about 2,270 feet below the land surface, water was encountered in limestone and had sufficient artesian pressure to cause the well to flow at the rate of about 100 gallons per minute.

Volcanic rocks.--The Chiricahua Mountains are almost entirely volcanic, consisting of explosively erupted and lava-flow materials. Thin beds of sandstone are interbedded with some volcanic rocks and suggest that volcanic activity was occasionally interrupted long enough to permit deposition of sediments. In general these older volcanic rocks are poor aquifers. At least two periods of Quaternary volcanic activity occurred. Some flows are at the land surface east of the City of Douglas. Other flows interbedded with the valley fill have been encountered at depths greater than 300 feet, as shown by the log of well (D-24-27)15baa (table 37) and logs of other wells.

Alluvial fill

Older fill.--The older fill is known to be at least 1,600 feet thick (table 37) and thins from the axis of the basin toward the mountain fronts. Drillers' logs indicate a high ratio of clay and silt to sand and gravel in this older alluvium. Clay and silt form as much as 80 percent of the total material penetrated in many wells. Caliche and gypsum layers were reported in many well logs. Although the alluvial fill in general has low permeability, it forms the ground-water reservoir from which all irrigation wells in the basin withdraw water. Wells drilled in the valley between the Chiricahua and Swisshelm Mountains encountered as much as 1,100 feet of alluvium.

Recent fill.--Recent fill is found in the channels of Whitewater Draw and its tributaries. It is the source of water for stock and domestic wells in mountain canyons. The thickness of known Recent fill ranges from a few inches to 30 feet or more. No distinction has been made between Recent fill and older fill on plate 29.

Ground water

Occurrence

Ground water in the Douglas basin is found in the poorly consolidated and unconsolidated valley fill of the basin trough. The principal aquifers are in the older fill and consist of sand and gravel lenses interbedded with clay and silt. These aquifers are generally interconnected and form a common ground-water reservoir.

The depth to water in the valley fill (plate 29) ranges from near land surface in the vicinity of Whitewater Draw near the International Boundary to more than 470 feet in the northeastern part of the basin and upland areas. In the irrigated areas along the axis of the valley, the depth to water ranges from 25 to 125 feet and the water in the shallow aquifers is not under artesian pressure. Most of the irrigation wells obtain water from nonartesian aquifers at depths less than 600 feet. The greatest depth at which an aquifer was encountered in the older fill was in a well in sec. 14, T. 24 S., R. 27 E. Water-bearing sand and gravel was penetrated between 1,046 feet and the bottom of the well at 1,095 feet. A water-bearing sand was encountered between 990 and 1,012 feet in well (D-21-25)1d. Other deep wells in the City of Douglas area have encountered water under pressure in aquifers at depth. In several wells the pressure was great enough to cause the water to flow to the land surface. The yield from these deep aquifers is not known, but it is believed that their permeability is low.

Depth-to-water measurements reveal an important difference between the occurrence of water on the east side of the basin and that on the west side. On the east side of the valley the depth to water increases away from Whitewater Draw. When depths of from 200 to 250 feet are reached, an abrupt change in the depth to water occurs. East of this area, the depth to water is generally less than 70 feet. This sharp break in depth to water is believed to be due to a pediment. The pediment is covered by a veneer of alluvium which, in places, is too thin to provide space for the storage of ground water. West of Whitewater Draw the depth to water becomes progressively greater until the water table abuts against the hard rock of the mountain front.

Source and movement

The discussion of sources of ground water in Part I, "Regional hydrology," is applicable to the Douglas basin.

It can be seen from the ground-water contours in plate 30 that the general movement of ground water in the basin is from the recharge areas near the mountains toward the axis of the valley and thence southward. Some ground water moves toward the interior of the basin among the buttes of Turkey Creek and Ash Creek Ridges. The steepest slopes of the water table are from the sides of the valley toward the axis. Near the axis of the valley the slope of the water table is about 10 feet per mile southward. The changes that have occurred since 1913 in slope of the water table in the vicinity of the irrigated areas can be attributed to the pumping from wells.

Recharge

The principal source of recharge to the ground-water reservoir of the Douglas basin is runoff emerging from the mountain areas and flowing onto the coarse valley fill near the mountain fronts or in wash channels underlain by coarse sediments. The general pattern consists of washes emerging from the mountains, yet not maintaining a well-defined channel to Whitewater Draw, which attests to the water-absorbing character of the Recent valley fill in these areas. A large part of the water that percolates into these coarse sediments finds its way to the water table. On the basis of rainfall-runoff-recharge relationships, described in Part I of this report, it is estimated that the average recharge from this source is of the order of 20,000 acre-feet per year.

Only the precipitation that falls, or runs off in the Recent alluvium of the wash channels, is believed to reach the water table as recharge. The area of Recent alluvium in wash channels is small and, therefore, the amount of recharge in this manner is small.

The large percentage of clay in the soils and the presence of caliche layers near the land surface effectively retard the downward percolation of irrigation water applied to the land. It was reported that several moisture-penetration tests made by the Soil Conservation Service after excessive irrigations showed no increase in water content of the soil below a depth of 5 feet. It is believed that the amount of deep percolation from irrigation water is small, probably not much greater than 5 percent.

It has been determined from ground-water contours (pl. 30) that the surface-water drainage divide at the northern boundary of the basin does not coincide with the ground-water divide, but is basinward from the ground-water divide. Therefore, recharge occurring in the area between these divides will move toward the Douglas basin. The amount of water moving into the Douglas basin in this manner has been estimated to be in the order of 2,000 acre-feet per year.

Discharge

Natural means.--The discharge of ground water by evaporation is dependent on the water table being within 10 feet of the land surface. Such areas in the Douglas basin are limited to the channel of Whitewater Draw near the International Boundary and in some washes in mountain canyons. Because these areas are small, it is estimated that the discharge by evaporation is negligible.

The potential phreatophytes of the basin are mesquite, salt bushes, and some grasses. Of these plants, probably only mesquite is capable of obtaining ground water from depths exceeding 10 feet. On the basis of use of water by phreatophytes in other areas of southern Arizona, it is estimated that the total use of ground water by all phreatophytes in the Douglas basin does not exceed 15,000 acre-feet annually. The estimate included determination of areal extent of phreatophytes on the basis of aerial photographs, field studies to determine plant density, and depth-to-water measurements to aid in approximating the annual use in acre-feet per year per acre of 100 percent density.

The only ground waters discharged to areas outside the basin are as surface flow and underflow to Mexico. Records of surface flow in Whitewater Draw show that about 300 acre-feet of ground water is discharged annually in this manner. Data are inadequate with which to determine the amount of underflow from the basin, but it is believed to be relatively small.

Wells.--Most of the artificial discharge in the Douglas basin is pumpage from irrigation wells (pl. 31). Smaller amounts of ground water are pumped from municipal and industrial wells. Minor ground-water withdrawals are made for stock and domestic use throughout the valley. Although deep artesian conditions exist in certain localities the pressures are not sufficient to supply water without pumping.

Ground water has been pumped in the basin for irrigation since 1910. Prior to 1939 pumpage for irrigation probably did not exceed 5,000 acre-feet annually. A notable increase in the amounts of ground water used for irrigation is revealed by the following:

Year	Pumpage (acre-feet)
1945	8,000
1946	12,500
1947	17,000
1948	22,000
1949	30,000
1950	35,000
1951	38,000

In 1951 a total of 14,000 acres (pl. 31) was irrigated from about 270 wells. Municipal and industrial pumpage amounted to about 3,000 acre-feet in the same year.

Irrigation wells (table 37) in the Douglas basin range in diameter from 6 to 20 inches and in depth from 50 to more than 600 feet. The rate of discharge ranges from 80 to 1,500 gallons per minute and averages 380 gallons per minute. The discharges from irrigation wells range from 3 to 100 gallons per minute per foot of drawdown, with an average specific capacity of 12. Pumping lifts average about 100 feet, with a range from 50 feet near Whitewater Draw to more than 165 feet in wells west of Douglas and east of McNeal. The depth to the nonpumping water level in irrigation wells ranges from 25 feet to 125 feet and averages 50 feet.

Storage

Water-level fluctuations

Net declines or rises of water levels in wells indicate changes in underground storage. Figure 24 shows graphs of water-level fluctuations in selected wells in the basin. Wells (D-19-26)26aba, (D-20-26)11ddd, (D-20-26)33add, and (D-21-26)24bab, show that fluctuations have been greatest in the irrigated areas near Elfrida and McNeal. Net declines of the water table in these irrigated areas (pl. 32) averaged about 7 feet for the period 1946-51, the maximum net decline being about 11 feet. In the irrigated area west of Douglas net water-level declines ranged from 2 to $4\frac{1}{2}$ feet during the same period. In general, water-level declines caused by pumping for irrigation have not occurred in wells much beyond the fringe of the irrigated areas. Net declines of the water table in the City of Douglas area have been less than those of the Elfrida-McNeal area, as shown by the hydrographs (fig. 24) for wells (D-23-27)27cdd, (D-24-27)3ccc, and (D-24-27)5bcc.

Seasonal water-level fluctuations indicate local temporary changes in ground-water storage. Seasonal fluctuations in the basin are caused principally by cones of depression in the water table as they expand from pumping wells and are largest in the irrigated areas. Figure 24 shows seasonal fluctuations of as much as 12 feet in well (D-20-26)11ddd. There is some evidence that in local areas the spread of the cones of depression is apparently slow.

Changes in storage

By using the water-table-decline map (pl. 32) it was calculated that about 1,110,000 acre-feet of sediments was dewatered in the period 1947-51. Assuming a coefficient of drainage of 8 percent, based on studies in other areas, the total amount of ground water taken out of storage in the last 5 years was 88,000 acre-feet or an average of about 17,000 acre-feet a year.

Latent storage

On the basis of calculations of the volume of saturated fill to a depth of 300 feet below the land surface and an estimated coefficient of drainage of 8 percent, the quantity of ground water contained in the Douglas basin as latent storage was estimated to be less than 5,000,000 acre-feet. Data from well logs, well cuttings, pumping tests, and well discharges indicate that the mean coefficient of drainage for the alluvium in the valley may be as low as 4 or 5 percent. On the basis of a coefficient of 5 percent, the quantity in latent storage was estimated to be about 3,000,000 acre-feet.

Underlying storage

On the basis of the depth-to-water map (pl. 29), the average depth to water level in the basin was estimated to be about 60 feet. Inasmuch as the municipal and industrial pumpage in the basin is appreciable, these areas have been included in the calculations for underlying storage. The total area for which the computation is made is about 72,000 acres. The amount of saturated sediments from the water table down to 300 feet below the land surface is estimated to be about 17,500,000 acre-feet. Using the estimated 8 percent as the coefficient of drainage, it was computed that the amount of water in underlying storage in the sediments to a depth of 300 feet below land surface would be about 1,400,000 acre-feet. However, compaction and cementation of the alluvial fill increases with depth, resulting in a decrease of the percentage value for the coefficient of drainage. Therefore, the above estimate of underlying storage is high. Quantitative data are not available with which to establish the amount by which this estimate should be reduced.

Quality of ground water

Analytical data for water from 112 wells in the basin were used to determine the quality of the ground water in the Douglas basin. Table 39 lists the analyses of the waters from a few of these wells.

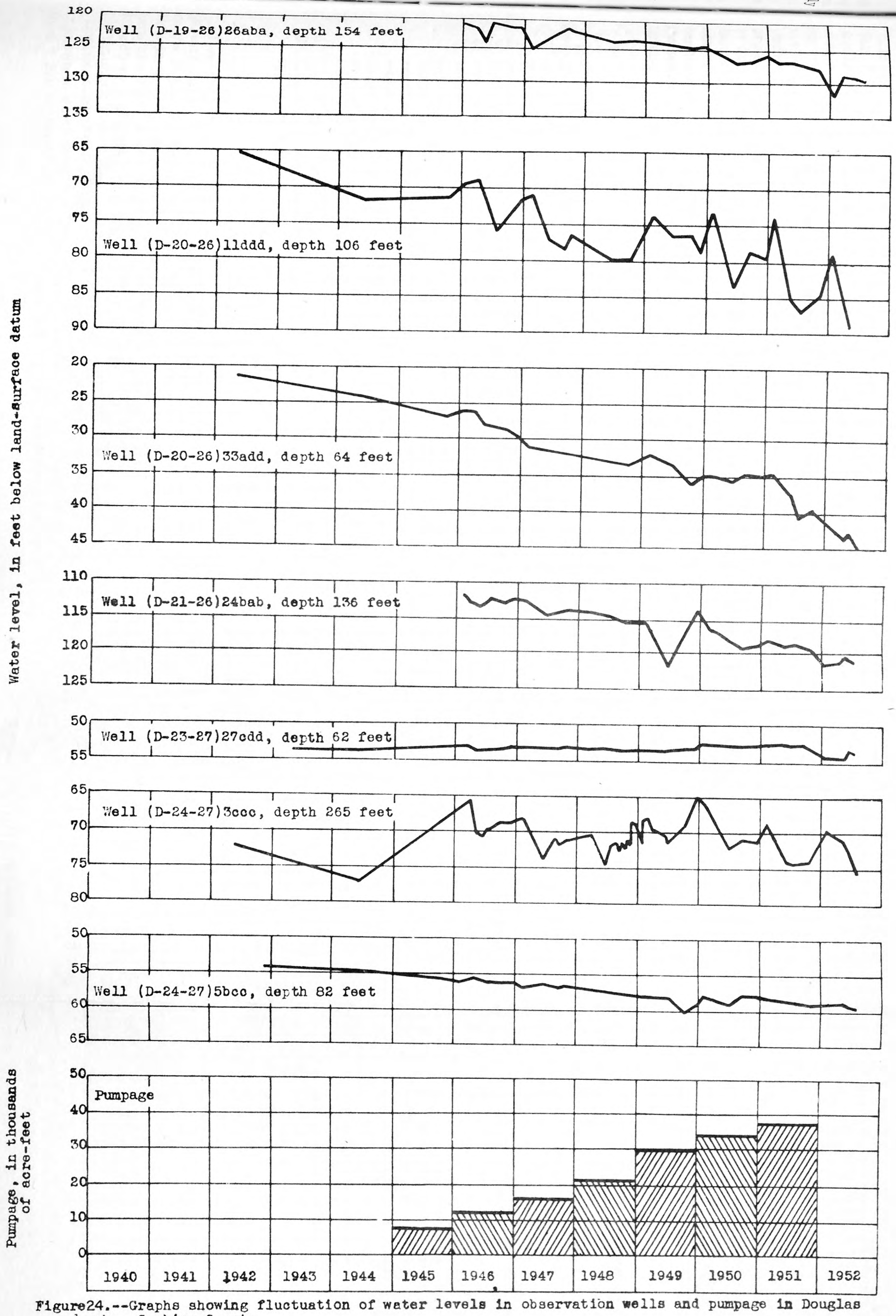


Figure24.--Graphs showing fluctuation of water levels in observation wells and pumpage in Douglas basin, Cochise County.

In general, waters in the basin are considered, by standards set forth in Part I, Quality of water, to be "excellent to good" for irrigation use. Waters from most of the wells sampled contain moderate amounts of dissolved solids ranging from 100 to 500 parts per million, only 14 of the wells sampled having waters that contained more than 500 parts per million. The dissolved solids are mostly calcium, sodium, and bicarbonate. Gypsum beds east of Douglas contribute calcium and sulfate to ground waters in that part of the basin. The ground waters of the basin have more than 100 parts per million of hardness as $CaCO_3$, except in the area just west of Douglas. Water of unusually low hardness is pumped by the City of Douglas from its wells west of town. The waters of the basin are generally good for domestic use except for moderate hardness and excessive amounts of fluoride in local areas. In a few places in the basin ground waters are too highly mineralized to be satisfactory for domestic use.

Problems

The following factors must be determined more accurately before the ground-water resources of the basin can be properly evaluated:

1. Rates of infiltration in the coarse material along the mountain fronts and in wash channels, and from irrigated fields.
2. Precipitation and runoff relationship in the hard-rock areas.
3. Change in the coefficient of drainage with depth.
4. Permeability of the alluvial fill in the vicinity of Douglas and the International Boundary, and underflow across the boundary. Determination of underflow cannot be made until the relation of the interbedded basalt and valley fill has been determined with respect to movement of ground water. A corollary problem is the quality-of-water anomaly--why large differences in quality of water occur in short distances. Solution of these problems will also aid in determining areas of highest well yield and best quality of water in the vicinity.
5. Use of ground water by phreatophytes.
6. Water-bearing character of the older sedimentary rocks underlying the alluvial fill.

Summary

The Douglas basin is a part of a large northwest-trending valley in southeastern Arizona. The basin is bounded on the north by a series of low ridges, on the east and west by mountain ranges, and on the south by the International Boundary. The basin is about 40 miles long, 30 miles wide and includes an area of about 1,200 square miles. The drainage of the basin is southward into Mexico by Whitewater Draw and its tributaries. The hard rocks composing the mountains and ridges of the area are of the crystalline and metamorphic complex, older sedimentary rocks, and volcanic rocks. The older alluvial fill is known to be at least 1,600 feet thick. The Recent fill ranges in thickness from a few inches to 30 feet or more and is of small areal extent.

The older alluvial fill contains the principal aquifers in the basin and furnishes water for irrigation, public supply, and industrial wells. Artesian aquifers are known to exist at depth in local areas but the character and extent of these aquifers is not known.

The principal source of recharge to the basin is infiltration of runoff in the coarse sediments along the mountain fronts. It is estimated that about 20,000 acre-feet of water is recharged to the reservoir annually from this source.

The principal means of discharge from the ground-water reservoir is by wells. In 1951 about 270 wells furnished 38,000 acre-feet of water to irrigate about 14,000 acres of land. In addition, municipal and industrial wells pumped about 3,000 acre-feet.

This heavy pumping has resulted in an average net decline of the water table amounting to about 7 feet in the irrigated areas in the period 1946-51. On the basis of this decline, the average amount of water that has been withdrawn from underlying storage is estimated to be about 17,000 acre-feet per year in that period.

Most of the ground water in the basin is "excellent to good" for irrigation use. The waters are generally also considered good for domestic use except for moderate hardness and excessive amounts of fluoride or dissolved solids in local areas.

Further study is needed before it will be possible to evaluate fully the ground-water resources of the Douglas basin.

Table 37.--Records of representative wells and springs in the Douglas basin, Cochise County, Ariz.

Well or spring no.	Depth of well (feet)	Water level: Depth below land-surface datum (feet) a/	Water level: Date of measurement	Type of lift b/	Use of water c/	Analysis on file	Log on file	Remarks
(D-18-24)								
34cc	d/	-	9/51	-	S	X	-	Walnut Spring; discharge ½ gpm.
(D-18-26)								
21ddd	89	73.85	1/52	C,W	S	-	-	
(D-19-26)								
1aaa	-	124.03	8/51	C,W	D,S	-	-	
29bab	-	43.36	1/52	T,E	I	-	-	Observation well.
(D-19-29)								
10dd	d/	-	10/51	-	-	X	-	In John Long Canyon; discharge, 15 gpm.
21dc	d/	-	10/51	-	D	X	-	Tributary of Rucker Canyon; discharge, 2 gpm.
(D-20-24)								
21ca	d/	-	9/51	-	S	X	-	Antelope Spring; discharge ½ gpm.
(D-20-26)								
6aba	72	49.60	1/52	T,E	I	X	-	Discharge, 610 gpm, measured.
16daa	130	48.28	1/52	T,E	I	-	X	Discharge, 520 gpm, measured.
33add	-	38.78	1/52	T,E	I	-	-	Hydrograph, fig. 24.
(D-20-27)								
18daa	600	81.90	1/52	T,E	I	-	X	Discharge, 270 gpm, measured.
(D-21-25)								
1dd	1012	3.77	3/52	C,W	S	-	-	
25aaa	-	67.75	1/52	C,W	D	-	-	
(D-21-26)								
23ab	505	95.94	1/52	T,E	I	-	X	Discharge, 600 gpm, estimated.
24bab	136	121.43	1/52	C,W	D	X	-	Hydrograph, fig. 24.
26dcd	364	112.75	12/51	T,E	D,I	-	X	Discharge, 330 gpm, measured.
28dcd	250	58.20	12/51	T,E	I	-	X	Discharge, 283 gpm, measured.

a/ Depths were corrected to land-surface datum from measuring point.
b/ C, cylinder; T, turbine; G, gasoline; W, windmill; E, electric.
c/ I, irrigation; D, domestic; S, stock; N, not used; Ind., industrial; P, public supply.
d/ Spring.

Table 37.--Records of representative wells and springs in the Douglas basin --continued.

Well or spring no.	Depth of well (feet)	Water level: Depth below land-surface datum (feet) a/	Water level: Date of measurement	Type of lift b/	Use of water c/	Analysis on file	Log on file	Remarks
(D-21-27)								
28ccc	–	222.81	12/51	C,W	S	–	–	
(D-21-28)								
3baa	1517	800	–	–	–	–	X	
21bc	d/	–	10/51	–	S	X	–	Leslie Spring; discharge 60 gpm.
(D-22-24)								
29bc	d/	–	9/51	–	–	X	–	In Soto Canyon; discharge 4½ gpm.
(D-22-26)								
4dad	250	67.72	12/51	T,G	I	–	X	Discharge, 170 gpm, measured.
34ada	145	61.79	2/52	T,E	I	–	–	Discharge, 340 gpm, measured.
(D-22-27)								
5b	4210	–	–	None	N	X	–	Discharge, 90 gpm, estimated; oil test hole.
34cd	420	–	–	–	–	–	X	Discharge, 55 gpm, reported.
(D-23-26)								
1aa	186	66.60	1/52	T,E	I	–	–	Discharge, 145 gpm, measured.
(D-23-27)								
23daa	197	179.30	12/51	None	N	–	–	
(D-23-28)								
30cc	230	193.03	12/51	C,W	D,S	–	–	
(D-24-26)								
6acc	210	184.68	1/52	C,W	D	–	–	Observation well.
(D-24-27)								
3cdd	27	22.44	2/52	C,W	D,S	X	–	Hydrograph, fig. 24.
5bcc	68	58.37	1/52	C,W	D,S	X	–	Hydrograph, fig. 24.
10db	d/	–	2/52	–	–	X	–	
10dbb	350	61.0	2/52	T,E	P	X	–	Discharge, 1000 gpm, reported.
13bbd	250	101.05	1/52	T,E	Ind.	–	–	Discharge, 150 gpm, reported.
15baa	450	62.90	2/52	T,E	Ind.	–	X	Discharge, 950 gpm, reported.
(D-24-28)								
7abc	400	151.83	2/52	T,E	I	–	X	

Table 38.--Logs of representative wells in Douglas basin, Cochise County, Ariz.

	Thickness (feet)	Depth (feet)
(D-20-26)16daa		
Soil and clay	31	31
Sand, water	1	32
Clay	12	44
Sand, water	6	50
Clay	12	62
Sand, water	3	65
Clay	11	76
Sand, water	3	79
Clay	10	89
Sand and gravel	3	92
Clay	20	112
Sand and gravel	2	114
Clay	6	120
Clay and gravel	13	133
TOTAL DEPTH		133
(D-20-27)18daa		
Sand, clay and boulders	86	86
Sand	2	88
Clay	434	522
Granite	18	540
Gravel	8	548
Granite or blue quartz	22	570
Gravel	6	576
Granite	14	590
Sand and gravel with gold-bearing quartz	10	600
TOTAL DEPTH		600
(D-21-26)23abb		
Topsoil	5	5
Caliche and clay	10	15
Clay	77	92
Sand, gravel, and water	2	94
Clay	14	108
Gravel and water	3	111
Clay	49	160
Sand	2	162
Clay	39	201
Sand	3	204
Clay	96	300
Clay, tough and gravelly	30	330
Clay, sticky	16	346
Gravel	4	350
Clay	20	370
Clay	63	433

	Thickness (feet)	Depth (feet)
Gravel	4	437
Clay	9	446
Gravel	3	449
Clay	11	460
Gravel	16	476
Clay	6	482
Gravel	5	487
Clay	5	492
Gravel	9	501
Clay	4	505
TOTAL DEPTH		505
(D-21-26)26dcd		
Topsoil, black	4	4
Rocks, grey clay, and conglomerate	16	20
Clay, red and hard	50	70
Clay, soft and sandy	16	86
Sand and gravel, dry	6	92
Conglomerate, light red and hard	17	109
Water	6	115
Clay, red and soft, and conglomerate	41	156
Water	2	158
Clay, grey, with hard and soft streaks	28	186
Conglomerate, light red and soft	31	217
Clay, grey and soft	3	220
Conglomerate, light brown and hard	35	255
Water	2	257
Clay and conglomerate, grey and hard	22	279
Clay, hard and in streaks, water rose 2 feet	1	280
Clay and conglomerate, grey and in streaks	58	338
Water	2	340
Clay and hard conglomerate, grey and in streaks	24	364
TOTAL DEPTH		364
(D-21-26)28dcd		
Topsoil	4	4
Clay, small amount of water at 54 feet	50	54

Table 38.--Logs of representative wells in Douglas basin--continued.

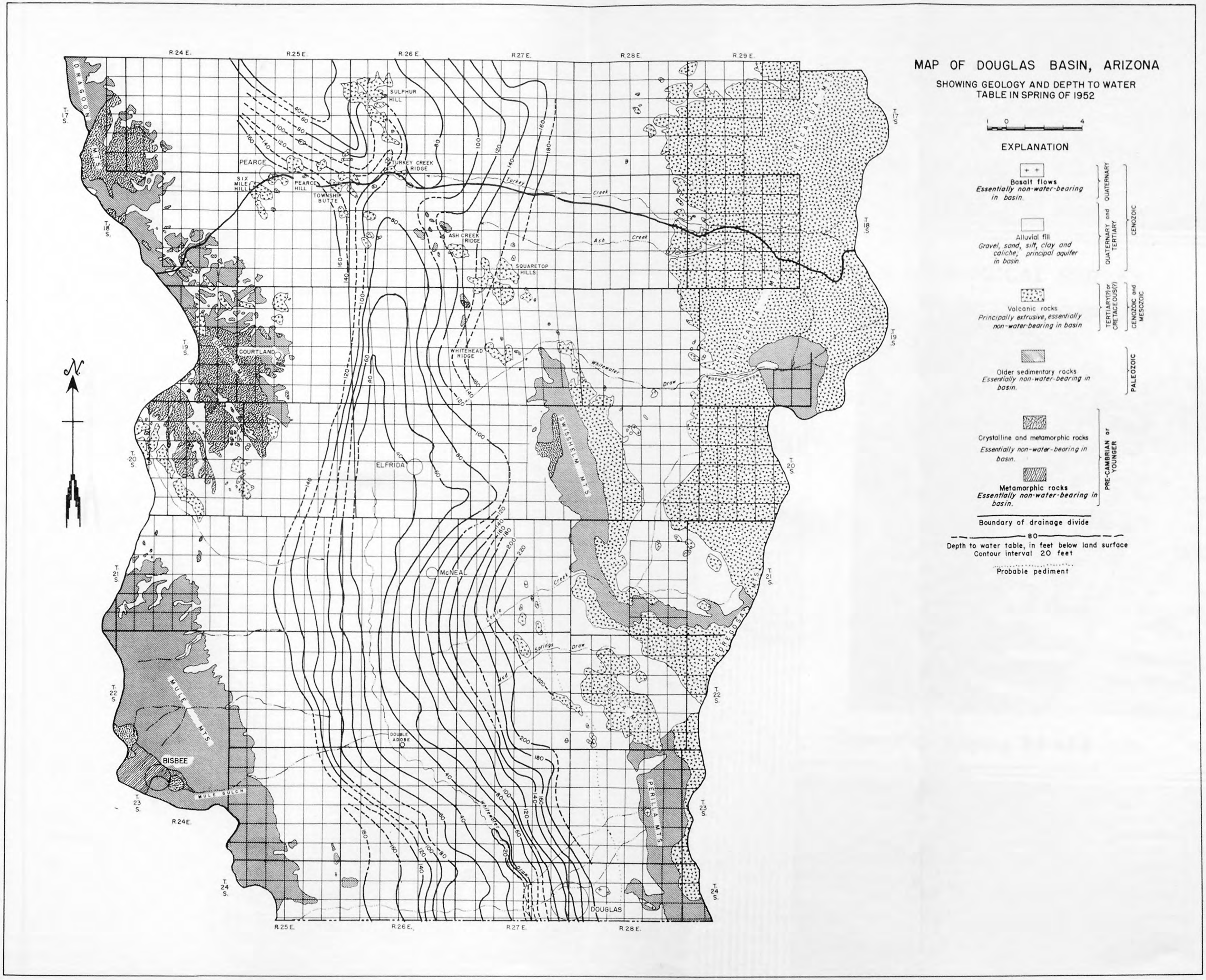
	Thickness (feet)	Depth (feet)
Clay - - - - - - - - - -	12	66
Clay - - - - - - - - - -	20	86
Sand and gravel with water - - - - - - - - -	1	87
Clay - - - - - - - - - -	99	186
Clay, jointed - - - - - -	2	188
Clay, sandy with water	12	200
Clay - - - - - - - - - -	50	250
TOTAL DEPTH		250
(D-21-28)3baa		
Fill - - - - - - - - - -	1020	1020
Limestone; water would bail out at 1165 feet	180	1200
Porphyry - - - - - - - -	65	1265
Limestone - - - - - - - -	252	1517
TOTAL DEPTH		1517
(D-22-26)4dad		
Soil, sandy - - - - - - -	15	15
Clay, red - - - - - - - -	22	37
Clay and boulders - - - -	5	42
Sand and gravel - - - - -	4	46
Clay and small rocks -	19	65
Sand and gravel with water - - - - - - - - -	2	67
Clay and small rocks -	4	71
Clay, red - - - - - - - -	18	89
Sand and gravel with water - - - - - - - - -	4	93
Clay and small rocks -	23	116
Clay - - - - - - - - - -	19	135
Caliche - - - - - - - - -	10	145
Clay, and rocks - - - - -	5	150
Caliche - - - - - - - - -	16	166
Clay, red, with rocks -	66	232
Sand and gravel with water - - - - - - - - -	11	243
Clay, red - - - - - - - -	7	250
TOTAL DEPTH		250
(D-22-27)5b		
Clay and silty sand - - -	110	110
Red and grey pebbly sand	280	390
Red, silty sand - - - - -	110	500
Red, coarse sand - - - -	120	620
Red and grey coarse sand	640	1260
Grey and red sand - - - -	360	1620
Interbedded limestone and quartzite - - - - - -	645	2265
Pink quartzite and limestone - - - - - - - - - -	60	2325
Limestone and shale - -	430	2755
Red sandstone - - - - - -	130	2885
Alternating beds sandstone and dolomite - -	210	3095
Red-brown and grey dolomite - - - - - - - - - -	130	3225
Various colored dolomite	70	3295
Grey limestone - - - - - -	145	3440
Grey sandstone - - - - - -	245	3685
Various colored quartzite	120	3805
Quartzite and sandstone	80	3885
Arkosic quartzite - - - -	35	3920
Granite - - - - - - - - -	75	3995
Granite - - - - - - - - -	215	4210
TOTAL DEPTH		4210
(D-23-26)1aa		
Soil and clay - - - - - -	60	60
Clay and sand with water	30	90
Gravel with water - - - -	20	110
Clay strata and sand strata with water - - - -	40	150
Clay, red - - - - - - - -	36	186
TOTAL DEPTH		186
(D-24-27)15baa		
Topsoil - - - - - - - - -	3	3
Sandy soil - surface water	30	33
Gravel - - - - - - - - - -	27	60
Fine sand - - - - - - - -	8	68
Gypsum - - - - - - - - - -	2	70
Red, sticky clay - - - - -	144	214
Light brown clay - - - - -	127	341
Malpais and clay - - - - -	5	346
Malpais - surface water disappeared - - - - - - -	18	364
Conglomerate - - - - - - -	14	378
Malpais - - - - - - - - - -	17	395
Sand - - - - - - - - - - -	3	398
Red clay - - - - - - - - -	32	430
Brown clay - - - - - - - -	25	455

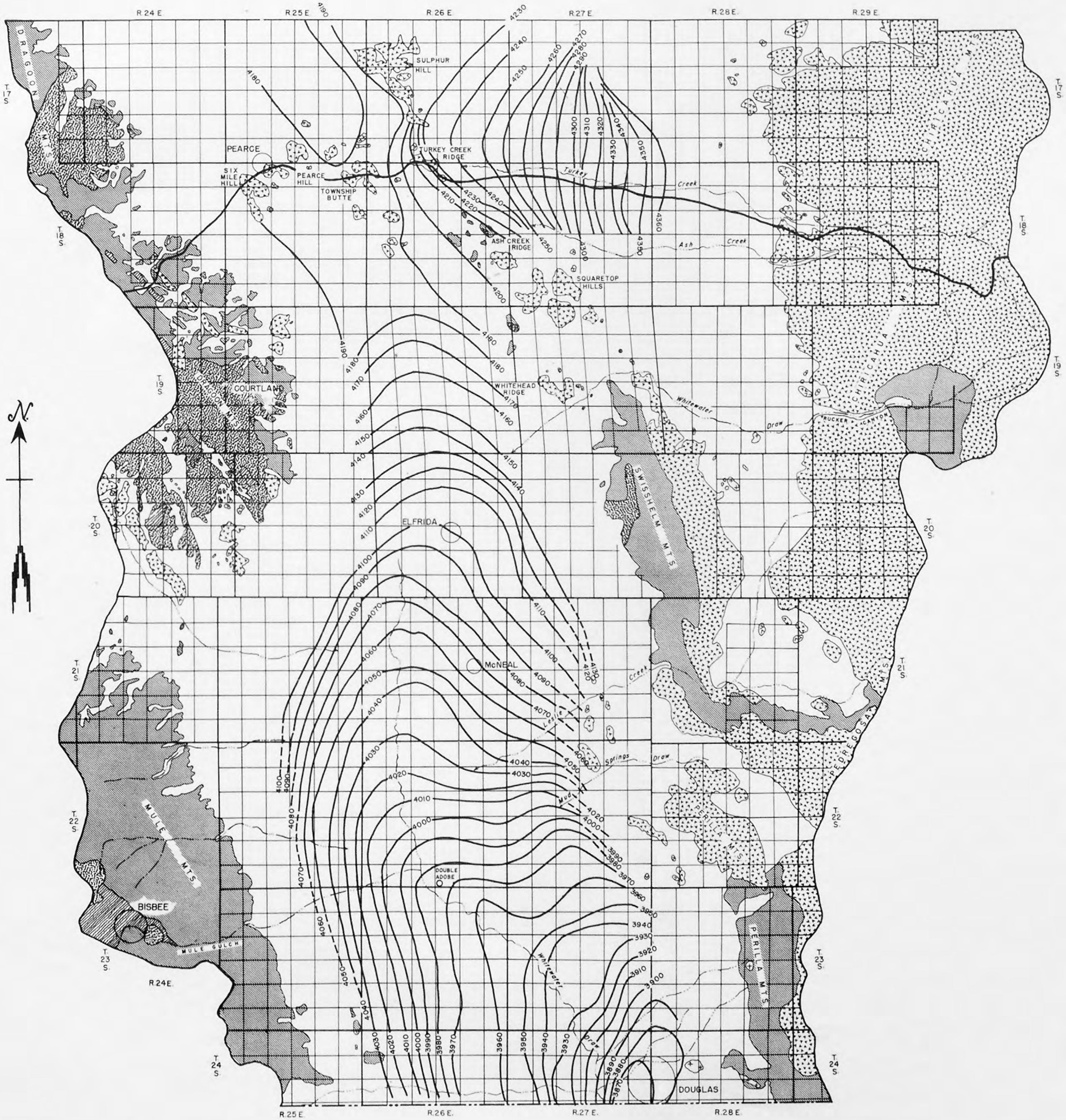
Table 38.--Logs of representative wells in Douglas basin--continued.

	Thickness (feet)	Depth (feet)
Sand	2	457
Finer sand	33	490
Light brown clay	55	545
Hard sand	10	555
Coarse sand and gravel	4	559
Light brown clay	6	565
Sand	35	600
Hard clay	14	614
Sand	12	626
Coarse sand and gravel	4	630
Hard clay	8	638
Hard sand	4	642
Coarse sand	5	647
Sticky clay	27	674
Hard sand and gravel	4	678
Sticky clay	12	690
Fine sand	4	694
Sticky clay	9	703
Hard sand	5	708
Sticky clay	2	710
Hard sand	6	716
Hard clay	15	731
Hard sand	16	747
Sticky clay	14	761
Hard sand	20	781
Very sticky clay	52	833
Strúck water		833
Water, sand and gravel	23	856
Clay	32	888
Sand	47	935
Hard clay	15	950
TOTAL DEPTH		950
(D-24-28)7abc		
Topsoil	2	2
Caliche	3	5
Boulders and clay	29	34
Clay, red	9	43
Conglomerate	106	149
Gravel, water	3	152
Conglomerate	28	180
Gravel, water	6	186
Conglomerate	29	215
Gravel, water	2	217
Malpais (i.e.basalt)	105	322
Water	10	332
Clay, red	3	335
TOTAL DEPTH		335

Table 39.--Analyses of water from representative wells in Douglas basin, Cochise County, Ariz.
(Parts per million except specific conductance and percent sodium)

Well no.	Date of collection	Temperature (°F.)	Specific conductance (micromhos at 25° C.)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Total hardness as $CaCO_3$	Percent sodium
(D-18-25)5ac	5-22-46	77	398	46	9.3	25	175	22	16	2.0	16	222	153	26
(D-18-26)15bb	5-28-46	70	286	30	5.2	26	141	18	6.0	3.0	3.0	161	96	37
(D-19-26)30ab	2-12-52	69	261	34	7.0	10	129	10	8.0	2.0	3.8	176	114	16
(D-19-28)28bbb	6-13-46	69	310	32	2.6	37	164	17	9.0	2.0	1.4	182	90	47
(D-20-26)12ba	2-27-46	70	237	29	1.6	25	136	12	5.0	0.8	0.8	141	79	41
(D-21-25)23ab	2-12-52	69	613	36	7.6	86	202	42	59	2.8	11	374	121	61
(D-21-26)24bab	3-27-46	73	383	38	13	30	222	11	9.0	1.6	5.8	218	148	31
(D-21-27)13cd	8-15-47	-	563	69	12	39	254	50	21	0.4	20	368	222	28
(D-22-25)24da	2-12-52	69	410	66	7.9	11	245	7.8	6.0	0.0	4.5	251	197	11
(D-22-26)13dd	8-27-47	73	366	37	6.5	54	163	26	15	0.4	3.9	223	119	49
(D-23-26)3aa	5-31-46	67	923	66	16	109	237	106	112	0.7	2.7	529	230	51
(D-23-27)19da	5-28-52	80	7130	380	212	966	249	1140	1790	1.0	4.2	4640	1820	54
(D-23-28)15ac	8-18-47	80	634	63	34	31	368	35	14	0.8	5.7	365	297	18
(D-24-26)1cb	2-5-46	-	623	62	17	51	264	49	44	0.8	3.9	358	224	33
(D-24-27)3cdd	5-28-52	78	988	4.5	1.1	209	176	96	153	2.6	2.5	575	16	97
(D-24-28)11bca	3-13-52	67	2950	556	154	54	207	1810	48	1.2	16	2770	2020	5


MAP OF DOUGLAS BASIN, ARIZONA
SHOWING GEOLOGY AND DEPTH TO WATER TABLE IN SPRING OF 1952
EXPLANATION
Basalt flows
Essentially non-water-bearing in basin.
Alluvial fill
Gravel, sand, silt, clay and caliche; principal aquifer in basin
Volcanic rocks
Principally extrusive, essentially non-water-bearing in basin
Older sedimentary rocks
Essentially non-water-bearing in basin.
Crystalline and metamorphic rocks
Essentially non-water-bearing in basin.
Metamorphic rocks
Essentially non-water-bearing in basin.
QUATERNARY
QUATERNARY and TERTIARY
CENOZOIC
TERTIARY(?) or CRETACEOUS(?)
CENOZOIC and MESOZOIC
PALEOZOIC
PRE-CAMBRIAN or YOUNGER
Boundary of drainage divide
80
Depth to water table, in feet below land surface
Contour interval 20 feet
Probable pediment
R.24 E.
R.25 E.
R.26 E.
R.27 E.
R.28 E.
R.29 E.
T. 17 S.
T. 18 S.
T. 19 S.
T. 20 S.
T. 21 S.
T. 22 S.
T. 23 S.
T. 24 S.
DRAGOON MTS
SULPHUR HILL
PEARCE
SIX MILE HILL
PEARCE HILL
TOWNSHIP BUTTE
TURKEY CREEK RIDGE
Turkey Creek
Ash Creek
ASH CREEK RIDGE
SQUARETOP HILLS
CHIRICAHUA MTS
COURTLAND
WHITEHEAD RIDGE
Whitewater Draw
RUCKER CANYON
SWISSHELM MTS
ELFRIDA
McNEAL
Leslie Creek
Springs Draw
Mud
PEDREGOSA MTS
PERILLA MTS
MULE MTS
BISBEE
MULE GULCH
DOUBLE ADOBE
Whitewater Draw
DOUGLAS
N



MAP OF DOUGLAS BASIN, ARIZONA

SHOWING CONTOURS OF THE WATER TABLE AS OF SPRING OF 1952

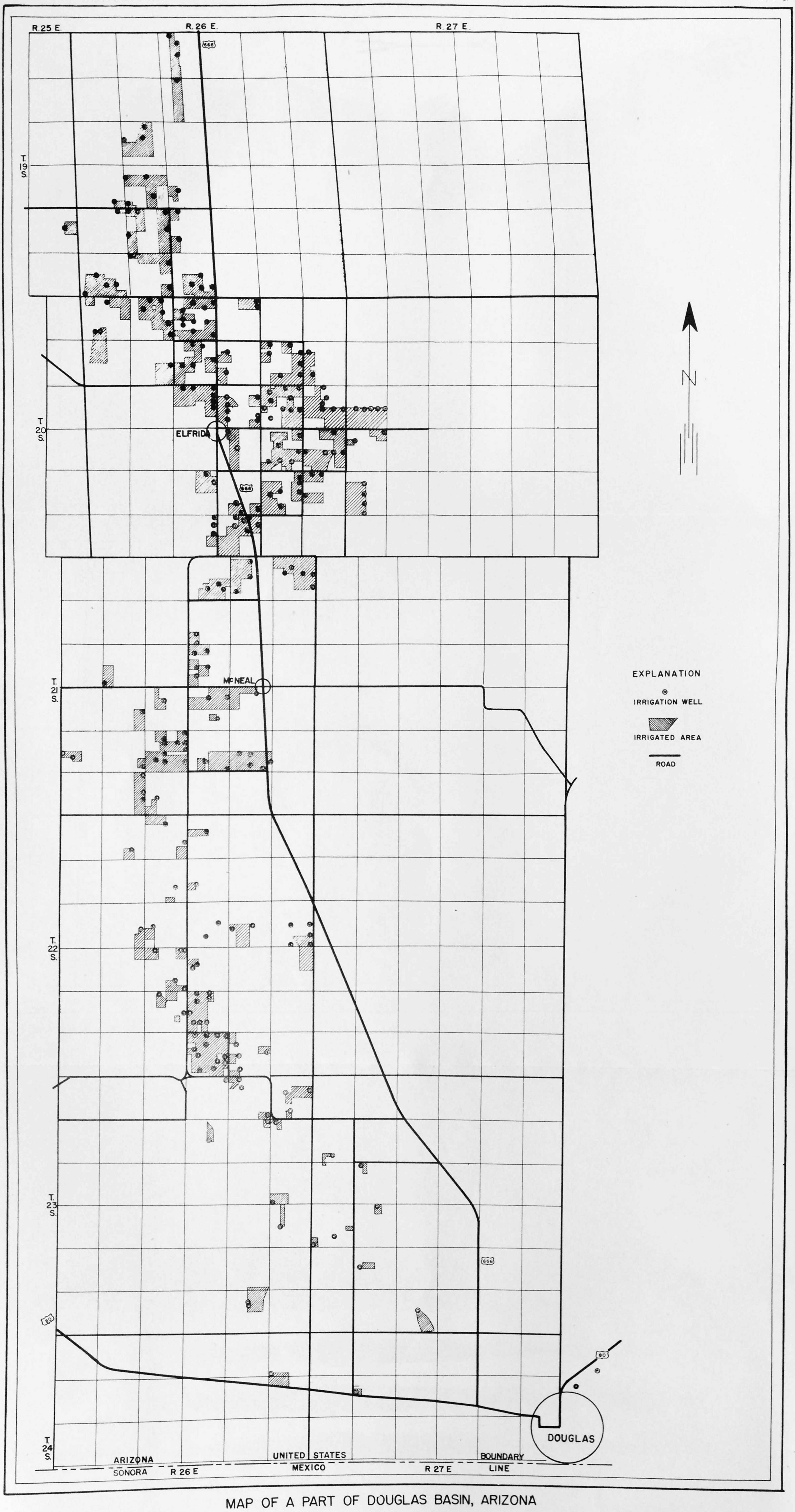
1 0 4 MILES

EXPLANATION

—— 4180 ——

ELEVATION OF CONTOURS OF WATER TABLE

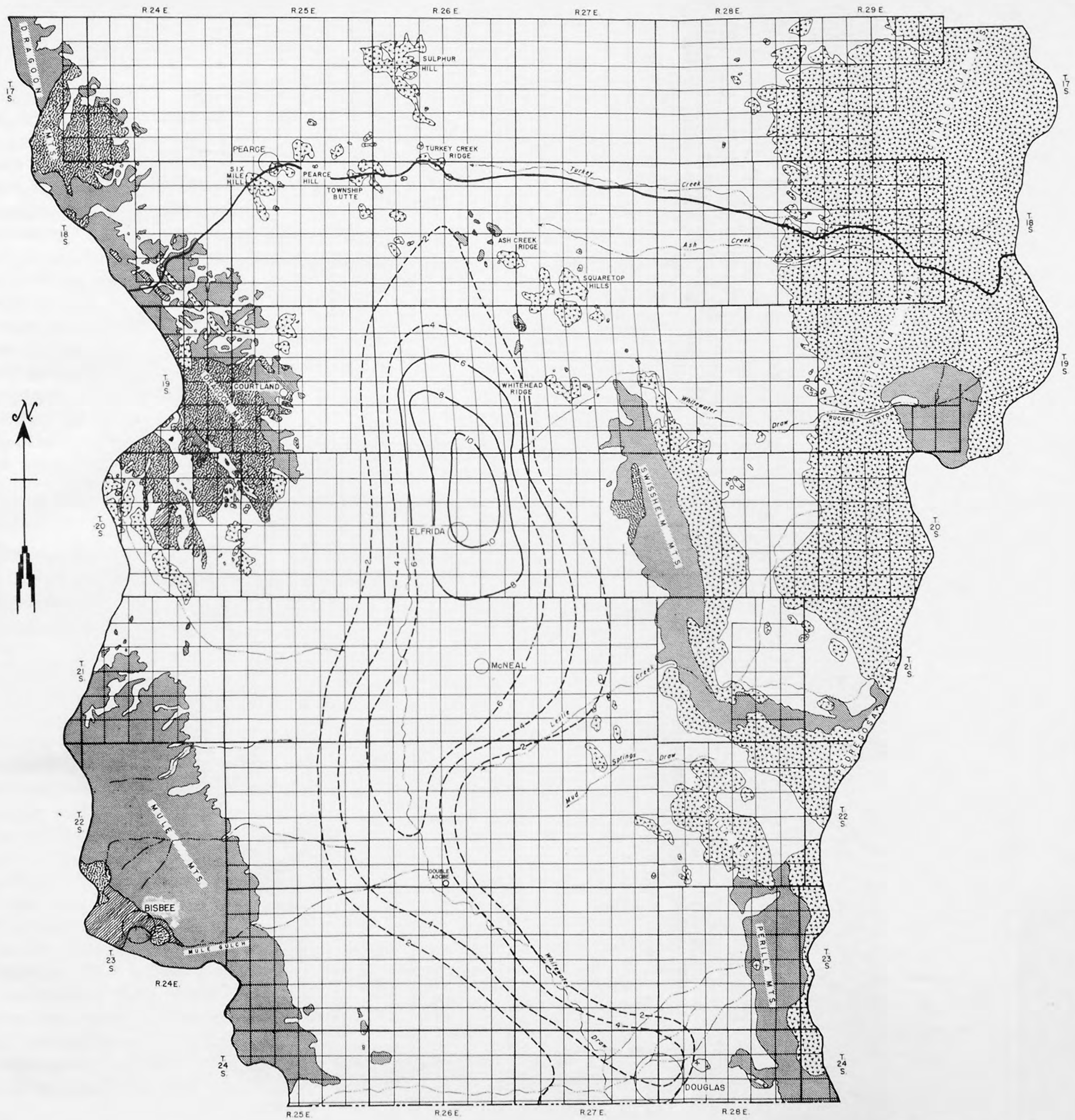
(SEE PLATE 29 FOR EXPLANATION OF GEOLOGIC SYMBOLS)



MAP OF A PART OF DOUGLAS BASIN, ARIZONA

SHOWING IRRIGATION WELLS AND IRRIGATED AREAS

1 0 3 MILES



MAP OF DOUGLAS BASIN, ARIZONA

SHOWING DECLINE OF THE WATER TABLE

0 4 MILES

EXPLANATION

6

DECLINE OF WATER TABLE IN FEET FROM SPRING OF 1947 TO SPRING OF 1952

(SEE PLATE 29 FOR EXPLANATION OF GEOLOGIC SYMBOLS)

OTHER AREAS IRRIGATED WITH GROUND WATER

By J. H. Feth, L. A. Heindl, P. W. Johnson, and H. N. Wolcott

There are many areas in Arizona, other than those described in the preceding chapters, in which ground water is used for irrigation. Irrigated tracts within these areas range from a few hundred to a few thousand acres . Many of these areas are of great local importance, although for the most part they have no direct bearing on the problems of water supply in the large irrigated basins of central and southern Arizona.

The occurrence of ground water has been investigated by the Geological Survey in only a few of the smaller irrigated areas in Arizona, because available funds and personnel have been fully employed in regions of more intensive ground-water use.

For the sake of completeness, a brief comment is made in this chapter on some of these other areas. Work has been done in some of these areas and a few reports have been prepared by the Geological Survey. In general, however, only meager information is available.

Plate 1 shows the generalized outlines of some of the areas mentioned in this chapter; others may be located on the map by reference to a town or a stream. The areas are presented alphabetically, by counties.

Apache County

About 17,000 acres was irrigated in Apache County in 1951 (Barr and Seltzer, 1952, p. 16), largely with surface water but in part with ground water. In areas where ground water is used, water levels in observation wells show slight declines (Halpenny and Cushman, 1952, in preparation) but no definite trend is apparent.

St. Johns area

An unmeasured amount of ground water is withdrawn from aquifers in the Coconino sandstone for irrigation in an area surrounding St. Johns in the valley of the Little Colorado River. It is estimated that annual withdrawals for irrigation are in the order of 1,000 acre-feet.

At several places along the Little Colorado River in the reach between St. Johns and Lyman Reservoir, travertine cones have been built by deposition from warm, highly mineralized spring waters. These spring cones attain heights of more than 100 feet and, in extreme cases, diameters of nearly half a mile. A smaller number of cones occur on Concho Creek, about 15 miles west of St. Johns. The waters discharging from the springs add large amounts of mineral matter, principally common salt, to the Little Colorado River. The sources of the mineralized waters are believed to be artesian aquifers in older sedimentary rocks that occur at considerable depth beneath the land surface. The origin of the artesian pressure and the reasons for localization of the springs are not known, although the linear arrangement of the spring cones suggests that faulting may determine the paths along which the artesian waters rise.

Hunt area

The Hunt area is a small farming community on the Little Colorado River in T. 14 N., R. 26 E. Springs and surface flow of the Little Colorado River firnish some water for irrigation. The Coconino sandstone, the principal aquifer in the area, supplies water under artesian pressure to wells, some of which flow. Water of poor quality is obtained for domestic and stock use at relatively shallow depths in the region, from the Moenkopi formation and the Shinarump conglomerate. Agricultural development in the area is limited by the amount of arable land and by a short growing season. It is estimated that about 1,000 acre-feet of ground water was used for irrigation in 1951.

Springerville-Round Valley area

A total of about 3,000 acres was irrigated in Round Valley, near Springerville, in 1947 (Barr, 1948, p. 16). The expansion of irrigated acreage since 1948 is not known, nor has the amount of ground water used annually been determined. It is probable, however, that pumpage for irrigation does not exceed 2,000 acre-feet per year.

Cochise County

Southern San Simon Valley

More than 1,000 acres of land is irrigated in the southern extension of San Simon Valley. Irrigation wells are from 200 to 1,000 feet deep and the water levels range from about 70 to 100 feet. A maximum yield of about 3,000 gallons per minute has been reported but yields are generally less than 1,000 gallons per minute. Aquifers occur in sand and gravel lenses from 70 to 350 feet below the surface. Between 350 feet and 1,000 feet, little except clay is encountered. The quality of water is considered generally good for irrigation and domestic use, except locally where the fluoride content is slightly higher than the suggested maximum.

South of the irrigated area the alluvial fill is partly covered by Quaternary lava flows and cinder beds. Water for domestic and stock use is obtained from springs and small wells.

The southern San Simon Valley was included in a Geological Survey reconnaissance report on the San Simon Valley (Schwennesen, 1917).

San Bernardino Valley

The San Bernardino Valley lies in the extreme southeastern corner of Arizona. It is a southwest-trending extension of the San Simon-Safford structural trough. This valley drains southward into Mexico. Much of the valley is covered by Quaternary volcanic flows and cinder cones and part of the area is covered with alluvial fill.

About 300 acres of land was irrigated in the San Bernardino Valley in 1952. No detailed information is available regarding the use of ground water for irrigation. Springs and wells supply water for domestic and stock use. The log of a well in sec. 32, T. 21 S., R. 32 E., shows a series of lava flows with four interbedded sandy clay layers which contained water. The well is 726 feet deep and the water level was reported to be nearly 600 feet below land surface in 1949.

Graham County

Upper Aravaipa Creek

Aravaipa Creek heads at the northwest end of the structural trough occupied by the Willcox and Douglas basins. The creek is a tributary of the San Pedro River and drains an area of about 550 square miles. Alluvial fill occupies about 200 square miles. Approximately 3,000 acres is cultivated along the inner valley. Aravaipa Creek is perennial for a considerable part of its length. Water for irrigation is supplied by surface-water diversions and withdrawals from wells. During the period 1932-41, Aravaipa Creek contributed an average annual flow of about 20,000 acre-feet to the San Pedro River.

Ground water for irrigation is withdrawn from wells constructed in Recent alluvium underlying the flood plain of Aravaipa Creek. Some domestic and stock wells obtain water from older alluvium. Depths to water range from a few feet along the Aravaipa Creek to about 400 feet in the older alluvium.

Mohave County

Big Sandy Valley

Big Sandy Valley is in Tps. 13 to 21 N., R. 13 W. Wickieup, the main settlement in the valley, is about 50 miles southeast of Kingman. In 1940, about 700 acres was irrigated, partly by ground water pumped from wells drilled in Recent alluvium. It is reported that in 1951 about 1,000 acres was irrigated. A reconnaissance study of this area was made by the Geological Survey (Morrison, 1940).

Ground-water movement is toward the axis of the valley and southward along Big Sandy River. Swampy areas along the river near Wickieup suggest that ground water is forced to the surface by a granite barrier to the south or that it rises along fault planes.

Depths to water in 1940 averaged less than 25 feet along the river bottom in the vicinity of Wickieup and ranged from 40 to 70 feet in the areas north and south. The possibility of the presence of artesian water in the Wickieup area was suggested by Morrison (1940, p. 6).

Virgin River Valley

About 1,500 acres is reported to be irrigated along the Virgin River in the northwest corner of Arizona near the town of Littlefield. The cultivated land lies along the flood plain of the Virgin River, and is irrigated partially with ground water. No information is available regarding the amount or quality of ground water withdrawn.

Several small irrigated areas have been developed in the north-trending valleys of the "Arizona Strip" and near Fredonia.

Navajo County

Between 15,000 and 16,000 acres was reported to be under irrigation in Navajo County in 1951 (Barr and Seltzer, 1952, p. 16). It is estimated that 3,500 to 4,000 acres of the total was irrigated either with ground water or with ground water and surface water combined. The use of ground water for irrigation is limited largely to four areas.

A memorandum report on the Joseph City area was prepared by the Geological Survey (Babcock, 1948), and other information is available in Water-Supply Paper 836-B (Harrell and Eckel, 1939), and in a mimeographed report (Babcock and Snyder, 1947). The Geological Survey has made an investigation of the ground-water resources of the Snowflake, Taylor, and Hay Hollow areas, in cooperation with the State Land Department. This investigation is nearly completed and a report is in preparation.

Annual water-level fluctuations in observation wells in the four areas in Navajo County were small in 1951 (Halpenny and Cushman, 1952, in preparation).

Joseph City area

Joseph City is on Highway 66 about 10 miles west of Holbrook. In the vicinity of Joseph City about 800 acres is irrigated with surface water when available; otherwise, with ground water from wells that penetrate artesian aquifers in the Coconino sandstone. In addition, about 1,500 acres of pastureland is subirrigated with water discharging at or near the land surface from artesian seepage. The waters used for irrigation vary in chemical quality; surface flow in the Little Colorado River sometimes being mineralized to an undesirable extent. Ground water from the Coconino sandstone is acceptably low in dissolved solids except in a few places north of the river, where it is contaminated by a mixture of salty water derived from overlying formations.

Snowflake area

About 45 miles south of Holbrook, 2,500 acres or more is irrigated, some 400 acres with ground water entirely, and the remainder with surface flow from Silver Creek. The ground water is obtained from the Coconino sandstone. Many wells in the area show artesian rise. In addition to water for irrigation, the Coconino sandstone furnishes water for the public supply at Snowflake and to numerous domestic and stock wells. The water is of acceptable quality for irrigation, domestic, and stock use.

Area west of Taylor

In an area about 2 miles west of Taylor and 3 to 5 miles southwest of Snowflake, about 500 acres is irrigated with ground water from the Coconino sandstone. In addition, a few irrigation wells withdraw water from the Coconino sandstone in an area extending a distance of 10 to 15 miles south of Snowflake along Silver Creek. A well drilled in 1951 in Shumway in the bottomland of Silver Creek encountered water in the Coconino sandstone under sufficient pressure to flow about 100 gallons per minute.

Hay Hollow

Hay Hollow, about 15 miles northeast of Snowflake, contained about 600 acres of irrigated land in 1952. The area occupies a structural depression separate from the valley of Silver Creek. Wells in Hay Hollow obtain irrigation water from the Coconino sandstone. Several of the irrigation wells flowed when first drilled. Some still flow during the winter and early spring, after the pumps have been idle for several months. During the irrigation season the artesian pressure diminishes, and water levels are a few feet to 30 feet below land surface.

Yavapai County

Chino Valley and Big Chino Valley

Chino Valley and Big Chino Valley are principally in Tps. 16 and 17 N., R. 4 W., 15 to 30 miles north of Prescott. These valleys are in the heawaters of the Verde River, and are shown on plate 1 as "Chino Valleys." Irrigation development is greatest in Chino Valley, the southernmost of the two. Irrigated lands in the area were estimated to total about 4,200 acres in 1947 (Barr, 1948, p. 16). The water used for irrigation was obtained from artesian wells that tap aquifers in alluvium interbedded with basalt and tuff.

The Ground Water Branch of the Geological Survey made a reconnaissance study of the geology of part of Chino Valley in 1946, but has not investigated hydrologic conditions in either valley. The Agricultural Engineering Department, University of Arizona, has conducted a continuing program of water-level measurements and other studies in the area for many years. A report on some phases of the geology of the region is in preparation by the Mineral Deposits Branch of the Geological Survey.

Peeples Valley

Peeples Valley occupies a hard-rock basin in the Weaver Mountains about 30 miles southwest of Prescott. The drainage basin has an area of about 55 square miles and the valley lands occupy about 10 square miles. The Geological Survey made a reconnaissance study of the ground-water resources of Peeples Valley in 1947 (Babcock and Brown).

Water in quantities sufficient for irrigation is obtained from Recent alluvium which in places attains a thickness of 500 feet. It was estimated that 150 acre-feet of ground water was withdrawn for irrigation in 1945, and that about 300 acre-feet escaped from the valley by surface flow, underflow, and evapotranspiration. The extent to which the ground-water supplies of the basin have been developed since 1946 is not known.

Upper Verde Valley

The Verde River, a perennial stream, flows southeastward in part of its course through a structural trough about 30 miles long and 10 miles wide, in which Cottonwood, Camp Verde, and smaller communities are situated. The basin is bordered on the northeast by the scarp of the Mogollon Rim and on the southwest by Mingus Mountain and the Black Hills. The northwest termination is near the mouth of Sycamore Creek, where the river has cut through a range of hills composed of older sedimentary rocks and volcanic flows. At the southeast end of the valley there is a narrow gorge cut by the river through a mass of volcanic rocks which at one time apparently impounded a lake within the basin.

Details of geologic structures on Mingus Mountain have been mapped by the Mineral Deposits Branch of the Geological Survey. This work is now being extended across the northwest end of the Verde River Valley. Few hydrologic data have been obtained in the basin.

Irrigation utilizes both surface water and ground water. Water is obtained from wells and from a number of springs having aggregate discharge of about 50 to 100 second-feet. The wells derive water from shallow aquifers in Recent alluvium near the river, from aquifers of intermediate depth in lake beds, and from artesian aquifers at considerable depth either within or below the lake-bed sequence. In 1947 there was 6,000 to 7,000 acres under irrigation in the basin and in the flood plain of Oak Creek, tributary to the basin (Barr, 1948, p. 16). How much of this land was irrigated with ground water is not known.

The chemical quality of the water obtained from the springs is suitable for most purposes. The water is used for domestic supplies, irrigation, and raising trout at a State fish hatchery. Wells in Recent alluvium near the river produce water generally of good quality. The artesian wells that have been sampled yield water of acceptable quality. The fluoride content of waters from springs and wells is consistently low, many analyses showing an absence of fluoride in detectable amounts.

Yavapai-Yuma Counties

Valleys of Date Creek drainage system

Skull Valley is an intermontane basin about 10 miles southwest of Prescott. The basin is principally in T. 13 N., R. 4 W. Five to 10 miles farther south, Kirkland Creek occupies a comparable valley. Small quantities of ground water are withdrawn from alluvial fill for irrigation in these two valleys.

At least two areas along Date Creek are irrigated in part with water pumped from wells. One area is near the settlement of Date Creek in Yavapai County, T. 11 N., R. 6 W.; the other area, in Yuma County, is in T. 10 N., R. 11 W.

A memorandum report was issued by the Geological Survey (Babcock and Brown, 1948) following a reconnaissance of the geology and occurrence of ground water in the valley of Date Creek in Yavapai County. This report stated that water in quantities sufficient for irrigation was obtained from a few wells that penetrated Recent alluvium. The thickness of alluvium in one place is more than 500 feet. Other data on that area are few, and the downstream area, in Yuma County, has not been investigated.

The amount of land irrigated with ground water in these areas and the amount of ground water withdrawn annually are not known.

Yuma-Maricopa Counties

McMullen Valley and Harquahala Plains

The broad alluvial areas of McMullen Valley and Harquahala Plains are drained by Centennial Wash. McMullen Valley occupies a southwest-trending trough between the Harcuvar and Harquahala Mountains. The valley is some 30 miles long from the headwaters of Centennial Wash to the narrows, a few miles southeast of Salome. There, Centennial Wash swings abruptly southeast and passes into the Harquahala Plains.

Ground-water development in McMullen Valley has been small, and the only data now available are based upon the logs of a few railroad, stock, and domestic wells. This information indicates a rapidly decreasing depth to water from more than 400 feet near Aguila to approximately 30 feet in the vicinity of Salome. In the narrows near Salome, movement of ground water is impeded by a shallow bedrock channel and, until recently, there was surface flow for a short distance. Within the past year, several wells have been drilled upstream from the rock narrows, and ground water is now being transported in canals to irrigate land in the upper end of the Harquahala Plains. It is reported that this development has lowered the water table on the upstream side of the narrows sufficiently to eliminate surface flow. Attempts to develop water for irrigation elsewhere in McMullen Valley have thus far been unsuccessful .

Little is known about ground-water conditions in the upstream part of the Harquahala Plains except that the water table lies several hundred feet below the land surface. Southeastward from the head of the valley the depth to water gradually decreases, and successful irrigation development is under way in T. 2 N., R. 9 W. There was approximately 1,000 acres of land under cultivation in the spring of 1952, and irrigation wells were yielding as much as 3,000 gallons per minute from depths of about 250 feet.

There is no information upon which to base an estimate of the amount of recharge into this valley or of the amount of ground water in storage. It is probable that recharge is relatively small, but that the storage capacity of the ground-water reservoir is moderately large.

Palomas Plain

Palomas Plain is an alluvial area that extends northwest from the Gila River between a spur of the Gila Bend Mountains and the Palomas Mountains. The area is about 15 miles wide where it borders the river and narrows to about 6 miles in the northwestern part, between the Little Horn and Kofa Mountains. Hyder, a station on the Southern Pacific Railroad, and Agua Caliente, a hot-springs resort, are about on the axis of the plain at the southern end, near the Gila River.

Increased agricultural development in the area has been reported during the past year, but the Geological Survey has not had an opportunity to collect more than a small amount of information about the ground-water resources. Drilling for water has been confined to lands in the southeast part of the valley, where depths to water are not great. No data are available regarding yields or quality of water from the wells recently drilled. Some of the older wells in the vicinity are reported to have encountered water with a high content of dissolved solids; in other wells the quality of the water was satisfactory for domestic use (Ross, 1923, pp. 206, 216). A well drilled by the Army near Hyder during World War II yielded sufficient potable water to supply a camp.

Depths to water range from a few feet along the flood plain of the Gila River to as much as several hundred feet in the northwest part of the valley.

No major drainage enters the area from the northwest, and the underflow of the Gila River is the only potential source of large amounts of recharge. Ground water from the vicinity of the river will move into the area if the water table in the Palomas Plain is lowered sufficiently. The quality of the water from this source is poor.

Part III

PROBLEMS RELATING TO USE OF GROUND WATER

By L. C. Halpenny and others

INTERRELATION OF GROUND-WATER AREAS

Various areas and basins in the State have been discussed in Part II as individual units, but little emphasis has been placed upon the interrelation of the units. In some localities, notably in the case of the Willcox and Douglas basins, and in those of most of the smaller areas described at the end of Part II, there is little or no relation among the various areas, and the ground-water resources of each locality may properly be regarded as an entity.

In a few other places, the Duncan and Safford basins, for example, there is a tenuous connection and interrelation with other basins. However, in each of the two basins named above, the lack of arable land still undeveloped places a definite limitation upon the expansion of irrigation development and restricts the quantity of ground-water withdrawals to an amount less than the average annual recharge. Depletion of storage is seasonal rather than perennial, and the ground-water reservoirs usually are refilled each year. Water utilization in these two upstream areas in the Gila River drainage system has approached a maximum, and possible future development will have little influence upon areas farther downstream.

The interrelation of the bodies of ground water underlying the principal irrigated areas, in Maricopa, Pinal, and Pima Counties, constitutes a formidable complication in estimating, for an individual area, quantities relating to recharge, discharge, and storage.

Constictions and ground-water barriers at several places within the region impede the movement of ground water from one area to another. For this reason, and because of differing geologic and hydrologic characteristics, it has proved desirable to discuss the region in terms of individual areas. The boundaries of the areas are in part arbitrary and in part represent natural hydrologic barriers.

The interrelated areas in central and southern Arizona differ in other important respects from the individual basins in the southeastern part of the State. The differences lie in the large amount of arable land that remains undeveloped in Maricopa, Pinal, and Pima Counties, and in the fact that ground-water withdrawal in these areas is largely from storage. As a result, the depletion of storage in these areas is persistent, and further expansion of irrigated acreage will increase the rate of depletion.

Farther down the Gila River, areas of ground-water development also are interrelated. Expansion of agriculture in Rainbow Valley, for example, will eventually affect water levels in wells along the Gila River below Gillespie Dam. Increased development in the Palomas Plain area will also have its effect on ground-water supplies along the Gila River. By the time sufficient surface water has been brought into the Wellton-Mohawk area to irrigate 75,000 acres, water levels in wells along the river downstream from Dome are likely to rise.

GROUND-WATER--SURFACE-WATER INTERRELATIONS

In the broadest sense, seepage from surface water is the source of almost all recharge to ground-water reservoirs in Arizona. This interpretation includes various occurrences: (1) Flow in perennial and intermittent streams along the axes of the basins; (2) runoff at mountain fronts; (3) water in canals and ditches; and (4) water applied for irrigation.

Individual areas in which the ground-water--surface-water interrelations are prominent have been discussed separately in Part II of this report. Important among such areas are the Duncan and Safford basins, in which the stage of the water table in Recent alluvium is related to the availability of surface flow in the Gila River. Recharge to shallow aquifers in the Upper San Pedro basin is in large part from runoff in the San Pedro River. In the Upper Santa Cruz basin, stream-flow losses within the basin generally greatly exceed surface flow past the Rillito narrows. This loss of runoff in the river is due mostly to recharge of ground water and in part to evapotranspiration. In the Douglas basin, Whitewater Draw is an intermittent stream for most of its course, recharge in the upper reaches is relatively large, and precipitation on mountainous areas drained by Whitewater Draw is sufficiently heavy to cause runoff to occur with some frequency.

Reference to the discussion of individual basins makes it clear that those basins occupied by perennial streams, or by streams having large influent-seepage losses, have not shown large, perennial declines of water levels in wells. In contrast, the areas in which little annual recharge occurs from through-flowing streams are those in which declines of water levels in wells have been greatest.

Quantitative studies of the relationship of runoff to recharge in Arizona have been made by the Geological Survey only in the Queen Creek area, the Santa Cruz Valley, and the Safford basin. Data from these studies are valuable, but they are far from adequate for a complete understanding of the relationship between ground water and surface water throughout the region.

Effluent seepage of ground water contributes to stream flow in the lower reaches of several of the basins described in Part II. Although ground water was discharged in this manner under natural conditions in some of the basins that have a constriction in cross-sectional area of the alluvial fill, irrigation with surface water has tended, in some areas, to increase the quantitiy of effluent seepage by increasing recharge. Examples of areas of effluent seepage are at the mouth of the San Pedro River, the confluence of the Gila and Salt Rivers, and the downstream end of the Lower Santa Cruz area.

USE OF GROUND-WATER--SURFACE-WATER SUPPLIES

In those areas where surface water is available for irrigation, ground water is withdrawn only when surface-water supplies are inadequate. Withdrawals of ground water increase seasonally, in response to a dry period, or annually, in response to a series of drought years. In most of the surface-water irrigation districts where ground water is pumped, the quantity of underlying storage is small in comparison with the annual rate of withdrawal by pumping. The net result is that the quantity of ground water in underlying storage in these areas can be seriously depleted in a drought lasting more than a few years. For example, in the San Carlos Irrigation District, a part of the Lower Santa Cruz area, the water level has declined enough to reduce well yields and, reportedly to make it uneconomical to operate some of the pumps. In the Safford basin in the past few years, a decline in well yields has required the drilling of many additional wells to supply the demand for ground water.

The period 1942-52 has been unique in two respects in the history of ground-water development in Arizona. First, the period was essentially one of prolonged drought, with subnormal supplies of surface water. Second, the surface-water shortage was aggravated by an increased demand for water. The decade was marked by ever-increasing financial returns for agricultural products, with a resulting demand for more intensive cultivation and for bringing new lands under cultivation.

In the established surface-water irrigation districts, these two factors tended to increase the withdrawal of ground water. A tendency developed to grow crops of greatest financial return, some of which required more water than crops formerly grown. In some areas part of the land was allowed to lie fallow each year and the remaining land was cultivated intensively. In other areas nearly all lands were farmed each year, resulting in increased withdrawal of ground water.

Other factors complicate the problem of maintaining a sustained supply of water in established surface-water irrigation districts. Heavy withdrawals of ground water outside some districts have altered the slope of the water table and have changed the direction of ground-water movement. Local areas have become waterlogged at the downstream end of some irrigation districts in spite of heavy withdrawals of ground water, because it is not always possible to lower the water table uniformly. The problem of increasing salinity of the available water supply is becoming more important as a result of more intensive use and re-use of water for irrigation.

RELATION OF QUALITY OF WATER TO USE

Transpiration by phreatophytes

The relation between use of water by phreatophytes and chemical quality of ground water is known only in a general way. It is known that transpiration by phreatophytes will result in increasing the concentration of dissolved solids in the ground water not transpired. Destruction of phreatophytes would not materially affect the total load of dissolved salts leaving a basin if the water otherwise used by the plants were put to beneficial use within the basin.

Industrial use

Discharge of industrial waste waters, or leaching of undesirable constituents from any of the waste products of industrial processes, is at present only a minor problem in a few areas in Arizona.

Some industrial processes require water of specified mineral content and the relationship of industrial use of water to its quality must be considered. Use of water by industry is increasing in Arizona, and the quality problem is likely to become of greater importance in the future.

Irrigation use

Changes in the quality of water downstream along the Gila River drainage system constitute one of the principal problems relating to the water supply of the region. Speaking generally, waters of the Gila River system become progressively more highly mineralized as they move downstream, by use and re-use of water for irrigation. This process is discussed in Part I, under "Quality of ground water."

In a few places, sources of water high in dissolved mineral matter have been found. The hot springs at Clifton, for example, add more than 50 tons of salts to the Gila River daily. It is possible that a thorough study of the source of this salty water might result in discovery of a method by which the salt could be permanently prevented from moving downstream. The resulting improvement in quality of water, not only in the Safford basin, but all the way downstream to the Colorado River, would more than offset the loss of the water discharged by the springs.

To some extent the progressive downstream increase in mineral content of ground waters along the Gila River probably existed prior to the development of irrigation in the region. It has been of increasing importance since man began to use water for irrigation. The following statement by Hem (Babcock, Brown, and Hem, 1947, p.11) indicates that, at least in some areas, the concentration of dissolved mineral matter is increasing annually:

> Many wells in the younger fill now yield water much more highly mineralized than they yielded 10 or even 5 years ago. The downward trend of water levels in the area has been accompanied by an upward trend in the dissolved-solids content of the water....Well 689 had the most highly mineralized water of the area in 1946. This water has increased about 10 times in dissolved-solids concentration since 1927.

ADDITIONAL STUDIES NEEDED

The Geological Survey was requested, when preparing the present report, to point out those factors of the ground-water problem that require additional study in order to be evaluated precisely. The study of ground water is an indirect science and, in making a quantitative ground-water investigation, each of the components cannot be evaluated absolutely, no matter how well staffed or well financed a project may be. For example, it is impossible to measure the rainfall in an area; the amount can be approximated by assuming that the amount of rainfall measured in a series of gages is equivalent to the rainfall in the entire area. By increasing the number of rain gages, the determination can be made more nearly precise. All component factors of a ground-water investigation are measured by a comparable process of sampling; the more individual measurements that are made, the more accurate will be the result.

The ground-water investigations made by the Geological Survey in Arizona to the date of writing this report range in scope from a brief reconnaissance to intensive studies of a particular phase of the ground-water problem. A report on the Date Creek area (Babcock and Brown, 1948) can be used as an example of a reconnaissance investigation, and the phreatophyte studies in the Safford area (Turner and others, 1941; Gatewood and others, 1950) can be used as an example of an intensive investigation. It is important to point out that the financing has been such that most of the investigations necessarily have been of the reconnaissance type, and only a few have been of the intensive type.

The foregoing statements are presented in order that the problem of evaluating ground-water supplies in Arizona will be viewed in its proper perspective. With these considerations in mind, the following comments are made regarding additional data needed in order fully to evaluate the ground-water resources of Arizona.

In all the areas described in this report, more comprehensive data are needded to determine more accurately the annual recharge. For the principal methods of recharge, infiltration along mountain fronts and seepage from irrigated fields, considerable study would be required for a more precise evaluation. Additional information about precipitation and runoff is needed. Continuing measurements should be made to determine stream-flow losses near the margins of the alluvial fill, similar to the studies made on Queen Creek (Babcock and Cushing, 1942).

To determine more accurately the quantity of ground water in storage, field and laboratory tests on a large scale would be required. Information obtained thereby would enable better determinations of the coefficients of drainage of the aquifers and the rates of ground-water movement.

More accurate data about natural discharge of ground water are desirable, particularly regarding nonbeneficial discharge by phreatophytes. In the light of present knowledge, the greatest potential source of additional water for irrigation in the arid parts of the West is considered to be salvage of water by control of phreatophytes. As explained in Part I, certain phases of the phreatophyte problem should be evaluated if a program of phreatophyte eradication is undertaken.

The inventory of the quantity of ground water withdrawn annually should be extended to include the entire State, and additional well-discharge measurements should be made to improve the over-all accuracy of the inventory.

Many additional data are needed about deep aquifers in the region: Electrical-conductivity logs and flow-meter measurements of the discharge from each aquifer should be made in the deep wells; samples of drill cuttings should be collected, examined, and tested for permeability; pumping tests should be made; and the quality of the water should be determined.

The increasing concentration of dissolved solids in the ground waters of some of the irrigated areas has been mentioned. The extent to which continued development of ground water may affect its quality needs careful study. The limitations imposed by deterioration of quality are not always realized, and the entire subject is one about which current knowledge is limited.

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GLOSSARY

The following list of definitions is provided as an aid to the reader. The sources for the definitions are so widespread that individual references are not listed. The basic sources for most of the ground-water terms are publications of the Geological Survey, many of which were written by O. E. Meinzer.

ACIDIC DIKE.--A light-colored dike composed of igneous material that is predominantly silica.

ACRE-FOOT.--A term used to describe a volume of water. One acre-foot is equal to the volume which would cover an acre to a depth of 1 foot, or 325,829 gallons.

AGGLOMERATE.--A rock made up of both coarse and fine volcanic material, which may also include sedimentary detrital fragments.

ALKALI FLAT.--See "playa."

ALKALI-LADEN LAND.--Land containing, at or near the surface, certain soluble mineral salts, generally sodium or potassium carbonate, in sufficient quantity to be detrimental to agriculture, or to make the soil sterile.

ALLUVIAL.--An adjective denoting that which is transported by running water.

ALLUVIAL CONE.--A steeply sloping, fan-shaped mass of loose rock deposited by a stream at the place where it emerges from an upland into a broad valley or plain.

ALLUVIAL DIVIDE.--A drainage divide developed in alluvium.

ALLUVIAL FAN.--A sloping, fan-shaped mass of loose rock material deposited by a stream at the place where it emerges from an upland into a broad valley or a plain. If the mass of material has steep slopes it is generally called an alluvial cone, but if the slopes are relatively flat it is called an alluvial fan.

ALLUVIAL FILL.--Same as "alluvium."

ALLUVIAL PLAIN.--A plain resulting from the deposition of alluvium by water where the surface is almost level. See "flood plain."

ALLUVIUM.--A general term for all detrital deposits resulting from the operations of running water. In intermontane basins refers to the deposits of rock waste washed down from the mountains.

ANDESITE.--A generally dark-colored volcanic rock containing moderate amounts of silica with plagioclase feldspars predominating. See "dacite."

AQUIFER.--A water-bearing formation, or part of a formation. See "water-bearing formation."

ARTESIAN.--An adjective referring to ground water under pressure.

ARTESIAN SPRING.--A spring whose water issues under artesian pressure, usually a fault spring.

ARTESIAN WATER.--Ground water that has artesian pressure head; that is under sufficient pressure to rise above the zone of saturation. In popular usage, refers to ground water under sufficient pressure to rise to the surface and flow.

ARTESIAN WELL.--A well in which the water is under hydrostatic pressure. It may be a flowing or a non-flowing artesian well.

BACCHARIS.--A plant of the genus Baccharis. Commonly called batamote. It is a phreatophyte in most places where it grows in Arizona.

BACTERIAL ANALYSIS.--An analysis of the organic material in water to determine its sanitary condition. This type of analysis is not made by the Quality of Water Branch, Geological Survey.

BASAL.--Pertaining to the lowest natural level; basic, fundamental.

BASALT.--A dark-gray, black, brown, or brownish-red dense to fine-grained igneous rock formed as a surface flow or as a shallow intrusive body.

BASALTIC.--Pertaining to basalt or one of its characteristics.

BASIN.--A depression in the surface of the land. In this report "basin" refers to a geographic area in which ground-water conditions are somewhat uniform.

BEDROCK.--Solid rock that either underlies the valley fill or is exposed on the land surface. Its water-bearing properties are generally limited.

BICARBONATE.--HCO_3. The most common constituent of the dissolved matter of most surface and ground water.

BORON.--The element, B. A constituent of the dissolved matter in some water. In irrigation waters it is harmful to some plants, particularly citrus.

CALCAREOUS BEDS.--Beds of sedimentary material containing noticeable amounts of calcium carbonate.

CALCIUM.--The element calcium, Ca. A constituent of limestones and of the dissolved matter in water.

CALICHE.--A lime-rich deposit formed in the soils of certain semiarid regions.

CAPILLARY OPENING.--A small opening of such size that water can be held in it at a considerable height above the level at which it is held by hydrostatic pressure alone, due to the attraction of the molecules in the walls of the opening for the molecules of water and the attraction of the molecules of water for one another.

CENOZOIC.--The latest era of geologic time, divided into the Tertiary and Quaternary periods.

CHEMICAL ANALYSIS.--The determination of the amount and kinds of mineral matter in solution in water samples. Does not include an analysis of the organic or suspended matter contained in the water.

CHLORIDE.--The element chlorine, Cl. A common constituent of the dissolved matter in water.

CIENAGA.--A swamp or swampy place.

CLASTIC DEPOSITS.--Deposits composed of fragments derived from older rocks.

CLIMATOLOGY.--The science which treats of climates and their phenomena.

CLOSED BASIN.--A basin without drainage outlets or with outlets higher than the level of the lake or playa which it may contain. See "interior drainage."

COEFFICIENT OF DRAINAGE.--The amount of water in saturated rock free to drain by gravity alone within a specified time, expressed as percentage of the total volume of rock. See "coefficient of storage."

COEFFICIENT OF PERMEABILITY.--The rate of flow of water, in gallons per day, under prevailing conditions, through each foot of thickness of a given aquifer in a width of 1 mile, for each foot per mile of hydraulic gradient. Sometimes called "field coefficient of permeability."

COEFFICIENT OF STORAGE.--The cubic feet of water discharged from each vertical column of the aquifer with a base of 1 foot square as the water level falls 1 foot. See "coefficient of draingage."

COEFFICIENT OF TRANSMISSIBILITY.--The rate of flow of water, in gallons per day, under prevailing conditions, through the whole thickness of an aquifer in a width of one mile, for each foot per mile of hydraulic gradient.

COLD SPRING.--A spring whose water is cooler than or equal to the mean annual temperature of the region.

CONGLOMERATE.--A sedimentary rock composed of water-transported pebbles of other rocks, cemented together or compacted. A consolidated gravel.

COTTONWOOD.--A tree of the genus Populus. Many cottonwood trees in Arizona are phreatophytes.

DACITE.--A generally light-colored volcanic rock containing moderate amounts of silica with the plagioclase feldspars predominating. Contains more silica than does andesite.

DECLINE.--The decrease in yield of a well; a lowering of the water table.

DECOMPOSITION.--The action of chemical agents that destroys the identity of mineral particles by chemical change.

DETRITAL ROCK.--A rock made up of the debris of other rock.

DETRITUS.--Material worn from rocks. A general term applicable to several grades or types.

DIATOM.--A microscopic water plant that secretes siliceous material.

DIATOMACEOUS BEDS.--Beds of sedimentary material containing noticeable amounts of the remains of diatoms.

DISCHARGE OF GROUND WATER.--Withdrawal of water from a ground-water reservoir by natural or artificial means.

DISINTEGRATION.--The physical break-up of rocks without the destruction of their indentity.

DOLOMITE.--A carbonate of calcium and magnesium, $(Ca, Mg)CO_3$. A rock that approximates the mineral dolomite in composition; a magnesian limestone.

DRAINAGE, COEFFICIENT OF.--See "coefficient of drainage."

DRAINAGE DIVIDE.--The boundary between two drainage basins.

DRAINAGE SYSTEM.--A surface stream or lake and all the tributary streams that drain into it.

DRILLER'S LOG.--A record of information obtained by the well driller regarding the rocks passed through in drilling.

DRY LAKE.--See "playa."

DUTY OF WATER.--The quantity of irrigation water required to mature a given area of a given crop, expressed in acre-feet per acre.

EFFLUENT SEEPAGE.--Diffused discharge of ground water to the land surface, generally into a stream or lake.

ELECTRIC LOGGING.--A method of recording the effect of electric current on some of the properties of the formations penetrated by a well. It is useful for correlation purposes but obtains information only in uncased holes. See "gamma-ray logging."

EPHEMERAL STREAM.--A stream that flows only in direct response to precipitation, and whose channel is at all times above the water table.

EROSION.--The general wearing away of the land by wind, running water, and other agencies. It includes all processes by which earthy matter or rock is loosened and removed and includes weathering, abrasion, and transportation.

ESTUARY.--An arm of the sea at the lower end of a river.

EVAPORATION.--Discharge of water to the atmosphere.

EXTRUSIVE ROCKS.--Igneous rocks which have cooled after reaching the surface. They may be in the forms of flows or of fragments resulting from explosive eruptions.

FANGLOMERATE.--Cemented, coarse, detrital rock which originally was deposited in an alluvial fan.

FAULT.--A natural rock fracture in which the blocks of rock on opposite sides of the fracture are dislocated or offset with reference to each other.

FAULT SPRING.--A spring whose water rises, usually under artesian pressure, along a fault in a rock formation.

FISSURE.--A crack, break, or fracture in the rocks. A general term.

FLOOD PLAIN.--A strip of low, relatively smooth land bordering a stream and built of sediment carried by the stream. Sometimes used synonymously with alluvial plain.

FLUCTUATION OF WATER TABLE.--The upward or downward movement of the water table.

FLUORIDE.--The element fluorine, F. An occasional constituent of the dissolved matter in water.

FORMATION.--A large and persistent bed of some one kind, or more or less related kinds, of rock; a unit that can be shown readily on a geologic map.

FRACTURE.--An open break in rock. Size is not an item in the definition.

GAMMA-RAY LOGGING.--A method of recording the gamma-ray radiations of the formations penetrated by a well. It is particularly useful in obtaining data from cased holes. See "electric logging."

GEOLOGY.--The science which treats of the origin, history, and structure of the earth, as recorded in the rocks.

GEOPHYSICAL.--Relating to the physics of the earth. As used in this report refers to studies of the structure of the earth through its electrical, magnetic, and gravity properties.

GNEISS.--A visibly crystalline, coarsely or crudely foliated or banded rock.

GRADIENT.--The slope of a river course, rock bed, or the water table. Usually expressed in feet per mile, percent slope, or degrees.

GRANITE.--A hard igneous rock of visibly crystalline texture, consisting essentially of quartz and feldspar and often containing smaller quantities of micas, amphiboles, and pyroxenes.

GRAVIMETRIC EXPLORATION.--A method of geophysical prospecting which measures variations in the gravitational field of the earth.

GROUND WATER.--Water in the earth which completely fills the pore spaces of the rocks which it occupies.

GROUND-WATER BARRIER.--See "ground-water dam."

GROUND-WATER BASIN.--A trough containing a series of water-bearing formations and partly encircled by impermeable rock barriers.

GROUND-WATER DAM.--An impermeable body which impedes the horizonatal movement of ground water and thus causes storage of ground water behind the dam.

GROUND-WATER DIVIDE.--A line on the water table from which the water table slopes downward on each side. It is similar to a drainage divide on the surface.

GROUND-WATER EQUATION.--A method of showing the balance between the amount of ground water entering a basin and the amount of ground water leaving a basin, taking in consideration the amounts of water that may be added to or withdrawn from ground-water storage.

GROUND-WATER FLOW.--The movement of ground water along the hydraulic gradient.

GROUND-WATER GEOLOGY.--That part of the science of geology which treats of the relation of the structure and composition of the earth's crust to the occurrence of ground water.

GROUND-WATER RESERVOIR.--The aquifer or aquifers in a ground-water basin.

GYPSUM.--Hydrous calcium sulfate, $CaSO_4 \cdot 2H_2O$. A mineral often deposited by the evaporation of desert lakes and by hot springs.

HARDNESS.--The quantity of calcium carbonate equivalent to the calcium and magnesium in the water, expressed in parts per million.

HOT SPRING.--A spring in which the water has a temperature above that of the human body.

HYDRATE.--A compound formed by the union of water with some other substances and represented as actually containing water.

HYDROLOGY.--The science that is concerned with the occurrence of water in the earth, its physical and chemical reactions with the rest of the earth, and its relation to the life of the earth.

HYDROSTATIC PRESSURE.--Pressure due to still water.

IGNEOUS ROCKS.--Rocks produced by the cooling and solidification of molten rock material which comes from below the surface of the earth. See "intrusive rocks" and "extrusive rocks."

IMPERMEABLE ROCK.--A rock that will not transmit perceptible quantities of water under ordinary pressures.

INCISED CHANNEL.--A channel which has been cut down into existing rocks by stream action. It is characterized by steep banks.

INFILTRATION GALLERY.--A drift or tunnel into a ground-water reservoir.

INFLOW.--The total amount of water from all sources entering a basin.

INFLUENT SEEPAGE.--Movement of water in the zone of aeration from the ground surface toward the water table.

INTERCALATED.--A term applied generally to a body of one kind of rock material interbedded with another.

INTERFERENCE OF WELLS.--The overlapping of the areas of influence of two or more wells.

INTERIOR DRAINAGE.--A system of drainage with no surface outlet. See "closed basins."

INTERMITTENT SPRING.--A spring that is dry part of the time.

INTERMITTENT STREAM.--A stream that flows for long periods but is dry at times.

INTERMONTANE.--Lying between mountains.

INTERSTICES.--Space in a rock or soil that is not occupied by solid mineral matter.

INTRUSIVE ROCKS.--Igneous rocks which have solidified without reaching the surface.

JOINT.--A natural rock fracture within a once continuous block.

LACUSTRINE.--An adjective denoting a lake origin.

LAMINAR FLOW.--Motion of a fluid in which the particles move substantially in parallel paths.

LATENT STORAGE.--The amount of water that is free to drain by gravity from the saturated rock within the alluvial basins. The term does not consider whether the water can be either economically obtained or utilized.

LATITE.--A volcanic rock containing moderate amounts of silica and approximately equal amounts of orthoclase and plagioclase feldspars. Almost a dacite.

LAVA.--Fluid rock which issues from a volcano or a fissure in the earth's surface. The same material, solidified by cooling.

LIMESTONE.--A sedimentary rock consisting essentially of the mineral calcite (calcium carbonate). It may be shaly, sandy, or dolomitic, depending on the impurities.

LOG.--A record of the rocks passed through in drilling. See "driller's log," "electric logging," and "gamma-ray logging."

MAGMA.--The molten material from which igneous rocks are formed by solidification.

MAGNESIUM.--The element magnesium, Mg. A distinctive constituent of certain limestone, dolomite, and of the dissolved matter in most water.

MAGNETOMETRIC EXPLORATION.--A method of geophysical prospecting which measures variations in magnetic forces.

MESQUITE.--A tree of the genus Prosopis. Mesquite in some parts of Arizona is a phreatophyte.

MESOZOIC.--One of the eras of geologic time, following the Paleozoic and succeeded by the Cenozoic.

METAMORPHIC ROCKS.--Rocks produced by the alteration of igneous, sedimentary, or other metamorphic rocks, chiefly through the agencies of heat and pressure.

NITRATE.--Nitrogen trioxide, NO_3. A constituent of the dissolved matter in water. The final oxidation product of dissolved organic material containing nitrogen.

NONARTESIAN.--Ground water which is under no hydrostatic pressure and consequently does not rise above the water level.

OLDER ALLUVIAL FILL.--Alluvial fill of probable Tertiary and Pleistocene age. Generally the material into which channels have been incised and partly refilled with Recent alluvium.

OUTFLOW.--The total amount of water leaving a basin as surface and ground-water flow. Does not include water lost by evaporation and transpiration.

PALEOZOIC.--One of the eras of geologic time, following the pre-Cambrian and succeeded by the Mesozoic era.

PARTS PER MILLION.--The parts by weight of dissolved matter in water per million parts of water.

PEDIMENT.--A plain which lies at the foot of some mountains in arid regions, formed by the erosion of the hard rocks and covered with a thin veneer of alluvium. As used in this report, the term also refers to an extension of this rock surface towards the axes of the basins under a thickening mantle of alluvium, and to buried bedrock surfaces above the main water table.

PERCHED WATER.--Ground water which lies above the level of the main water table of the area. Perched water is kept from moving downward to the level of the main water table by an underlying lens or bed of clay or other impermeable material.

PERCOLATION.--Movement of water through the pore spaces of a rock or soil.

PERENNIAL SPRING.--A spring that flows at all times.

PERENNIAL STREAM.--A stream that flows at all times.

PERMEABILITY.--The capacity of an aquifer for transmitting water. Permeability is a measure of the rate at which ground water will move through the aquifer under a given hydraulic gradient. See "coefficient of permeability."

PERVIOUS.--Having a texture that permits water to move perceptibly under the pressure ordinarily found in subsurface water.

PHREATOPHYTE.--A plant whose root system obtains moisture from the ground-water reservoir.

PHYSIOGRAPHY.--A description of the natural features of the surface of the earth.

PIEZOMETRIC SURFACE.--The imaginary surface to which water in an artesian aquifer will rise under its full head. Also called pressure surface.

PLAYA.--A level or nearly level area that occupies the lowest part of a completely closed basin and that is covered with water at irregular intervals, forming a temporary lake. It is generally underlain by evenly stratified beds of clay or silt and may contain large amounts of soluble salts. Sometimes called "dry lake," "alkali flat," or "salina."

PLEISTOCENE.--The earlier of the two geologic epochs comprised in the Quaternary period.

POROSITY.--The pore space in a rock, expressed as the percentage of the total volume of the rock occupied by pore space.

POTASSIUM.--The element potassium, K. A common constituent of the dissolved matter in ground waters.

PRE-CAMBRIAN.--A general term for all time and for all rocks laid down prior to the Paleozoic era.

PRECIPITATION.--Rainfall and snowfall.

PRESSURE SURFACE.--The imaginary surface to which the water from an artesian aquifer will rise under its full head. Also called piezometric surface.

PUMICE.--A general term applied to volcanic rocks that contain so many vesicles as to resemble froth.

PYROCLASTIC TUFF.--A rock made up of volcanic ash and dust.

QUATERNARY.--The latest period of geologic time.

RECENT.--The later of the two geologic epochs of the Quaternary period.

RECENT ALLUVIAL FILL.--Alluvial fill of Recent age.

RECHARGE.--The addition of water to a ground-water reservoir by natural or artificial means.

RECHARGE AREA.--The area where recharge to an aquifer occurs.

RECOVERY.--The securing of ground water from saturated rocks; the act of ground water returning to its static level after being drawn down by pumping.

RHYOLITE.--A volcanic rock containing a high percentage of silica.

RUNOFF.--That part of the natural precipitation that flows off the surface of the land in the form of visible streams.

SALINA.--See "playa."

SALINE.--Salty. Applied to minerals, rocks, formations containing minerals, or to water having the taste of common salt.

SALT CEDAR.--A phreatophyte of the genus Tamarix.

SATURATED ROCK.--Rock whose interstices are all filled with ground water.

SCHIST.--A foliated or laminated metamorphic crystalline rock with a tendency to split along the foliation.

SEASONAL SPRING.--A spring that is wet or dry according to the seasons of the year.

SEDIMENT.--Material in suspension in water or recently deposited from suspension.

SEDIMENTARY ROCKS.--Rocks laid down as sediment through the agency of water, wind, or glaciers. Sandstone, limestone, shale, and conglomerate are common examples.

SEEPAGE.--Percolation of water into or out of a ground-water reservoir.

SEISMIC.--Pertaining to, characteristic of, or produced by natural or artificial earthquakes or earth-vibrations.

SEISMOGRAPHIC EXPLORATION.--A method of geophysical prospecting which records the time of arrival of successive seismic wave-fronts set off by explosives.

SHEET FLOOD.--A flood which spreads as a thin sheet of water over a large area and is not concentrated in channels. Sheet floods are of short duration, generally being measured in minutes or hours, and the water is always muddy. They are characteristic of alluvial areas in southern Arizona.

SHEET RUNOFF.--Runoff which spreads as a thin sheet of water over a large area and is not concentrated in channels.

SILICA.--Silicon dioxide, SiO_2. A common constituent of intrusive, sedimentary, and metamorphic rocks; a common constituent of the dissolved matter in water.

SILT.--Sediment, the particles of which are smaller than fine sand and coarser than clay.

SODIUM.--The element sodium, Na. A major constituent of ordinary salt, NaCl, and a common constituent of the dissolved matter in water.

SOLUBLE SALTS.--An indefinite phrase referring to any or all of the common soluble salts carried in solution, or precipitated from, surface and ground waters. The most common constituents are calcium, magnesium, sodium, potassium, bicarbonate, chloride, and sulfate. See "suspended matter," "bacterial analysis", "chemical analysis."

SPRING.--A place where water flows naturally from a rock or soil upon the land, or into a body of surface water.

SPECIFIC CONDUCTANCE.--A measure of the conductance of a water sample to an electric current. In general, the greater the conductance, the greater the concentration of dissolved solids in the water.

STAGE OF WATER TABLE.--The altitude of the water table at a given time and place.

STATIC LEVEL.--The water level in a nonpumping well outside the area of influence of any pumping well. This level registers one point on the water table in a water-table well or one point on the pressure surface in a confined-water well.

STORAGE, COEFFICIENT OF.--See "coefficient of storage."

STRATA.--Plural of stratum.

STRATUM.--A layer of rock more or less similar throughout, a lithologic unit. It may consist of one or more beds, and may constitute a formation or a member, or be only one of several strata in such formation or member.

STRUCTURAL TROUGH.--A topographic feature including a large valley and its bordering mountains. The term is applied to those features that are believed to be due to relative uplift of the mountains and depression of the valley.

SULFATE.--An oxide of sulfur. A common constituent of the dissolved matter in water.

SURFACE FLOW.--The movement of surface water, generally in stream channels.

SURFACE WATER.--All water in lakes, ponds, streams, and reservoirs.

SUSPENDED MATTER.--Solid particles mixed with but undissolved in water.

TERRACE.--A long and narrow plain or bench bordering a lake or stream.

TERTIARY.--The first period of the Cenozoic era.

TOPOGRAPHY.--The general configuration of the land surface, including the position of its streams, mountains, lakes, etc.

TOTAL DISSOLVED SOLIDS.--The sum of the determined constituents dissolved in water, with the bicarbonate computed as carbonate because the bicarbonate in water changes to carbonate as the water is evaporated. Expressed as "parts per million" or as tons of dissolved matter per acre-foot of water.

TRACHYTE.--A generally light-colored volcanic rock containing moderate amounts of silica with the orthoclase feldspars predominating. Related to rhyolite.

TRAJECTORY.--The curve which a moving body describes in space.

TRAJECTORY METHOD.--A means of calculating discharge from wells by measurements related to the curve through space described by a stream of water discharging from a pipe.

TRANSMISSIBILITY, COEFFICIENT OF.--See "coefficient of transmissibility."

TRANSPIRATION.--Discharge of water to the atmosphere by a growing plant.

TUFF.--A rock made up of volcanic ash and dust.

TURBULENT FLOW.--Fluid flow in which the velocity at a given point changes constantly in magnitude and direction. The opposite of "laminar flow."

UNCONFORMITY.--An erosional break in the continuity of sedimentation.

UNDERFLOW.--Movement of ground water through a definite underground channel.

UNDERFLOW CHANNEL.--A channel through which ground water moves as underflow, usually underlying a surface stream. The channel is limited on the bottom and sides by relatively impermeable beds.

UNDERLYING STORAGE.--See description of concept in Part I of this report.

VALLEY FILL.--Same as "alluvium."

VESICLE.--A small cavity in an igneous rock, formed by the expansion of a bubble of gas or steam during the solidification of the rock.

VOLCANIC.--Formed by, or derived from, material solidified from a molten magma that has poured out as lava over the earth's surface or violently exploded from volcanoes.

VOLCANIC ASH.--The finely divided, fragmental rock material violently blown from volcanoes during explosive eruptions.

VOLCANIC BRECCIA.--See "agglomerate."

WARM SPRING.--A spring whose water is warmer than mean annual temperature of the region but cooler than the temperature of the human body.

WATER-BEARING FORMATION.--A rock formation that will yield ground water in usable quantity to wells and springs. See "aquifer."

WATER-BEARING PROPERTIES.--The properties of a rock that control its porosity and permeability, and hence its ability to store and transmit water. The water-bearing properties depend mainly on the size and number of interstitial openings and the degree of cementation and compaction.

WATER-LOGGED LAND.--Land in which the water table is at or near the surface and upon which commercial crops cannot be produced. The soil is water-saturated; there is no zone of aeration; and root systems are drowned for lack of air in the soil interstices.

WATER TABLE.--The upper surface of the saturated portion of a nonartesian water-bearing formation.

WATER-TABLE CONTOUR.--A line connecting points of equal elevation of the water table.

WATER-TABLE WELL.--A well which obtains water that is not under hydrostatic pressure.

WEATHERING.--The decomposition and disintegration of rocks by surface agents and processes.

WILLOW.--A plant of the genus Salix. Some willows in Arizona are phreatophytes.

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