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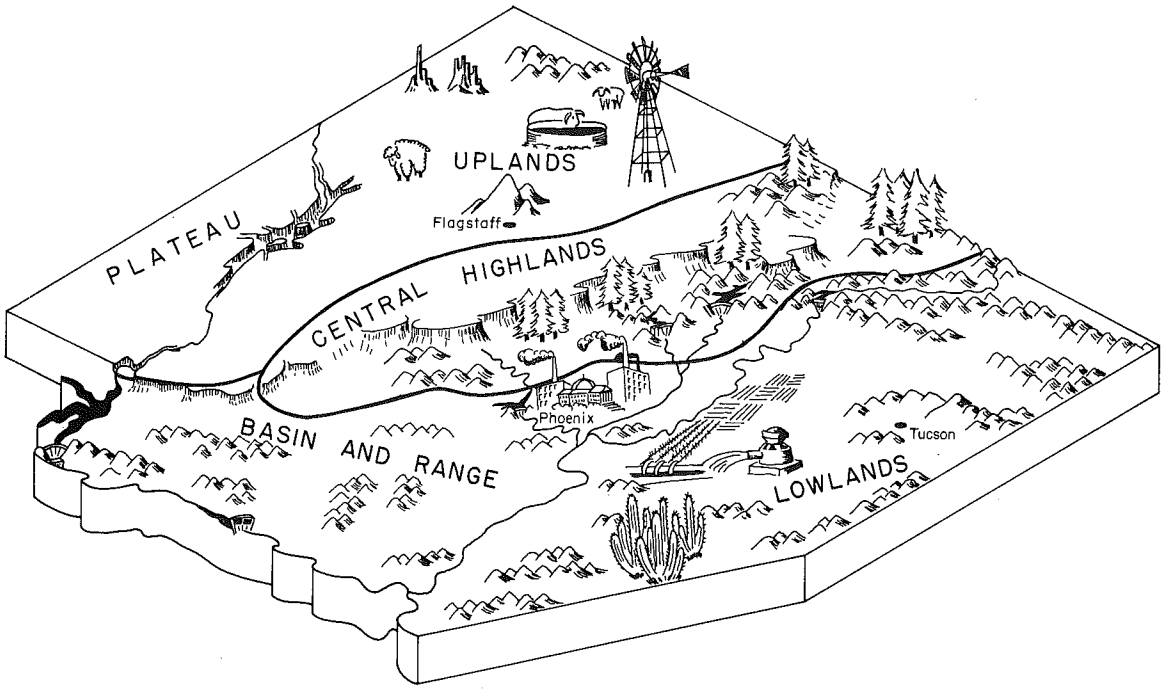
ANNUAL REPORT ON GROUND WATER IN ARIZONA SPRING 1961 TO SPRING 1962

BY

NATALIE D. WHITE, R.S. STULIK, AND OTHERS



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ANNUAL REPORT ON GROUND WATER IN ARIZONA
SPRING 1961 to SPRING 1962

By

Natalie D. White, R. S. Stulik, and others

ABSTRACT

By

Natalie D. White

The underground reservoirs are the chief source of water in Arizona and these water supplies must be protected through adequate management and proficient use. Water problems related to inadequate supplies, equitable distribution of the available supply, and deterioration in quality of water become more complicated with the increasing demand for water that accompanies an expanding economy. A cooperative program between the State of Arizona and the U. S. Geological Survey providing for ground-water studies has been in operation since 1939; since 1942, the State Land Commissioner has been the cooperative representative for the State. The current cooperative ground-water program in Arizona consists of three major parts: (1) statewide ground-water survey, (2) comprehensive ground-water investigations in selected areas, and (3) studies related to specific hydrologic problems. The "Annual Report on Ground Water in Arizona" is a summary and analysis of the hydrologic data collected under the statewide ground-water survey during the period spring 1961 to spring 1962.

The occurrence of ground water is fundamentally related to the character, distribution, and structure of the rocks. In Arizona, these geologic characteristics, and, hence, the occurrence of ground water, differ greatly in each of the physiographic provinces within the State. The Basin and Range lowlands province is characterized by broad, gently sloping valleys bounded by high, rugged mountain ranges. Most of the ground water in the province is stored in the alluvial material that fills the basins. In the Plateau uplands province, the chief aquifer is the Coconino Sandstone of Permian age—a fine-grained well-sorted highly crossbedded sand that underlies nearly all the area. In places the Coconino Sandstone contains large amounts of cemented material, and, thus, it is not uniform in its water-yielding capacity throughout the area. In the mountainous Central highlands province, the rocks are largely impervious and contain little space for the storage of water except in areas where they are fractured and faulted.

Of the three provinces, the Basin and Range lowlands is the most highly developed from the standpoint of water use; during the last few decades there has been extensive development of the water supply in this province. The vast reserves of ground water are being depleted because the current annual rate of recharge to the ground-water reservoirs is negligible in comparison to the large amounts of ground water withdrawn each year. The trend of the water levels in nearly all the highly developed areas in the Basin and Range lowlands province continued downward in 1961. The greatest declines were in the Salt River Valley and the lower Santa Cruz basin. Large declines in water level were measured also in the Willcox basin of Sulphur Spring Valley and in the Bowie and San Simon areas of the San Simon basin. Small rises in water level were measured in the Duncan and Safford basins partly due to the availability of surface water. Some rises in water level also were measured in a few other areas, such as parts of the San Pedro River valley and Aravaipa Valley where the ground-water reservoir is recharged from flow in a river or stream. The Plateau uplands and Central highlands provinces are largely undeveloped and the pumping of ground water for irrigation or other purposes is small. Hence, there have been no large, sustained declines of the water levels in these areas up to the present time. There have been some small declines in the water level in a few areas where ground water is pumped for irrigation or other uses.

Pumpage of ground water in Arizona in 1961 amounted to about 4.7 million acre-feet—slightly more than in 1960. The Salt River Valley and the lower Santa Cruz basin accounted for about 75 percent of the total amount of ground water pumped in the State. Although the use of ground water for municipal and industrial purposes is increasing, more than 90 percent of the ground water used in 1961 was for the irrigation of crops.

INTRODUCTION

By

Natalie D. White

The greatest single influence on nearly any type of development in arid zones, such as Arizona, is the availability of adequate water supplies. Although it is not recognized generally, the underground reservoirs are the chief source of water in Arizona. The occurrence of ground water in the State is influenced, directly and indirectly, by such natural factors as physiography, climate, and geology. Thus, an understanding of the relation of these factors, particularly geology, to the occurrence of ground water is necessary to the adequate management and proficient use of the ground-water supplies for the most productive benefit to the expanding economy. Water problems related to inadequate supplies,

equitable distribution of the available supply, and deterioration in quality of water may arise wherever there is an accelerated development of water resources. These problems become more complicated with the increasing demand for water, making the need for a comprehensive evaluation of the water resources more pressing each year. The solutions to these problems, as well as efficient management of the available water supply, must be based on adequate knowledge of the hydrologic and geologic factors that control the ground-water system.

A cooperative program between the State of Arizona and the U. S. Geological Survey providing for ground-water studies has been in operation since 1939. Since 1942, the State Land Commissioner has represented the State in the cooperation. In the early years, the program consisted largely of the collection of basic data—well inventory, periodic water-level measurements, water samples for chemical analysis, and drill cuttings for cataloging and analysis. Beginning in 1956, and continuing to the present time, the cooperative program was enlarged to include a more comprehensive compilation and analysis of the hydrologic and geologic data in order to better understand the hydrologic interrelations of the ground-water system.

The report discusses ground-water conditions throughout the State by basins and areas. This is a change from previous reports where the ground-water conditions were discussed by counties. A map showing the location of the basins and an index by counties are given in the report. Changes and trends in water levels, ground-water pumpage in the principal areas of agricultural development, surface-water diversions, climate, and chemical quality of water, as well as the relation of geology to the occurrence of ground water also are discussed. Illustrations include: (1) hydrographs showing comparative changes in the stage of water levels in selected wells for the last 10 years; (2) graphs showing cumulative changes in the water level and pumpage in the Salt River Valley, 1930-62, and in the lower Santa Cruz basin in Pinal County, 1940-62; (3) maps showing contours of the change in ground-water levels for the 5-year period 1957-62 in the Salt River Valley, lower Santa Cruz, Willcox, Douglas, and San Simon basins; and (4) a map showing some features of the Gila River flood-plain alluvium (Safford basin).

Scope of the Federal-State Cooperative Ground-Water Program

The current cooperative ground-water program in Arizona consists of three major parts: (1) statewide ground-water survey; (2) comprehensive ground-water investigations in selected areas; and (3) studies related to specific hydrologic problems. The three phases of the program are closely related and to a large extent are interdependent. The statewide ground-water survey provides the long-term basic data necessary to any type of ground-water investigation. Whenever the need arises for study of a specific area or some special problem, the basic data that have been collected over a long period of years are invaluable.

The overall objectives of the cooperative ground-water program are: (1) to evaluate the changes in ground-water levels as related to the development of ground-water supplies; (2) to delineate the present areas of greatest development and the areas where undeveloped ground water may support future development; (3) to determine the geology and hydrology of areas as related to the ground-water regimen; (4) to determine the changes in the chemical quality of water; (5) to determine net changes in ground-water storage from continuous records of fluctuations of water levels in selected wells; (6) to add to the knowledge of subsurface geology by the collection, cataloging, and study of drill cuttings and drillers' logs from water wells and oil tests; and (7) to compute total pumpage by collecting discharge and power records from specific areas.

Statewide Ground-Water Survey

The collection of basic hydrologic and geologic data is an integral part of the studies needed to analyze the ground-water resources throughout the State. Particular emphasis has been directed toward the collection of data in areas of extensive irrigational and industrial development; however, some ground-water information is obtained for nearly all parts of the State. The work includes well inventories, periodic water-level measurements, collection of water samples for chemical analysis, and collection and cataloging of drill cuttings from recently completed wells. The Geological Survey acts as a central storehouse where this basic ground-water information is available to farmers, industrialists, professional engineers and geologists, well drillers, and many others who request it.

The results of the statewide ground-water survey provide much of the basic geologic and hydrologic data necessary to accomplish the overall objectives of the cooperative ground-water program. This report is the annual summary of the statewide ground-water survey.

Comprehensive Ground-Water Investigations in Selected Areas

Comprehensive ground-water investigations are necessary in areas where ground-water conditions are becoming critical due to overdevelopment, where ground-water development is beginning, or where there is some special problem or interest. These more comprehensive investigations, in general, include: (1) surface and subsurface geologic mapping; (2) collection of additional basic data to augment that obtained under the statewide survey; (3) determinations of the hydrologic characteristics of the aquifers; and (4) studies of the chemical quality of the water. An investigation of this scope will result in an overall evaluation of the water resources of an area.

Studies Related to Specific Hydrologic Problems

There is an increasing need in Arizona for investigations of particular problems related to the occurrence, movement, recharge, storage, discharge, and chemical quality of ground water not necessarily confined to any one basin or area. Subjects covered under this phase of the cooperative program include the following:

(1) Subsidence, cavings, and earthcracks related to the compaction of sediments due to dewatering.

In several areas in Arizona, water levels have declined as much as 200 feet as a result of the withdrawal of ground water in quantities greatly in excess of the rate of replenishment. This excessive decline of water levels indicates dewatering of large volumes of sediments which may cause compaction of the sediments and result in subsidence, cavings, or earthcracks. Change in the quality of the ground water may result from compaction and squeezing out of poor-quality water from the less permeable beds of silt and clay.

(2) Determination of the occurrence, extent, and yield of deeper aquifers.

In many areas in Arizona, wells are being deepened because of the lowering of the water table. In some instances the deepening of wells has increased the yield; conversely, the yield of other wells in the same area, deepened in the same way, has decreased. Studies of the subsurface geology, particularly the composition and distribution of the sediments as related to the hydrologic characteristics of transmissibility, storage, and yield, are necessary to delineate the areas where the deeper aquifers can provide quantities of water of good quality.

(3) Research into new methods of collection and analysis of geohydrologic data.

Recent technical advances have resulted in the development of new methods for collecting geologic and hydrologic data. For the most part, these methods were first used and proven valuable in the field of oil exploration; however, similar methods are applicable to ground-water studies. Electric, gamma-ray, temperature, and conductivity logs, and other geophysical methods are used to determine the subsurface characteristics. Likewise, the analysis of the data has been advanced by the use of electronic computer methods. The use of an electrical-analog computer to analyze the geohydrologic data from basins in Arizona is one method that may give the needed refinement to the semiquantitative analysis previously made by standard mathematical methods. The electrical-analog method is now being applied to the data for a basin in southern Arizona.

Current Projects in Arizona

The following investigations were being conducted and were in various stages of completion under the three phases of the Federal - State cooperative ground-water program in Arizona in 1961. (1) The state-wide collection of basic geologic and hydrologic data; (2) Geohydrology and utilization of water in Willcox basin, Cochise County; (3) Determination of the productivity of aquifers at depth in Salt River Valley, Maricopa County; (4) Change in water yield by defoliation and vegetation removal, Cottonwood Wash, Mohave County; (5) Electrical - analog analysis of hydrologic data for the San Simon basin, Cochise and Graham Counties; and (6) Basin potential of Sycamore Creek, Maricopa County. Reports were in various stages of preparation or review for the following: (1) Subsurface geologic and hydrologic studies of western Pinal County; (2) Geology and ground-water resources of the central part of Apache County; and (3) Geology and ground-water resources of Big Sandy Valley, Mohave County.

In addition to the work done by the Geological Survey in cooperation with the Arizona State Land Department, agreements were in effect with several other cooperators. A cooperative project with the city of Flagstaff is for the purpose of determining the availability of ground water for municipal supply. Cooperative projects with the University of Arizona under the Arid Lands program consist of geohydrologic studies as related to water utilization in the Safford Valley, and a ground-water resources investigation in the Tucson basin. Work for the Navajo Tribe consists of studies to determine the feasibility of developing ground-water supplies on the reservation.

Work also is done by the Geological Survey for other Federal agencies. A ground-water investigation in cooperation with the U. S. Army is being conducted at the Fort Huachuca Military Reservation southeast of Tucson; a report is in preparation presenting the results of an investigation at Luke Air Force Base near Phoenix. A project for the Bureau of Indian Affairs is the well-location development program for the southeastern part of the Hualapai Indian Reservation. Reports are in various stages of preparation for the Navajo - Hopi country and the Papago Indian Reservation. Projects for the National Park Service include aquifer evaluation studies at Saguaro National Monument, Chiricahua National Monument, Navajo National Monument, and Lake Mead National Recreational Area.

The study of ground-water conditions in the Verde Valley area of the Mogollon Rim region is a Federal Geological Survey project; the report describing the results of this study is in review.

List of Publications

The following reports on the ground-water resources and geology of Arizona were prepared for release by the Ground Water Branch of the Geological Survey in the period from July 1961 through June 1962.

Water regimen of the inner valley of the San Pedro River near Mammoth, Arizona (a pilot study), by Harry G. Page: U. S. Geol. Survey open-file report, January 1962. 50 p., 5 figs., 4 tables. For publication as U. S. Geol. Survey Water-Supply Paper 1669-I.

A small area along the San Pedro River near Mammoth, Pinal County, Ariz., was selected as the site of a preliminary investigation of the water regimen of the inner valley of an intermittent stream in a semiarid basin. Three principal alluvial units are exposed, and the study evaluates the feasibility of determining quantitatively their interrelations with respect to ground-water recharge and discharge and their combined relation to streamflow. Qualitatively, the regimen in the reach studied involves loss in streamflow, change in ground-water storage, discharge by pumping and evapotranspiration, and movement of ground water between the alluvial units.

Analysis and evaluation of available hydrologic data for San Simon basin, Cochise and Graham Counties, Arizona, by Natalie D. White: U. S. Geol. Survey open-file report, August 1961. 63 p., 15 figs., 4 tables. For publication as U. S. Geol. Survey Water-Supply Paper 1619-DD.

The objectives of the study which this report describes were to analyze the available hydrologic and geologic data by standard methods and to determine if the data are adequate for quantitative analysis. The study shows where more and better data and other methods of analysis may give more accurate quantitative results. The newly developed electrical-analog method is promising for future data analysis. Nearly all the deposits in the San Simon basin are classified as older alluvial fill, which has been divided into four geologic units—the "lower unit," the "blue clay unit," the "upper unit," and the "marginal zone." Hydrologically, the lower unit constitutes the "lower aquifer," and the saturated part of the upper unit constitutes the "upper aquifer." Ground water is under artesian conditions in the lower aquifer and under water-table conditions in the upper aquifer and in the marginal zone where the upper and lower aquifers form a hydrologic unit. The report indicates that inasmuch as artesian pressure in the lower aquifer declined about 80 feet from 1915 to 1960, water is being "mined" in the basin—which means it is being withdrawn at a faster rate annually than it is being returned by recharge to the aquifer.

The following short papers were published in U. S. Geol. Survey Prof. Papers 424-C and 424-D.

Facies distribution and hydrology of intermontane basin fill, Safford basin, Arizona, by Edward S. Davidson, 1961. Article 204, p. 151-153, fig. 204.1.

Miocene and Pliocene history of central Arizona, by F. R. Twenter, 1961. Article 205, p. 153-156, figs. 205.1-205.3.

Ancient erosional cycles of the Little Colorado River, Arizona and New Mexico, by M. E. Cooley and J. P. Akers, 1961. Article 237, p. 244-248, figs. 237.1-237.3.

Effects of a buried anticline on ground water in the Navajo sandstone in the Copper Mine-Preston Mesa area, Coconino County, Arizona, by N. E. McClymonds, 1961. Article 321, p. 79-82, figs. 321.1-321.4.

The following short papers have been approved for publication in U. S. Geol. Survey Prof. Paper 450-B.

Late Pleistocene and Recent erosion and alluviation in parts of the Colorado River system, Arizona and Utah, by M. E. Cooley.

The relation of faulting to the occurrence of ground water in the Flagstaff area, Arizona, by J. P. Akers.

Annual report on ground water in Arizona—spring 1960 to spring 1961, by Natalie D. White, R. S. Stulik, E. K. Morse, and others: Arizona State Land Dept. Water Resources Rept. No. 10, December 1961. 93 p., 32 figs., 2 tables.

This annual report is a summary of the basic hydrologic data collected during the period spring 1960 to spring 1961. The report discusses the changes or trends in ground-water conditions throughout the State by counties and areas, ground-water pumpage in the principal areas of agricultural development, surface-water diversions, climate, chemical quality of water, and some principles of ground-water hydrology. The data contained in the report indicate that in most developed areas ground water is being removed from storage in excess of the rate of replenishment, resulting in the continuous decline of water levels. Pumpage of ground water in Arizona in 1960 amounted to about 4-½ million acre-feet, slightly less than in 1959. More than 90 percent of the ground water used in Arizona is for irrigation, and more than 75 percent of it is pumped from aquifers in the Salt River Valley and lower Santa Cruz basin.

Ground-water conditions in the Rainbow Valley and Waterman Wash areas, Maricopa and Pinal Counties, Arizona, by Natalie D. White: U. S. Geol. Survey open-file report, December 1961. 113 p., 10 figs., 8 tables. For publication as U. S. Geol. Survey Water-Supply Paper 1669-F.

This report describes the results of an investigation undertaken by the U. S. Geological Survey at the request of the Bureau of Land Management. Information was needed regarding the availability of ground water as a basis for controlling additional

agricultural development. The area discussed is in south-central Arizona and includes two valleys—the Rainbow Valley and Waterman Wash areas—where ground water is used for irrigation. The two valleys are separated by a low saddle cut on granite that has been partly covered by alluvium. In the Rainbow Valley area ground water is under water-table conditions in the sand and gravel lenses of the alluvial fill, and to some extent in lavas near the Gila River south of Gillespie Dam. Water levels in the area are declining in response to the discharge of ground water in excess of replenishment. In the center of the irrigated area, the water table declined more than 100 feet in the 9-year period 1952-61. For the most part, the ground water in the Waterman Wash area is under water-table conditions although some water may be under artesian conditions locally. In 1960, about 60,000 acre-feet of ground water was pumped from the aquifer in the Waterman Wash area. It is estimated that more than 80 percent of this water was removed from storage. Water-level declines for the period 1952-61 ranged from about 20 feet on the edge of the irrigated area to more than 80 feet in the center. Seven million acre-feet of ground water is estimated to be available from storage in the area from a depth of about 300 to 800 feet below the land surface. By definition, this is the amount of water in storage that will drain by gravity to wells. The ability to actually withdraw the full amount is contingent upon several factors.

Arizona Geological Society Digest, v. 4: Arizona Geological Society, November 1961.

This annual report consists of a collection of papers, progress reports, abstracts, and notes pertaining to current geologic work in Arizona and the Southwest. Five papers were written by personnel of the U. S. Geological Survey, Ground Water Branch. These are: (1) The geology of the central part of Apache County, Arizona (a preliminary report), by J. P. Akers; (2) The relation of geology to hydrology in the Segi Mesas area, Utah and Arizona, by M. E. Cooley and W. F. Hardt; (3) Late Cenozoic geohydrology in the central and southern parts of Navajo and Apache Counties, Arizona, by M. E. Cooley and J. P. Akers; (4) Correlation of ground-water quality with different sediment types, lower Santa Cruz basin, Arizona, by L. R. Kister and W. F. Hardt; and (5) Subsidence cracks in alluvium near Casa Grande, Arizona, by E. F. Pashley, Jr.

Agricultural Resume for 1961

According to Jimmye S. Hillman (1962), a total of 1,210,835 acres was cropped in Arizona in 1961, more than 50,000 acres less than in 1960. This figure includes both irrigated and dry-land crops. In other years when irrigated acreage has been given separately from total acreage

cropped, the dry-land acreage amounted to only about 20,000 acres for the State. Dry farming is practiced in only a few areas, mostly in Apache and Navajo Counties.

There were slight increases in cropped acreage in Cochise, Coconino, Navajo, and Pima Counties, and decreases in the remaining counties. Maricopa (522,650 acres), Pinal (271,755 acres), Yuma (178,980 acres), and Cochise (83,900 acres) Counties continued to have the largest total acreage under cultivation. Cotton continued to account for the largest amount of acreage in the State; a total of 393,000 acres of cotton was under cultivation in 1961—about 33,000 acres less than in 1960. Alfalfa was grown on about 227,000 acres in 1961. Ground water continued to be the major source of irrigation water for the cultivated acreage in the State, and declining water levels are thus a major problem in connection with Arizona's agriculture.

In 1961 the gross cash income of Arizona farmers and ranchers amounted to 503.5 million dollars as compared to 483.9 million dollars in 1960 (Hillman, 1962). This is an increase of 19.6 million dollars or 4.1 percent. Hillman (1962) states: "Increases in value were made all along the line with the exception of vegetables, feed crops, poultry and eggs, sheep, and certain miscellaneous livestock. Cotton and citrus made notable gains. *** Cotton, cattle, and vegetables accounted for 73.7 percent of the total crop and livestock value."

Climate

In 1961 precipitation was below average in most of Arizona (U. S. Weather Bureau, 1962); the exception was in the southeast part of the State which includes Pima, Santa Cruz, Cochise, Graham, and Greenlee Counties. In this area precipitation was nearly 2 inches above average in 1961. It was more than 3 inches below average in Maricopa and Pinal Counties, where the greatest amount of ground water is pumped, and in Mohave County, where little ground water is pumped. Precipitation was nearly 3 inches below average in Yavapai County, nearly 2 inches below average in Gila County, and about 1-½ inches below average in Yuma County. It was less than an inch below average in the northwestern part of the State.

A summary of the precipitation pattern throughout the State by months shows that in January rainfall was below average except in the southeastern part of the State where it was only slightly above average. In February precipitation was below average throughout the State and in March it was below average in the entire southern part of the State and in Mohave County. In April and May rainfall was deficient throughout the State and in June it was below average except in the southeastern part where it was about average. July precipitation was below average except in Yavapai and Gila Counties. In August precipitation was above average throughout the State. The precipitation pattern in September varied greatly in relation to the average for the month. It was below average in Mohave, Yuma, Maricopa, and Pinal Counties, about aver-

age in the northeastern part of the State, and below average in the southeastern part and in Yavapai, Gila, and Yuma Counties. October and November were deficient in rainfall except in the southeastern part of the State. Precipitation was above average in December except in Mohave County where it was less than half an inch below average.

One of the most distinctive characteristics of Arizona's climate is the wide range in temperatures occurring over the State. The extremes in temperature are caused by large differences in altitude and a considerable range in latitude. There are also wide variances in seasonal temperatures in parts of the State. The lowest mean monthly temperatures throughout the State are usually recorded in January and the highest in July. In January the average temperatures range from 20°F to 25°F on the Kaibab Plateau and in the San Francisco and White Mountains to about 55°F along the lower Gila River. In July the same regions have average temperatures of about 55°F and 95°F, respectively. In addition to seasonal variations in temperature, there is a wide range in daily temperatures. Particularly in late winter and spring, it is not unusual for the temperature to vary by 40° from early morning to midafternoon (Sellers, 1960). In some of the valley areas, variations of more than 50° are not uncommon. According to the U. S. Weather Bureau (1962) records, the extremes of temperature in Arizona in 1961 were 121°F at Davis Dam on June 24 and -32°F at Many Farms in Apache County on December 12.

Table 1 shows the total precipitation and average temperatures and departures from the long-term means for several weather stations in Arizona for 1961.

Precipitation controls the gross water supply of an area including water available for recharge to the ground-water reservoirs. However, many other factors exert control on the net supply. Evapotranspiration probably is the most important of these factors. In Arizona nearly 95 percent of the precipitation is consumed by evaporation or transpired by natural vegetation, largely nonbeneficial. This and other factors working together leave only about 1.0 percent per year of the total precipitation available for recharge to the ground-water reservoirs. Most of this recharge enters the ground-water reservoirs from runoff through the coarse alluvial materials adjacent to the mountain fronts.

Well-Numbering System

The well numbers used by the Geological Survey in Arizona are in accordance with the Bureau of Land Management's system of land subdivision. The land survey in Arizona is based on the Gila and Salt River meridian and base line, which divide the State into four quadrants (fig. 1). These quadrants are designated counterclockwise by the capital letters A, B, C, and D. All land north and east of the point of origin is in A quadrant, that north and west in B quadrant, that south and west in C quadrant, and that south and east in D quadrant. The

Table 1.--Total precipitation and average temperature in 1961 at selected stations and departures from long-term means. (U. S. Weather Bureau, 1962)

Station	Precipitation (inches)	Departure (inches)	Temperature (°F)	Departure (°F)
Bowie	15.41	-	62.8	-
Buckeye	4.23	-	69.6	-
Casa Grande	8.23	0.15	70.9	1.2
Chandler	5.67	-	70.5	-
Chino Valley	11.15	-	-	-
Davis Dam	2.72	-	72.6	-
Douglas Smelter	12.45	.83	63.5	.4
Duncan	13.03	-	58.9	-
Eloy	8.53	-	71.0	-
Flagstaff	18.95	.48	45.3	.7
Gila Bend	6.22	.31	-	-
Globe	16.48	1.08	62.4	.6
Holbrook	5.66	-2.09	53.7	-1.5
Kingman	7.83	-	62.1	-
Litchfield Park	4.79	-3.07	70.8	.6
Mesa	5.07	-2.62	69.6	1.4
Nogales	16.47	-	60.5	-
Payson	18.96	-	55.7	-
Phoenix Airport	4.43	-2.73	70.2	.8
Pinedale	16.45	-1.37	-	-
Prescott Airport	11.38	-4.60	55.6	.4
Safford	11.52	2.80	-	-
St. Johns	10.75	-.62	53.3	.9
Snowflake	9.71	-2.02	50.7	-
Tucson, University of Arizona	10.25	-.18	69.1	1.3
Wellton	4.19	-	69.7	-
Wikieup	5.35	-5.23	66.5	-
Willcox	14.20	-	57.6	-
Williams	19.09	-2.04	49.9	.9
Yuma Airport	2.17	-1.22	74.6	-.1

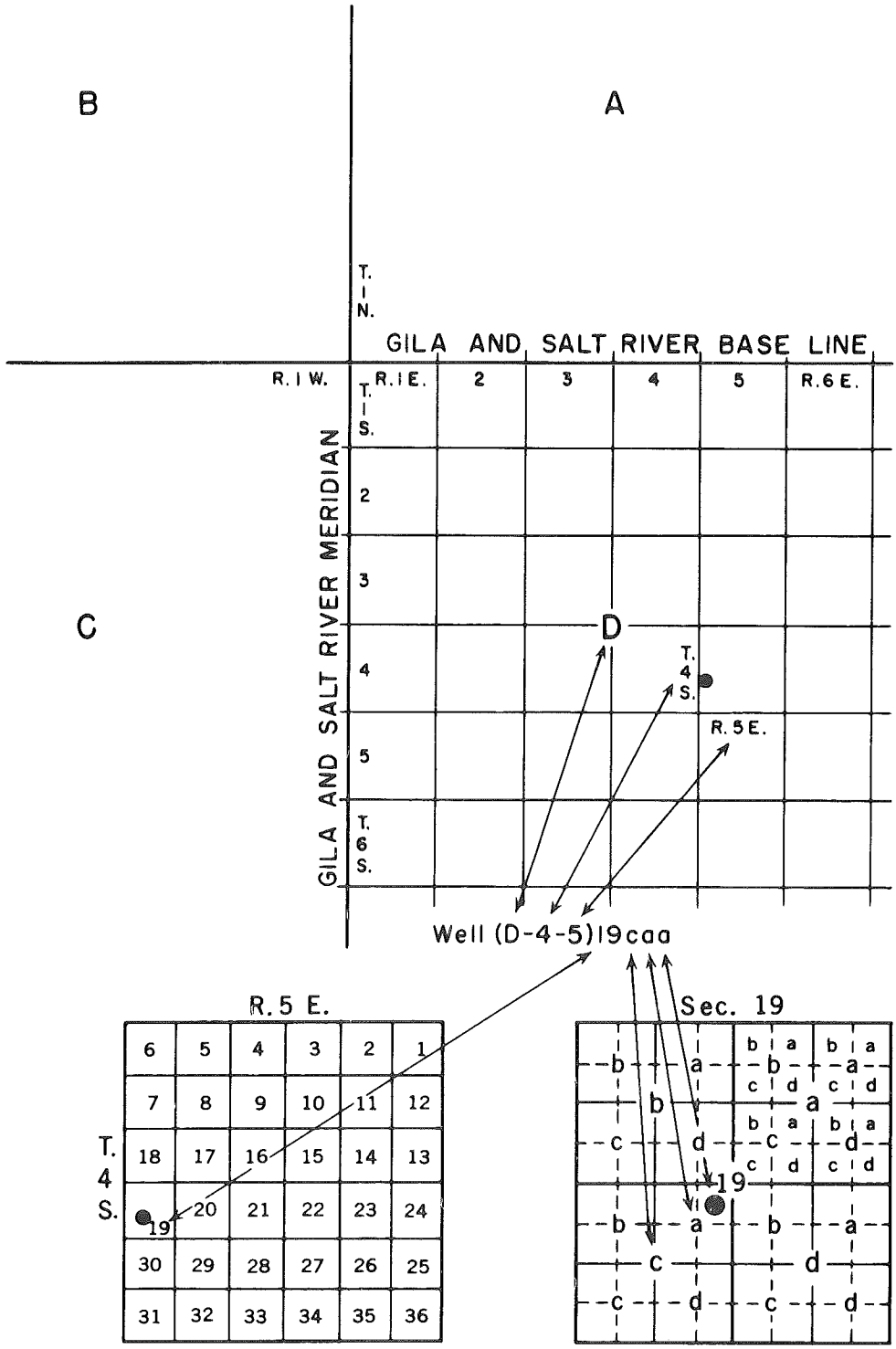

Figure 1 -- Sketch showing well-numbering system in Arizona.

first digit of a well number indicates the township, the second the range, and the third the section in which the well is situated. The lowercase letters a, b, c, and d after the section number indicate the well location within the section. The first letter denotes a particular 160-acre tract (fig. 1), the second the 40-acre tract, and the third the 10-acre tract. These letters also are assigned in a counterclockwise direction, beginning in the northeast quarter. If the location is known within a 10-acre tract, three lowercase letters are shown in the well number. In the example shown, well number (D-4-5)19caa designates the well as being in the NE¼NE¼SW¼ sec. 19, T. 4 S., R. 5 E. Where there is more than one well within a 10-acre tract, consecutive numbers beginning with 1 are added as suffixes.

Personnel

This report is prepared by the combined efforts of most members of the staff in the Arizona district. The sections that discuss ground-water conditions by basins or areas were, in general, prepared by the person most familiar with the particular area. Persons outside the district who contributed to the report were H. C. Schwalen, Agricultural Engineer, who prepared the sections on the upper Santa Cruz basin, Avra-Marana area, and the Chino Valley artesian area; and R. J. Shaw who collected the field data on which these discussions were based. These men are connected with the Agricultural Engineering Department, University of Arizona. Authorship of the individual sections is shown in the table of contents.

In addition to those persons listed as authors several other people contributed substantially to the preparation of the report. W. D. Potts prepared the drawing showing the occurrence of ground water in alluvial basins; and G. S. Smith and R. H. Rascop prepared the illustrations. Others who worked on the report include William Kam, A. C. Hill, R. D. Penley, C. L. Jenkins, M. F. Smith, and J. E. Williams. The report was compiled and coordinated by N. D. White.

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GEOLOGY AS RELATED TO GROUND WATER

By

Natalie D. White

The occurrence of ground water in any area is fundamentally related to the character, distribution, and structure of the rocks it contains, that is, to the geology of the area. The rocks that form the earth's crust contain numerous openings called interstices which provide space for the storage of water. The many kinds of rocks differ greatly in the number, size, shape, and arrangement of interstices, and hence in the ability to store water. In addition to its ability to store water, each rock type is distinctive in its ability to transmit water, and in its effect upon the chemical quality of the water. The characteristics of a rock that are important to the storage, transmission, and chemical quality of ground water are a result of a great diversity of geologic processes taking place over long periods of time, forming and, later, altering the rocks. Thus, in order to fully evaluate the ground-water resources of an area, it is necessary to understand the origin and subsequent history of the rocks of a region.

Based on their origin, rocks are said to be igneous, sedimentary, or metamorphic. Igneous rocks are those that were produced by the cooling and solidification of molten materials derived from great depths below the surface where the earth is very hot. Sedimentary rocks are those that were produced by the deposition of materials weathered from older rocks, derived from the remains of animals and plants, or precipitated out of solution in water. Metamorphic rocks are those that were produced by the alteration of other rocks, chiefly through the agencies of heat and pressure. Each of these broad classes of rocks are further divided on the basis of origin, texture, and composition into many and varied types, each of which has definite and distinct water-bearing qualities. A complete discussion of rock types is beyond the scope of this report. The following paragraphs will discuss the broad aspects of rock types and their relation to the occurrence of ground water within the three physiographic provinces in Arizona. The physiographic provinces are synonymous with the water provinces described by White, Stulik, Morse, and others (1961). Definitions of some of the terms used here are given in the section entitled "Regional Hydrology."

Basin and Range Lowlands Province

The Basin and Range lowlands province is characterized by broad, gently sloping valleys bounded by high, rugged mountain ranges. These alternating mountains and valleys were produced by large-scale faulting in which the mountain blocks were pushed upward and the basins were dropped. Subsequent to the faulting, the valleys were filled with alluvial material eroded from the mountain masses. The mountain masses are composed chiefly of granite, gneiss, schist, and quartzite and some are capped with volcanic rocks. Along some of the mountain fronts the hard rocks have been planed by erosion to gently sloping rock surfaces that resemble the alluvial slopes. These rock slopes are called "pediments." Where they pass beneath the alluvial fill they may have gradients only slightly greater than those of the fill, but at the structural boundary the depth of the alluvial cover becomes abruptly much greater. The pediments are important in evaluating the ground-water resources of an area because the bedrock surfaces of the pediments are usually above the water table in the valleys, and thus reduce the storage capacity of the aquifers in the valleys.

The occurrence of ground water in the Basin and Range lowlands province is related directly to the geologic history of the rocks of the area. A complete discussion of the complicated events that occurred over a geologically long period of time resulting in the present relations of mountains to valleys is beyond the scope of this report. However, a brief discussion of the major stages of erosion and sedimentation that formed the alluvial valleys in which most of the ground water is stored will indicate the importance of geologic history to the occurrence of ground water.

During early and middle Tertiary time, large-scale movement along predominantly northwest-trending faults formed the general outlines of the Basin and Range structural pattern. It is probable that some movement on a smaller scale continues to the present time. Subsequent to the major faulting that formed the mountains and valleys, several stages of erosion and sedimentation filled the valleys with the materials that now form the major aquifers in the region. Deposited on the basement rocks of most of the valley floors is a coarse indurated, conglomeratic material eroded from the upfaulted mountain blocks. Concurrent with this period of sedimentation, volcanic eruptions locally deposited lavas that interfinger with the conglomerate; in some areas the basin drainages were dammed forming lakes and playas in which fine-grained sediments were deposited. Subsequent erosion and deposition of material derived from the mountains filled the valleys. Continued volcanism supplied lavas which in places interfinger or interbed with the valley alluvium.

This older alluvial fill, which represents several ages and environments of deposition, occupies much of each structural basin and in many areas is the principal aquifer. The older fill consists of lenses of gravel, sand, clay, and silt in varying thicknesses; locally, it may

be as much as 3,000 feet thick. In general, the deposits grade in texture from large boulders near the mountains to fine-grained sediments along the axes of the valleys. In the upper part of the older fill, considerable thicknesses of lake-bed clay are common. Locally, these clay beds contain lenses of gravel and sand that yield some ground water to wells. In some basins these clay beds form a confining layer and the ground water in permeable sand and gravel beds beneath is under artesian pressure. Ground water in the coarse materials above the lake beds is under water-table conditions.

The present drainages, cut on the older alluvium, have been filled to various depths with unconsolidated deposits of gravel, sand, and silt. This Recent alluvial fill along the flood plains of the present streams in the Basin and Range lowlands province in many basins provides large amounts of ground water. The amount of ground water that can be obtained from the Recent fill in any particular area depends upon the depth and areal extent of the deposits.

Other rock types store and transmit small quantities of ground water in the Basin and Range lowlands province, but they are insignificant in comparison to the amount obtainable from the alluvial-fill materials.

The chemical quality of the ground water stored in the aquifers of the alluvial fill varies widely. However, in most areas it is of suitable quality for most uses. In a few areas, the ground water is highly saline—a result of solution of the rock through which the water passes.

Plateau Uplands Province

Although all three of the principal rock types—igneous, sedimentary, and metamorphic—are present, the sedimentary rocks are the most important to the occurrence of ground water in the area. These include sandstone, siltstone, claystone, and limestone. The sandstone and limestone are capable of storing and transmitting water and form the chief aquifers in the area. The siltstone and claystone are highly impermeable and form confining beds throughout most of the area. Where the water-bearing sandstone and limestone formations alternate with these confining beds, water in the aquifers is under artesian pressure.

The Coconino Sandstone of Permian age—a fine-grained well-sorted highly crossbedded eolian sand—underlies nearly all the area and is the chief aquifer. However, in places the Coconino Sandstone contains large amounts of cement and, thus, it is not uniform in its water-yielding capacity throughout the area. The Navajo Sandstone of Triassic(?) and Jurassic age is fine grained, well sorted, and generally is not tightly cemented. It is the second most important aquifer in the Plateau uplands province and is the principal water-bearing formation in the western part of the Navajo Indian Reservation. Locally, water is obtained from other formations both older and younger than the

Coconino Sandstone and Navajo Sandstone discussed above. In parts of the area, volcanic materials yield small amounts of ground water where underlain by impervious materials. In other areas these volcanic materials are porous and water percolates downward into the underlying formations. Along the Little Colorado River and its principal tributaries, shallow alluvium stores some ground water. However, the alluvium usually is fine grained and does not yield large amounts of ground water to wells.

The chemical quality of the ground water in the Plateau uplands province is variable—much of it is unfit for use. This variation in quality is due to the differences in the mineral composition of the rocks that form the aquifers. Water in the Coconino Sandstone—the chief aquifer in the area—varies greatly in quality. In general, water in the Coconino Sandstone is good to fair in the southern part of the province and is more highly mineralized to the north. Water in the Navajo Sandstone is generally of good to fair quality throughout the province. A knowledge of the stratigraphy can help to determine in advance what quantity of water will be obtained and whether it is of suitable quality for use.

Central Highlands Province

The Central highlands province is composed of all types of rocks—sedimentary, igneous, and metamorphic—and each type has distinctive water-bearing characteristics. The geologic structure of the province is also an important feature in appraising its water resources.

The most prominent structural feature of the Central highlands province is the Mogollon Rim—an escarpment consisting mostly of Paleozoic sedimentary rocks such as sandstone, siltstone, claystone, and limestone. Along the base of the Mogollon Rim many springs issue from the Coconino Sandstone and the underlying Supai Formation of Pennsylvanian and Permian age and Redwall Limestone of Mississippian age. The intrusive igneous rocks, mostly granites, which form the core of this province and are exposed extensively, are impervious and contain little space for the storage of water. However, in places, they are fractured and faulted and small amounts of water are stored in these fracture openings. Where these fractures are at the surface, ground water may issue as springs. Volcanic rocks, which form a large part of the surface area of the region, are permeable and water moves downward into the underlying rocks. In a few small valleys alluvial sediments provide storage for minor amounts of ground water.

For the most part, the streams in the Central highlands carry water of good quality, especially in the upper reaches. The stream beds are partly in granites, schists, and volcanic rocks which are not readily soluble. When stream beds are cut into sedimentary rocks, the water is more highly mineralized and may carry large amounts of sediment immediately following thunderstorms. In addition, some of the springs in the area contribute highly mineralized water to the streams. The

amount of mineralization in the spring water depends upon the formations through which the water has passed.

REGIONAL HYDROLOGY

By

Natalie D. White

The foregoing section described briefly the influence of the geology on the occurrence of ground water for each of the water provinces in Arizona. Of the three water provinces, the Basin and Range lowlands is the most highly developed from the standpoint of water use. The following paragraphs will discuss several aspects of ground-water hydrology with respect to this province. Definitions of terms used in this and the foregoing sections are given below.

Geologic and Hydrologic Terms

Geology is the science which treats of the origin, history, and structure of the earth, as recorded in the rocks. Ground water is water in the earth which completely fills the pore spaces of the rocks which it occupies. Hence, ground-water geology is that part of the science of geology that treats of the relation of the structure and composition of the earth to the occurrence of ground water.

In geologic terms, a rock is any naturally formed aggregate or mass of mineral matter constituting an essential part of the earth's crust—the external part of the earth, accessible to geological investigations. The earth's crust consists of layers, or strata, of rocks of various kinds, and massive bodies of rock that underlie or intersect the layered series. A rock formation is a more or less distinct unit of the earth's crust—a large and persistent bed of some one kind, or more or less related kinds, of rock. Rock formations range from a few feet to several hundreds of feet in thickness and, areally, may extend over great distances, either at the surface or buried beneath other formations.

At considerable depths, rocks generally are consolidated or indurated except where they are broken by fractures or joints. The shifting of the earth's crust results in differential movement along zones of weakness causing the rock formations to fold and, in many instances, to break. Most structural features of the earth are formed by, or associated with, this movement. The deep-seated breaks or faults often are the avenues whereby molten rock (magma) or volcanic lava reaches, and is extruded over, the land surface by the process of volcanism. Solidification of the lava results in volcanic rocks; the type depends upon the constituents of the original magma and the type of rocks through which it passes.

Near the surface, rocks have been broken and decomposed by various mechanical and chemical processes, collectively called "weathering." In some places, the weathering process has affected the rocks to depths of 100 feet or more. However, as the unconsolidated materials near the surface are subject to erosion—the process by which earthy matter or rock is loosened or dissolved and removed from place to place over any part of the earth's surface—the consolidated rocks are exposed at the surface in many places. The consolidated rocks are more resistant to erosion, and, where they cap rocks more susceptible to erosion or where they are associated with geologic structure, they form many different land shapes such as mesas, buttes, and escarpments. On the other hand, where the transporting agencies—water, wind, ice, etc.—have deposited their loads the unconsolidated materials, or alluvium, may be hundreds or thousands of feet thick as in some of the basins in southern Arizona. This detrital material also is referred to as alluvial fill, alluvial material, or valley fill. The group of processes whereby material derived by decomposition and disintegration from any kind of rock is transported by natural forces and deposited together with other materials derived from any source whatever, is called "sedimentation." The consolidation of these materials by various cementing agents and other forces gives rise to some terms that, in many instances, are descriptive of the former unconsolidated material. Consolidated silt is called "siltstone;" clay, "claystone;" sand, "sandstone;" cemented gravel is called "conglomerate," Limestone, although sometimes formed largely of fragments of older limestone and plant and animal skeletons, is more commonly derived from precipitation from solution of the calcium carbonate of ground water and surface water. These and more detailed rock classifications are based on origin, texture, and composition.

The large masses of rocks or formations are classified also on the basis of their relative age. Where undisturbed from their original stratigraphic position, the older rocks underlie the younger rocks. Thus, each formation can be assigned to one of the major divisions or eras of geologic time and to the subdivisions of the eras—periods and epochs. Formational names are given to masses of rock that have a large measure of unity in general characteristics and (or) time of formation. Table 2 is a chart showing the major divisions of geologic time. The formational names used in this report are identified according to geologic age in the following paragraph.

In Arizona, the mountain complexes are composed mainly of granite, gneiss, schist, and quartzite which, for the most part, are assigned to the Precambrian Period. The Supai Formation is considered to be of the Pennsylvanian and Permian Periods of the Paleozoic Era and the Coconino Sandstone is Permian. The Navajo Sandstone is assigned to the Triassic and Jurassic Period, and the Dakota Sandstone and Toreva Formation to the Cretaceous Period of the Mesozoic Era. In Arizona, the youngest rocks are the unconsolidated sediments deposited along the present drainage systems; these are considered to be of the Pleistocene and Recent Epochs, Quaternary Period of the Cenozoic Era. Where no distinction can be made of deposits laid down during these

Table 2. --Major stratigraphic and time divisions in use by the U. S. Geological Survey

Era	System or Period	Series or Epoch	Estimated ages of time boundaries in millions of years Holmes1/	Kulp2/
Cenozoic	Quaternary	Recent		
		Pleistocene	1	1
	Tertiary	Pliocene	11	13
		Miocene	25	25
		Oligocene	40	36
		Eocene	60	58
		Paleocene	70	63
Mesozoic	Cretaceous[3]	Upper (Late) Lower (Early)	135	135
	Jurassic	Upper (Late) Middle (Middle) Lower (Early)	180	181
	Triassic	Upper (Late) Middle (Middle) Lower (Early)	225	230
Paleozoic[3]	Permian[3]	Upper (Late) Lower (Early)	270	280
	Carboniferous systems: Pennsylvanian[3]	Upper (Late) Middle (Middle) Lower (Early)		
	Carboniferous systems: Mississippian[3]	Upper (Late) Lower (Early)	350	345
	Devonian	Upper (Late) Middle (Middle) Lower (Early)	400	405
	Silurian[3]	Upper (Late) Middle (Middle) Lower (Early)	440	425
	Ordovician[3]	Upper (Late) Middle (Middle) Lower (Early)	500	500
	Cambrian[3]	Upper (Late) Middle (Middle) Lower (Early)	600	600?
Precambrian[3]		Informal subdivisions such as upper, middle, and lower, or upper and lower, or younger and older may be used locally.	3,000+	

1/ Age values given are the Holmes time scale (Holmes, 1960).

2/ Ages given are the Kulp time scale (Kulp, 1961).

3/ Includes provincial series accepted for use in U. S. Geological Survey reports.

epochs, the material is referred to as younger fill. Some of the deposits in the valleys are assigned to the Tertiary Period of the Cenozoic Era.

Hydrology is the science that relates to the water of the earth; hence, ground-water hydrology is that part of the science of hydrology that treats of the water within the earth. The characteristics of rock formations that relate to the occurrence of ground water are an important part of the science of ground-water hydrology.

An interstice in a rock or soil is a space that is not occupied by solid mineral matter. Interstices may be occupied by air, water, or other gases or liquids. As interstices provide space for the storage of water, they are of fundamental importance in any study of the ground-water resources of an area. A rock is saturated with respect to water if all the interstices are filled with water. The porosity of a rock is its property of containing interstices and may be expressed quantitatively as the ratio of the aggregate volume of its interstices to its total volume. This ratio is usually expressed as a percentage. A permeable or pervious rock is one that permits water to move through it perceptibly under the pressures ordinarily found in subsurface water, as opposed to impermeable or impervious rocks that will not transmit perceptible quantities of water under ordinary pressures. The hydrostatic pressure at a given point in a body of water at rest is the pressure exerted by the water at the point. The hydrostatic pressure of ground water is due generally to the weight of water at higher levels in the same zone of saturation—the zone in which the permeable rocks are saturated with water under hydrostatic pressure. The water-bearing properties of a rock are the factors that control its ability to store and transmit water. The water-bearing properties depend mainly on the number, size, shape, and arrangement of interstitial openings which in turn are related to the degree of cementation and compaction.

A water-bearing formation is a rock formation that contains and will yield ground water in usable quantities to wells and springs. An aquifer is a water-bearing formation, or part of a formation, and is synonymous with ground-water reservoir. A ground-water basin is a trough containing a series of water-bearing formations and partly, or wholly, encircled by impermeable rock barriers. The permeability of the material comprising a formation is a measure of the material's capacity to transmit water under pressure. The coefficient of permeability has been expressed by Meinzer (Stearns, 1928) as the rate of flow of water in gallons per day through a cross-sectional area of 1 square foot under a hydraulic gradient of 1 foot per foot. The hydraulic gradient of an aquifer is the rate of change in elevation per unit of distance. The capacity of an aquifer to transmit water can also be expressed as the coefficient of transmissibility—the rate of flow of water, in gallons per day, through a vertical strip of the aquifer 1 foot wide extending the full saturated height of the aquifer under a hydraulic gradient of 100 percent.

Ground water may occur under artesian or nonartesian conditions. Artesian is an adjective referring to ground water under pressure;

thus, an artesian aquifer is one in which the water is under sufficient pressure to rise above the zone of saturation, artesian water is ground water that has artesian-pressure head, and an artesian well is a well in which the water rises under pressure above the zone of saturation. A flowing artesian well is one in which the water is under sufficient pressure to cause the water to flow at the land surface as opposed to a nonflowing artesian well in which the water rises above the zone of saturation but does not flow at the surface. An impermeable body or layer of materials, usually clay or silt, overlying the zone of saturation forms the confining layer which causes the water to be under pressure. Under nonartesian conditions the water level in the well coincides with the upper surface of the zone of saturation, called the "water table." Hence, the term "water-table aquifer" is synonymous with nonartesian aquifer and refers to an aquifer in which the water is not under pressure.

Recharge is the addition of water to a ground-water reservoir by natural or artificial means, and discharge is the removal of water from a ground-water reservoir by natural or artificial means. Percolation is the movement of water through the saturated interstices of a rock or soil. Seepage is the percolation of water into or out of the ground-water reservoir. Influent seepage is movement of water into the ground-water reservoir and effluent seepage is movement of water out of the ground-water reservoir. The term "infiltration" has essentially the same meaning as seepage. Underflow is the movement of ground water through an underflow channel consisting of a permeable deposit, usually sand and gravel, underlying a surface stream and limited on the bottom and sides by relatively impermeable beds. Evaporation is the natural discharge of water to the atmosphere in which water is changed from the liquid state to a gaseous state. Ground water from the zone of saturation is evaporated in two ways: directly from the soil or rocks after it has been lifted nearly to the surface by capillarity; and, where the roots of plants take water directly from the zone of saturation or from the capillary fringe. The process by which water vapor is discharged from the living plants is called "transpiration." Evapotranspiration is the process by which water is returned to the atmosphere by direct evaporation or by transpiration from vegetation, no attempt being made to distinguish between the two.

Occurrence of Ground Water

The chief aquifers in the Basin and Range lowlands of southern Arizona are permeable beds of sand and gravel in the older and younger alluvial fill. Because of its greater extent, vertically and areally, the older alluvial fill supplies a greater volume of ground water than the younger fill; however, yields from individual wells in the older alluvium may be less.

In the older alluvial fill, there are water-bearing beds of sand and gravel at many different depths interfingered with relatively imper-

meable lenses containing silt and clay. Although in most areas the aquifers are interconnected and there is a single water table, in parts of some valleys the water-bearing beds are more or less completely separated by impervious beds of clay and silt. Such an impervious bed overlying a saturated sand and gravel bed effectively confines the lower aquifer and causes the water in it to be under artesian pressure. Water in permeable material above the clay beds and in parts of the valleys where the clay beds are not present is under water-table conditions. Figure 2 shows the occurrence of ground water in a typical alluvial basin.

The younger alluvial fill is commonly not more than a few hundred feet thick and the water is under water-table conditions. In some areas the younger fill is entirely above the regional water table and thus does not contain ground water.

Recharge of Ground Water

The ground-water reservoir in the alluvial basins of southern Arizona is recharged from several sources: (1) runoff from precipitation in adjacent mountain ranges; (2) infiltration of excess irrigation water; (3) underflow from outside the basin; and (4) direct penetration of precipitation.

Runoff from Precipitation in Adjacent Mountain Ranges

Although a large part of the precipitation on the mountain ranges adjacent to the valleys in the Basin and Range lowlands of southern Arizona is lost to the atmosphere by evaporation or transpiration, a part becomes runoff and reaches the coarse alluvial materials at the mountain fronts where it may recharge the ground-water reservoir. It has been estimated (Coates and others, 1955) that about 10 percent of the precipitation on the mountain areas becomes runoff; Babcock and Cushing (1942) estimate that perhaps as much as 50 percent of the runoff is recharged to the ground-water reservoir at the mountain fronts. These percentages would not be exact for all the alluvial basins in southern Arizona, but data indicate that they probably are in the right order of magnitude.

Infiltration of Excess Irrigation Water

A part of the water applied to the land for irrigation in the valleys is returned to the ground-water reservoir by infiltration. In some areas as much as 25 percent of the water applied to irrigated fields may be recharged to the ground-water reservoir (Feth, 1952); in other areas the amount of recharge from this source probably is negligible (Coates

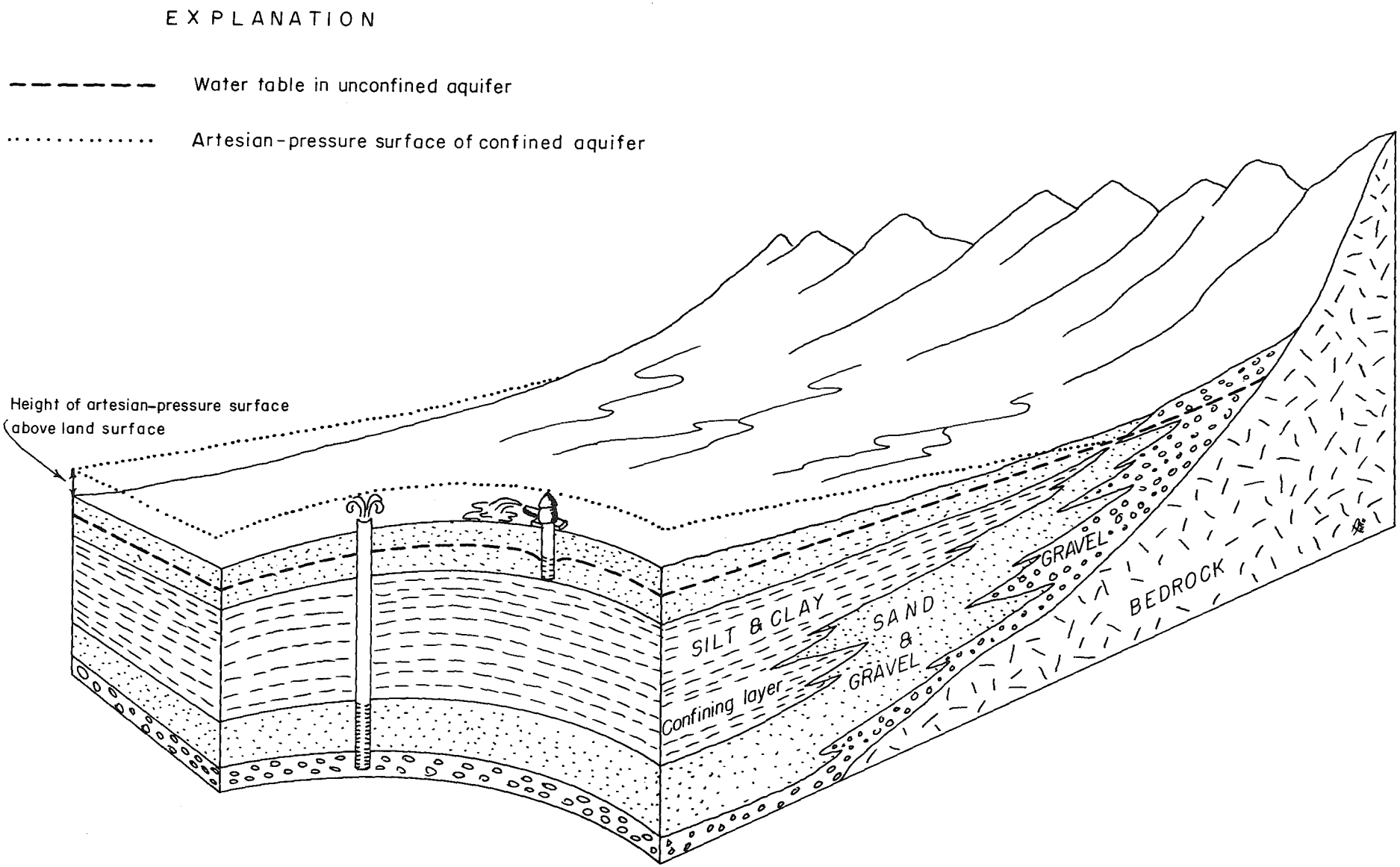


Figure 2.--The occurrence of ground water in a typical alluvial basin.

and Cushman, 1955). The amount of recharge for any given time interval is a function, not only of the amount of water applied, but also of the rate at which the water percolates toward the zone of saturation. The rate at which this water moves downward depends upon the permeability of the materials through which it must pass. Other factors, such as depth of the root zone, capillarity, temperature, and amount of direct sunlight on the ground, influence the recharge to ground water from this source. Some water also is recharged to the ground-water reservoir where it flows through unlined canals from the source to the point of use.

The process described is actually a recirculation of water from storage within the basin and cannot be considered as a gain to the ground-water storage.

Underflow from Outside the Basin

The ground-water reservoir in some basins is recharged by the movement of water by underflow from upstream areas through permeable materials underlying stream channels or other areas not completely obstructed by the hard-rock barriers that separate the basins. This movement of water between basins is recharge to the lower basin but at the same time it is discharge from the upper basin.

Direct Penetration of Precipitation

Most of the rain that falls on the valley floors in the Basin and Range lowlands of southern Arizona evaporates directly from the soil zone or is transpired by vegetation before it can percolate downward to the ground-water reservoirs. Some water may seep downward to the ground-water reservoir where the precipitation falls directly on the coarse-grained materials along the washes that traverse the valley floor but the amount probably is negligible. In the mountain areas most of the precipitation either becomes runoff or is evaporated because of the steep slopes and impermeable character of the rocks.

Movement of Ground Water

Several factors influence the direction and rate of ground-water movement through the aquifers of the alluvial basins in southern Arizona. These are: (1) the hydraulic gradient; (2) the permeability of the material; and (3) the cross-sectional area of the saturated zone.

Other conditions being equal, ground water will move through porous material under the force of gravity downgradient toward the point of lower head. The slope of the water table in an area approximates, but

generally is less than, the slope of the land surface, except where it is controlled by subsurface barriers such as local cementation, clay bodies, buried hard-rock hills, or fault zones that cause irregularities in the gradient of the water surface.

Under natural conditions the direction of movement of ground water in the alluvial basins is generally from the margins toward the axis of the basin and along the axis in the direction of the slope of the land gradient. The rate of movement of ground water in alluvial basins probably ranges from only a few feet per year to several hundreds of feet per year. Within a basin the most rapid movement probably is toward the axis from sources of recharge along the margins of the basin. Development of ground water in an area modifies both the direction and rate of movement; the amount and nature of the modification depends on the volume of ground water removed and the pattern of removal.

The direction of movement of ground water within a basin, either under natural or modified conditions, can be determined by constructing contours of the water surface. These contours are lines connecting all points of equal altitude of the water surface. The altitude of the water surface is determined by subtracting the depth to water from the altitude of the land surface at the point of measurement. The direction of ground-water movement is at right angles to the contours. If the permeability of the sediments is known the amount of water moving through a given area also can be determined by using the relation $Q = PIA$, where Q is the discharge in gallons per day, P is the coefficient of permeability in gallons per day per square foot, I is the hydraulic gradient in feet per foot determined from the spacing of the contours, and A is the cross-sectional area in square feet through which the discharge occurs. This relation may also be used to determine the permeability of the sediments if the amount of discharge at some place is known.

Discharge of Ground Water

Ground water is discharged from the alluvial basins in southern Arizona by both natural and artificial means. Natural means of discharge include: (1) evaporation; (2) transpiration; (3) underflow out of the basin; (4) effluent seepage; and (5) spring discharge. The artificial discharge of ground water from a basin is by pumping or artesian flow from wells.

Natural Discharge of Ground Water

Locally, small amounts of ground water may be discharged by direct evaporation in areas where the water table is near the surface. However, in most of the alluvial basins in southern Arizona, the water table is now sufficiently below the surface to prevent any significant amount of discharge in this manner. White (1932) indicates that as the

depth to water approaches 10 feet the discharge of ground water by evaporation is negligible. Thus, discharge by evaporation probably is not significant except in a few places along intermittent stream channels. However, as explained in the section on the recharge of ground water, evaporation takes a large part of the precipitation that might otherwise become ground water.

In southern Arizona large amounts of ground water are transpired from the ground-water reservoir by phreatophytes—plants that sink their roots to or below the capillary fringe and use ground water. In many areas the growth of these plants is quite dense and they use thousands of acre-feet of ground water each year. Several studies are being conducted on the possible salvage of water by eradication of these plants.

In some basins ground water is discharged as underflow to downstream basins through permeable materials underlying stream channels, or through the saturated material lying between the hard-rock barriers that separate the basins.

Some ground water may be discharged by effluent seepage into stream channels where the water table intersects the stream bed. Ground water provides the base flow of some streams, and during periods of high runoff these same streams may supply water to the ground-water reservoir.

Ground water is discharged by springs where the water table intersects the land surface or where water from deep artesian aquifers finds an outlet through fractures or fault zones.

Artificial Discharge of Ground Water

Large amounts of ground water are withdrawn from the aquifers in the alluvial basins in southern Arizona by means of pumping from wells. Individual well discharges range from only a few gallons per minute for small domestic and stock wells equipped with windmills to several thousand gallons per minute for many of the large irrigation wells equipped with large pumps powered by electricity or natural gas. Some flowing wells provide small supplies of water, but in many instances, because of the decline of water levels, artesian wells are now equipped with pumps to obtain sufficient water. With slight variations, the annual withdrawal of ground water in Arizona has been about 4-½ million acre-feet for the last 9 years. These large withdrawals of ground water have resulted in declining water levels in the highly developed basins, indicating that a large part of the water is being withdrawn from ground-water storage in the basins—that is, the withdrawal is in excess of the replenishment.

Surface-Water Runoff, Storage, and Diversions

By

D. D. Lewis

The Surface Water Branch, U. S. Geological Survey, reports that runoff of Arizona streams was below normal at all key gaging stations during the entire 1961 water year, with only occasional exceptions. This continued the trend of the last half of the 1960 water year. Runoff was deficient (in the lower quartile) at each key gaging station in at least half the months of the 1961 water year. Monthly mean discharges of the Little Colorado River and the Verde River were record-low for the month in January and February. Yearly mean discharge of the Salt River near Roosevelt was record-low; records are continuous since 1913.

Following is a list of key gaging stations with yearly mean discharge for the 1961 water year and its relation to the normal or median discharge, based on the period 1931-60.

Station	Discharge (acre-feet)	Percent median
Colorado River near Grand Canyon . . .	7,050,000	62
Little Colorado River near Cameron . .	38,780	23
Gila River at head of Safford Valley, near Solomon	90,410	44
Salt River near Roosevelt	170,700	44
Verde River below Tangle Creek, above Horseshoe Dam	164,200	57
San Pedro River at Charleston	22,390	62

Storage in principal reservoirs in Arizona as of March 31, 1962, is shown below, compared with the storage the previous year.

Reservoir	Contents, in acre-feet March 31, 1962	March 31, 1961
Lake Pleasant	17,970	26,620
Verde River system.	103,900	45,790
San Carlos Reservoir	154,100	317
Salt River system	1,118,000	1,140,000

In recent years construction of stock ponds by private and public agencies has increased rapidly. Although no known inventory exists, it is believed that there are many hundreds of stock ponds in Arizona. Individual ponds are of small capacity, but their combined effect on the hydrology of the river basins in the State is considerable.

Total diversion of streamflow to Arizona lands during the 1961 water year exceeded 2,300,000 acre-feet. About 1,600,000 acre-feet was diverted from the Colorado River for use by the Colorado River Indian Reservation, the Gila Project, and the Valley Division of the Yuma Project. These projects use only surface water for irrigation. About 600,000 acre-feet of the water diverted from the Colorado River was returned to the river or discharged across the Arizona-Sonora boundary.

About 700,000 acre-feet of water was diverted from the Gila River basin during the 1961 water year. Of this amount, 624,800 acre-feet was diverted from the Salt River at Granite Reef Dam. The other significant surface-water diversions are in the Duncan-Safford areas and for the San Carlos Project. Each of these is used in combination with ground water.

Figure 3 shows a comparison of diversions and reservoir storage with similar data for previous years.

GROUND-WATER CONDITIONS BY AREAS

By

Natalie D. White

When a well is drilled in an area and ground water is withdrawn, the water levels in the vicinity of the well are drawn down creating a cone of depression in the water table that allows water to flow into the well. As more water is withdrawn from the well, the cone deepens and expands. As more wells are drilled in an area the cones of depression begin to overlap causing interference between wells and eventually resulting in regional dewatering of the aquifer. If recharge to the aquifer is insufficient to compensate for the amount of water being withdrawn, the process of dewatering will continue until the aquifer is depleted. In many of the developed areas in Arizona the amount of ground water being withdrawn is significantly larger than the amount being added to the aquifers and the ground-water reservoirs are said to be operating on a depletion cycle. The steady decline of water levels over a period of years is evidence of this depletion.

The periodic measurement of water levels and an analysis of the trend of rise or decline are important parts of an overall appraisal of the ground-water conditions in a basin. To obtain consistent results in the analysis of the water-level trends, it is necessary to measure the

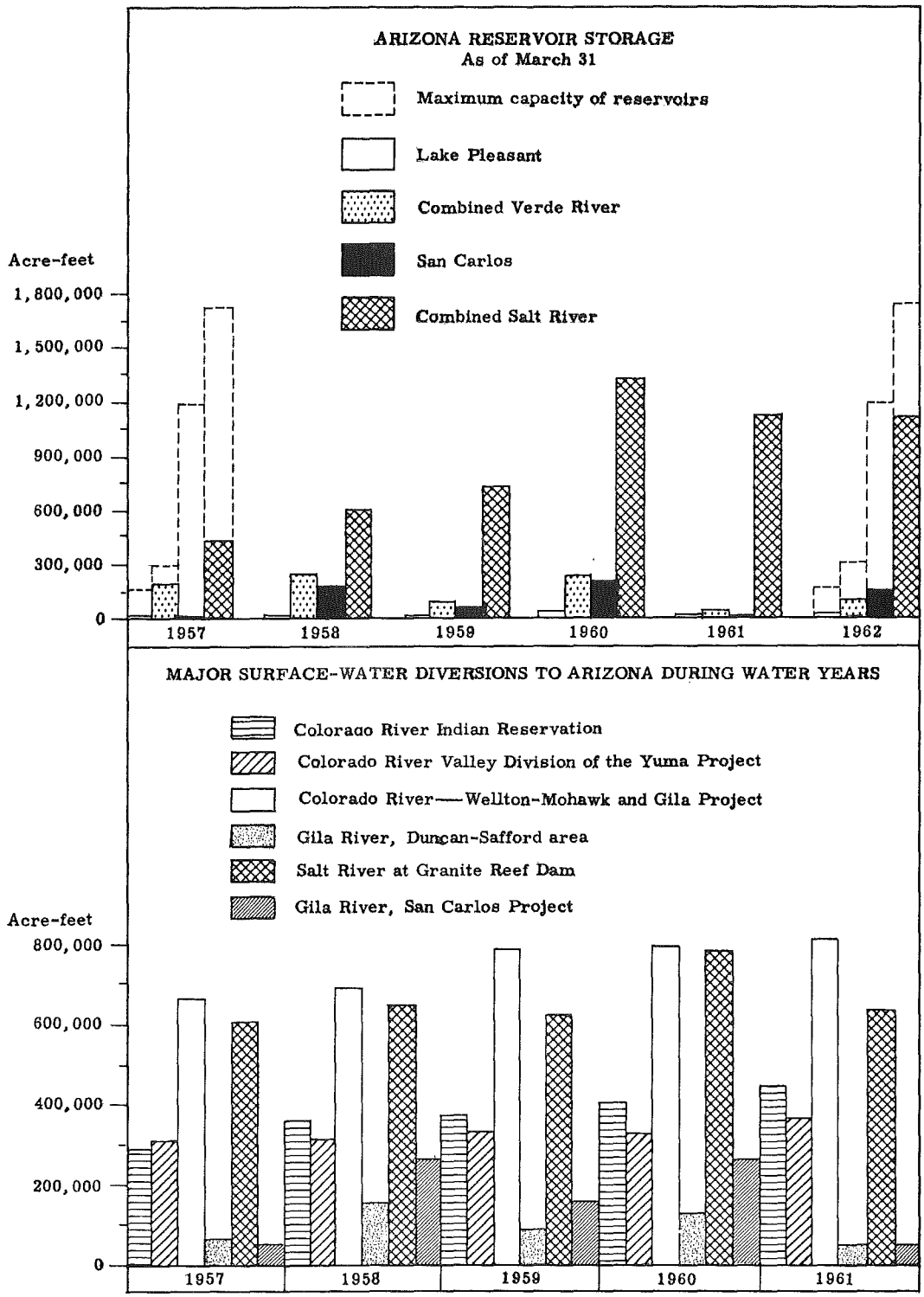


Figure 3. —Surface-water reservoir storage and diversions in Arizona.

water levels in a basin at about the same time each year. The Geological Survey makes extensive water-level measurements during the first 3 months of each year when pumping is at a minimum and water levels are recovering from the previous year's pumping and are approaching more stable conditions. Other measurements made throughout the year and data from continuous water-stage recorders at strategic points throughout the State help to establish the trend of the water levels in relation to the pumping regimen.

Arizona may be divided into three water provinces which are synonymous with the physiographic provinces: (1) the Basin and Range lowlands in the southern part of the State; (2) the Plateau uplands in the northern part of the State; and (3) the Central highlands, which, in part, are transitional between the other two provinces.

Each of these provinces has certain distinctive ground-water characteristics and ground water occurs under different geologic conditions. The Basin and Range lowlands consist of broad, gently sloping valleys and basins and high, isolated mountain ranges that rise sharply above them. For the most part, the basins are filled with alluvial materials ranging up to several thousand feet in thickness. The unconsolidated or weakly consolidated sediments within this alluvium store large amounts of ground water and yield it readily to wells. In the Plateau uplands province, water-bearing sandstones constitute a large storage reservoir for ground water, but well yields generally are small because the rocks are fine grained and do not transmit water freely. However, in a few areas faults and fractures increase the permeability of the formation, permitting water to move more freely, and well yields are large. The Central highlands consist mostly of rugged mountain masses made up of indurated igneous, metamorphic, and crystalline rocks, and well-consolidated sedimentary rocks. These materials contain little space for the storage of ground water. Small amounts of ground water are stored in fractured and faulted zones; where the fractures are at the surface, ground water issues as springs. A few small valleys between the mountains contain varying thicknesses of alluvial sediments that store some ground water.

Figures 4 and 5 show outlines of the three water provinces, and give generalized pictures of the amount of ground water pumped and the average change in ground-water levels in Arizona for the period 1940-60, respectively. Comparison of the two illustrations shows that water-level declines are greatest in the areas of greastest pumping.

The following paragraphs discuss the current ground-water conditions in the major developed basins and areas in each of the water provinces. Figure 6 outlines the various basins and areas, and table 3 is an index to locate the basins by counties.

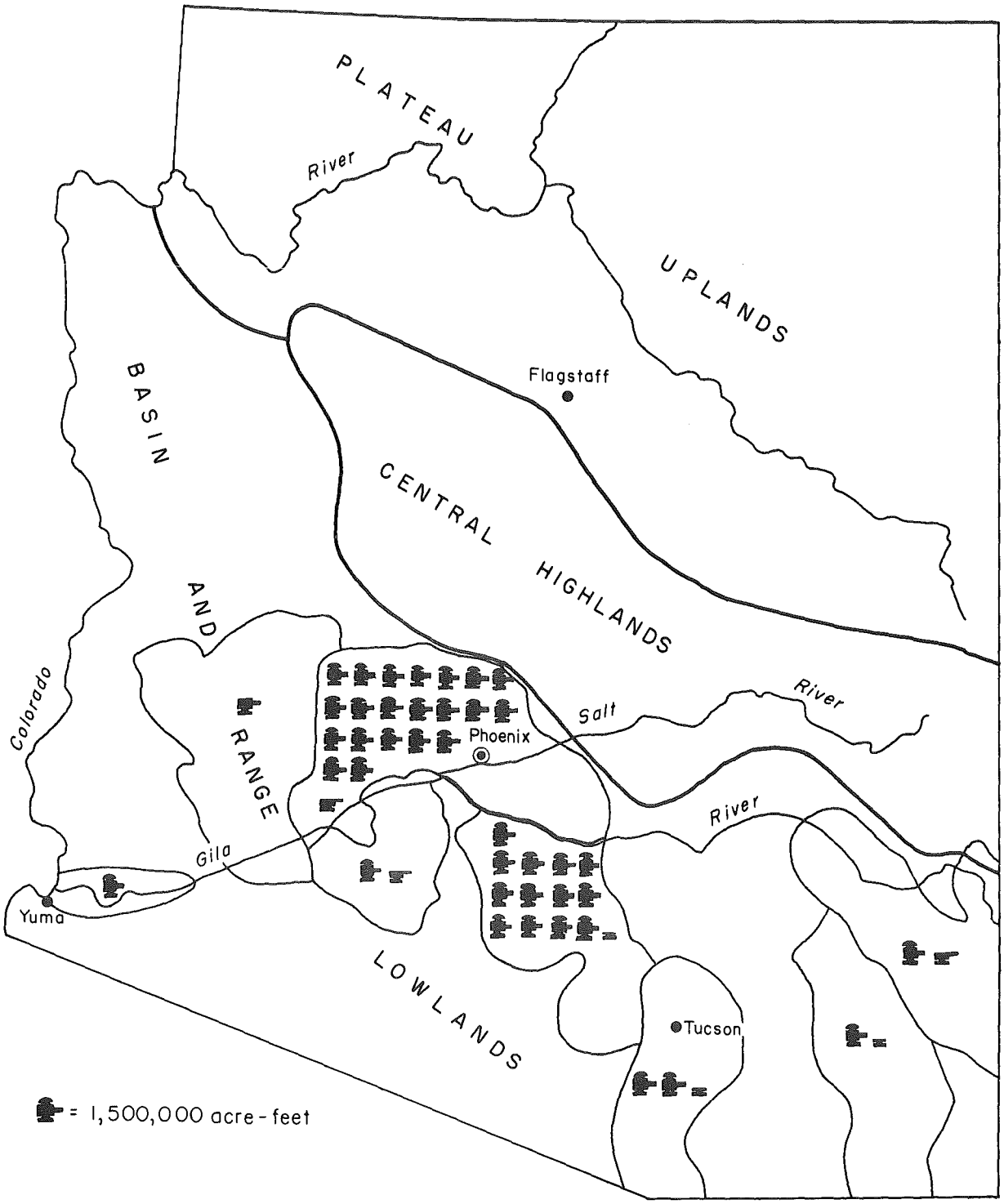


Figure 4.--Ground-water pumpage in Arizona, 1940-60, inclusive.

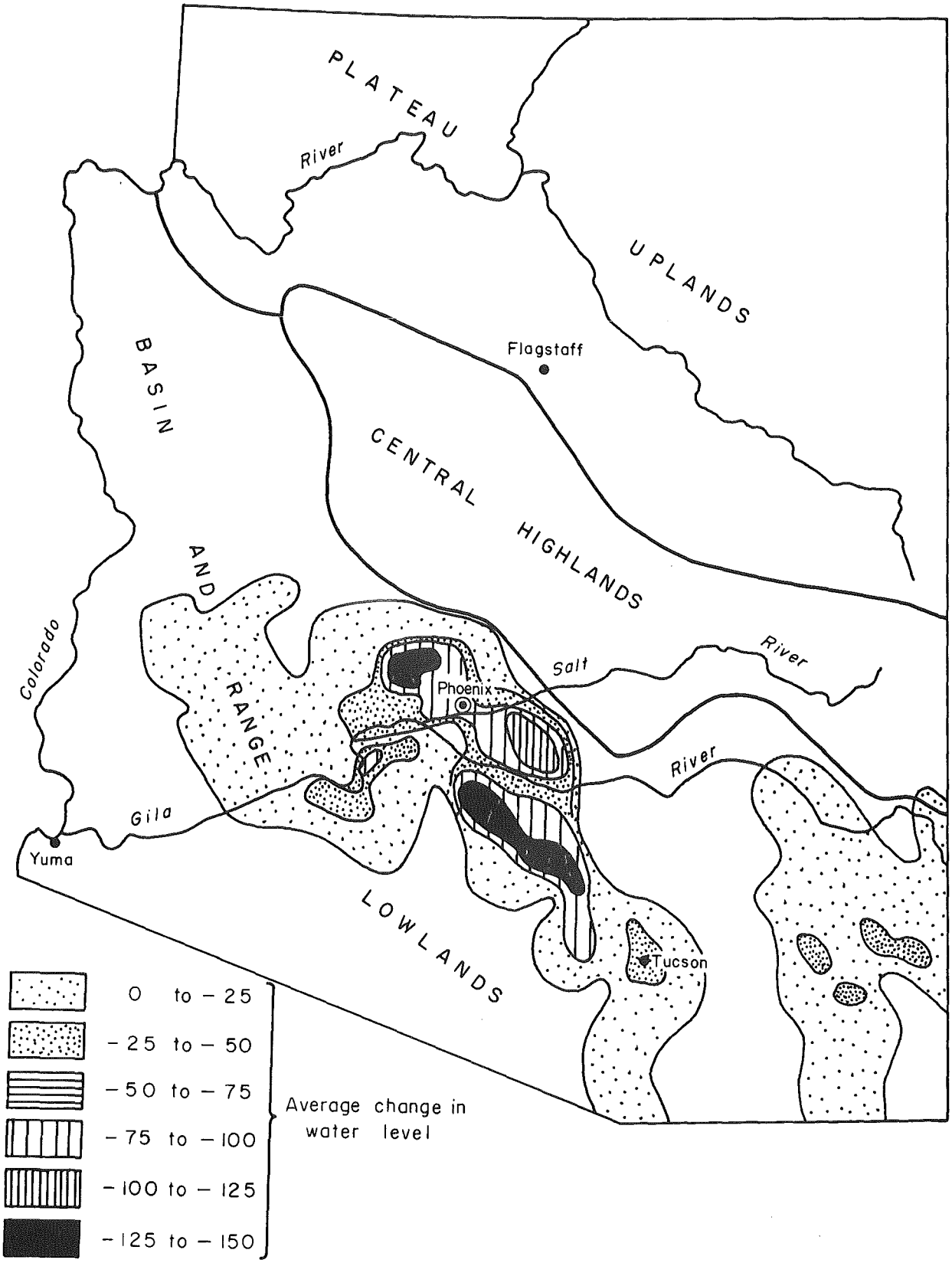
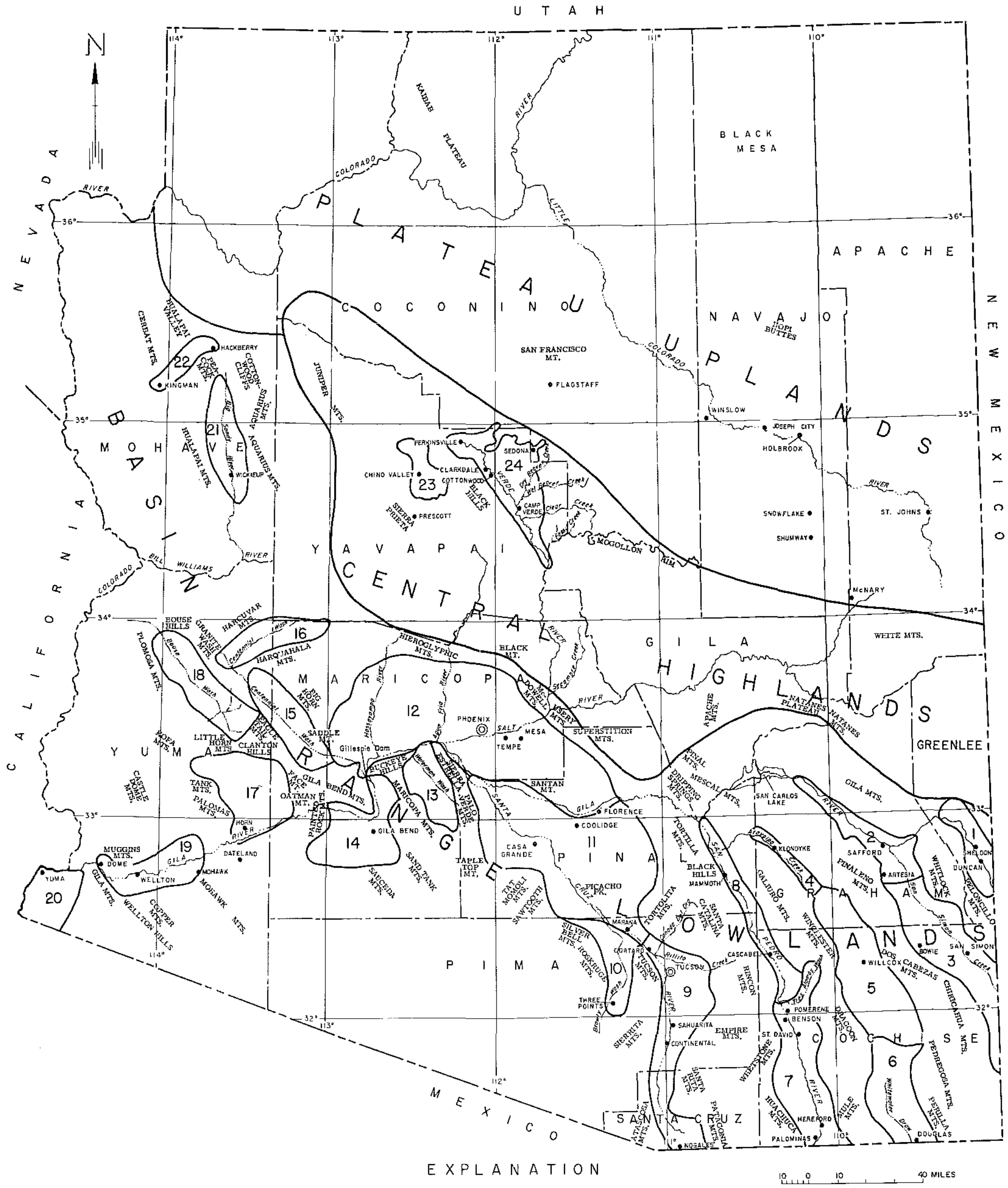


Figure 5. --Approximate average change in water levels in developed basins in Arizona, 1940-60, inclusive.



EXPLANATION

BASINS AND AREAS

1. DUNCAN BASIN
2. SAFFORD BASIN
3. SAN SIMON BASIN
4. ARAVAIPA VALLEY
5. WILLCOX BASIN
6. DOUGLAS BASIN
7. UPPER SAN PEDRO BASIN
8. LOWER SAN PEDRO BASIN
9. UPPER SANTA CRUZ BASIN
10. AVRA-MARANA AREA
11. LOWER SANTA CRUZ BASIN AND ADJACENT AREA ALONG GILA RIVER
12. SALT RIVER VALLEY
13. WATERMAN WASH AREA
14. GILA BEND AREA
15. HARQUAHALA PLAINS AREA
16. MCMULLEN VALLEY AREA
17. PALOMAS PLAIN AREA
18. RANEGRAS PLAIN AREA
19. WELLTON-MOHAWK AREA
20. SOUTH GILA VALLEY, YUMA MESA, AND YUMA VALLEY AREA
21. BIG SANDY VALLEY
22. KINGMAN-HACKBERRY AREA
23. CHINO VALLEY
24. VERDE VALLEY

Figure 6.--Map of Arizona showing basins and areas for which ground-water conditions are discussed.

Table 3.--Index to locate basins and areas by counties

	Number on index map	Page in text
Apache County		100
Cochise County		
San Simon basin	3	44
Bowie area		45
San Simon area		45
Rodeo area		48
Sulphur Spring and Aravaipa Valleys	4, 5, 6	48
Aravaipa Valley	4	50
Willcox basin	5	50
Douglas basin	6	55
San Pedro River Valley	7, 8	57
Upper San Pedro basin	7	57
Lower San Pedro basin	8	60
Coconino County		104
Gila County		111
Graham County		
Safford basin	2	40
Sulphur Spring and Aravaipa Valleys		48
Aravaipa Valley	4	50
Willcox basin	5	50

Table 3.--Index to locate basins and areas by counties—Continued

	Number on index map	Page in text
Greenlee County		
Duncan basin	1	40
Maricopa County		
Salt River Valley	12	80
Queen Creek-Higley-Gilbert-Magma area		80
Tempe-Mesa-Chandler area		85
Phoenix-Glendale-Tolleson-Deer Valley area		87
Paradise Valley area		87
Litchfield Park-Beardsley-Marinette area		89
Liberty-Buckeye-Hassayampa area		89
Lower Hassayampa-Tonopah area		91
Lower Centennial area		91
Waterman Wash area	13	91
Gila Bend area	14	92
Harquahala Plains area	15	94
McMullen Valley area	16	94
Palomas Plain area	17	95

Table 3. --Index to locate basins and areas by counties—Continued

	Number on index map	Page in text
Mohave County		
Big Sandy Valley	21	98
Kingman-Hackberry area	22	99
Navajo County		102
Pima County		
Upper Santa Cruz basin	9	61
Cortaro-Canada del Oro area		61
Tucson area		62
Sahuarita-Continental area		64
Avra-Marana area	10	66
Pinal County		
Lower Santa Cruz basin and adjacent area along the Gila River	11	71
Eloy area		72
Casa Grande-Florence area		75
Stanfield-Maricopa area		77
Salt River Valley	12	80
Queen Creek-Higley-Gilbert-Magma area		80
San Pedro River Valley		57
Lower San Pedro basin	8	60

Table 3. --Index to locate basins and areas by counties—Continued

	Number on index map	Page in text
Santa Cruz County		
Upper Santa Cruz basin	9	61
Santa Cruz County area		66
Yavapai County		
Chino Valley	23	106
Verde Valley	24	109
Yuma County		
Harquahala Plains area	15	94
McMullen Valley area	16	94
Palomas Plain area	17	95
Ranegras Plain area	18	96
Wellton-Mohawk area	19	96
South Gila Valley, Yuma Mesa, and Yuma Valley area	20	97

Basin and Range Lowlands Province

By

Natalie D. White

During the last few decades there has been extensive development of the water supply in the Basin and Range lowlands province. About 80 percent of the population and more than 90 percent of the irrigated acreage are concentrated in this province which makes up about 45 percent of the total area of the State. The vast reserves of ground water are being depleted because the current annual rate of recharge to the ground-water reservoirs is negligible in comparison to the large amounts of ground water withdrawn each year.

The trend of the water levels in nearly all the highly developed areas in the Basin and Range lowlands province continued downward in 1961. The following paragraphs give discussions of the ground-water conditions in all the developed areas in the province by basins and areas beginning on the eastern edge of the State. Figure 6 is an index map showing the locations of the basins discussed.

Duncan Basin

By

E. S. Davidson

Ground-water development in the Duncan basin (fig. 6, No. 1) in Greenlee County has been limited to the flood plain of the Gila River. Measurement of water levels in eight observation wells shows a general rise in water levels of from 1 to 4 feet from spring 1961 to spring 1962. The water level rose about a foot in well (D-8-32)32 near Franklin, and about 4 feet in well (D-7-31)4 north of Sheldon (fig. 7). The general overall rise is about 2 feet in the Virden-Duncan part of the valley, and may be as much as 4 feet in the York-Sheldon part.

Pumping during the 1962 growing season is not expected to produce any significant decline of water levels, and if the flow of the Gila River remains above average the water table may continue the general rise dated from 1957.

Safford Basin

By

E. S. Davidson

The major part of the land irrigated by ground water in Safford basin (fig. 6, No. 2) lies along the course of the Gila River, generally in the flood plain of the river. In addition, some ground water is used for irrigation in the Artesia area a few miles south of the town of Safford.

Low flow of the Gila River in the irrigation season of 1961 produced some of the lowest summer and fall water-table levels in the Safford basin since 1956-57. Fortunately, capricious southwest precipitation produced more Gila River flow during the 3-month period January through March 1962 than the total annual flow in 1961—with the result that despite low flow in 1961-62, spring water levels are 2 to 4 feet higher than in the spring of 1961.

The materials underlying the flood plain of the Gila River constitute the principal developed aquifer in the Safford basin at this time. This

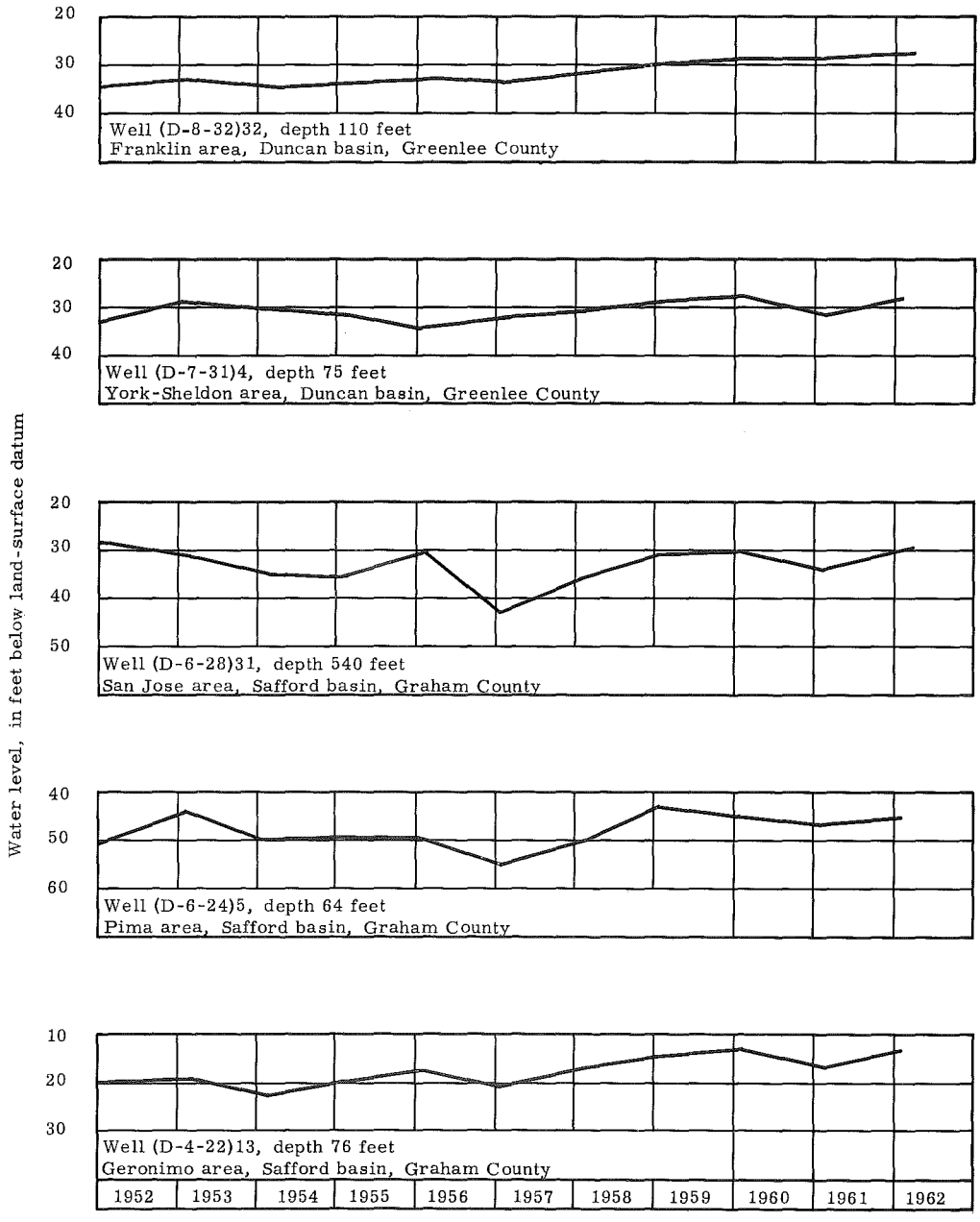


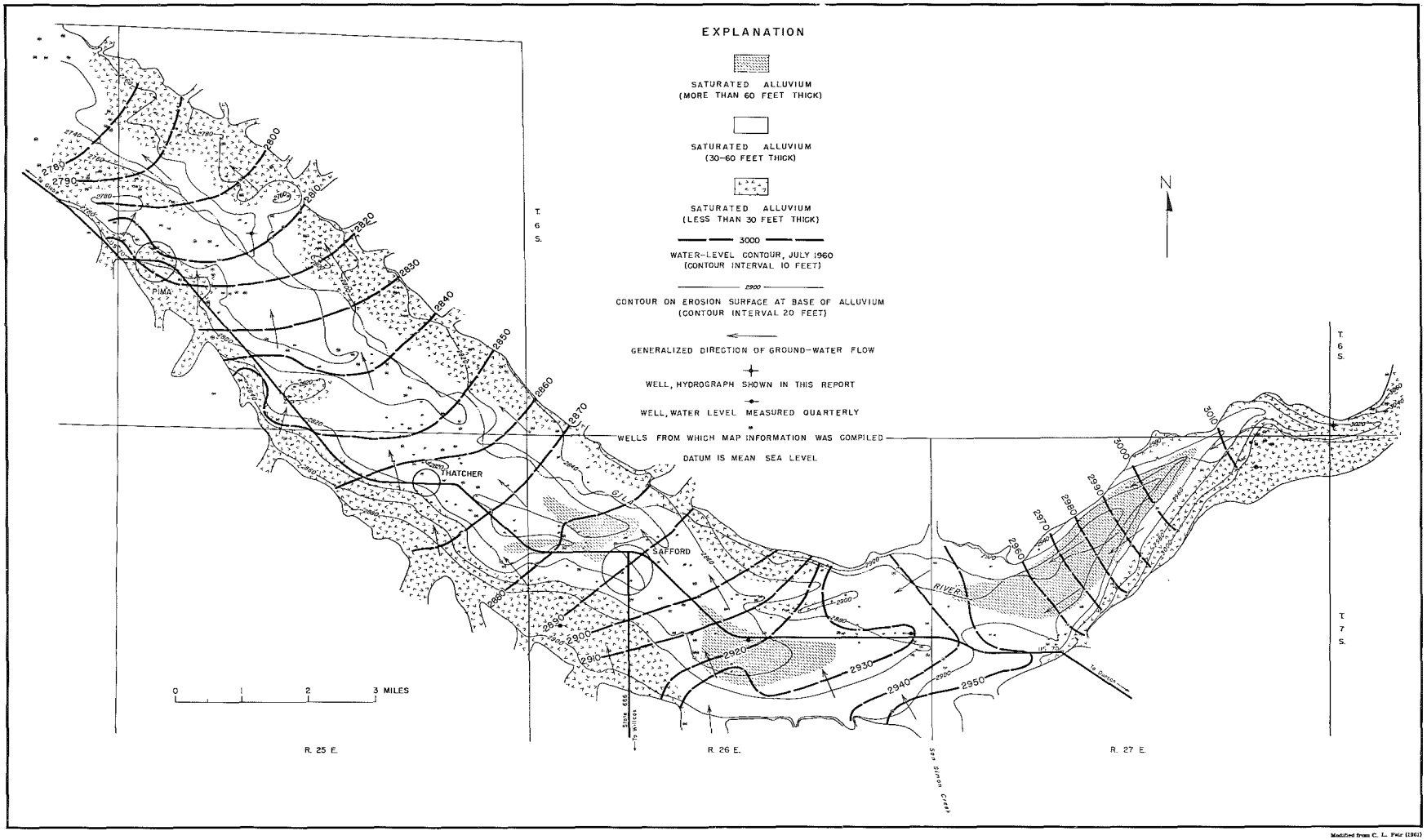
Figure 7. —Water levels in selected wells, Duncan and Safford basins.

aquifer is about 100 feet thick near Safford and thins to 40 or 50 feet thick near Pima and downstream. The alluvium of the aquifer consists of highly permeable gravel and sand in most places, and rests on a practically impermeable silt and clay portion of the "basin-fill" sediments which fill the entire Safford basin from the Gila to the Pinaleno Mountains. Figure 8 shows some features of the alluvium of the Gila River flood plain most pertinent to ground-water storage and use. Contours, or lines of equal altitude, of the base of the alluvium of the Gila River flood plain show the shape of the base and thus picture the deepest and shallowest parts of this important aquifer. The approximate altitude of the water table in July 1960 is contoured also. Arrows on the map show the general direction of ground-water flow. Ground water in the northern part of the alluvium moves directly downstream, but in much of the southern part of the alluvium it moves to the northwest, or in a cross-stream direction. This movement indicates that, in addition to ground-water recharge to the alluvium from the Gila River and irrigation canals, a considerable amount of ground water moves into the alluvium from sediments in the San Simon basin and in the area between the Pinaleno Mountains and the Gila River. The inflow of ground water from the south enters all along the course of the Gila River and is not channeled entirely in beds of the large washes tributary to the Gila, although the beds of the large washes probably carry a large part of the inflow. Because the movement of ground water in the northern part of the alluvium is predominantly downstream, a very small to negligible amount of ground water enters the alluvium of the Gila River flood plain from sediments between the Gila Mountains and the Gila River.

Water levels in the wells penetrating the alluvial fill of the Gila River flood plain generally rose about 2 feet from spring 1961 to spring 1962. Hydrographs of wells (D-6-28)31 near San Jose, (D-6-24)5 near Cork, and (D-4-22)13 near Geronimo, all show this trend (fig. 7). This rise in water levels from 1961 to 1962 is part of a general 5-year rise in levels that started in 1957 when water levels in the Gila River alluvium reached their lowest point in recent years. Water levels range from 15 to 50 feet below land surface; in general, the water table is nearer the surface in the vicinity of the Gila River, but there are exceptions.

Artesian water for irrigation in the Gila River flood plain is produced from aquifers not directly connected hydraulically with the flood-plain alluvium; but, as noted in the 1961 report, these waters contain moderate to very high amounts of total solids injurious to soils for crop use and are not extensively used for irrigation in the area.

In the Artesia area south of Safford water levels rose slightly, and west of Cactus Flat the water level in one well which taps artesian aquifers rose 10 feet from spring 1961 to spring 1962. Essentially unchanged conditions from the spring of 1961 or a rise of about a foot seems to be the rule in this area, however. In the last 5 years, water levels in the few measured wells have declined several feet, but the sample of measured wells may not be adequate to define the regional trend in the area. Most wells in the Artesia area are flowing, but



Modified from C. L. Fair (1961)

Figure 8.--Outline of Gila River flood plain, Graham County, Ariz., showing configuration of base of alluvium, water-level altitudes, and thickness of saturated alluvium.

some of these wells cease to flow in the summer due to cones of depression formed by heavy pumping of nearby wells for irrigation water. Water levels in the few nonflowing wells ranged from a few feet to about 60 feet below land surface in the spring of 1962.

Gila River streamflow during the winter of 1961 and spring of 1962 was above average, and thus considerable surface water is available for irrigation use on Gila River flood-plain cropland in the Safford basin. The estimated 1962 summer pumpage is not expected to produce more than moderate declines in the water table, and these declines probably will be counterbalanced by recharge from Gila River flow in the winter of 1962.

San Simon Basin

By

Natalie D. White

The San Simon basin (fig. 6, No. 3), in the southeast corner of Arizona, is part of a structural trough that extends northwestward from about Rodeo, New Mexico, to Globe, Arizona. It is bounded on the southwest and west by the Chiricahua, Dos Cabezas, and Pinaleno Mountains, and on the east by the Peloncillo Mountains, which extend southeastward into New Mexico. To the north, the San Simon basin merges with the Safford basin. The area is drained by San Simon Creek which enters the upper or south end of the valley in New Mexico at an altitude of about 4,000 feet and flows into the Gila River in the Safford basin near Solomon at an altitude of about 3,000 feet. The gradient of the valley is about 20 feet per mile; on the sides of the valley the slopes are much greater, and gradients of more than 100 feet per mile are common.

Nearly all the deposits in the San Simon basin are classified as older alluvial fill and have been divided into four geologic units—the "lower unit," the "blue clay unit," the "upper unit," and the "marginal zone." Hydrologically, the lower unit constitutes the "lower aquifer," and the saturated part of the upper unit constitutes the "upper aquifer." Ground water is under artesian conditions in the lower aquifer and under water-table conditions in the upper aquifer and in the marginal zone where the lower and upper aquifers form a hydrologic unit. The movement of ground water in the basin generally is from the bordering mountain ranges toward the axis of the valley and along the axis from southeast to northwest. The major source of recharge to the aquifers probably is seepage from ephemeral streams near the mountain fronts.

There are two major areas of development in the basin: (1) the Bowie area, centered around the town of Bowie on the west side of the basin about 3 miles from the base of the Dos Cabezas Mountains; and (2) the San Simon area, centered around the town of San Simon near San Simon Creek on the east side of the basin. Another smaller area

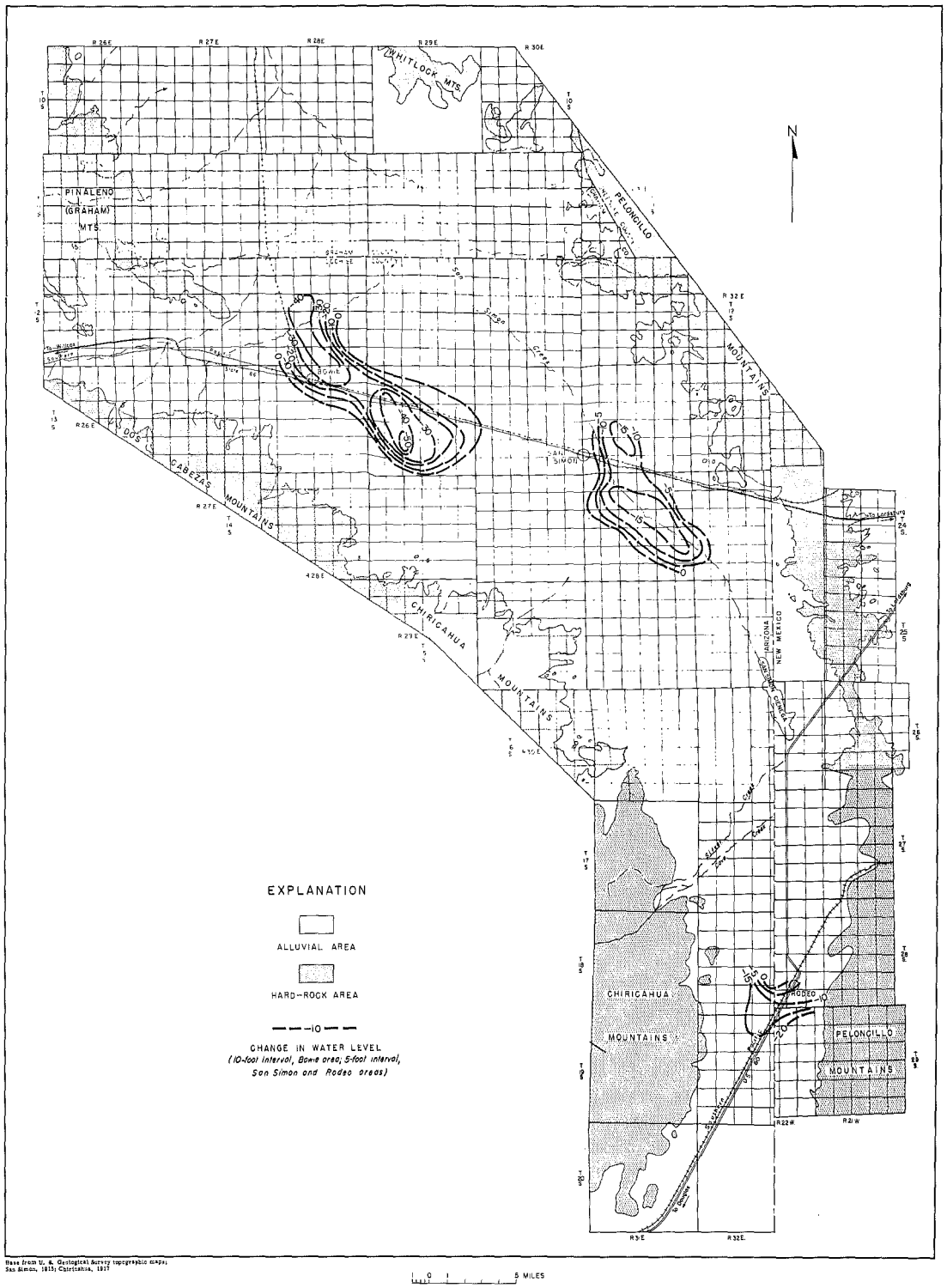
of development is on the Arizona-New Mexico State line near the town of Rodeo, N. Mex.

Bowie area.--In the Bowie area, the water levels in the artesian wells ranged from about 105 to 180 feet, and averaged about 150 feet below land surface in the spring of 1962. Water-level fluctuations in these wells ranged from slight rises to declines of nearly 12 feet in the period spring 1961 to spring 1962; for the period spring 1957 to spring 1962 water-level declines ranged from less than half a foot to more than 50 feet (fig. 9). The average decline in the Bowie area was about 5 feet for the period spring 1961 to spring 1962 and about 35 feet for the 5-year period spring 1957 to spring 1962. The water level in well (D-13-29)18 (fig. 10) declined nearly 12 feet from spring 1961 to spring 1962, about 43 feet during the 5-year period spring 1957 to spring 1962, and about 105 feet since spring 1952.

In the undeveloped area between Bowie and San Simon, the water level in the artesian wells is somewhat shallower than in the two areas of development. The water level was only 13 feet below land surface in an artesian well about 9 miles southeast of Bowie in the spring of 1962. However, this well was flowing in spring 1957—indicating a decline in artesian pressure of at least 13 feet in the 5-year period spring 1957 to spring 1962 (fig. 9). The decline may be due partly to the pumping of these wells only and partly to the spread of the cone of depression caused by pumping in the developed area.

Several wells have been drilled in the marginal zone in the area a few miles south of Bowie. The water level, measured in four of these wells in the spring of 1962, ranged from slightly more than 260 to nearly 360 feet below land surface. Water-level declines in these wells ranged from less than 10 to nearly 20 feet from spring 1961 to spring 1962; in the 5-year period spring 1957 to spring 1962, water-level declines ranged from about 40 to more than 65 feet. The water level in well (D-13-28)16 (fig. 10) declined about 7 feet from spring 1961 to spring 1962 and more than 60 feet in the period spring 1957 to spring 1962. The hydrograph (fig. 10) shows that the water level in this well fluctuates erratically, although the general trend is downward; this pattern seems to predominate in the wells in this area. There are no shallow water-table wells in the Bowie area.

San Simon area.--The depth to water in the artesian wells in the San Simon area ranged from about 25 to 80 feet below land surface in the spring of 1962; the average depth to water in the area was about 55 feet. Water-level fluctuations ranged from a rise of nearly 4 feet to a decline of nearly 15 feet for the period spring 1961 to spring 1962; the average change in water level during this period was a decline of about 3 feet. In the 5-year period spring 1957 to spring 1962 (fig. 9) water-level fluctuations ranged from a rise of about 4 feet to a decline of about 24 feet and averaged about 10 feet of decline. The water level in artesian well (D-14-31)3 (fig. 10) declined about a foot from spring



Base from U. S. Geological Survey topographic maps, San Simon, 1915; Chiricahua, 1917

Figure 9-- Map of San Simon basin, Cochise and Graham Counties, Ariz., showing change in ground-water level from spring 1957 to spring 1962.

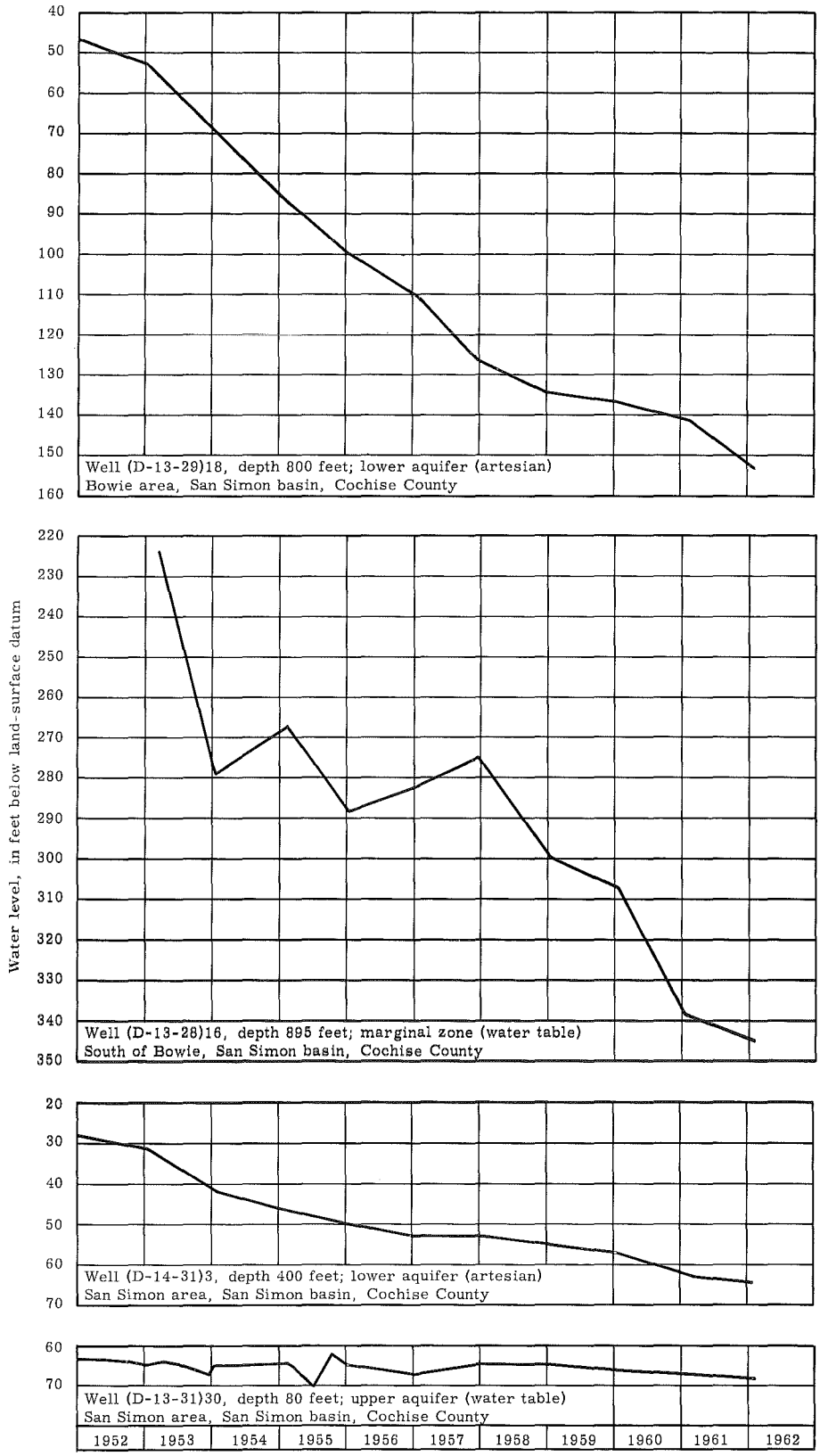


Figure 10. —Water levels in selected wells in the San Simon basin.

1961 to spring 1962, nearly 12 feet in the period spring 1957 to spring 1962, and about 36 feet since spring 1952.

The water level was measured in only three of the water-table wells in the San Simon area in spring 1962. The depth to water in these wells averaged about 65 feet below land surface and water-level fluctuations ranged from a rise of about 2 feet to a decline of about 2 feet in the period spring 1961 to spring 1962. In the period spring 1957 to spring 1962, water-level fluctuations ranged from a rise of about 6 feet to less than half a foot of decline. The water level in well (D-13-31)30 (fig. 10) declined about 1-½ feet from spring 1961 to spring 1962, less than half a foot from spring 1957 to spring 1962, and about 5 feet since the spring of 1952.

Rodeo area.--The development of ground water for irrigation is comparatively minor in this area; nevertheless there has been some decline in the water level as a result of the withdrawal of water in excess of the rate of replenishment. The water level, measured in 10 wells in this area, ranged from about 105 to 150 feet below land surface in the spring of 1962; the average depth to water was about 130 feet. Water-level fluctuations in the area ranged from no change to a decline of nearly 7 feet from spring 1961 to spring 1962. In the 5-year period spring 1957 to spring 1962 water-level fluctuations ranged from a rise of about a foot to a decline of about 20 feet (fig. 9). The water level in well (D-18-32)11 (fig. 11) about 2-½ miles north of the developed area near Rodeo declined less than half a foot from spring 1961 to spring 1962, and rose about 2-½ feet from spring 1957 to spring 1962. The water level in this well probably fluctuates only in response to its own pumping. Well (D-17-31)25 (fig. 11) is near two intermittent streams; the seemingly erratic fluctuations of the water level probably are the result of recharge—indicated by rising water levels—when the creeks are flowing and of the pumping of the well in dry periods—indicated by declining water levels.

Sulphur Spring and Aravaipa Valleys

By

S. G. Brown

The trough occupied by the Sulphur Spring and Aravaipa Valleys (fig. 6, Nos. 4, 5, and 6) is bordered by two parallel mountain chains which extend from the Gila River on the north to Mexico on the south. The east side of the trough is bordered by the Pinaleno, Graham, Dos Cabezas, Chiricahua, Pedregosa, and Perilla Mountains. The west side is bordered by the Galiuro, Winchester, Little Dragoon, Dragoon, and Mule Mountains. The mountains bordering the east side are higher than those on the west. The trough is divisible into three areas: (1) Aravaipa Valley (fig. 6, No. 4), which drains northwestward 44 miles

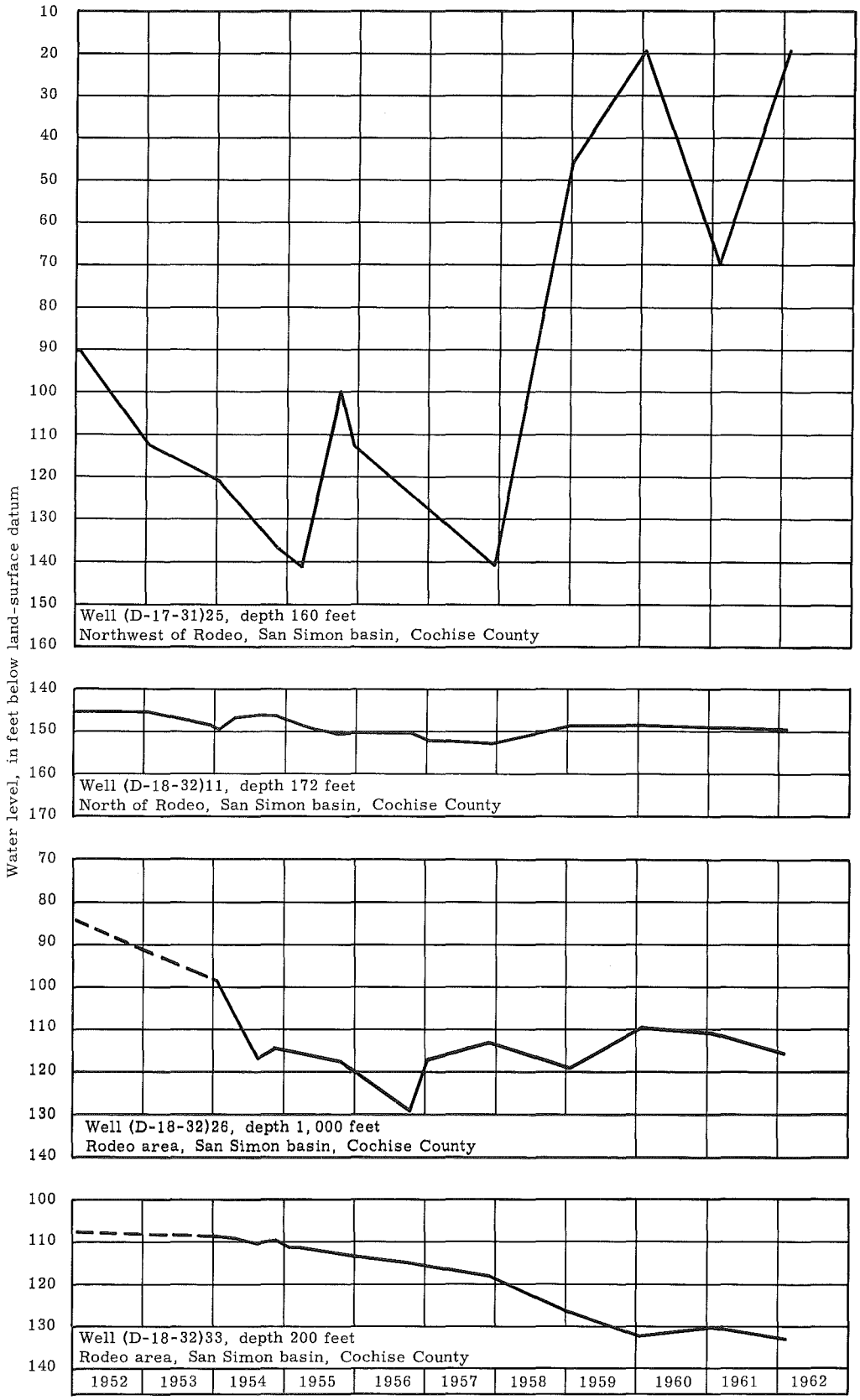


Figure 11. —Water levels in selected wells in the southern part of the San Simon basin.

to the San Pedro River about 15 miles upstream from the confluence of the San Pedro and Gila Rivers, and is structurally a continuation of the main Sulphur Spring Valley (fig. 6, Nos. 5 and 6); (2) Willcox basin (fig. 6, No. 5), a basin of interior drainage, which occupies the northern three-fifths of the Sulphur Spring Valley; and (3) Douglas basin (fig. 6, No. 6), occupying the southern two-fifths of the Sulphur Spring Valley. Douglas basin is drained by Whitewater Draw which is tributary to the Yaqui River in Mexico. From the headwaters of Aravaipa Creek to the International Boundary along the axis of the Sulphur Spring Valley is a distance of about 90 miles. The long trough, occupied by Sulphur Spring Valley and Aravaipa Creek, and the mountain areas tributary to it comprise an area of more than 3,300 square miles. Ground-water conditions in each of these three areas will be discussed separately below.

Aravaipa Valley.--Depth to water has been measured regularly since 1949 in five wells in the upper Aravaipa Valley (fig. 6, No. 4) between Klondyke and the headwaters of Aravaipa Creek. Hydrographs of four of these wells are shown in figure 12. These wells are situated as follows: (D-9-22)19 in the headwaters area of Aravaipa Creek, a short distance northwest of the surface divide between Willcox basin and Aravaipa Creek drainage; (D-8-21)18, 6 miles southeast of Klondyke; (D-6-19)35, 4-½ miles northwest of Klondyke; and (D-9-21)11, 9 miles southeast of Klondyke. Comparison of the four hydrographs (fig. 12) shows that in wells (D-6-19)35, (D-8-21)18, and (D-9-21)11 water levels have risen since 1957. Water levels in well (D-9-22)19 do not show this trend; however, the water-level measurements may reflect, in part, the intermittent pumping of the well for stock water. From 1961 to 1962 the water level in five observation wells in upper Aravaipa Creek basin rose an average of about 2 feet. Changes in water level from 1961 to 1962 ranged from a decline of nearly 8 feet in well (D-9-22)19 to a rise of about 12-½ feet in well (D-7-20)21. Changes in water level during the 5-year period 1957-62 ranged from a decline of about 9 feet in well (D-9-22)19 to a rise of nearly 15 feet in well (D-7-20)21; the average fluctuation was a rise of about 6 feet.

Water levels in wells in the upper Aravaipa Creek basin respond quickly to recharge from surface runoff in Aravaipa Creek and its tributary canyons to the shallow alluvium tapped by the wells.

Willcox basin.--The Willcox basin (fig. 6, No. 5) in the northern part of the Sulphur Spring Valley extends from the drainage divide at the headwaters of Aravaipa Creek southward to a drainage divide among the buttes and ridges south of the town of Pearce. The altitude of the valley floor ranges from about 4,135 feet at the Willcox playa to about 4,470 feet at the lowest point of the drainage divide at the headwaters of Aravaipa Creek.

There are two main cultivated areas in the Willcox basin—the Stewart area and the Kansas Settlement area. A third area, not as extensively

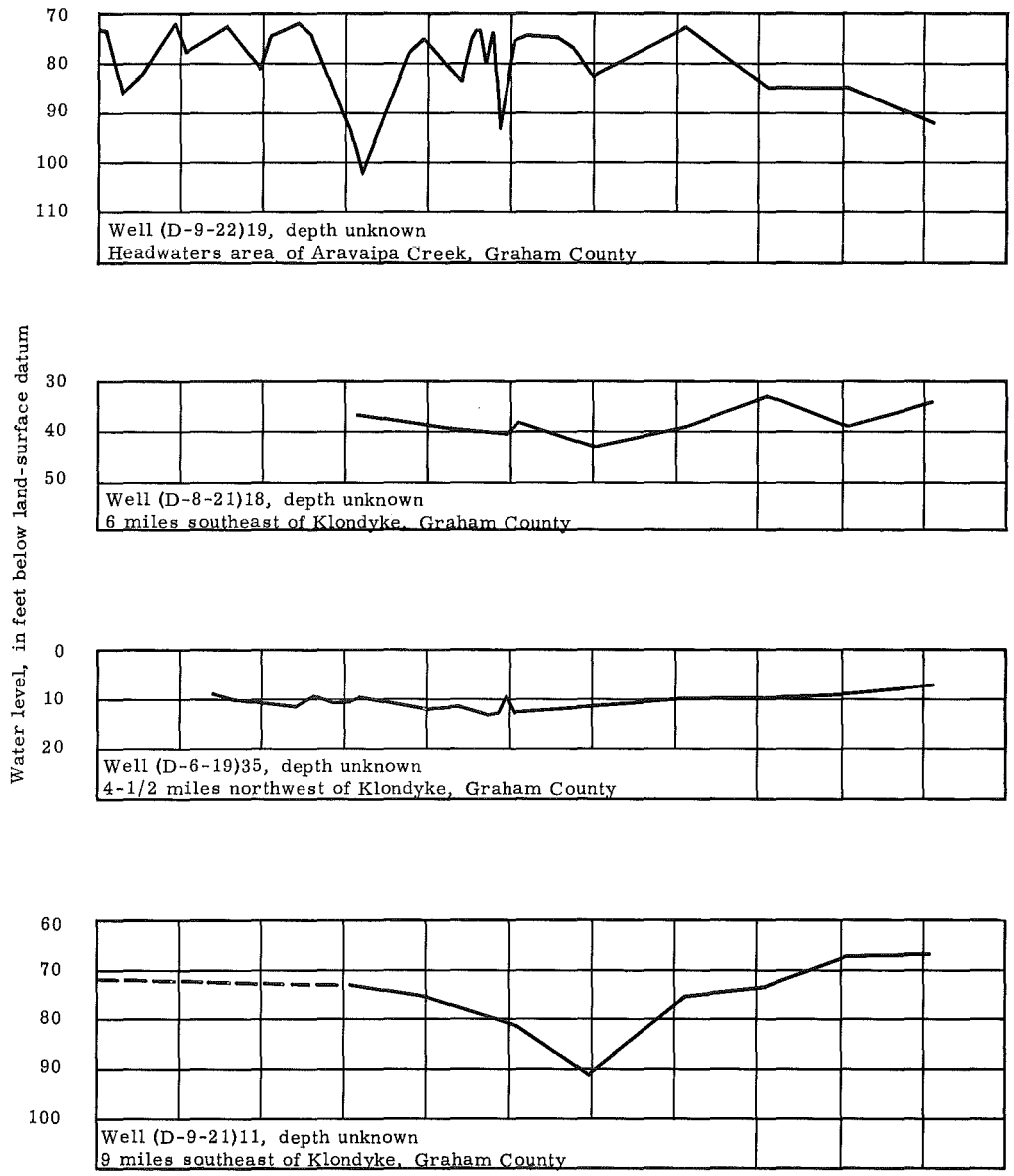


Figure 12.—Water levels in selected wells in Aravaipa Valley.

developed as the Stewart and Kansas Settlement areas, is called the Pearce-Cochise area. Total irrigated acreage amounts to about 20,000 acres in the Stewart area, about 35,000 acres in the Kansas Settlement area, and about 5,000 acres in the Pearce-Cochise area. The natural ground-water gradient in the Willcox basin is toward the playa—a dry lake in about the center of the basin. North of the playa from the divide near Aravaipa Creek the ground-water movement is southward, and south of the playa in the vicinity of Pearce it is northward. Most of the time the playa is dry and occasionally encrusted with white salts; at times it is covered by a shallow body of water derived from runoff. Many years ago, the water table probably was at the surface of the playa. A water-table contour map, based on water-level measurements made in the spring of 1960, shows that the pumping of ground water for irrigation in the Stewart area has caused a deep cone of depression that intercepts all of the underflow that formerly moved to the playa from this area. A similar cone of depression has developed in the Kansas Settlement area. These cones of depression have reduced the amount of subsurface flow to the playa and thereby reduced the loss of water to the atmosphere by evaporation. Continued pumping will reverse the gradient and allow the water beneath the playa to move toward the heavily pumped areas.

In the Stewart area, north of Willcox, water-level fluctuations during the period 1957-62 ranged from a rise of about a foot to a decline of about 20 feet (fig. 13). The average net change in water levels during the 5-year period 1957-62, measured in 27 observation wells, was a decline of nearly 9 feet.

From the spring of 1957 to the spring of 1962, water-level fluctuations in the Kansas Settlement area ranged from rises of 11 to 15 feet in the low-lying area of shallow ground water west of the Kansas Settlement road to declines of more than 80 feet in the center of the area of heavy withdrawal in the north-central part of T. 16 S., R. 26 E. (fig. 13). The average decline in the Kansas Settlement area, as measured in 40 wells, was about 36 feet.

In the Pearce-Cochise area during the period 1957-62, water levels were measured in 10 wells. Fluctuations for the 5-year period ranged from a rise of about 5 feet to a decline of about 12 feet (fig. 13). The average of the fluctuations measured in the 19 wells was a decline of about 4 feet. Pumping in the Pearce-Cochise area is not as concentrated as that in either of the heavily irrigated—Stewart and Kansas Settlement—areas. Hydrographs of depth to water in selected wells in each of the areas mentioned are shown in figure 14.

Since about 1960, interest has developed in three general areas in the Willcox basin for subdivision into small farm and residence lots of only a few acres. Because of this interest and the number of requests received by this office for ground-water data in these three areas, a general outline of ground-water conditions is included here.

The first such area is mainly in the north half of T. 18 S., R. 27 E., and lies on the divide between the Willcox and Douglas basins. In the spring of 1962, the depth to water, measured in five wells, ranged from 94 feet below land surface in sec. 35, T. 17 S., R. 26 E., to 165

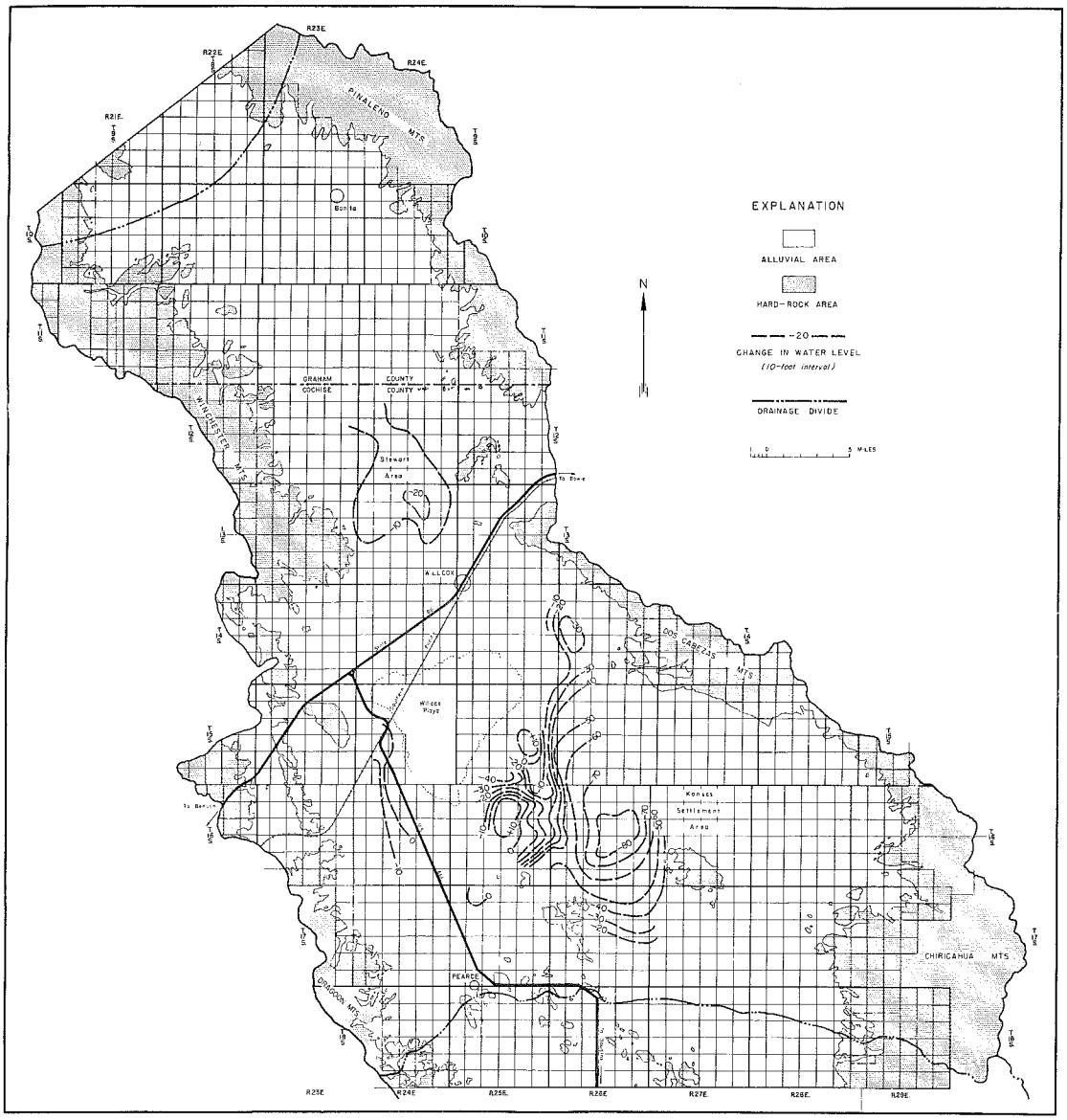


Figure 13.--Map of Willcox basin, Cochise and Graham Counties, Ariz., showing change in ground-water level from spring 1957 to spring 1962.

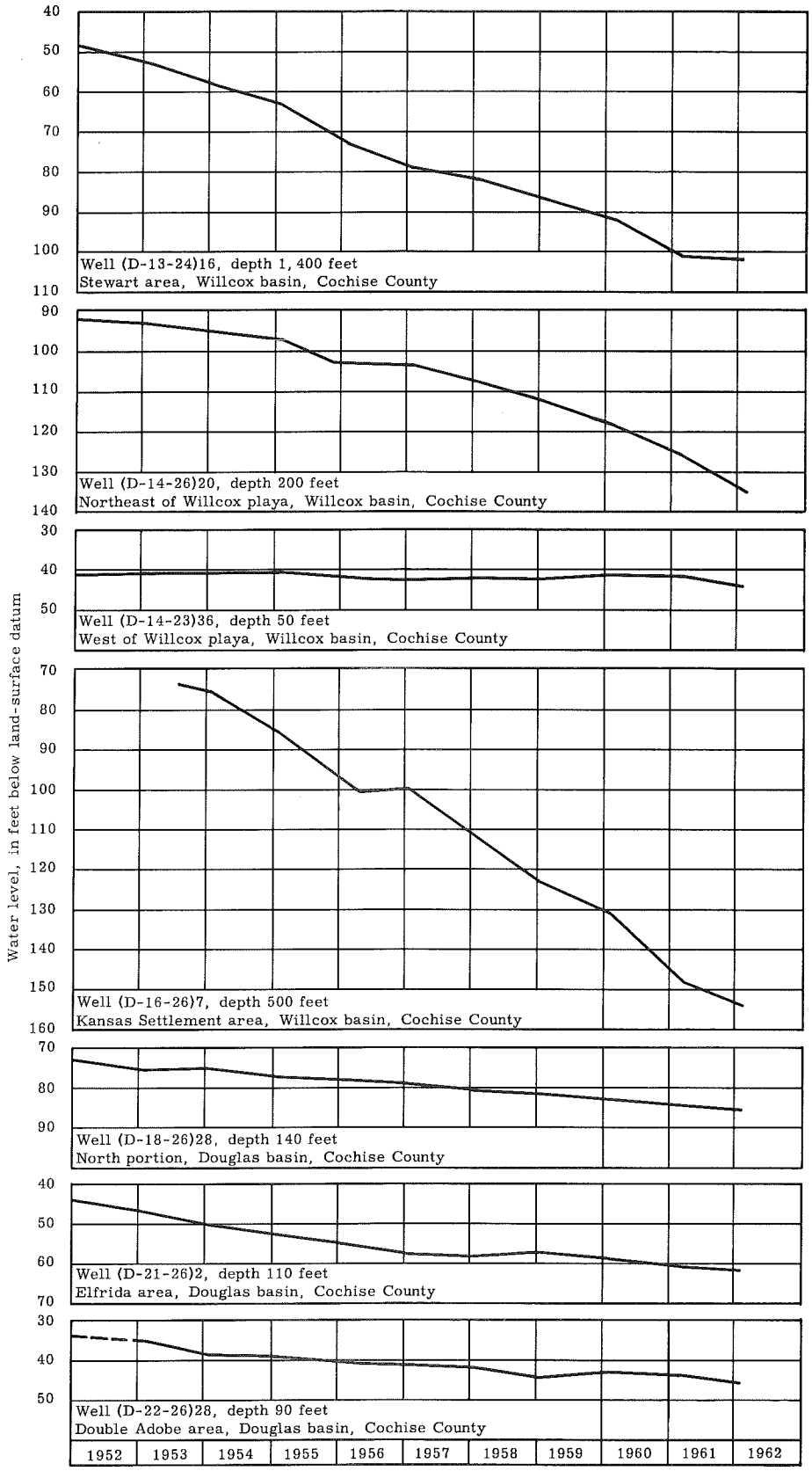


Figure 14. —Water levels in selected wells in Sulphur Spring Valley.

feet in sec. 16, T. 18 S., R. 27 E. In T. 18 S., R. 27 E., depth to water measured in wells in section 5 was 133 feet; in section 6, 118 feet; and in section 7, 124 feet. Water levels in this area have fluctuated only slightly—in general, the trend has been downward at the rate of about a foot each year. Increased withdrawal of ground water probably will increase the rate of decline. This area is about 3 to 4 miles south of the southern end of the highly developed Kansas Settlement area where heavy demands for irrigation water have resulted in large annual declines.

The second area of potential development, roughly triangular in shape, is west of U. S. Highway 666, north of Pearce, south of Cochise, and east of the Dragoon Mountains. In T. 16 S., R. 24 E., depth to water ranges from 111 feet below land surface in section 21 to 127 feet in section 8. In one well in section 10, the depth to water was reported to be 70 feet. In T. 17 S., R. 24 E., depth to water ranges from 80 feet in section 1 near U. S. Highway 666 to more than 330 feet in section 32 near the mountain front. Some wells drilled close to the mountain front have been known to yield little or no water. As stated before, water levels in 10 wells in the Pearce-Cochise area have declined an average of about 4 feet during the 5-year period 1957-62. In 3 of the 10 wells, water levels rose 4 to 5 feet, and water levels in the remaining 7 wells declined from 3 to 12 feet during the period 1957-62. Increased consumptive use will result in accelerated water-level declines.

The third area of potential development for small homesites is in the northwest part of T. 12 S., R. 24 E. The depth to water in wells in section 8 ranges from 108 to 115 feet below land surface, and from 104 to 112 feet in section 17. In T. 11 S., R. 23 E., depth to water in wells ranges from 126 feet in section 35 to 146 feet in section 8. The depth to water in a well in sec. 35, T. 10 S., R. 23 E., was 245 feet below land surface in February 1962. Water-level declines in this area ranged from 5 to 13 feet for the period 1957-62. Expanding use of ground water for irrigation has increased the rate of decline in recent years.

Douglas basin.--The Douglas basin (fig. 6, No. 6), in the southern part of the Sulphur Spring Valley, extends from the drainage divide among the buttes and ridges south of the town of Pearce to the International Boundary and southward into Mexico. The valley is tributary to the Yaqui River drainage and is drained by Whitewater Draw. In the 2 miles north of the International Boundary, Whitewater Draw is perennial, its base flow being supplied by ground water from the alluvium of the Douglas basin. The general movement of ground water is from the flanks of the valley toward the axis and Whitewater Draw, and southward into Mexico. Water-level declines in the Douglas basin have been small compared to similar basins in southern Arizona. Figure 15 shows the overall changes in water levels for the period 1957-62. Depth to water was measured in 87 wells in this 5-year period. Declines in 28 of these wells exceeded 5 feet for the 5-year period. In

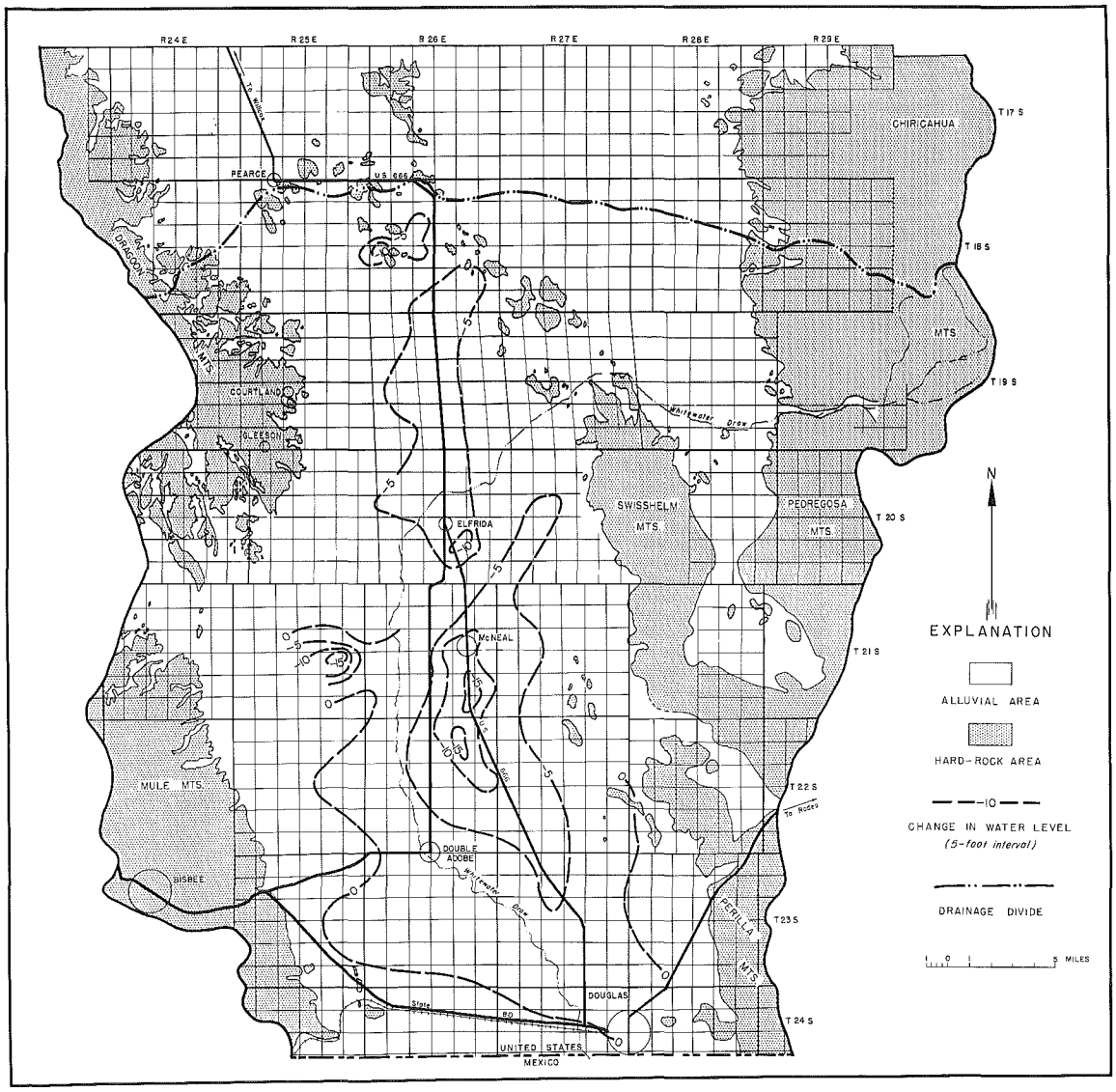


Figure 15.--Map of Douglas basin, Cochise County, Ariz., showing change in ground-water level from spring 1957 to spring 1962.

7 wells the 5-year declines exceeded 10 feet, but exceeded 15 feet in only 3 wells. The maximum decline of about 18 feet was measured in a well about 6 miles west of McNeal. The average 5-year decline was slightly more than 4 feet for this period.

The average change in depth to water from spring 1961 to spring 1962 was a decline of about half a foot, as compared to an average decline of nearly 2 feet from spring 1960 to spring 1961.

Hydrographs of the depth to water in three wells in the Douglas basin are shown in figure 14. Depth to water in the Douglas basin ranges from 40 to 130 feet and in most areas is less than 100 feet below land surface.

San Pedro River Valley

By

Natalie D. White

The San Pedro River heads in Sonora, Mexico, flows northward and crosses into Arizona just south of Palominas at an altitude of about 4,500 feet above mean sea level. From Palominas, the river trends about N. 10° W. for a distance of about 58 miles to the Narrows at Tres Alamos. This part of the valley, from the International Boundary to the Narrows, is called the upper San Pedro basin (fig. 6, No. 7). From the Narrows, the San Pedro River trends northwest for a distance of about 65 miles and drains into the Gila River near Winkleman at an altitude of about 2,000 feet above mean sea level. This part of the valley is called the lower San Pedro basin (fig. 6, No. 8). The San Pedro River has a total drainage area of 4,483 square miles of which 696 square miles is in Mexico, according to records of the U. S. Geological Survey, Surface Water Branch. This also includes 562 square miles of the drainage of Aravaipa Creek which drains into the San Pedro River.

Upper San Pedro basin.--The upper San Pedro basin (fig. 6, No. 7) is defined as that part of the north-trending San Pedro River valley between the International Boundary on the south and the Narrows at Tres Alamos damsite, about 8 miles north of Pomerene, Ariz. It is bounded on the east by the southern end of the Winchester Mountains, and the Little Dragoon, Dragoon, and Mule Mountains; on the west it is bounded by the Rincon, Whetstone, and Huachuca Mountains. As defined, the upper San Pedro basin is entirely within Cochise County, is about 58 miles long, and ranges from 15 to 35 miles wide. The drainage area of the San Pedro River above the Narrows is about 2,500 square miles, of which about 1,800 is in the United States and the remainder is in Mexico, according to records of the U. S. Geological Survey, Surface Water Branch.

The trough of the upper San Pedro basin is filled with alluvial material ranging in thickness from a few feet to at least 1,500 feet. Nearly all the ground water in the basin is stored in this alluvial material. The ground-water reservoir in the upper San Pedro basin is recharged chiefly by runoff from precipitation in the mountains and surface flow in the river. The movement of ground water in the basin is similar to the land-surface drainage—the ground-water divide is in Mexico and the water moves from south to north along the axis of the valley, similar to the San Pedro River. Water also moves toward the center of the valley from the bordering mountains.

In the upper San Pedro basin ground water is under water-table conditions in the unconsolidated sand and gravel of the Recent alluvium along the flood plain of the river. Wells drilled in this material commonly yield from 500 to 1,000 gpm (gallons per minute) and a few wells yield as much as 2,000 gpm. In and adjacent to the flood plain of the San Pedro River, wells have penetrated artesian aquifers in the older alluvium in two areas in the basin—the Palominas-Hereford area in the extreme southern part and the St. David-Pomerene area in the northern part of the basin. The artesian aquifers are in sand and gravel zones within clay beds of the older alluvium at several depths below the land surface. Wells that penetrate these artesian aquifers yield as much as 1,000 gpm. Some wells drilled on the flanks of the valley outside the artesian areas also penetrate the older alluvium. The clay layers encountered in these wells are relatively thin and the ground water is under water-table conditions. These wells yield up to about 400 gpm.

Although the upper San Pedro basin has not been extensively developed and the pumping of ground water is at a minimum, some ground water is withdrawn from both the water-table and the artesian aquifers for irrigation, chiefly in the area between St. David and Pomerene and in the area between Palominas and Hereford. The shallow water-table aquifers in the Recent alluvium along the flood plain of the San Pedro River are recharged from flow in the river and by seepage from irrigation water. The water level in five of these wells measured in the spring of 1962 ranged from about 15 to 80 feet below land surface; water-level fluctuations in these wells ranged from a decline of less than half a foot to a rise of about 8 feet in the 5-year period spring 1957 to spring 1962. The hydrograph for well (D-16-20)34 (fig. 16), a water-table well near the San Pedro River, shows that the water level in this well fluctuates erratically, and no particular pattern of rise or decline is discernible. The water level in this well rose about 2 feet from spring 1961 to spring 1962, slightly less than 2 feet from spring 1957 to spring 1962, and about 3 feet since the spring of 1952. The water level in the water-table wells that penetrate the older alluvium on the flanks of the valley is much deeper than along the flood plain. In the wells measured in 1962 the water level ranged from about 50 to more than 200 feet below the land surface; however, miscellaneous measurements for other years show that the water level is more than 300 feet below land surface in parts of the outlying area. The water level in well (D-20-20)32 (fig. 16) declined about 6 feet in the period spring 1957 to spring 1962. The water level was measured in only two

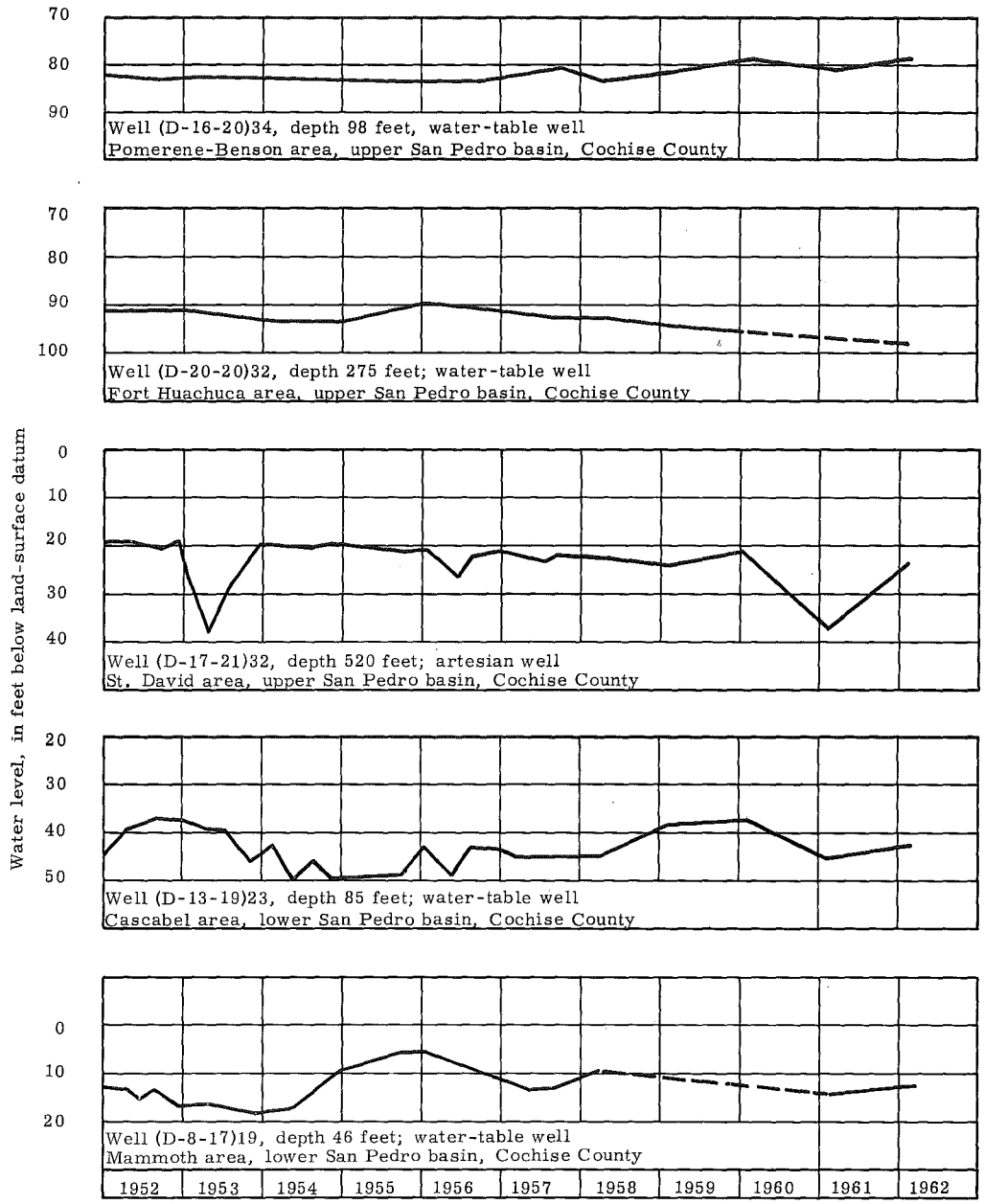


Figure 16. — Water levels in selected wells in the San Pedro River valley.

artesian wells in the upper San Pedro basin in the spring of 1962; the water level in each of these wells was about 25 feet below land surface. The hydrograph of well (D-17-21)32 (fig. 16) shows water-level fluctuations that probably are typical of the artesian wells along the flood plain of the river. The water level in this well declined about 2 feet in the period spring 1957 to spring 1962, and about 5 feet since the spring of 1952.

Lower San Pedro basin. --The lower San Pedro basin (fig. 6, No. 8) is defined as that part of the San Pedro River valley between the Narrows at Tres Alamos, and the mouth of the river near Winkleman. Although the drainage of Aravaipa Creek is a part of the San Pedro drainage basin, it is excluded here because it is a distinct structural trough and the ground-water conditions are different. In this part of the valley the San Pedro River trends northwest. The lower San Pedro basin is bounded on the west by the Rincon, Santa Catalina, Black, and Tortilla Mountains. The east boundary is formed by the Galiuro Mountains, except for the arbitrary line that excludes the drainage of Aravaipa Creek. Thus defined, the lower San Pedro basin is about 65 miles long, 15 to 30 miles wide, and has an area of about 1,420 square miles, based on records of the U. S. Geological Survey, Surface Water Branch. The larger part of the lower San Pedro basin is in Pinal and Cochise Counties, with lesser areas in Graham and Pima Counties.

Like the upper San Pedro basin, the trough of the lower San Pedro basin contains alluvial material; the thickness of this material in the lower San Pedro basin ranges from a few feet to at least 2,000 feet along the axis of the valley. Although there is some ground water in nearly all the rocks in the basin, the greater part of the usable ground water is in the older and younger alluvium. The sources of the ground water in the alluvium are runoff from precipitation in the mountain areas and flow in the San Pedro River; movement of ground water generally is toward the axis of the valley and northwestward along the axis toward the mouth of the river.

Along the flood plain of the San Pedro River, the Recent alluvium is from 60 to 150 feet thick and shallow wells drilled into this material supply most of the water used for irrigation in the valley. South of Mammoth several deep wells have penetrated the older alluvium along the flood plain of the river and these wells yield water under artesian pressure. Wells that penetrate the older alluvium on the flanks of the valley yield only small amounts of water and the water levels are deep.

The water level was measured in 20 wells in the lower San Pedro basin in the spring of 1962. Most of these were water-table wells along the flood plain of the San Pedro River. The water level in these wells was less than 60 feet below land surface in the spring of 1962. The water level in one well at the south end of the basin, about half a mile from the river, was 116 feet below land surface. For the period spring 1961 to spring 1962, water-level fluctuations in the lower San Pedro basin ranged from a rise of nearly 6 feet to a decline of slightly less than a

foot. Water-level fluctuations for the period spring 1957 to spring 1962 ranged from a rise of about 7 feet to a decline of about 5 feet. The water level in well (D-8-17)19 (fig. 16), near Mammoth, rose about 1-½ feet from spring 1961 to spring 1962, less than a foot from spring 1957 to spring 1962, and about half a foot since the spring of 1952. The water level in well (D-13-19)23 (fig. 16), about a mile south of Cascabel, rose slightly more than 3 feet from spring 1961 to spring 1962, and about 1-½ feet from spring 1957 to spring 1962. The water level in both these wells fluctuates seasonally and as a result of flow in the San Pedro River—rising during periods of runoff in the river and declining during dry periods. Some of the measurements undoubtedly are affected also by pumping of the wells just prior to the measurement.

Upper Santa Cruz Basin

By

H. C. Schwalen[1/]

The part of the Santa Cruz River valley extending from the Rillito Narrows, about 16 miles northwest of Tucson, south to the International Boundary is included in the area designated as the upper Santa Cruz basin (fig. 6, No. 9). For convenience it has been divided into the Cortaro - Canada del Oro, Tucson, Sahuarita - Continental, and Santa Cruz County districts or areas. Within the area as a whole, the annual water - level - measuring program includes some 1,500 wells. The accompanying hydrographs of representative wells in each of the districts provide a general picture of the changes in water levels for the 10-year period 1952-62.

A progress report giving the results of ground-water studies in this area by the Agricultural Engineering Department, University of Arizona, has been published as Report No. 205 (Schwalen and Shaw, 1961). It includes a detailed list of water levels in hundreds of wells for the period 1956-61, water-level lowering maps, and ground-water contour maps.

Cortaro-Canada del Oro area.--The Cortaro-Canada del Oro area is that part of the ground-water basin lying north of Rillito Creek between the Santa Catalina Mountains on the east and the Tucson Mountains on the west, and south and east of the Tortolita Mountains.

The Cortaro bottom lands occupy the flood plain along the Santa Cruz River from the Rillito Narrows to the junction with Rillito Creek.

1/ Agricultural engineer, Agricultural Engineering Department, University of Arizona.

Annual pumpage by the Cortaro Water Users' Association has averaged about 20,000 acre-feet for the last 40 years. A large part of this water is now exported to the Marana area and sewage effluent is used for the irrigation of most of the 3,200 acres of cropland within the Cortaro area.

Recharge to this area is primarily from flood flows in the Santa Cruz River, seepage from sewage effluent used for irrigation or wasted into the river, and the winter and spring runoff in the upper reaches of Canada del Oro. Changes in water levels in wells are in response to variations in pumping and the opportunities for recharge from the sources mentioned. A small annual loss in water level of between 1 and 2 feet has persisted throughout the major part of the area underlying the valley slopes. Fluctuations in water levels in the trough of the valley are mostly in direct response to the annual changes in pumping. The 1961-62 losses were about 3 feet in the lower part of the area and between 1 and 2 feet in the upper part. In the upper Canada del Oro there are rather wide fluctuations in the water level in wells adjacent to the stream channel. The 1962 measurements reflect the above-normal runoff from snowmelt, as illustrated in the hydrograph for well (D-11-4)2 (fig. 17); the water level rose about 23 feet in this well between 1961 and 1962.

Tucson area.--The Tucson area includes the wide central portion of the Santa Cruz River basin in which the city of Tucson is located and extends from Rillito Creek on the north to the San Xavier Mission on the south. Within it is the expanding metropolitan and suburban area of Tucson and a limited irrigated acreage of less than 4,800 acres, including 950 acres in the San Xavier Indian Reservation near the San Xavier Mission. The major pumping of ground water is for municipal, recreational, industrial, and domestic uses. The city of Tucson pumped 35,100 acre-feet from wells in this area in the year ending February 28, 1962. This is 80 percent of the requirements for the population of about 225,000 people served by the city system. Very little, if any, of this water is returned to the ground-water reservoir within the Tucson area; the sewage effluent is transported out of the area. The amount pumped may be considered as consumptive use or net withdrawal. Other uses in the area are estimated for 1961 as follows: private wells and domestic water companies 6,800 acre-feet; industrial, recreational, and Davis-Monthan Air Force Base 10,000 acre-feet; and consumptive use for irrigation 15,500 acre-feet. Thus, net withdrawals from the ground-water reservoir in this area during 1961 amounted to about 67,000 acre-feet.

In general, ground-water levels continue to lower; maximum losses in areas of locally heavy pumping were between 6 and 7 feet from 1961 to 1962. Pumping is somewhat seasonal; maximum draft is during the summer months and there is a shift from year to year in the location of the centers of heaviest pumping. The static condition of the water table is only partially obtained, and the comparative hydrographs of the water levels in individual wells or groups of wells may not be con-

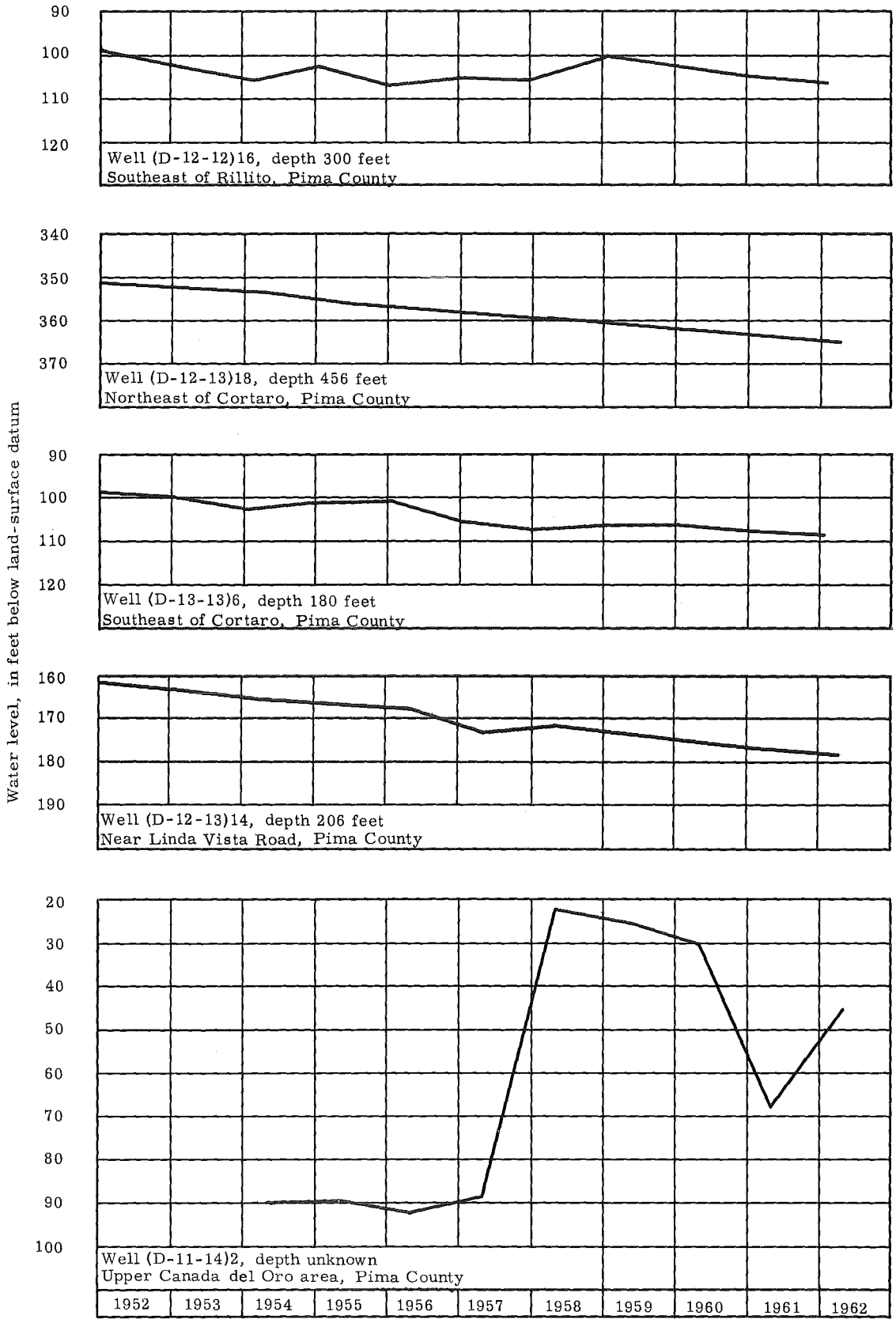


Figure 17. —Water levels in selected wells in the Cortaro-Canada del Oro area, upper Santa Cruz basin.

sistent. Average losses for the central part of the valley for 1961 were about 3 feet; in some small areas there were no losses. The hydrographs of selected wells (fig. 18) represent fairly well this general situation in the valley for the Rillito bottom-land area.

Water levels in wells on the Rillito flood plain respond rapidly to recharge from flow in the stream channel, and the amount of rise is related directly to the length of time the flow continues. Within the Recent fill the lateral movement of water is rapid and it levels out across the bottom land within a short time after the flow ceases. The flat, coarse, sandy stream channel of Rillito Creek provides excellent opportunity for recharge, particularly from the relatively clear, silt-free waters from snowmelt during the winter and spring.

Flow from melting snow in the Santa Catalina Mountains has been exceptionally large in spring 1962. Recharge in the area below the junction of Sabino and Rillito Creeks has been sufficient to bring the water table up to within a foot of the stream bed. Farther downstream, although the ground-water reservoir has not been filled, there were marked rises in water levels. The hydrograph for well (D-13-14)19 (fig. 18) at the University Farm on North Campbell Avenue shows a rise in the water level of 19 feet due to recharge from the flow in Rillito Creek. This well is located about 700 feet from the channel.

Sahuarita-Continental area. --The Sahuarita-Continental area includes that portion of the Santa Cruz River valley extending south from the irrigated land in the San Xavier Indian Reservation near the San Xavier Mission to the Santa Cruz County line. Within the area are two of the oldest planned irrigation projects in the State for which the water supply was obtained from drilled wells with deep-well turbine pumps. The Tucson Farms Co. development of several thousand acres at Sahuarita was started between 1912 and 1914. The Inter-Continental Rubber Co. initiated their project for the production of guayule at Continental in 1917. Some of the wells drilled at that time are still in use, although some have been replaced with deeper wells as the result of the lowered water table.

Present pumping of ground water is mainly for irrigation and for industrial use in the more recently developed open-pit mining operations of low-grade copper ore on the west side of the valley. The crop survey of 1961 indicated nearly 13,000 acres of cropland was irrigated in the area with an estimated consumptive use of about 40,000 acre-feet of water. Use of water by the mining companies for milling of low-grade ore in 1961 is estimated to have been more than 5,000 acre-feet. In addition, pumping of ground water by the city of Tucson from their Santa Cruz wells amounted to 8,700 acre-feet for the year ending February 28, 1962. These wells are located from 1-½ to 2 miles east of the Santa Cruz River, and beginning 4-½ miles north of Sahuarita are spaced over a distance of about 6 miles in the direction of the city.

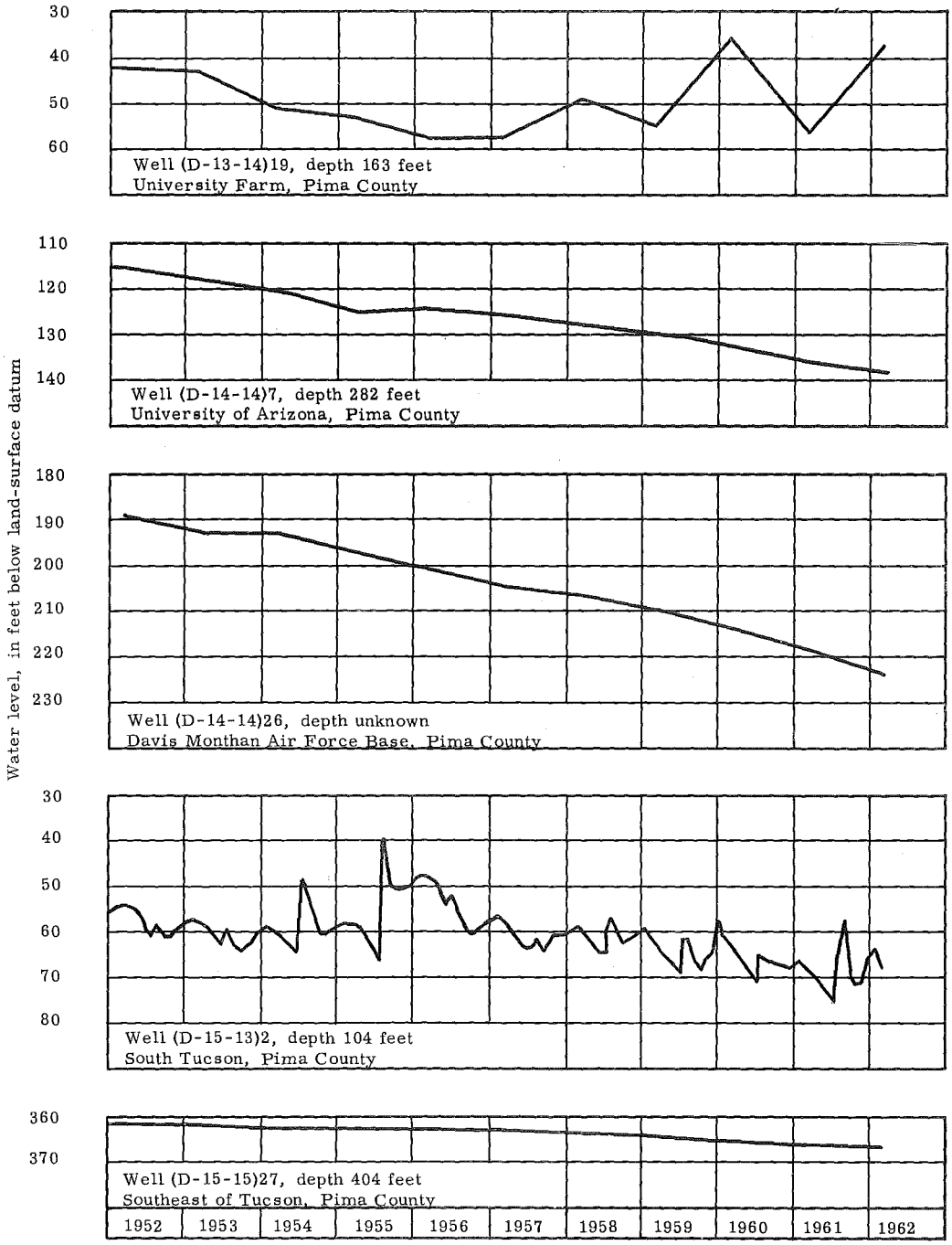


Figure 18. —Water levels in selected wells in the Tucson area, upper Santa Cruz basin.

Total net withdrawals of ground water during 1961 are estimated to have been about 54,000 acre-feet in the Sahuarita-Continental area.

Water levels in the pumping areas near Sahuarita and Continental lowered between 5 and 10 feet from 1961 to 1962. The losses in water level decreased toward the south and south of the Canoa Ranch there were rises in water levels.

The accompanying hydrographs (fig. 19) show typical water-level changes for the 10-year period 1952-62.

Santa Cruz County area.--The studies in Santa Cruz County include the main valley of the Santa Cruz River between the county line and the International Boundary and a small stretch of bottom land extending up Nogales Wash.

Pumping of ground water has varied but little during the last 10 years; the principal usage is for irrigation and for municipal purposes by the city of Nogales. The survey for 1961 showed an irrigated crop acreage of 5,100 acres and an estimated consumptive use of 20,600 acre-feet; municipal pumpage amounted to about 1,200 acre-feet.

Water-level measurements over the area as a whole for the last 10 years indicate that there has been no significant lowering of the water table. Recharge, which is primarily from flood flows in the Santa Cruz River, varies widely between wet and dry periods. Runoff in 1959-60 and the winter of 1961-62 was sufficient to bring spring water levels up to the highest of record in many wells.

The water level at the end of drought periods at the Nogales city pumping plant has at times been so low that pump capacities have been reduced. The well taps a small, shallow ground-water reservoir of limited capacity. The water level in this well was up to river-bed level in the spring of 1962 compared with a depth of 27.4 feet in 1961.

The accompanying hydrographs (fig. 20) show typical water-level fluctuations in the Santa Cruz County area for the last 10 years.

Avra-Marana Area

By

H. C. Schwalen[1]

The Avra-Marana area (fig. 6, No. 10), including the part of the lower Santa Cruz basin from Rillito Narrows northwest to Picacho Peak, is

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1/ Agricultural engineer, Agricultural Engineering Department, University of Arizona.

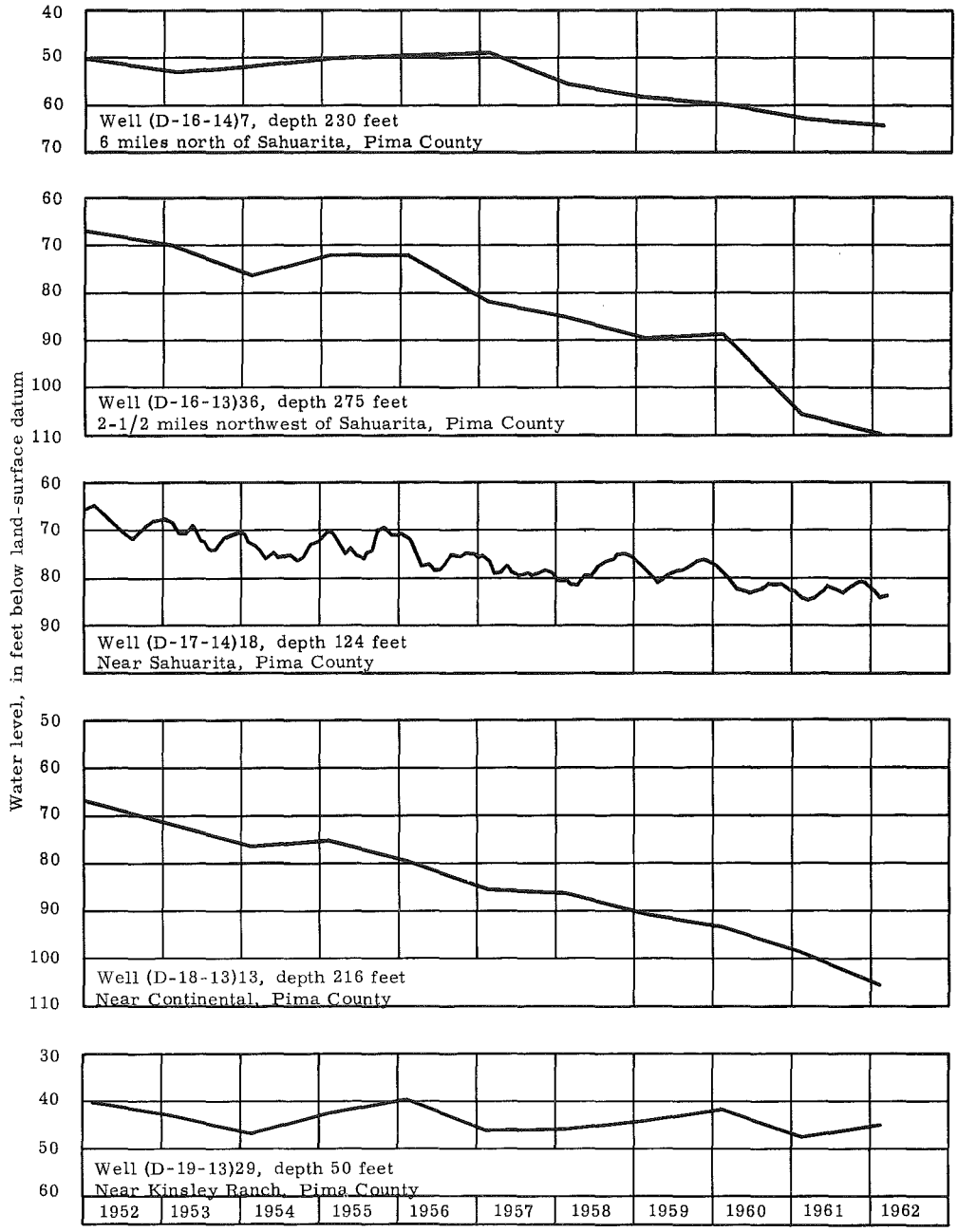

Figure 19. —Water levels in selected wells in the Sahuarita-Continental area, upper Santa Cruz basin.

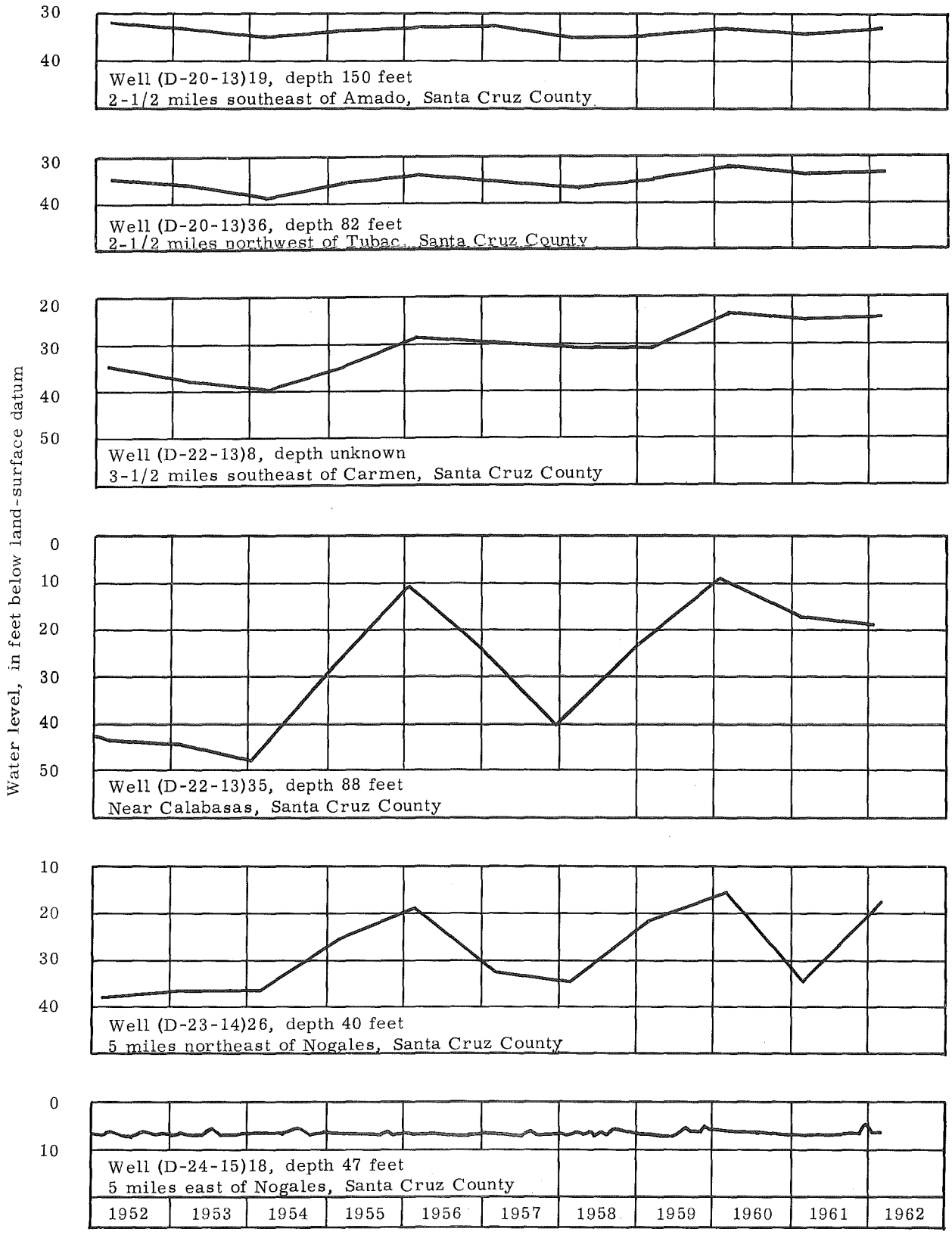

Figure 20.—Water levels in selected wells in the Santa Cruz County area, upper Santa Cruz basin.

that part of the Santa Cruz River drainage basin from south of Picacho Peak to the Rillito Narrows at the north end of the Tucson Mountains, and the Avra Valley south to Three Points. The area is drained by Brawly Wash which drains into the Santa Cruz River. The crop survey of 1961 showed that in the area there was 7,100 acres of irrigated cropland in Pinal County and 31,500 acres in Pima County, of which 1,600 acres was adjacent to Three Points. Thus, about two-thirds of the total irrigated acreage in Pima County is in the Avra-Marana area.

The water-level measuring program in the Avra-Marana area includes about 350 wells. Hydrographs of the water levels in six representative wells in the area are shown in figure 21. The wells were selected to give a general picture of the situation in the area as a whole and are not illustrative of either maximum or minimum changes.

The total use of ground water for irrigation in the Avra-Marana area, based upon the 1961 crop survey and estimated consumptive use by various crops, amounted to about 123,000 acre-feet. Of this about 21,000 acre-feet was used in Pinal County and 102,000 acre-feet in Pima County. It is estimated that of the use in Pima County about 17,000 acre-feet was imported into the area from the upstream Cortaro pumping area. In the above computations a net annual consumptive use for various crops was used as follows: cotton, 3.5 acre-feet; sorghum, 2.5 acre-feet; pastures, 4.0 acre-feet; truck, 2.5 acre-feet; and, alfalfa, 4.5 acre-feet. This is net use and does not include the return flow to ground water from infiltration of water applied to irrigated fields or through unlined canals.

Immediately south of Picacho Peak water levels show the encroaching effect of the downstream pumping in the Eloy area. Losses in water level at individual wells ranged from 5 to 15 feet in the period 1961-62.

Locally, water levels in the vicinity of Redrock were affected by winter irrigation of vegetables resulting in little opportunity for recovery of the water table. Maximum losses of up to 12 feet occurred between 1961 and 1962; the average loss was about 6 feet. During the 10-year period 1952-62, the general lowering of the water table in the northwest end of the Avra-Marana area was between 40 and 60 feet, but was as much as 90 feet at the west edge where it joins the Eloy pumping district.

In the areas of more concentrated pumping near Marana and extending south about 15 miles into the Avra Valley, the 1961-62 lowering of water levels amounted to about 6 to 7 feet. In the same areas accumulative lowering during the 10-year period amounted to about 70 feet. The lowering of the water table in the fringe areas has been considerably less—as little as 40 feet in parts of the area. Variations in the slope of the ground-water table and in losses in water levels in individual wells in the same general area indicate nonuniformity in the hydrologic characteristics of the ground-water basin.

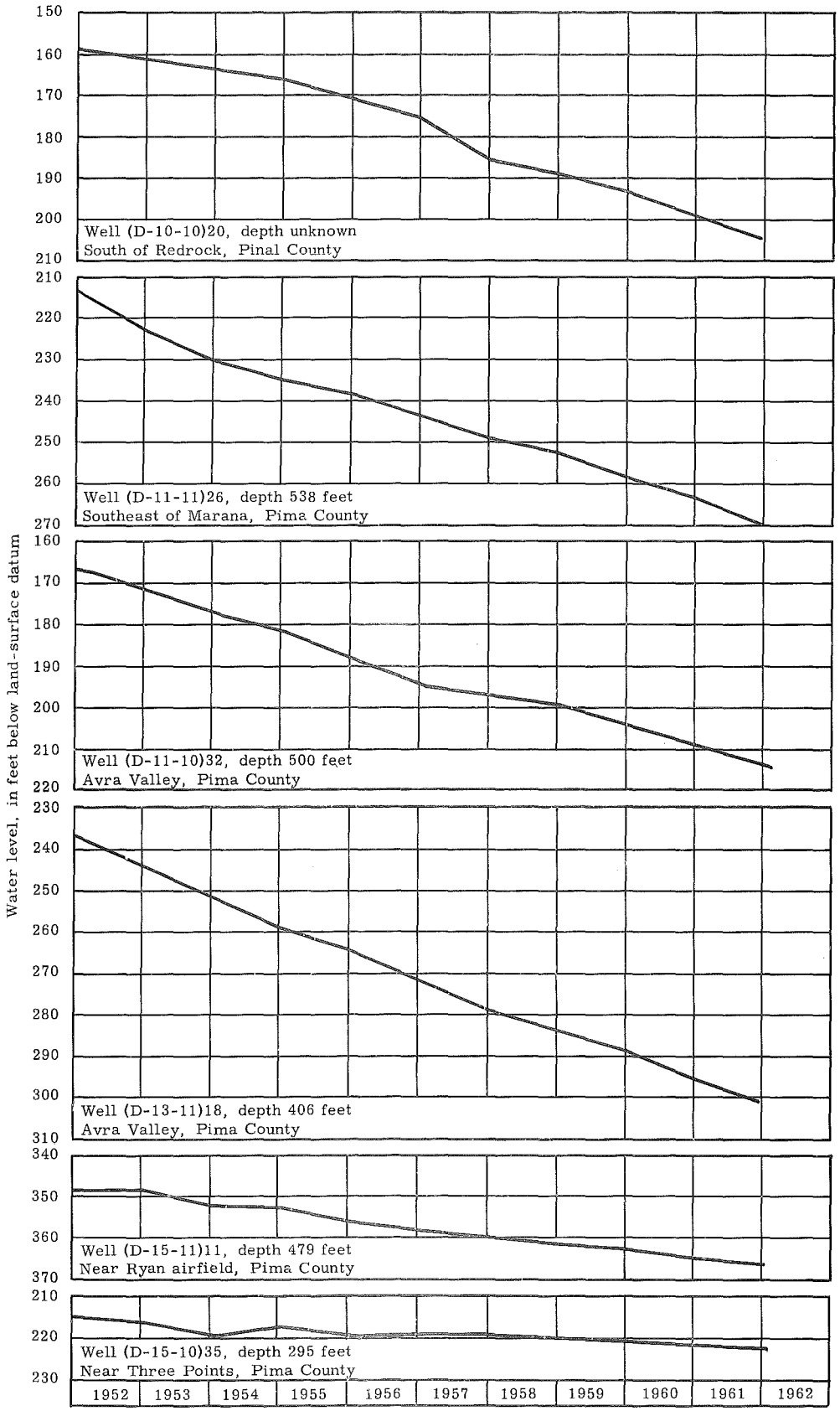

Figure 21. —Water levels in selected wells in the Avra-Marana area.

The annual lowering of water levels decreases to the south from the main pumping area, and in the vicinity of Ryan airfield and Three Points the 1961-62 loss was only 1 to 2 feet. In these same areas the loss for the 10-year period 1952-62 amounted to about 10 feet and was as much as 15 feet only in a small local area at Three Points.

Lower Santa Cruz Basin and Adjacent Area Along the Gila River

By

W. F. Hardt

The lower Santa Cruz basin and the adjacent area along the Gila River (fig. 6, No. 11) is the second largest agricultural area in the State and contains more than 90 percent of the irrigated acreage in Pinal County. This area, of about 2,000 square miles, consists of the lower part of the Santa Cruz River drainage which is a part of the Gila River drainage. It is bounded on the north by the Gila River from Ashurst-Hayden Dam westward to Santan Mountain, and thence to the Pinal-Maricopa County line near the confluence of the Santa Cruz and Gila Rivers adjacent to the Sierra Estrella. The western boundary is formed by the Sierra Estrella, Palo Verde, Table Top, Tat Momoli, Silver Reef, and Sawtooth Mountains. The arbitrary eastern boundary of the area is a line extending north from the Tortolita Mountains to the Gila River. The common boundary of the lower Santa Cruz basin and the upper Santa Cruz basin is the Rillito Narrows between the Tucson and Tortolita Mountains in Pima County about 10 miles south of the Pinal County line.

Most of the irrigated acreage in the area is concentrated northwest of Redrock and west of the Picacho Mountains to the Gila River. This intensively developed area consists of more than 1,000 square miles of valley floor of low relief surrounded by mountain masses. The valley floor slopes gently from about 1,800 feet above mean sea level a few miles northwest of Redrock to 1,400 feet at Casa Grande and Coolidge. The lowest altitude in the basin is about 1,000 feet at the northwest corner of Pinal County between the Sierra Estrella and the Salt River Mountains.

According to Hillman (1962), 271,755 acres of land was cropped in Pinal County in 1961. Most of this was irrigated land in the lower Santa Cruz basin. This total acreage was a reduction of 14,145 acres from 1960 and 21,528 acres since 1959. The lack of water created by the economics of deep pumping lifts may be one of the reasons for the reduction in agricultural acreage, particularly west of Stanfield and Maricopa adjacent to the Table Top and Palo Verde Mountains and the Haley Hills, and in parts of the Eloy area. The recent emphasis on converting agricultural land to subdivision and homesites has also taken some land out of production.

The movement of ground water in the lower Santa Cruz basin is northwestward toward the Gila River. Before irrigation development and pumping, the ground water moved down the Santa Cruz Valley through Redrock and Eloy toward the Sacaton Mountains. Part of the flow was diverted toward Coolidge and thence to the Gila River, and part of the flow was toward Stanfield, Maricopa, and the Gila River.

The rapid agricultural growth since 1940 has resulted in heavy ground-water withdrawals. The pumping of ground water has influenced the subsurface flow and created cones of depression in the water table. A ground-water divide has formed in the vicinity of Casa Grande due to extensive pumping in the agricultural areas east and west of the town, and ground water moves east toward Coolidge and west toward Stanfield. The ground-water divide is over a north-trending ridge where the permeable alluvial sediments are comparatively thin, well yields are small, and water quality is poor. No ground water moves from the Eloy area to the Stanfield area, except possibly between the Casa Grande and Silver Reef Mountains. Ground-water depressions are numerous between Stanfield and Maricopa and some water moves west toward the Table Top and Palo Verde Mountains and the Haley Hills. Ground-water movement is also toward the southwest corner of the Sacaton Mountains.

The area of irrigation development in the lower Santa Cruz basin of Pinal County is arbitrarily divided into three subareas (fig. 22): (1) the Eloy area; (2) the Casa Grande-Florence area; and, (3) the Stanfield-Maricopa area. Data from wells in the Gila River area have been included in the Casa Grande-Florence or Stanfield-Maricopa areas to be correlative with work of previous years. Cumulative net changes in water level from 1940 to spring 1962 in the three areas (fig. 23) show the tremendous decline of the water table in the alluvial-basin reservoir.

Eloy area.--The depth to water in the Eloy area ranged from 100 to nearly 350 feet below land surface in the spring of 1962. The shallow water levels are southwest and north of the Casa Grande Mountains. In the central part of the area most of the water levels range from 225 to 275 feet below land surface. The deeper water levels—generally more than 300 feet—are in the area southeast of Eloy along the west side of the Picacho Mountains and Picacho Peak. Water-level fluctuations from spring 1961 to spring 1962 ranged from rises of 1 to 16 feet to declines of 25 feet. Most of the yearly declines were less than 10 feet. Rises in the water table were measured sporadically throughout the area in about 15 wells. The rises probably were related more to well mechanics than to hydrologic conditions in the aquifer. Maximum yearly declines of more than 7 feet were measured along the west side of the Picacho Mountains and Picacho Peak, a few miles southeast of the Sawtooth Mountains, and northwest of Eloy adjacent to the Casa Grande Canal. Elsewhere in the Eloy area the yearly declines were generally less than 5 to 7 feet.

In the 5-year period spring 1957 to spring 1962 water-level declines were as great as 60 feet (fig. 22) between Eloy and the Picacho Moun-

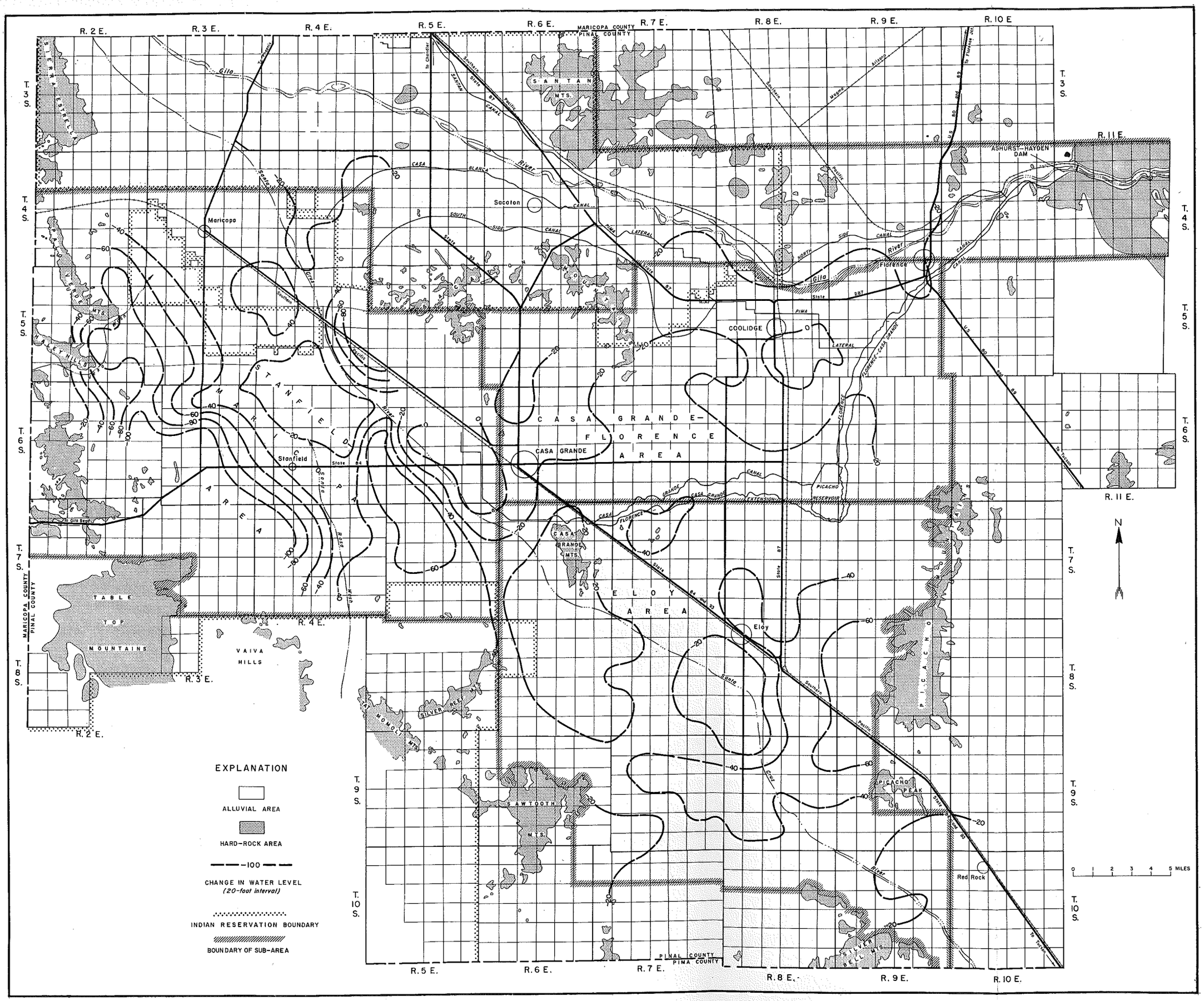

Figure 22.--Map of lower Santa Cruz basin and adjacent areas, Pinal County, Ariz., showing change in ground-water level from spring 1957 to spring 1962.

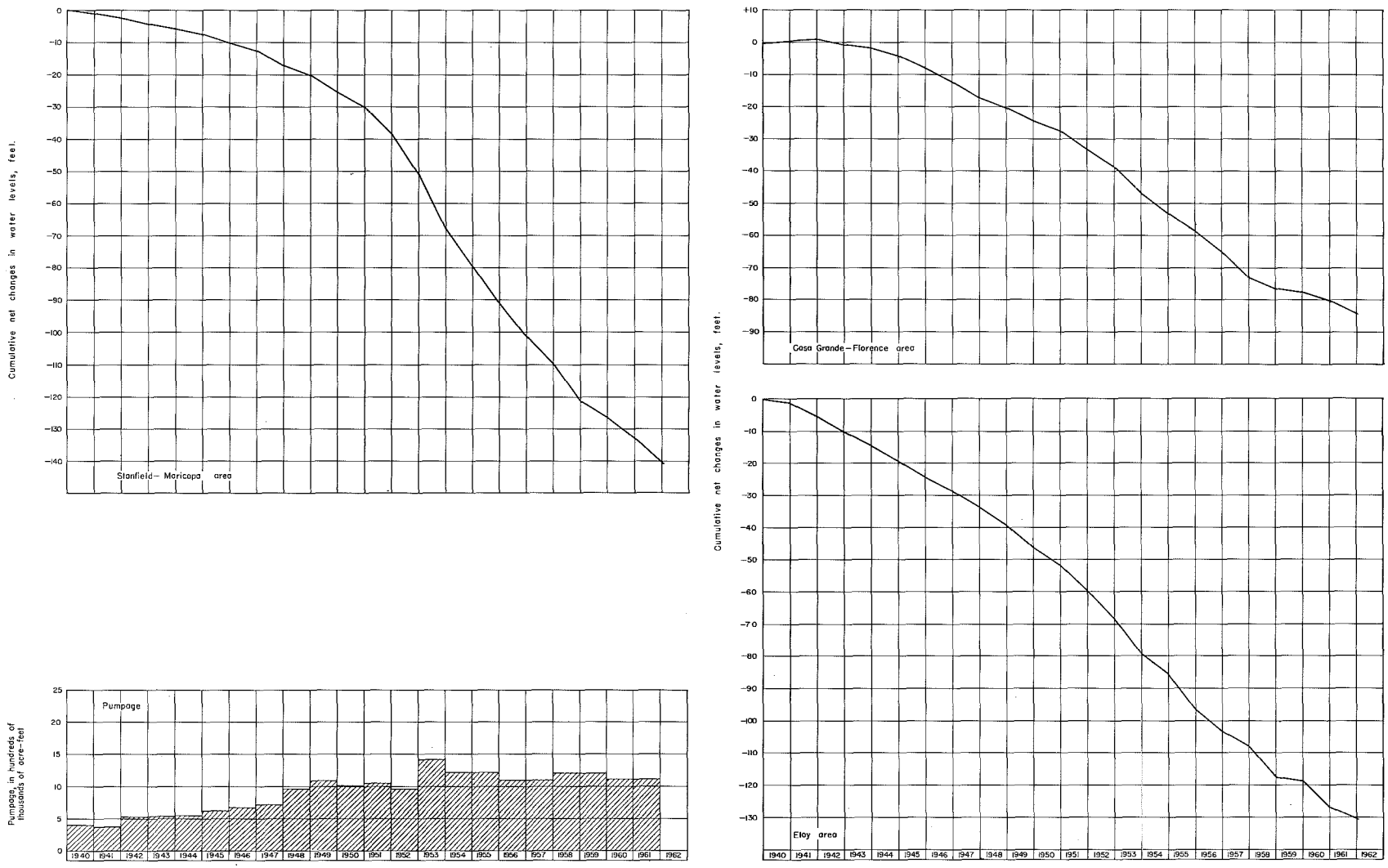

Figure 23.—Cumulative net changes in water levels by areas and total annual pumpage in the lower Santa Cruz basin within Pinal County.

tains. Areas where declines were generally about 20 feet or less were (1) in the Redrock area, (2) a few miles southeast of the Sawtooth Mountains, (3) between the Casa Grande and Sawtooth Mountains, and (4) a few miles south of Eloy. In the central part of the area declines generally ranged from 20 to 40 feet. Declines ranged from 40 to 60 feet in a small area 5 miles east of the Casa Grande Mountains near the Casa Grande Canal, and east of Eloy extending south to T. 9 S., R. 8 E., and in a narrow band westward to the Sawtooth Mountains. In a small area about 8 miles south of Eloy, the existing water table is below a shallower, partly dewatered horizon which continues to drain through the well perforations to the lower aquifer. Previous water-level measurements were from the cascading water and indicated no decline in water levels, whereas the water table was declining. Recharge from the upper horizon could create a ground-water mound and an area of less decline.

The water level in well (D-7-7)27 (fig. 24), 3 miles northwest of Eloy, declined about 2 feet from spring 1961 to spring 1962, about 14 feet from spring 1957 to spring 1962, and about 42 feet from spring 1952 to spring 1962. The hydrograph shows a fairly uniform yearly decline in the water table of 6 feet from spring 1951 to spring 1957. The water-level measurement in spring 1959 may have been influenced by pumping. The rate of decline from spring 1957 to spring 1962 was about 3 feet per year.

Casa Grande-Florence area.--The depth to water in the spring of 1962 ranged from 65 to 150 feet below land surface near Casa Grande, about 160 feet between Casa Grande and Coolidge, and about 140 feet along the Gila River from Florence to Coolidge. In the undeveloped area south of Florence and east of the Florence-Casa Grande Canal, water levels generally are more than 200 feet below land surface. Water levels in wells along the Gila River channel range from 140 feet at Coolidge to less than 100 feet below land surface at Sacaton. In the period spring 1961 to spring 1962 water-level fluctuations ranged from rises of 1 to 10 feet to declines of 25 feet. Many of the yearly declines were less than 5 feet. Most of the yearly rises in the water table were in the Gila River area near Sacaton. The largest declines from spring 1961 to spring 1962 were: (1) adjacent to the east side of the Sacaton Mountains; (2) in the vicinity of Casa Grande; and, (3) along the Florence Canal from the Gila River to the Picacho Reservoir. In 1961, only 62,450 acre-feet of surface water was diverted from the Gila River at Ashurst-Hayden Dam. This amount of diversion was more than 178,000 acre-feet less than diverted in 1960, and is the lowest amount diverted since 1953.

In the 5-year period spring 1957 to spring 1962, water-level fluctuations (fig. 22) ranged from little or no decline a few miles southeast of Coolidge to as much as 20 to 40 feet in the south-central part of the area. In the vicinity of Casa Grande, the declines were generally less than 20 feet, except for a small area north of town where 5-year declines were generally more than 20 feet. Along the Gila River from Ashurst-Hayden Dam to Florence, the declines were generally less

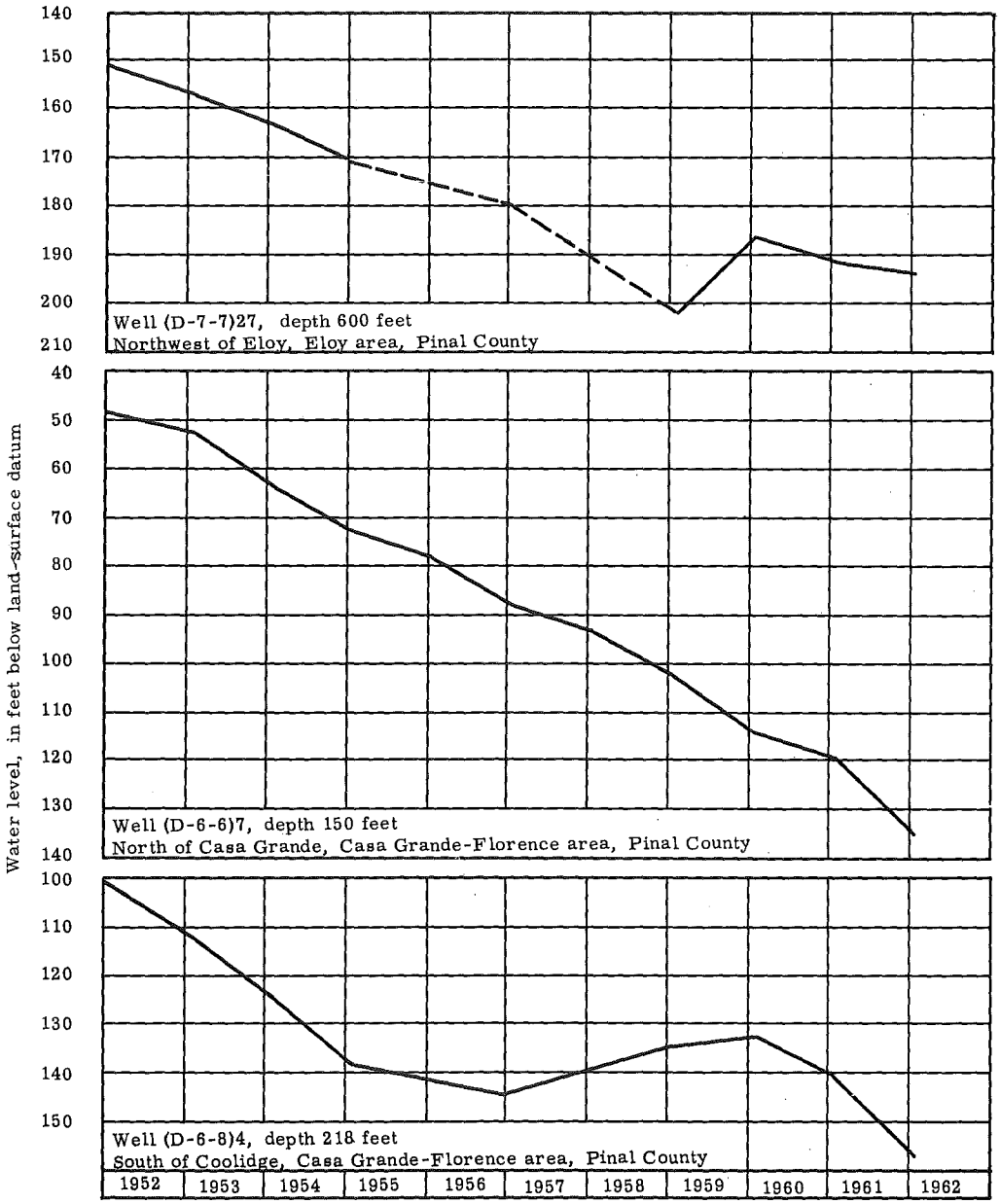

Figure 24. —Water levels in selected wells in the Eloy and Casa Grande-Florence areas, lower Santa Cruz basin.

than 20 feet; from Florence to midway between Coolidge and Sacaton, the declines were about 20 feet. At Sacaton and downstream about 10 miles, the 5-year water-level declines in wells were consistently between 13 and 19 feet. South of the Gila River for a distance of about 6 miles between the Sacaton Mountains and Florence, the declines for the period spring 1957 to spring 1962 were generally less than 20 feet, except where noted.

The water level in well (D-6-6)7 (fig. 24) near Casa Grande declined about 15 feet from spring 1961 to spring 1962, about 47 feet from spring 1957 to spring 1962, and more than 87 feet since spring 1952. The depth to water in this well in April 1940 was about 28 feet below land surface or about 107 feet higher than in spring 1962. The hydrograph shows that the water table has declined at a fairly uniform rate of about 8 to 9 feet yearly, except for a slight increase in the last few years. The water level in well (D-6-8)4 (fig. 24), 3 miles south of Coolidge, declined about 17 feet from spring 1961 to spring 1962, about 12 feet from spring 1957 to spring 1962, and nearly 57 feet since spring 1952. From spring 1957 to spring 1960, the water level in this well rose about 12 feet due to unknown geohydrologic conditions. Since spring 1960 the trend of the water table has been downward. The water-level measurement in spring of 1962 may have been influenced by nearby pumping. The depth to water in this well in April 1940 was 54 feet below land surface, or more than 100 feet higher than in spring 1962.

Stanfield-Maricopa area.--The depth to water below land surface in the spring of 1962 varied considerably throughout the area, ranging from about 50 feet 2 miles west of Casa Grande to about 400 to 500 feet south of the Palo Verde Mountains and 5 to 10 miles west of Stanfield adjacent to the mountains. The first static water level of more than 500 feet in the lower Santa Cruz basin was measured by the Survey in the spring of 1962 in sec. 13, T. 6 S., R. 2 E. The depth to water in this well was 515 feet below land surface. There are shallow water levels of 50 to 100 feet in an area 2 to 5 miles west of Casa Grande. A few miles farther west, the depth to water ranges from 250 to 350 feet below land surface. The ground-water gradient in this area is more than 75 feet per mile. Elsewhere in the Stanfield-Maricopa area, the depth to water below land surface is 100 to 150 feet at Maricopa and 250 feet at Stanfield, although it varies considerably short distances away. Two miles southwest of Stanfield water levels are more than 400 feet below land surface, and 2 miles northeast of Stanfield water levels range from 240 to 280 feet below land surface. In the central part of the area between Stanfield and Maricopa the depth to water ranges from 150 to 300 feet below land surface, being shallower toward Maricopa. West of Maricopa toward the mountains, the water levels range from less than 100 to nearly 300 feet below land surface. South of Stanfield water levels range from 200 to 475 feet below land surface. In parts of the Stanfield-Maricopa area, particularly south of Stanfield, there may be a shallow, nearly dewatered aquifer draining through wells to the deeper aquifer. Shallow wells bottoming in clay or silt could have

water levels substantially higher than deeper wells, although well yields would be less. All these water levels are essentially static—measured in the spring of 1962; pumping levels are much lower during the irrigation season.

Water-level fluctuations from spring 1961 to spring 1962 ranged from rises of 15 feet to declines of 40 feet. The wide variation in net change in the water table is due partly to local pumping schedules related to the time of the water-level measurement. Rises in the water table were measured sporadically throughout the area. Maximum yearly declines ranging from 10 to 40 feet were in the following areas: (1) south of the Palo Verde Mountains along the western edge of the Stanfield-Maricopa area; (2) south of Stanfield; and, (3) near the Sacaton Mountains. In the central part of the area the water levels generally declined less than 10 feet—in many parts less than 5 feet—for the period spring 1961 to spring 1962. A few miles west of Casa Grande, on the bedrock ridge, 1-year declines ranged from less than a foot to 14 feet.

In the 5-year period spring 1957 to spring 1962 declines were as great as 100 feet (fig. 22). The greatest declines were in the southwestern part of the basin near the mountains. Declines of at least 80 feet were measured (1) adjacent to the Palo Verde Mountains and Haley Hills, and (2) adjacent to the southwestern part of the Sacaton Mountains. Large declines also were measured in the area 5 miles east of Stanfield along the west side of the buried ridge. In the central part of the area from Stanfield to Maricopa, the 5-year declines generally ranged from 20 to 40 feet. A few miles northwest of Casa Grande there has been little or no decline in the water table during the last 5 years. Only a small amount of ground water is pumped in this area and some surface water from a canal may be recharged to the aquifer. There is a small area of complex hydrology 4 miles southeast of Stanfield. Apparently there is some interaquifer movement of water through well casings and declines are minimized.

The water level in well (D-7-5)5 (fig. 25), about 5 miles southwest of Casa Grande, declined about 15 feet from spring 1961 to spring 1962, nearly 71 feet from spring 1957 to spring 1962, and more than 157 feet since spring 1952. The hydrograph shows a uniform decline of about 14 feet per year since spring 1955. This well is adjacent to the west side of the north-trending ridge where water-level declines are greater than average for the Stanfield-Maricopa area. The water level in well (D-4-3)22 (fig. 25), about a mile east of Maricopa, declined nearly 8 feet from spring 1961 to spring 1962, about 32 feet from spring 1957 to spring 1962, and more than 68 feet since spring 1953. The hydrograph shows yearly declines of about 7 to 8 feet since spring 1953 and an increase since spring 1960.

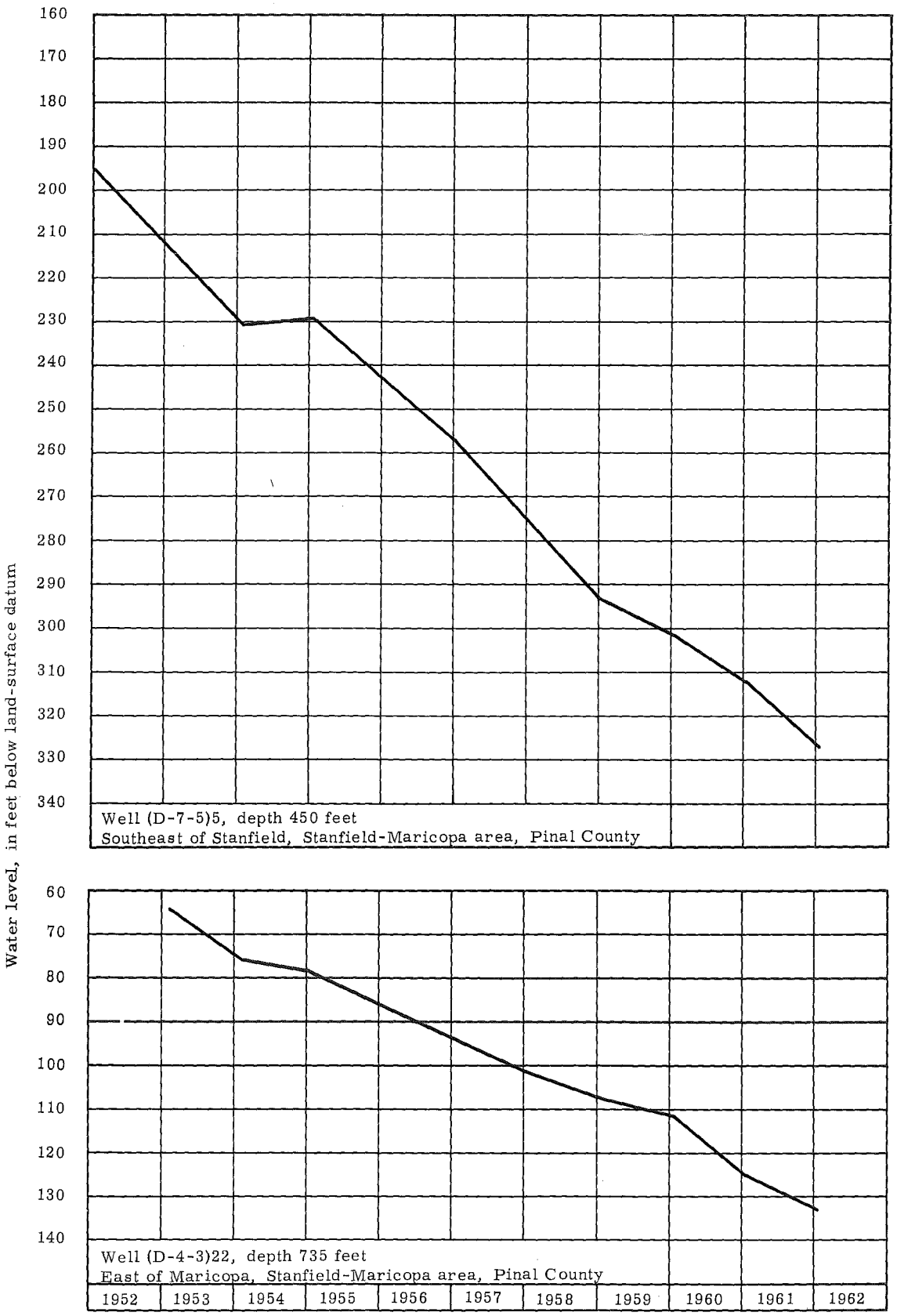

Figure 25. —Water levels in selected wells in the Stanfield-Maricopa area, lower Santa Cruz basin.

Salt River Valley

By

R. S. Stulik

The Salt River Valley (fig. 6, No. 12) comprises the valley lands in the vicinity of Phoenix and tributary valleys such as Paradise Valley and Deer Valley, as well as lands west of the Hassayampa River and the lower reaches of Centennial Wash. Most of the area is drained by the Salt, Agua Fria, and Hassayampa Rivers, but a small part on the east and south is drained by the Gila River. The area is bounded on the north by the Hieroglyphic Mountains and Black Mountain; on the northeast and east by the McDowell, Usery, and Superstition Mountains; on the south by the Gila River to Santan Mountain; then by the Maricopa-Pinal County line to the Sierra Estrella; and on the southwest and west by the Buckeye Hills, Gila Bend Mountains, Saddle Mountain, and an arbitrary line from the Big Horn Mountains to the Hassayampa River.

The Salt River Valley is subdivided into the following areas: (1) Queen Creek-Higley-Gilbert-Magma area, (2) Tempe-Mesa-Chandler area, (3) Phoenix-Glendale-Tolleson-Deer Valley area, (4) Paradise Valley area, (5) Litchfield-Beardsley-Marinette area, (6) Liberty-Buckeye-Hassayampa area, (7) lower Hassayampa-Tonopah area, and (8) lower Centennial area. These areas are delineated and named on the map showing declines of the water level in the Salt River Valley area (fig. 26). Figures 27, 28, and 29 show the cumulative net changes in water levels in various parts of the Salt River Valley since 1930. Figure 29 also shows the total pumpage for the Salt River Valley area.

In the Salt River Valley the direction of ground-water movement conforms, in general, to the direction of slope of the land surface. In some places the natural direction of movement has been reversed and ground water is now moving toward major cones of depression that have resulted from heavy withdrawals. As of the spring of 1962, there were three such depressions in the area—northeast of Gilbert, in Deer Valley, and northwest of Litchfield Park. Most of the ground water in the eastern part of the Salt River Valley flows toward the depression northeast of Gilbert. In the central part of the valley most of the ground water flows to the west, but some of it flows toward the depression in Deer Valley. In the northwestern section of the valley, the ground water generally flows southward toward the depression northwest of Litchfield Park, but some water flows toward the depression in Deer Valley. In the Liberty-Buckeye-Hassayampa area the water generally flows to the southwest, but some water flows north toward the depression near Litchfield Park. In the area west of the Hassayampa River the ground water flows southward toward Gillespie Dam.

Queen Creek-Higley-Gilbert-Magma area.--During 1961 most of the water levels in wells in the Queen Creek-Higley-Gilbert-Magma area

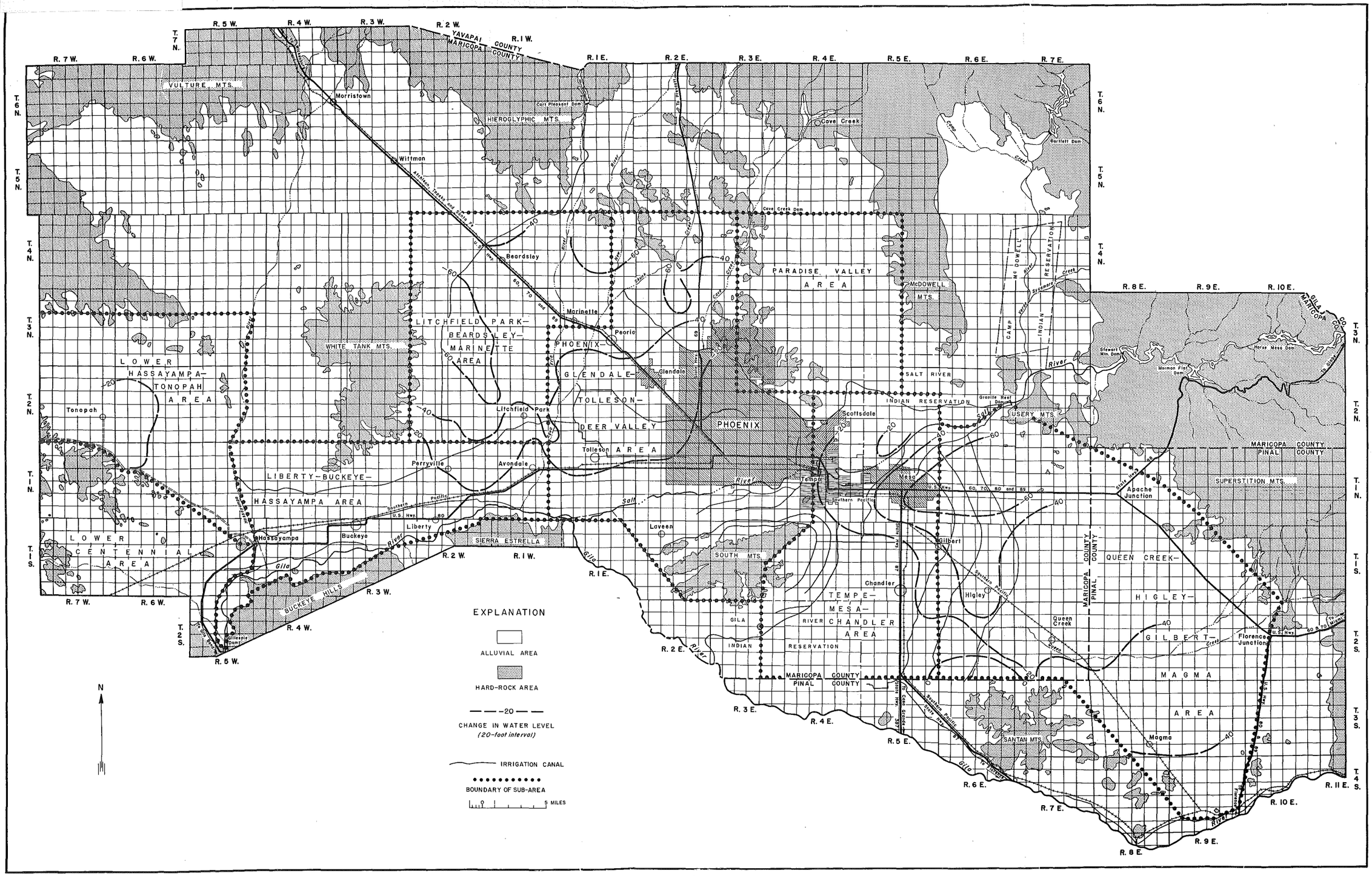

Figure 26.--Map of Salt River Valley area, Maricopa and Pinal Counties, Ariz., showing change in ground-water level from spring 1957 to spring 1962.

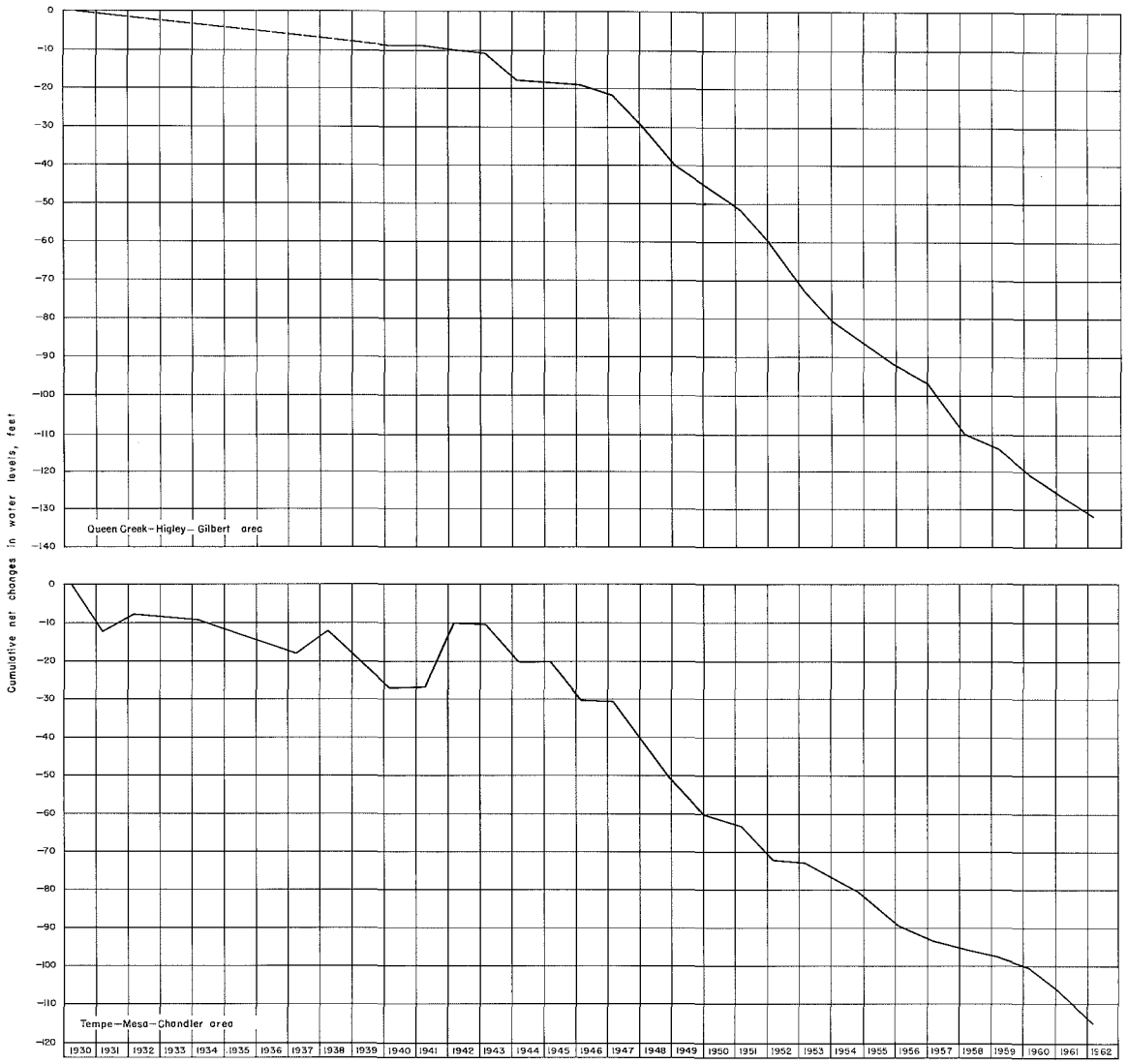

Figure 27.--Cumulative net changes in water levels in the Queen Creek-Higley-Gilbert and Tempe-Mesa-Chandler areas of the Salt River Valley.

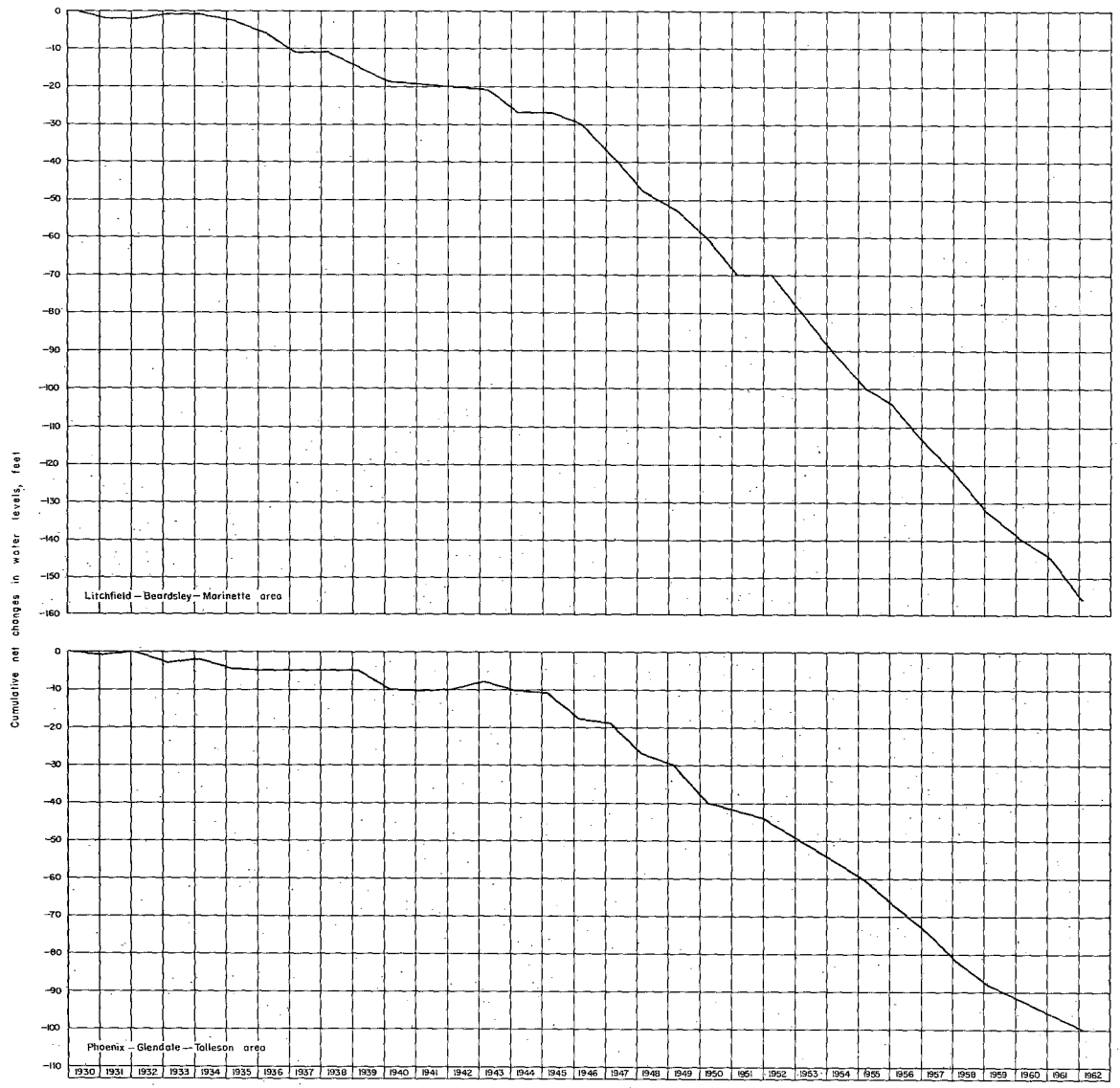

Figure 28.—Cumulative net changes in water levels in the Litchfield-Beardsley-Marinette and Phoenix-Glendale-Tolleson areas of the Salt River Valley.

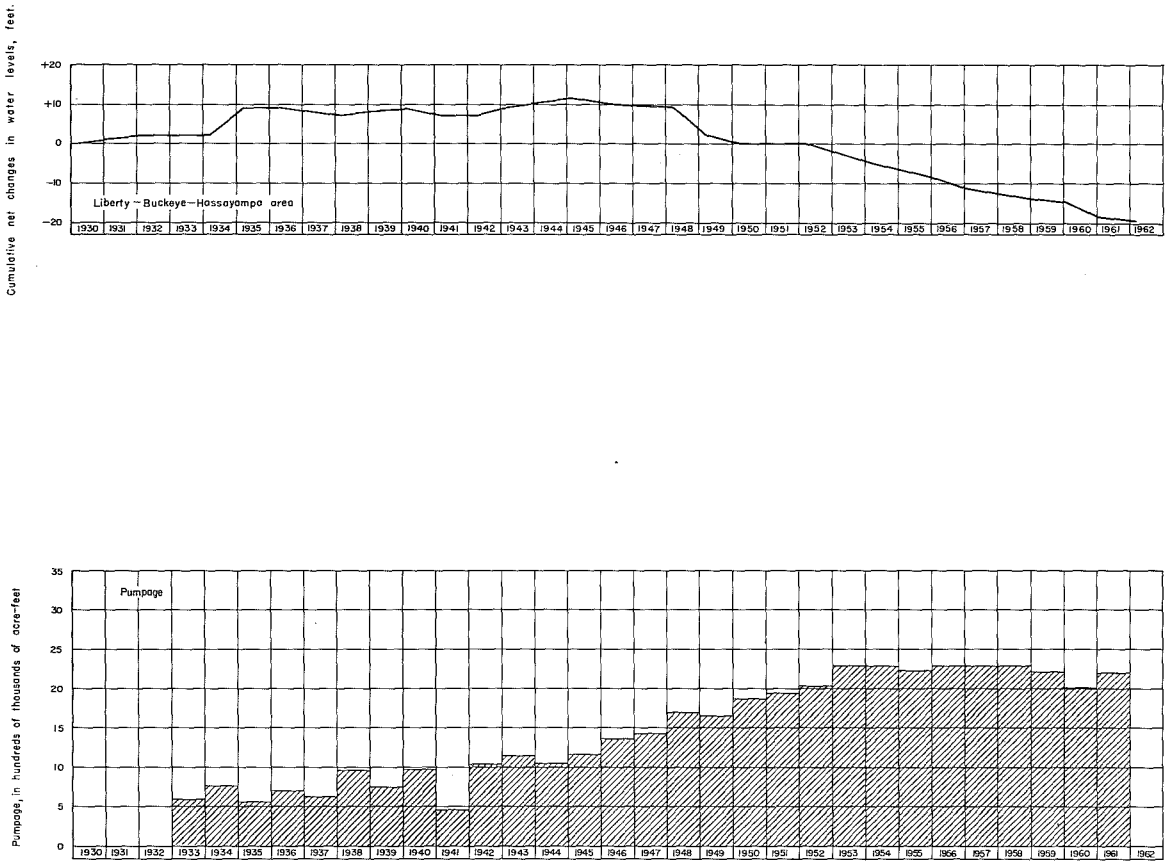

Figure 29.--Cumulative net changes in water levels in the Liberty-Buckeye-Hassayampa area and total annual pumpage in the Salt River Valley.

continued to follow the previously observed downward trend of the water table (fig. 27). In the period spring 1961 to spring 1962, water-level fluctuations ranged from a decline of about 30 feet east of Mesa to a rise of about 2 feet south of Higley. In the 5-year period spring 1957 to spring 1962, water-level changes ranged from small rises southeast of Chandler to declines of more than 60 feet northeast of Mesa. Declines of about 60 feet also occurred near Magma. The minimum declines were observed in the southwestern part of the area (fig. 26).

In the northeastern part of the area the water level in well (A-1-6)23 (fig. 30) declined about 31 feet from spring 1961 to spring 1962, more than 70 feet from spring 1957 to spring 1962, and more than 150 feet since 1952.

The water level in well (D-2-10)8 (fig. 30) in the extreme eastern part of the area had a minimum decline because there is no pumping of ground water for irrigation nearby. However, a steady decline amounting to about 14 feet has occurred since the spring of 1952, possibly because of irrigation pumping 8 miles to the west.

As in previous years the water table in the southwestern part of the area declined but little and in some places there were rises of several feet. For example, there has been little net change in the water level in well (D-2-5)13 (fig. 30) about 5 miles southwest of Higley since the spring of 1952 and it has risen about 5 feet since 1958. Ground water is used only to supplement surface-water irrigation in this part of the area, and seepage from the canals influences the water-table fluctuations.

In the spring of 1962 water levels in observed wells in the cultivated parts of the Queen Creek-Higley-Gilbert-Magma area ranged from about 450 feet below land surface in a well south of Granite Reef Dam to 57 feet in an abandoned irrigation well about 7 miles southwest of Higley. The depths to water below land surface near Magma were about 330 feet, near Higley about 165 feet, and near Queen Creek about 310 feet.

Tempe-Mesa-Chandler area. --In the period spring 1961 to spring 1962 water-level fluctuations in the Tempe-Mesa-Chandler area ranged from a rise of 2 feet to a decline of 20 feet. For the most part the larger declines were in the area northeast of Mesa where pumping is concentrated. The declines were least near Tempe and south of Chandler. The overall downward trend of the water levels in this area has continued since the early 1940's (fig. 27).

During the 5-year period spring 1957 to spring 1962 the water table declined more than 60 feet in Mesa and about 20 feet in Tempe (fig. 26). Declines throughout the rest of the area were generally progressively less to the south and were about 10 feet south of Chandler. In the spring of 1962 the depth to water below the land surface was about 310

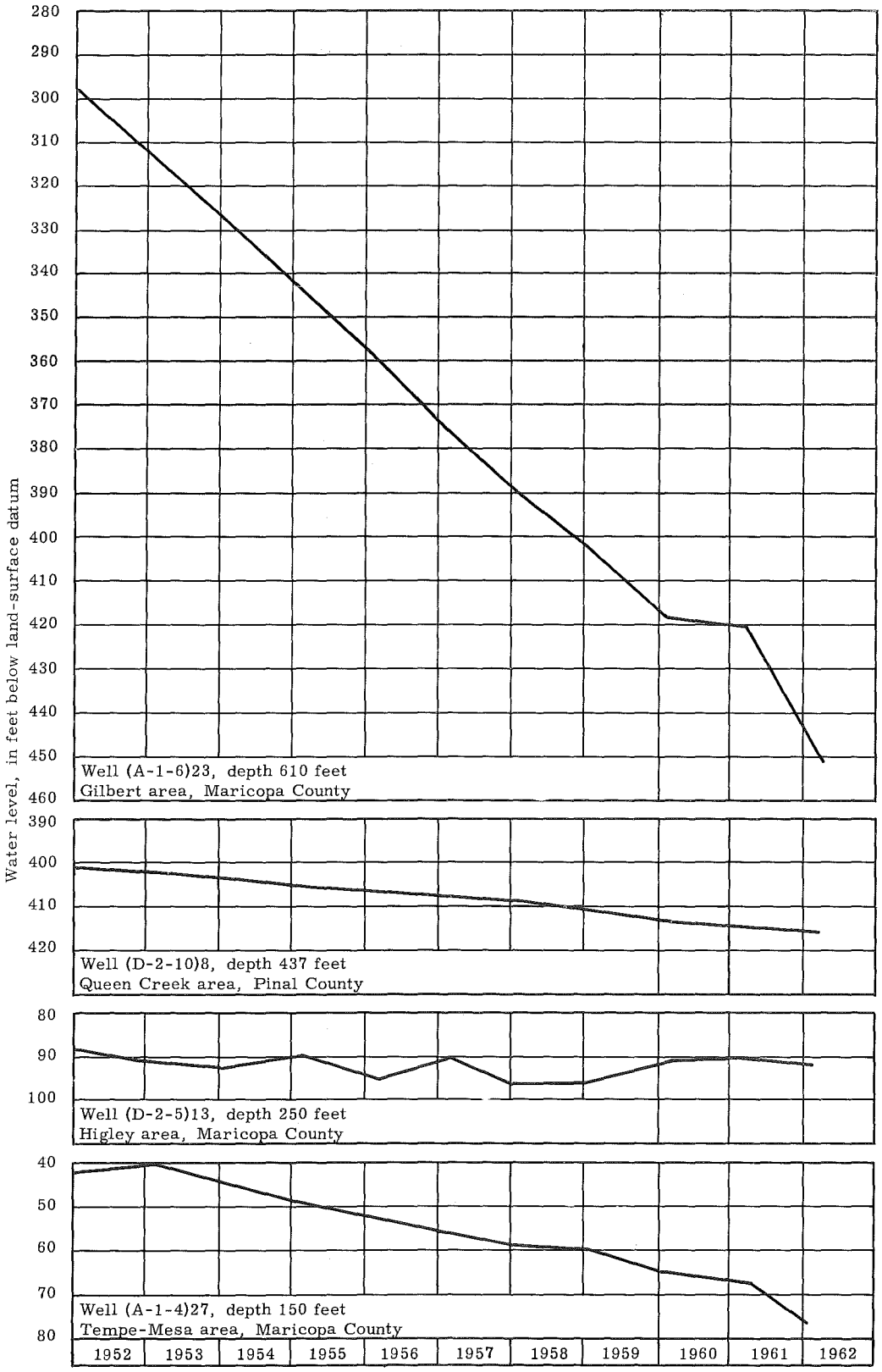

Figure 30. —Water levels in selected wells in Queen Creek-Higley-Gilbert-Magma and Tempe-Mesa areas, Salt River Valley.

feet northeast of Mesa, about 155 feet near Chandler, about 235 feet at Mesa, and less than 80 feet at Tempe. The shallowest water level measured in the area was 76 feet below land surface in an abandoned irrigation well a mile south of Tempe. The hydrograph of well (A-1-4) 27 (fig. 30) shows the continuous downward trend of water levels in the area between Tempe and Mesa.

Phoenix-Glendale-Tolleson-Deer Valley area.--During the period spring 1961 to spring 1962 water-level fluctuations ranged from rises of about 10 feet to declines of about 17 feet. The declines were greatest in Deer Valley. Although much acreage in Deer Valley has been converted from agricultural to residential and industrial use, the water levels continue to decline—as shown by the hydrograph for well (A-3-2) 2 (fig. 31). In the area south of the Arizona Canal in the Salt River Project the water-level declines decreased toward Tolleson. The cumulative net changes in water levels in the Phoenix-Glendale-Tolleson area (fig. 28) show the accelerated decline beginning in the early 1940's. Ground water is used in the Salt River Project to supplement surface-water supplies; therefore, ground-water demands within the project are not as great as elsewhere. The water levels rose in some wells in north Phoenix where they are affected by seepage from the Arizona Canal.

During the 5-year period spring 1957 to spring 1962 water-level fluctuations ranged from almost no change to declines of more than 60 feet in Deer Valley (fig. 26). As in previous periods, the largest declines were in Deer Valley near Skunk Creek and the New River. Along the mountains to the north and south of Phoenix the water-level declines were small because of canal seepage and lack of concentrated pumping. The 5-year declines in the center of the Phoenix-Glendale-Tolleson-Deer Valley area were about 20 to 40 feet. In the spring of 1962 depth to water below land surface was about 50 feet in central Phoenix, 205 feet in Glendale, 305 to 440 feet in Deer Valley, and about 155 feet in Tolleson. In north Phoenix, adjacent to the Arizona Canal, water levels were less than 20 feet below land surface.

Paradise Valley area.--There were minor water-level fluctuations in the Paradise Valley area in the period spring 1961 to spring 1962. Pumping of ground water for agricultural purposes in Paradise Valley always has been minor compared to other parts of the Salt River Valley. All the irrigation wells are in the southern half of the area, and it was here that the declines were greatest during the period spring 1961 to spring 1962.

For the 5-year period spring 1957 to spring 1962 water-level declines in the area were less than 20 feet and, therefore, do not fall within the contour interval of the decline map (fig. 26). In the spring of 1962 measured depths to water in Paradise Valley ranged from about 430 feet to 170 feet below land surface.

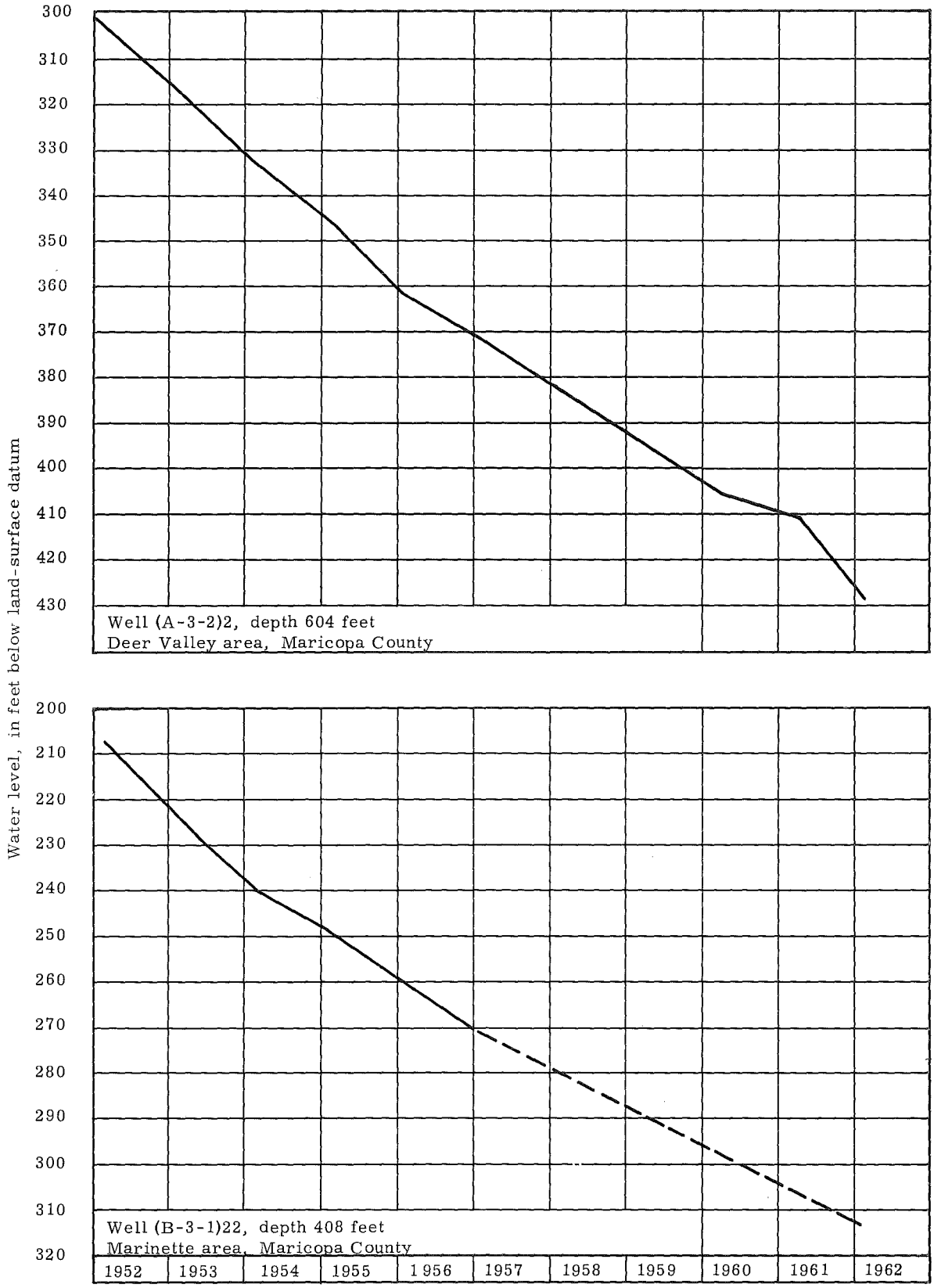

Figure 31. —Water levels in selected wells in Deer Valley and Marinette areas, Salt River Valley.

Litchfield Park-Beardsley-Marinette area. --Ground water constitutes the major source of water available for agriculture in the Litchfield Park-Beardsley-Marinette area. Figure 28 shows the cumulative net changes in the water levels and indicates the effect of increased pumping beginning in the early 1940's. The hydrograph for well (B-3-1)22 (fig. 31) shows the effects of pumping in this area during the last 10 years. For the period spring 1952 to spring 1962 the water level in this well declined more than 100 feet.

In the northern part of this area most of the wells were pumping during 1961 and measurements were difficult to obtain. As a result the decline from spring 1961 to spring 1962 is difficult to calculate. However, the hydrograph for well (B-4-1)8 (fig. 32) indicates that the water level in this part of the area is following the trend of previous years. The water level in this well has declined about 70 feet during the 10-year period spring 1952 to spring 1962.

During the 5-year period spring 1957 to spring 1962 water-level declines ranged from more than 60 feet in the western part of the area to less than 20 feet in the southern part of the area (fig. 26). The maximum declines were in areas of deep water levels. In the spring of 1962 the average depth to water in the northeastern part of the area was about 370 feet below land surface; along the northeast edge of the White Tank Mountains the depth to water was more than 420 feet. The White Tank Mountains are an effective barrier to ground-water movement from the west into the area east of the mountains and west of Litchfield Park. In the spring of 1962 the minimum depth to water was about 146 feet in an irrigation well along the canal southwest of Litchfield Park. In the vicinity of Litchfield Park the depth to water ranged from about 146 to 330 feet below land surface; near Marinette the average water level was about 305 feet, and near Beardsley about 300 feet.

Liberty-Buckeye-Hassayampa area. --Water-level fluctuations in this area from spring 1961 to spring 1962 ranged from a rise of 3 feet to a decline of more than 6 feet. Water levels in most of the Liberty-Buckeye-Hassayampa area follow the same downward trend as in other areas in the Salt River Valley (fig. 29). However, the rate of decline is much less because the shallow water table probably is recharged by irrigation water applied to cultivated land upstream. The hydrograph of well (B-1-4)34 (fig. 32) shows the typical water-level trend for this area. During the 5-year period spring 1957 to spring 1962 water levels in the Liberty-Buckeye-Hassayampa area fluctuated slightly and most of the declines were less than 20 feet (fig. 26). The water levels in the area west of Buckeye generally declined less than 10 feet, but in the vicinity of Perryville water levels declined more than 20 feet. In the spring of 1962 the depth to water below land surface in the irrigation wells in the area ranged from about 30 feet southwest of Buckeye to about 215 feet north of Perryville.

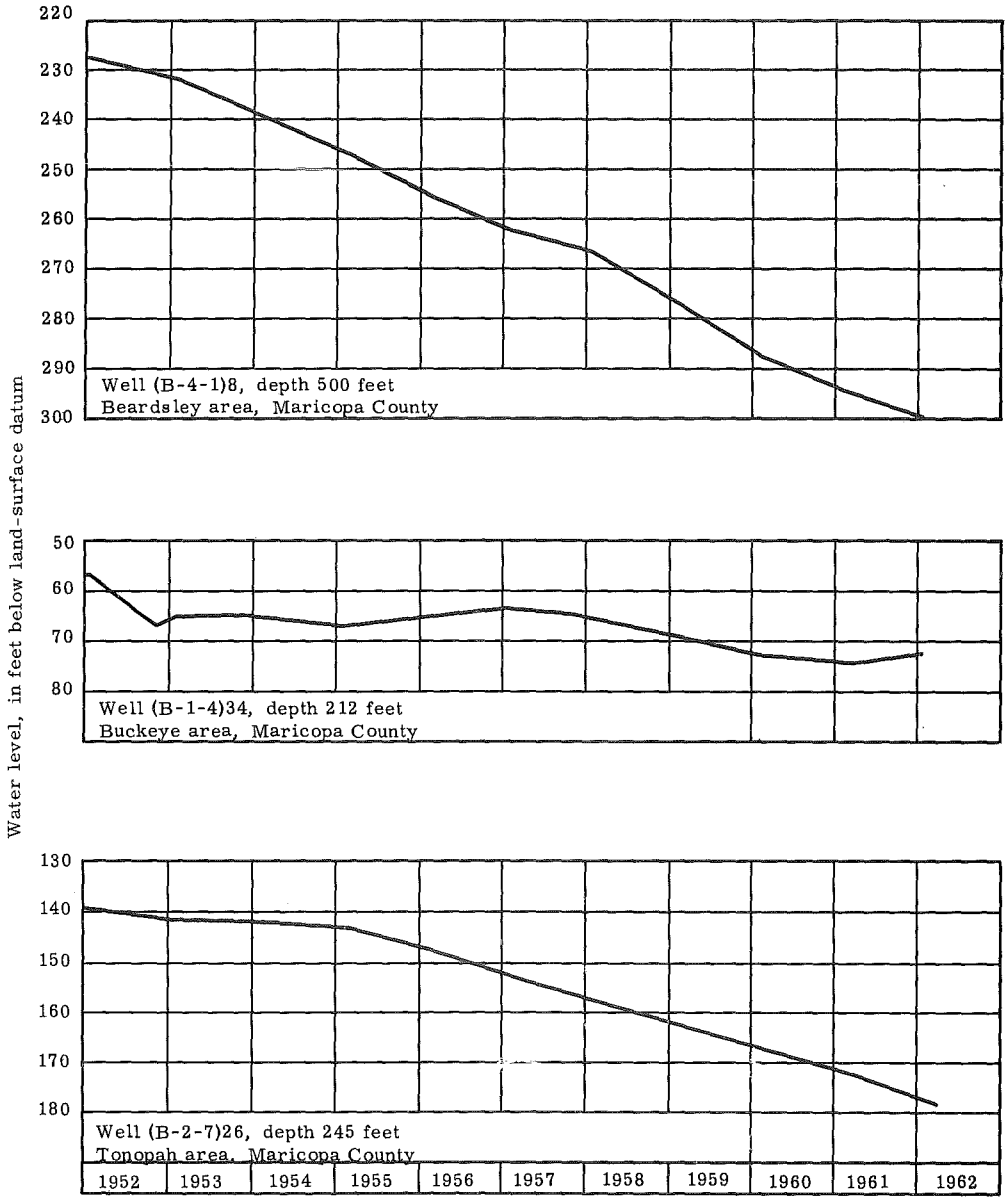

Figure 32. --Water levels in selected wells in the Beardsley, Buckeye, and Tonopah areas, Salt River Valley.

The depth to water at Hassayampa is less than 50 feet below the land surface; near Buckeye the water table is about 85 feet below land surface. At Liberty and adjacent to the Gila River south to the Gillespie Dam water levels are about 50 feet below land surface.

Lower Hassayampa-Tonopah area.--The steady rate of decline of the water levels in the lower Hassayampa-Tonopah area began about 1955 because of the increase in pumping of ground water for agriculture. At present there are about 60 active irrigation wells in the area; most of them are near Tonopah. During the period spring 1961 to spring 1962 the water levels in the area generally continued to decline; the greater declines were near Tonopah. The hydrograph for well (B-2-7)26 (fig. 32) shows the fluctuations of the water level in a well before and after irrigation development in a typical alluvial basin in southern Arizona.

During the 5-year period spring 1957 to spring 1962 water-level declines within the area ranged from less than a foot to more than 30 feet. Water levels in the cultivated areas surrounding Tonopah declined more than 20 feet (fig. 26). During this period water levels rose in several wells—particularly in those wells along the floodplain of the Hassayampa River. In the spring of 1962 water levels in the area ranged from about 13 feet below land surface in an abandoned well near the Hassayampa River to about 240 feet northeast of Tonopah.

Lower Centennial area.--Water-level declines in the lower Centennial area during the period spring 1961 to spring 1962 were as great as 12 feet. The greater declines were in irrigation wells in the western part of the area where there has been new development in the last 2 years. In the spring of 1962 depths to water in the area ranged from about 26 feet below land surface near the junction of Centennial Wash and the Gila River to more than 250 feet in an irrigation well in the lower part of T. 1 N., R. 6 W.

Waterman Wash Area

By

R. S. Stulik

The Waterman Wash area (fig. 6, No. 13) is bounded on the north by outliers of the Sierra Estrella and the Buckeye Hills, and on the east by the Sierra Estrella and Palo Verde Mountains. On the south the area is bounded by the southern range of the Maricopa Mountains, and the Booth and Haley Hills. On the west the Waterman Wash area is separated from the Rainbow Valley area by the Maricopa Mountains and a low alluvial ridge extending northward from the Maricopa Mountains to the Buckeye Hills. The area of about 400 square miles is drained by Waterman Wash, a northwest-trending intermittent stream.

The area is underlain by alluvial fill similar in character to that of other basins in the semiarid regions of southern Arizona. Ground water occurs under water-table conditions in the sand and gravel lenses of the alluvial fill.

Only the northern part of Waterman Wash has been developed for agriculture, and it is in this part that most of the water-level declines have taken place. During the period spring 1961 to spring 1962 water-level fluctuations ranged from no change to a decline of about 7 feet. The water level in well (C-2-2)25 (fig. 33) has declined about 35 feet since the spring of 1957. The water level in well (C-3-1)1 (fig. 33) south of the irrigated area declined about 13 feet in the period spring 1952 to spring 1962. The depth to water in the Waterman Wash area ranged from about 150 to more than 365 feet below the land surface in the spring of 1962.

Gila Bend Area

By

R. S. Stulik

The Gila Bend area (fig. 6, No. 14) is that part of the Gila River valley extending from Gillespie Dam on the Gila River to a point 36 miles downstream near the Painted Rock Narrows. The area is bounded by the Gila Bend Mountains and the Buckeye Hills on the north, the Maricopa and Sand Tank Mountains on the east, the Sauceda Mountains on the south, and the Painted Rock Mountains on the west.

Ground water generally moves southward parallel to the Gila River. In the northern end of the area a cone of depression has formed owing to the continual pumping of ground water. A part of this water is pumped into the Gillespie Canal and is used to irrigate land downstream.

In the spring of 1962 more than 125 irrigation wells were in operation in the Gila Bend area. About 60 of these wells are in the northeastern part of the Gila Bend basin, known as Rainbow Valley.

The Rainbow Valley area is a southwest-trending valley lying between the Buckeye Hills and the northern edge of the Maricopa Mountains which drains into the Gila River about 4-½ miles below Gillespie Dam. It is hydrologically a part of the Gila Bend area and is separated from it on the south by an arbitrary line that forms an extension of the drainage divide in the northern part of the Maricopa Mountains. Ground-water movement in the area is southwestward toward the Gila River and from north to south along the river. Water-level fluctuations in the Rainbow Valley area during the period spring 1961 to spring 1962 ranged from a small rise to a decline of about 5 feet. The water level in well (C-4-4)9 (fig. 33), just south of Rainbow Valley, declined about 5 feet during 1961 and about 80 feet since 1953.

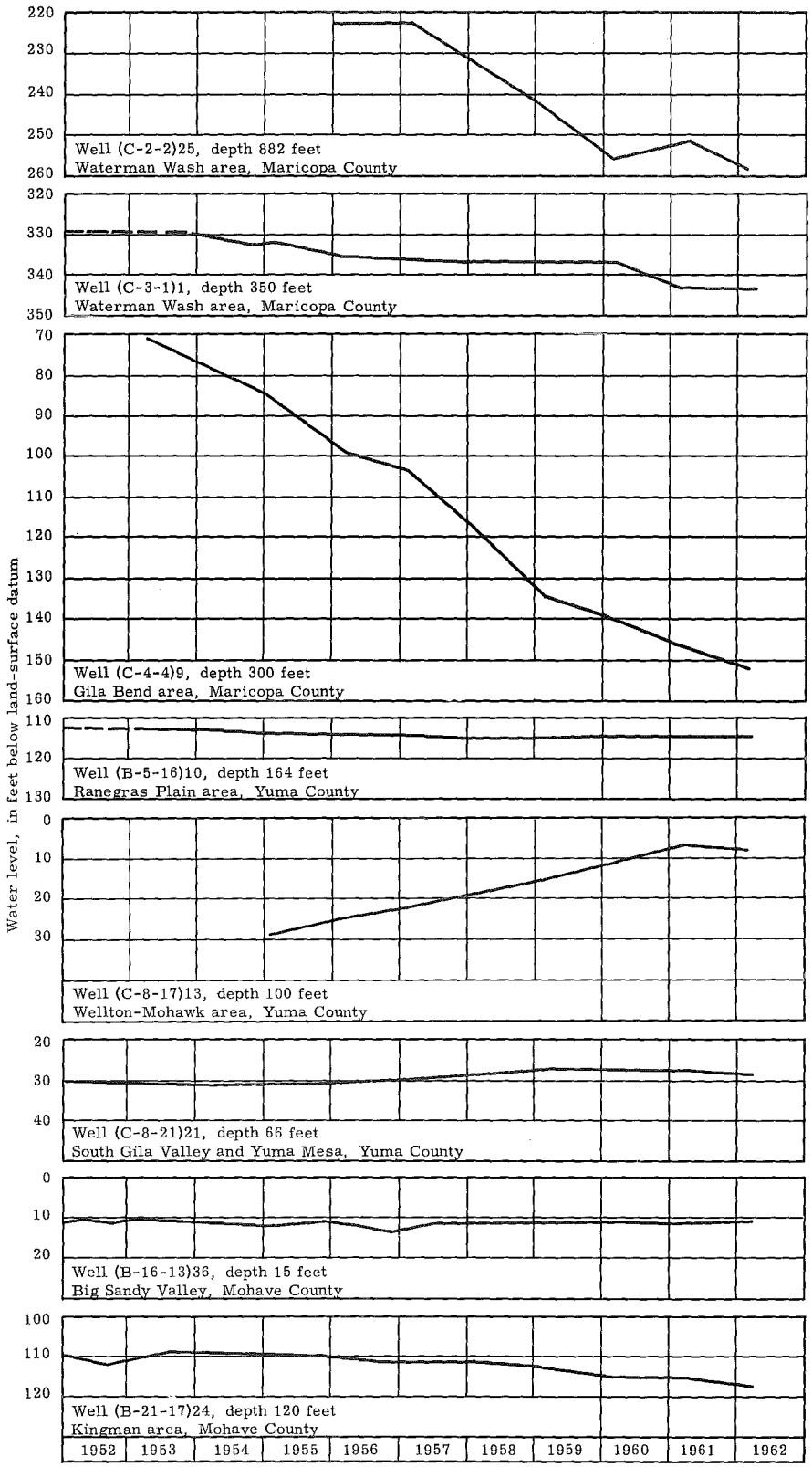

Figure 33. —Water levels in selected wells in several areas in the Basin and Range lowlands province.

In the western part of the Gila Bend basin, water-level fluctuations for the period spring 1961 to spring 1962 ranged from a rise of about 10 feet to a decline of about 10 feet.

Harquahala Plains Area

By

R. S. Stulik

The Harquahala Plains area (fig. 6, No. 15) is a northwest-trending basin drained principally by Centennial Wash. It is bounded on the northeast by the Big Horn Mountains, on the northwest by the Harquahala and Little Harquahala Mountains, on the southwest by the Eagle Tail Mountains, and on the southeast by Saddle Mountain and the Gila Bend Mountains.

In the spring of 1962 more than 75 irrigation wells were in use in the Harquahala Plains area as compared to about 30 during 1956. Most of the development is in the southeastern part of the area where the yields of the wells range from about 800 to 3,000 gpm. Data pertaining to the decline of water levels in the area have been difficult to obtain during previous years because of year-round pumping. During the spring of 1962 measurements in several wells in the center of the cultivated area indicated average yearly declines of about 15 feet.

In the spring of 1962 measured depths to water below land surface ranged from about 18 feet in the extreme southeast to more than 350 feet in the center of the cultivated area.

McMullen Valley Area

By

R. S. Stulik

The McMullen Valley area (fig. 6, No. 16) is a northeast-trending valley about 40 miles long lying between the Harcuvar and Harquahala Mountains. The western half of the area is within Yuma County and the eastern half is in Maricopa and Yavapai Counties.

The use of ground water for irrigation in the area dates back to the early 1900's when small acreages were irrigated in the Harrisburg Valley southeast of Salome. However, more than half the present irrigation wells in McMullen Valley have been drilled since 1955. The two areas of most recent development are near the towns of Wenden and Aguila.

During the period spring 1961 to spring 1962 measured water-level fluctuations near Aguila ranged from a decline of about 2 feet northwest of Aguila to a decline of about 15 feet in a domestic well north of Aguila. Both of these wells are on the fringe of the cultivated area and therefore are not indicative of the decline within the pumped area. Records of water-level fluctuations in several irrigation wells within the cultivated area showed declines in excess of 30 feet during the period from spring 1959 to spring 1962. Because of year-round pumping in the area it is difficult to obtain more detailed data.

During the period spring 1961 to spring 1962 water-level fluctuations in the vicinity of Salome ranged from a small rise southeast of Salome to a decline of about 2 feet south of Salome. This part of McMullen Valley is not developed as extensively as the Aguila area and water levels are nearer the land surface. Because of pumping, data in the vicinity of Wenden were not available. Depths to water below land surface in McMullen Valley during the spring of 1962 ranged from about 95 feet south of Salome to about 490 feet near Aguila.

Palomas Plain Area

By

R. S. Stulik

Palomas Plain (fig. 6, No. 17) is an alluvial area that extends northwest from the Gila River bounded by Oatman and Face Mountains on the east and the Palomas, Tank, and Kofa Mountains on the west. On the north it is bounded by the Little Horn Mountains and the Clanton Hills. The area lies within both Yuma and Maricopa Counties, but most of the agricultural development is in Yuma County.

During the period spring 1961 to spring 1962 water-level fluctuations in wells in and near the Palomas Plain area ranged from a rise of about 6 feet in an abandoned well east of Horn to a decline of about 5 feet in an abandoned well several miles southwest of the area near Dateland. The majority of data in the area showed little change in water levels. In the spring of 1962 the depth to water below land surface in the irrigated areas ranged from about 21 feet along the Gila River to about 269 feet north of Hyder.

Ranegras Plain Area

By

R. S. Stulik

The Ranegras Plain area (fig. 6, No. 18) is in northern Yuma County and is bounded on the north by the Bouse Hills, on the south by the Eagle Tail Mountains, on the east by the Granite Wash Mountains, and on the west by the Plomosa Mountains.

Agricultural development in the Ranegras Plain area has increased very little in the last several years. In 1960 there were about 15 irrigation wells equipped to pump water, but not all these wells were in operation.

From spring 1961 to spring 1962 water-level fluctuations in the Ranegras Plain area ranged from a rise of about 4 feet to a decline of about a foot. The hydrograph for well (B-5-16)10 (fig. 33) shows water-level fluctuations typical of the undeveloped parts of the area. Essentially, there has been no change in the water level in this well during the last 10 years. The depth to water in the Ranegras Plain area in the spring of 1962 ranged from about 33 to 237 feet below land surface.

Wellton-Mohawk Area

By

R. S. Stulik

The Wellton-Mohawk area (fig. 6, No. 19) is a flat desert plain that extends from Dome upstream along the Gila River for a distance of about 46 miles. The area is bounded on the west by the Gila Mountains; on the north by the Muggins and Castle Dome Mountains; on the east by outliers of the Mohawk Mountains; and on the south by the Wellton Hills, the Copper Mountains, and an arbitrary line extending northeast along U. S. Highway 80 to the Mohawk Mountains.

Pumping of ground water for irrigation has nearly ceased in the area because of the operation of the Wellton-Mohawk reclamation project which began in 1957. Water levels began to rise and continued to rise through 1960. During the early part of 1961 about 65 drainage wells went into operation in the area and water levels began to decline again.

Water-level fluctuations during the period spring 1961 to spring 1962 ranged from a rise of about 4 feet to a decline of about 14 feet. The water level in well (C-8-17)13 (fig. 33) rose more than 20 feet during the period spring 1955 to spring 1962; however, it declined more than a foot from spring 1961 to spring 1962. The depth to water below land

surface in the Wellton-Mohawk area in the spring of 1962 ranged from about 4 feet in a well near the Gila River to about 80 feet in the area north of Texas Hill.

South Gila Valley, Yuma Mesa, and Yuma Valley Area

By

F. J. Frank

The south Gila Valley (fig. 6, No. 20) is that part of the Gila River flood plain south of the Gila River and bounded on the east, west, and south by the Gila River Terrace, also referred to as the Yuma Mesa. Ground water is the principal source of irrigation water.

The Yuma Mesa (fig. 6, No. 20) is bounded on the north by the south Gila Valley, on the west by the Yuma Valley, and arbitrarily on the south by the Mexican border. In this area the principal source of water for irrigation is the Colorado River. Supplemental ground water is used, particularly on the outer fringes of the area.

The Yuma Valley (fig. 6, No. 20) is along the Colorado River flood plain and is bounded on the north and west by the Colorado River, on the south by the Mexican border, and on the east by the Yuma Mesa, where Colorado River water is the principal source of irrigation water. However, adjacent to the Colorado River from the city of Yuma south to the Mexican border, considerable amounts of ground water are used for irrigation.

For the most part the water levels in the south Gila Valley declined during the period spring 1961 to spring 1962; the rate of decline is proportional to the distance from drainage wells installed by the U. S. Bureau of Reclamation during the winter and spring of 1961. The water level in wells several miles from the drainage system declined about half a foot, but the water level in wells in the immediate vicinity of the drainage wells declined as much as 11 feet, from spring 1961 to spring 1962. The water level in well (C-8-21)21 (fig. 33) declined about half a foot from spring 1961 to spring 1962. The water level in wells located on the outlying fringe of the valley, adjacent to the irrigated area, showed no change during the period. The water levels in most of the wells were about 17 feet below land surface in spring 1962.

The water levels continued to rise on the Yuma Mesa from spring 1961 to spring 1962. The water levels in this area started to rise during the month of June, reached maximum levels during September and October, and thereafter declined steadily. This period of fluctuation coincides with maximum use of Colorado River water for the irrigation of extensive citrus groves located on the Yuma Mesa. However, during the period spring 1961 to spring 1962 the overall trend was a rise in water levels of from 1 to 2 feet. In a few wells on the edge of the mesa

above the south Gila Valley, near the U. S. Bureau of Reclamation drainage wells, a decline in water level of almost 2 feet was noted.

During the period spring 1961 to spring 1962, the majority of the data collected in the Yuma Valley area showed no change in water levels. The water levels in wells adjacent to the Colorado River in the area irrigated by ground water reach a maximum decline of about 1 to 2 feet during August and start to recover during October, but there is little long-term change. Although some of this seasonal fluctuation may have been influenced by pumping, it can also be attributed partly to the fluctuation in flow of the Colorado River. In parts of the Yuma Valley adjacent to the Yuma Mesa and irrigated with Colorado River water, a rise in water levels of 1 to 2 feet was noted. The water levels in this part of the area tend to rise during August, September, and October and thereafter gradually decline with no overall change. Throughout the center of the valley, which is irrigated primarily with Colorado River water, there was little or no change in water levels during the period. Depth to water below land surface in spring 1962 ranged from about 11 to 19 feet.

Big Sandy Valley

By

R. S. Stulik

The Big Sandy Valley (fig. 6, No. 21) is drained by the Big Sandy River which receives water from Trout and Burro Creeks, and Cottonwood and Little Sandy Washes as well as many other washes. The area is more than 60 miles long and is bounded by the Hualapai, Peacock, Rawhide, and Artillery Mountains on the west, and the Cottonwood Cliffs and Aquarius Mountains on the east.

In parts of the area the Big Sandy River has cut its course into a series of predominantly fine-grained lake-bed deposits, and the saturated alluvial fill that now occupies this course is the major source of ground water in the valley. For this reason most of the agricultural development in the area is along the flood plains of the Big Sandy River, and the wells are shallow and readily affected by recharge from the river. The fine-grained lake-bed deposits seem to contain or yield very little water and wells drilled into these beds are usually unsatisfactory. The main sources of ground water other than the alluvium of the flood plains are (1) wells drilled into fracture zones in hard rock, (2) wells drilled into small isolated pockets of alluvium, and (3) springs. The quantities of water obtained from these sources are too limited for irrigation but are adequate for stock or domestic supplies. However, the location of these water supplies generally is difficult to predict and the sources usually are affected readily by climatic conditions.

Water-level fluctuations in wells in the flood plain of the Big Sandy River during the period spring 1961 to spring 1962 ranged from a rise of about 2 feet to a decline of about 16 feet. The hydrograph of well (B-16-13)36 (fig. 33) shows water-level fluctuations typical for this part of the area. The water level in this well declined about a foot during the 10-year period spring 1952 to spring 1962. Depth to water below land surface ranged from 11 feet near Wickieup to about 375 feet below land surface in a stock well near the extreme north end of the area.

Kingman-Hackberry Area

By

R. S. Stulik

The Kingman-Hackberry area (fig. 6, No. 22) trends in a northeast direction from near the city of Kingman to the town of Hackberry. The area is bounded on the southeast by the Peacock Mountains and the northern end of the Hualapai Mountains. On the northwest it is bounded by the southern end of the Cerbat Mountains and by Hualapai Valley; the area drains into the Hualapai Valley. As described, the Kingman-Hackberry area is about 27 miles long and averages about 6 miles in width. The area is largely undeveloped and may not be suitable for large agricultural development.

Ground-water pumping in the Kingman-Hackberry area is mostly for public supply. Water-level fluctuations near Kingman ranged from a rise of about 2 feet to a decline of about 2 feet during the period spring 1961 to spring 1962. The water level in well (B-21-17)24 (fig. 33) indicates the trend in this area. During the period spring 1961 to spring 1962 declines ranged from less than a foot to about 5 feet in the wells near Hackberry. The depth to water below land surface in this area ranged from about 30 feet in a well north of Kingman to about 520 feet in an abandoned well near Antare.

A few miles north of the Kingman-Hackberry area, three wells are used to irrigate land near Truxton. The depth to water below the land surface in one of these wells was about 145 feet in the spring of 1962. The water level in this area did not fluctuate appreciably during the period spring 1953 to spring 1962.

Plateau Uplands Province

By

Natalie D. White

The Plateau uplands province is largely undeveloped and the pumping of ground water for irrigation or other purposes is small. Hence, there has been no sustained decline of the water levels in this province up to the present time. However, there is some evidence of increased development of ground water for irrigation in the Snowflake area of Navajo County and near Tuba City in Coconino County. An increase in population in the Flagstaff area and new pulp mills at Snowflake and in the Red Lake area of the Navajo Indian Reservation also may cause increased use of ground water. Because development is not concentrated in any particular areas, the ground-water conditions in this province are discussed by counties.

Apache County

By

M. E. Cooley

Ground water in Apache County (fig. 6) is under unconfined (water table) and confined (artesian) conditions in the consolidated sedimentary rocks and under unconfined conditions in the weakly consolidated alluvial fill. The main water-yielding units are: the Coconino Sandstone, and gravels underlying volcanic rocks, in the southern part of the area; and, the Navajo Sandstone in the northern part of the area. Water is withdrawn from the alluvium in the Red Lake area north of Fort Defiance and along Chinle Wash.

Most wells in Apache County produce water for stock and domestic purposes and the yields range from 5 to 50 gpm. The depth to water is as much as 1,000 feet, although most water levels are less than 500 feet below land surface. Locally, in the Hunt-St. Johns area and near Round Rock Trading Post, wells flow or show a strong artesian rise. Irrigation wells in the Hunt-St. Johns area yield between 800 and 2,000 gpm from the aquifer system in the Coconino Sandstone. Other wells completed in the alluvium near Chinle and at Red Lake yield 100 to 200 gpm.

There has been no observable long-term decline of water levels in Apache County, although artesian wells in the heavily pumped area near Hunt have ceased to flow. The water levels in these wells show seasonal fluctuation, declining during the summer pumping season but recovering during the winter. A recorder has been installed on well (A-14-26)18 (fig. 34) and the hydrograph shows this trend. Well (A-13-28)

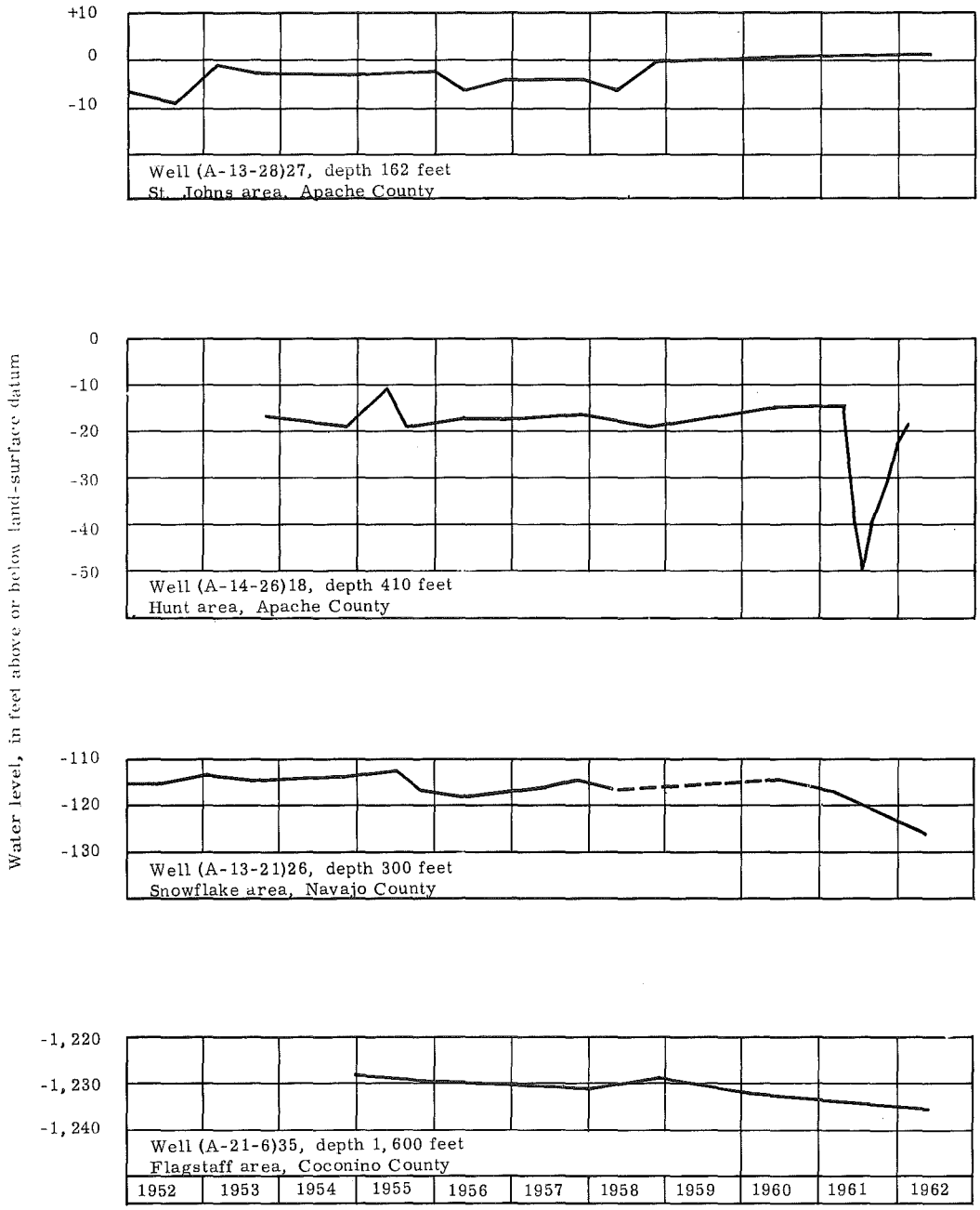

Figure 34. —Water levels in selected wells in the Plateau uplands province.

27 (fig. 34) was flowing slightly when measured in the spring of 1962. Both of these wells penetrate the Coconino Sandstone.

Precipitation of the past winter was heavy, as indicated by records of most weather stations in Apache County for October 1961 to February 1962, and was about a third greater than the mean precipitation for these months. As a result, yields of springs increased and water levels rose in wells located near the recharge areas. At Red Lake the static water level in a well completed in the alluvium was about 20 feet below land surface—about a foot higher than it was when the well was drilled in 1958. In the southern part of the county, the water level in many of the ephemeral lakes, such as Laguna Salada, in internally drained basins, is controlled by the local ground-water table in the alluvium and the volcanic rocks. Before last winter Laguna Salada had been dry, but by March 1962 recharge to the alluvial sediments which completely surround the lake and some surface runoff had filled the lake to the approximate level it occupied in November 1936, as evidenced from aerial photographs flown at that date.

Navajo County

By

P. W. Johnson

Navajo County (fig. 6), in northeastern Arizona, is more than 200 miles long, averages nearly 50 miles wide, and includes a total area of about 9,800 square miles. About 56 percent of the area—about 5,500 square miles—is included in the Navajo and Hopi Indian Reservations. Of the remaining 44 percent—about 4,300 square miles—about 950 square miles is in the Fort Apache Indian Reservation, and about 850 square miles belongs to Sitgreaves National Forest. The remaining land is used for cattle, agricultural, and industrial purposes, and supports the major part of the population of the county. The towns of Winslow, Holbrook, Joseph City, and Snowflake are within this area.

Precipitation in Navajo County for 1961 ranged from about 14 to 17 inches in the southern Mogollon Rim area, from about 5 to 8 inches in the Winslow-Holbrook area in the central part of the county, and from about 8 to 12 inches in the northern part of the county. There is some recharge to ground water from precipitation where the aquifers are exposed at the surface or where they are overlain by permeable rocks that allow water to percolate downward.

The principal aquifers yielding water to wells in Navajo County are the Coconino Sandstone in the area south of Holbrook and Winslow, the Navajo Sandstone in the extreme northern part of the Navajo Indian Reservation, and the Dakota Sandstone and Toreva Formation in the Black Mesa area in the central and southern parts of the Navajo Indian Reservation. Some water is obtained at shallow depths from the allu-

vium along the Little Colorado River and its tributaries. Ground water is discharged by springs from volcanic rocks and associated sediments in the area south of Shumway and in the Hopi Buttes.

The Coconino Sandstone has a wide areal extent and is present at the surface or lies in the subsurface throughout most of the northern part of Arizona. It is the principal aquifer yielding water to all irrigation wells and to most of the domestic and stock wells in the Snowflake, Holbrook, and Winslow areas. Wells developed in the Coconino yield from 25 to 2,000 gpm depending upon their location with respect to the recharge areas, to structure, and to fracturing. For the most part, water levels in the Coconino range from a few feet to more than 500 feet below land surface, but, locally, some wells flow.

The Coconino Sandstone dips northward and is at depths of 1,000 feet or more in the Black Mesa basin where it is overlain by younger beds. Locally, the Navajo Sandstone, Dakota Sandstone, and Toreva Formation are aquifers and supply most of the water used by the Navajo and Hopi Indians. Yields from wells in these formations are small, generally from about 5 to 25 gpm. Water levels range from a few feet to more than 500 feet and, locally, where the aquifers are confined, the water is under artesian pressure and may flow at the surface.

Many small springs—yielding less than 5 gpm—issue from the lavas and other materials derived from volcanism in the Hopi Buttes area. South of Shumway ground water in the lavas and associated sediments is more plentiful and of excellent quality. In this area numerous springs yield substantial amounts of water; the largest is Silver Spring which discharges about 2,000 gpm.

The quality of the ground water in Navajo County ranges from good to poor. The best water generally is in the Coconino Sandstone and the Navajo Sandstone. High concentrations of fluoride make some of the water from the Dakota Sandstone unsuitable for domestic use. In most of the area south of the Little Colorado River the water contains less than 1,000 ppm (parts per million) of dissolved solids, and, locally, less than 200 ppm. However, near the Little Colorado River and north of it the dissolved-solids concentration may exceed 30,000 ppm.

During 1961 the pulp mill about 12 miles west of Snowflake started production of paper products. The water supply for the mill comes from a well field about 4 miles west of Snowflake. The wells penetrate the Coconino Sandstone and yield sufficient amounts of water for present production. Continual pumping has lowered the water levels in the observation wells in the well field; although the extent of the cone of depression caused by pumping in the well field has not been determined, it is possible that part of the decline in the city well, (A-13-21)26 (fig. 34), can be attributed to this pumping. If additional wells are drilled and more water is withdrawn from the aquifer the cone will deepen and expand.

In general, fluctuations of the water levels in most of Navajo County are slight and show no long-term trends. Water-level fluctuations are greatest in the Snowflake-Hay Hollow area where, for the most part, they reflect the seasonal use of water. Water levels decline during the summer when ground water is pumped for irrigation but partially recover after the pumping season. At the present time, recharge is nearly sufficient to replace the water withdrawn, although drilling of new wells and continued pumping in the area will result in a more marked decline in the water level. In parts of the county where there is little pumping of ground water, water-level fluctuations reflect seasonal and annual differences in precipitation.

Coconino County

By

J. P. Akers

Coconino County (fig. 6) is in the southern part of the Colorado Plateau characterized by horizontally stratified sedimentary rocks and lava fields that are dissected by deep canyons. Altitudes range from about 1,500 feet above mean sea level in the gorge of the Colorado River at the western boundary of the county to 12,611 feet on San Francisco Mountain north of Flagstaff.

Sedimentary rocks in the northeastern part of Coconino County near the western part of Black Mesa are about 10,000 feet thick. However, in most of the area southwest of the Little Colorado River erosion has removed more than half of these rocks. Lava flows as much as 600 feet thick cover extensive areas along the southern boundary of the county.

South of the Colorado and Little Colorado Rivers the most important aquifer is the Coconino Sandstone which consists mostly of very fine to fine grains of quartz. The Coconino is present in the subsurface in nearly all of Coconino County, but in most of the area northwest and west of Flagstaff it does not contain water.

Wells in the Coconino Sandstone generally yield small to moderate amounts of water. The largest yields—from 250 to 500 gpm—are obtained in the Leupp area and in the Woody Mountain well field which supplies municipal water for the city of Flagstaff. Wells in the Woody Mountain well field were located to take advantage of increased permeability due to fracturing of the Coconino Sandstone by faulting. Water levels in the Coconino range from about 100 feet below land surface near the Little Colorado River to more than 1,400 feet in the Doney Park area. In most of the area south of the Little Colorado River the water is under water-table conditions.

The quality of water in the Coconino Sandstone is progressively worse northeastward from Flagstaff. Near Flagstaff, the water contains less than 150 ppm dissolved solids; at Wupatki National Monument it contains slightly more than 1,000 ppm and north of the Little Colorado River the dissolved-solids content is so high that the water is unfit for most uses.

There are small perched zones of water in lava and in the Kaibab Limestone of Permian age in the area south and west of the Little Colorado River, but it is not possible to determine the location of these zones from surface methods. The amount of water stored is small and the yield from wells in these perched water zones ranges from 2 to 20 gpm. The water generally is suitable for domestic use.

Northeast of the Little Colorado River the most important aquifer is the Navajo Sandstone. Wells in the Navajo Sandstone generally yield from 10 to 30 gpm; however, a few wells between Copper Mine and Page yield only 2 to 3 gpm, and on the north side of the Colorado River near Page one well is reported to yield about 1,000 gpm. In a few areas near Copper Mine the Navajo Sandstone is dry.

Most of the water in the Navajo Sandstone in Coconino County is under water-table conditions. However, in and near Tuba City the water is under artesian pressure and some wells tapping the Navajo Sandstone flow at the surface. In this area the yields of wells range from 50 to 250 gpm. The quality of the water in the Navajo Sandstone within Coconino County is suitable for domestic use.

Along the streams alluvium supplies small quantities of water to wells in some parts of Coconino County. A few shallow wells, yielding from 10 to 50 gpm, have been developed along Rio de Flag at the northwestern edge of Flagstaff. Data obtained during the spring of 1962 indicate that a considerable part—perhaps as much as 50 percent—of the surface water in Rio de Flag enters the alluvium and lava in the reach between the city reservoirs and the railroad in Flagstaff. A few wells in alluvium along the Little Colorado River near Leupp yield from 30 to 50 gpm of slightly brackish water.

A considerable amount of water for the city of Flagstaff is obtained from glacial deposits on San Francisco Mountain. These deposits readily absorb and transmit water and the amount of water available from them depends on precipitation. In wet years, the yield may be more than 200 million gallons; in dry years, it may be less than 100 million gallons.

The movement of ground water in the consolidated sedimentary rocks in Coconino County is controlled largely by a broad structural arch formed by the Kaibab uplift and the Mormon Mountain anticline. The arch trends northward and ground water, in general, moves away from the crest of the arch to the east and northeast, and to the west and southwest in the area extending about 15 miles north of Tuba City. Water in this area moves generally southward in a shallow structural trough toward springs and artesian wells in and near Tuba City.

Water levels and the yields of springs in alluvium, glacial deposits, and lava fluctuate in response to changes in precipitation. However, water levels in the Coconino and Navajo Sandstones indicate little, if any, fluctuation due to changes in precipitation. Water levels indicate only minor fluctuations in the Tuba City area in spite of a considerable increase in ground-water use. Records of water levels in the Woody Mountain well field do not indicate any significant changes (fig. 34).

Central Highlands Province

By

Natalie D. White

The relatively heavy precipitation in the Central highlands province is the chief source of water for perennial streamflow in the Gila, Salt, and Verde Rivers, and other streams. The surface water that flows southward toward the Basin and Range lowlands province is impounded in reservoirs for use in the alluvial valleys. Because the Central highlands province is areally the smallest of the water provinces in Arizona, and because it is made up largely of rugged mountain masses, the development of ground water is small. Ground water is pumped for irrigation in only a few small alluvial valleys between the mountains. Ground-water conditions in these areas are described below.

Chino Valley

By

H. C. Schwalen[1/] and R. S. Stulik

For this report, Chino Valley (fig. 6, No. 23) is described as extending from just north of Watson Lake to about 5 miles north of Paulden in the north-south direction; in the east-west direction it is an irregularly shaped area bounded roughly by a low-lying extension of the Black Hills on the east and the Juniper Mountains and Sierra Prieta on the west. The valley is not highly developed, but some ground water is used for irrigation in two areas described below.

Chino Valley artesian area. — This small artesian area is about 20 miles north of Prescott in Yavapai County. The town of Chino Valley is in the center of the known artesian basin which is between 6 and 7

1/ Agricultural engineer, Agricultural Engineering Department, University of Arizona—prepared section on "Chino Valley Artesian Area."

miles in length in a north-south direction and averages about 3 miles in width. The southern part of the area is within the Chino Valley Irrigation District which obtains a limited supply of surface water from storage in the Willow Creek and Lake Watson reservoirs. Because of the high pumping lift in this part of the artesian basin—almost 300 feet at the extreme south end—there are only a few pumping plants within the irrigation district.

Artesian water was first encountered in a flowing well in 1930, in sec. 3, T. 16 N., R. 2 W. The artesian aquifer is found in buried lava flows, volcanic ash, and cinders interbedded with valley-fill formation. The upper confining bed consists of a relatively thick bed of silt and clay, or possibly, in some areas, an impervious lava flow. The artesian-pressure surface is nearly level; the slope is only a few feet from south to north and from east to west. However, the land surface has a comparatively steep slope from south to north. Thus, in the spring of 1962 the depth to water in a well tapping the artesian strata in the south end of the area was 269.5 feet below land surface. A flowing well 6 miles north, in the lower end of the area, had a positive head of more than 37 feet above land surface.

During the last 10 years there has been little change in the area irrigated with artesian water. The survey of 1961 indicated slightly more than 3,600 acres of cropland under irrigation. Considering the altitude and the kind of crops grown, it is believed that water requirements are high. The slopes would be considered steep for Arizona conditions and surface runoff would be greater than normal. Seepage from canals and excess irrigation water are losses from the standpoint of the artesian reservoir. Using an average value of 3.5 acre-feet per acre for crop requirements results in a computed withdrawal of water for irrigation in 1961 of almost 13,000 acre-feet from the artesian aquifer. The city of Prescott also obtains part of its municipal supply from the artesian basin in Chino Valley. Its pumpage in 1961 was reported to be 1,840 acre-feet. Total estimated pumpage in 1961 thus amounted to about 15,000 acre-feet from the artesian supply.

There were 60 pumping plants operating in the area in 1961, including the three wells owned by the city of Prescott, in addition to eight flowing wells. During the last 20 years there has been a residual loss of about 40 feet in artesian pressure or water levels throughout the area. Hydrographs of the spring water-level measurements, after recovery from the previous season's pumping, in a few representative wells are presented (fig. 35). During the pumping season there is a rapid drop in artesian pressure or water level throughout the artesian area; in the lower end of the area the drop is as much as 35 feet. Recovery at the end of the pumping season is equally rapid with the result that the normal annual lowering of the water level averages about 2 feet per year.

The water levels in wells from 6 to 7 miles east of the center of pumping show almost the same residual annual losses (fig. 35), but the seasonal effects from pumping are negligible.

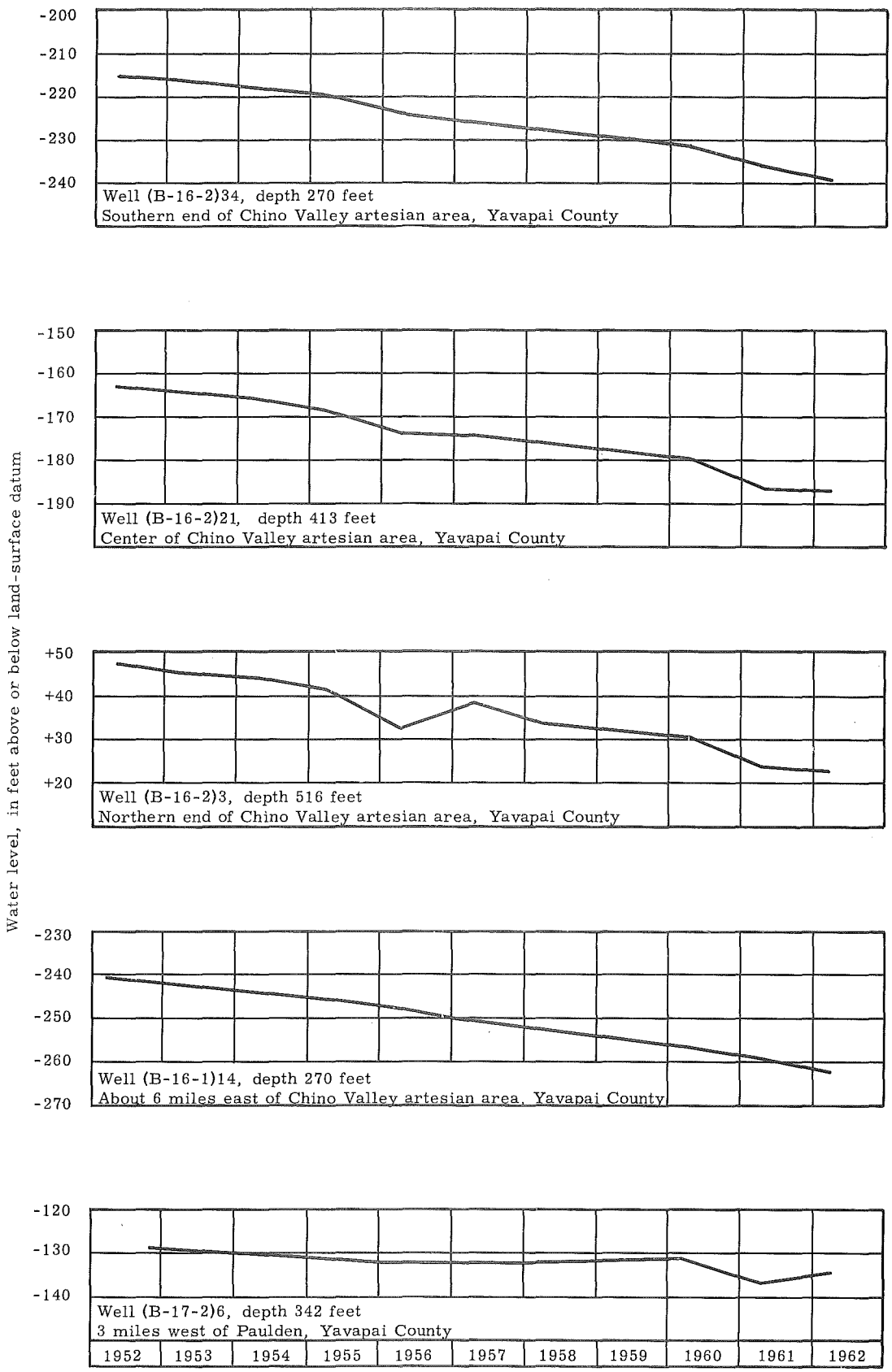

Figure 35. —Water levels in selected wells in Chino Valley.

Water levels and artesian pressures in the spring of 1961 and 1962 showed the effect of winter and early spring pumping before water levels were measured. Hydrographs (fig. 35) indicate that in neither year was full recovery of the artesian-pressure surface attained.

Shallow water-table wells in the irrigated area show a cyclic variation in water level opposite to that in the artesian wells. During the irrigation season the water level rises as much as 10 to 12 feet in some wells and then drops during the winter months. Thus, they furnish evidence of recharge to the shallow water table from percolation losses in adjacent irrigated fields.

Paulden area.--Water-level fluctuations in the Paulden area of Chino Valley during the period spring 1961 to spring 1962 ranged from a rise of about 8 feet to a decline of about 7 feet. Wells are the only source of irrigation water near Paulden, and the hydrograph for well (B-17-2) 6 (fig. 35) shows the water-level trend in the area. In the spring of 1962 depths to water in the area ranged from about 7 feet to more than 355 feet below land surface.

Verde Valley

By

R. S. Stulik

The Verde Valley (fig. 6, No. 24) is a northwest-trending valley extending from the junction of Fossil Creek and Verde River to Perkinsville. It is bounded on the west by the Black Hills and on the east by the Mogollon Rim. Verde River, Oak Creek, West Clear Creek, and Beaver Creek are the main streams in the valley. The towns of Clarkdale, Cottonwood, Camp Verde, and Sedona lie within the area.

The Verde Valley area is divided into the Clarkdale-Cottonwood-Camp Verde area and the Sedona area. In the Clarkdale-Cottonwood-Camp Verde area the principal source of ground water is the Verde Formation of Pliocene(?) or Pleistocene age. In the Sedona area the principal source of ground water is the Supai Formation of Pennsylvanian and Permian age.

Clarkdale-Cottonwood-Camp Verde area.--In this area water is used mainly for farming, domestic, and industrial purposes. The three major sources of water supplies in the Clarkdale-Cottonwood-Camp Verde area are (1) the Verde River and its tributaries, (2) shallow wells near the river, and (3) deeper wells that penetrate the Verde Formation. The Verde Formation is a lake-bed deposit composed of alternating strata of limestone, sandstone, conglomerate, siltstone, and claystone. In some parts of the valley there is sufficient artesian

pressure to cause the wells to flow. Although most of the water used for agriculture in the valley is diverted from the Verde River, there are about 11 irrigation wells in the area. One of the wells is reported to flow at a rate of more than 300 gpm. The depths of the nonflowing wells range from 125 to 800 feet and the water levels range from about 30 to 150 feet below land surface.

More than 150 domestic wells have been drilled to depths of more than 100 feet; most of the wells are in the Verde Formation. The water rose under artesian pressure in most of the wells during drilling; near Cottonwood, Page Springs, McGuireville, and Camp Verde there are about 25 flowing wells. In the nonflowing wells, depths to water range from a few feet to more than 200 feet below land surface. Monthly measurements of selected wells and reported data from well owners and drillers suggest that water-level fluctuations are caused primarily by recharge from precipitation and runoff and not by the effects of pumping. Most of the industrial wells drilled by the mining companies in the Verde Valley were abandoned when the mines closed; however, several are now used for public supply.

During the period spring 1961 to spring 1962 water-level fluctuations ranged from a rise of about 9 feet to a decline of 3 feet. Measured depth to water ranged from about 16 feet to about 140 feet below land surface in spring 1962.

Sedona area.--Prior to 1949 water supplies for the Sedona area were limited to use of surface flow in Oak Creek and shallow wells adjacent to the creek. During the last few years the increase in population has required the development of more convenient and dependable domestic water supplies. During 1949 a successful domestic well was drilled to a depth of 530 feet about 3 miles west of Sedona. Since that time more than 40 wells have been drilled and bottomed in the Supai Formation, which is the major source of domestic water supplies, exclusive of Oak Creek. Measured depths to water in selected wells in this area ranged from 135 to 580 feet below land surface. The altitude of the water surface in the Supai Formation throughout the area ranged from about 3,500 feet along the west edge to about 4,000 feet along the east edge, and the depth to water at any given site will be influenced by the altitude of the land surface at the site. There are several major faults and structures within the area that probably also affect the depth to water. Water-level measurements in several wells indicated some decline during the period spring 1961 to spring 1962, but data are insufficient to determine the overall amount of decline in the area.

Northwest of Sedona water for stock purposes is obtained from the Redwall Limestone at a depth of about 800 feet.

Gila County

By

P. W. Johnson

Gila County (fig. 6) is slightly east of the center of the State and is almost entirely within the Central highlands province. Therefore, it is in an area of high precipitation and limited ground-water supplies. Total precipitation for 1961 ranged from about 12 to 24 inches and averaged about 16 inches. The northern boundary of the county is formed in part by the Mogollon Rim and the southern boundary by the Gila and San Carlos Rivers. The western and eastern boundaries are likewise irregular, giving an overall wedge-shaped appearance to the county as viewed on a map. The major perennial streams of the State form part of the drainage system of the county.

The mountainous terrain of the region affords only limited areas for agricultural development. Gila County has the lowest cropped acreage of any county in the State—slightly more than 1,000 acres in 1961 (Hillman, 1962). Development is restricted mostly to the flood plains along the principal streams which drain the region. Ground water occurs as discharge from the numerous springs in the mountains, perched supplies in the crystalline rocks, and as storage in the alluvial deposits along the drainage system. The principal use of ground water is for mining; agricultural, stock, and domestic consumption account for the remaining water used.

In Gila County, ground-water levels are measured in and near the city of Globe, in the Dripping Springs Valley, and in the San Carlos Valley of the San Carlos Indian Reservation. The Globe area is on the northern slope of the Pinal Mountains; Pinal Creek and its tributaries drain the area and flow northward into the Salt River. Most wells are shallow, and the water levels fluctuate in response to surface flow and local domestic pumping. In general, the water levels in wells rose during the period spring 1961 to spring 1962; in many wells gains for the 1-year period were equal to or greater than the total gain for the 5-year period 1957-62. The overall rise in water levels in the area during the 5-year period probably can be attributed to the above-average precipitation during the last few years.

The Dripping Springs Valley lies between the Pinal and Mescal Mountains on the north and the Dripping Springs Mountains on the south, and drains southward into the Gila River. Most of the water levels are shallow and fluctuate in response to surface flow along the valley. Water levels are generally rising in the area, although from spring 1961 to spring 1962 the water level declined in some of the wells measured.

The San Carlos Valley is in a trough traversed by the San Carlos River, which flows southward to the San Carlos Reservoir. The basin is

bounded on the east by Natanes Mountain; on the south by San Carlos Lake; on the west by the Mescal, Pinal, and Apache Mountains; and on the north, in part, by the Natanes Plateau. Much of the irrigated acreage in the county is along the flood plain of the San Carlos River and its tributaries. The water levels are shallow and the ground water is recharged by summer floods. No decline in water level has been recorded.

USE OF GROUND WATER

By

J. T. Hollander, E. K. Morse, and R. S. Stulik

About 4.7 million acre-feet of ground water was pumped in Arizona in 1961—slightly more than in 1960. The rest of Arizona's annual water supply was obtained from surface water diverted from streams or released from reservoirs. Since 1945 ground water has made up at least half of the State's total annual water supply; from 1955 through 1961 about two-thirds of the State's annual water needs were supplied by ground water. Thus, about 2 gallons of water is pumped from underground storage for each gallon obtained from surface-water supplies.

The greater use of ground water compared with surface water is one of several factors that figure prominently in the Arizona water picture. About 90 percent of the ground water pumped in Arizona is used to grow crops, mostly in the highly developed areas in the Basin and Range lowlands water province (fig. 6). Of the principal areas of ground-water development, the Salt River Valley and the lower Santa Cruz basin account for about 50 percent and 25 percent, respectively, of the total annual pumpage in the State. Irrigation wells in other smaller agricultural areas account for about another 15 percent of the total annual pumpage and the remaining 10 percent is from municipal, domestic, and industrial wells.

The amount of ground water pumped in 1961 has been computed from an analysis of well-discharge measurements and power-consumption records for several of the major irrigated areas in the Basin and Range lowlands province. For some areas, an estimate of the amount of ground water pumped was based on the number of acres irrigated. Most of the data on irrigated acreage were rough estimates supplied by county agricultural agents.

Salt River Valley

About 2,200,000 acre-feet of ground water was pumped from underground storage in the Salt River Valley during 1961—about 10 percent

Upper Santa Cruz Basin

In 1961 about 200,000 acre-feet of ground water was pumped from underground storage in the upper Santa Cruz basin for all purposes. Municipal use of ground water in the Tucson area has more than doubled in the last 5 years—a result of the population increase—whereas, the amount of ground water pumped for irrigation use has not changed greatly. Nevertheless, irrigation use is still more than double that for all other purposes. In 1961, the pumping of ground water for irrigation amounted to about 140,000 acre-feet, and municipal, domestic, and industrial use accounted for about 60,000 acre-feet.

Avra-Marana Area

In 1961 pumpage in the Avra-Marana area amounted to about 105,000 acre-feet. Almost 22,000 acre-feet was pumped in the vicinity of Marana, and about 80,000 to 85,000 acre-feet was pumped in the rest of the Avra-Marana area. The Avra-Marana area drains into the lower Santa Cruz basin; the two areas are separated along an arbitrary line described in the section on ground-water conditions. Nearly all the ground water pumped in the area is used for irrigation of farmland.

Willcox Basin

The Willcox basin in north-central Cochise County includes three main agricultural areas comprising about 65,000 to 70,000 acres of developed land distributed as follows: Kansas Settlement area, southeast of the Willcox playa, about 40,000 acres; Stewart area, north of State Highway 86, about 21,000 acres; and, Cochise-Pearce area, southwest of the playa, about 8,000 acres. Water for irrigation is obtained solely by pumping from underground storage. At least 90 percent of the ground water pumped in the Willcox basin is used to irrigate crops; less than 10 percent is for commercial, domestic, and cooling purposes. Water pumped in 1961 in the Willcox basin for all uses amounted to about 185,000 acre-feet.

Other Areas

Surface flow diverted from the Gila River plus supplemental ground water pumped from the inner-valley sediments are used to irrigate crops in the Safford basin. The crop acreage entitled to surface-water diversion is limited by decree, and each year almost all of the arable land is farmed. The amount of supplemental ground water pumped in a given year is, therefore, almost entirely dependent on the amount of river flow available for diversion. During 1961 surface water diverted

more than in 1960. The increase in use of ground water was due to the fact that less surface water was available in 1961. Pumpage in the area has varied between about 2,000,000 and 2,400,000 acre-feet for the last 10 years. Most of the ground water is used to irrigate crops; less than 10 percent is for municipal, industrial, and domestic use.

The Salt River Valley is divided into eight subareas (fig. 26). Although the data do not permit a complete breakdown by subarea, the pumpage in the Salt River Valley may be conveniently considered in terms of the location of the subareas east or west of the Agua Fria River. East of the Agua Fria River in the Queen Creek-Higley-Gilbert-Magma subarea, about 165,000 acre-feet of ground water was pumped in 1961—nearly 10 percent more than in 1960. In the other three subareas east of the Agua Fria—the Phoenix-Glendale-Tolleson-Deer Valley, the Tempe-Mesa-Chandler, and the Paradise Valley subareas—the pumpage in 1961 totaled about 1,300,000 acre-feet. Pumpage generally was greater in 1961 than in 1960 in these subareas, except for a decrease of about 65,000 acre-feet in the metropolitan area of Phoenix. This decrease in pumpage in the Phoenix metropolitan area is not new, but reflects the continued conversion—apparently more conspicuous in 1961—of agricultural lands to residential use. In the Tonopah subarea west of the Agua Fria River, about 6,000 acres was irrigated in 1961. An analysis of pump-discharge-measurement and power-consumption data indicates that about 35,000 acre-feet of ground water was pumped in this area in 1961. West of the Agua Fria River, the total pumpage during 1961 in the Litchfield Park-Beardsley-Marinette, the Liberty-Buckeye-Hassayampa, the lower Centennial, and the Tonopah subareas was nearly 750,000 acre-feet. This was an increase of about 10 percent over the 1960 pumpage in the four subareas west of the Agua Fria.

Lower Santa Cruz Basin

In 1961 the total pumpage in the lower Santa Cruz basin in Pinal County was nearly 1,150,000 acre-feet. This water was used mainly to irrigate crops in three large areas of development in Pinal County. The amount of water used for domestic, municipal, and industrial purposes is extremely small compared with that used for irrigation. In 1961 the pumping of ground water for irrigation in the Pinal County part of the basin was distributed as follows: Casa Grande-Florence area, about 350,000 acre-feet; Stanfield-Maricopa area, about 470,000 acre-feet; and, Eloy area, about 300,000 acre-feet. Municipal, domestic, and other nonirrigation use is estimated to have been about 15,000 acre-feet in 1961.

The total annual pumpage in the lower Santa Cruz basin has not differed significantly in the period 1956-61, inclusive.

from the Gila River into irrigation canals in the Safford basin amounted to slightly less than 36,000 acre-feet—a near-record low. It is estimated that about 135,000 to 165,000 acre-feet of ground water, therefore, was required in 1961 to supplement the available surface-water supply for irrigation.

The only source of water for irrigation in the San Simon basin is from underground storage. It is estimated that about 65,000 to 85,000 acre-feet of ground water was required to irrigate the 18,500 acres of farmland cultivated in 1961.

The Waterman Wash area is about 25 miles southwest of Phoenix. Most of the pumpage is in the northern part of the area where the agricultural development is concentrated. In the southern part of Waterman Wash area ground water is pumped mainly to water stock. In 1961 the pumpage in the Waterman Wash area is estimated to have been about 65,000 acre-feet.

In the Gila Bend area, which includes Rainbow Valley in its northeastern part, nearly 45,000 acres was irrigated in 1961. Therefore, it is estimated that about 200,000 acre-feet of ground water was pumped in this area in 1961.

In 1961 an estimated 25,000 acres was irrigated in the Harquahala Plains area. Ground-water pumpage to meet irrigation requirements on this acreage in 1961 is estimated to have been about 100,000 acre-feet.

In 1961 about 18,000 irrigated acres was cropped in McMullen Valley. The pumpage is estimated to have been about 75,000 acre-feet.

About 4,000 acres was farmed in the Palomas Plains area in 1961. Ground water pumped to meet irrigation requirements is estimated at about 15,000 acre-feet.

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