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ANNUAL REPORT ON GROUND WATER IN ARIZONA SPRING 1962 TO SPRING 1963

BY
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PREPARED BY THE GEOLOGICAL SURVEY,
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ANNUAL REPORT ON GROUND WATER IN ARIZONA, SPRING 1962 TO SPRING 1963

By

Natalie D. White, R. S. Stulik, E. K. Morse, and others

ABSTRACT

By

Natalie D. White

The availability of adequate water supplies has a greater influence on the economy of arid or semiarid regions than any other factor. In Arizona, the ground-water reservoirs are the main source of water supply. These supplies, although sufficient at the present time, are nevertheless being depleted because the current rate of withdrawal far exceeds the rate of replenishment. If the economy of Arizona continues to expand at its present rate, some method must be found for conserving the known supplies and for augmenting them where possible. Proper management of the ground-water resources requires comprehensive knowledge of the hydrogeologic characteristics that control the ground-water system. A cooperative program to provide the hydrogeologic knowledge needed has been in operation between the State of Arizona and the U.S. Geological Survey 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 1962 to spring 1963.

The occurrence of ground water in Arizona is controlled by the geology and physiography of the three water provinces. These provinces are: (1) the Plateau uplands province in the northern part of the State, (2) the Basin and Range lowlands province in the southern part of the State, and (3) the Central highlands province. The Central highlands province is transitional between the other two provinces.

Of the three provinces, the Basin and Range lowlands province is the most highly developed from the standpoint of water use. The alluvial materials of the basin store large amounts of ground water and yield it readily to hundreds of irrigation, industrial, and domestic wells. Becuase 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 water levels in nearly

all the highly developed areas are declining. In 1962, the greatest declines were in the Salt River Valley and the lower Santa Cruz basin. However, large declines in water level also were measured in the Willcox basin of Sulphur Spring Valley and in the Bowie and San Simon areas of San Simon basin. In areas where surface water was available, such as the Duncan and Safford basins, there were some rises in water level. The Plateau uplands and Central highlands provinces are largely undeveloped, and the pumping of ground water for irrigation or other uses is small. Hence, there have been no large, sustained declines of the water levels in these areas. 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 1962 amounted to about 4.5 million acre-feet---slightly less than in 1961. The decrease is due partly to the availability of surface water during the growing season. The Salt River Valley and the lower Santa Cruz basin continue to be the areas of largest use of ground water, although the percentage of the total amount pumped in the State for these areas is decreasing. More than 90 percent of the ground water pumped in the State as a whole in 1962 was used for irrigation; however, in a few areas the percentage of municipal and industrial use is increasing.

INTRODUCTION

By

Natalie D. White

The availability of adequate water supplies has a greater influence on the economy of arid or semiarid regions, such as Arizona, than any other factor. The economy of Arizona is essentially an agricultural one, particularly in the southern part of the State. In arid or semiarid regions, agriculture cannot depend on rainfall for the growth of crops and, therefore, must resort to irrigation. Some of the water used for irrigation is derived from surface reservoirs that store water from runoff or directly from streamflow when it is available. However, the amount of surface water available is not sufficient for the demands of the vast agricultural lands of southern Arizona. Thus, while it is not generally recognized, ground-water reservoirs are currently the main source of water in Arizona. These supplies, although sufficient at the present time, are not inexhaustible; they are being depleted because the current rate of withdrawal far exceeds the rate of replenishment. Therefore, if the economy of Arizona continues to expand at its present rate, some method must be found for conserving the known supplies and for augmenting them where possible.

Proper management of the ground-water resources requires comprehensive knowledge of the hydrogeologic characteristics that control the storage capacity and the transmission of water through the water-bearing rocks. Quantitative solutions are needed for problems involving the occurrence, movement, and chemical quality of ground water and the effects of withdrawal and replenishment on the ground-water reservoirs. These require detailed and sometimes costly

hydrologic investigations; continued data collection and new methods of hydrogeologic analysis are needed to adequately describe the various parameters that exert influence on the ground-water system.

In July 1939, a district office of the U. S. Geological Survey, Ground Water Branch, was established in Tucson, Ariz., and a cooperative agreement was put into effect between the Geological Survey and the State Water Commissioner for equal financial participation in a planned program of ground-water studies. The Federal-State cooperation has continued to the present time; since 1942, the State has been represented by the State Land Department. During the early years, the program consisted mostly of collecting basic data concerning the development of ground-water resources; the information included well inventories, periodic water-level measurements, measurements of the discharge of wells, chemical analyses of water samples, and descriptions and analyses of drill cuttings. This information helped to document the effects of the increasing withdrawal of ground water in many parts of the State. However, as more and more water was withdrawn from the ground-water reservoir, it became apparent that more intensive studies were needed; beginning in 1956, and continuing to the present time, the Federal-State program was enlarged to include more comprehensive compilation and analysis of the hydrologic and geologic data. Particular emphasis has been directed toward obtaining quantitative answers on the amount of water available, the long-term and short-term effects of withdrawal, the chemical character of the water, and the control that geology has on ground-water hydrology.

This report shows the trend toward intensive analysis of the geologic and hydrologic data collected during the year spring 1962 to spring 1963 and includes discussions on ground-water conditions in selected basins and areas throughout the State. Changes and trends in water levels throughout the State, ground-water pumpage in the principal areas of agricultural development, surface-water diversions, climate, and the chemical quality of water also are discussed. Special sections in this year's report that describe several aspects of hydrology are: "Methods of Analysis of Hydrologic Data," "Hydrology of the Plateau Uplands Province," and "Effect of Flood of September 1962 on Ground Water in the Santa Cruz Valley." Principal maps and diagrams illustrating variations in the hydrologic conditions include: (1) hydrographs showing comparative changes in the stage of water levels in selected wells in the State for the last 10 years; (2) graphs showing cumulative changes in the water level and pumpage in the Salt River Valley, 1930-63, and in the lower Santa Cruz basin in Pinal County, 1940-63; (3) maps showing contours of the change in ground-water levels for the 5-year period 1958-63 in the Salt River Valley, lower Santa Cruz, and Douglas basins, and for the 10-year period 1953-63 in the Willcox basin; (4) maps showing the altitude of the water level in the Willcox and Douglas basins, in the San Pedro River valley, and in the western part of the Salt River Valley; (5) a map of the Plateau uplands province showing altitudes of water levels in the principal aquifers and the direction of movement and points of natural discharge in the hydrologic basins; (6) a map of Coconino County showing the availability of ground water; and (7) tables summarizing the hydraulic properties of the aquifers and the chemical quality of the ground water in the Plateau uplands province.

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

Water problems relating to insufficient supplies, equitable distribution and protection of the available supply, and deterioration in quality of water are likely to arise wherever ground water is pumped in large quantities. Because the solutions to these problems depend on adequate knowledge of the occurrence, movement, recharge, discharge, and chemical quality of the ground water and because these factors are functions of the geologic and hydrologic environment, studies must be made in relation to the particular problem rather than to an area or basin. Some of the subjects covered under this phase of the cooperative program include:

(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) 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, conductivity, and temperature logs are used to determine the subsurface characteristics of the materials encountered during drilling. Where these can be correlated with drillers' logs or analyses of cuttings from the same wells and with the hydraulic characteristics of the well, much can be determined about the areal characteristics of the aquifers by so logging other wells in the area for which no other data exist. Likewise, the analysis of geologic and hydrologic data has been advanced by the use of electronic methods. The use of electrical-analog methods to analyze the geohydrologic data from basins in Arizona may give the needed refinement to the semiquantitative analysis previously made by standard mathematical methods. Both the electrical-analog and the standard mathematical methods are more fully discussed in the section entitled "Methods of Analysis of Hydrologic Data" in this report.

Ground-Water Projects in Arizona

The following investigations were being conducted and were in various stages of completion under the Federal-State cooperative ground-water program in Arizona in 1962. (1) The statewide collection of geologic and hydrologic data; (2) Geohydrology and utilization of water in Willcox basin, Cochise County; (3) Change in water yield by defoliation and vegetation removal, Cottonwood Wash, Mohave County; (4) Electrical-analog analysis of hydrologic data for the San Simon basin, Cochise and Graham Counties; (5) Basin potential of Sycamore Creek, Maricopa County; (6) Investigation of geology and ground-water conditions in the Dateland-Hyder area, Yuma County; and (7) Study of ground-water conditions in the Beardsley area, Maricopa County. Reports in final stages of preparation are: (1) Subsurface geologic and hydrologic studies of western Pinal County; (2) Geology and ground-water resources of Big Sandy Valley, Mohave County; and (3) A basic-data report and hydrologic atlases describing the chemical quality of water and general geohydrology of the Willcox basin.

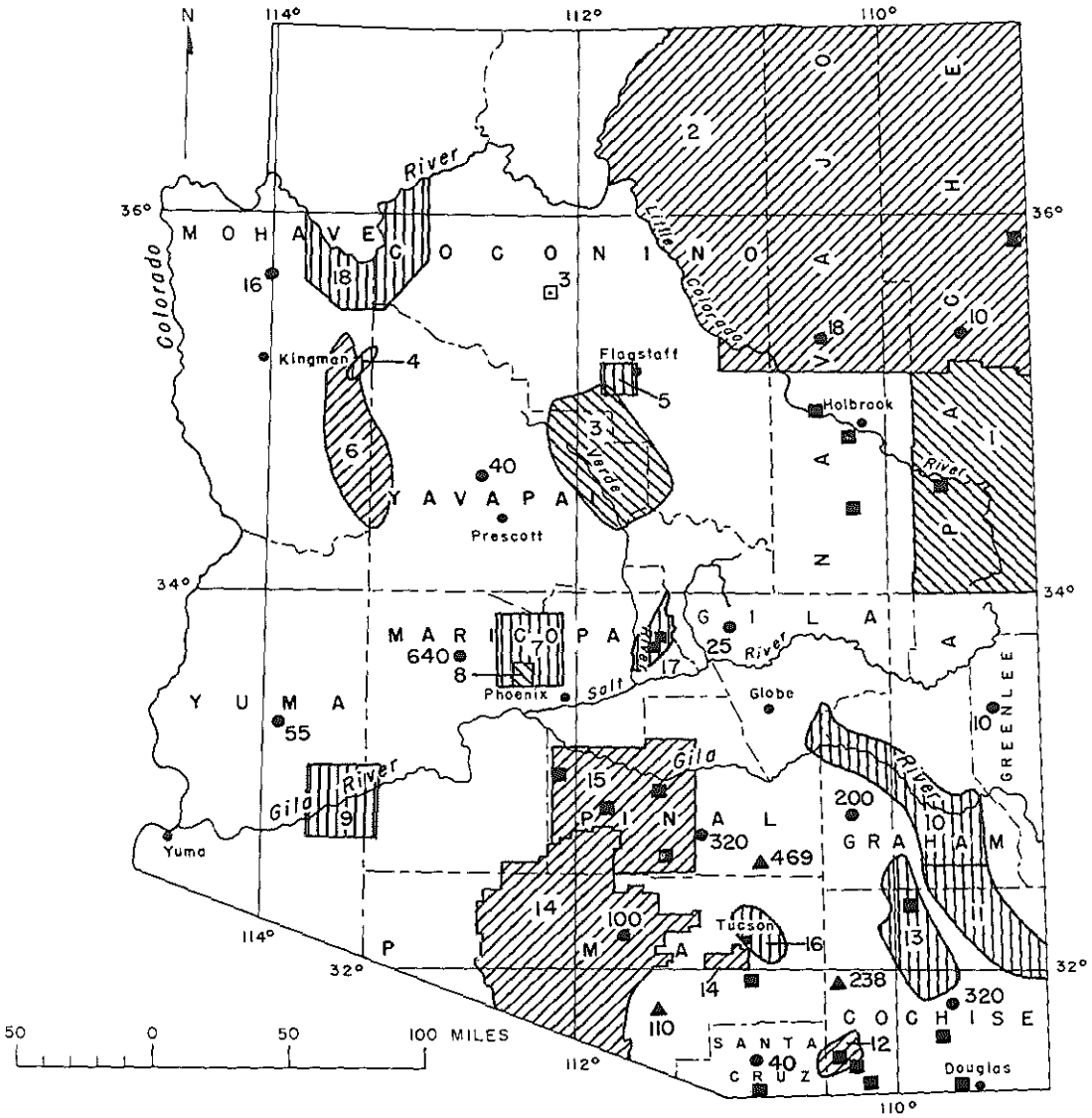
In addition to the work done by the Geological Survey in cooperation with the Arizona State Land Department, agreements were in effect with several other cooperators. Cooperative projects with the University of Arizona under the Arid Lands program consist of geohydrologic studies as related to water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

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. Spot investigations for water supplies were made for the National Park Service in several places in Arizona. Projects for the Bureau of Indian Affairs are the well-location and development programs concerning the southeastern part of the Hualapai Indian Reservation and the area near Gallup bordering the southeastern part of the Navajo Indian Reservation. In addition, several reports are almost completed for the Navajo and Hopi Indian Reservations and the Papago Indian Reservation.

Figure 1 is a pictorial summary of the status of current ground-water work in Arizona.

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 1962 through June 1963.



AREAS OF INVESTIGATIONS

1. Apache County
2. Navajo-Hopi Indian Reservations
3. Verde Valley area
4. Cottonwood Wash
5. City of Flagstaff
6. Big Sandy Valley
7. Beardsley area
8. Luke Air Force Base
9. Dateland-Hyder area
10. Arid-lands study (Safford Valley)
11. San Simon basin
12. Fort Huachuca
13. Willcox basin
14. Papago Indian Reservation
15. Western Pinal County
16. Tucson basin
17. Sycamore Creek
18. Hualapai Indian Reservation (southeastern part)

Area where field investigation is in progress

Area for which a report is in preparation

Area for which a report was released July 1962-June 1963

●40 Active observation wells (figure indicates number of observation wells in county)

▲110 Well-discharge measurements made in 1962 (figure indicates number of measurements made in county)

■ Site where continuous water-stage recorder is in operation

Figure 1.—Map of Arizona showing summary of ground-water programs.

Geology and ground water in the central part of Apache County, Arizona, by J. P. Akers: U.S. Geol. Survey open-file report, September 1962. 205 p., 24 figs., 6 tables. For publication as a U.S. Geol. Survey Water-Supply Paper.

The central part of Apache County, Ariz., includes an area of about 3,300 square miles between the Navajo Indian Reservation to the north and U.S. Highway 60 to the south. Sedimentary rocks discussed in this report range from Pennsylvanian to Quaternary in age, and from 2,000 to more than 6,000 feet in thickness. The Coconino Sandstone, of Permian age, underlies the entire area and constitutes one of the best aquifers in the area. The Permian Kaibab Limestone is present in the southern two-thirds of the area. It contains water where it is fractured and combines with the Coconino Sandstone to form a single hydrologic unit that yields from 6 to 74 gpm (gallons per minute) of water per foot of drawdown. In the southern part of the area these aquifers contain water suitable for domestic use, but in the northern part of the area the water is unsuitable for most purposes, probably because it is contaminated by highly mineralized water that leaks upward from the Pennsylvanian and Permian Supai Formation. Some of the sandstone units of the Upper Cretaceous rocks contain water of suitable quality for domestic use and wells in these units yield from 10 to 1,000 gpm. The Bidahochi Formation of Pliocene age locally yields from 10 to 50 gpm of water suitable for domestic use. The lava, where it occurs in the area, contains water generally suitable for domestic use. The other formations in the area either are dry or contain only small amounts of water locally.

Geology of the Cameron quadrangle, Arizona, by J. P. Akers, J. H. Irwin, P. R. Stevens, and N. E. McClymonds, with a section on uranium deposits by W. L. Chenoweth: U.S. Geol. Survey Geol. Quad. Map GQ-162.

This report summarizes the stratigraphy, structure, and economic deposits of the Cameron quadrangle located about 55 miles north of Flagstaff, Ariz. The geologic map shows the surface geology and structural features and is accompanied by a structural section and an explanatory text, which describe the stratigraphy, structure, geologic history, uranium deposits, construction materials, and ground-water resources of the quadrangle. Except for three lava flows and a cinder cone, the area is underlain by northeasterly dipping sedimentary rocks that have been folded and faulted in the western half of the quadrangle. Several deposits of unconsolidated dune sand occur in the eastern half of the area, and several deposits of unconsolidated gravels border the Little Colorado River upstream from Cameron.

Possibilities for future water-resources development at Fort Huachuca, Arizona, by S. G. Brown: Proc. 6th Annual Watershed Symposium, September 1962, p. 20-22, 3 figs.

This report is a brief discussion of the several possibilities for

developing additional water supplies at Fort Huachuca, Ariz. The six wells at the Fort Huachuca well field produce more than 5 mgd (million gallons per day), which is more than sufficient to supply the present needs of the Post. However, the water levels are declining, which indicates that water is being pumped from the aquifer faster than it is being recharged, and Post officials deemed it necessary to determine where and how additional water could be obtained for the Post supply when it is needed. The report suggests that floodflow and underflow from Garden and Huachuca Canyons could provide a source of readily available water that could be conveyed by gravity directly to the Post reservoir. Excess runoff would provide water to be recharged artificially to the Post well field.

Geologic and hydrologic aspects of test-well drilling, by P. W. Johnson, Natalie D. White, and H. G. Page: U.S. Geol. Survey open-file report, April 1962. 112 p., 14 figs., 2 tables. Prepared under the auspices of The Agency for International Development.

This report contains information on test-well drilling compiled for use in the training of participants from foreign countries. The data pertain largely to the geologic and hydrologic aspects of test-well drilling and supplement instructions on well-drilling procedures covered by numerous handbooks.

Geology and ground water of the Luke area, Maricopa County, Arizona, by R. S. Stulik and F. R. Twenter: U.S. Geol. Survey open-file report, April 1963. 74 p., 8 figs., 5 tables. For publication as a U.S. Geol. Survey Water-Supply Paper.

This report discusses the geology and ground-water supplies in the Luke Air Force Base area. An investigation was made in the area by personnel of the Geological Survey at the request of the Corps of Engineers and the U.S. Air Force when their attempts failed to augment the inadequate water supply. Promising locations for test wells were selected and drilling and sampling techniques were suggested by the Survey.

Reconnaissance of headwater springs in the Gila River drainage basin, Arizona, by J. H. Feth and J. D. Hem: U.S. Geol. Survey Water-Supply Paper 1619-H, 1963. 51 p., 4 pls., 7 figs., 5 tables.

The report describes the geologic setting of many of the springs that are the source of much of the water in the Gila, Salt, and Verde Rivers. The combined flow of springs in the Arizona sections of the Gila River headwaters is more than 150,000 acre-feet of water per year, most of which is ultimately used for irrigation in the Salt River Valley. However, the flow is equivalent to less than 2 percent of the precipitation. Limestone forms the principal source rocks, and most of the water is chemically suited for irrigation. However, in some places salty springs discharge water of damaging quality. The report includes suggestions for increasing the flow of water of good quality, and indicates the possibility that saline waters might be

diverted at their sources.

Geology and ground water in the Verde Valley of the Mogollon Rim region, Arizona, by F. R. Twenter and D. G. Metzger: U.S. Geol. Survey open-file report, February 1963. 309 p., 41 figs., 11 tables. For publication as a U.S. Geol. Survey Water-Supply Paper.

The report describes the geology, geologic structure, and ground-water hydrology in Verde Valley and includes a geologic map of the area. The ground water in the Verde Valley is mostly in two formations: (1) the Verde Formation of late Tertiary or Quaternary age, and (2) the Supai Formation of Pennsylvanian and Permian age. Some ground water can also be found in the Coconino Sandstone of Permian age. The chemical quality of the surface water and ground water is suitable for plants and animals. Most of the ground water in the Verde Valley area has a dissolved-solids content of less than 500 ppm (parts per million). South of Camp Verde, the water from the Verde Formation has a dissolved-solids content of more than 90,000 ppm.

Geohydrologic data in the Navajo and Hopi Indian Reservations, Arizona, New Mexico, and Utah—Part I, Records of ground-water supplies, by G. E. Davis, W. F. Hardt, L. K. Thompson, and M. E. Cooley: Arizona State Land Dept. Water Resources Rept. No. 12-A, April 1963. 159 p., 3 figs.

The report contains information on 846 drilled wells, 537 dug wells, and 955 springs that discharge ground water from 13 principal aquifers in the Navajo and Hopi Indian Reservations. Wells tap ground-water reservoirs at depths ranging from a few feet to more than 2,000 feet below the land surface. Most well yields are generally between 10 and 25 gpm. In some deep wells the pumping lift is more than 800 feet and the yield may be less than 5 gpm.

Geohydrologic data in the Navajo and Hopi Indian Reservations, Arizona, New Mexico, and Utah—Part II, Selected chemical analyses of the ground water, by L. R. Kister and J. L. Hatchett: Arizona State Land Dept. Water Resources Rept. No. 12-B, May 1963. 58 p., 2 figs.

The report is a compilation of selected chemical analyses of water from wells and springs, and contains an explanation of the source and significance of the chemical constituents in the ground water from the reservations. The total dissolved-solids content of the ground water ranges from 100 to nearly 30,000 ppm. The quality of the water differs from one water-bearing formation to another and also within the same formation.

The following short reports were published in New Mexico Geol. Soc., Guidebook, 13th Field Conf., October 1962:

The significance of the volcanic rocks in the Fossil Creek area, Arizona, by F. R. Twenter. p. 107-108, 2 figs.

New fossil localities in the Verde Formation, Verde Valley, Arizona, by F. R. Twenter. p. 109-114, 4 figs.

Rocks and water in Verde Valley, Arizona, by F. R. Twenter. p. 135-139, 4 figs., 2 tables.

The following abstracts were approved for publication in the Geol. Soc. America Bull., which will be available in December:

Stratigraphy and structure of Tertiary and Quaternary rocks of southeastern Arizona, by E. S. Davidson and M. E. Cooley.

Synoptic Cenozoic geologic history of the Colorado Plateaus and Basin and Range provinces of Arizona, by M. E. Cooley and E. S. Davidson.

Folds in the Tanque Verde, Rincon, and southern Santa Catalina Mountains, Pima County, Arizona, by E. Frederick Pashley, Jr.

Agricultural Resume for 1962

According to Jimmye S. Hillman (1963), a total of 1,168,665 acres was cropped in 1962, about 42,000 acres less than in 1961. This includes both irrigated and dry-land crops; however, based on data from previous years, only about 20,000 acres is dry farmed. Dry farming is practiced in only a few areas, mostly in Apache and Navajo Counties.

Maricopa (501,370 acres), Pinal (258,095 acres), Yuma (181,010 acres), and Cochise (77,520 acres) Counties continued to have the largest amount of acreage under cultivation. There were slight increases in cultivated acreage in Graham, Navajo, Yavapai, and Yuma Counties and decreases in the remaining counties. The increase in acreage in Graham and Yuma Counties in 1962 only partly offset corresponding decreases between 1960 and 1961; the decreasing trend that has been apparent in Pinal and Maricopa Counties for several years continued in 1962. Cotton accounts for the largest amount of acreage in the State: cotton was grown on 401,000 acres in 1962—only 7,000 acres more than in 1961. A total of 210,000 acres of alfalfa was under cultivation in 1962—about 17,000 acres less than in 1961. Ground water continued to be the major source of irrigation water for the cultivated acreage in the State, and thus, declining water levels are a major problem in connection with Arizona's agriculture. Figure 2 shows the total irrigated acreage and ground water pumped in the State for the period 1946-62.

Climate

The wide range in climatic conditions in Arizona is the result of the large differences in altitude throughout the State, a considerable range in latitude, and the distribution of mountain ranges. Altitudes range from less than 140 to more than 12,600 feet, and the State extends throughout nearly 6° of latitude

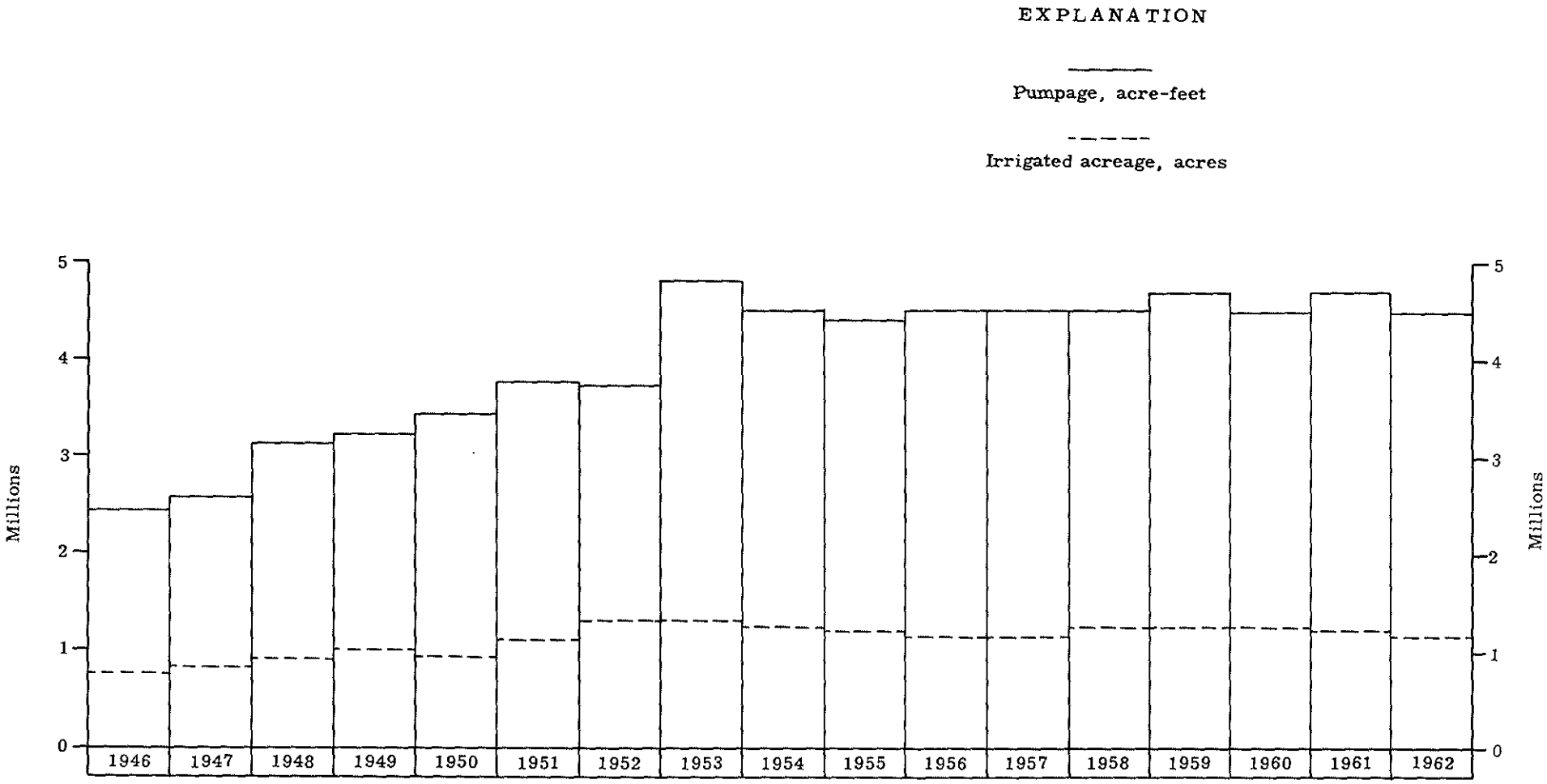


Figure 2.--Pumpage of ground water compared to irrigated acreage, 1946-62.

and 6° of longitude. Average annual precipitation in Arizona ranges from less than 5 inches in the lower desert area to more than 30 inches on the summits of the higher mountains; average annual temperatures may differ by as much as 20° to 25°. The lowest temperatures occur at the higher elevations in northern Arizona, and the highest temperatures occur along the lower Colorado and Gila River drainages in the southwestern part of the State. Figure 3 gives a generalized picture of the average precipitation and the average annual temperatures for the State. The illustration is not intended to show details in the distribution of precipitation and temperature; for example, in a zone of low rainfall certain high elevations may have as much as 30 inches of precipitation. The same range of values would be true for the distribution of temperature.

About half of Arizona receives less than 10 inches of precipitation annually. In general, the regions of low rainfall are those in which the highest temperatures and longest growing seasons occur. Thus, a large part of the precipitation evaporates or transpires from natural vegetation, largely nonbeneficial, and only a small part is utilized for growth of beneficial plants or is available for recharge to the ground-water reservoirs. It has been estimated that only about 1.0 percent per year of the total precipitation becomes available for recharge to the ground-water reservoirs.

According to records of the U.S. Weather Bureau (1962), precipitation was below average throughout Arizona in 1962. It was nearly 4 inches below average in Maricopa and Pinal Counties in the south-central part of the State where the greatest amount of land is cultivated and the most ground water is pumped; it was nearly 1½ inches below average in the southeast part of the State (Pima, Santa Cruz, Cochise, Graham, and Greenlee Counties) where large amounts of ground water also are used to irrigate farmland. In Gila, Yavapai, Apache, Coconino, Navajo, and Mohave Counties---where less acreage is under cultivation---the precipitation was from slightly more than 1½ to nearly 4½ inches below average in 1962. In Yuma County, where much of the irrigation of farmland is with water from the Colorado River, the precipitation was nearly 1½ inches below average in 1962. The above analysis was based on the monthly "Climatological Data" sheets (U.S. Weather Bureau, 1962) because the "Annual Summary" was not available this year; for this reason, the figures may require some adjustment when the "Annual Summary" is published.

Table 1 shows the total precipitation and average temperatures and departures from the long-term means for several weather stations in Arizona for 1962.

A significant feature of the 1962 precipitation pattern in Arizona was the large storm of September 25 and September 26 in the area extending from Sells, through most of the Avra Valley, across the Tucson Mountains, and to Oracle and Safford. Total rainfall was 6 or 7 inches in Avra Valley southwest of Marana, about 4 inches in the Sells area, and more than 2 inches in the Safford area. Extensive flooding resulted from the heavy precipitation, and flood runoff reached the Stanfield-Maricopa area in Pinal County near the confluence of the Santa Cruz and Gila Rivers. A discussion of the possibility of recharge to the ground-water reservoir from the flood is discussed elsewhere in this report.

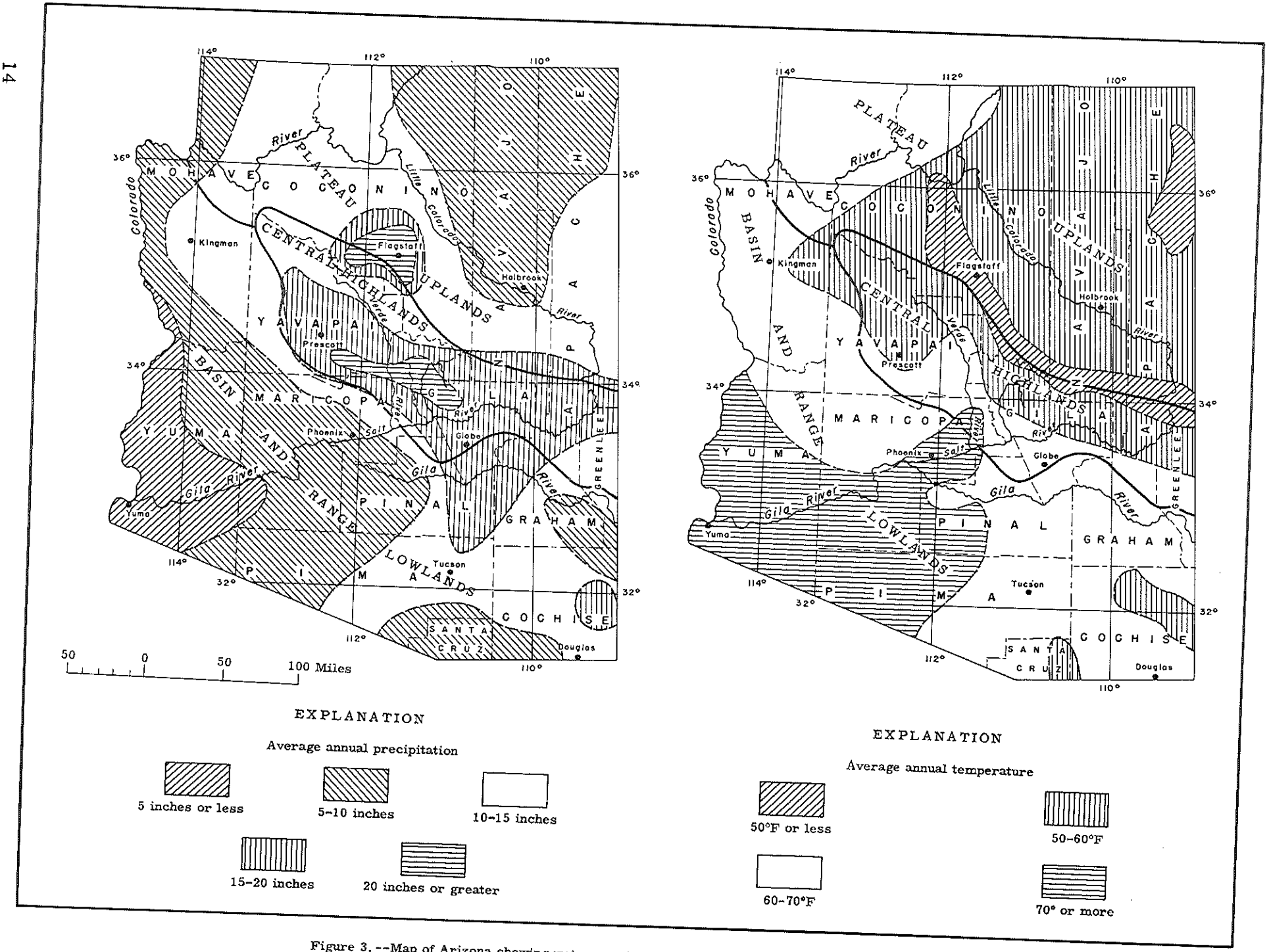


Figure 3.--Map of Arizona showing water provinces and average precipitation and temperature.

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

Station	Precipitation (inches)	Departure (inches)	Temperature (°F)	Departure (°F)
Bowie	10.26	-	63.4	-
Buckeye	5.44	-	70.0	-
Casa Grande	5.96	-2.12	70.9	1.2
Chandler	4.01	-	71.1	-
Chino Valley	8.53	-	55.7	-
Davis Dam	1.44	-	73.6	-
Douglas Smelter	8.44	-3.18	64.2	-3.7
Duncan	8.71	-	59.4	-
Eloy	5.70	-	71.0	-
Flagstaff	18.11	- .36	45.5	.9
Gila Bend	4.14	-1.77	72.3	-
Globe	17.95	2.55	61.9	.1
Holbrook	4.87	-2.88	53.9	-1.3
Kingman	8.94	-	62.8	-
Litchfield Park	4.23	-3.63	70.9	.7
Mesa	4.97	-2.72	70.1	1.9
Nogales	15.16	-	60.6	-
Payson	16.89	-	56.1	-
Phoenix Airport	3.90	-3.26	70.7	1.3
Pinedale	11.13	-6.69	49.7	-
Prescott Airport	10.53	-5.45	56.0	.8
Safford	11.37	2.65	65.0	-
St. Johns	7.95	-3.42	53.8	1.4
Snowflake	9.98	-1.75	50.5	-
Tucson, University of Arizona	10.17	- .26	69.4	1.6
Wellton	2.36	-	70.1	-
Wikieup	8.39	-2.19	66.7	-
Willcox	9.55	-	58.7	-
Williams	18.54	-2.59	50.3	1.3
Yuma Airport	1.16	-2.23	75.1	.4

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. 4). These quadrants are designated counterclockwise by the capital letters A, B, C, and D. All land north and east of the point of origin is in A quadrant, that north and west in B quadrant, that south and west in C quadrant, and that south and east in D quadrant. The first digit of a well number indicates the township, the second the range, and the third the section in which the well is situated. The lowercase letters a, b, c, and d after the section number indicate the well location within the section. The first letter denotes a particular 160-acre tract (fig. 4), 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. 4S., R. 5E. 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 through the combined efforts of the members of the staff in the Arizona district. The sections in which ground-water conditions by basins or areas are discussed were, in general, prepared by the person most familiar with the particular area. Authorship of individual sections is shown in the table of contents. Others, not on the staff of the U.S. Geological Survey, Ground Water Branch, who contributed to the report were H. C. Schwalen, who prepared the sections on the upper Santa Cruz basin, Avra-Marana, and the Chino Valley artesian area, and R. J. Shaw who collected the field data on which these discussions were based. They are employed by the University of Arizona, Agricultural Engineering Department.

In addition to those persons listed as authors, several other people contributed substantially to the preparation of the report. G. S. Smith, F. H. Rascop, and W. D. Potts prepared the illustrations. Others who worked on the report include William Kam, Ann C. Hill, Clara L. Rauh, Carol L. Jenkins, Helen S. Price, and Patsy E. Nickles. The data upon which the report is based were collected by E. K. Morse, R. S. Stulik, T. W. O'Brien, R. L. Thompson, F. E. Arteaga, and H. W. Steppuhn.

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Many irrigation districts, cities, well drillers, water and power companies, government agencies, and individuals provided exceptional cooperation in furnishing information. The following organizations were particularly helpful:

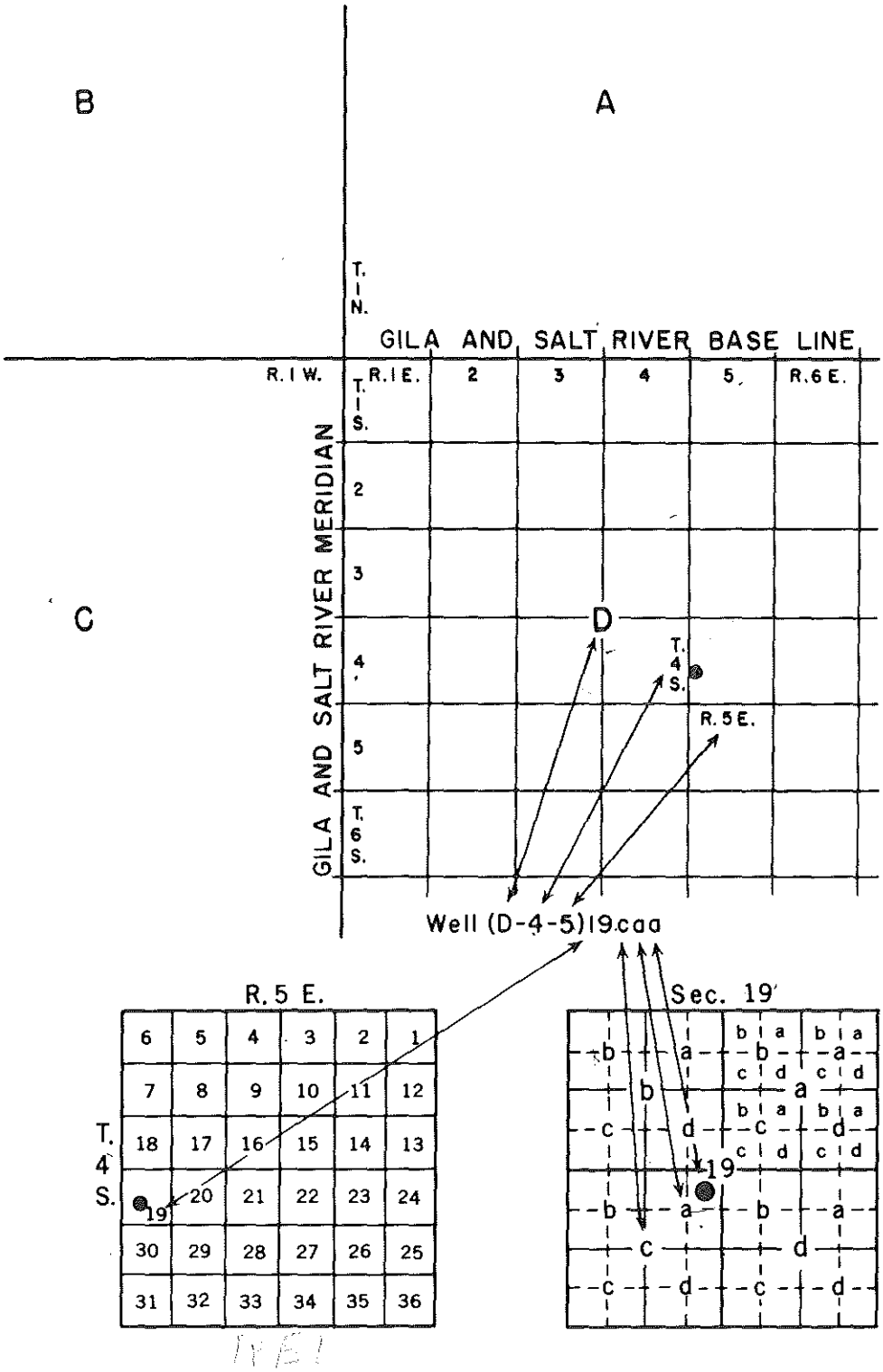


Figure 4.-- Sketch showing well-numbering system in Arizona.

Arizona Corporation Commission, Arizona Public Service, Arizona Water Company, Buckeye Irrigation District, city of Phoenix, city of Tucson, Cortaro Farms, Gila Water Commissioner, Goodyear Farms, Maricopa County Municipal Water Conservation District, Roosevelt Irrigation District, Roosevelt Water Conservation District, Salt River Valley Water Users' Association, Salt River Power District, San Carlos Irrigation District, Southwest Gas Corporation, Sulphur Springs Valley Electrical Cooperative, Tucson Gas, Electric Light and Power Company, U.S. Bureau of Indian Affairs, U.S. Bureau of Reclamation, U.S. Weather Bureau, and Surface Water and Quality of Water Branches of the U.S. Geological Survey.

METHODS OF ANALYSIS OF HYDROLOGIC DATA

By

Natalie D. White

The science of hydrology has been recognized for a long time as a branch of the natural or earth sciences, but until recently it had not had much recognition as a distinctive science. Hydrology is concerned with the behavior of water as it occurs in the atmosphere, on the surface of the ground, and underground. Thus, it includes the description or study of the earth with respect to water. Like all earth sciences, it uses all the basic sciences as tools, but in addition, techniques and methods have been developed that are distinctive of hydrology.

The movement of water as it relates to the earth is often referred to as the "hydrologic cycle." This phenomenon is the central concept of the science of hydrology; it describes the circulation of water from the sea, through the atmosphere, to the land, and thence by numerous circuitous paths, back to the sea. The water that, as a part of the hydrologic cycle, moves downward beneath the surface of the earth and remains in storage there for various periods of time is called ground water. In most hydrologic literature, this term is applied only to the water that occurs in the zone of saturation where all the openings in the subsurface materials are filled with water. The study of the occurrence and behavior of the water that is stored underground is one of the most important parts of the science of hydrology. This is particularly true in arid and semiarid zones where surface-water supplies are not sufficient for the needs of the growing population, and civilization is thus highly dependent on supplies from the ground-water reservoir. The ground-water reservoir helps to regulate the movement of water through other phases of the hydrologic cycle---it serves to hold back water that otherwise would move too rapidly through the cycle to be available for human, animal, or plant use. It also helps to control streamflow, by supplying the minimum flow of perennial streams during periods of no rainfall.

Although there was some appreciation in biblical times of the hydrologic cycle and the occurrence of ground water in springs and wells, it was not until the fundamental principles of geology were established in the latter part of the 18th century that the behavior of water underground could be related to the rocks of the earth. Since the supply of water was not critical during the 19th century,

little attention was paid to the development of hydrology as a science. Hence, the terminology and methods of the science of ground-water hydrology are to some extent still in the formative stage. For this reason, it frequently is difficult to fully evaluate a particular problem and to select the best method for solving it. The following paragraphs summarize and evaluate some of the methods in common use, and describe one of the newer methods of analysis that has been developed in the last few years.

Standard Mathematical Methods of Analysis

During the more than 20 years of its existence in the State of Arizona, the Ground Water Branch of the U.S. Geological Survey has collected a substantial quantity of data concerning the water resources of the State. These data include: (1) water-level measurements, which have been used to construct hydrographs for individual wells and to prepare maps showing the altitude of the ground-water table and the decline of the water table in given areas; (2) individual well-discharge measurements, which aid in the computation of specific capacities and the total pumpage of ground water; (3) drillers' logs and well-cutting samples, which help to delineate the subsurface geology; (4) chemical-quality analyses of water samples from the aquifers to supplement information from other sources concerning the geohydrology of the aquifer and to determine the overall suitability of the water for various uses. All these basic-data techniques are vital to a detailed investigation of the ground-water resources.

The change (rise or decline) of the water level in a well is related directly to several factors: the type of aquifer material that the well penetrates, the discharge rate of the well and the overall pumping pattern, and the characteristics of the well itself. When a well is drilled and water is withdrawn from the aquifer, water levels near the well are drawn down forming a cone of depression around the well, thus allowing water to move into the well and to be discharged at the surface. As more and more water is discharged from the well, the cone of depression expands laterally and deepens. If heavy withdrawal continues for a relatively long time, the cones from other wells overlap and regional dewatering of the aquifer occurs. The rate at which this dewatering occurs is a function of the characteristics of the aquifer materials and the rate at which ground water is withdrawn from the area. Hydrographs of the water levels in many wells throughout an area show the trend of ground-water levels in relation to the pumping regimen. Comparison of these hydrographs for different areas will indicate the differences in the trend of the ground-water levels, which are a function of the different types of aquifers.

Water-level measurements in individual wells are also used to prepare maps showing contours of the altitude of the water level. Many facts about the aquifer or aquifers in an area can be ascertained from a study of these contour maps. The direction of ground-water movement can be determined, and calculations regarding the amount of water moving through an aquifer can be made from an analysis of ground-water contours and other basic data. The direction of movement of ground water in a basin is down the slope of the water table. Thus, flow lines can be constructed that will show the general path of water from the area of recharge toward the place of discharge, such as a heavily

pumped area. The shape of the network formed from the flow and contour lines is determined by the transmissibility of the aquifer and the amount of water moving through the aquifer. Thus, if the amount of recharge into or the discharge out of an area is known, then the transmissibility of the aquifer or the quantity of water moving through it can be computed with a fair degree of accuracy.

Successive water-level measurements in the same wells over a period of time are used to prepare maps showing contours of the change in the position of the water table or piezometric surface. Like the hydrographs, these maps are used to relate the decline of the water level to the pumping regimen and to the aquifer characteristics. Maps of the altitude of the water surface and of the change in the water level also help to delineate areas where ground-water conditions are becoming critical due to overdevelopment and areas where conditions are conducive to further development.

Measurements of the discharge from individual wells are used in conjunction with power records in the computation of the amount of ground water pumped each year. If the amount of drawdown in the water level caused by a given pumping rate is known, the specific capacity of the well can be computed. A number of specific-capacity values for a particular area or basin gives some knowledge of the transmissibility of the aquifer.

Where a sufficient number of drillers' logs and analyses of well cuttings are available for an area, much of the subsurface geology can be analyzed and correlated in terms of hydrologic significance. There are several methods for using this information to study the subsurface geology of the basins. (1) Drillers' logs and analyses of well cuttings can be used to construct cross sections and fence diagrams, which give a generalized picture of the character and extent of the various aquifers. (2) A method has been devised (Davis and others, 1959) for computing the average specific yield and the amount of water that can be withdrawn from storage by pumping in an area based on an analysis of drillers' logs. The method has been used in several recent reports and will not be described further here (Davis and others, 1959; White, 1961). (3) A study of the logs of wells in an area can also give some idea of the water yield to be expected from wells.

The chemical quality of the water from wells is significant because certain constituents make the water unusable for some purposes. Even more important in a ground-water study, however, is the fact that ground water can be identified as to source because of its quality. In some places the chemical constituents in the ground water may be the only clue to the presence of a particular soluble material in an aquifer or in rocks adjoining the aquifer.

The foregoing paragraphs describe some of the analyses that can be made using the basic data collected in Arizona under the statewide ground-water program. Another more specialized method for studing the characteristics of a ground-water reservoir is the so-called "aquifer test." It consists of measuring the rate of discharge of a pumping well, the water level in the pumping well and several nearby observation wells during the period of pumping, and the subsequent recovery of the water level to normal conditions. The transmission and storage characteristics of the ground-water reservoir near the pumped

well can then be computed from these data. Many good references are available describing the procedures used in this type of testing (Ferris and others, 1962; Brown, 1953).

The flow-net method for analyzing ground-water movement employs a map showing contours (equipotential lines) of the altitude of the water surface on which flow lines or lines showing the generalized direction of ground-water movement are constructed. Once the flow net has been constructed the transmissibility of the aquifer can be computed. Several practical applications of the flow-net method have been described in the literature (Bennett and Meyer, 1952; White, 1961).

Any one or several of the foregoing methods of analysis applied to data for a given area or basin will give much information on the ground-water resources of the area. However, in many instances, these analyses of the ground-water resources have been only quasi-quantitative in nature, and more refined methods are needed for obtaining more accurate and detailed quantitative solutions. This is particularly true in areas where accelerated development of the water resources has resulted in critical overdraft, deterioration in the quality of the water, or difficulties related to equitable distribution of the available supply. The geohydrologist needs to be able to predict the future of the water resources in a basin as related to use. This requires more exact quantitative methods of analyzing the water resources than have been available previously.

Analysis by Electrical-Analog Method

The flow of ground water in aquifers is analogous to the flow of electric current, and electronic equipment and instrumentation have been developed that will simulate conditions to be expected in a ground-water reservoir or system. Voltage differences in the electrical system correspond to head changes in the aquifer, and the flow of electric current measured in amperes corresponds to the quantity of ground water moving through the aquifer. In an electrical system, a resistor retards the free flow of current; in the ground-water system, the subsurface materials retard the free flow of fluid. A capacitor in an electrical circuit stores electrical energy in a manner similar to the way in which permeable subsurface materials store ground water. Thus, a resistance-capacitance electrical circuit serves as an exact analog for the flow of ground water in an aquifer. The electrical responses of the analog model are shown on an oscilloscope, and are similar to a hydrograph of water levels in the ground-water system.

It is easily recognized that the electrical-analog model will be an extremely useful tool in the analysis of complicated ground-water systems. The model is constructed so that the geometric configuration of the network of resistors and capacitors simulates the extent, shape, and hydraulic properties of the ground-water reservoir, and the electrical resistance and capacitance units are in direct ratio to the transmission and storage characteristics of the aquifer. Hydrologic boundaries, such as rivers and lakes, may be simulated by adding power (current) at the desired locations. Impermeable barriers are usually represented by restricting or diverting the flow of current. The construction of the analog model of an aquifer is dependent on available subsurface

geologic information, which serves as the "frame-work" for the hydrology. Thus, the responses of the model are only as correct as the geologic data used to build the model.

Analysis of the hydrologic data by electrical-analog methods for any basin may make it possible not only to appraise the water resources of an area and the current trend of development but also to predict what may happen in the future under different specified sets of circumstances. One of the chief advantages of the electrical-analog method over the standard mathematical methods described in the foregoing section is that it provides a means of analyzing large masses of data quantitatively in a short time.

REGIONAL HYDROLOGY

By

Natalie D. White and Maurice E. Cooley

Nearly all ground water originates as precipitation, percolates downward over long periods of time through the consolidated and unconsolidated rocks that make up part of the earth's crust, and is stored there at varying distances below the land surface. Rocks that store and transmit appreciable quantities of ground water are called aquifers. Two characteristics of an aquifer, porosity and permeability, determine the amount of water it can store and the rate at which water can move through it. The porosity of a rock or soil is a measure of the amount of void spaces in which water can be stored. It is expressed quantitatively as the percentage of void space in the total volume of material. The permeability of a water-bearing formation is a measure of its capacity to transmit water; it may be expressed 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. Different aquifers may have widely varying porosities and permeabilities, and even within the same aquifer these characteristics may vary from place to place both horizontally and vertically. Thus, the characteristics of the aquifers, to a large extent, control the yield and the general movement of ground water and in many areas indicate a close relation between the hydrology and geology.

Water Provinces in Arizona

The occurrence of ground water in Arizona is controlled by the geology and physiography of the three water provinces (fig. 3). These provinces are (1) the Plateau uplands or Colorado Plateaus province in the northern part of the State, (2) the Basin and Range lowlands province in the southern part of the State, and (3) the Central highlands province. The Central highlands province is transitional between the other two provinces.

Plateau Uplands Province

The Plateau uplands province includes a variety of landforms — canyons, buttes, mesas, and volcanic mountains. The altitude ranges from about 4,000 to 13,000 feet above mean sea level but is mostly between 5,000 and 7,000 feet. The most spectacular physiographic feature of the province is the Grand Canyon of the Colorado River, which cuts across the northwest corner of the State.

The soil covering in the Plateau uplands province in most places is thin, and vegetation is sparce below altitudes of 6,000 feet. Juniper-pinon pine forests abound between 6,000 and 7,000 feet, and forests of yellow pine and fir and some spruce mantle areas receiving heavy rainfall above 7,000 feet. Grasses and shrubs provide pasture for cattle and sheep at all altitudes and support a large part of the economy of the area.

The climate in the Plateau uplands province is generally hot and dry in areas below 4,500 feet and cool and moist in areas above 7,000 feet. Precipitation is greatest in an area along the Mogollon Rim extending in a narrow band from the White Mountains northwestward past San Francisco Mountain near Flagstaff to the Kaibab Plateau north of the Grand Canyon. The evaporation potential is high in much of the province owing to the generally high temperatures that occur at altitudes below 7,000 feet. There are only a few perennial streams in the area and these are maintained by discharge from the ground-water reservoirs.

The major aquifers in the Plateau uplands province are fine grained sandstone units, which occur between nearly impermeable layers composed of siltstone and claystone. The sandstone units provide fairly large reservoirs for the storage of ground water, but well yields are generally small except where the rocks have been fractured and faulted, thereby increasing the permeability and allowing the water to move more freely through the aquifer. The siltstone and claystone layers act as aquicludes, thus confining the water in the underlying aquifers under artesian pressure. A more complete discussion of the hydrology of this province is given in the section "Hydrology of the Plateau Uplands Province."

Basin and Range Lowlands Province

The Basin and Range lowlands province is characterized by isolated mountain blocks separated by broad alluvial-floored basins; the altitudes of the basin surfaces range from about 100 to as much as 4,500 feet above mean sea level. The altitudes of the mountain blocks are as much as 10,000 feet above mean sea level and usually are between 1,000 and 4,000 feet above the floors of the subjacent basins. Most of the valleys in the Basin and Range country trend north to northwest, and the undisturbed movement of ground water within them is parallel to the flow direction of the present major streams in the valleys.

The climate in the Basin and Range lowlands province is varied but generally is arid to semiarid except on the summits of the high mountains. In the desert

basins, the temperatures are very high and rainfall is meager. The combination of low precipitation, high temperatures, and low humidity at altitudes below 5,000 feet causes a high evaporation potential. The result is that most of the available moisture is returned to the atmosphere or is utilized by vegetation chiefly in the areas where rainfall occurred.

The alluvial materials of the basins that yield water readily to wells range in thickness from a few hundred to more than 3,000 feet. The alluvium, generally weakly consolidated, stores large amounts of ground water that are tapped by hundreds of irrigation, industrial, and domestic wells. The water-bearing materials in the various basins and in different parts of the same basin vary widely in their ability to store and transmit water. The occurrence of thick sequences of clay or silt beds at various horizons in the subsurface restricts the movement and decreases the yield of ground water. In some places, thick and areally extensive clay and silt beds form aquicludes; water in the permeable beds beneath these may be under artesian pressure.

The mountains in the Basin and Range lowlands province generally consist of granitic, volcanic, and well-cemented sedimentary rocks that are impervious and do not store substantial amounts of ground water. However, these rocks are important to ground-water occurrence because they serve to form an impermeable barrier bordering and underlying the permeable sediments in the alluvial basins. Some of the water that moves as runoff from these mountainous regions recharges the ground-water reservoirs in the thick alluvial material of the basins.

Large cones of depression in the ground-water reservoirs of the alluvial basins have been formed in the last several decades due to heavy pumping from wells. The natural pattern of ground-water movement has been altered by these cones, particularly in the areas of large agricultural development where the withdrawal of ground water is greatly in excess of the rate of replenishment. The development of these large cones and the resultant dewatering of the aquifers are indicated by the downward trend of the water levels shown on several maps in this report.

A more complete discussion of the ground-water hydrology of the Basin and Range lowlands province is given by White, Stulik, and others (1962).

Central Highlands Province

The Central highlands province forms a topographic high in the central part of the State separating the Plateau uplands from the Basin and Range lowlands province. The province consists principally of rugged, sharply pinnacled ranges and volcanic mountains, which are several thousand feet higher in altitude than the adjoining valleys of the Basin and Range lowlands and generally lower than the high mesas on the Colorado Plateaus. In most areas the Mogollon Rim approximates the ground-water divide and the surface-water drainage divide between the Little Colorado and the Salt River systems.

Arizona receives its greatest amounts of precipitation in the Central highlands

province where summer thundershowers are common and winter snowfall is heavy. The amount of precipitation is affected by the altitude—mean annual precipitation ranges from 10 inches in valleys along the southwestern edge of the province to more than 30 inches on some of the higher mountain ranges. Considerable snowfall occurs in areas above 7,000 feet on the tops of mountain ranges, along the Mogollon Rim, and in the White Mountains. Although most of this relatively heavy precipitation is evaported from the land surface or transpired from vegetation, it maintains heavy streamflow that is utilized extensively for agricultural irrigation in the Phoenix basin. A large part of this streamflow is funneled through a narrow gorge of the Salt River east of Phoenix where the water is impounded in storage reservoirs—Roosevelt Lake, Apache Lake, and others—and the water is transported from the reservoirs for use in the cultivated valleys of the Basin and Range lowlands. The streamflow of the Verde and the Gila Rivers upstream from Coolidge Dam is also derived from the Central highlands. Part of the precipitation that inflitrates to the ground-water reservoir reemerges from springs and helps to maintain perennial reaches of streams throughout the province.

The occurrence of ground water in the Central highlands province is dependent on the types of surface and subsurface rocks, the structural attitude of these rocks, the configuration of the mountains and valleys, and the unconsolidated sediments in the volcanic mountains and in the alluvial-floored valleys. For the most part, the mountain ranges and much of the area adjoining the Mogollon Rim consist of hard dense rocks of igneous and metamorphic origin and consolidated sedimentary rocks. These rocks contain little space for the storage of ground water. Locally, fractures developed along faults and joints provide open spaces for the accumulation of some ground water; many springs issue from such fractures. There are several valleys in the area that have been filled with loosely cemented material—Chino Valley, Verde Valley, Tonto basin, the San Carlos River valley, and the valley occupied by the towns of Globe and Miami. The alluvium in these valleys provides for the storage of relatively small amounts of ground water when compared to the large ground-water reservoirs in the Basin and Range province. A considerable amount of water is in the unconsolidated layers interbedded with the volcanic rocks, and most of this water is discharged directly to the streams draining to the Salt and Gila Rivers.

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 quite variable at key gaging stations during the 1962 water year. The Colorado, Gila, and Salt Rivers had excessive flow (in upper quartile), whereas the San Pedro River had deficient flow (in lower quartile). The Little Colorado and Verde Rivers had near-normal flow. In general, excessive flows occurred at all key stations from fall to spring. Deficient flows occurred mostly during the summer months owing to the absence of the usual

storms. The monthly mean discharge of the Colorado River was record-high for February. Monthly mean discharges of the Salt and San Pedro Rivers were record-low for August. The yearly discharge of the San Pedro River was the lowest since the beginning of record in 1913.

Record-breaking floods occurred September 26-28, 1962, owing to rainfall totaling more than 6 inches just west of Tucson. The Papago Indain Reservation, where runoff was the highest within the knowledge of residents, suffered extensive damage to roads, buildings, and livestock. Severe losses occurred in the lower Santa Cruz River basin owing to inundation of cotton crops, machinery, and buildings. Although total runoff from this flood was more than 100,000 acre-feet, less than 20 percent of the total runoff reached the Gila River and none reached Painted Rock Dam.

Following is a list of key gaging stations with yearly mean discharge for the 1962 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 . .	15,250,000	135
Little Colorado River near Cameron	157,800	92
Gila River at head of Safford Valley, near Solomon	444,700	218
Salt River near Roosevelt	718,400	184
Verde River below Tangle Creek, above Horseshoe Dam	320,800	112
San Pedro River at Charleston	13,270	37

Storage in principal reservoirs in Arizona as of March 31, 1963, is shown below, compared with the storage of the previous year.

Reservoir	Contents, in acre-feet March 31, 1963	March 31, 1962
Lake Pleasant	2,800	17,970
Verde River system	31,290	103,900
San Carlos Reservoir.	120,800	154,100
Salt River system	1,018,000	1,118,000

Total diversion of streamflow to Arizona lands during the 1962 water year was more than 2,840,000 acre-feet. About 1,700,000 acre-feet was diverted from the Colorado River for use by the Colorado River Indain Reservation, the Gila Project, and the Valley Division of the Yuma Project. These projects use only surface water for irrigation. About 750,000 acre-feet of the water diverted from the Colorado River was returned to the river or discharged across the Arizona-Sonora boundary.

About 1,170,000 acre-feet of water was diverted from the Gila River basin during the 1962 water year. Of this amount, 800,600 acre-feet was diverted from the Salt River at Granite Reef Dam. The other significant surface-water diversions are in the Duncan-Safford area and for the San Carlos Project. Each of these is used in combination with ground water.

Figure 5 shows a comparison of diversions and reservoir storage with similar data for previous years.

HYDROLOGY OF THE PLATEAU UPLANDS PROVINCE

By

Maurice E. Cooley

The Plateau uplands or Colorado Plateaus province includes that part of northern Arizona east of Grand Wash Cliffs and north of the Mogollon Rim (Fenneman, 1928) (fig. 6). Nearly all of Apache, Navajo, and Coconino Counties and the northeastern part of Mohave County are in this province. The Colorado Plateaus province, in contrast to the other provinces of Arizona, has been carved entirely from consolidated sedimentary rocks. Broad alluvial areas, which are common in the other provinces, are uncommon in the Colorado Plateaus province, and the alluvial deposits occur only as narrow strips along the larger drainages. The sedimentary rocks consist mostly of a sequence of alternating resistant sandstone beds and soft shaly units. Differential erosion of these rocks gives the plateau country its characteristic mesa and butte topography.

Precipitation

The amount and distribution of precipitation in the Arizona part of the Colorado Plateaus province are controlled largely by the orographic effect of the high southern and western border areas—the Grand Wash Cliffs, the Kaibab Plateau, the Mogollon Rim, and the ranges of the Central highlands. Altitudes in the high border areas generally range from 6,500 to 9,000 feet above mean sea level, and they are a barrier to the movement of air masses that bring in moisture from the Gulf of Mexico and the Pacific Ocean. As a result, the windward side of the high border areas of the plateaus and the Central highlands receives considerable precipitation—the highest in the State—but the leeward side of the Colorado Plateaus is within a rain shadow where

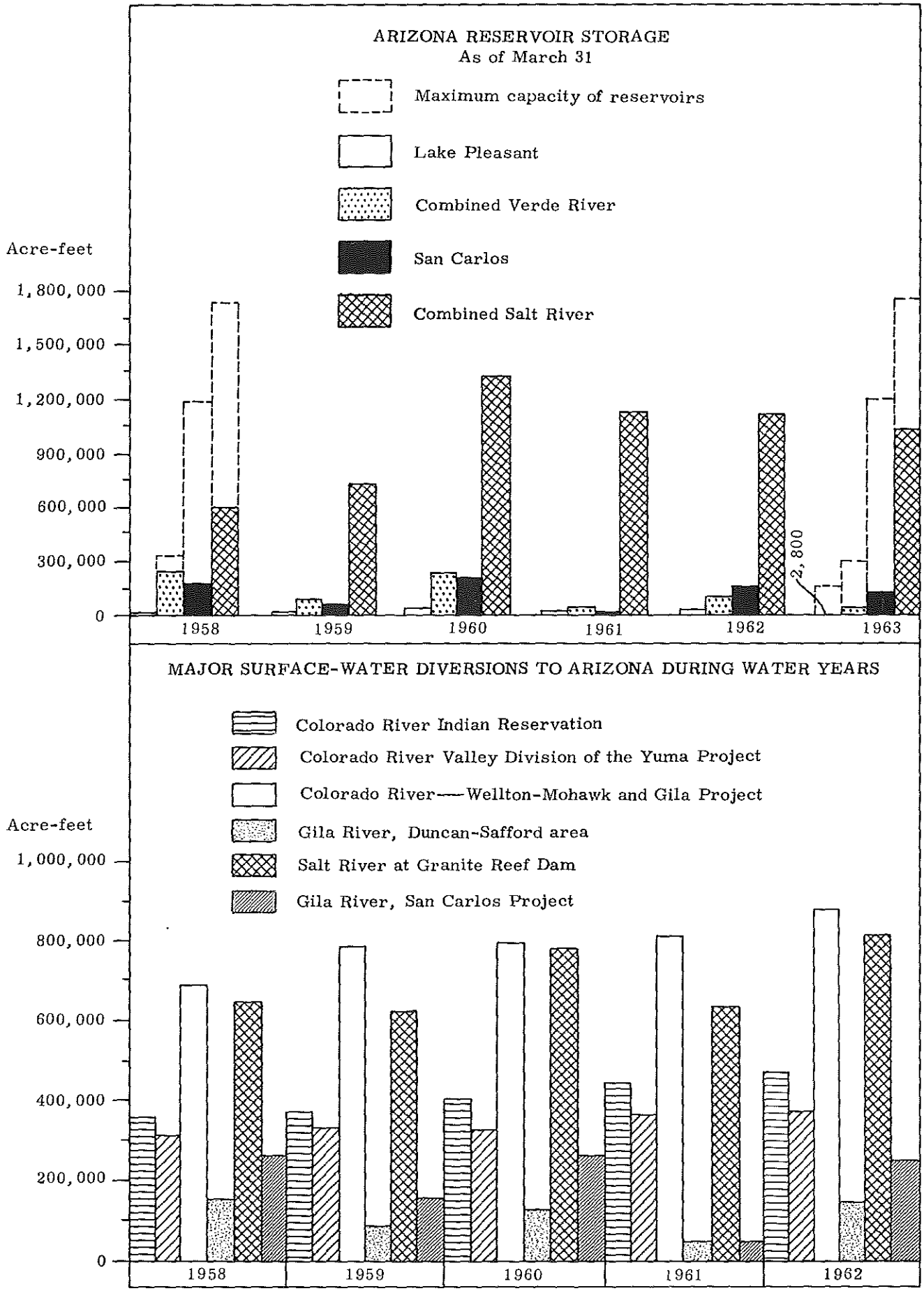


Figure 5. --Surface-water reservoir storage and diversions in Arizona.

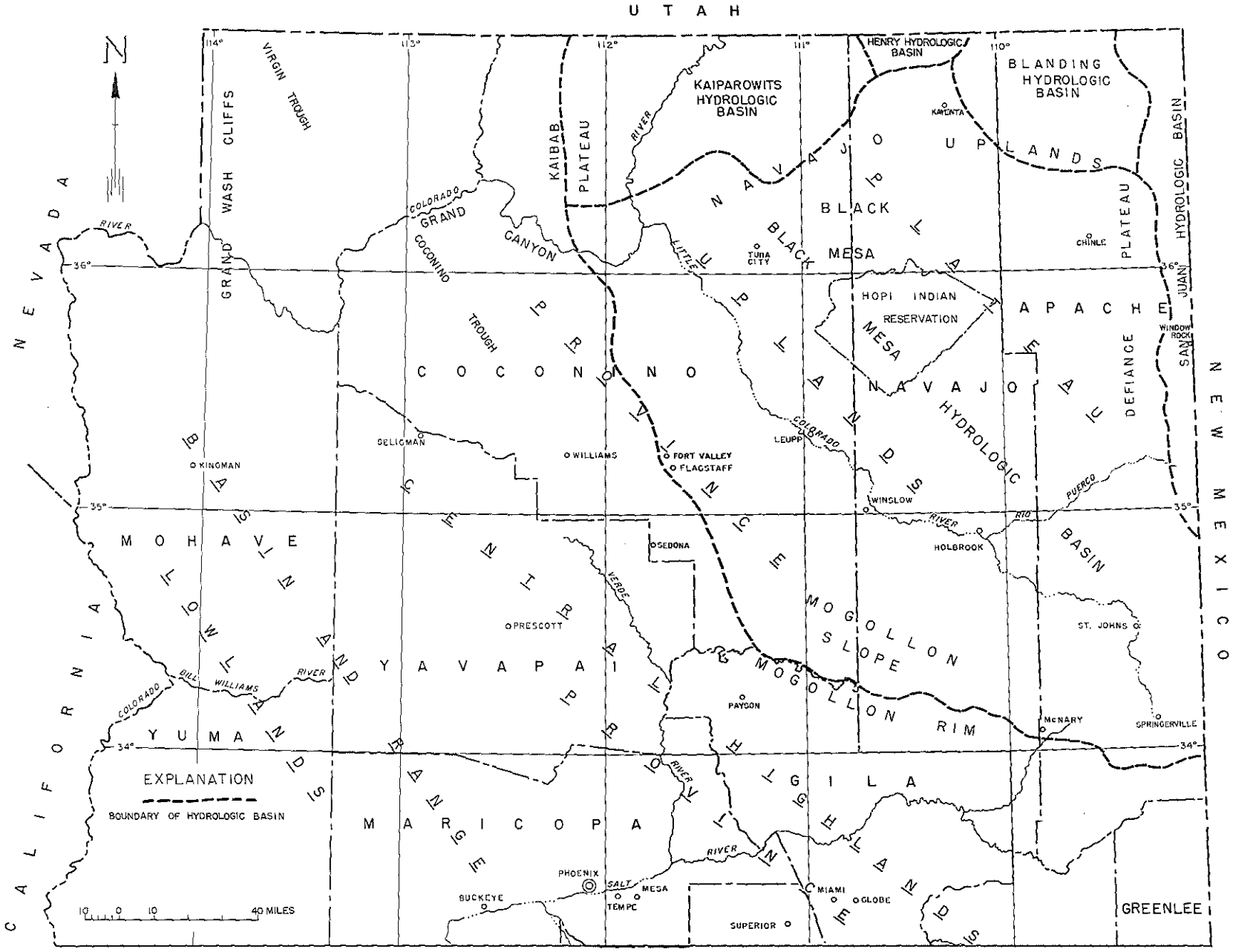


Figure 6.--Map of northern Arizona showing the hydrologic basins and place names.

precipitation is low. The Colorado Plateaus is also within a smaller rain-shadow effect from the high mountains that adjoin the other parts of the plateau.

The orographic effect of the high border areas on precipitation is indicated by the rainfall records of stations maintained by the U. S. Weather Bureau in the area near Flagstaff (table 2). The average annual precipitation at stations in the Colorado Plateaus province ranges from 22.56 inches at Fort Valley on the San Francisco Plateau to 6.37 inches at Leupp in the valley of the Little Colorado River. The rainfall data show that at Williams and Payson, along the windward side of the orographic barrier, annual precipitation is slightly more than it is at Flagstaff, which is on the summit area. Sedona and Payson, along the base of the Mogollon Rim at about the same altitude as the stations on the leeward side of the barrier in the valley of the Little Colorado River, receive from 2 to 3 times more precipitation than Leupp, Winslow, or Tuba City.

Characteristics of the Aquifers

The chief withdrawal of ground water in the Colorado Plateaus province is from the Coconino and Navajo Sandstones and from the other aquifers listed in table 3. For the most part, these aquifers are in consolidated sedimentary rocks and are composed of fine-grained sandstone units that do not transmit water readily. Permeabilities generally are less than 10 gpd (gallons per day) per square foot, in contrast to those for the coarse valley fill of the Basin and Range province that are about 1,000 gpd per square foot.

Much of the ground water is in three multiple aquifer systems, that is in aquifers that include more than one stratigraphic unit (fig. 7). The C multiple aquifer system includes the Coconino Sandstone and its lateral equivalents the De Chelly Sandstone in the Defiance Plateau and the De Chelly Sandstone Member of the Cutler Formation in the Monument upwarp. It may include also the overlying Kaibab Limestone and the topmost beds of the underlying Supai Formation in the Mogollon slope-Kaibab Plateau area. The N multiple aquifer system is in the northern part of Coconino, Navajo, and Apache Counties and consists of the Navajo Sandstone, the Kayenta Formation, and the Lukachukai Member of the Wingate Sandstone. The D multiple aquifer system is composed chiefly of the Dakota Sandstone and is well developed in Black Mesa and along the Arizona-New Mexico State line, where the Dakota Sandstone overlies the Cow Springs Sandstone or sandstone beds of the Morrison Formation.

The Navajo Sandstone and the Coconino Sandstone and its lateral equivalent, the De Chelly Sandstone, are more than 500 feet thick over large areas of northern Arizona, but the other aquifers are usually less than 200 feet thick. All these water-yielding beds or aquifers are separated by thick, relatively impervious layers consisting mainly of sandy siltstone, siltstone, and mudstone. The fine-grained character of all the aquifers precludes rapid movement of ground water and large yields to wells.

Specific capacities computed for wells drilled into the aquifers in northern Arizona vary considerably, usually ranging from 0.3 to 5.0 gpm per foot of drawdown although most are less than 1.0 gpm per foot of drawdown. Specific

Table 2. --Mean annual precipitation for stations near Flagstaff (Sellers, 1960)

Station	Length of record (years)	Altitude (feet above mean sea level)	Mean annual precipitation (inches)	Location of station on orographic barrier along southwestern border of Colorado Plateaus
Flagstaff	1899-1951	6,903	20.27	Top
Fort Valley	1909-57	7,347	22.56	Top
Grand Canyon	1904-57	6,965	15.81	Top
Leupp 1/	1914-53	4,700	6.37	Leeward side
Payson	1893-1957	4,848	21.48	Windward side
Sedona 1/	1943-53	4,223	16.56	Windward side
Tuba City	1898-1957	4,936	6.72	Leeward side
Williams	1898-1957	6,750	21.88	Windward side
Winslow	1898-1957	4,880	8.05	Leeward side
Wupatki 1/	1939-53	4,908	7.75	Leeward side

1/ From Smith (1956)

Table 3.--Hydraulic properties of aquifers in the Plateau uplands province computed from pumping and bailing tests

Geologic source	PUMP TESTS					BAIL TESTS					REMARKS
	Number of tests	Coefficient of transmissibility (gpd per foot)	Coefficient of storage	Specific capacity (gpm per foot of drawdown)	Yield (gpm)	Number of tests	Specific capacity (gpm per foot of drawdown)		Yield (gpm)		
							Range	Average	Range	Average	
Alluvium	12	325- 63,800	$5x10^{-4}$-0.25	0.80- 68.9	10 - 241	48	0.12-75.00	-----	5-275	-----	Coefficient of storage computed from five tests.
Bidahochi Formation	1	60	-----	0.12	4	6	.04-26.9	-----	12-250	-----	
Toreva Formation	1	18	-----	.12	15	27	.05- 1.20	0.32	4- 60	18	
Dakota Sandstone	-----	------	-----	------	-----	20	.02 - .40	.13	3- 36	16	
Morrison Formation	5	677	-----	.45 - .92	13 - 350	10	.02- 2.20	-----	6- 19	-----	Coefficient of transmissibility computed from one test.
Cow Springs Sandstone	2	21	-----	.07 - .16	9 - 16	3	.07 - .27	-----	8- 40	-----	Coefficient of transmissibility computed from one test.
Entrada Sandstone	-----	------	-----	------	-----	6	.02- 3.50	-----	5- 35	-----	
Navajo Sandstone	4	450 - 3,800	0.005	.74 - 5.24	30 - 150	74	.4 - 7.00	.85	5-170	23	Coefficient of transmissibility computed from three tests; coefficient of storage computed from one test.
Lukachukai Member of Wingate Sandstone	-----	------	-----	------	-----	5	.02 - .70	-----	7 - 8	-----	
Sandstone beds of the Chinle Formation	1	2,000	-----	1.35	50	19	.02- 3.33	-----	1- 60	-----	
Coconino Sandstone	10	3,000->60,000	-----	1.11->40	50->1,000	-----	-----	-----	-----	-----	
De Chelly Sandstone	3	310 - 755	-----	.21 - 1.21	25 - 150	36	.01- 3.0	.66	3-200	23	
Supai Formation	-----	------	-----	------	-----	4	.01 - .92	-----	1- 24	-----	Defiance Plateau area.

capacities of more than 15 gpm per foot of drawdown have been computed only for wells in the Coconino Sandstone, the Bidahochi Formation, and the alluvium (table 3). Several aquifers—mainly the Supai Formation, the Wingate Sandstone, the Cow Springs Sandstone, the Dakota Sandstone, and the Wepo Formation—are tapped by wells that have specific capacities of less than 1.0 gpm per foot of drawdown.

The coefficients of transmissibility (computed from pumping tests) of the aquifers of northern Arizona—except for the Coconino Sandstone and the alluvium—generally are less than 1,200 gpd per foot (table 3). The coefficients of transmissibility of the aquifers in the consolidated rocks, for the most part, range from 500 to 1,000 gpd per foot for about 80 percent of the area that is north of the Little Colorado River and Rio Puerco. However, coefficients of transmissibility of the Coconino Sandstone—the chief aquifer in the area south of the Little Colorado River and Rio Puerco—may be more than 50,000 gpd per foot and most are between 15,000 and 30,000 gpd per foot.

Coefficients of permeability computed from pumping tests of wells tapping aquifers in the consolidated rocks are extremely low; some are less than 1 gpd per square foot. Most values range from 1 to 3 gpd per square foot, and only parts of the Navajo and Coconino Sandstones have permeabilities of more than 5 gpd per square foot. The coefficients of permeability of the Coconino Sandstone range up to 70 gpd per square foot, and these are the highest permeabilities reported for any consolidated aquifer in the southern part of the Colorado Plateaus province.

Coefficients of transmissibility and permeability computed from pumping tests of wells completed in the flood-plain alluvium are the highest in northern Arizona and reflect the diverse character of these alluvial deposits. Locally, the coefficients of transmissibility may be more than 60,000 gpd per foot, and values ranging from 1,500 to 5,000 gpd per foot are common in many areas. Coefficients of permeability of the water-yielding beds in the alluvium may exceed 100 gpd per square foot and seldom are less than 10 gpd per square foot.

Hydrologic Basins

The Arizona part of the Colorado Plateaus province is divided into several hydrologic basins that control the regional occurrence, movement, and natural discharge of the ground water. The area east of the Kaibab Plateau includes parts of five hydrologic basins, of which the largest is Black Mesa basin (fig. 7). The other four basins—San Juan, Blanding, Henry, and Kaiparowits basins—extend into the adjoining States. West of the Kaibab Plateau ground-water movement is controlled by the large normal faults in the area and by the configuration of the gentle structural slope. Low areas on this structural slope are referred to informally as troughs, of which the Coconino and Virgin troughs seem to be the most prominent. Black Mesa basin is the principal hydrologic basin in northern Arizona, and the following discussion is concerned chiefly with this basin.

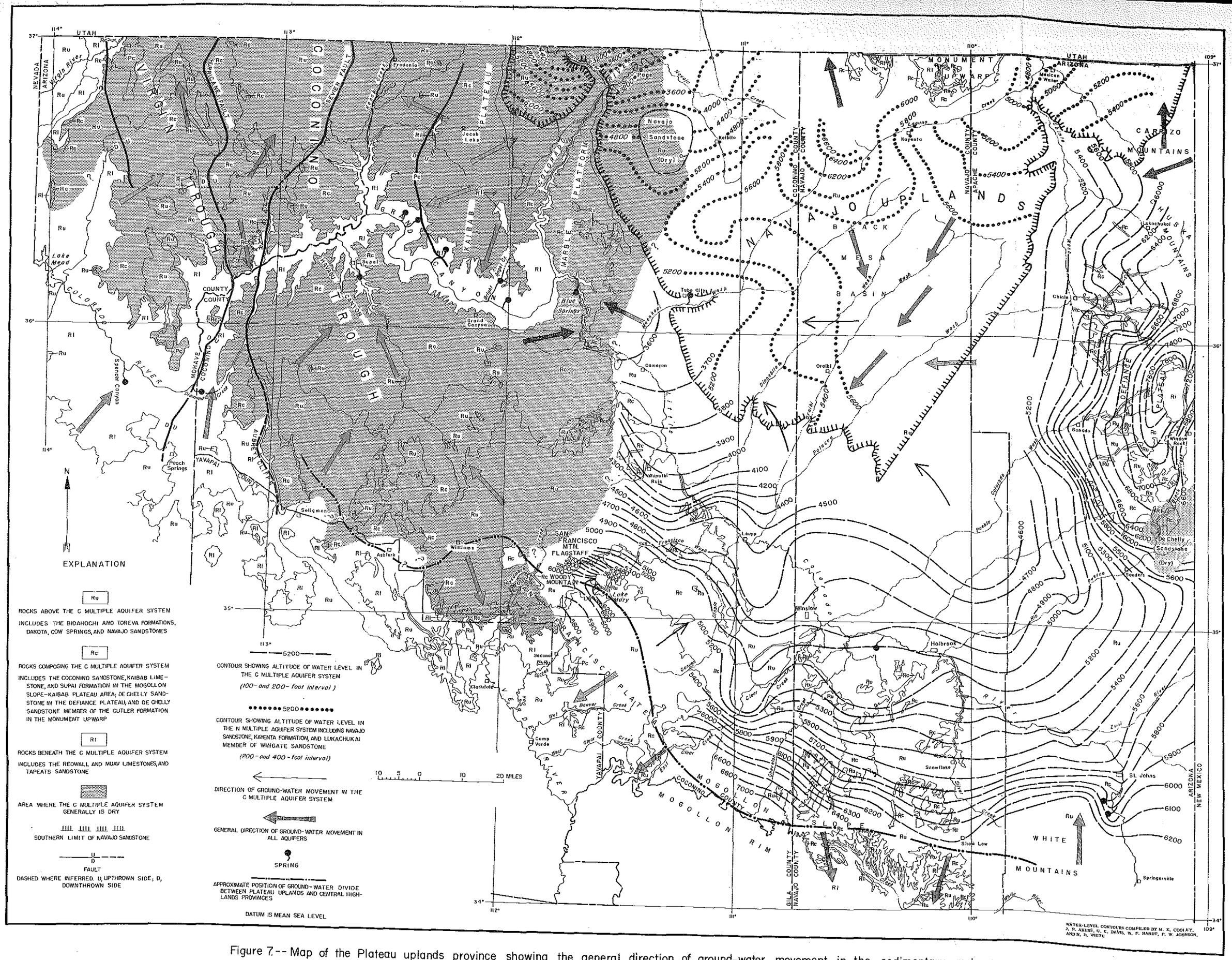


Figure 7.--Map of the Plateau uplands province showing the general direction of ground-water movement in the sedimentary rocks.

Recharge and Movement of Ground Water

Ground-water recharge in northern Arizona is from precipitation that falls on the upturned rocks exposed on the highlands along the flanks of the hydrologic basins. The principal recharge areas are the White Mountains, the Mogollon slope, the San Francisco Plateau, the Kaibab Plateau, the Navajo Uplands, and the Defiance Plateau (fig. 7). These areas probably contribute more than 80 percent of the ground-water recharge to the aquifers of northern Arizona. The recharge areas are generally above 6,000 feet and usually receive more than 15 inches of precipitation annually.

Regional movement of ground water in the aquifers of Black Mesa basin is toward the Little Colorado River; in San Juan, Blanding, and Henry basins ground-water movement is toward the San Juan River; in the Kaiparowits basin and the Coconino trough it is toward the Colorado River; and in the Virgin trough it is toward the Virgin River. The Colorado and San Juan Rivers serve as the only hydrologic connecting link between the basins, but the flow of these rivers upstream from a particular basin is not directly a part of the hydrologic system of that basin. All the ground water that originates in the basins of the Colorado Plateaus except that in the Virgin trough is funneled through the channel of the Colorado River in Grand Canyon before leaving the Colorado Plateaus.

Black Mesa basin has a total area of 28,000 square miles and is the principal hydrologic basin in northeastern Arizona. Ground water moves for long distances in the basin, but this regional movement occurs mainly in the C and N aquifer systems. The ground water in both aquifers is unconfined near the areas of recharge but is under high artesian pressures in the center of the basin.

The C aquifer system receives recharge on the Defiance Plateau, the Mogollon slope, and in the Grand Canyon region in the southwestern part of the Colorado Plateaus province. Some ground water moves westward and basinward from the Defiance Plateau, but most water in the aquifer in the Black Mesa hydrologic basin moves northward and northeastward from the Mogollon slope and the San Francisco Plateau. The ground water moving northward converges with the water moving westward and forms a flow system that is oriented generally west-northwestward along the broad southwestern flank of Black Mesa basin (fig. 7).

The N aquifer system is recharged principally in the Navajo Uplands area. Water-level contours indicate that there is little recharge to the aquifer system from the south. This is due to the deep burial of the aquifer and to thinning and wedging out of the Navajo Sandstone in a southeastward direction. Therefore, water in the Navajo Sandstone in Black Mesa basin moves southward from the recharge area and thence northeastward in a broad arc toward Chinle Wash or southwestward toward Moenkopi Wash (fig. 7).

The other aquifers in Black Mesa basin are exposed as narrow bands, which outline roughly the general circular shape of the central part of Black Mesa basin. Ground-water movement in these aquifers is basinward and toward the

points of discharge along Moenkopi, Polacca, and Pueblo Colorado Washes and the Rio Puerco and Little Colorado River.

Natural Discharge of Ground Water

Black Mesa basin is unique in that about two-thirds of the ground water moving through the basin discharges at Blue Spring and several other springs near the confluence of the Little Colorado and Colorado Rivers. The yield from Blue Spring is chiefly from the C aquifer system because ground-water discharge from the N aquifer system and other aquifers is evaporated or used for irrigation near the points of discharge. The yield from Blue Spring measured at the mouth of the Little Colorado River is 222 cfs (cubic feet per second) or 161,000 acre-feet per year. Other main areas of ground-water discharge from springs are between St. Johns and Springerville, between Winslow and Holbrook, and near Tuba City. A small amount of ground water also moves through the Navajo Sandstone from Black Mesa basin into Blanding basin and discharges into Chinle Wash (fig. 7). The total amount of ground water that discharges from the several aquifers in Black Mesa basin is estimated to be about 225,000 acre-feet annually, and this amount is about 1½ percent of the total annual precipitation that falls in the area of Black Mesa basin.

In that part of the Colorado Plateaus province west of Black Mesa basin, ground water is controlled principally by the northward-plunging Coconino and Virgin troughs and by the Hurricane, Sevier, and other large normal faults. The Coconino trough is bounded on the east by the gentle western slopes of the Kaibab and San Francisco Plateaus and on the west by the Hurricane fault and the fault along Aubrey Cliffs. Ground water in the trough moves generally toward the points of discharge in Havasu Canyon near the Indian village of Supai and along Kanab Creek. The Virgin trough lies chiefly along the down-thrown side of the Hurricane fault and is bordered on the west by Grand Wash Cliffs. Ground water in this trough moves northward and apparently discharges into the Virgin River just north of the Arizona-Utah State line.

Effects of Fracturing

Fracturing, as a result of prominent jointing and faulting of the consolidated sedimentary rocks, greatly influences the occurrence, yield, and movement of ground water in the C aquifer system in many parts of northern Arizona. The fractures range in width from the thickness of a sheet of paper to several feet; some of the large ones have been explored by speleologists (written communication, Robert A. Schley, 1963) or have been noted by drillers during the drilling of deep wells. The trends of the fractures as determined from the regional fault and joint pattern comprise a tightly spaced network that extends from the White Mountains northwestward across the Mogollon slope and San Francisco Plateau, Marble Platform, Kaibab Plateau, and into the western Grand Canyon region. Most of the fractures are aligned to the northwest, north, and northeast, and there is a general convergence of the fractures in the area of San Francisco Mountain near Flagstaff.

In many parts of Navajo and Apache Counties and in the Flagstaff area of Coconino County fracturing increases the overall permeability of the rocks and thus increases the yield of water to wells. Wells completed in the highly fractured parts of the Coconino Sandstone in the valley of the Little Colorado River may yield 1,000 gpm, and the coefficients of transmissibility of the aquifers are more than 50,000 gpd per foot. In parts of the Coconino Sandstone where fracturing is not developed extensively, coefficients of transmissibility are lower and may range from 10,000 to 20,000 gpd per foot. Although the yields are lower, fracturing is largely responsible for the success in obtaining a permanent ground-water supply for the city of Flagstaff at Woody Mountain and Lake Mary (Akers, 1962a, p. 97-100).

In part of Coconino County and in Mohave County in the Colorado Plateaus province, intense fracturing of the consolidated rocks and the cutting of the deep canyons along the Colorado River have drained large parts of the Coconino Sandstone. In these areas the Coconino is too permeable to retain a sufficient amount of ground water to be utilized by wells. Ground water moves downward along the fractures from the Coconino through the underlying Supai Formation and collects in the Redwall (Mississippian) and Muav (Cambrian) Limestones. The Redwall and Muav Limestones are the basal units of the ground-water system in this part of the Colorado Plateaus, as they are underlain chiefly by shaly rocks that in turn are underlain by the granitic and metamorphic basement rocks. Ground water in the limestones then moves laterally along solution channels, which probably are controlled by fractures, and discharges from large springs situated in canyons tributary to the Grand Canyon. These springs include Blue Spring, which is the main point of discharge from Black Mesa basin in the canyon of the Little Colorado River mentioned previously; springs that are recharged on the Kaibab Plateau and maintain the flow of Bright Angel Creek and other creeks below the north rim of the Grand Canyon; springs in Havasu Canyon, which drain the southern part of the Coconino trough; and springs along Diamond Creek and in Spenser Canyon (fig. 7). The total ground-water discharge from all these springs is about 275,000 acre-feet per year.

Chemical Quality of the Ground Water

The ground water in northern Arizona has a wide range in the types and amounts of dissolved chemical constituents. The dissolved-solids content ranges from 90 to 60,000 ppm for about 1,500 water samples analyzed. Water from the flushed aquifers in the Navajo, Wingate, Coconino, and De Chelly Sandstones on the Mogollon slope, the San Francisco Plateau, the Navajo Uplands, and the Defiance Plateau is lowest in dissolved solids (table 4). Water containing the greatest amount of dissolved solids is from the area of Black Mesa north of the Little Colorado River. In this area water from the Coconino Sandstone and, locally, from other water-yielding beds in the consolidated rocks and from the alluvium contains more than 10,000 ppm dissolved solids.

The principal constituents of the ground water are bicarbonate, sulfate, calcium, sodium, and chloride ions. Combinations of these ions form five general types,

Table 4.--Selected chemical analyses of the ground water in the Plateau uplands province showing the range of concentration of the dissolved solids, in parts per million

Geologic source	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium and Potassium (Na + K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (parts per million)	Hardness as $CaCO_3$		Remarks
												Calcium, magnesium	Non-carbonate	
Alluvium	4-63	4-2,870	1-2,040	5-12,000	34-1,000	0- 79	2-8,890	2-27,500	0 - 11.0	0 - 439	143-47,100	18-15,500	0-15,500	
Bidahochi Formation	3-28	2 - 80	1 - 16	8 - 366	127 - 292	0- 39	6 - 492	5 - 157	0 - 2.8	.1- 15	132- 1,070	8 - 244	0 - 53	
Chuska Sandstone	20-61	23 - 71	5 - 11	3 - 23	48 - 278	0 - 5	3 - 24	3 - 12	.1 - .4	.1- 11	138 - 299	43 - 222	0 - 9	
Toreva Formation	7-26	3 - 298	1 - 96	6 - 228	79 - 479	0- 16	12-1,200	3 - 100	.1- 1.8	.1-154	130- 1,890	12- 1,140	0 - 940	
Dakota Sandstone	6-42	1 - 330	1 - 103	6- 1,430	130-1,550	0- 39	8-3,540	6 - 500	.1-10	.2- 10	165- 5,560	9- 1,080	0- 1,210	
Morrison Formation	6-28	5 - 373	2 - 188	9 - 695	81-1,200	0- 73	11-1,980	3 - 374	.1- 4.0	0 - 200	168- 2,960	20- 1,700	0- 1,520	
Cow Springs Sandstone	7-18	7 - 221	2 - 106	24 - 949	208 - 898	0- 18	17-2,380	12 - 118	.2-51	.1- 18	264- 3,760	20 - 988	0 - 572	
Entrada Sandstone	9-27	2 - 262	1 - 64	15 - 543	83 - 539	0- 16	6-1,930	5- 2,230	.2- 1.2	.3- 33	196- 2,870	11 - 916	0 - 848	
Navajo Sandstone	6-29	1 - 135	1 - 64	1 - 295	57-2,300	0- 45	3 - 625	1 - 171	0 - 2.4	0 - 80	90- 1,030	6 - 598	0 - 512	
Lukachukai Member of Wingate Sandstone	9-29	2 - 67	1 - 21	6 - 308	99 - 470	0-247	7 - 250	3 - 121	.1- 1.2	.1- 18	122 - 867	10 - 254	0 - 42	
Sandstone beds of the Chinle Formation	4-28	1 - 304	1 - 587	6 - 871	135 - 740	0- 33	16-4,110	5 - 375	.2- 1.6	.2 - 9.8	171- 6,410	5- 3,170	0- 2,820	
Coconino Sandstone	10-20	19 - 300	8 - 80	13 - 350	113 - 700	0 - 0	11 - 650	4 - 500	.1- 4.0	.4 - 3.0	133- 2,500	83- 1,000	0 - 450	Does not include analyses having an extremely high amount of chloride.
De Chelly Sandstone	7-20	18 - 457	7 - 147	5 - 190	117 - 532	0 - 6	9-1,560	3 - 122	0 - 2.0	0 - 17	126- 2,270	90- 1,740	0- 1,640	

which are classified as calcium bicarbonate, sodium bicarbonate, sodium sulfate, calcium sulfate, and sodium chloride. Most water having less than 500 ppm of dissolved solids is classified as either calcium or sodium bicarbonate, and water containing more than 500 ppm is classified as sodium sulfate, calcium sulfate, or sodium chloride. Gradations between these chemical types are indicated commonly, and much of the highly mineralized water is a bicarbonate-sulfate type.

The minor constituents of ground water that usually are analyzed are fluoride, nitrate, magnesium, silica, and iron. The concentrations of these ions vary considerably throughout the Colorado Plateaus province, but, except for fluoride and nitrate, they are not objectionable for most ground-water use. Concentrations of nitrate are generally low in the natural ground water from drilled wells and from springs in northern Arizona, but water from dug wells in many parts of the Navajo and Hopi Indian Reservations may contain more than 45 ppm of nitrate, which is the upper safe limit for domestic use set by the U. S. Public Health Service (1962). The amount of fluoride in ground water from large parts of the area north of the Little Colorado River is above the range considered safe for consumption by children. A concentration of more than 1.5 ppm of fluoride may have adverse effects on the teeth of children, and concentrations greater than 4 ppm may cause cumulative fluorosis and skeletal effects. More than 4 ppm of fluoride is common in water from the Dakota Sandstone, the Cow Spring Sandstone, the Entrada Sandstone, the Wepo Formation, the Chinle Formation, and the alluvium in the general area of the Hopi Indian Reservation and surrounding parts of Black Mesa basin.

RECHARGE OF GROUND WATER TO THE ALLUVIAL AQUIFERS IN THE BASIN AND RANGE LOWLANDS

By

J. T. Hollander and Natalie D. White

General Principles

Sources of recharge to ground-water reservoirs in the alluvial-filled basins in the Basin and Range province are: (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. Most reports of investigations of ground-water resources in specific areas include estimates of the percentage of available water that is recharged to the aquifer from each of the above sources. It is generally agreed that the principal source of ground-water recharge to alluvial basins in Arizona is runoff from precipitation on adjacent mountain ranges. Although percentages differ according to soil conditions, altitude, temperature, humidity, and evaporation (Coates and Cushman, 1955, p. 28; Halpenny and others, 1952), many investigators agree that about 10 percent of the precipitation on the mountain areas becomes runoff and that perhaps as much as 50 percent of this runoff infiltrates the coarse alluvial material at the mountain front and percolates toward the ground-water reservoir. Recharge from direct penetration of precipitation is commonly considered negligible in arid regions except along stream courses, where the materials overlying the aquifer are coarse and the water table is at a fairly shallow depth. In some basins the ground-water reservoir may be recharged by underflow—by water moving from upstream basins through permeable materials underlying stream channels, or other places not completely obstructed by the hard-rock barriers that separate the basins. Although this movement of water between basins is recharge to the lower basin, it is at the same time discharge from the upper basin. Some water also is added to the ground-water reservoir by infiltration of excess irrigation water applied to the land. However, this process actually is a recirculation of water from storage within the basin and cannot be considered as a gain to ground-water storage.

The above discussion briefly summarizes the usual treatment of the sources of recharge to alluvial reservoirs of the Basin and Range lowlands. One factor, often neglected, is time of travel—the very slow movement of water in the subsurface materials—and the influence that this might have on the total amount of downward-moving water that reaches the ground-water reservoirs, particularly in areas of very deep water levels. In addition, any discussion of recharge by infiltration from the land surface must consider the mechanics of water movement in the unsaturated zone—presently the subject of several research projects in the Ground Water Branch of the Geological Survey. The discussion here will be limited to some elements that influence the downward movement of water toward or into the ground-water reservoir.

With respect to the occurrence of water, the subsurface materials above the bedrock floor may be divided into two zones. The "zone of saturation," as

defined by Meinzer (1923, p. 21), is the zone in which the permeable rocks are saturated with water under hydrostatic pressure. The "zone of aeration" is the zone extending from land surface to the zone of saturation and in which the interstices of the permeable rocks are not, except temporarily, filled with water under hydrostatic pressure. In this zone, the interstices either are not filled with water, or if they are, it is held by capillarity. The upper surface of the zone of saturation is the water table except where the zone is overlain by an impermeable body. The zone of aeration is divided into three parts: the belt of soil water, the intermediate belt, and the capillary fringe. The relations between the zones are illustrated in figure 8, which is adapted from Meinzer (1923). The belt of soil water occurs immediately below the land surface; water from this belt can be discharged into the atmosphere by plants, direct evaporation from the soil, or both. The capillary fringe contains capillary interstices some or all of which are filled with water that is continuous with the water in the zone of saturation (Meinzer, 1923, p. 26). This fringe, in which the pressure is less than atmospheric, overlies the zone of saturation and, depending upon certain conditions, may either transmit water into the zone of saturation or extract water from it by capillary action. The intermediate belt of the zone of aeration lies between the belt of soil water and the capillary fringe (Meinzer, 1923, p. 26). Water that moves into this belt may continue downward under the force of gravity through the capillary fringe and into the zone of saturation, or it may be held by molecular attraction in the capillary interstices of the intermediate belt. The belt of soil water and the capillary fringe generally are thin, the thickness being controlled by local conditions, but because the intermediate belt (fig. 8) is the residual part of the zone of aeration, it may be absent or it may be several hundred feet thick.

Where the water table is only a few feet below the land surface, conditions in the belt of soil water may determine whether a given amount of rainfall or other applied water provides recharge to the zone of saturation (Remson, Randolph, and Barksdale, 1960). The intermediate belt may be virtually nonexistent, and, if the moisture content of the belt of soil water is sufficient to allow water to move downward by gravity, the water probably will pass through the capillary fringe and into the zone of saturation. The critical stage at which a soil has a moisture content sufficient to allow water to move by gravity is called "field capacity." The field capacity of the soil must be exceeded before any water is available for recharge to the ground-water reservoir. During periods when precipitation exceeds evapotranspiration, the belt of soil water can reach and remain at about field capacity. If excess precipitation continues for a sufficient period of time for the soil to exceed field capacity, water can move downward by gravity.

In many areas in southern Arizona the water table is several hundred feet below the land surface, and, hence, the zone of aeration is several hundred feet thick. Proportionally the thickness of the belt of soil water is only a small part of the zone of aeration, and the larger part is the intermediate belt. Under these circumstances, although the belt of soil water may have reached field capacity, unless the amount of water infiltrating at the surface is sufficient to bring the thick intermediate belt up to field capacity also, recharge to the saturated zone cannot take place. Sufficient water must be applied to bring the entire zone of aeration to field capacity before significant ground-water recharge can take place. This is not to say that in order for any recharge to occur the belt of soil water and the intermediate zone for a whole basin must

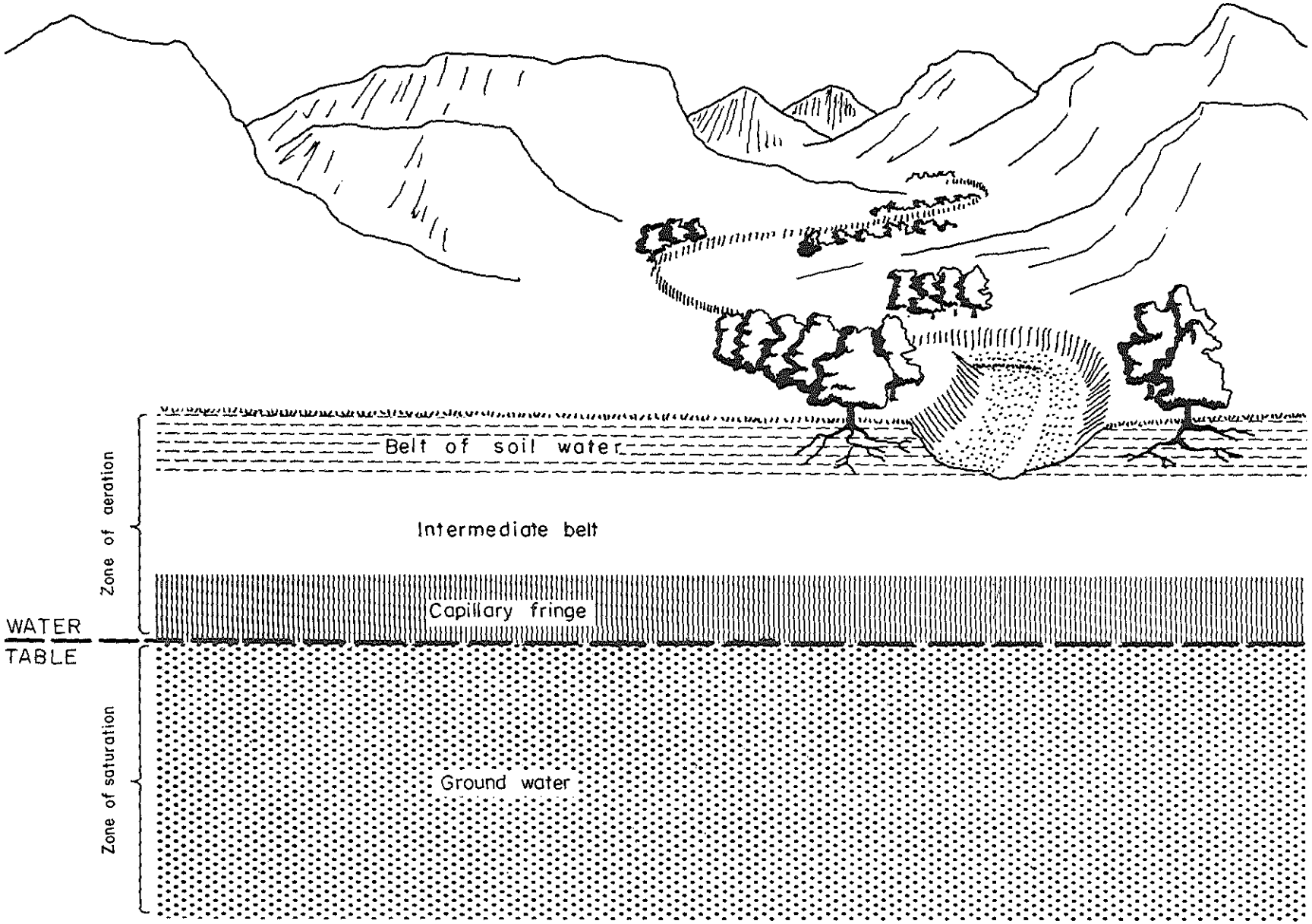


Figure 8. --Sketch showing subsurface zones with respect to the occurrence of water.

be brought up to field capacity; on the contrary, recharge will occur in any small area where field capacity has been attained even for a short time.

The permeability of the various rock materials in the zone of aeration is one of the factors in determining whether field capacity is reached and exceeded, thereby allowing water to move by gravity into the zone of saturation. More permeable materials, such as gravel and coarse sand, allow water to move readily; whereas less permeable clay and silt do not. In the alluvial basins of southern Arizona, the texture of the subsurface materials differs greatly, ranging from coarse gravel and sand mixtures to nearly impermeable silt and clay. The distribution of these materials is characterized by frequent changes horizontally and vertically. Clay commonly is present in lenticles that interfinger with coarser deposits, so that within relatively short distances the rate of percolation of downward-moving water could change rapidly. A clay lens would nearly halt the downward movement of water through the zone of aeration.

In summary, the thickness and prior moisture content of the zone of aeration determine the amount of water application necessary for ground-water recharge. The amount of any given water application and the nature of the subsurface sediments affect the time required for ground-water recharge to occur.

The above discussion points out some of the reasons ground-water recharge in the areas of deep water levels in the Basin and Range lowlands of southern Arizona may be negligible. The high evapotranspiration potential, the great thickness of dry material above the water table, the presence of nearly impermeable lenses within the subsurface materials, and low rainfall and runoff combine to limit ground-water recharge. Nevertheless, runoff from precipitation is the greatest source of recharge to the ground-water reservoir in the Basin and Range lowlands province, and, therefore, interest in the possibility of recharge from flood runoff is high. A torrential rainstorm and subsequent flooding occurred in the Santa Cruz Valley in September 1962, and there has been much speculation as to its effect on the ground-water reservoir in the area.

Effect of Flood of September 1962 on Ground Water in the Santa Cruz Valley

A severe rainstorm caused floods in the Santa Rosa, Brawly, Sells, and Greens Washes—tributaries to the Santa Cruz River—between September 25 and 27, 1962. According to records of the Surface Water Branch, U.S. Geological Survey (Lewis, 1963), at least 40,000 acre-feet of water flooded the Brawly Wash drainage; the peak discharge of Brawly Wash was 38,000 cfs. Other peak discharges were: 53,000 cfs, Santa Rosa Wash at Vaiva Vo; 17,000 cfs, Greens Wash near Chuichu; and 12,800 cfs, combined discharges of Santa Rosa and Greens Washes near Stanfield. The total volume of water discharged by this flood must have been considerably in excess of 125,000 acre-feet, according to Lewis (1963). However, the runoff in the Santa Cruz River near Laveen, about 12 miles northwest of the map boundary (fig. 9), was only 17,400 acre-feet, indicating that most of the water disappeared before it reached this point. The Ground Water Branch, U.S. Geological Survey, as part of the cooperative

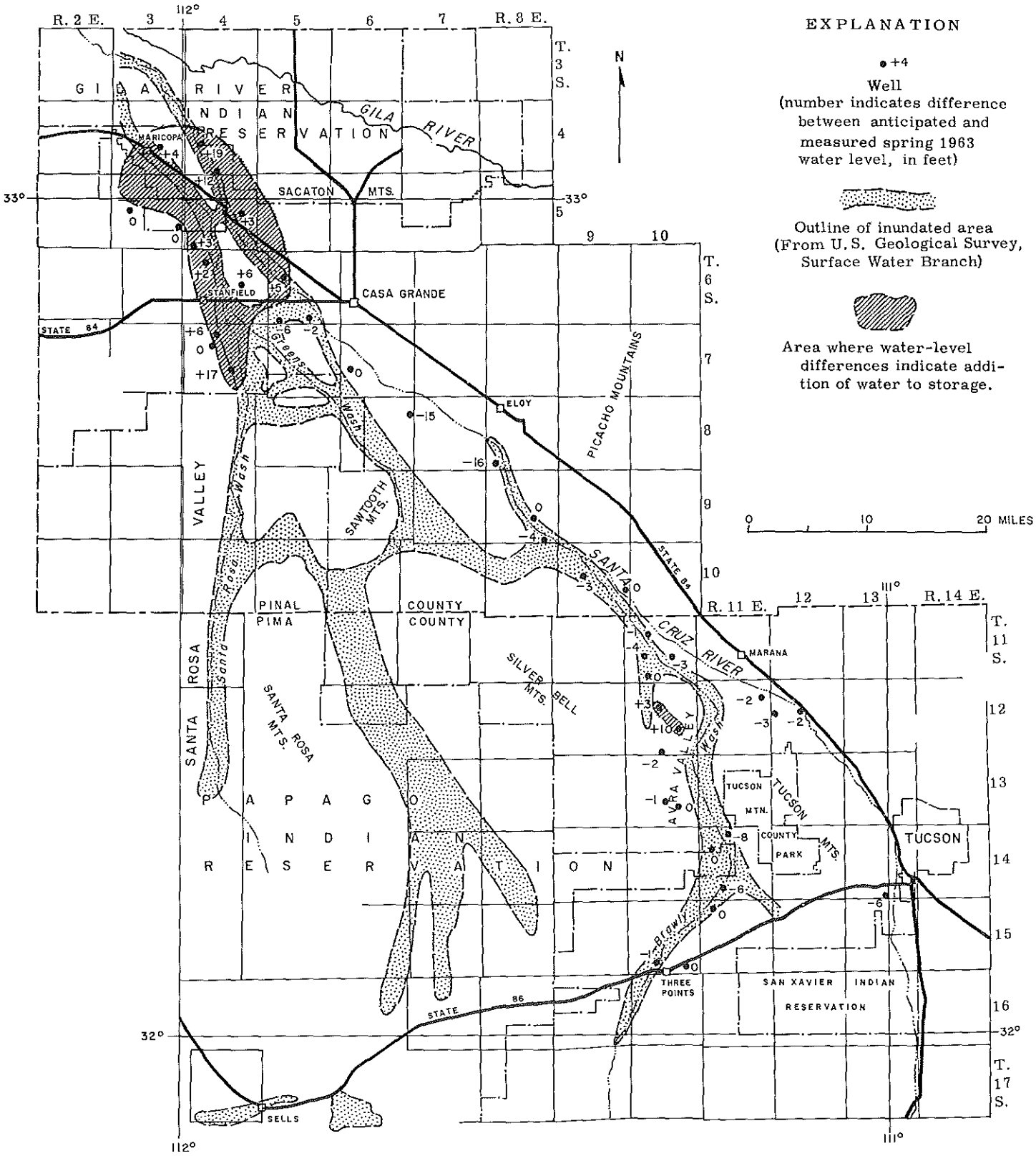


Figure 9.--Map of part of Santa Cruz Valley showing inundated area and water-level response in selected wells.

program with the Arizona State Land Department, made a reconnaissance to determine if storage in ground-water reservoirs in the flooded area increased significantly. The reconnaissance indicated that it did; the analysis of the data is discussed below.

Water levels were measured in 66 wells in the flooded area from October 5-16. It was possible to analyze the data for only 38 of the wells due to the inadequacy of previous measurements in the rest. Analysis showed that water levels in about half the wells were higher than expected. It was not possible, however, to determine if the higher levels were due solely to the flood.

The 38 wells were remeasured in the spring of 1963 along with the many regular observation wells; anticipated spring 1963 water levels were estimated by extrapolating the hydrographs of spring water levels of the preceding 5 years. The differences between the anticipated levels and the measured levels are plotted on figure 9, and hydrographs of the levels in selected wells are shown on figure 10.

In the upstream part of the flood area from Three Points northwestward through Avra Valley to a few miles north of the Pima-Pinal County line (fig. 9), the measured spring levels in most wells were nearly the same or lower than the anticipated spring levels except in two wells, where levels were higher—probably owing to factors other than regional recharge from flood runoff but possibly indicating very local recharge.

From about 10 miles south of Stanfield to Maricopa, measured water levels were from 2 to 19 feet higher than anticipated. The high levels extend over about 150 square miles or nearly 100,000 acres (fig. 9).

Cumulative declines of water level were computed, using all data available for the 150-square-mile area and based on 1955 as a "zero" year. The hydrograph of the declines (fig. 11) shows a definite decrease in the rate of annual decline in the period 1962-63—at least 4 feet and possibly as much as 8 feet. The cumulative-decline hydrograph (fig. 11) for the entire Stanfield-Maricopa area, based on the same period of record, also shows a slight decrease in the rate of decline—probably as a result of recharge in the 150-square-mile area of high water levels.

Pumpage, pumping schedules, and patterns of pumping relative to the location of observation wells in 1962 were virtually the same as those in 1961. Higher-than-expected levels in the spring of 1963, therefore, cannot be attributed to changes in these factors. Thus, analysis of the available data indicates that the ground-water reservoir from Stanfield to Maricopa was recharged from the flood of September 1962 but that recharge probably was negligible through Avra Valley to Three Points. The area south of Stanfield to Maricopa is subject to recharge from Santa Rosa Wash when precipitation is normal (written communication, W. F. Hardt, 1963). Also, at the time of the flooding, the zone of aeration in places may have been near field capacity, as the area had been heavily irrigated for 6 months.

The median "rise" in water level in the 150-square-mile area is about 5 feet. If the specific yield of the aquifer is between 10 and 20 percent (written com-

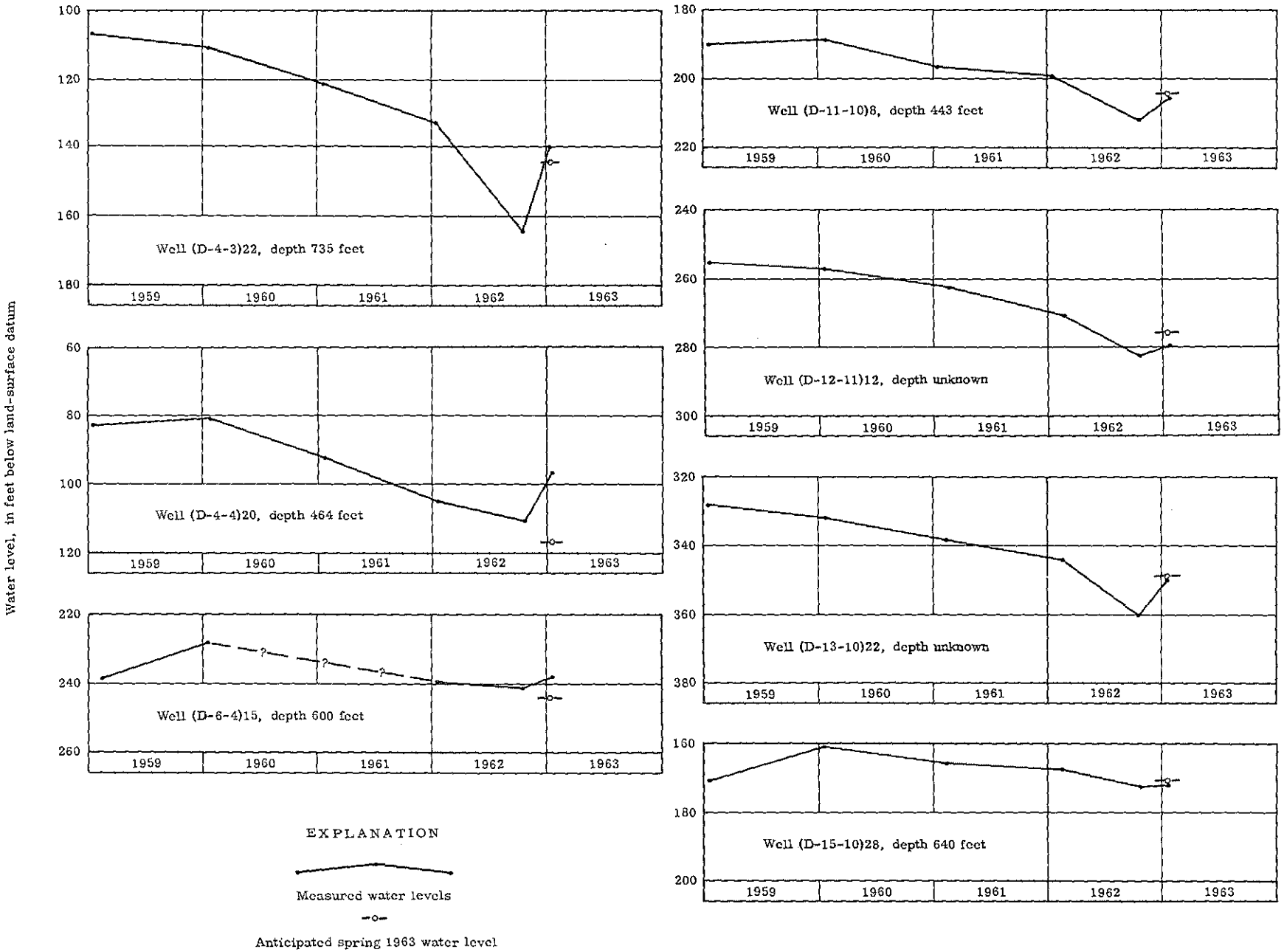


Figure 10.--Water levels in selected wells in the inundated area of Santa Cruz Valley.

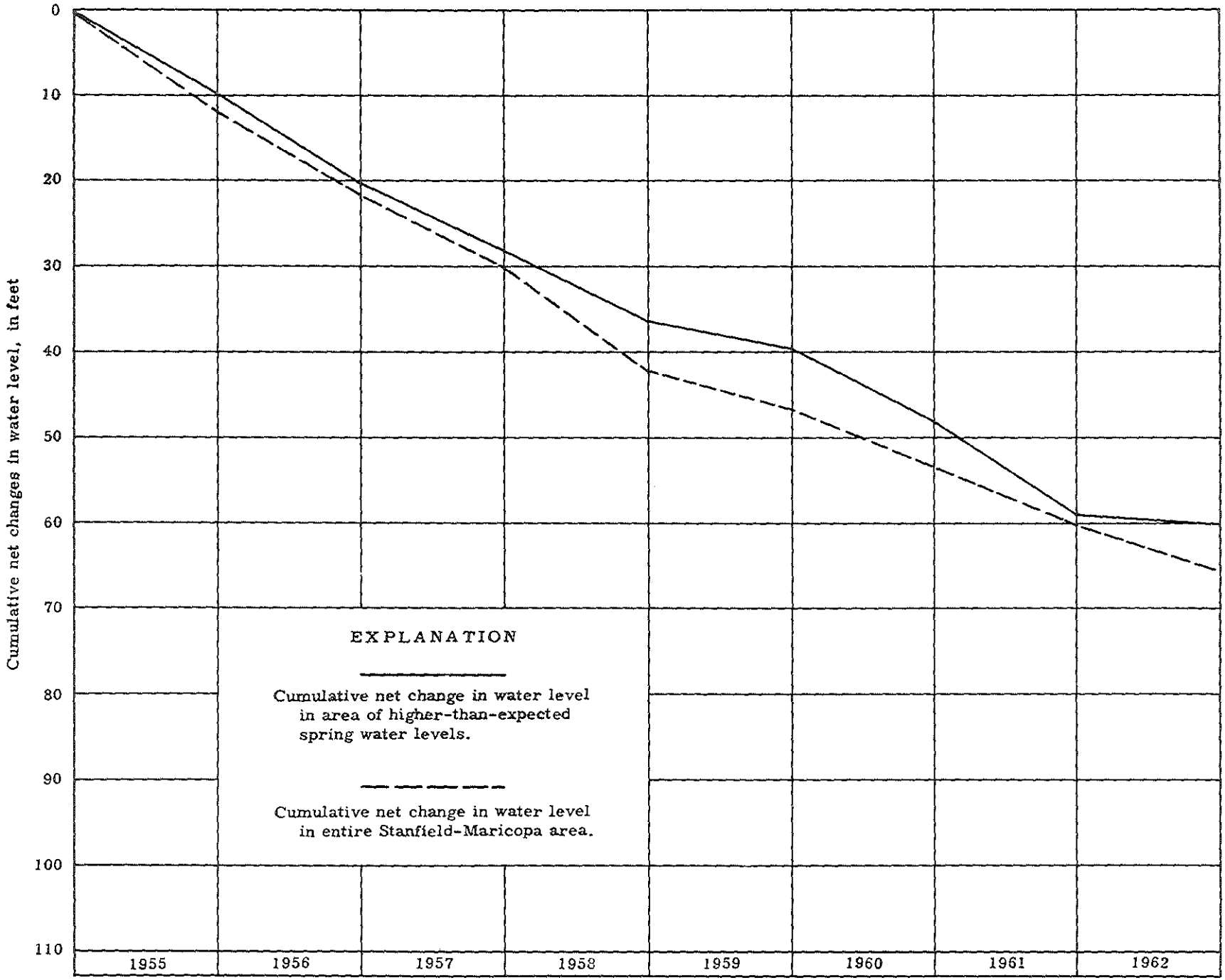


Figure 11.--Cumulative net changes in water level in part of Santa Cruz Valley.

munication, W. F. Hardt, 1963), the increment to ground-water storage contributed by the flood is between 50,000 and 100,000 acre-feet.

One may conclude from this study that this ground-water reservoir accepts recharge only in areas where surface materials are premeable and other conditions are favorable; in other areas, most runoff may be retained near the surface to be evaporated or transpired before it can infiltrate to the ground-water reservoir.

GROUND-WATER CONDITIONS BY AREAS

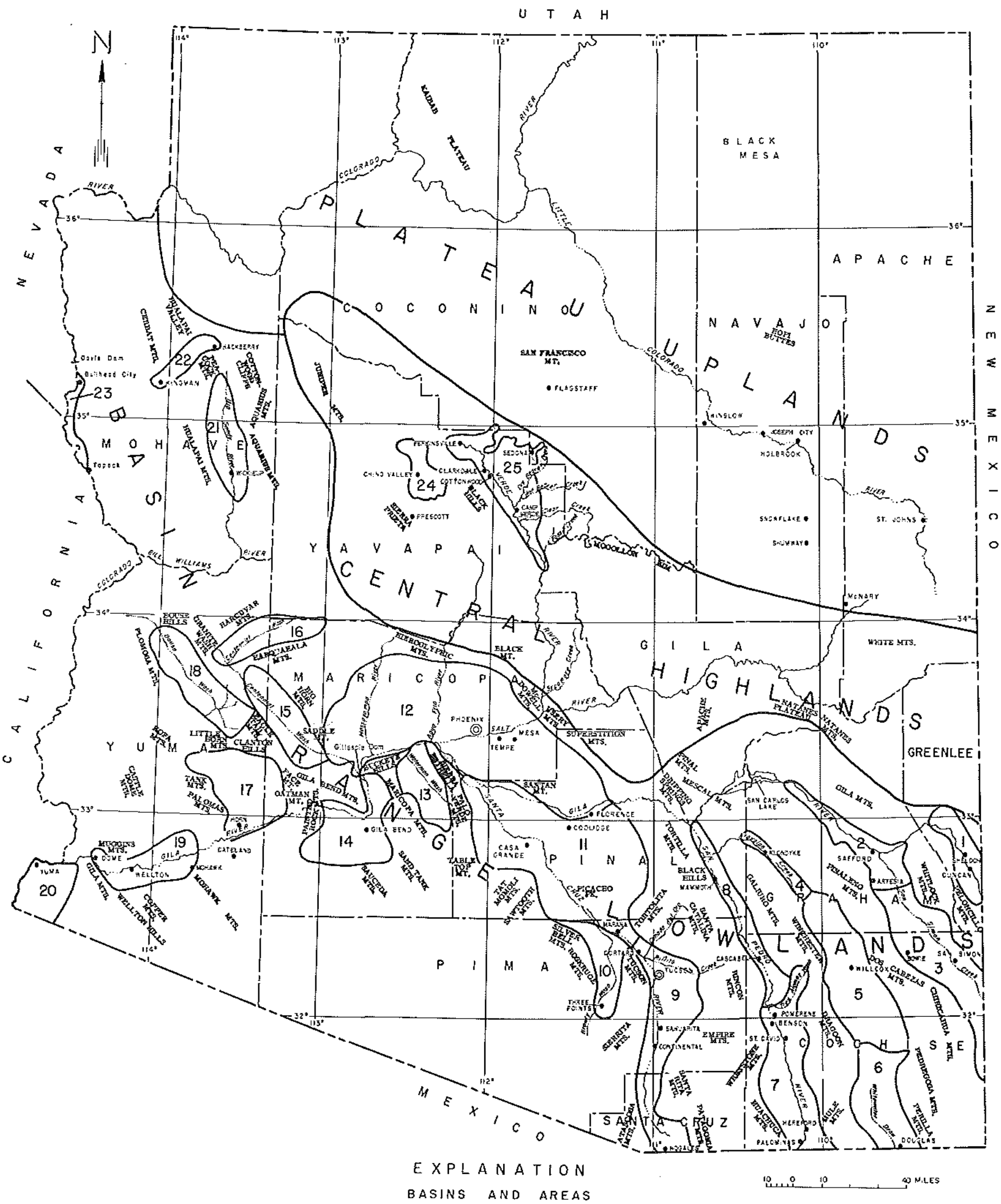
By

Natalie D. White

The development of the ground-water resources in Arizona has reached a stage wherein the trend of the water levels in nearly all the developed basins, particularly in southern Arizona, is downward---indicating the withdrawal of ground water in excess of the rate of replenishment. Prior to development of ground water by man, the aquifer was in a state of approximate hydrologic balance; that is, the average recharge from all sources was equal to the average discharge, and ground-water storage was at a maximum. However, when a well is drilled in an area and ground water is withdrawn, the water levels near the well are drawn down, which creates a cone of depression in the water table that allows water to flow into the well. As more wells are drilled and more water is withdrawn from the aquifer, the cones of depression of individual wells begin to deepen and spread; these cones subsequently overlap, which causes interference between wells and eventually results in regional dewatering of the aquifer. If the withdrawal of ground water in excess of the rate of replenishment continues, the aquifer is then said to be operating on a depletion cycle, and if the process continues long enough, the aquifer will eventually be dewatered.

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. To obtain consistent results in the analysis of the water-level trends, it is necessary to measure the water levels 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 approaching stable conditions after recovering from the previous year's pumping. Other measurements made throughout the year at strategic points in the State provide additional information on the trend of the water levels.

The following sections describe the current ground-water conditions in the major developed basins and areas in each of the water provinces in Arizona. Figure 12 shows the division into water provinces and outlines the various basins and areas. Table 5 is an index to locate the basins by counties.



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. COLORADO RIVER AREA SOUTH OF DAVIS DAM
24. CHINO VALLEY
25. VERDE VALLEY

Figure 12.--Map of Arizona showing basins and areas for which ground-water conditions are discussed.

Table 5.--Index to locate basins and areas by counties

	Number on index map	Page in text
Apache County		118
Cochise County		
San Simon basin	3	56
Bowie area		57
San Simon area		57
Rodeo area		59
Sulphur Spring and Aravaipa Valleys	4, 5, 6	61
Aravaipa Valley	4	61
Willcox basin	5	61
Douglas basin	6	64
San Pedro River valley	7, 8	68
Upper San Pedro basin	7	74
Lower San Pedro basin	8	74
Coconino County		122
Gila County		130
Graham County		
Safford basin	2	55
Sulphur Spring and Aravaipa Valleys		61
Aravaipa Valley	4	61
Willcox basin	5	61
Greenlee County		
Duncan basin	1	53

Table 5.--Index to locate basins and areas by counties—Continued

	Number on index map	Page in text
Maricopa County		
Salt River Valley	12	94
Queen Creek-Higley-Gilbert-Magma area		95
Tempe-Mesa-Chandler area		102
Phoenix-Glendale-Tolleson-Deer Valley area		102
Paradise Valley area		105
Litchfield Park-Beardsley-Marinette area		105
Liberty-Buckeye-Hassayampa area		108
Lower Hassayampa-Tonopah area		108
Lower Centennial area		108
Waterman Wash area	13	109
Gila Bend area	14	109
Harquahala Plains area	15	111
McMullen Valley area	16	112
Palomas Plain area	17	112
Mohave County		
Big Sandy Valley	21	116
Kingman-Hackberry area	22	117
Colorado River area south of Davis Dam	23	117

Table 5.--Index to locate basins and areas by counties—Continued

	Number on index map	Page in text
Navajo County		119
Pima County		
Upper Santa Cruz basin	9	76
Cortaro-Canada del Oro area		76
Tucson area		78
Sahuarita-Continental area		80
Avra-Marana area	10	82
Pinal County		
Lower Santa Cruz basin and adjacent area along the Gila River	11	84
Eloy area		88
Casa Grande-Florence area		92
Stanfield-Maricopa area		93
Salt River Valley	12	94
Queen Creek-Higley-Gilbert-Magma area		95
San Pedro River valley		68
Lower San Pedro basin	8	74
Santa Cruz County		
Upper Santa Cruz basin	9	76
Santa Cruz County area		80
Yavapai County		
Chino Valley	24	126
Verde Valley	25	127

Table 5.--Index to locate basins and areas by counties—Continued

	Number on index map	Page in text
Yuma County		
Harquahala Plains area	15	111
McMullen Valley area	16	112
Palomas Plain area	17	112
Ranegras Plain area	18	113
Wellton-Mohawk area	19	113
South Gila Valley, Yuma Mesa, and Yuma Valley area	20	114

Basin and Range Lowlands Province

By

Natalie D. White

The Basin and Range lowlands province is by far the most extensively developed of the three provinces from the standpoint of ground-water use. It contains more than 90 percent of the cultivated land in the State and about 80 percent of the population, which results in a need for large amounts of water. The growing season is long throughout most of the province, and the environment generally is favorable for crops and light industry. More than 1 million acres of land is irrigated using about 6.5 million acre-feet of water annually; municipal, industrial, and domestic use account for another half a million acre-feet annually.

The lower Santa Cruz basin and the Salt River Valley area continue to account for the greatest amount of ground-water use in the State; thus, it is in these areas where the declines in water level are greatest. Other areas where there are significant declines in the water level related to the withdrawal of ground water in excess of the rate of replenishment include the Stewart and Kansas Settlement areas of the Willcox basin, Avra Valley in Pima County, and the Bowie and San Simon areas of the San Simon basin in Cochise County. The ground-water conditions in individual basins throughout the Basin and Range province, beginning in the southeast corner of the State and going generally westward and northward, are discussed in the following paragraphs.

Duncan Basin

By

E. S. Davidson

The Duncan basin (fig. 12, No. 1) is similar to the Safford area described in the following section, as most wells are drilled in alluvium in the inner valley underlying the flood plain of the Gila River. The water table ranges in depth from a few feet to about 40 feet below land surface. The water levels in most of the wells did not change from spring 1962 to spring 1963, but the water level in a well a mile northwest of Franklin rose 2 feet and that in a well a mile northwest of Duncan rose 3 feet in this period. The water table in the basin was 2 to 8 feet higher in spring 1963 than in spring 1958. Hydrographs of the water level in wells (D-7-31)4 and (D-8-32)32 (fig. 13) illustrate the water-table rise in the region. This rise in the water table in Duncan basin, in contrast to other areas of the State, is in response to streamflow in the Gila River, part of which is diverted for irrigation on the adjoining flood plain.

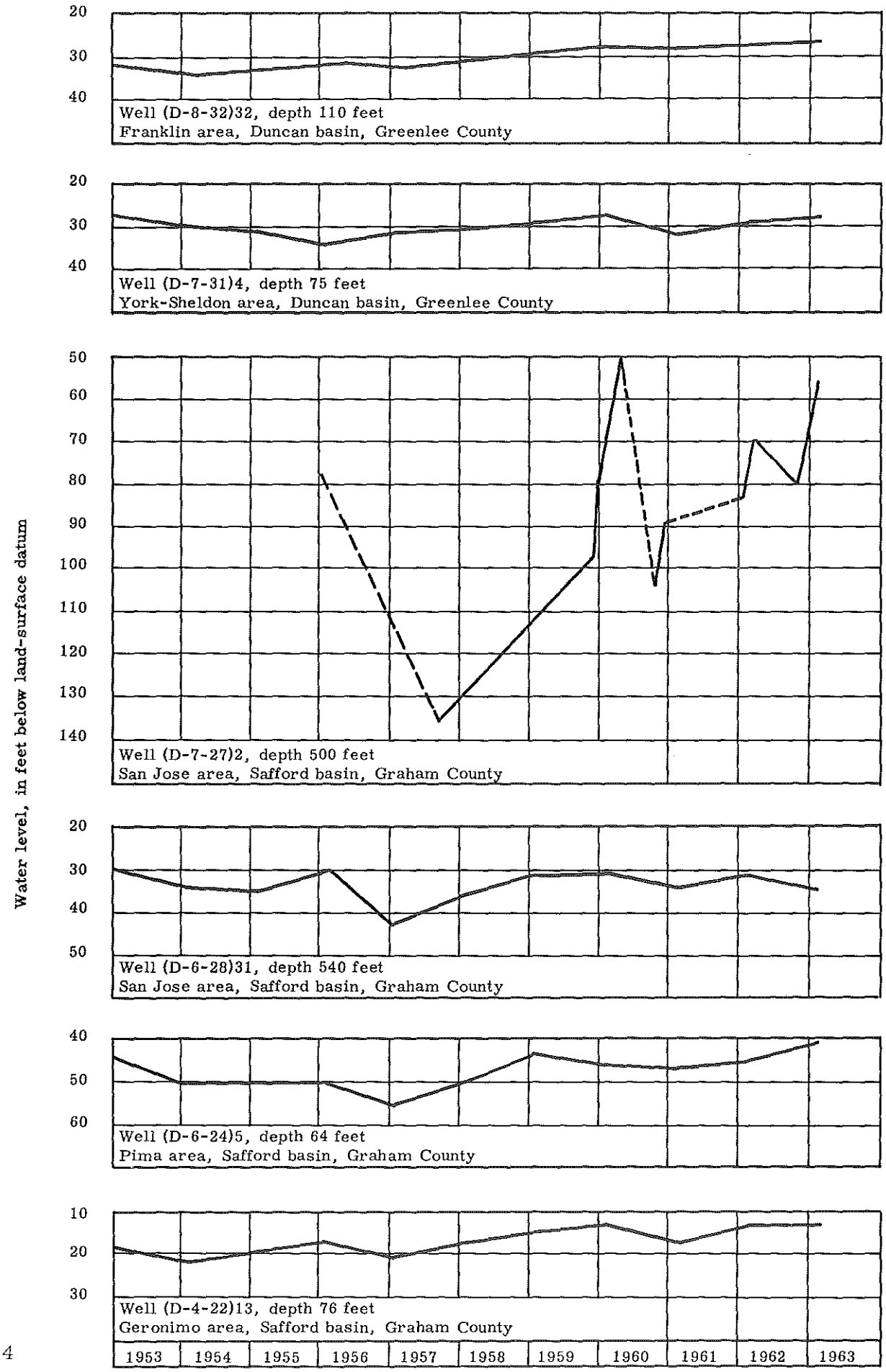


Figure 13.--Water levels in selected wells, Duncan and Safford basins.

Safford Basin

By

E. S. Davidson

Ground water in the Safford basin (fig. 12, No. 2) is withdrawn principally from alluvium in the inner valley that underlies the flood plain of the Gila River. Shallow wells are completed in this alluvium, and the water table was from a few feet to 58 feet below land surface in spring 1963. A few deep artesian wells tap deeply buried aquifers in the basin, but because of the poor quality of water and uncertain production of these aquifers in some areas, they are not extensively developed. Some of these wells flow, but in some places the artesian head is not great enough to produce a flowing well and the static water level is as much as 136 feet below land surface.

The water table in the inner valley of the Safford basin represents the upper surface of ground water in the alluvium of the Gila River as defined and illustrated by Davidson (White, Stulik, and others, 1962, p. 40). The water table rose 2 to 9 feet from spring 1962 to spring 1963, continuing the general rise that dates from 1957. This continuous rise is due to the fact that available streamflow in the Gila River recharges the alluvium; the streamflow also provides water for irrigation, thereby reducing the need for ground water. For the 5-year period spring 1958 to spring 1963 the rise in the ground-water table ranged from 2 to 15 feet. Hydrographs of the water level in wells (D-6-28)31, (D-6-24)5, and (D-4-22)13 (fig. 13) illustrate the general rise of the water table in this aquifer.

Some groundwater is pumped or allowed to flow from deep artesian aquifers in the Safford basin, but these aquifers are not developed extensively. Meager data near the head of Safford Valley indicate a rise in the pressure surface in the artesian aquifer of a foot to 28 feet in the period January 1961 to February 1963. The hydrograph of the water level in well (D-7-27)2 (fig. 13) illustrates the general rise in artesian head in the Safford basin. Well (D-7-27)11, about a mile southwest of the illustrated well, taps the same aquifer as well (D-7-27)2 and flowed as much as 50 gpm in the spring of 1963, due to the fact that the altitude of the artesain head rose above land surface at the well.

In the Artesia area south of Safford, shallow wells tap ground water under water-table conditions, and deep wells tap aquifers containing artesian water under a pressure head at the surface of as much as 30 pounds per square inch in some places. Most of the artesian wells flow, especially during the fall and winter, when the pressures are not reduced by pumping of other nearby artesian wells. Data are too meager to enable an accurate evaluation of irrigation pumping in the area, but the water levels are declining at the rate of a foot to 2 feet per year; the water-level decline for the last 5 years is 7 feet.

In the Cactus Flat area declines of 2 to 3 feet a year have been measured in wells with water levels not more than 40 or 50 feet below land surface. Deeper water levels and those almost directly controlled by artesian pressure are variable, but the apparent trend is a decline of 3 feet or slightly less in the 5-

year period spring 1958 to spring 1963.

San Simon Basin

By

Natalie D. White

The San Simon basin (fig. 12, No. 3), in the southeast corner of Arizona, is part of a structural trough that extends from south of the International Boundary to Globe, Ariz. The trough trends slightly northeast to near Rodeo, New Mexico, and then northwest to an arbitrary boundary between the San Simon and Safford basins. The San Simon basin is bounded on the east by the Peloncillo Mountains, which extend southeastward into New Mexico; the Chiricahua, Dos Cabezas, and Pinaleno Mountains bound the basin on the southwest and west. The southern drainage divide of the San Simon basin is about 10 miles south of Apache, Ariz. San Simon Creek enters the basin 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 San Simon Creek is about 20 feet per mile; the slopes from the mountain base to the creek have gradients of about 80 feet per mile.

The alluvial materials of the San Simon basin have been divided into four lithologic units (White, 1963)---the "lower unit," the "blue clay unit," the "upper unit," and the "marginal zone." The lower unit, consisting of stream and lake-bed deposits of clay, silt, sand, and gravel, overlies the bedrock and is a continuous unit throughout the entire basin. The blue clay unit overlies the lower unit except in the areas near the mountains and separates the lower and upper units. The unconsolidated stream deposits of silt, sand, and gravel that constitute the upper unit overlie the blue clay unit and are continuous throughout the basin. Near the margins of the valley the blue clay unit wedges out, and the lower and upper units coalesce to form a continuous body, designated the marginal zone. Because the marginal deposits are on the basin edges, and therefore near their sources, the sediments tend to be composed of coarser materials than those near the center of the basin. Hydrologically, the lower unit constitutes the "lower aquifer," and the saturated part of the upper unit constitutes the "upper aquifer;" the blue clay unit acts as an aquiclude. 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 single hydrologic unit. Generally, the movement of ground water in the basin is from the bordering mountain ranges valleyward and from southeast to northwest following the longitudinal axis of the basin except in areas where pumping of ground water has lowered the water levels forming cones of depression toward which the water moves from all directions.

There are two major areas of ground-water development in the basin: (1) the Bowie area, centered around the town of Bowie on the west side of the basin; and (2) the San Simon area, centered around the town of San Simon near San Simon Creek on the east side of the basin Development is gradually spreading westward from the San Simon area and eastward from the Bowie area, so that

in future years the areas of development and, hence, the cones of depression caused by pumping in the two areas will coalesce. Another smaller area of development in the basin is on the Arizona-New Mexico State line near the town of Rodeo, N. Mex.

Bowie area. --In most parts of the Bowie area ground water is under artesian head. However, several wells have been drilled in the marginal zone along the basin flank a few miles south of Bowie where ground water is under water-table conditions. In addition, on the southwestern edge of the area where the clay unit is comparatively thin, the water level in a few wells has dropped below the bottom of this unit, which forms a confining layer so that these wells are now operating under water-table conditions. The water level in wells in the Bowie area ranged from less than 120 to about 365 feet below land surface in the spring of 1963.

Water-level fluctuations in the artesian wells ranged from less than a foot to about 13 feet for the period spring 1962 to spring 1963. For the 5-year period spring 1958 to spring 1963, the water-level declines in these wells ranged from about a foot to more than 40 feet. The water level in well (D-13-29)18 (fig. 14) declined about 8 feet from spring 1962 to spring 1963, about 34 feet in the 5-year period spring 1958 to spring 1963, and nearly 110 feet from spring 1953 to spring 1963.

Only three of the known marginal-zone wells have records for the 5-year period spring 1958 to spring 1963; the water-level declines in these wells for the 5-year period were about 40, 55, and more than 100 feet, respectively. For the period spring 1962 to spring 1963, the water levels in these same wells declined about 9, 11, and 39 feet, respectively. The water level in well (D-13-28)16 (fig. 14) declined nearly 40 feet from spring 1962 to spring 1963, and more than 100 feet from spring 1958 to spring 1963.

In the essentially undeveloped area between Bowie and San Simon, the depth to water is somewhat shallower than in the two areas of development; one well about 10 miles southeast of Bowie was flowing in the spring of 1963. However, the cones of depression from the two developed areas are extending into this area, and the water level in a well about 9 miles southwest of Bowie has dropped to 21 feet below land surface; this well was flowing in 1957. The water level in another well about 3½ miles northwest of San Simon declined about 40 feet from spring 1952 to spring 1963, probably as a result of spreading of the cone of depression from the San Simon pumped area.

In the north-central part of the basin where there is no agricultural development a few small stock wells were flowing in spring 1963.

San Simon area. --Ground water occurs under artesian head in the lower aquifer and under water-table conditions in the shallow upper aquifer in the central part of the area and in the marginal zone on the fringes of the area.

The depth to water in the artesian wells in the San Simon area ranged from less than 20 to nearly 150 feet below land surface in the spring of 1963. The water-level changes in these wells ranged from a slight rise to a decline of nearly 25 feet for the period spring 1962 to spring 1963. For the 5-year period spring

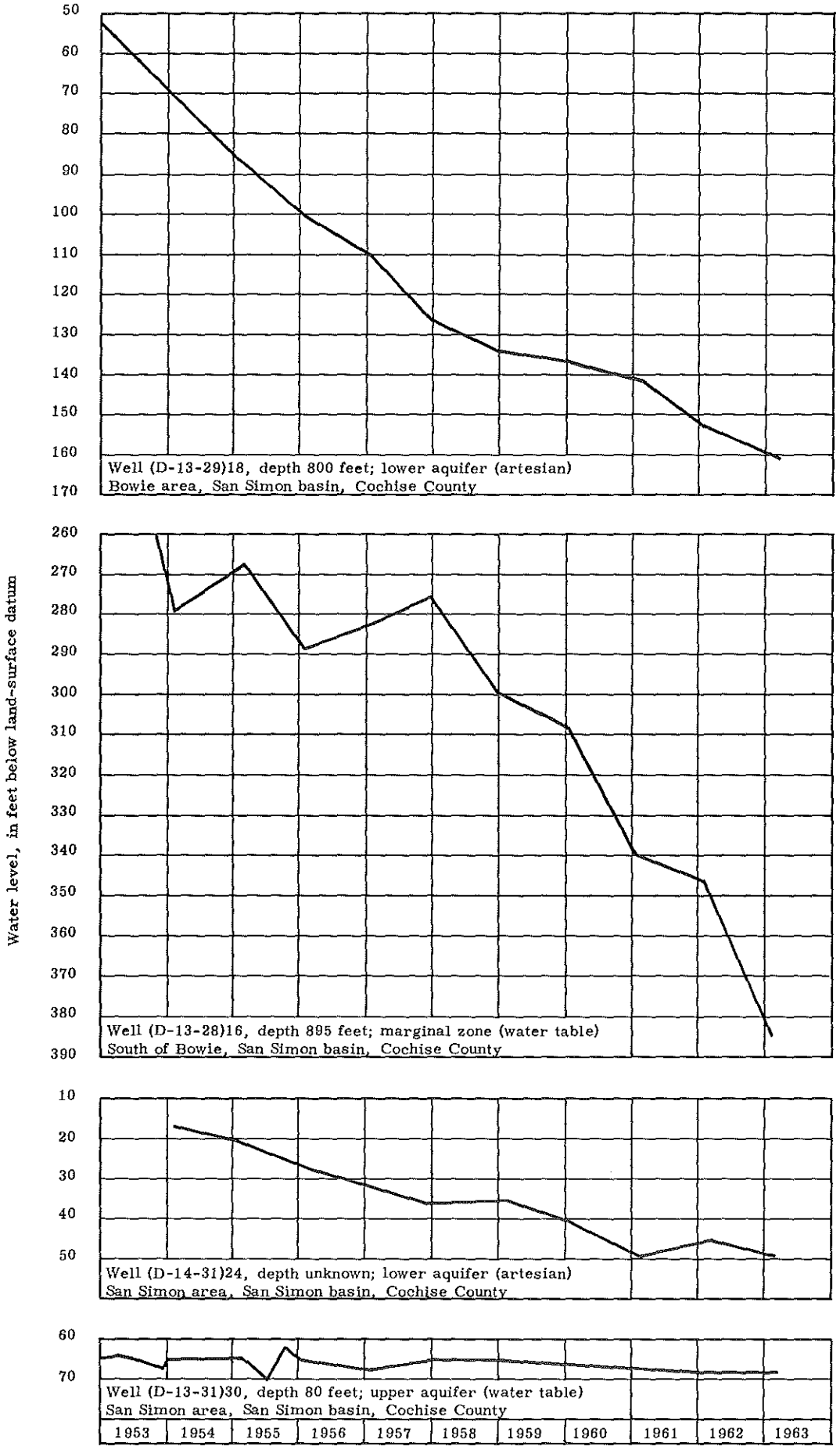


Figure 14. --Water levels in selected wells in the San Simon basin.

1958 to spring 1963 the water levels in these wells declined from about a foot to as much as 30 feet. The water level in well (D-14-31)24 (fig. 14) declined about 3 feet in the period spring 1962 to spring 1963 and about 13 feet in the 5-year period spring 1958 to spring 1963.

Water levels were measured in 11 wells in the San Simon area and the less-developed area to the west in the spring of 1963. The range in water level in these wells was from about 40 to 80 feet below land surface in spring 1963. The water-level declines in the water-table wells for which data were available ranged from less than a foot to about 6 feet from spring 1962 to spring 1963 and from about a foot to 4 feet for the 5-year period spring 1958 to spring 1963. The water level in well (D-13-31)30 (fig. 14) declined less than a foot from spring 1962 to spring 1963, about 4 feet from spring 1958 to spring 1963, and about 4 feet in the 10-year period spring 1953 to spring 1963.

In and near the San Simon Cienaga water levels are less than 25 feet below land surface. In the spring of 1963 several auger holes were drilled in and near the cienaga by the Ground Water Branch of the U. S. Geological Survey. The water levels in these and in nearby windmill wells ranged from about a foot to nearly 25 feet below land surface. The shallower water levels are in the southern part of the cienaga. Only 2 miles to the east and to the west of the cienaga, the water level measured in wells in the spring of 1963 was nearly 160 feet below land surface.

Rodeo area. --The development of ground water for irrigation in the Rodeo area is comparatively minor; however, water levels are declining in the irrigated area near Rodeo, which indicates the withdrawal of ground water in excess of the rate of replenishment. Therefore, the rate of replenishment or recharge to the water-bearing sediments in this area must be extremely low. In the spring of 1963 the water level was measured in 15 wells in the irrigated area near Rodeo; the water levels in these wells ranged from about 65 to nearly 160 feet below land surface; the depths to water in this area averaged about 125 feet. In the period spring 1962 to spring 1963 the water-level changes in this area ranged from a slight rise to a decline of about 7 feet. In the 5-year period spring 1958 to spring 1963 water-level declines ranged from less than 5 to more than 20 feet. The water level in well (D-18-32)26 (fig. 15) declined about 7 feet from spring 1962 to spring 1963, about 10 feet in the 5-year period spring 1958 to spring 1963, and about 31 feet since spring 1953. About 2½ miles north of Rodeo, the water level in well (D-18-32)11 (fig. 15) was about 153 feet below land surface in the spring of 1963---about 3 feet lower than in the spring of 1962 but about the same as in the spring of 1958. In the area between Rodeo and the San Simon Cienaga the development of ground water for irrigation is comparatively recent, and data are insufficient to determine any significant pattern of water-level changes. Well (D-17-31)25 (fig. 15) is outside the cultivated area near the junction of two intermittent streams, and the water level is affected by streamflow.

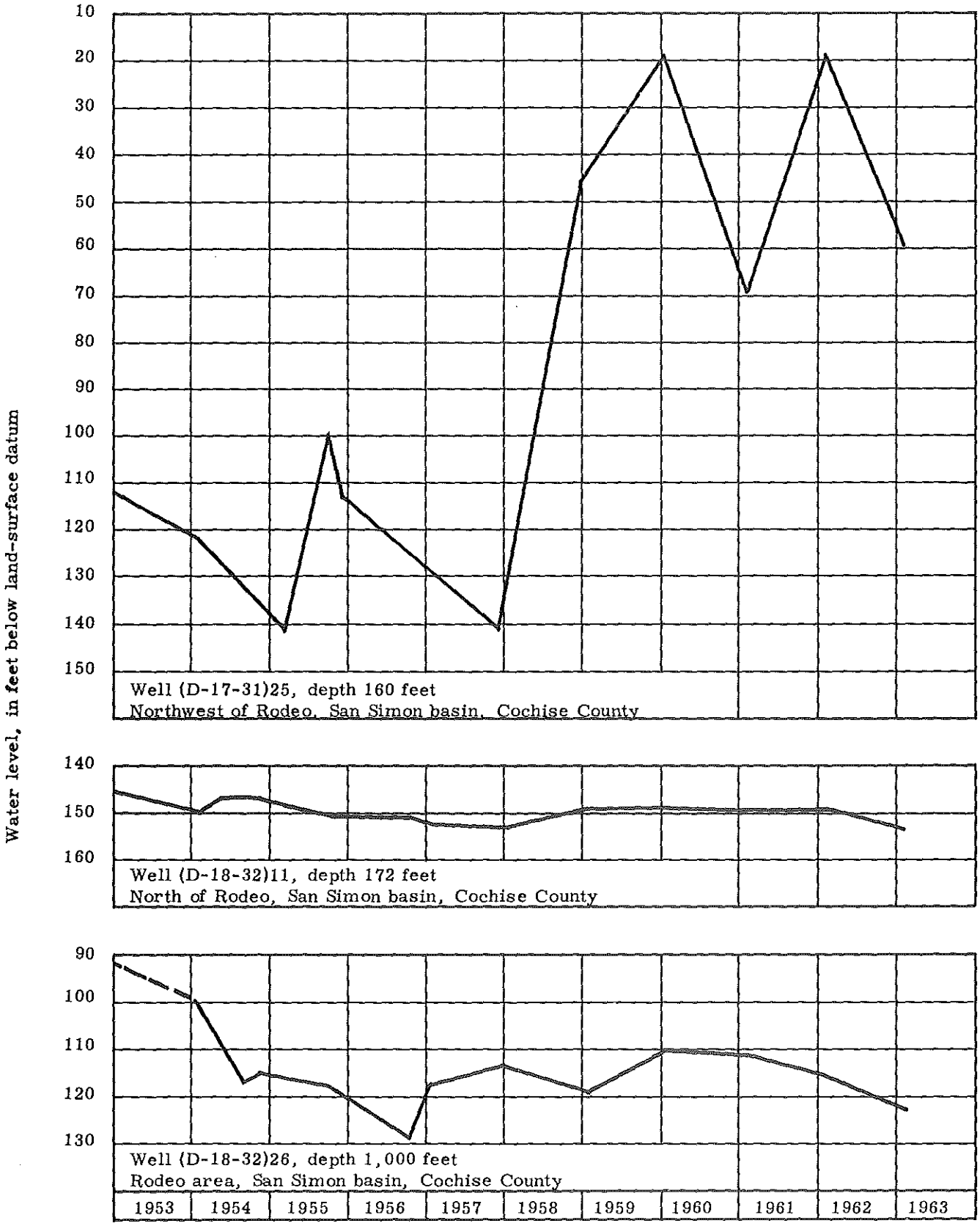


Figure 15.--Water levels in selected wells in the southern part of the San Simon basin.

Sulphur Spring and Aravaipa Valleys

By

S. G. Brown and H. H. Schumann

The trough occupied by the Sulphur Spring and Aravaipa Valleys (fig. 12, Nos. 4, 5, and 6) is bordered by two parallel chains of mountains, which extend from the Gila River on the north to Mexico on the south. The Pinaleno, Dos Cabezas, Chirichua, Pedregosa, and Perilla Mountains extend along the east side of the trough and are higher than the Galiuro, Winchester, Little Dragoon, Dragoon, and Mule Mountains, which border the trough on the west. The trough is divisible into three areas: (1) Aravaipa Valley (fig. 12, No. 4), which drains northwestward and is structurally a continuation of the main Sulphur Spring Valley (fig. 12, Nos. 5 and 6); (2) Willcox basin (fig. 12, No. 5), a basin of interior drainage, which occupies the northern three-fifths of the Sulphur Spring Valley; and (3) Douglas basin (fig. 12, No. 6), which drains southward and occupies the southern two-fifths of the Sulphur Spring Valley. 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.

Aravaipa Valley.--From the headwaters of Aravaipa Creek, the Aravaipa Valley (fig. 12, No. 4) trends northwestward for a distance of 44 miles and drains into the San Pedro River at a point about 15 miles upstream from the confluence of the San Pedro and Gila Rivers. The area is largely undeveloped and the pumping of ground water is at a minimum.

Hydrographs of water levels in four wells in the Aravaipa Valley are shown in figure 16. All these wells are drilled into the shallow alluvium along Aravaipa Creek, and the water levels respond quickly to recharge from precipitation and from flow in Aravaipa Creek, and to pumping. From spring 1962 to spring 1963 the average change in water levels in wells measured in upper Aravaipa Valley was a rise of about 4 feet; water-level changes ranged from a rise of about 8 feet to a decline of slightly more than a foot.

Willcox basin.--The Willcox basin (fig. 12, 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 in 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.

Before pumping for irrigation began, the ground-water gradient in the Willcox basin was toward the playa--a dry lake in the center of the basin. North of the playa from the divide near Aravaipa Creek, ground-water movement was southward, and south of the playa it was northward. The water-table map (fig. 17) of the Willcox basin shows contours of the altitude of the water surface for spring 1963. The contours are lines connecting points of equal altitude on the water table and, hence, show the shape of the water table. This map was prepared from more than 300 depth-to-water measurements made in wells during January and February of 1963.

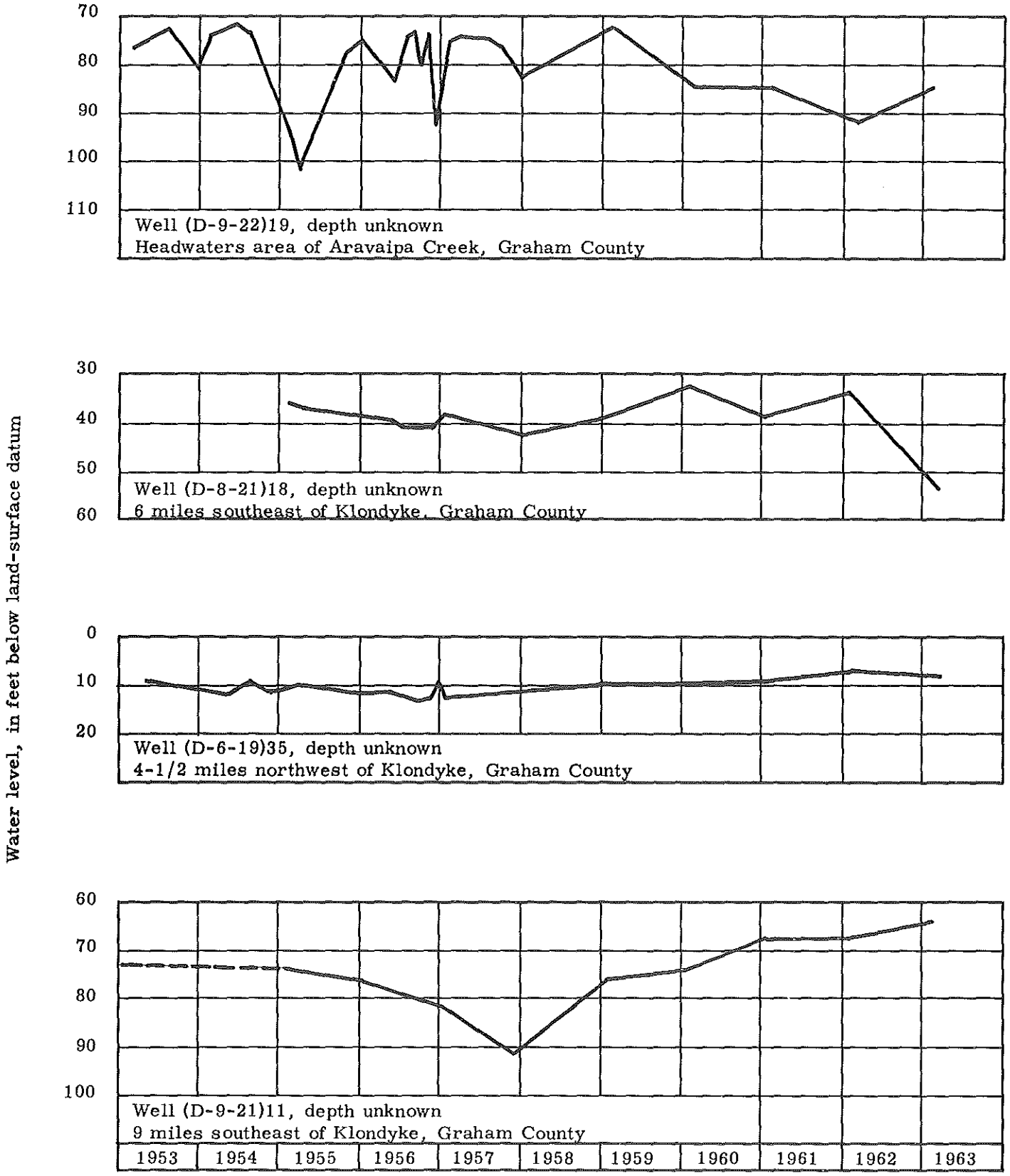


Figure 16. --Water levels in selected wells in Aravaipa Valley.

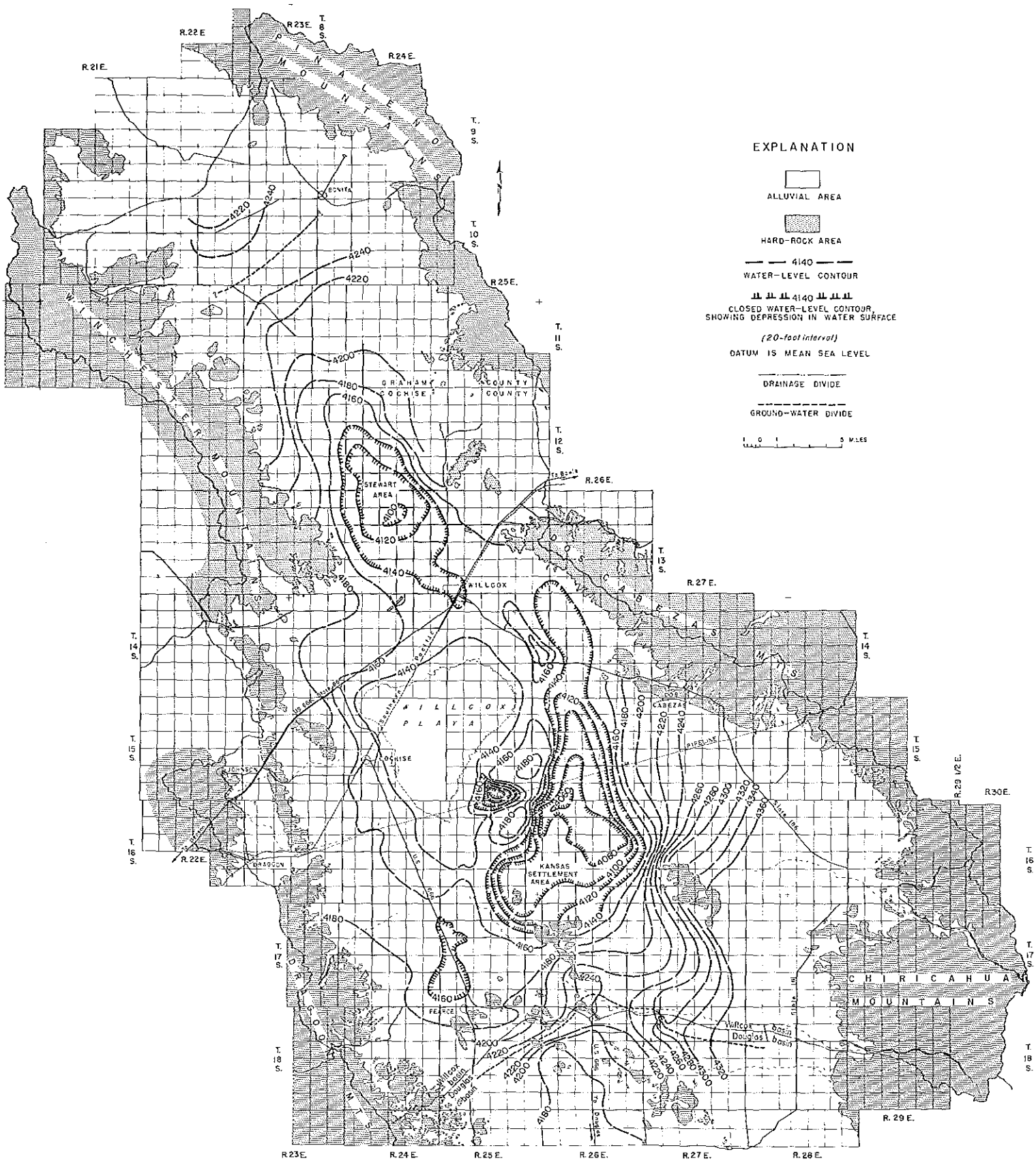


Figure 17.-- Map of Willcox basin(northern Sulphur Spring Valley), Cochise and Graham Counties, Ariz., showing altitude of the water level, Spring 1963.

The salient features of the map are the two large cones of depression. The northernmost cone encompasses the town of Willcox and most of the irrigated area known as the Stewart area. The southernmost cone of depression includes all the Kansas Settlement area and extends northward to a point 5 miles east of Willcox. Smaller cones of depression are developing in the irrigated area north of Pearce, and one also is centered in Sec. 33, T. 15S., R. 25E., just west of the large cone of depression in the Kansas Settlement area. These cones of depression have reduced the amount of subsurface flow to the playa, and thereby have reduced the loss of water to the atmosphere by evaporation.

Total irrigated acreages in 1962 in the three main cultivated areas of the Willcox basin---the Stewart area, the Kansas Settlement area, and the Pearce-Cochise area---were estimated to be 21,000, 30,000, and 7,200 acres, respectively. During the 1962 irrigation season about 160,000 acre-feet of water was pumped in the entire Willcox basin. Thus, it can be estimated that in 1962 about 60,000 acre-feet was pumped in the Stewart area, 80,000 acre-feet was pumped in the Kansas Settlement area, and about 20,000 acre-feet was pumped in the Pearce-Cochise area. During the 10-year period spring 1953 to spring 1963, an estimated 1,500,000 acre-feet of ground water was pumped from wells in the Willcox basin. Of this amount, about 435,000 acre-feet was from the Stewart area, about 894,000 acre-feet was from the Kansas Settlement area, and about 171,000 acre-feet was from the Pearce-Cochise area. In response to this pumping, water levels declined in these areas.

Figure 18 is a map of the Willcox basin showing the change in water levels during the 10-year period 1953-63. It is apparent that there are two major areas of decline---in the Stewart area in the northern part of the basin and in the Kansas Settlement area in the southern part of the basin. Measured declines in the Stewart area ranged from 2 to 39 feet and averaged almost 17 feet in the area extending from Willcox north to the Graham County line. Water-level changes measured in the Pearce-Cochise area ranged from a rise of 5 feet to declines of as much as 21 feet. The average of the measured changes in water levels was a decline of about 9 feet. Measured water-level changes in the Kansas Settlement area ranged from rises of 17 feet in a limited area near the Willcox playa to declines of more than 120 feet, and averaged more than 40 feet of decline for the 10-year period over a much larger area.

Hydrographs of depth to water in several wells in each of the areas mentioned are shown in figure 19.

Douglas basin.--The Douglas basin (fig. 12, No. 6), in the southern part of the Sulphur Spring Valley, extends from the drainage divide in 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-mile reach 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.

Figure 20 is a map showing the altitude of the water table in spring 1963. The lines on the map are contour lines connecting points of equal altitude of the

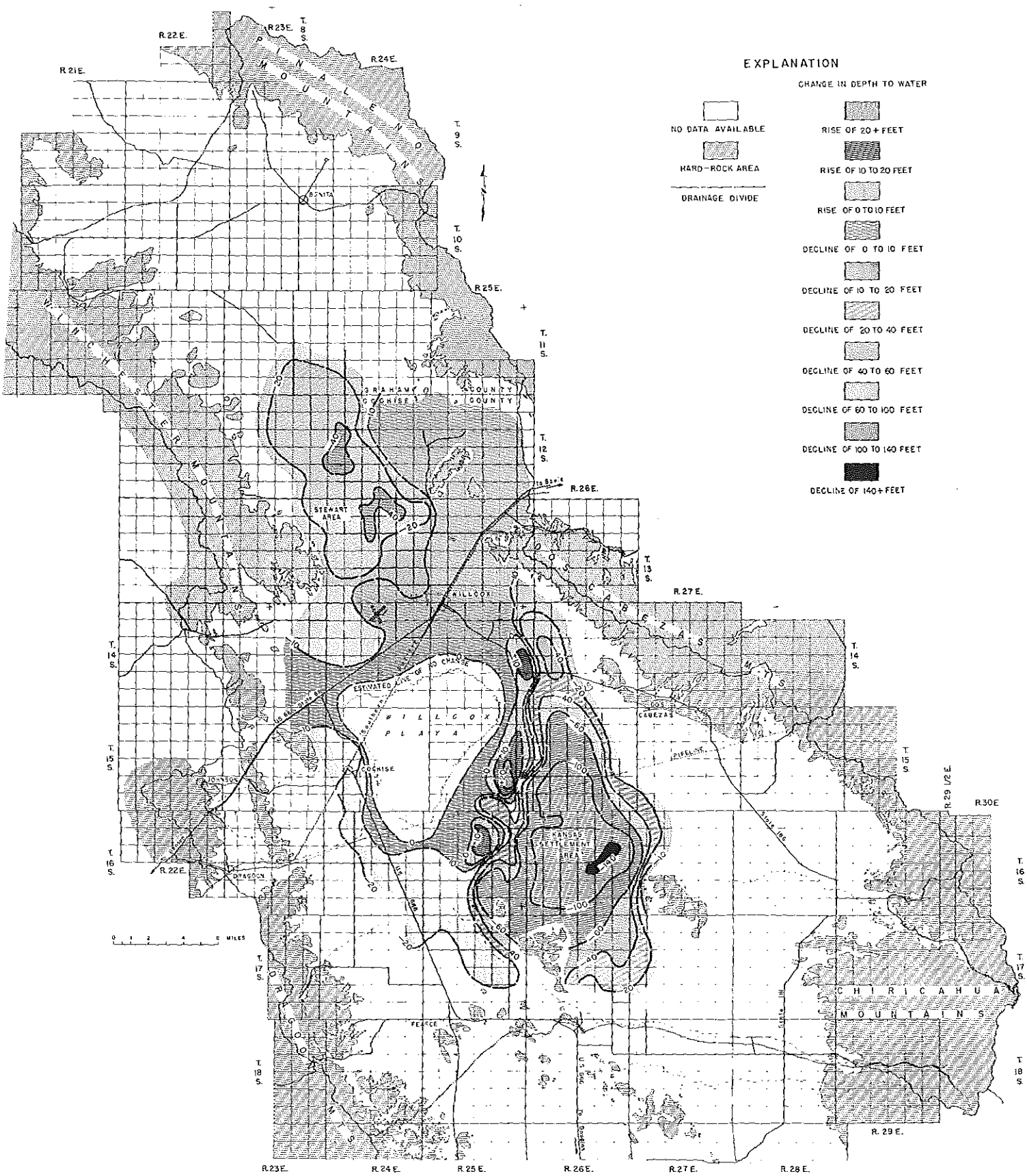


Figure 18.-- Map of Willcox basin, Cochise and Graham Counties, Ariz., showing change in ground-water level from spring 1953 to spring 1963.

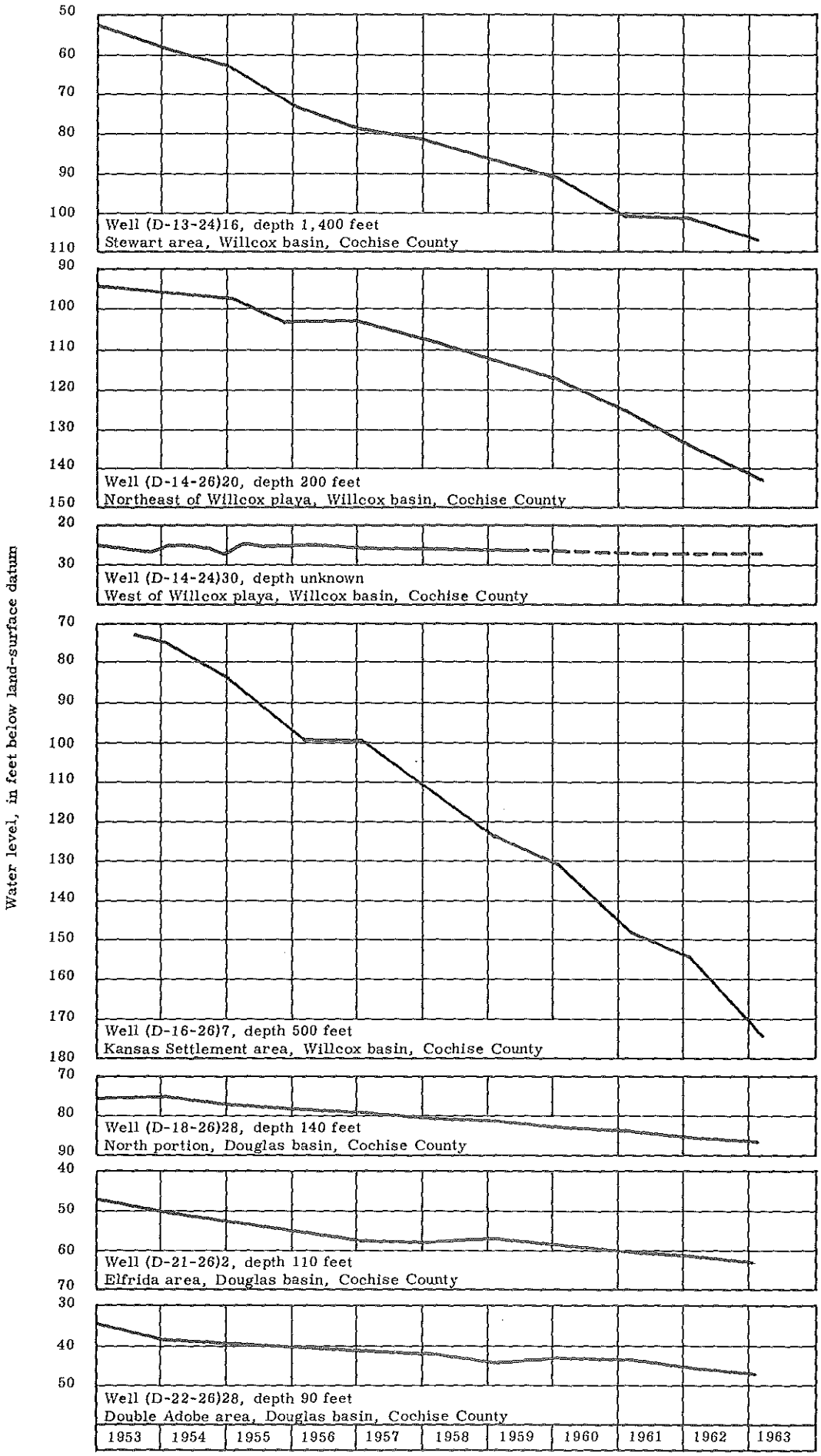


Figure 19.--Water levels in selected wells in Sulphur Spring Valley.

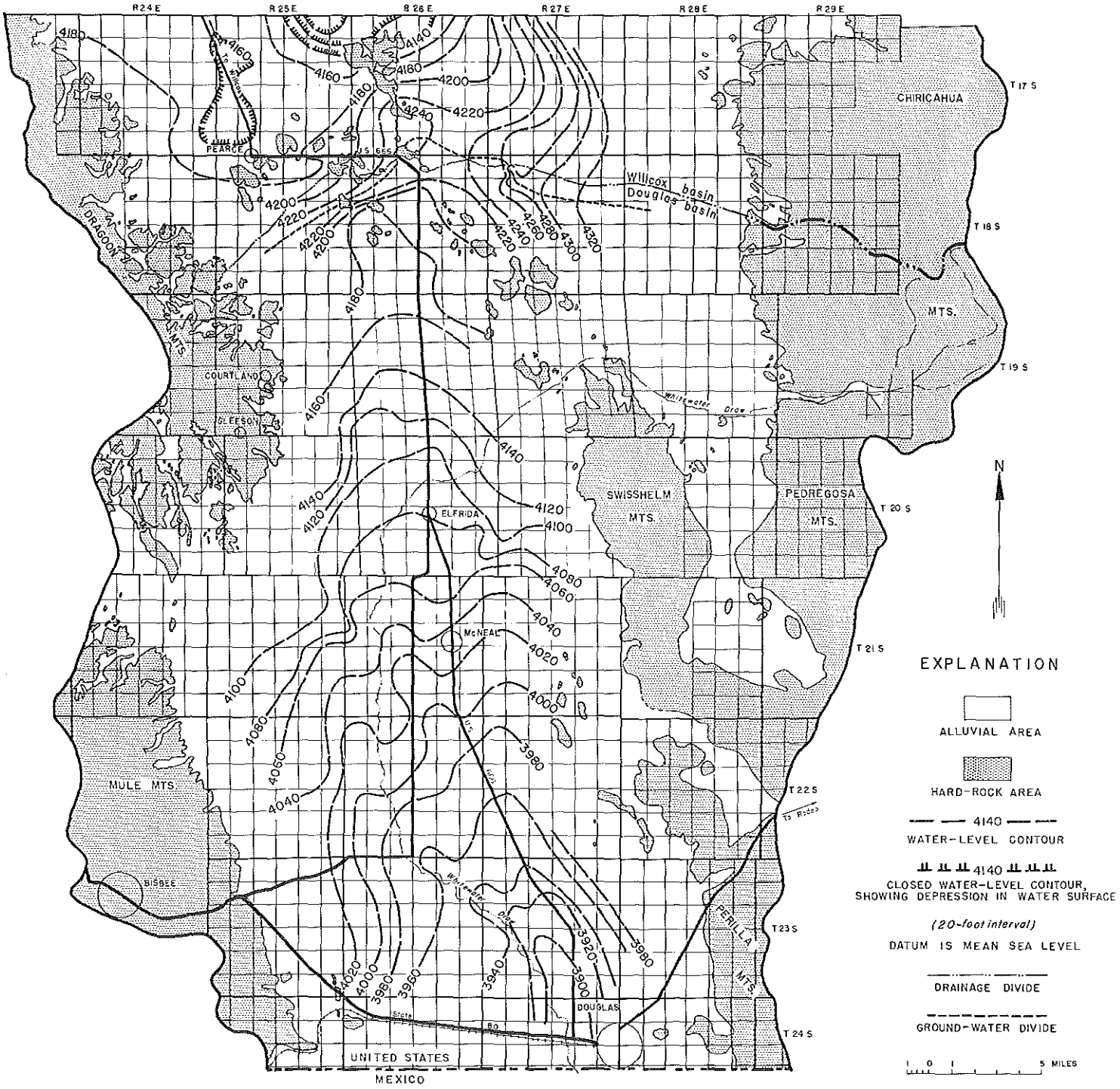


Figure 20.--Map of Douglas basin (southern Sulphur Spring Valley), Cochise County, Ariz., showing altitude of the water level, spring 1963.

water table. This map shows that ground water in the Douglas basin moves from the recharge areas near the mountains where creek and washes emerge onto the valley slope and from the northern end of the basin south of the buttes and ridges near Pearce and Turkey Creek toward the center of the basin and southward generally paralleling Whitewater Draw. No large or well-formed cones of depression are apparent.

During the 5-year period spring 1958 to spring 1963 measured water levels in the Douglas basin declined an average of 5 feet in 89 wells, ranging from rises of about 8 feet to a decline of as much as 46 feet in one well about 6 miles west of McNeal. Water-level declines in the Douglas basin have been small compared to those in the Willcox or the San Simon basins. Figure 21 shows the changes in water levels in the Douglas basin for the 5-year period spring 1958 to spring 1963. Of the 89 wells in which depth to water was measured during the 5-year period, the decline exceeded 10 feet in only 7 wells but exceeded 5 feet in 33 wells. Depth to water in the Douglas basin ranges from 30 to about 150 feet and in most areas is less than 100 feet below land surface.

San Pedro River Valley

By

E. S. Davidson and Natalie D. White

The San Pedro River heads in Sonora, Mexico, and crosses into Arizona just south of Palominas at an altitude of about 4,500 feet above mean sea level. The total drainage area of the San Pedro River valley (fig. 12, Nos. 7 and 8) is 4,483 square miles of which 696 miles is in Mexico, according to records of the U.S. Geological Survey, Surface Water Branch. Few large tributary streams empty into the San Pedro River. The largest tributary is Aravaipa Creek, which has a drainage area of 562 square miles.

From the International Boundary the San Pedro River valley trends about N.10°W. for a distance of about 60 miles to the Narrows. This part of the valley is called the upper San Pedro basin (fig. 12, No. 7). It is bounded on the east by the south 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 60 miles long, and ranges from 15 to 35 miles wide. From the Narrows, the San Pedro River flows 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. 12, No. 8). It is bounded on the west by the Rincon, Santa Catalina, Black, and Tortilla Mountains and on the east by the Galiuro Mountains. Upper Aravaipa Creek, a part of the San Pedro drainage basin, is excluded here because ground-water conditions are discussed elsewhere in this report. The larger part of the lower San Pedro basin is in Pinal and Cochise Counties, with lesser areas in Graham and Pima Counties.

The rocks in the San Pedro River valley are divided, according to their control

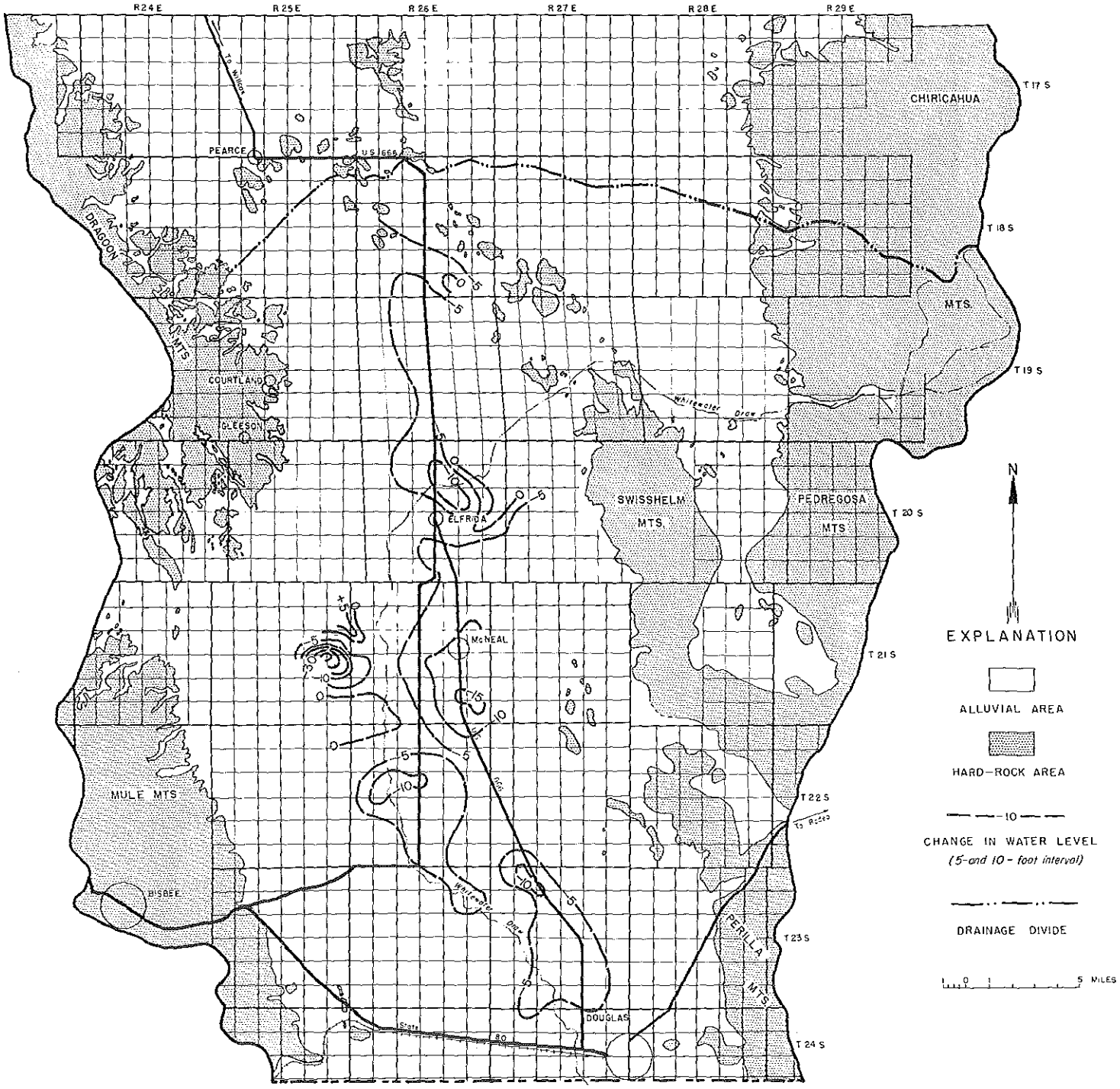


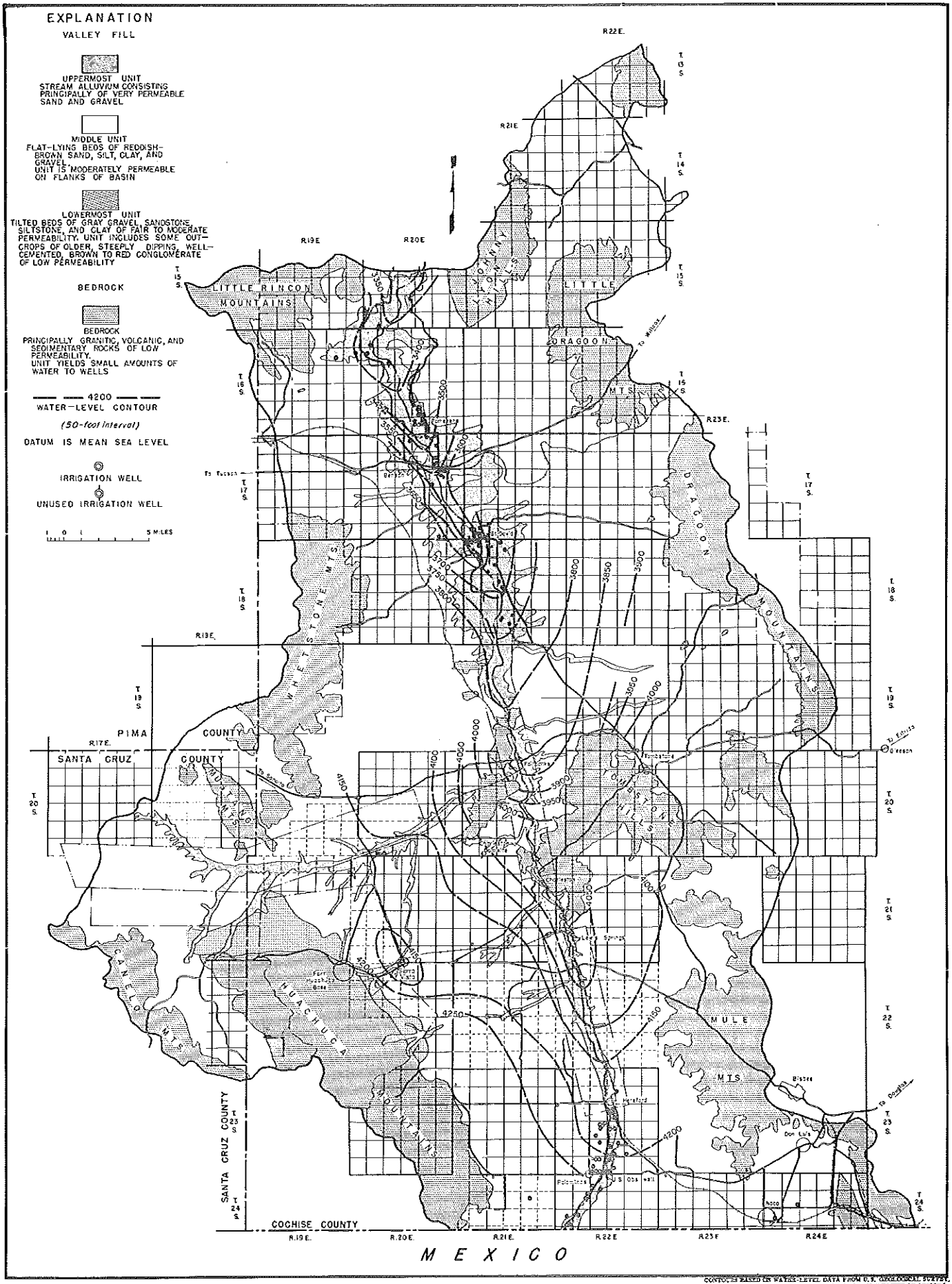
Figure 21.--Map of Douglas basin, Cochise County, Ariz., showing change in ground-water level from spring 1958 to spring 1963.

of ground-water hydrology, into two broad groups in this report. These are the nearly impermeable granitic, volcanic, and well-cemented sedimentary rocks, which form the floor and framework of the trough of the San Pedro River valley, and the generally highly permeable weakly cemented valley-fill sediments, which are deposited in the trough of the San Pedro River valley. A similar division of "alluvial fills" and "bedrock below older alluvium" was used (Halpenny, 1952, p. 69-86) in an excellent summary description of the upper and lower San Pedro basin, which also includes well logs, well tables, quality-of-water analyses, and cross sections. The valley-fill sediments, which yield large quantities of ground water to wells, are divided into three principal units (fig. 22 and 23). The lowest and oldest unit consists of tilted beds of gray gravel to clay; the middle unit is essentially flat-lying beds of reddish-brown sand, silt, clay, and gravel; and the uppermost and most permeable unit consists of sand and gravel underlying the flood plain of the San Pedro River and its tributaries.

Bedrock---the granitic, volcanic, and sedimentary rocks that form the floor and framework of the San Pedro trough---crops out in the mountain ranges and underlies the valley fill of the San Pedro River valley at depths of as much as 2,000 feet. These rocks are extensively faulted and locally folded and were involved in the major structural movements that produced much of the mountains and valleys of the Basin and Range province. The San Pedro River flows across extensive outcrops of bedrock at Charleston and at the Narrows. The granitic and volcanic rocks generally yield only small amounts of water to wells and that only where they are sufficiently fractured to provide open conduits for transmission of ground water. The sedimentary rocks yield water to wells in some areas where many fractures are present or where sandstone and conglomerate beds are not so well cemented as to be impermeable. Some of the ground water encountered in beds of the sedimentary rocks is under artesian pressure.

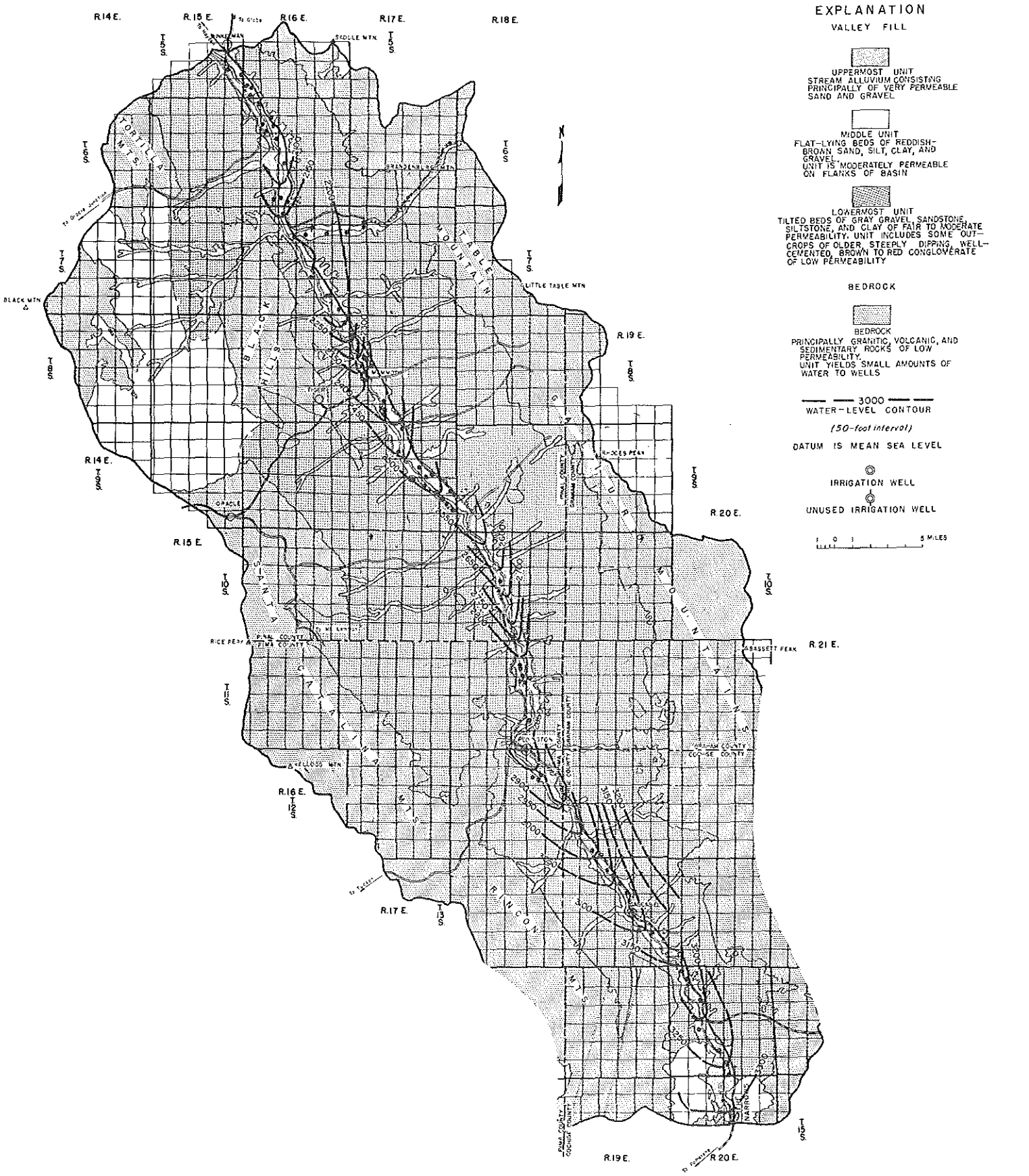
Outcrops of a steeply dipping well-cemented brown to red conglomerate unit, which is part of the sedimentary rock mass making up the trough framework, are included in the lowest unit of the valley-fill sediments, notably in the area north of the Huachuca Mountains (fig. 22) and along the boundary between the bedrock and the valley fill in the part of the valley north of the Narrows (fig. 23). Some wells in the lower San Pedro basin, particularly those more than a few hundred feet deep, were completed in the conglomerate and produce moderate quantities of ground water under artesian pressure. It is not possible at this time to predict the overall distribution or possible ground-water production from this conglomerate, but yields are generally low.

The lowest unit of the valley-fill sediments floors the entire San Pedro trough and crops out extensively in the valley north of the Narrows. The beds tilt 10° to 15° toward the center of the valley and are offset as much as several hundred feet by generally northwest-trending faults. The lowest unit of the valley fill consists of a variable and lenticular sequence of gray gravel, conglomerate, sandstone, and lesser amounts of other sediments, such as bedded gypsum, clay, and siltstone. Because of the vertical and lateral variability of these sediments and the variability in the degree of cementation, the hydrologic characteristics of the lowest unit vary widely from bed to bed and areally from well to well. Fine-grained beds, well-cemented layers, and, where present, the overlying middle unit act as a confining layer on underlying more permeable



CONTOURS BASED ON WATER-LEVEL DATA FROM U.S. GEOLOGICAL SURVEY, GROUND WATER BRANCH AND E. F. BOLLYDAY, UNIVERSITY OF ARIZONA, GEOLOGY GENERALIZED FROM: STITZ, GALPENNY AND OTHERS, 1959, P. 49; GILULY (1956), EATON (WRITTEN COMMUNICATION, 1961), DAVIDSON (WRITTEN COMMUNICATION, 1961).

Figure 22.-- Generalized geohydrologic map of the upper San Pedro basin.



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GEOLOGY GENERALIZED FROM: BENDER (BALLENTINE AND OTHERS, 1952, P. 17), GILLULY (1956), BRYAN (WRITTEN COMMUNICATION, 1951), DAVIDSON (WRITTEN COMMUNICATION, 1953).

Figure 23.--Generalized geohydrologic map of the lower San Pedro basin.

beds of the lowest unit; thus, the lowest unit contains water under artesian pressure in some areas. The lowest unit of the valley fill is a fair to good aquifer. In some places it may be so "tight" that only dry holes result; in other places, 1,000 gpm or more of water can be obtained from properly constructed wells. The sediments making up the lowest valley-fill unit may be as much as 1,000 feet thick in the central part of the trough but usually are from 300 to 700 feet thick.

The middle unit---the flat-lying reddish-brown silt to coarse gravel---is well exposed near Benson where the dominant sediment is clay and silt. This unit contains coarse materials near the mountains on the southwest and northeast, and it may be composed entirely of bouldery gravel near the mouths of major canyons entering the San Pedro River valley from these mountain ranges. In the area north of the Narrows the middle unit has been removed by stream erosion; south of the damsite area it overlies the gray gravel unit described above. The middle unit is about 300 to 700 feet thick near Benson and to the south. It is thinnest along the course of the San Pedro River. Where this unit contains coarse-grained sediments that are saturated it yields moderate to large quantities of ground water. The fine-grained beds of the middle unit restrict ground-water movement and act as a confining layer for the underlying more permeable beds. Thus, wells drilled through the fine-grained beds of this unit and tapping underlying permeable saturated sediment are generally at least weakly artesian, and some flow.

The uppermost unit of the valley fill consists of sand and gravel deposits that underlie the flood plain of the San Pedro River and its tributaries. This unit is the most permeable aquifer in the San Pedro River valley. As shown on figures 22 and 23, the uppermost unit forms comparatively narrow and shoestringlike deposits; the deposits are as much as 150 feet thick. In the area near Benson the deposits are 2 to 3 miles wide, but north of the Narrows the riverbed is cut in resistant gray gravel of the lowest unit and they are only about a mile wide. South of Charleston, the deposits are a mile wide or less. Because the sand and gravel of the upper unit is very permeable, the unit yields water readily to wells and also readily accepts recharge from the intermittent flow of the San Pedro River. This unit is the main discharge area for all ground water in the San Pedro River valley, which moves generally from the valley sides to the central part of the valley, now occupied by this unit. Many wells tapping these deposits in the valley produce more than 1,000 gpm.

Prominent terraces are developed on the valley-fill sediments in the San Pedro River valley. They occur at several levels between 25 and 1,000 feet above the bed of the San Pedro River. The upper surface of the terraces is underlain by deposits of cobbly to bouldery brown sand from 5 to more than 150 feet thick. These deposits, although highly permeable, are discontinuous and trenched by dry washes so that they do not retain ground water; therefore, they are unable to act as ground-water reservoirs.

The ground-water reservoir in the San Pedro River valley is recharged chiefly by runoff from percipitation in the mountains and by surface flow in the San Pedro River. Generally, the movement of ground water is from the flanks of the valley toward the axis and northwestward along the axis toward the mouth of the river. Figures 22 and 23 show contours of the altitude of the water level

in the basin. Ground water moves at right angles to the contours, and thus the map gives a generalized picture of the pattern of movement of ground water; it also indicates that there is recharge to the ground-water reservoir by runoff from the bordering mountains. The slope of the water surface along the axis of the valley averages between 15 and 20 feet per mile but varies greatly at different places throughout the valley. Gradients as high as 50 feet per mile are not uncommon. The slope from the sides of the valley toward the axis is somewhat greater in most places.

Upper San Pedro basin.--In the upper San Pedro basin the development of ground water is at a minimum, although some ground water is withdrawn from the water-table and artesian aquifers for irrigation, chiefly in the areas between Palominas and Hereford and between St. David and Pomerene. The depth to water in the shallow water-table wells along the flood plain of the river ranged from about 15 to 85 feet below land surface in the spring of 1963. Water-level fluctuations in these wells are erratic due to recharge from flow in the San Pedro River and irregular pumping of the wells. Water-level declines ranged from less than half a foot to about 2 feet for the 5-year period spring 1958 to spring 1963 and from about a foot to nearly 8 feet from spring 1962 to spring 1963. The water level in well (D-16-20)34 (fig. 24) declined about 6 feet from spring 1962 to spring 1963, but no overall pattern of rise or decline is discernible. Along the flood plain of the San Pedro River some of the artesian wells were flowing in the spring of 1963, although the water levels in some artesian wells were nearly 50 feet below land surface. Changes in the water level in well (D-17-21)32 (fig. 24) seem typical of these wells; the water level in this well is declining slightly, although the measurement made in the spring of 1963 was affected by recent pumping of the well. The water levels in the deeper wells on the flanks of the valley ranged from about 30 to more than 300 feet below land surface in the spring of 1963. These wells may be partly artesian and partly water table, due to the presence of confining layers as explained above. The water level in well (D-20-20)32 (fig. 24) declined less than half a foot from spring 1962 to spring 1963.

Lower San Pedro basin.--Most of the water used for irrigation in the lower San Pedro basin is withdrawn from shallow wells in the streambed alluvium---the uppermost unit of the valley fill---along the flood plain of the river. South of Mammoth a few deep wells along the flood plain of the river are completed mainly in the lower unit of the valley fill and yield water under artesian pressure; deep wells on the flanks of the basin yield only small amounts of water.

The depth to water in the wells along the flood plain of the river generally is less than 60 feet below land surface but increases rapidly to the northeast and southwest away from the river. Water-level fluctuations in wells in the lower San Pedro basin are somewhat erratic depending mainly on the flow in the river and the pattern of pumping. In the period spring 1962 to spring 1963 water-level changes ranged from a rise of about 2 feet to a decline of about 5 feet; in the period spring 1958 to spring 1963 water-level changes ranged from a rise of about 5 feet to a decline of 8 feet. The water level in well (D-13-19)23 (fig. 24), about a mile south of Cascabel, rose about 2 feet from spring 1962 to spring 1963 and about 5 feet from spring 1958 to spring 1963. The water level in well (D-8-17)19 (fig. 24), near Mammoth, declined about 5 feet from spring 1962 to spring 1963 and about 7 feet from spring 1958 to spring 1963.

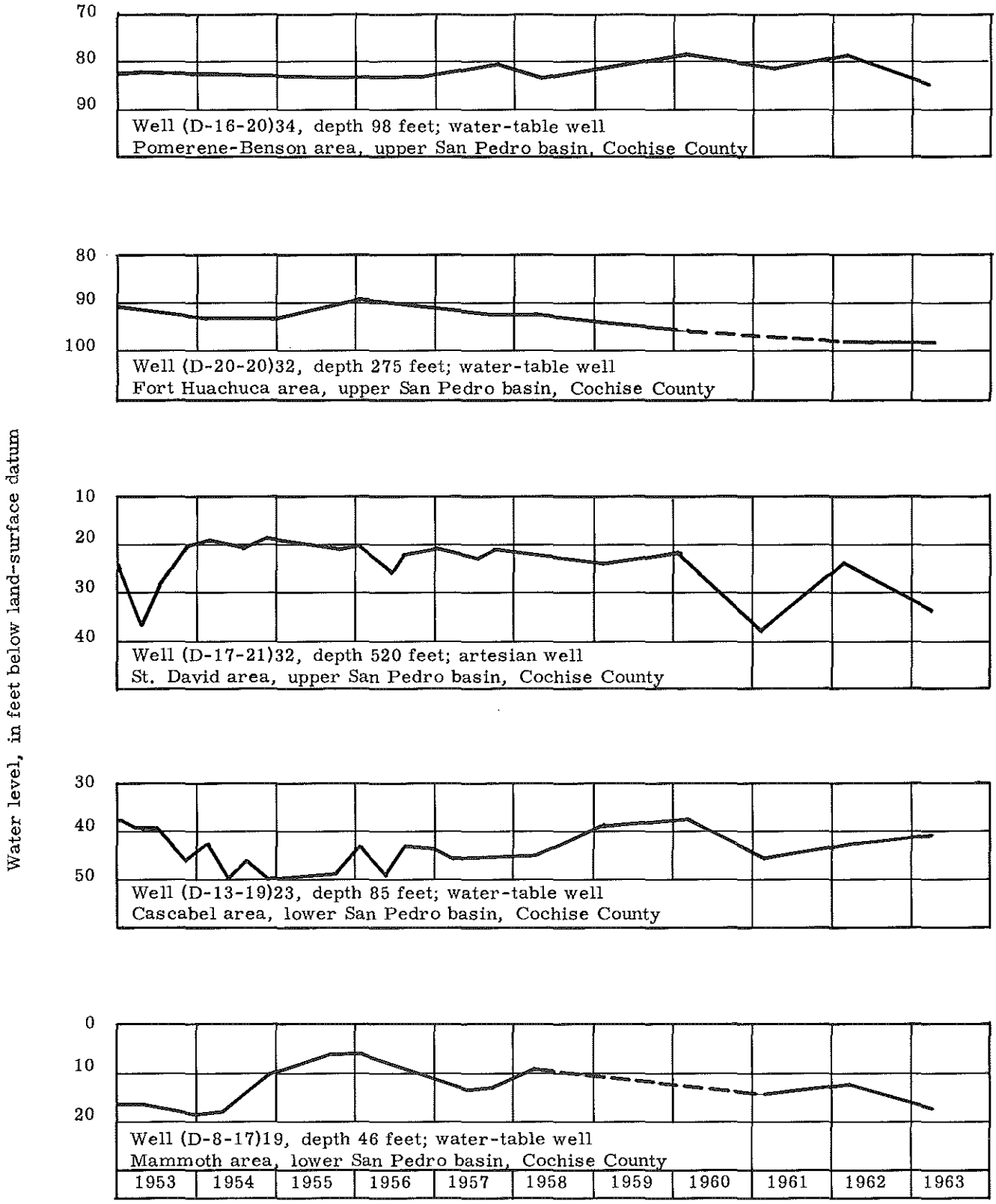

Figure 24.--Water levels in selected wells in the San Pedro River valley.

The water level in both these wells fluctuates mainly in response to 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 designated as the upper Santa Cruz basin (fig. 12, No. 9). For convenience it has been divided into the Cortaro-Canada del Oro, Tucson, Sahuarita-Continental, and Santa Cruz County districts or areas. The annual water-level-measuring program of the Agricultural Engineering Department was initiated in 1946 with financial assistance from Pima County and the city of Tucson. The present program includes measurement of about 1,500 wells.

Cortaro-Canada del Oro area.--The Cortaro-Canado 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 between the Rillito Narrows and the junction with Rillito Creek. Pumping of ground water in this part of the area is principally by the Cortaro Water Users' Association. Total pumpage in the last 5 years was about 81,000 acre-feet; nearly 90 percent of this water has been exported for use below the Cortaro Narrows. Except for 1962, annual pumpage during this 5-year period was considerably less than the average of 20,000 acre-feet for the last 20 years. Pumpage was increased to about 21,000 acre-feet in 1962, but only 2,400 acre-feet was used for irrigation on the Cortaro bottom lands. In addition, about 4,000 acre-feet of ground water was pumped from privately owned wells in 1962 to irrigate about 1,000 acres of land. On the valley slopes south of the Tortolita Mountains and along Canada del Oro, pumping of ground water has been limited to that required for the irrigation of about 200 acres of farmland and two golf courses, and for domestic use. The total amount of ground water pumped in 1962 from the Cortaro-Canada del Oro area is estimated at 28,000 acre-feet.

Ground-water recharge in this area is primarily from flood-flows in the Santa Cruz River, deep percolation losses from irrigated lands, and seepage from waste sewage effluent flowing in the Santa Cruz River. During years of heavy winter precipitation, the spring runoff provides a source of recharge in the upper part of Canada del Oro. The water level in well (D-11-14)2 (fig. 25),

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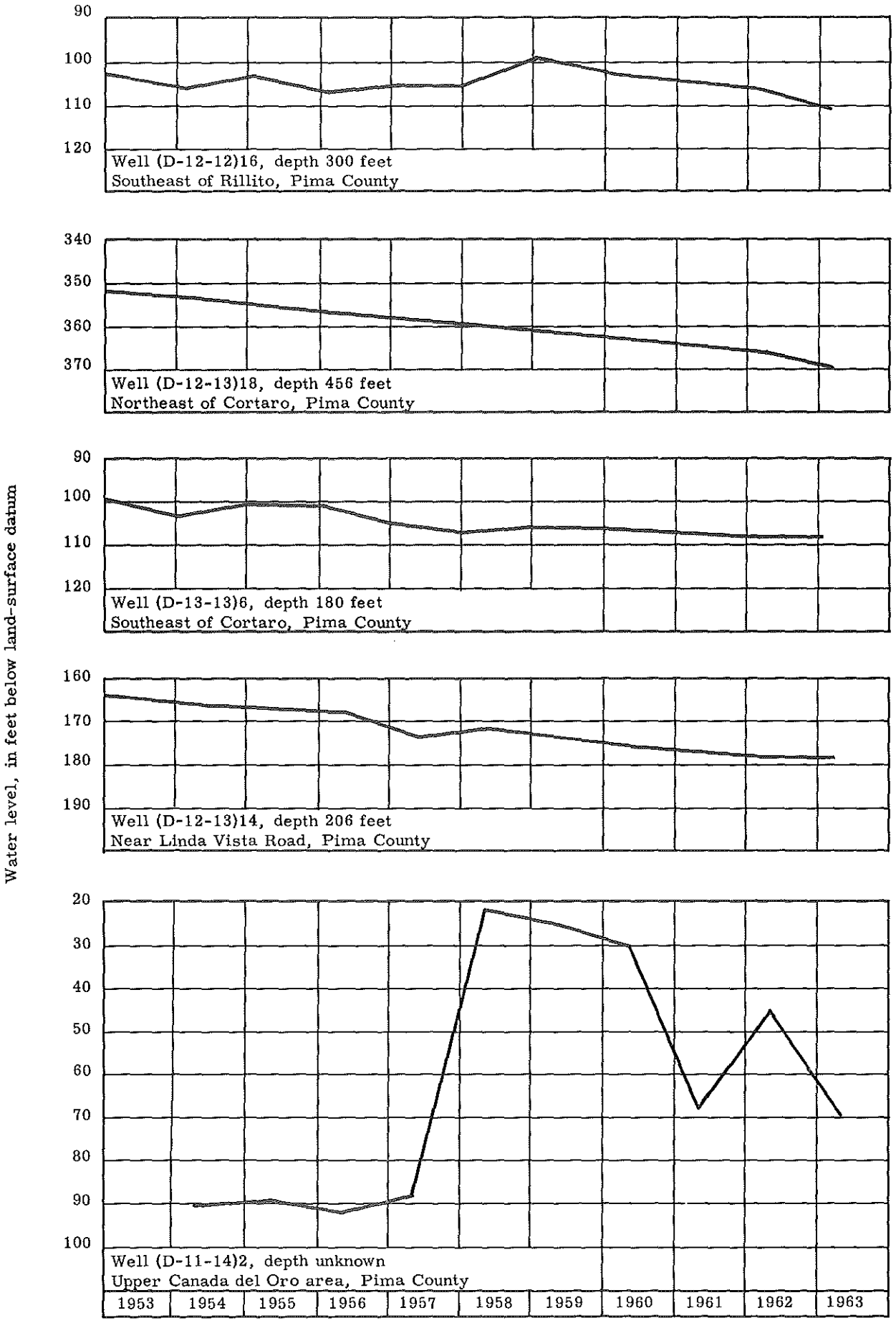

Figure 25. --Water levels in selected wells in the Cortaro-Canada del Oro area, upper Santa Cruz basin.

adjacent to the stream channel, shows the effect of this recharge.

Changes in water level from spring 1962 to spring 1963 reflect the variations in pumping and opportunities for recharge in the area. Along the Santa Cruz River between Cortaro and the Rillito Narrows there were declines of a foot to 4 feet owing to increased pumping of ground water. Between Cortaro and the junction of Rillito Creek with the Santa Cruz River there were rises in water level of a foot to 2 feet, which may be attributed to recharge from sewage effluent used or wasted in this area. On the valley slopes south of the Tortolita Mountains, water levels rose from a foot to 2 feet from spring 1962 to spring 1963. Along the upper part of Canada del Oro water levels declined from 10 to 15 feet---a leveling-out of the temporarily high water levels along the stream channel in spring 1962. Along lower Canada del Oro and underlying the adjacent valley slopes the average decline was from a foot to 2 feet, about the same as in recent years.

Tucson area.--The wide central part of the Santa Cruz River valley from Rillito Creek on the north to the San Xavier Mission on the south has been designated as the Tucson area. With the exception of the Casas Adobes area along Canada del Oro, it includes all the expanded Tucson urban development. Each year agricultural use of ground water is becoming relatively less important; only about 3,700 acres of land was irrigated in the area in 1962, of which 725 acres was in the Papago Indian Reservation adjacent to San Xavier Mission.

The city of Tucson obtains its entire municipal water supply from the upper Santa Cruz basin---the major part coming from wells in the Tucson area. Total pumpage by the City of Tucson Water Utility for 1962 was 44,700 acre-feet---32,300 acre-feet was pumped from wells in the Tucson area. In addition, pumping from the ground-water basin by other agencies and for other uses was estimated to have been as follows: domestic water companies, 8,300 acre-feet; Davis Monthan Air Base, 1,630 acre-feet; schools and recreational facilities, 4,000 acre-feet; industrial use, 6,800 acre-feet; and irrigation, 13,000 acre-feet (consumptive use). The total withdrawal of ground water from the Tucson area in 1962 is estimated to have been about 66,000 acre-feet, excluding the small direct use by phreatophytes in the limited shallow water-table areas. As the return flow in the form of sewage effluent---amounting to about 18,600 acre-feet---is, for the most part, transported out of the area, the total amount may be considered consumptive use.

The water-level measurements in the spring of 1963 indicate a continuation of the downward trend of the water table throughout the entire area with only a few exceptions. For the most part, the exceptions are along Rillito Creek and its mountain tributaries where rises in water level occur following periods of heavy runoff. However, winter and spring runoff in 1962-63 was comparatively light, and water levels in some places along the creek declined as much as 10 or 12 feet. Farther upstream on Tanque Verde Creek there was a small area with a rise in water level of between a foot and 2 feet. In the central part of the Tucson area water-level declines ranged from 2 to 8 feet. In the fringe areas the general decline in water level was between a foot and 2 feet. Along the Santa Cruz River, the average decline was between 4 and 6 feet with isolated wells showing greater losses. The hydrographs of key wells shown in figure 26 illustrate the variations in water-level changes at different places in

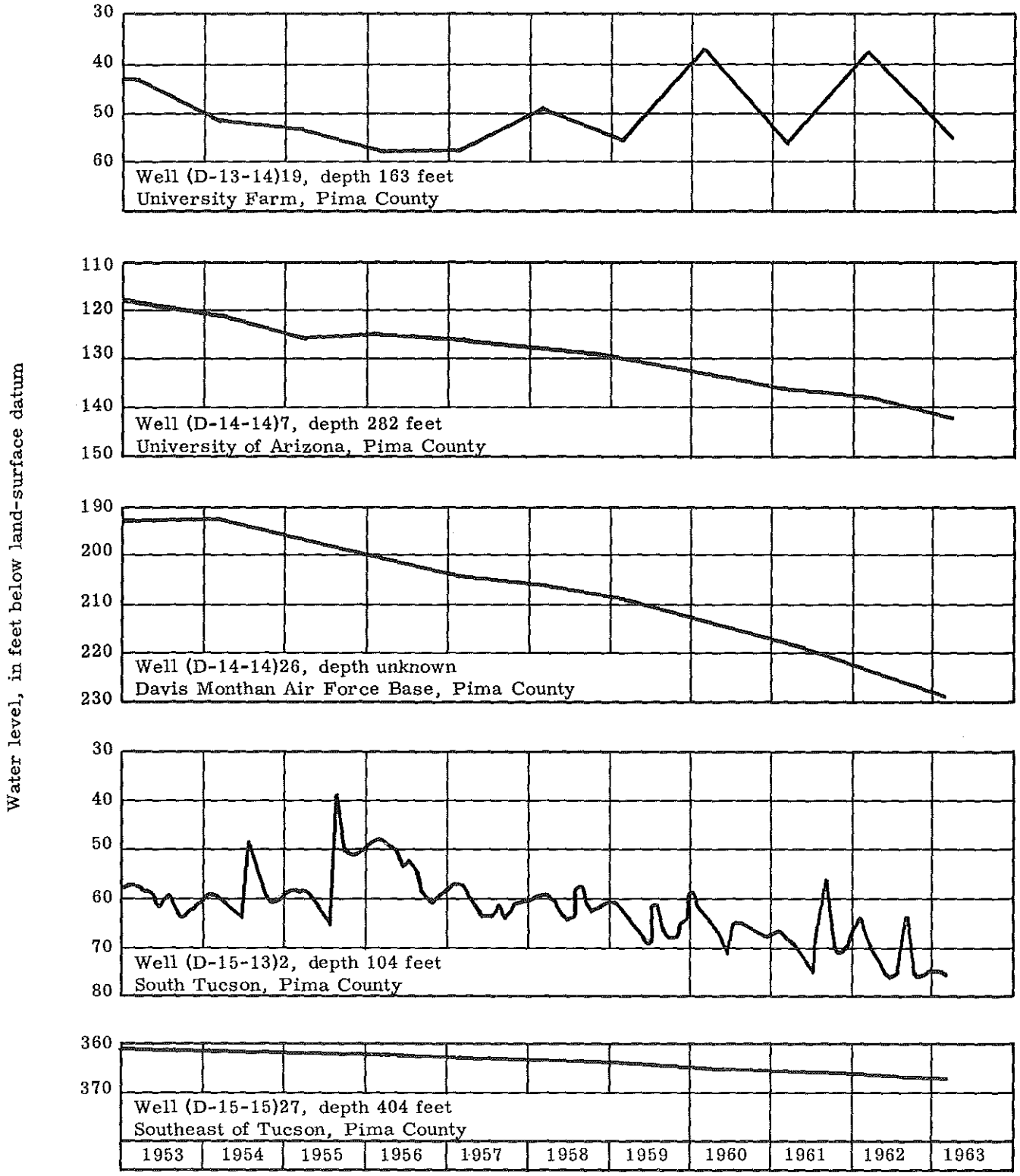

Figure 26.--Water levels in selected wells in the Tucson area, upper Santa Cruz basin.

the Tucson area.

Sahuarita-Continental area.--The Sahuarita-Continental area includes that part of the main Santa Cruz River valley extending from the irrigated lands adjacent to San Xavier Mission in the Papago Indian Reservation to the Pima-Santa Cruz County line. The oldest concentrated area of land irrigated with ground water in Pima County and also the recently developed open-pit mines with water requirements for milling purposes are in this area.

Urban encroachment on agriculture is just beginning here, and the major use of ground water, as in the past, is for irrigation. However, crop surveys by personnel of the Agricultural Engineering Department indicate a reduction of almost 900 acres from 1961, leaving a total of about 12,000 acres irrigated in 1962. Included in this acreage is about 4,300 acres in skip-row cotton planting. Consumptive use of water for all skip-row cotton has been averaged at 3 acre-feet per acre instead of the figure of 3.5 acre-feet for solid plantings used in previous years. Total computed consumptive use for irrigation in this area, with adjustment for skip-row planting, was 37,800 acre-feet. The city of Tucson increased the amount of ground water pumped from its wells in the Sahuarita area by 3,700 acre-feet in 1962 over that pumped in 1961. Total pumpage by the city in the Sahuarita-Continental area in 1962 was about 12,400 acre-feet. Pumpage by the mining companies, chiefly for milling of low-grade ores, increased in 1962 to an estimated 7,300 acre-feet. This amount is based upon a consumptive use of 200 gallons of water per ton of ore milled, which is believed sufficient to include all other mine use. There is, however, considerable question as to the actual consumptive use of water by the mining industry. Recovery and reuse of water may vary widely, and the exact amount of pumped water returned to the ground-water reservoir is not known. Total consumptive use of water in the Sahuarita-Continental area for 1962 for all purposes was about 57,500 acre-feet.

The changes in water level from spring 1962 to spring 1963 vary widely. Near Continental there were rises in water level of a foot or more, which are attributed to changes in seasonal demand for water due to differences in crop plantings. However, water levels are continuing to decline in most of the area, and declines are as much as 5 to 7 feet in the irrigated area north of Sahuarita and on the west side of the valley trough where pumping of ground water by the mines is greatest. South of Continental water-level declines ranged from 2 feet to as much as 5 feet in a small area a mile north of the Pima-Santa Cruz County line. In the fringe areas a few miles east of the bottom land, average declines were less than 2 feet. Hydrographs of the water level in selected wells for the 10-year period 1953-63 are given in figure 27.

Santa Cruz County area.--The ground-water studies in Santa Cruz County include only the trough of the main valley of the Santa Cruz River from the Pima-Santa Cruz County line to the International Boundary and a narrow strip of bottom land along Nogales Wash.

The survey of crop acreage by the Agricultural Engineering Department indicates a total of nearly 5,400 acres irrigated in 1962, for which the consumptive use of water is estimated at 18,600 acre-feet--slightly less than in 1961, although the total crop acreage increased by about 300 acres. Most of the

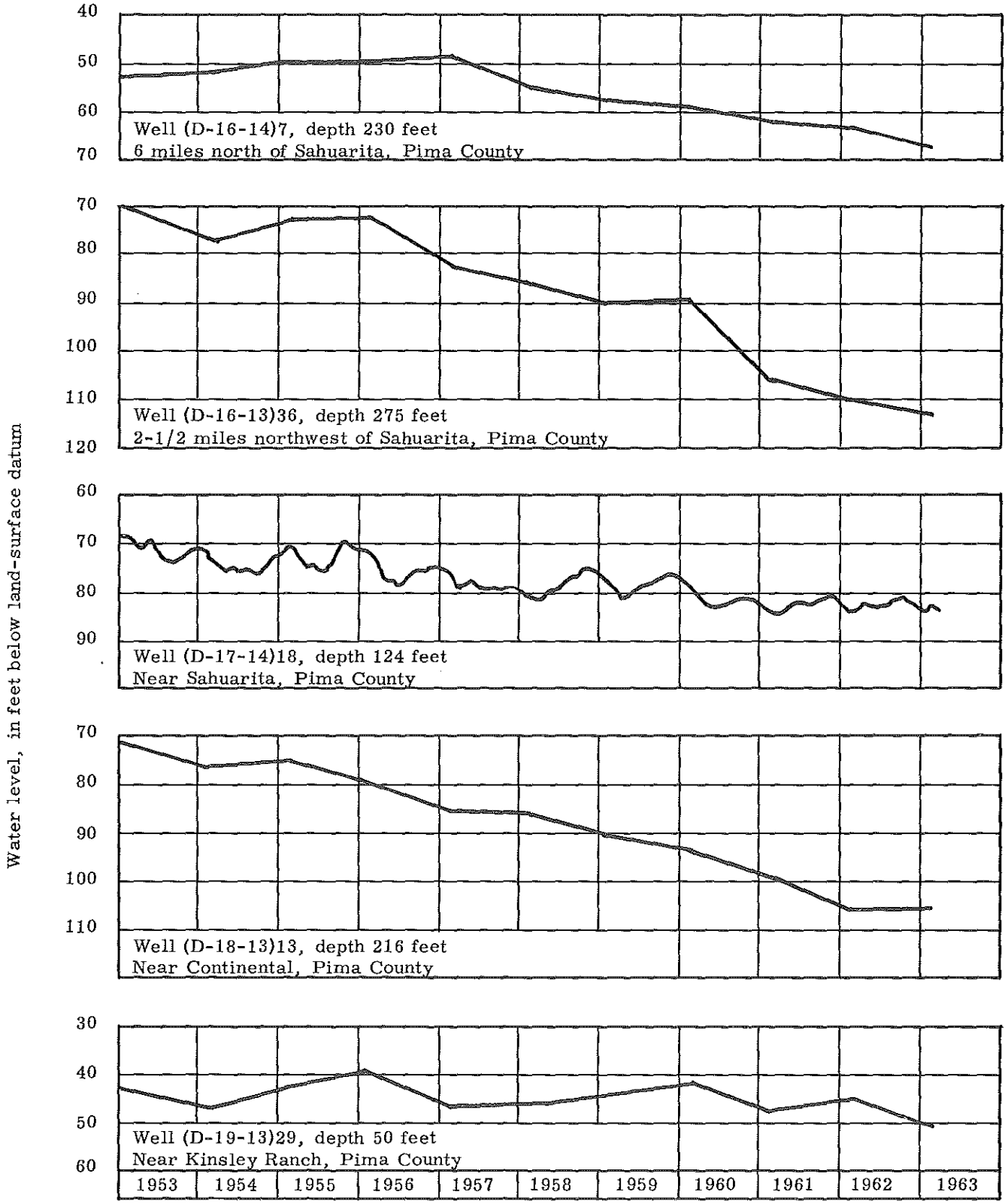

Figure 27.--Water levels in selected wells in the Sahuarita-Continental area, upper Santa Cruz basin.

increase in acreage was in the area immediately upstream from the Nogales, Ariz., pumping plant. Reported pumpage of ground water by the city was 1,300 acre-feet, and estimated use by the golf course near Tubac was 500 acre-feet. Total consumptive use of ground water in the area for 1962 was about 20,400 acre-feet.

The 1963 spring water-level measurements indicate declines of from a foot to 2 feet since the spring of 1962 for most of the area. From about 8 miles above the junction of Sonoita Creek with the Santa Cruz River, declines in water level increased upstream, with maximum declines of more than 15 feet near Calabasas. From spring 1962 to spring 1963, the water level in wells at the Nogales, Ariz., pumping plant declined about 42 feet. The water level was 44 feet below the well sump, the lowest it has been in any spring during the last 25 years, although pumpage at the city plant in 1962 was only about 100 acre-feet more than in 1961. The decline may be attributed partly to the lack of recharge from flow in the Santa Cruz River. Flow in the Santa Cruz River during the spring and summer of 1962 was well below normal. The water level in well (D-23-14)26 (fig. 28), about a mile north of the city plant in the same small ground-water basin, declined more than 20 feet from spring 1962 to spring 1963.

Avra-Marana Area

By

H. C. Schwalen 1/

The Avra-Marana area (fig. 12, No. 10), including the part of the lower Santa Cruz basin from Rillito Narrows northwest to Picacho Peak, is that part of the Santa Cruz River drainage basin from south of Piacacho Peak to the Rillito Narrows at the north end of the Tucson Mountains, and Avra Valley south to Three Points. The area is drained by Brawly Wash, which is tributary to the Santa Cruz River.

According to the 1962 crop survey by the Agricultural Engineering Department, the Pinal County part of the area contains 5,200 acres of irrigated cropland with a computed consumptive use of 16,600 acre-feet of pumped water. Computations of net annual consumptive use for various crops have been based on the following: cotton, 3.5 acre-feet; safflower, 3.5 acre-feet; grain, 2.5 acre-feet; sorghum, 2.5 acre-feet; truck, 2.5 acre-feet; alfalfa, 4.5 acre-feet; pasture, 4.0 acre-feet; and miscellaneous, 3.0 acre-feet. The only other important use of ground water was by the Arizona Public Service Company for cooling purposes at the Red Rock steam plant. The amount of water pumped in 1962 was 1,480 acre-feet, which may be considered consumptive use. The total computed consumptive use in the Avra-Marana area in Pinal County was about 18,000 acre-feet.

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

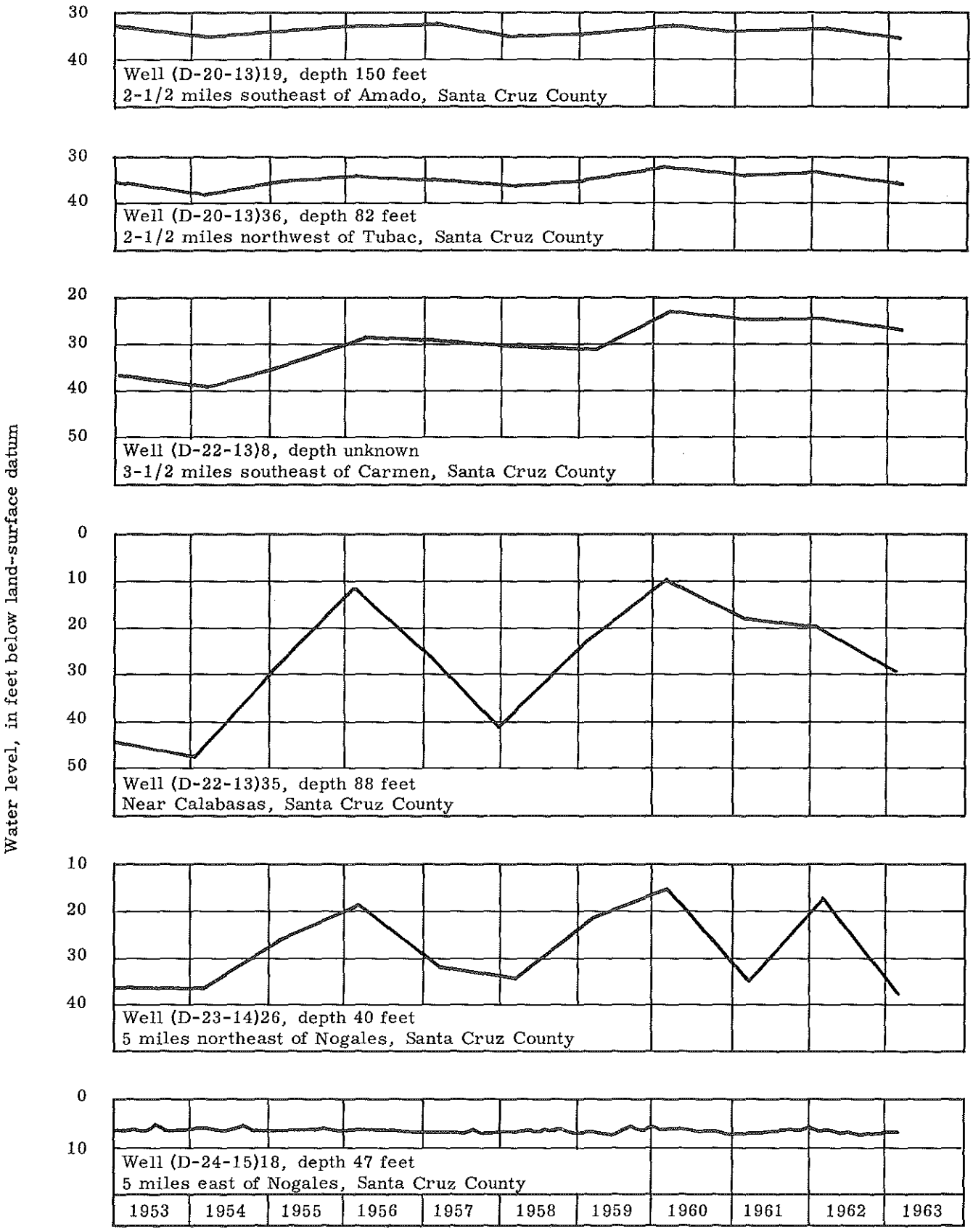

Figure 28.--Water levels in selected wells in the Santa Cruz County area, upper Santa Cruz basin.

About 29,000 acres of land was irrigated in the Avra-Marana area in Pima County in 1962, with a computed consumptive use of 101,000 acre-feet of water. However, about 18,600 acre-feet of ground water was imported into the Avra-Marana area by the Cortaro Water Users' Association from the Cortaro area above the Rillito Narrows. Consumptive use of this imported water was about 15,000 acre-feet, which must be deducted from the gross figure of 101,000 to obtain the actual consumptive use of ground water from storage in the Avra-Marana area. In addition, consumptive use of ground water for industrial purposes at the Silverbell mine and the El Paso Natural Gas Company plant plus domestic water requirements at Marana has been estimated to be about 2,000 acre-feet per year. The total computed consumptive use of ground water in the Pima County part of the Avra-Marana area for 1962 is estimated to have been 88,000 acre-feet. The total consumptive use in the Avra-Marana area in Pima and Pinal Counties thus amounted to 106,000 acre-feet in 1962.

Changes in water level from spring 1962 to spring 1963 vary widely within the area as a whole (fig. 29). In the Pinal County part of the area there was a maximum decline in water level of more than 20 feet where this area joins the Eloy district. Just north of the Pima County line there were lesser declines, and in a small area in the trough of the valley there was a slight rise in water level. The same small rise and adjacent reduced decline were observed near the Santa Cruz River immediately south of the Pima-Pinal County line and also farther upstream near the river. This condition may be due to less pumping in these places, or it may reflect some possible recharge from the unprecedented flood of September 1962 in Brawly Wash and the Santa Cruz River. The floodwaters covered thousands of acres of land in the lower part of Avra Valley and along the Santa Cruz River below the junction of the two streams.

Declines in water level of 5 to 8 feet were prevalent in the major part of the irrigated area near Marana and for about 12 miles southward into the Avra Valley but were negligible at the south end of the valley. In a small isolated irrigated area at Three Points declines of from 2 to 4 feet occurred.

Lower Santa Cruz Basin and Adjacent Area Along the Gila River

By

William F. Hardt

The lower Santa Cruz basin and the adjacent area along the Gila River (fig. 12, 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, is drained by the Santa Cruz River---a tributary of the Gila River. 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 area is bounded on the west 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 boundary between the lower Santa Cruz and upper Santa Cruz basins is the Rillito Narrows, which is between the Tucson

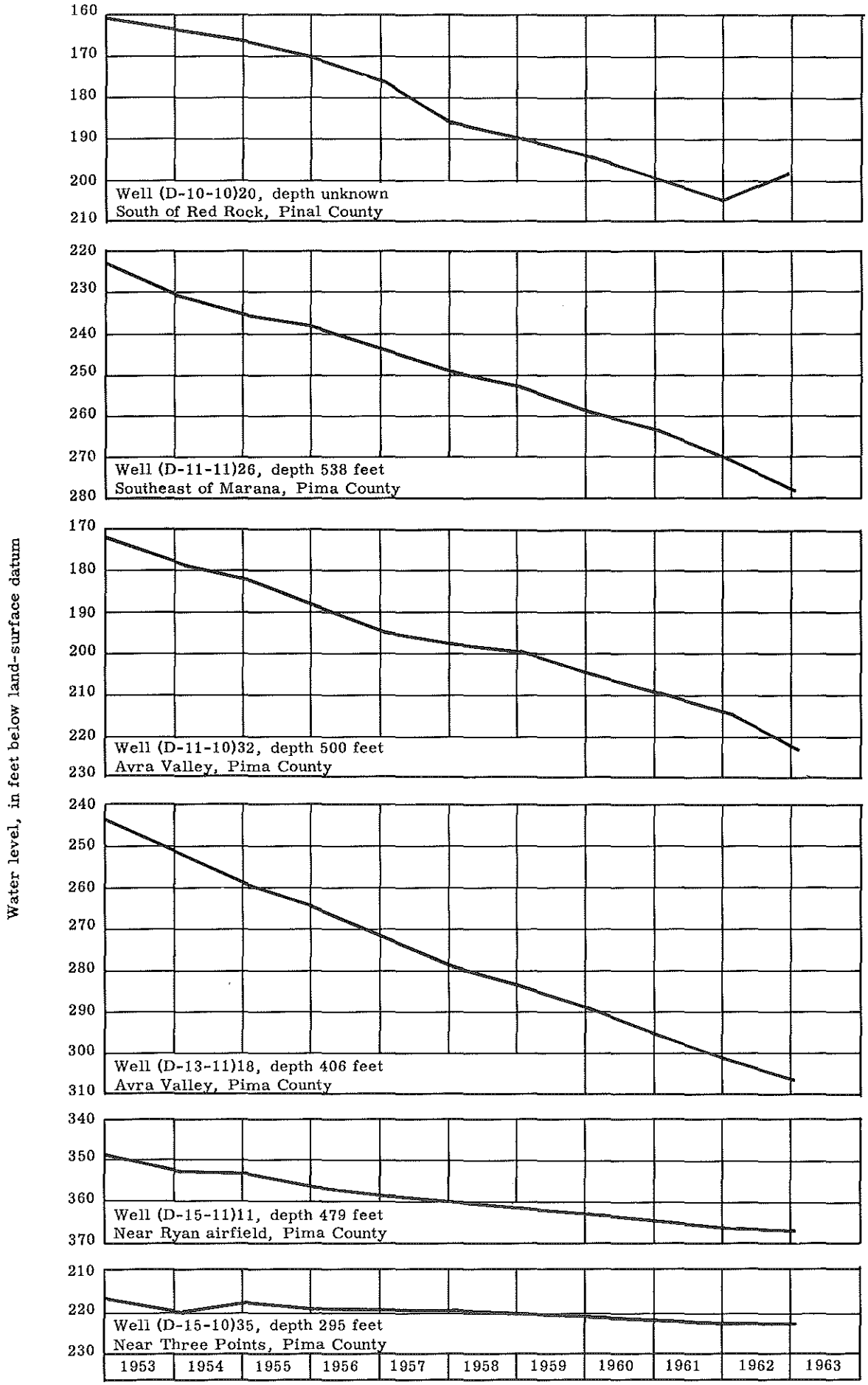

Figure 29.--Water levels in selected wells in the Avra-Marana area.

and Tortolita Mountains in Pima County about 10 miles south of the Pinal County line.

Most of the irrigated acreage is concentrated in an area of more than 1,000 square miles northwest of Red Rock and west of the Picacho Mountains to the Gila River. This intensively developed area is underlain by thick, generally weakly consolidated alluvium in a broad valley surrounded by mountain masses. The valley floor slopes gently northwestward from about 1,800 feet above mean sea level a few miles northwest of Red Rock 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 (1963), 258,095 acres of land was cropped in Pinal County in 1962, chiefly in the lower Santa Cruz basin. This acreage was a reduction of 13,660 acres from 1961 and 35,188 acres since 1959 when the decrease in acreage began. Since 1960 about 55 to 60 percent of the total county acreage has been in cotton production. Increased costs resulting from 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. Subdivision of agricultural land into homesites has also taken some land out of production.

The regional 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 River valley through Red Rock and Eloy toward the Sacaton Mountains. Part of the flow was diverted northward toward Coolidge and thence to the Gila River, and part of the flow was northwestward toward Stanfield, Maricopa, and the Gila River.

The rapid agricultural growth since 1940 has resulted in heavy ground-water withdrawals, resulting in two large depressions of the ground-water table centering principally near the towns of Eloy and Coolidge and Maricopa and Stanfield. A ground-water divide has formed between the cones of depression near Casa Grande; ground water moves east toward Coolidge and west toward Stanfield. The ground-water divide is above a north-trending buried ridge consisting of nonwater-yielding materials. The permeable alluvial sediments overlying the buried ridge are comparatively thin; well yields from these sediments are small, and the quality of water is poor. Because of the cone of depression near Eloy and Coolidge, little ground water now moves northwestward parallel to the Santa Cruz River to the Stanfield area, except possibly through the gap between the Casa Grande and Silver Reef Mountains. Ground-water depressions are deep and numerous between Stanfield and Maricopa. The deepest ones are along the eastern flank of the Table Top and Palo Verde Mountains and the Haley Hills and at 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. 30): (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 spring 1940 to spring 1963 in the three areas (fig. 32) show the tremendous decline of the water table in the

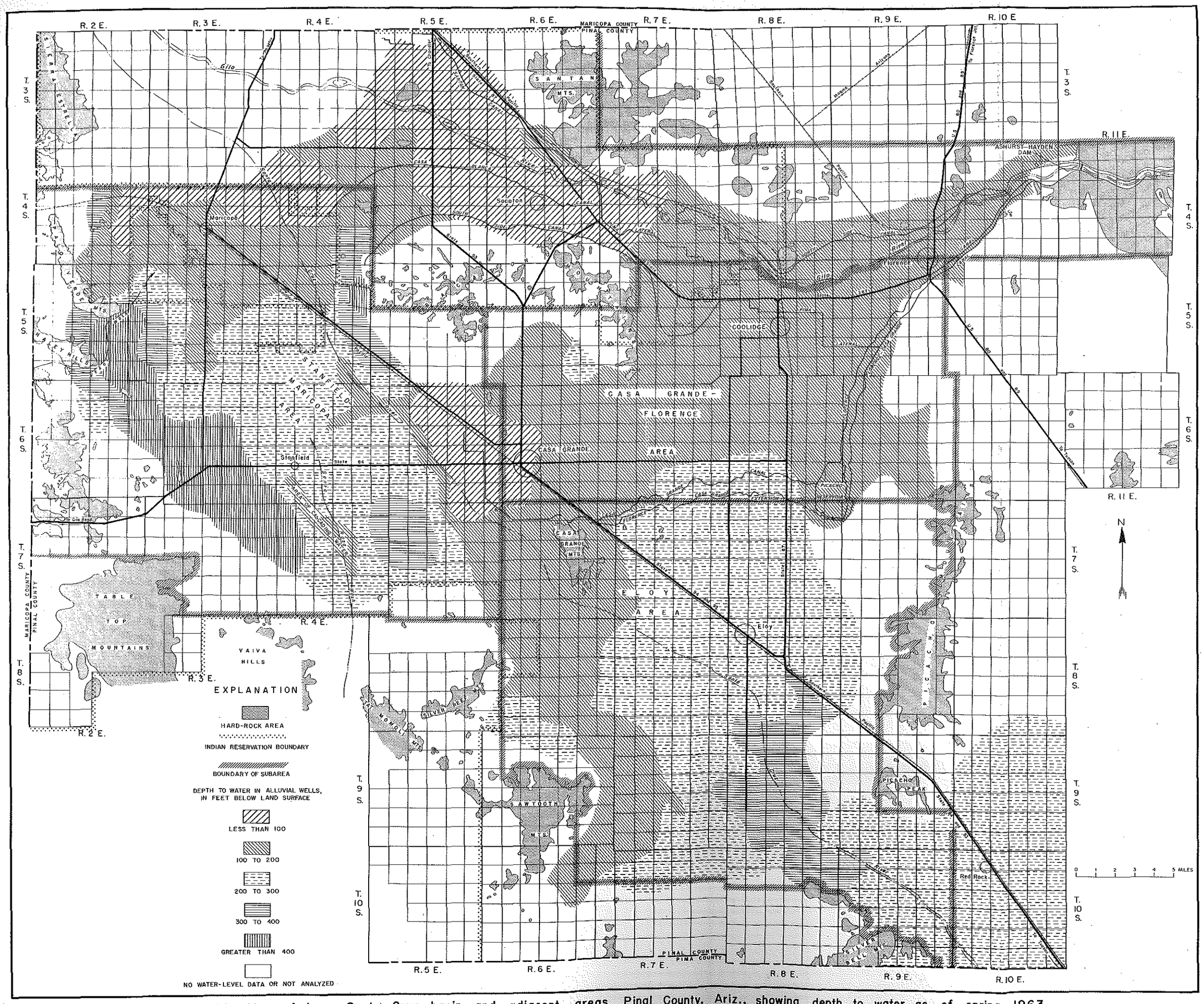

Figure 30.--Map of lower Santa Cruz basin and adjacent areas, Pinal County, Ariz., showing depth to water as of spring 1963.

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 1963. The shallow water levels are south and north of the Casa Grande Mountains and along the east side of the Sawtooth Mountains (fig. 30). In the central part of the area the water levels ranged from 200 to 300 feet below land surface. Near Eloy water levels were from 236 to 286 feet below land surface; at Red Rock the depth to water was 209 feet. 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 to the north end of the Silver Bell Mountains.

Water-level changes from spring 1962 to spring 1963 ranged from rises of a foot to 10 feet to declines of as much as 24 feet. Most of the yearly declines were less than 10 feet. Rises in the water table were measured sporadically throughout the area in 17 wells, although 6 of these wells were in an area extending from a mile to 7 miles south of Eloy. The rises probably were related more to well mechanics and pumping patterns than to hydrologic conditions in the aquifer. Maximum yearly declines of more than 10 feet were measured in the central part of the Eloy area between the Casa Grande Canal and Eloy and north of the Silver Bell Mountains. The minimum yearly declines of less than 5 feet were generally between the Casa Grande and Sawtooth Mountains.

In the 5-year period spring 1958 to spring 1963 water-level declines were as much as 60 feet (fig. 31) adjacent to the north end of the Silver Bell Mountains and 2 to 5 miles east of the Casa Grande Mountains along the south side of the Florence-Casa Grande Extension Canal. Areas where water levels did not decline in the 5-year period were south of the Casa Grande Mountains and along the east side of the Sawtooth Mountains. In the central part of the area declines generally ranged from 20 to 40 feet, although from Eloy southwest to the Sawtooth Mountains declines were less than 20 feet. Areas where declines were more than 40 feet were at the north end of the Sawtooth Mountains, 3 miles east of the Casa Grande Mountains, at the north edge of Eloy, 9 miles south of Eloy and northeast to State Highways 84 and 93, and along the northeast side of the Silver Bell Mountains.

The cumulative net decline in water level in the Eloy area since 1940 is about 136 feet (fig. 32). For the period spring 1962 to spring 1963, the net decline in water level was 5.3 feet based on data from 72 wells.

Large water-level declines are indicated by hydrographs of two wells in the Eloy area. The water level in well (D-7-7)27 (fig. 33), 3 miles northwest of Eloy, declined about 18 feet from spring 1962 to spring 1963, about 25 feet from spring 1960 to spring 1963, and about 54 feet from spring 1953 to spring 1963. The hydrograph shows a fairly uniform yearly decline in the water table of 6 feet from spring 1953 to spring 1957, although the water-level measurements in spring 1959 and spring 1963 may have been influenced by nearby pumping. In the spring of 1940 the water level in this well was 79 feet below land surface---about 132 feet higher than in the spring of 1963---indicating an average decline of 6 feet per year for the 23-year period.

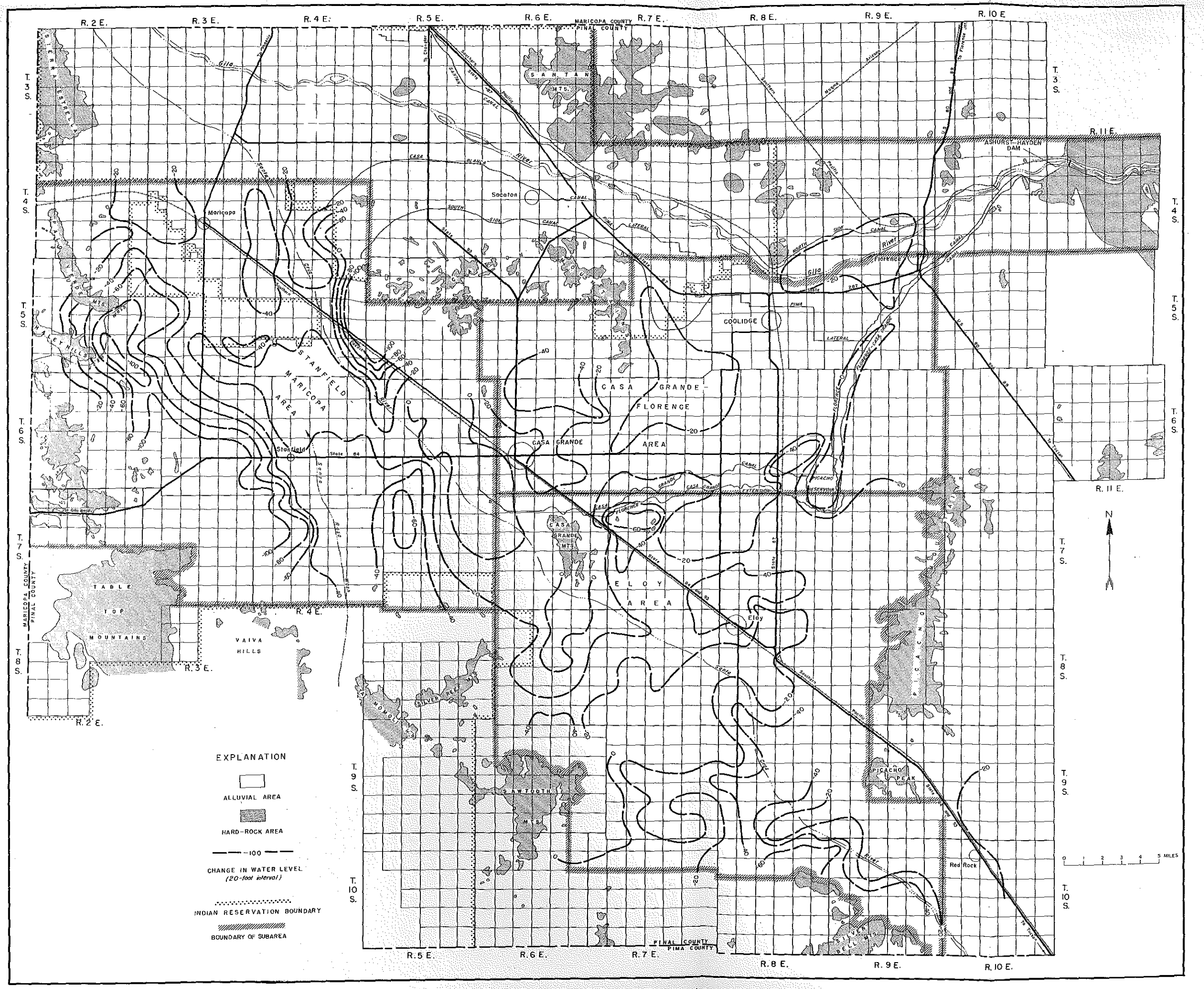

Figure 31.--Map of lower Santa Cruz basin and adjacent areas, Pinal County, Ariz., showing change in ground-water level from spring 1958 to spring 1963.

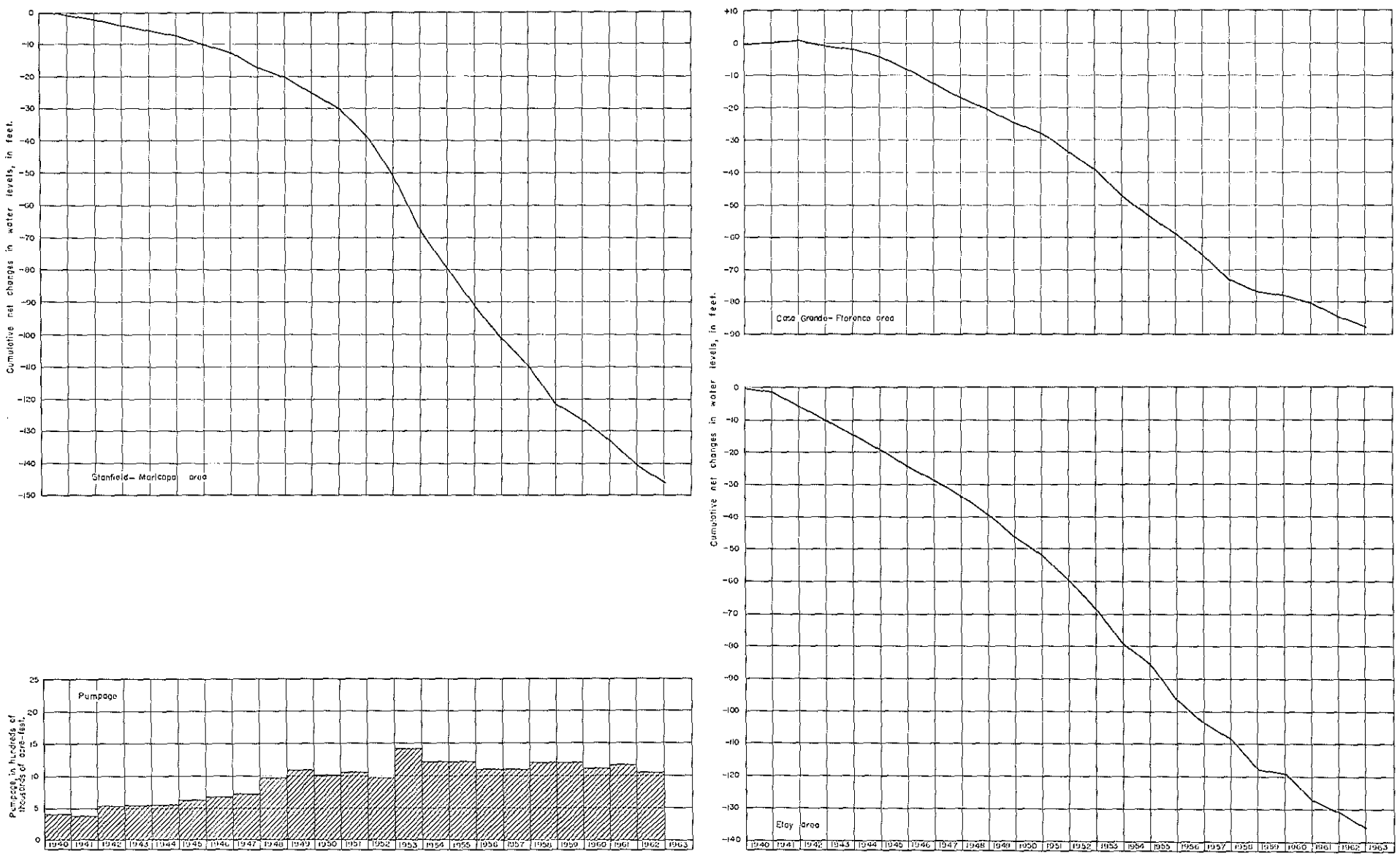

Figure 32.--Cumulative net changes in water levels by areas and total annual pumpage in the lower Santa Cruz basin within Pinal County.

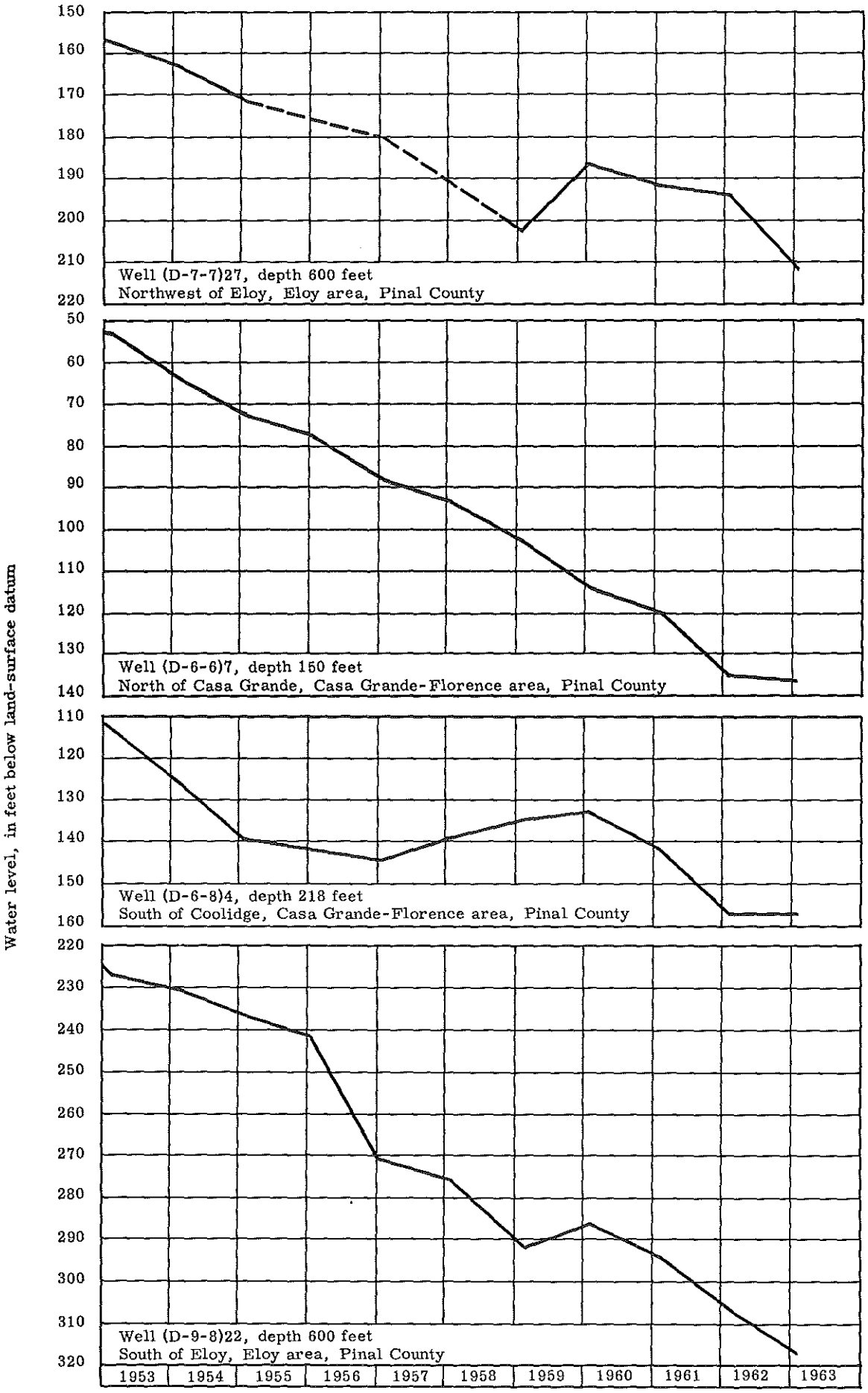

Figure 33. --Water levels in selected wells in the Eloy and Casa Grande-Florence areas, lower Santa Cruz basin.

The water level in well (D-9-8)22 (fig. 33), 9 miles south of Eloy, declined nearly 11 feet from spring 1962 to spring 1963, about 42 feet from spring 1958 to spring 1963, and about 91 feet from spring 1953 to spring 1963. The hydrograph shows a fairly uniform yearly decline in the water table of 5 feet from spring 1953 to spring 1956. The rate of decline increased to nearly 17 feet per year for the 3-year period spring 1956 to spring 1959, and decreased to about 10 feet per year from spring 1960 to spring 1963. The depth to water in this well in March 1942 was 148 feet below land surface or 169 feet higher than in spring 1963. For the 21-year period the average yearly decline in the water table in this well was 8 feet.

Casa Grande-Florence area. --The depth to water in this area in the spring of 1963 was less than 200 feet below land surface except in a few wells south of Florence, east of the Florence Canal, and adjacent to the Casa Grande Canal west of Picacho Reservoir (fig. 30). Water levels ranged from 65 to 150 feet below land surface near Casa Grande, were between about 145 and 170 feet along the Gila River from Florence to Coolidge, and were about 160 feet between Casa Grande and Coolidge. Water levels along the Gila River channel were about 35 feet at the Ashurst-Hayden Dam, 115 feet between Coolidge and Sacaton, 75 feet at Sacaton, and between 75 and 130 feet below land surface downstream from Sacaton to the Maricopa-Phoenix highway.

In the period spring 1962 to spring 1963 water-level changes in the Casa Grande-Florence area ranged from rises of a foot to 6 feet to declines of 17 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 between Coolidge and Sacaton and from a mile to 5 miles southeast of Coolidge. The largest declines from spring 1962 to spring 1963 were along the Casa Grande Canal 8 to 10 miles east of Casa Grande, and adjacent to the Florence Canal from Florence to the Picacho Reservoir.

Generally, the water-level declines in the Casa Grande-Florence area are less than in the other two areas because of the availability of surface water. In 1962 about 220,000 acre-feet of surface water was diverted from the Gila River at Ashurst-Hayden Dam. This amount of water diverted was about 157,000 acre-feet more than in the previous year and is comparable to the diversion in 1949, 1958, and 1960.

In the 5-year period spring 1958 to spring 1963, water-level changes (fig. 31) ranged from little or no decline along the main canals from about 4 miles southwest of Florence to the Picacho Reservoir and in the area west of Casa Grande to more than 40 feet of decline about a mile northwest of the Picacho Reservoir and 3 miles northeast of Casa Grande. The 5-year declines were generally more than 20 feet between Coolidge and the Sacaton Mountains, northeast of Casa Grande, and along the Gila River from Florence to Coolidge. Declines for the same period ranged from 10 to 19 feet along the Gila River between Coolidge and Sacaton and from 4 to 10 feet near Ashurst-Hayden Dam. Elsewhere in the Casa Grande-Florence area the declines for the 5-year period spring 1958 to spring 1963 were generally less than 20 feet.

The cumulative net decline in water level in the Casa Grande-Florence area since 1940 is about 88 feet (fig. 32). For the period spring 1962 to spring 1963,

the net decline in water level was 3.3 feet based on data from 106 wells.

The water level in well (D-6-6)7 (fig. 33), north of Casa Grande, declined about a foot from spring 1962 to spring 1963, nearly 43 feet from spring 1958 to spring 1963, and 83 feet since spring 1953. The depth to water in this well in April 1940 was about 28 feet below land surface, or about 108 feet higher than in spring 1963. The average yearly decline for the 23-year period was nearly 5 feet, although during the last 10 years the decline has been about 8 feet per year.

The water level in well (D-6-8)4 (fig. 33), 3 miles south of Coolidge, declined about half a foot from spring 1962 to spring 1963, nearly 18 feet from spring 1958 to spring 1963, and nearly 45 feet since spring 1953. From spring 1957 to spring 1960, the water level in this well rose about 12 feet. However, since spring 1960 the trend of the water table has been downward. 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 1963. The average yearly decline for the 23-year period was about 4½ feet.

Stanfield-Maricopa area.--The depth to water below land surface in the spring of 1963 varied considerably throughout the area, ranging from about 50 feet 2 miles west of Casa Grande to as much as 400 to 500 feet south of the Palo Verde Mountains and 5 to 10 miles west of Stanfield adjacent to the mountains (fig. 30). Shallow water levels between 50 and 100 feet were measured in wells 2 to 5 miles west of Casa Grande. A few miles farther west, the depth to water ranged from 200 to 350 feet below land surface. The ground-water gradient in this area is more than 75 feet per mile. 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. Water levels were 425 to 475 feet below land surface 2 miles southwest of Stanfield, and 2 miles northeast of Stanfield water levels were from 200 to 290 feet below land surface. In the area between Stanfield and Maricopa the depth to water ranged from 150 to 300 feet below land surface, being shallower toward Maricopa. West of Maricopa toward the mountains, the water levels ranged from less than 100 to more than 300 feet below land surface. In T. 4S., R. 2E., water levels in three wells in sections 13, 14, and 15 were 73, 177, and 309 feet below land surface, respectively. These wells vary in total depth and may penetrate different hydrologic zones. Southeast of Maricopa to within 2 miles of the Sacaton Mounatins, the depth to water is less than 200 feet but adjacent to the mountain is more than 400 feet below land surface.

In a narrow area extending from Stanfield southeast to the Santa Rosa Wash water levels were from 135 to 190 feet below land surface. This area may contain a shallow, nearly dewatered aquifer draining through wells to a deeper aquifer, or the aquifer may be recharged from Santa Rosa Wash. Thus, shallow wells bottoming in clay or silt could have water levels substantially higher than deeper wells in this area.

Water-level changes from spring 1962 to spring 1963 ranged from rises of a foot to 28 feet in 23 wells to declines of a foot to 35 feet in 49 wells. The wide variation in net change in the water level, in part, is due to pumping schedules related to the time of the water-level measurements. Rises in the water table

were measured sporadically throughout the area, although there were some consistent rises south of Stanfield near Santa Rosa Wash, 2 to 6 miles west of Casa Grande, and between Maricopa and the Sacaton Mountains. Maximum declines ranging from 15 to 35 feet were in the areas adjacent to the Palo Verde Mountains and southward to the Table Top Mountains, south and east of Stanfield, and along the west side of the Sacaton Mountains. In the central part of the Stanfield-Maricopa area the water levels generally declined less than 10 feet for the period spring 1962 to spring 1963. In the area overlying the buried bedrock ridge a few miles west of Casa Grande, declines from spring 1962 to spring 1963 ranged from a foot to 8 feet, although many of the water levels were higher than in spring 1962.

In the 5-year period spring 1958 to spring 1963 declines were as much as 100 feet (fig. 31) in a belt that extended from south of the Palo Verde Mountains to south of Stanfield and adjacent to the southwestern part of the Sacaton Mountains. Large declines were also measured about 6 miles southeast of Stanfield. In the area between Stanfield and Maricopa, the 5-year declines ranged from 20 to 40 feet. In the area a few miles west of Casa Grande there has been little or no decline in the water table during the last 5 years because only a small amount of ground water was pumped. North of Maricopa in the Indian lands, the lack of agricultural development has resulted in minimum water-level declines.

The cumulative net decline in water level in the Stanfield-Maricopa area since 1940 is about 146 feet (fig. 32). For the period spring 1962 to spring 1963, the net decline in water level was 5.4 feet based on data from 91 wells.

The water level in well (D-7-5)5 (fig. 34), about 5 miles southwest of Casa Grande, declined nearly 21 feet from spring 1962 to spring 1963, 72 feet from spring 1958 to spring 1963, and about 138 feet since spring 1953. The hydrograph shows a nearly uniform decline of about 15 feet per year since spring 1955. This well is adjacent to the west side of the north-trending buried ridge where water-level declines are above average for the Stanfield-Maricopa area. The depth to water in this well in February 1951 was 170 feet below land surface, or nearly 180 feet higher than in the spring of 1963. The water level in well (D-4-3)22 (fig. 34), about a mile east of Maricopa, declined 7 feet from spring 1962 to spring 1963, about 38 feet from spring 1958 to spring 1963, and 75 feet since spring 1953. The average yearly decline for the last 10 years has been about 7½ feet.

Salt River Valley

By

R. S. Stulik

The Salt River Valley (fig. 12, No. 12) is comprised of the valley lands near Phoenix, tributary valleys such as Paradise and Deer Valleys, 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; by the Pinal-Maricopa 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. 35). Figures. 36, 37, and 38 show the cumulative net changes in water levels in various parts of the Salt River Valley since 1930. Figure 38 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 altered, and ground water is now moving toward major cones of depression, which were caused by heavy withdrawals. As of the spring of 1963, 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 part of the Salt River Valley, the ground water generally flows southward toward the depression northwest of Litchfield Park, but some water flows toward the depression in Deer Valley (fig. 39). In the Liberty-Buckeye-Hassayampa area the water generally moves southwestward, but some moves northward toward the depression near Litchfield Park. In the area west of the Hassayampa River the ground water generally flows southward toward Gillespie Dam, but some water flows toward the depression southeast of Tonopah (fig. 39).

Queen Creek-Higley-Gilbert-Magma area.--During 1962 most of the water levels in wells in the Queen Creek-Higley-Gilbert-Magma area continued to follow the previously observed downward trend of the water table (fig. 36). In the period spring 1962 to spring 1963, water-level changes ranged from a decline of about 30 feet near Queen Creek to a rise of about 4 feet near Higley. In the 5-year period spring 1958 to spring 1963, 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 occured between Magma and Queen Creek. The minimum declines were observed in the southwestern part of the area (fig. 35).

In the northeastern part of the area the water level in well (A-1-6)23 (fig. 40) declined about 3 feet from spring 1962 to spring 1963, more than 60 feet from spring 1958 to spring 1963, and more than 140 feet since 1953.

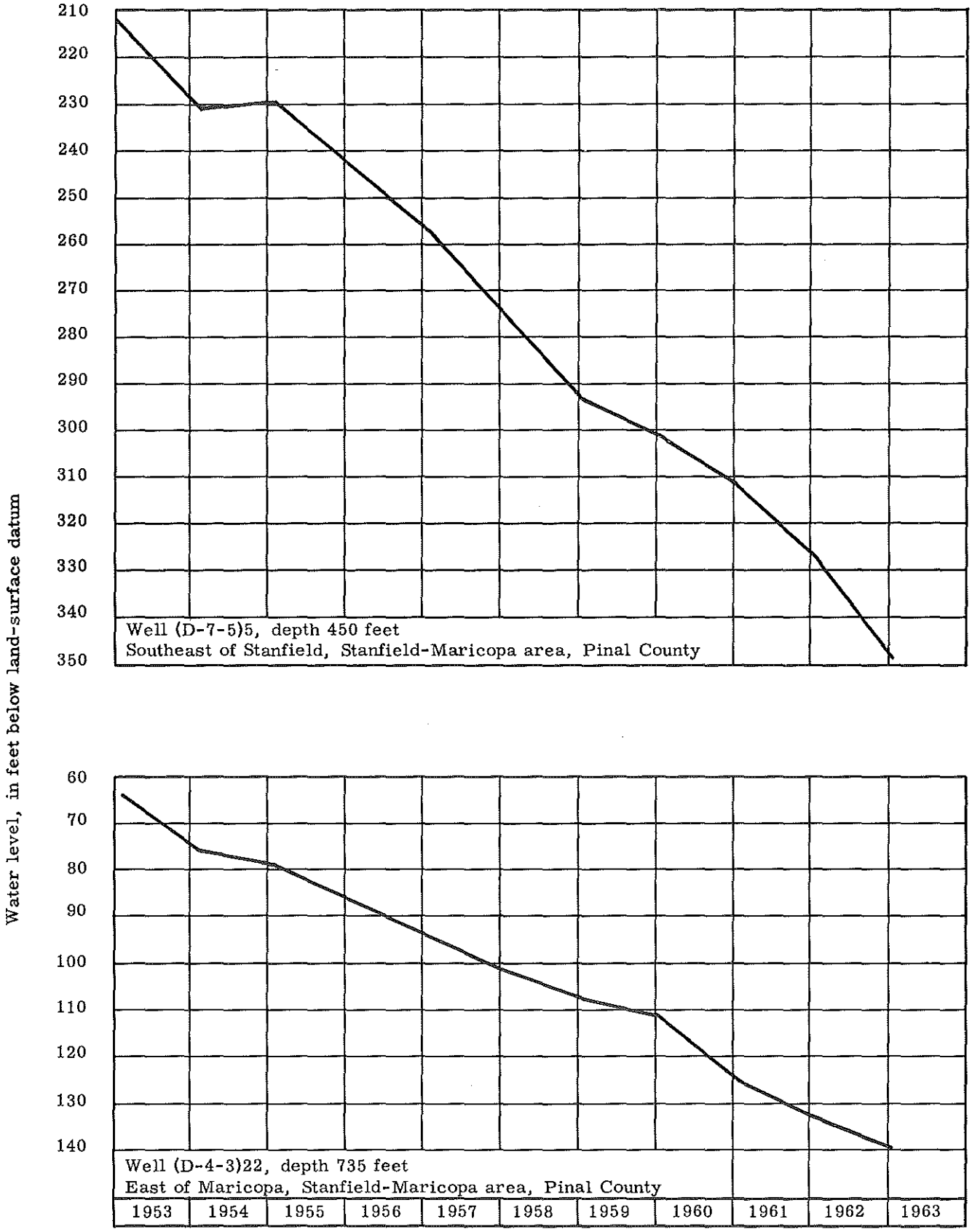

Figure 34.--Water levels in selected wells in the Stanfield-Maricopa area, lower Santa Cruz basin.

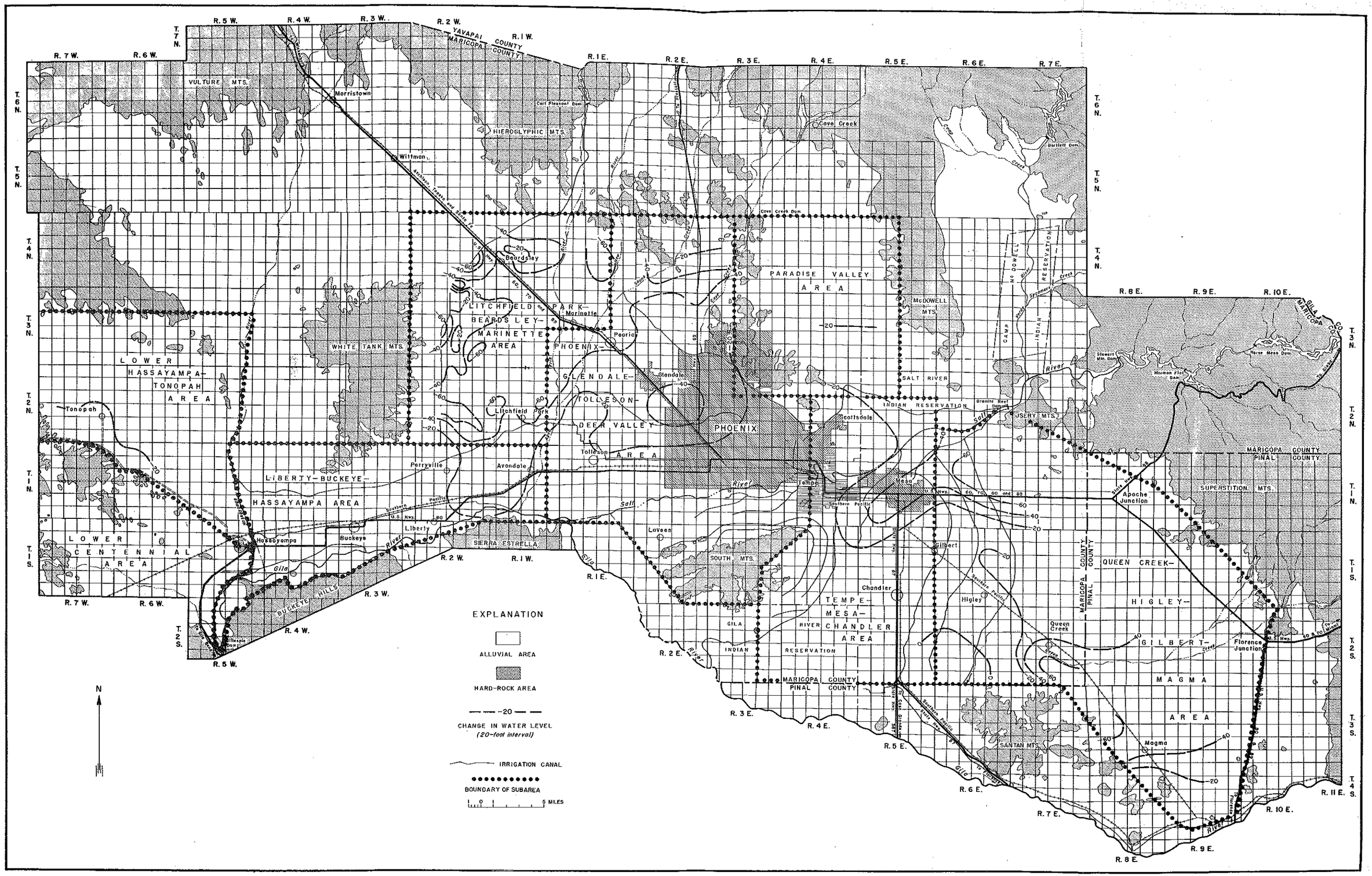

Figure 35.--Map of Salt River Valley area, Maricopa and Pinal Counties, Ariz., showing change in ground-water level from spring 1958 to spring 1963.

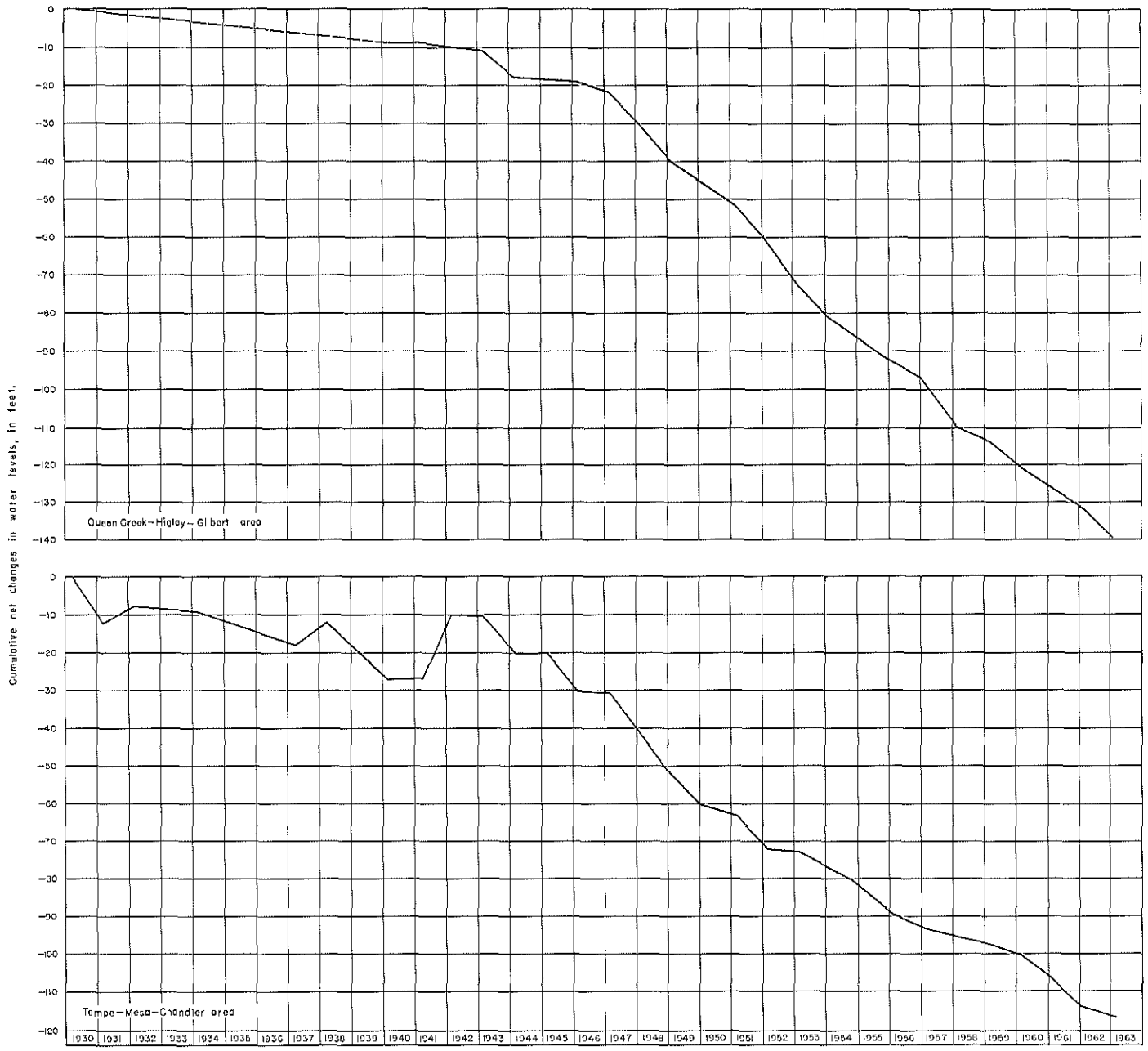

Figure 36.—Cumulative net changes in water levels in the Queen Creek-Higley-Gilbert and Tempe-Mesa-Chandler areas of the Salt River Valley.

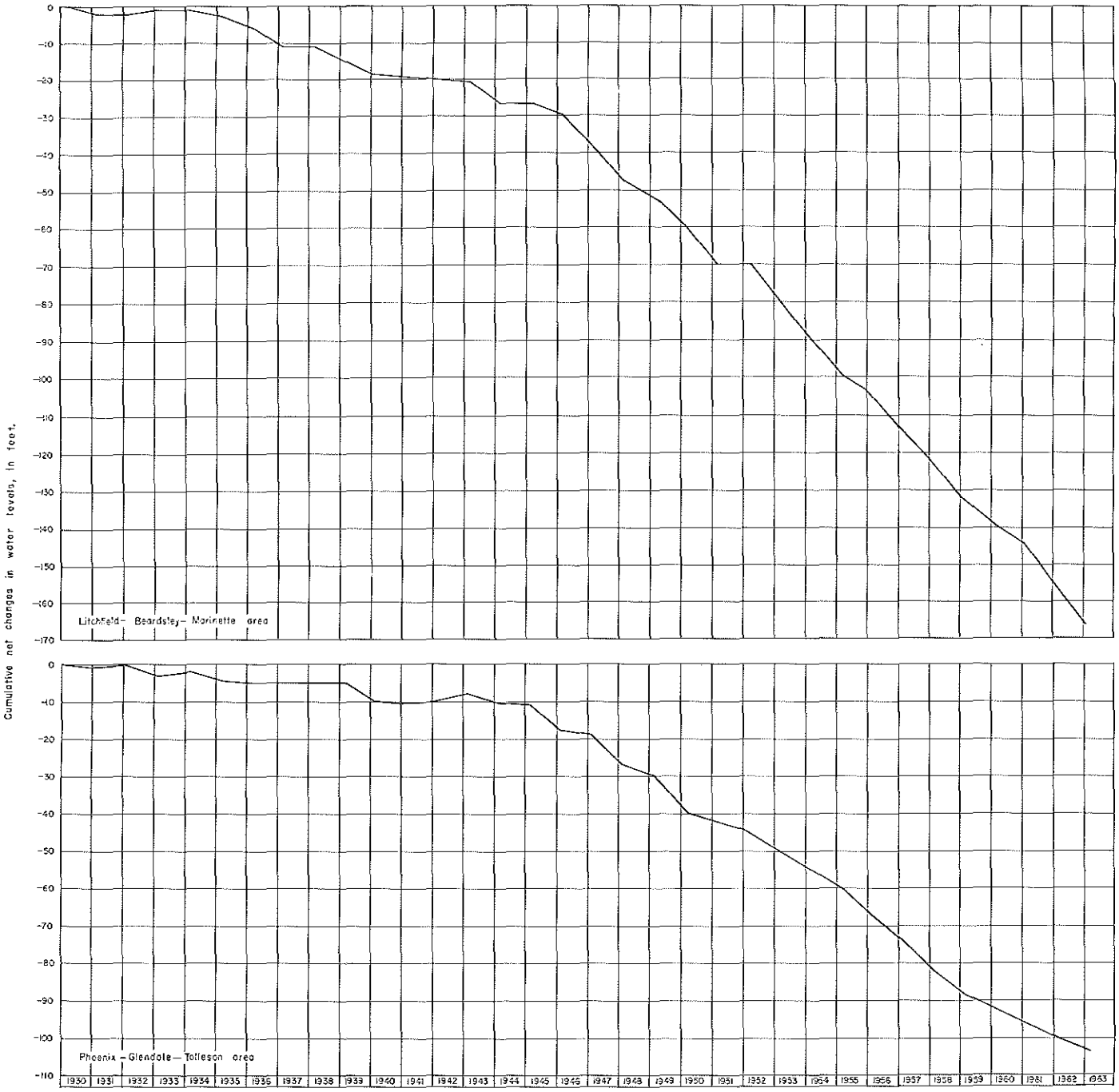

Figure 37.—Cumulative net changes in water levels in the Litchfield-Beardsley-Marinette and Phoenix-Glendale-Tolleson areas of the Salt River Valley.

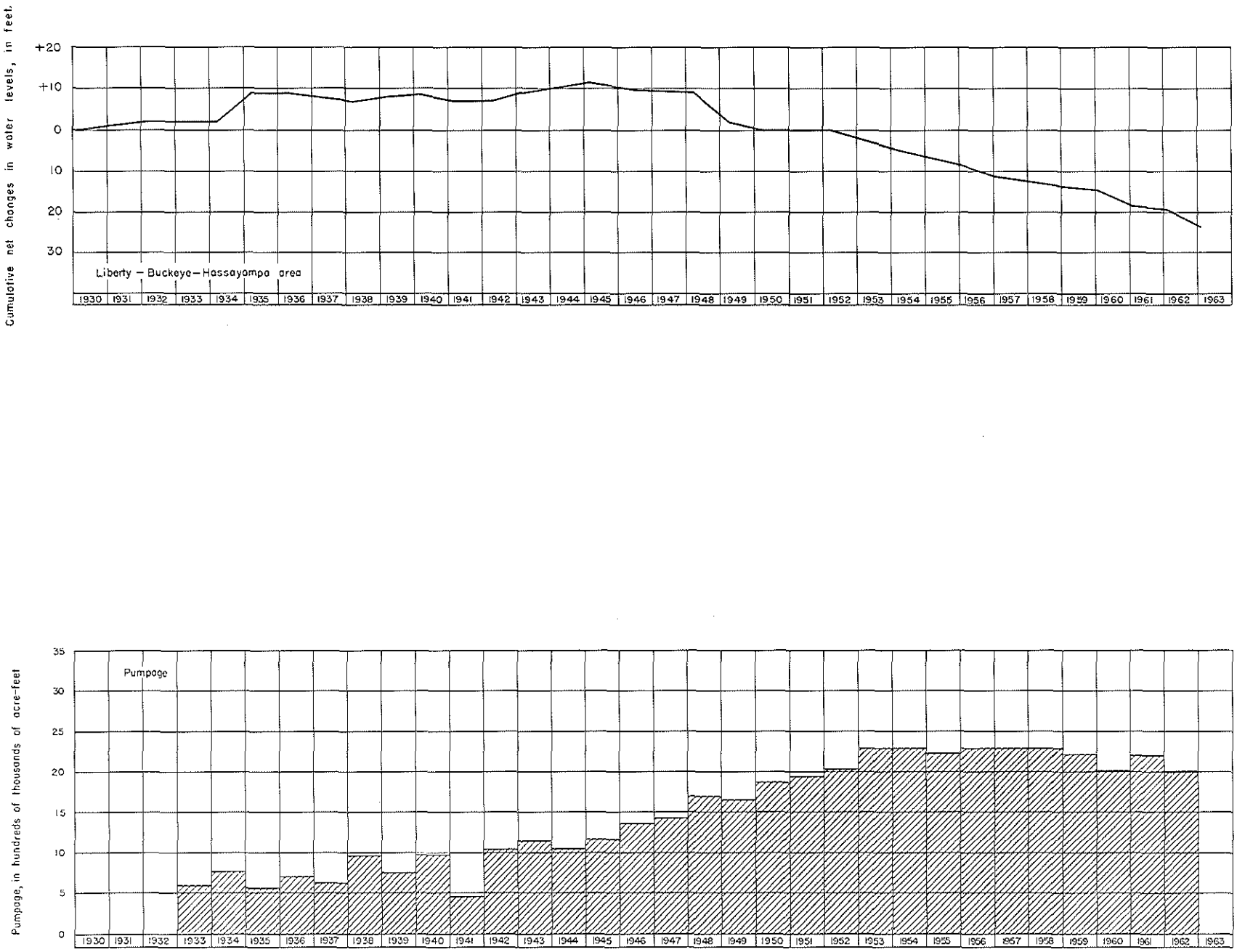

Figure 33.--Cumulative net changes in water levels in the Liberty-Buckeye-Hassayampa area and total annual pumpage in the Salt River Valley.

The water level in well (D-2-10)8 (fig. 40) 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 1953, possibly because of irrigation pumping 8 miles to the west.

As in previous years, the decline of the water table was slight in the southwestern part of the area 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. 40) about 5 miles southwest of Higley since the spring of 1953 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 changes.

In the spring of 1963 water levels in observation wells in the cultivated parts of the Queen Creek-Higley-Gilbert-Magma area ranged from about 465 feet below land surface in a well south of Granite Reef Dam to 55 feet in an abandoned irrigation well about 7 miles southwest of Higley. The depths to water below land surface near Magma were about 340 feet, near Higley about 165 feet, and near Queen Creek about 315 feet.

Tempe-Mesa-Chandler area. --In the period spring 1962 to spring 1963 water-level changes in the Tempe-Mesa-Chandler area ranged from a rise of less than a foot to a decline of 8 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. 36).

During the 5-year period spring 1958 to spring 1963 the water table declined more than 60 feet east of Mesa and about 20 feet in Tempe (fig. 35). 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 1963 the depth to water below land surface was about 315 feet northeast of Mesa, about 155 feet near Chandler, 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. 36) shows the downward trend of water levels in the area between Tempe and Mesa.

Phoenix-Glendale-Tolleson-Deer Valley area. --During the period spring 1962 to spring 1963 water-level changes ranged from rises of about 9 feet to declines of about 19 feet. The declines were greatest in Deer Valley. Although much acreage in Deer Valley has been converted from agricultural to residential use, the water levels continued to decline. The rate of decline of the water level in well (A-3-2)2 (fig. 41) was less in the period 1962 to 1963 than previously. This, in part, may be due to the decrease in pumping in this part of the area. 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. 37) 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

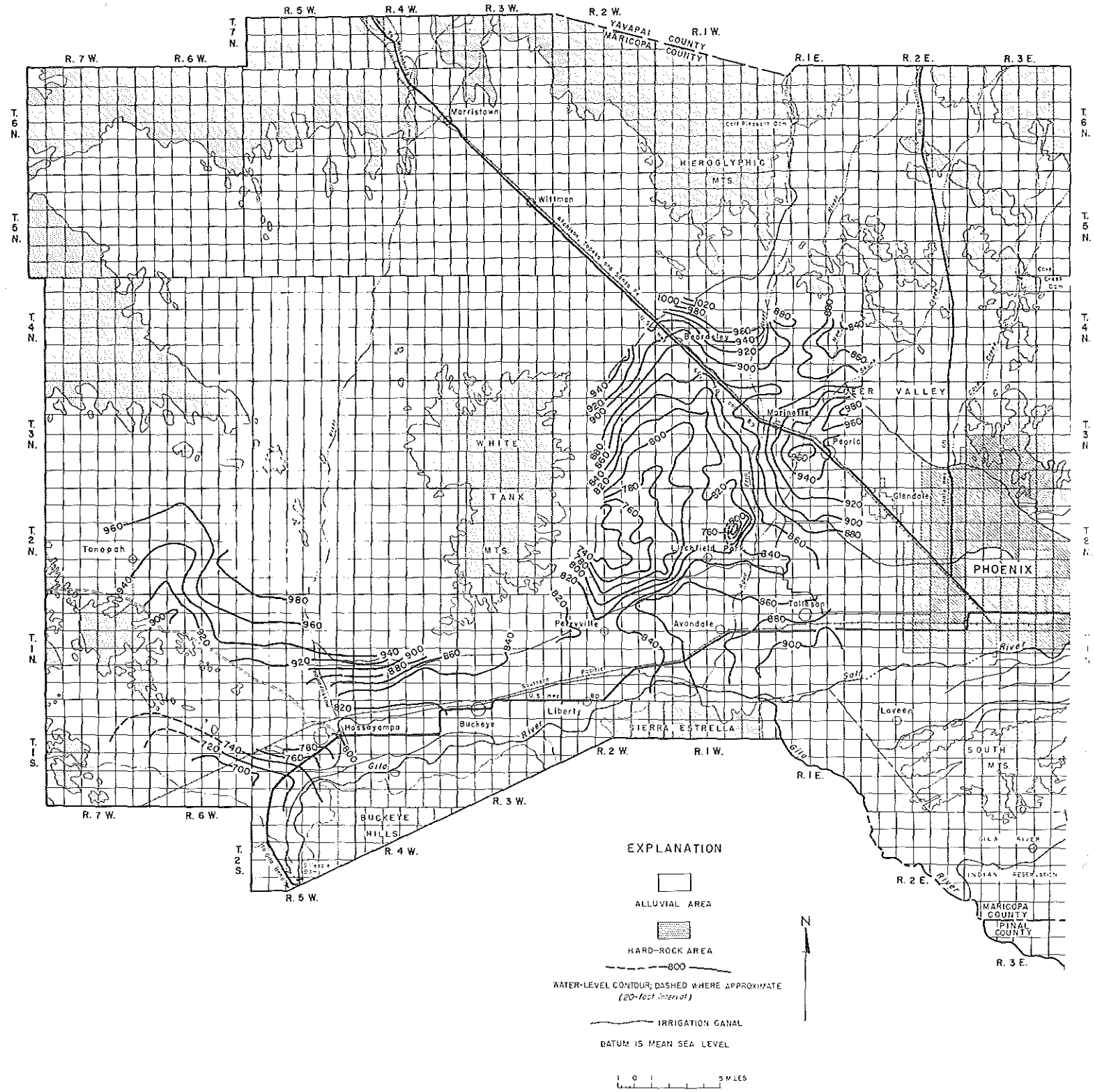

Figure 39.-- Map of western part of Salt River Valley, Maricopa County, Ariz., showing altitude of the water level, spring 1963.

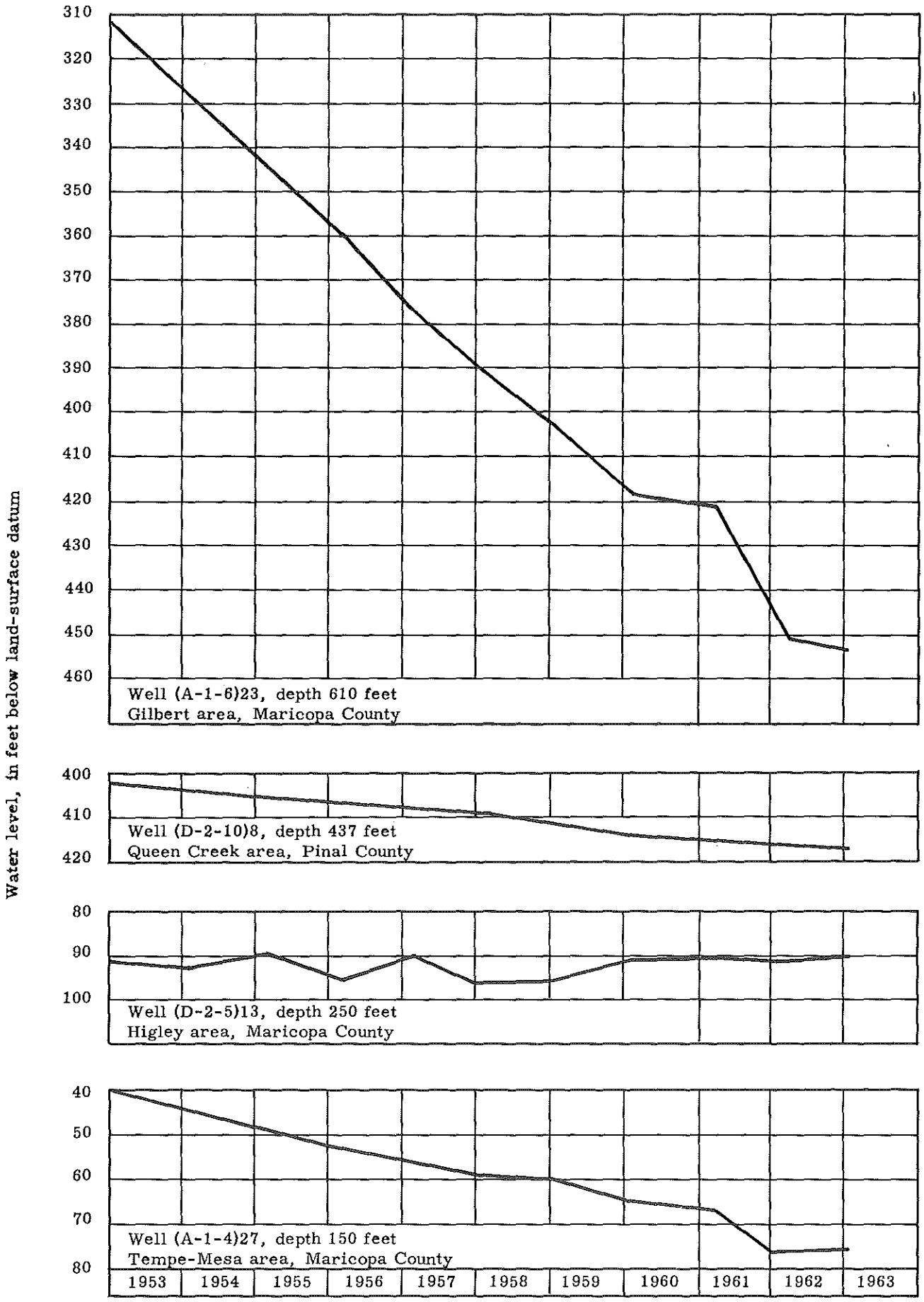

Figure 40.--Water levels in selected wells in Queen Creek-Higley-Gilbert-Magma and Tempe-Mesa areas, Salt River Valley.

water levels rose in some wells in north Phoenix where they are affected by seepage from the Arizona Canal.

In the 5-year period spring 1958 to spring 1963 water-level declines ranged from almost no change to declines of more than 40 feet in Deer Valley (fig. 35). As in previous periods, the largest declines were in Deer Valley near Skunk Creek and New River. Along the mountains to the north and south of Phoenix the water-level declines were small because of canal seepage and the 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 1963 depth to water below land surface was about 50 feet in central Phoenix, 210 feet in Glendale, 300 to 450 feet in Deer Valley, and about 155 feet in Tolleson. In north Phoenix, adjacent to the Arizona Canal, water levels were less thean 20 feet below land surface.

Paradise Valley area.--Water-level changes were minor in the Paradise Valley area in the period spring 1962 to spring 1963. 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 in the period spring 1962 to spring 1963.

For the 5-year period spring 1958 to spring 1963 water-level declines in the area ranged from almost no change to more than 20 feet (fig. 35). In the spring of 1963 measured depths to water in Paradise Valley ranged from about 440 to about 170 feet below land surface.

Litchfield Park-Beardsley-Marinette area.--Ground water constitutes the major source of water available for agriculture in the Litchfield Park-Beardsley-Marinette area. Figure 37 shows the cumulative net changes in the water levels and indicates the effect of increased pumping beginning in the early 1940's. The hydrographs for wells (B-3-1)22 (fig. 41) and (B-4-1)9 (fig. 42) show the effects of pumping in this area during the last 10 years. The water-level contour map (fig. 39) shows two prominent depressions, which are the result of concentrated pumping. One is north of Peoria in the northeast corner of the area, and the other is northwest of Litchfield Park along the front of the White Tank Mountains.

During the 5-year period spring 1958 to spring 1963 water-level declines ranged from more than 60 feet in the northern and western parts of the area to less than 20 feet in the southern part of the area (fig. 35). The maximum declines were in the same areas where the water-level contour map (fig. 39) shows depressions. In the spring of 1963 the depth to water in the northeastern part of the area was about 390 feet below land surface; along the northeast edge of the White Tank Mountains the depth to water was more than 438 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 1963 the minimum depth to water was about 150 feet in an irrigation well along the canal southwest of Litchfield Park. Near Litchfield Park the depth to water ranged from about 150 to 330 feet below land surface; near Marinette the water level was about 315 feet, and south of Beardsley about 400 feet below land surface.

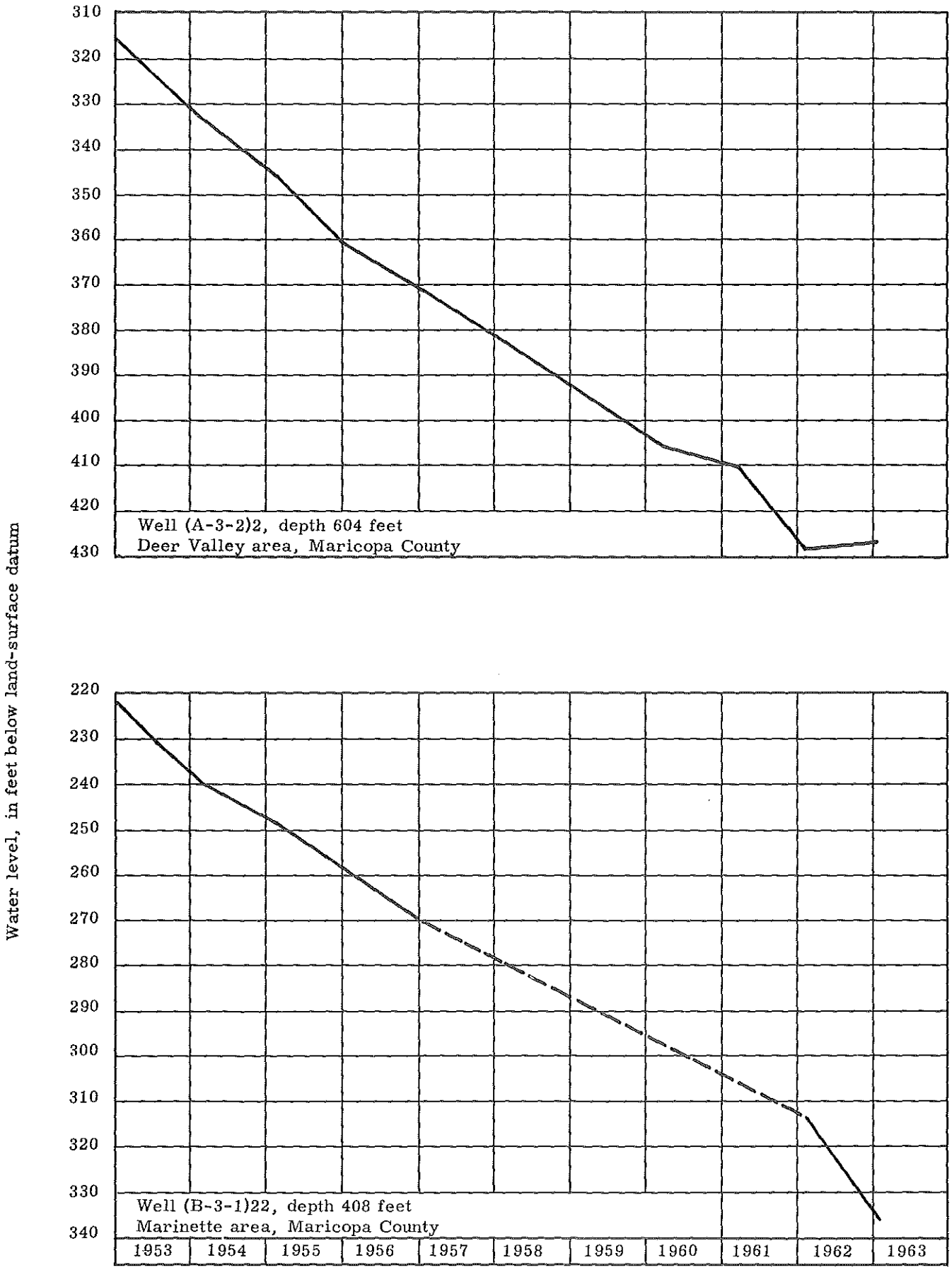

Figure 41.--Water levels in selected wells in Deer Valley and Marinette areas, Salt River Valley.

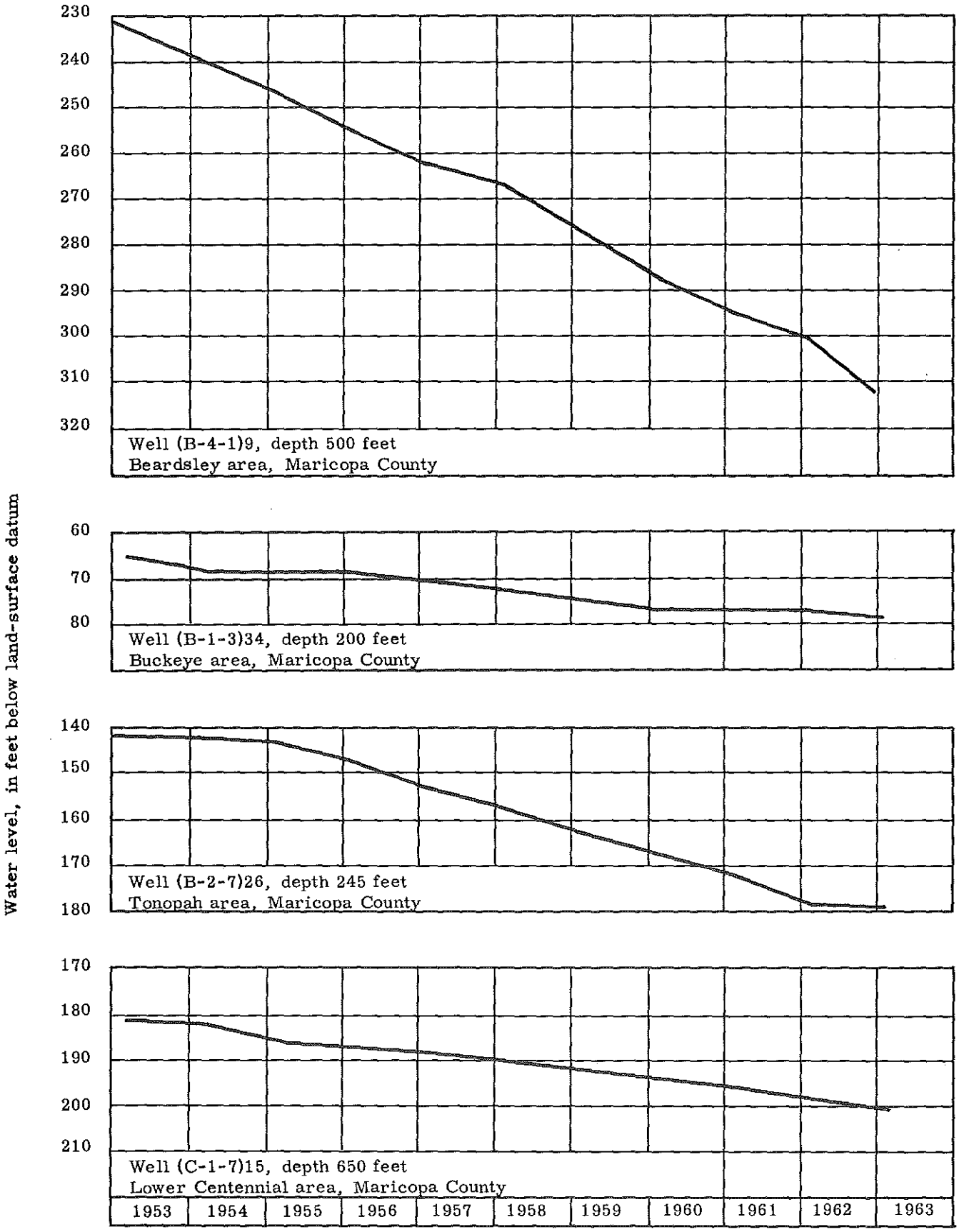

Figure 42.--Water levels in selected wells in the Beardsley, Buckeye, Tonopah, and lower Centennial areas, Salt River Valley.

Liberty-Buckeye-Hassayampa area. --Water-level changes in this area from spring 1962 to spring 1963 ranged from a rise of about a foot to a decline of more than 7 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. 38). 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-1-3)34 (fig. 42) shows the typical water-level trend for this area. During the 5-year period spring 1958 to spring 1963 water levels in the Liberty-Buckeye-Hassayampa area declined slightly and most of the declines were less than 20 feet (fig. 35). The water levels in the area west of Buckeye generally declined less than 15 feet, but near Perryville water levels declined more than 20 feet. In the spring of 1963 the depth to water below land surface in the irrigation wells in the area ranged from about 30 feet southwest of Buckeye to 217 feet north of Perryville.

The depth to water at Hassayampa is less than 50 feet below 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 generally less than 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. The withdrawal of ground water in this part of the area apparently has created a depression in the surface of the water table and some ground water moves toward the depression (fig. 39). During the period spring 1962 to spring 1963 the water levels in the area generally continued to decline; the greatest declines were near Tonopah. The hydrograph for well (B-2-7)26 (fig. 42) shows the changes in water level in a well before and after irrigation development in a typical alluvial basin in southern Arizona.

During the 5-year period spring 1958 to spring 1963 water-level declines within the area ranged from less than a foot to about 30 feet. Water levels in the cultivated areas surrounding Tonopah declined more than 20 feet (fig. 35). In the spring of 1963 water levels in the area ranged from about 18 feet below land surface in an abandoned well near the Hassayampa River to 243 feet northeast of Tonopah.

Lower Centennial area. --Water-level changes in the lower Centennial area during the period spring 1962 to spring 1963 ranged from slight rises to declines of about 4 feet. In the center of the area there is a prominent depression in the surface of the water table (fig. 39) and ground water moving south from Hassayampa appears to move toward this depression. Well (C-1-7)15 is on the western edge of this depression and the hydrograph for this well (fig. 42) shows the decline that has occurred in this well since 1953.

During the period spring 1958 to spring 1963 water-level declines within the area ranged from about 3 feet to more than 30 feet; however, data are not sufficient to plot a 20-foot-decline contour. In the spring of 1963 depths to water in the area ranged from about 27 feet below land surface near the junction of Centennial Wash and the Gila River to about 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. 12, 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 ephemeral 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 spring of 1963 most of the wells were pumping and adequate water-level decline data were not obtained. The hydrograph of well (C-2-2)25 (fig. 43) indicates that the downward trend of the water levels is continuing. The maximum depth to water measured in the spring of 1963 was 400 feet below land surface in a well a mile south of Mobile.

Gila Bend Area

By

R. S. Stulik

The Gila Bend area (fig. 12, 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 as a result of the 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 were in the northeastern part of the

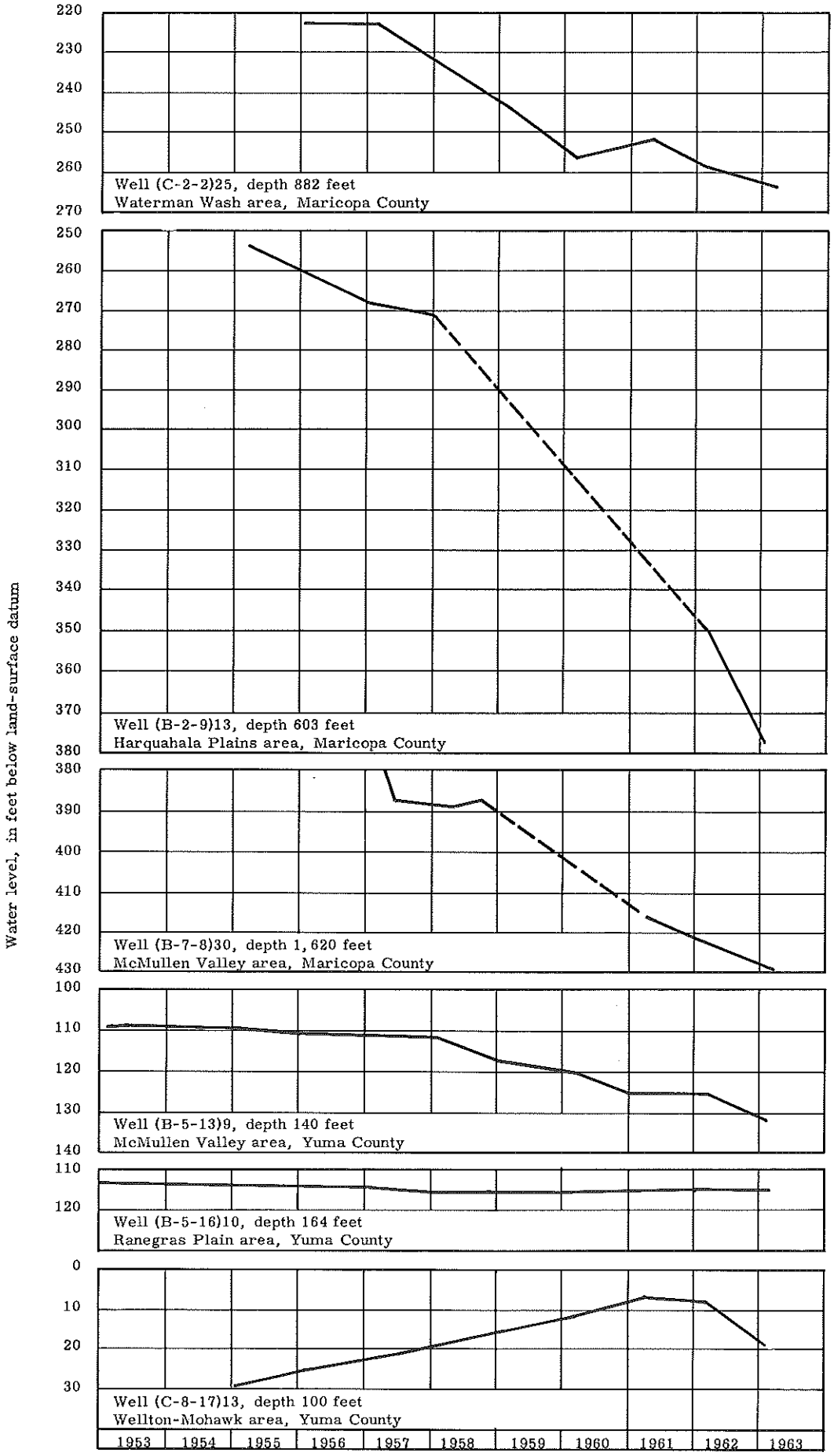

Figure 43.--Water levels in selected wells in several areas in the Basin and Range lowlands province.

Gila Bend basin, known as Rainbow Valley.

Rainbow Valley trends southwestward and is between the Buckeye Hills and the northern edge of the Maricopa Mountains. The main wash in the valley drains into the Gila River about 4½ 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 changes in the Rainbow Valley area during the period spring 1962 to spring 1963 ranged from a rise of less than a foot to a decline of less than a foot. Pumping in the area made it difficult to obtain adequate data.

In the western part of the Gila Bend basin water-level changes during the period spring 1962 to spring 1963 ranged from a rise of about 2 feet to a decline of about 3 feet.

Harquahala Plains Area

By

R. S. Stulik

The Harquahala Plains area (fig. 12, 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 1963 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 well yields 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 1963 measurements in several wells in the center of the cultivated area indicated average yearly declines of more than 20 feet. The hydrograph for well (B-2-9)13 (fig. 43) shows the decline in an irrigation well in the cultivated area.

In the spring of 1963 measured depths to water ranged from about 31 feet below land surface in the extreme southeast to about 380 feet in the center of the cultivated area.

McMullen Valley Area

By

R. S. Stulik

The McMullen Valley area (fig. 12, 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 more recent development are near the towns of Wenden and Aguila.

During the period spring 1962 to spring 1963 measured water-level changes near Aguila ranged from no change east of Aguila to a decline of about 5 feet north of Aguila. Both of these wells are on the fringe of the cultivated area and, therefore, are not indicative of the decline that may have taken place within the pumped area. The water levels in several irrigation wells within the cultivated area declined as much as 35 feet from spring 1959 to spring 1963. The hydrograph of well (B-7-8)30 (fig. 43) shows that the water level in this well has declined about 50 feet since the spring of 1957.

During the period spring 1962 to spring 1963 water-level changes near Salome and Wenden ranged from a rise of about a foot to a decline of about 8 feet south of Salome. The hydrograph of well (B-5-13)9 (fig. 43) shows the water-level changes prior to and after development of ground-water supplies for irrigation. This part of the McMullen Valley is not developed as extensively as the Aguila area and water levels are nearer the land surface. Depths to water below land surface in McMullen Valley during the spring of 1963 ranged from 103 feet south of Salome to 482 feet near Aguila.

Palomas Plain Area

By

R. S. Stulik

Palomas Plain (fig. 12, 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 is in Yuma and Maricopa Counties, but most of the agricultural development is in Yuma County.

During the period spring 1962 to spring 1963 water-level changes in wells in and near the Palomas Plain ranged from a rise of about 4 feet north of Hyder to a decline of about 3 feet several miles southwest of Hyder. The majority of measurements in the area showed little change in water levels. In the spring of 1963 the depth to water below land surface in the irrigated areas ranged from 21 feet along the Gila River to about 265 feet north of Hyder.

Ranegras Plain Area

By

R. S. Stulik

The Ranegras Plain area (fig. 12, 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 1962 to spring 1963 water-level changes in the Ranegras Plain area ranged from a rise of about 8 feet to a decline of about a foot. The hydrograph for well (B-5-16)10 (fig. 43) shows water-level changes 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 1963 ranged from about 33 to 228 feet below land surface.

Wellton-Mohawk Area

By

R. S. Stulik

The Wellton-Mohawk area (fig. 12, No. 19) is nearly a flat desert plain that extends from Dome upstream along the Gila River for a distance of 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 changes during the period spring 1962 to spring 1963 ranged from a rise of about 4 feet to a decline of about 11 feet. The water level in well (C-8-17)13 (fig. 43) rose more than 20 feet during the period spring 1955 to spring 1962; however, the water level in this well declined more than 12 feet from spring 1961 to spring 1963. The depth to water below land surface in the Wellton-Mohawk area in the spring of 1963 ranged from about 11 feet in a well northeast of Wellton to about 75 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. 12, No. 20) is that part of the Gila River flood plain south of the Gila River and bounded on the south by an extensive terrace known as the Yuma Mesa. Ground water is the principal source of irrigation water. Prior to the early part of 1961, water levels in the South Gila Valley were rising as a result of recharge from irrigation on Yuma Mesa to the south. This rise has been halted and the water table is now being controlled, largely, by nine drainage wells installed by the U.S. Bureau of Reclamation during the winter and spring of 1961. From spring 1962 to spring 1963 water levels in some of the wells declined slightly---about half a foot. However, little overall change in water levels in the South Gila Valley has been observed. The water level in well (C-8-21)21 (fig. 44) declined less than half a foot from spring 1962 to spring 1963. Depth to water below land surface in most of the area was about 17 feet in spring 1963.

Yuma Mesa (fig. 12, 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 boundary between the United States and Mexico. In this area the principal source of water for irrigation is the Colorado River. A small quantity of ground water is used and the use is expected to increase as more wells come into production, particularly on the outer fringes of the area. The water levels on the irrigated parts of Yuma Mesa rose about 2 feet from spring 1962 to spring 1963. In 1962 the water levels in this area started to rise in May and reached maximum levels during September and October. This period of rise coincides with maximum use of Colorado River water for the irrigation of extensive citrus groves. The water level in well (C-9-23)31 (fig. 44) shows this trend. Along the unirrigated outer margin of the Mesa, water levels changed but little. The depth to water below land surface on Yuma Mesa in the spring of 1963 ranged from about 38 feet in the irrigated parts of the Mesa to about 145 feet on the outer, undeveloped parts of the Mesa.

Yuma Valley (fig. 12, No. 20) is that part of the Colorado River flood plain bounded on the north and west by the Colorado River, on the south by the International Boundary, and on the east by Yuma Mesa. The Colorado River is the principal source of irrigation water in Yuma Valley. However, adjacent

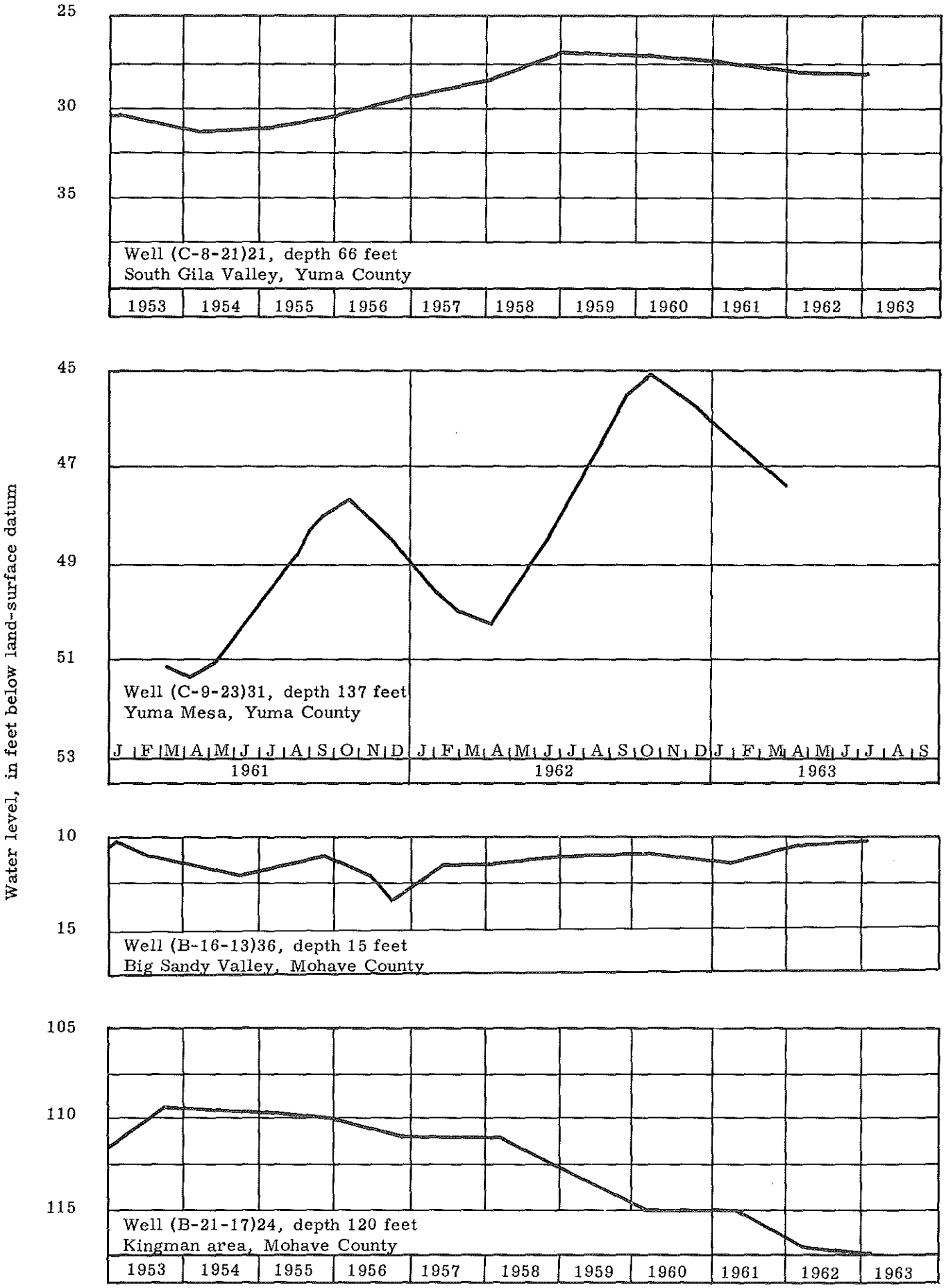

Figure 44.--Water levels in selected wells in several areas in Yuma and Mohave Counties.

to the Colorado River from the city of Yuma south to the International Boundary, significant amounts of ground water are used for irrigation. In most of Yuma Valley water levels are controlled largely by the drainage system and consequently changed very little from spring 1962 to spring 1963. However, in the center of Yuma Valley, which is irrigated with Colorado River water, water levels rose about half a foot. In wells adjacent to the Colorado River in the area irrigated by ground water, water levels are lowest in August and September; they start to rise in October and reach a peak in December and January. 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. Depth to water below land surface in Yuma Valley in spring 1963 ranged from 10½ to 18 feet.

Big Sandy Valley

By

R. S. Stulik

The Big Sandy Valley (fig. 12, 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 deposits of possible lake origin, 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 plain of the Big Sandy River, and the wells are shallow and readily affected by recharge from the river. The fine-grained deposits seem to contain or yield very little water, and wells drilled into these beds usually are unsatisfactory. The main sources of ground water other than the alluvium of the flood plain 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 changes in wells in the flood plain of the Big Sandy River during the period spring 1962 to spring 1963 ranged from a rise of about 14 feet to a decline of about 13 feet. The hydrograph of well (B-16-13)36 (fig. 44) shows water-level changes typical for this part of the area. The water level in this well declined about a foot during the 10-year period spring 1953 to spring 1963. Depth to water below land surface ranged from 11 feet near Wickieup to about 400 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. 12, 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 27 miles long and averages about 6 miles in width. Most of the area is 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 changes near Kingman ranged from a rise of about 2 feet to a decline of about 3 feet during the period spring 1962 to spring 1963. The water level in well (B-21-17)24 (fig. 44) indicates the trend in this area. During the period spring 1962 to spring 1963 declines ranged from less than a foot to about 6 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 land surface in one of these wells was about 145 feet in the spring of 1963. The water level in this well did not change appreciably during the 10-year period spring 1953 to spring 1963.

Colorado River Area South of Davis Dam

By

P. E. Dennis

Use of ground water in the Colorado River area south of Davis Dam (fig. 12, No. 23), extending from Bullhead City to Topock, is mostly for irrigation of crops on the flood plain of the Colorado River. Some water is also used for housing developments chiefly on the gravel-capped terraces about 75 to 150 feet above the river.

The crops grown on the flood plain are alfalfa, sorghum, barley, cotton, and vegetables; about 5,000 acres was cultivated in 1962. Some irrigation water is pumped from the river but most of it is pumped from wells. Most of the wells are from 100 to 150 feet deep, and the larger ones yield 2,000 to 3,000 gpm. Water levels were measured by the U.S. Geological Survey in 1953 in most of the existing irrigation wells. Remeasurement of water levels in some of these wells in the fall of 1962 showed a decline of from 2 to 6 feet in wells

nearest the river and little or no decline or even slight rises in wells near the edge of the flood plain and farthest removed from the river. The explanation probably is that the average water level in the river is lower than it was in 1953, and the wells near the river have drained down to the lower discharge level. No regional lowering of water levels as a result of present pumping was evident.

A large number of subdivisions for housing developments have been laid out, especially on the terraces overlooking the river flood plain. Wells have been drilled in only a few of the subdivisions, and even fewer wells were present on the terraces in 1953. In the few wells where comparative measurements could be made there had been a decline of from 2 to 6 feet during the 10-year period spring 1953 to spring 1963.

Plateau Uplands Province

By

Natalie D. White

Development of the ground-water resources for irrigation or other purposes in the Plateau uplands province is comparatively small, and no sustained declines of the water levels are evident at the present time. Only about 30,000 acres of land was cultivated in the province in 1962. Some recent development in a few areas is causing an increase in the use of ground water. These areas and types of development include: a small increase in agricultural development in the Snowflake area and near Tuba City, a new pulp mill at Snowflake, and an increase in population in the Flagstaff area. The effects of these increases in pumping of ground water are discussed in the following paragraphs. Because development in the Plateau uplands is not concentrated in particular areas, the ground-water conditions in this province are discussed by counties.

Apache County

By

Maurice E. Cooley

Ground water in Apache County (fig. 12) is withdrawn mainly from the Coconino Sandstone and Kaibab Limestone in the central part of the county between the Petrified Forest National Monument and Lyman Reservoir; from lavas, cinders, and gravelly alluvial sediments in the White Mountains region of the southern part of the county; and from the Navajo Sandstone near Chinle Wash and the De Chelly Sandstone on the Defiance Plateau in the northern part of the county. The ground water generally occurs under artesian conditions except on the Defiance Plateau, in the White Mountains, and in the flood-plain alluvium along the Little Colorado River, Rio Puerco, and some of the larger washes.

Most wells in Apache County are utilized for domestic and stock purposes and usually produce from 5 to 50 gpm. Many of these wells tap deeply buried aquifers, and the depths to water may be as much as 1,000 feet. Most water levels, however, are less than 500 feet below land surface. Irrigation wells completed in the Coconino Sandstone yield from 800 to 2,000 gpm, and many of these wells flow or show a strong artesian rise. A few wells in the alluvium near Red Lake yield 100 to 200 gpm, and possibly more than 300 to 400 gpm may be obtained from the alluvium along Chinle Wash near Chinle and along Pueblo Colorado Wash near Sunrise Trading Post.

As yet, there has been no long-term decline of the water levels in Apache County, although there are seasonal declines. The water level in many irrigation wells declines during the summer due to heavy pumping but recovers during the winter. The hydrograph (fig. 45) of the water level in an observation well equipped with a recorder---well (A-14-26)18, completed in the Coconino Sandstone---shows this seasonal change. Well (A-13-28)27 (fig. 45), completed in the Coconino Sandstone, was flowing in spring 1963 and apparently has shown little change during the last 4 years.

Navajo County

By

P. W. Johnson

Navajo County (fig. 12) is a long, narrow, rectangular-shaped area about 200 miles long and about 50 miles wide in northeastern and east-central Arizona. The area includes about 6,400,000 acres, of which about 67 percent belongs to the Indians, 10 percent is Federally owned or controlled, 5 percent is State owned, and 18 percent is privately owned. Part of the Navajo and Hopi Indian Reservations occupies more than 80 percent of the Indian land in Navajo County, or more than 3,500,000 acres. This land extends from the Arizona-Utah boundary on the north southward for more than 125 miles. The Fort Apache Indian Reservation accounts for the remaining Indian land, or about 700,000 acres in the extreme southern part of the county. Just north of the Apache Indian Reservation, a 20-mile wide strip of land extends across the county and is part of the Sitgreaves National Forest. The private and State land forms a checkerboard pattern throughout the remainder of the area between the forest land and the Navajo-Hopi land. There are also small parcels of private land within the boundaries of the forest land.

Arizona is divided into three physiographic and hydrologic provinces; most of Navajo County (about 80 percent) is in the Plateau uplands, and the remainder of the county (20 percent) is in the Central highlands. The Plateau uplands province is characterized by gently dipping sequences of sedimentary formations containing several usually well-defined aquifers. The Central highlands province---a rugged mountainous region of high precipitation, high runoff, and limited ground-water supplies---is a transitional zone between the Plateau uplands and the Basin and Range lowlands provinces of the southern part of the State.

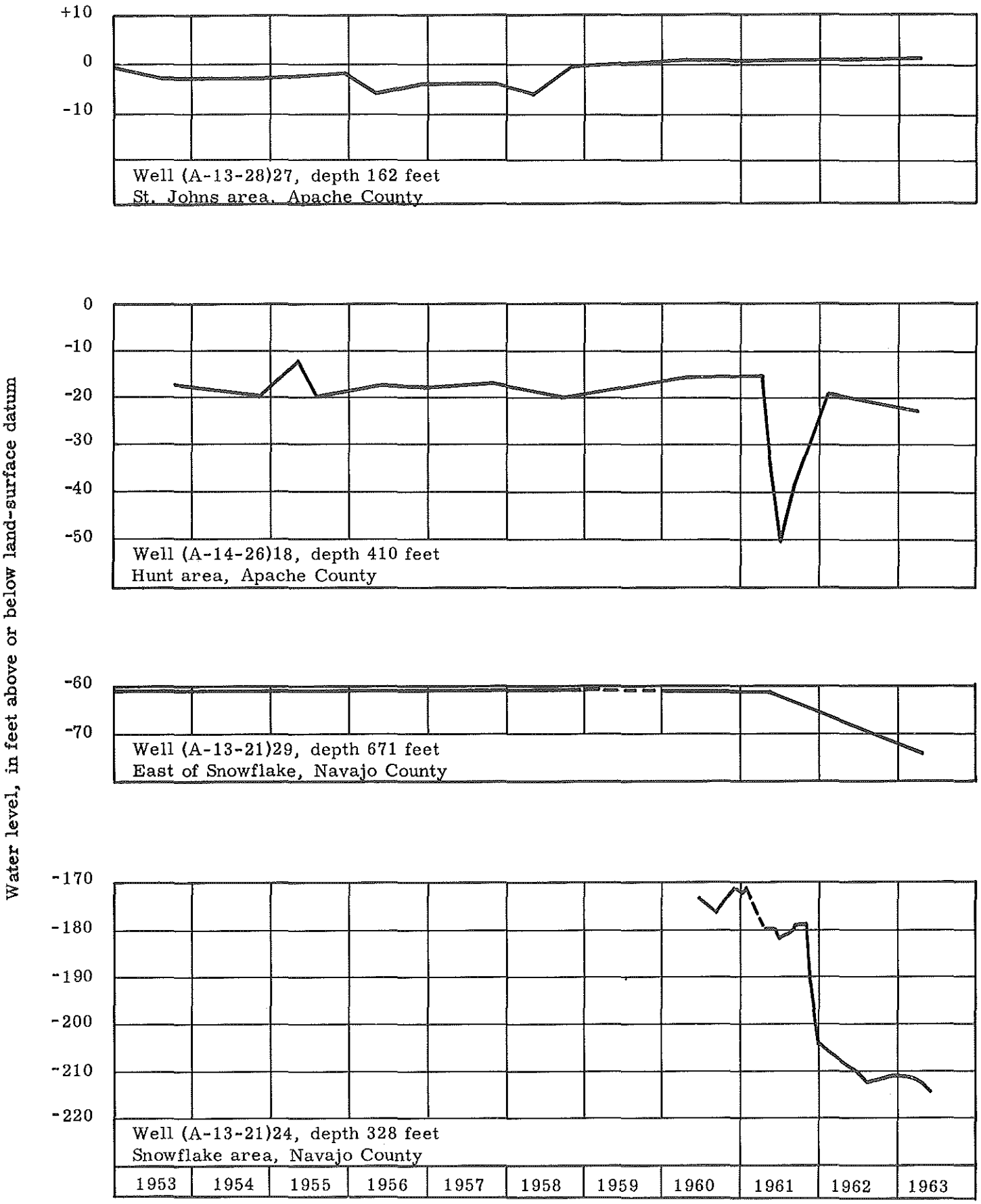

Figure 45.--Water levels in selected wells in the Plateau uplands province.

The development of the Indian lands includes some livestock, mining, and a little agriculture, but the bulk of the development of the county---consisting of cattle, lumber, agriculture, industry, and tourist trade---is centered in the area between the Navajo-Hopi and Apache Indian lands. The cities of Holbrook, Winslow, Joseph City, Snowflake, and Show Low are within this area.

The altitude of the land surface in Navajo County ranges from about 4,500 to 7,000 feet above mean sea level. The precipitation for 1962 was, for the most part, below normal and ranged from 10 to 17 inches in the southern part of the county along the Mogollon Rim, from 5 to 8 inches in the central part of the county, and from 8 to 12 inches in the northern part of the Navajo country.

The Coconino Sandstone is the principal aquifer yielding water to wells in the southern part of the county south of Winslow and Holbrook. In the extreme northern part of Navajo County the Navajo Sandstone furnishes limited quantities of water to wells, and in Black Mesa basin in the central and southern parts of the Navajo-Hopi land the Dakota Sandstone and Toreva Formation are the important aquifers. Some water is obtained at shallow depths from the alluvium along the Little Colorado River and Rio Puerco and their tributaries. Shallow wells obtain water from perched supplies in the volcanic rocks along and near the Mogollon Rim. Elsewhere, ground water is discharged by springs from volcanic rocks and associated sediments, either at the contact with underlying impermeable material or along fault or fracture zones. Below the Mogollon Rim escarpment many of the sedimentary formations are exposed, and springs discharge ground water at favorable stratigraphic or structural points.

The Coconino Sandstone has a wide areal extent and is present at the surface or is in the subsurface throughout most of northern Arizona. It is the principal aquifer south and west of the Little Colorado River and furnishes water to all irrigation and most domestic and stock wells in this area. The Coconino Sandstone yields water to wells in amounts ranging from a few to more than 2,000 gpm, depending on the location of the wells with respect to the recharge areas, to structure (faulting or fractures), and to the degree of cementation. Water levels in the Coconino Sandstone range from a few feet to more than 500 feet below land surface, but locally, where the aquifer is confined, artesian pressures are sufficient to cause the water to flow at the surface.

The Black Mesa basin is the structural low for the Plateau uplands of northeastern Arizona and is centered in Navajo-Hopi land in Navajo County. The dip of the strata is toward the basin, and thus the Coconino Sandstone in the southern part of the area dips northward and in Black Mesa basin it is in the subsurface at depths of 1,000 to about 4,000 feet. Here, the Coconino is overlain by a sequence of younger rocks, of which the Navajo Sandstone, Dakota Sandstone, and Toreva Formation and locally other formations are the best aquifers and supply most of the water to wells on the reservations. Yields from wells in these formations are generally small---5 to 25 gpm---and water levels are from a few feet to more than 500 feet below land surface. Locally, where the aquifer is confined, artesian conditions exist and pressures may be sufficient to cause the water to flow.

Ground water in Navajo County ranges in quality from good to poor, although

locally there are areas where the quality of the water exceeds this classification at either end of the range. In the recharge area to the south near the Mogollon Rim the water in the Coconino is excellent—containing less than 200 ppm total dissolved solids—while in the area north of the Little Colorado River the water in the Coconino may exceed 30,000 ppm total dissolved solids. The Navajo and Dakota Sandstones yield water of acceptable quality. Locally, high concentrations of fluoride make some of the water in the Dakota Sandstone unsuitable for drinking by young children.

A wood pulp mill about 12 miles west of Snowflake has been producing paper products since 1961 and presently is reported to be operating at full capacity. The amount of water used daily is about 10 million gallons, which is withdrawn by wells from the Coconino Sandstone. The well field is about 4 miles west of Snowflake. A recorder has been installed on one of the test wells in the well field and continuous records have been kept since June 1960. The trend of the water level in the well—(A-13-21)29—under pumping conditions in the well field is shown by the hydrograph (fig. 45). The hydrograph of the water level in well (A-13-21)24 (fig. 45), near the city of Snowflake about 4 miles east of the pulp mill well field, shows a sharp decline in the water level since 1961 when the mill started production. The continual spread of the cone of depression from the pumping well field indicates the withdrawal of ground water in excess of recharge. As additional water is withdrawn from the well field or from additional wells in the area, the cone will spread and deepen, resulting in the further lowering of the water levels.

The development in the Hay Hollow area about 15 miles northeast of Snowflake remains about the same as in previous years. The water in the area is under artesian pressure and the water levels in wells indicate a slight decline, but the data are not sufficient to indicate an overall trend.

Coconino County

By

J. P. Akers

The occurrence of ground water in Coconino County (fig. 12) is closely related to the geologic structure and physiography. The sedimentary formations consist mostly of siltstone, fine-grained sandstone, and limestone. Lava fields dotted with cinder cones cover extensive areas in the southern part of the county and overlie the Kaibab Limestone or erosional remnants of formations younger than the Kaibab. The Kaibab and the lava are exposed in most of the area west of the Little Colorado River and Echo Cliffs. Both these rock units are fractured in the area and they readily absorb rainwater and snowmelt. The absorbed water percolates downward into and even through the Coconino Sandstone. In some areas, mainly east of Flagstaff, this downward movement is stopped by impermeable beds in the Supai Formation, and the water table is within practical reach of water wells. However, in large areas west of Flagstaff the water continues to move downward in fractures associated with faults into formations beyond the practical reach of water wells. Figure 46 shows areas where

ground water is or is not available to water wells.

In general, structural conditions west of a line extending north and south from Flagstaff are unfavorable and those east are favorable for the accumulation of ground water. West of this line the Coconino Sandstone and the Supai Formation---the main aquifers in the county except in the Navajo Indian Reservation and the Paria Plateau---have been elevated and fractured by crustal movements or have been incised completely by erosion, and, for the most part, are drained of water. However, one or two wells a few miles southeast of Fredonia, at least one well on the Coconino Plateau, and a few wells near Bellemont obtain water from the Coconino or Supai. Most of the water entering the ground on the Coconino and Kaibab Plateaus is discharged ultimately from large springs emerging from the Redwall Limestone in canyons tributary to the Grand Canyon. The largest of these springs, Blue Spring in the gorge of the Little Colorado near its junction with the Colorado River, discharges water at a rate of about 220 cfs.

East of Flagstaff and south of the Little Colorado the area is a gently northward-sloping plain cut on the Kaibab and younger rocks. The Coconino Sandstone is exposed only in a few places and it and the underlying Supai Formation contain water. In this area the main structure is a broad slope that plunges northeastward toward the Black Mesa basin. This northeastward dip is reversed at the crest of the Mormon Mountain anticline, which extends 30 miles southeast of a point about 5 miles south of Flagstaff. Ground water on the northeast flank of the anticline and north of the Mogollon Rim moves northeastward; that on the southwest flank moves southwestward.

North of the Little Colorado River and east of Echo Cliffs the strata, in general, dip centripetally toward Black Mesa and Kaiparowits basins. In this area, except perhaps along the northern boundary of the county, the Coconino contains saline water under artesian pressure. In much of this area and on the Paria Plateau the Navajo Sandstone is exposed on the surface and contains fresh water under artesian and water-table conditions. On Black Mesa ground water occurs in the Dakota Sandstone and Toreva and Morrison Formations.

In the Flagstaff area of the San Francisco Plateau ground water is in the Coconino Sandstone at depths more than 600 feet below land surface and in isolated parts of the volcanic rocks and sediments that form the San Francisco volcanic field. Perched bodies of water overlying impermeable formations or residual soils occur sporadically at different horizons in the lava. Water also occurs in alluvium along some of the larger drainages and in glacial deposits on San Francisco Mountain. The glacial deposits supply considerable water to the city of Flagstaff.

In large areas in Coconino County even the small amount of ground water needed for stock is not available. Most wells drilled on the Coconino and Kaibab Plateaus have been dry or have not yielded enough water to be developed. The few wells that were developed commonly yield less than 5 gpm. Ground water does not occur within the practical reach of water wells in most of the area north of Cameron, west of Echo Cliffs, and east of the Colorado River. Probably, most formations within practical reach of water wells in the Kaibab Plateau have been drained of water.

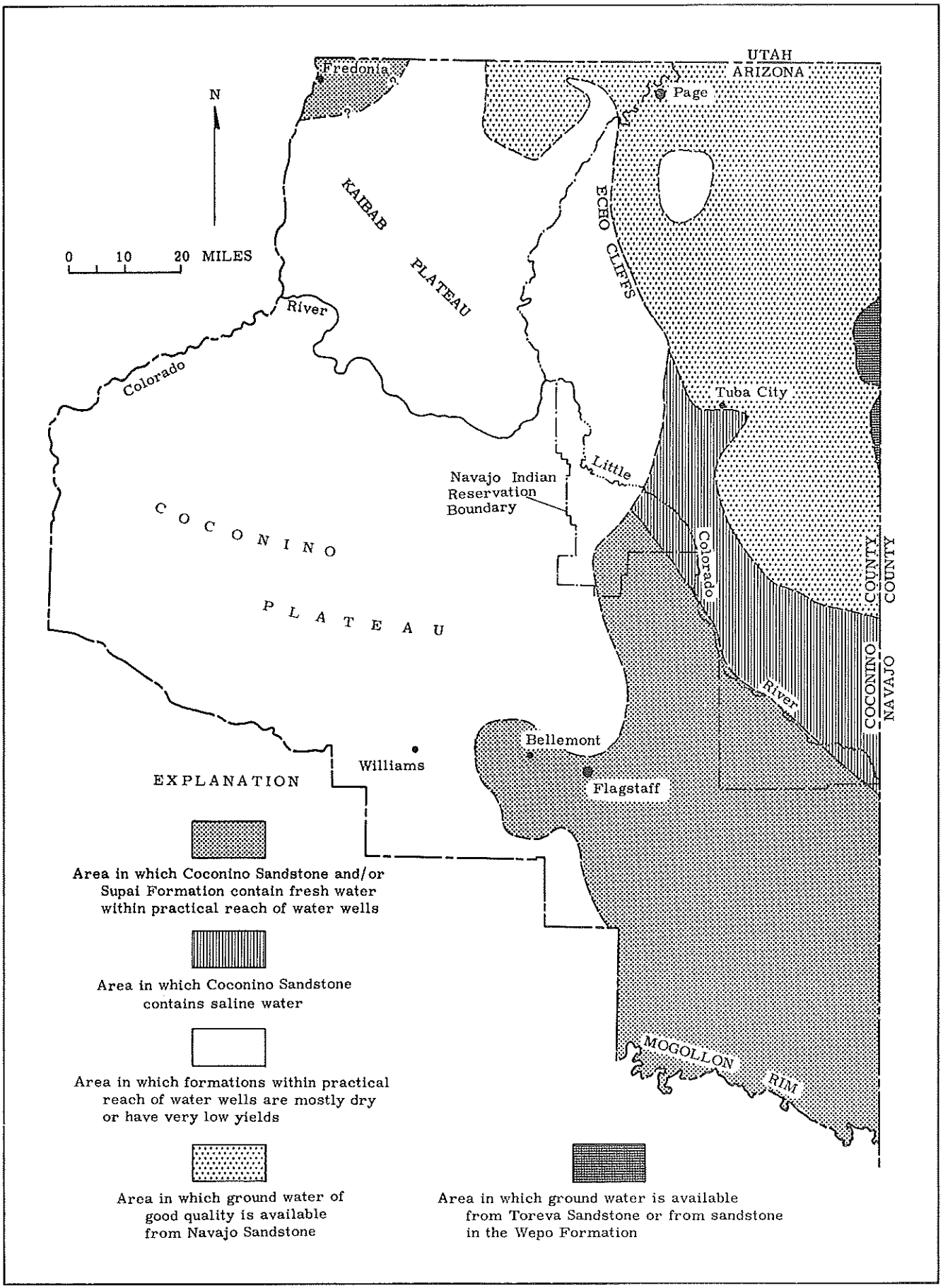

Figure 46. --Map of Coconino County showing generalized areas where ground water of good quality is or is not available within practical reach of water wells.

Little, if any, water is pumped in Coconino County exclusively for irrigation. Most of the ground water pumped is used for stock, domestic, or municipal supplies, but a small amount is used for industry near Page and Tuba City and at Flagstaff. Most stock and domestic wells are pumped at rates of less than 10 gpm.

The Flagstaff municipal water supply is augmented from deep wells which yield from 200 to 500 gpm from the Coconino Sandstone and Supai Formation, and from springs emanating from glacial deposits on San Francisco Mountain. Development of ground water to supply the city of Flagstaff is continuing. Well No. 5 is being drilled currently in the Woody Mountain well field about 6 miles southwest of Flagstaff and work to develop more water from glacial material on San Francisco Mountain continues. A new area was proved when a well was completed recently near the northwest end of Lake Mary about 8 miles southeast of Flagstaff. Pumping tests of this well indicate it will yield about 300 gpm of water from a pumping level of about 1,000 feet. A deep test well is being drilled currently for the city of Williams to explore the possibility of obtaining ground water to augment the water supply of the city.

Water for use in constructing the Glen Canyon Dam is pumped at a rate of as much as 1,300 gpm from individual wells in the Navajo Sandstone. Water for the uranium beneficiation plant near Tuba City is pumped from 4 wells in the Navajo Sandstone, which yield from 50 to 200 gpm each. The water supply for schools and communities in the part of the county within the Navajo Indian Reservation is obtained principally from wells in the Navajo Sandstone, which yield from 5 to 200 gpm.

Records are inadequate to show long-term changes in water levels. However, the water level in a National Park Service well, (A-42-8)36, near several wells pumped heavily for construction water at the Glen Canyon Dam, has lowered more than 10 feet since 1958. The water level in well (A-21-6)35, in the Woody Mountain well field owned by the city of Flagstaff, has changed little since it was drilled in 1954, but wells in this field are idle most of the time. Records of water levels in a shallow well, (A-21-7)5, in the alluvium in Antelope Valley on the north edge of Flagstaff indicate a temporary rise of more than 11 feet during a period of heavy runoff in September 1961.

Central Highlands Province

By

Natalie D. White

The Central highlands province is largely mountainous with only a few small alluvial valleys suitable for agricultural use. About 15,000 acres of land was cultivated in the province in 1962, and most of the cultivated land is in Chino and Verde Valleys. Some surface water from the Verde River is used to irrigate land in part of Verde Valley and for other purposes.

Chino Valley

By

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

In this report Chino Valley (fig. 12, No. 24) 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 the two areas described below. In addition, the city of Prescott, although it is outside the valley as described, pumps a part of its municipal water supply from this area. A few outlying wells pump water for domestic and stock supplies.

Chino Valley artesian area.--This small north-south trending artesian area is about 20 miles north of Prescott in Yavapai County. The small town of Chino Valley on U.S. Highway 89, which traverses the area, is in about the center of the area. The Chino Valley Irrigation District includes a little more than 2,500 acres in the south end of the area. The district obtains a limited and uncertain surface-water supply from storage in the Willow Creek and Watson Lake reservoirs but in some years there is no water available for district use. Pumping lifts in the south end of the area are about 300 feet, and, therefore, the use of pumped water for irrigation is limited to a few hundred acres.

Flowing artesian water was first discovered in 1930 in a well in sec. 3, T. 16 N., R. 2 W. The artesian aquifers are all associated with buried lava flows and may be interbedded with volcanic ash, cinders, and alluvial sediments. The upper confining bed consists of relatively thick-bedded silt and clay, and in some wells an impervious lava flow is reported just before encountering the artesian water. Flowing water is encountered only in the north end of the area because of the sharp drop in land-surface altitude of about 325 feet between the south and north ends of the area. However, the effects of the artesian pressure cause water to rise above the confining layer in most of the deep wells in the area. Water-table conditions are present in the shallow alluvial wells in the irrigated area, and the water levels in these wells rise due to recharge from irrigation water. Outside the irrigated area the water level in the shallow wells, used mostly for domestic and stock purposes, continued to decline. Prior to any pumping in the area the artesian-pressure and water-table surfaces in the wells within the basin formed an almost level surface.

The normal irrigation season begins about April following a winter period of recovery of the water level in the wells. However, during the winter of 1962-63 two large new wells in the extreme north end of the area were flowing most of the time. For the most part, this water was used either to irrigate pasture

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

or to fill a number of manmade lakes in connection with a real-estate subdivision. Use of ground water during this period may have amounted to several thousand acre-feet---an amount sufficient to seriously affect the normal recovery of artesian pressures and water levels in the area.

The accumulative lowering in the artesian area has been comparatively uniform at about 2 feet per year for a period of more than 20 years and similar head losses were expected during 1962-63. However, for the period spring 1962 to spring 1963 there were declines of between 10 and 12 feet in the north end of the artesian area, as shown by well (B-16-2)3 (fig. 47); between 7 and 9 feet in the central part, as shown by well (B-16-2)21 (fig. 47); and between 5 and 7 feet in the south end, as shown by well (B-16-2)34 (fig. 47).

In the area east of Granite Creek the declines in water-table wells reflected the excess withdrawal of water in the area for the past season. The hydrograph for well (B-16-1)14 (fig. 47) shows this decline.

The 1962 crop survey showed that 3,750 acres of land was irrigated within the artesian area; estimated pumpage was about 13,000 acre-feet. Pumping by the city of Prescott was slightly more than 1,900 acre-feet in 1962. Total computed withdrawal of ground water from the artesian basin in 1962 amounted to about 15,000 acre-feet exclusive of the 1962-63 winter withdrawals previously noted for use in filling subdivision lakes north of the area.

Paulden area.--From spring 1962 to spring 1963 water-level declines in the Paulden area of Chino Valley ranged from about half a foot to 4½ feet. Wells are the only source of irrigation water near Paulden, and the hydrograph for well (B-17-2)6 (fig. 47) shows the water-level trend in the area. In the spring of 1963 the water level in this well was 139 feet below land surface; a few miles south of Paulden the water level was only 7 feet below land surface. In the outlying parts of Chino Valley the water level in some wells is as much as 355 feet below land surface.

Verde Valley

By

R. S. Stulik

The Verde Valley (fig. 12, No. 25) 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 are 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. In the Sedona area the principal source of ground water is the Supai Formation.

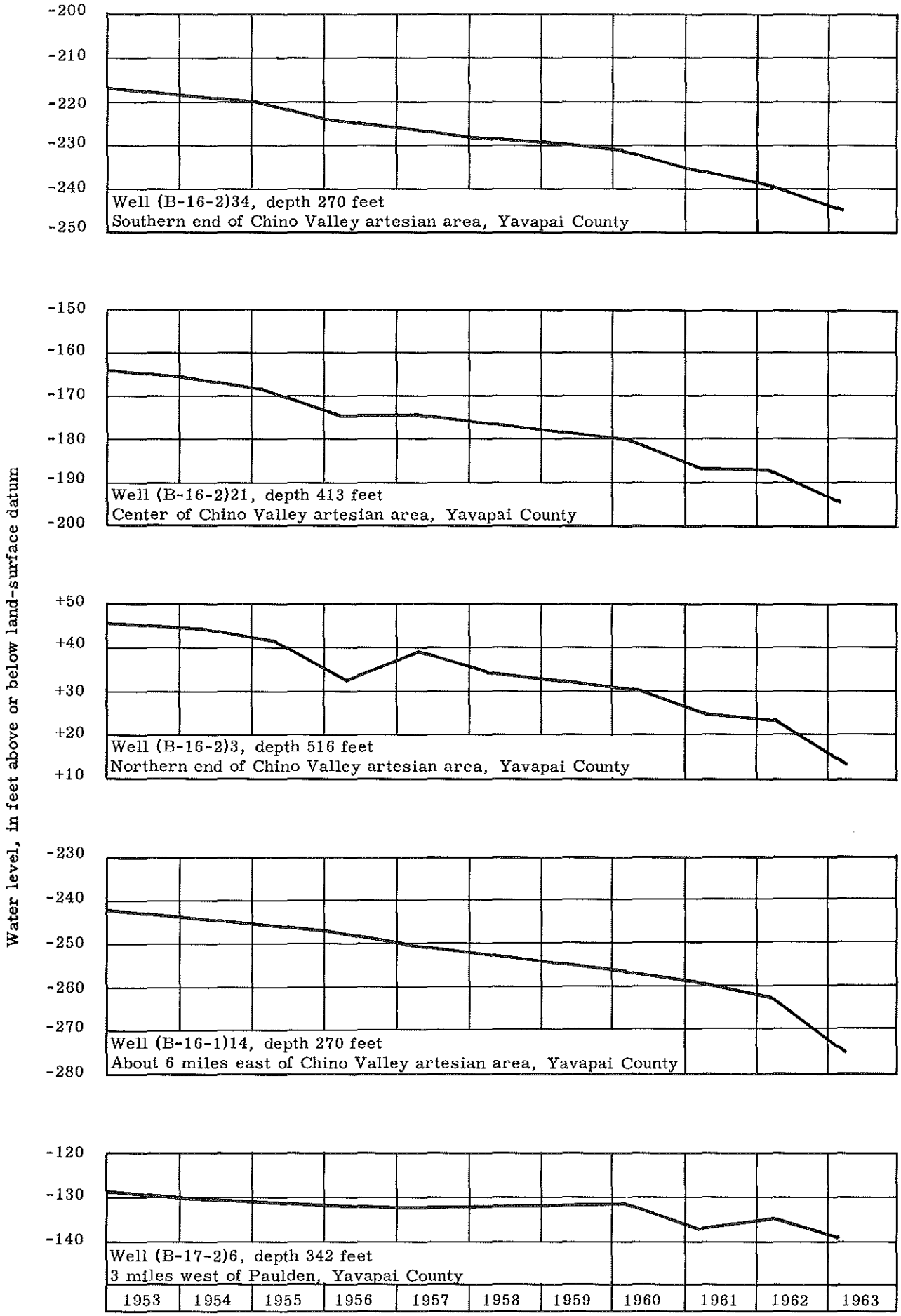

Figure 47.--Water levels in selected wells in Chino Valley.

Clarkdale-Cottonwood-Camp Verde area.--In this area water is used mainly for agricultural, 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 and stream-laid 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 11 irrigation wells in the area. One of the wells is reported to flow at a rate of more than 300 gpm.

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 were about 25 flowing wells in 1960. In the nonflowing wells, depths to water ranged 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 principally 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 1962 to spring 1963 water-level changes 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 1963.

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. The altitude of the water surface in the Supai Formation throughout the area ranges 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. During 1963, it was impossible to obtain additional data.

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. 12) is the fourth smallest county in Arizona, having a total area of about 3,040,000 acres, of which about 58 percent is Federally owned or controlled, 37 percent is land belonging to the Fort Apache Indian Reservation, 4 percent is private land, and 1 percent is State land (Hillman, 1963). The county is almost entirely within the Central highlands province in the east-central part of the State. It is an irregular triangular-shaped area bounded on the north by the Mogollon Rim and Navajo County, on the southeast by the San Carlos and Gila Rivers, and on the southwest by a line from the confluence of the Gila and San Pedro Rivers to Roosevelt Lake where it then jogs slightly west and follows along the crest of the Mazatzal Mountains and westward again along the Verde River and Fossil Creek. The area included within the county is mostly rugged mountainous terrain with altitudes as much as 8,000 feet.

Annually, the area receives from about 12 to more than 24 inches of precipitation and averages about 16 inches. Many of the major perennial streams of the State flow in and through the county and carry surface water to the reservoirs of the Gila and Salt River system. Ground-water supplies, however, are limited and occur as discharge from the numerous springs in the mountains, perched supplies in the crystalline rocks, and as storage in the alluvial deposits along the stream drainages.

Mining represents a major economic resource and copper is the chief mineral. The Globe-Miami district produces almost 10 percent of the total copper production of the State. Lumber and cattle are also important. Roosevelt and San Carlos Lakes and many of the mountain areas and streams afford recreation and tourist attractions, which are also of economic importance. Agriculture does not represent a major contribution to the economy of the county; in fact, Gila County has the lowest cropped acreage of any county in the State---a little more than 1,000 acres in 1962 (Hillman, 1963). Agricultural development is restricted mostly to the flood plains along the tributaries to the Gila and Salt River drainage.

Ground-water levels are measured in wells in and near the city of Globe, in the Dripping Spring Valley, and on the San Carlos Indian Reservation. The wells near the city of Globe are mostly along Pinal Creek or one of its tributaries. In general, the water levels in the wells are shallow and fluctuate in response to surface runoff in the drainage system. Water-level measurements, for the most part, show a slight decline from spring 1962 to spring 1963, although in comparison to the 5-and 10-year records some of the 1963 measurements indicate rises. No overall continual trend is discernible, which is expected in an area where the ground-water---surface-water runoff interrelations are closely allied.

The Dripping Spring Valley is in the southern tip of the county and is between the Pinal and Mescal Mountains on the northeast and the Dripping Spring

Mountains on the southwest. Runoff from the surrounding mountain areas drains southward to the Gila River, and the wells along the valley floor respond to the intermittent surface flow. In general, water levels are shallow, usually less than 100 feet below land surface. For the most part, water-level measurements show a rise from spring 1962 to spring 1963. However, the 5- and 10-year records of measurements do not consistently bear out this trend.

Measurements from a number of wells along Ranch Creek in the San Carlos Indian Reservation indicate a decline in water levels; however, no predictions of the water-level trend in the general area can be made on the basis of these data.

USE OF GROUND WATER

By

E. K. Morse and R. S. Stulik

About 4.5 million acre-feet of ground water was pumped in Arizona in 1962—slightly less than in 1961. Nearly all of this amount was used in the Basin and Range province. The rest of Arizona's annual water supply was obtained from surface water diverted from streams or released from reservoirs. In 1962 this surface-water supply amounted to about 2,840,000 acre-feet—about 540,000 acre-feet more than the available supply in 1961. This increase in water available from surface-water supplies probably accounts for the decrease in the amount of ground water pumped. The Salt River Valley and the lower Santa Cruz basin in Pinal County continue to be the largest users of ground water in the State, although the percentage of the total pumpage in the State used in these two areas is decreasing.

Salt River Valley

About 2,000,000 acre-feet of ground water was pumped from underground storage in the Salt River Valley, including the Waterman Wash area, during 1962—about 10 percent less than in 1961. The decrease in pumping can be attributed to several factors. About half of the decrease is the result of above-normal use of surface-water supplies. Early in 1962, in anticipation of exceptional spring runoff, water was released from reservoir storage and, therefore, pumping within the Salt River Project was held at a minimum until about May. Although the anticipated large spring runoff did not occur, the minimal pumping during the early months of 1962 resulted in a decrease in the annual pumpage. Some of the decrease in the amount of ground water pumped is due to the continued conversion of agricultural lands to residential use. Declining water levels and the accompanying decrease in well production are possible causes of some of the decrease in pumpage during 1962; however, analysis of power-consumption records shows a generally proportional decrease in power usage, indicating that the decline of water levels is not the major cause of the reduced amount of pumpage.

The Salt River Valley is divided into eight subareas (fig. 35). Although the data do not permit a complete breakdown by subarea, the pumpage in the Salt River Valley may be considered conveniently 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 160,000 acre-feet of ground water was pumped in 1962---slightly less than in 1961. 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 1962 totaled about 1,150,000 acre-feet. This is about 100,000 acre-feet less than the amount pumped in 1961.

Four Salt River Valley subareas---Litchfield Park-Beardsley-Marinette, Liberty-Buckeye-Hassayampa, lower Centennial, and Tonopah---and the Waterman Wash area are designated as west of the Agua Fria River for purposes of pumpage computations. The total pumpage in these areas during 1962 was nearly 700,000 acre-feet---a decrease of less than 10 percent from the 1961 pumpage.

Lower Santa Cruz Basin

In 1962 the total pumpage in the lower Santa Cruz basin in Pinal County was about 1,050,000 acre-feet. Most of this water is used to irrigate crops in the three major cultivated areas in the basin. Domestic, municipal, and industrial use of water in the lower Santa Cruz basin is minor compared to irrigation use. The amount of ground water pumped in each of the three major irrigated areas is as follows: Casa Grande-Florence area, about 310,000 acre-feet; Stanfield-Maricopa area, about 470,000 acre-feet; and, Eloy area, about 250,000 acre-feet. Other nonirrigation uses of water in the basin amounted to about 15,000 acre-feet in 1962.

Upper Santa Cruz Basin

The total amount of ground water withdrawn from the ground-water reservoir by wells in the upper Santa Cruz basin in 1962 was about 200,000 acre-feet. The upper Santa Cruz basin includes the rapidly growing city of Tucson, and thus the use of water for municipal, industrial, and domestic use is increasing, although it is considerably less than the amount used for irrigation in the basin. In 1962 municipal, industrial, and domestic use amounted to about 75,000 acre-feet.

Avra-Marana Area

The Avra-Marana area includes the Avra Valley and a small area near the town of Marana; it is separated from the lower Santa Cruz basin by an arbitrary line extending from the Rillito Narrows along the flood plain of the Santa Cruz River to the Pima-Pinal County line. Only ground water is used in this area to

irrigate the farmland under cultivation. In 1962, about 140,000 acre-feet of ground water was pumped for this purpose. The use of ground water for other purposes in the area is negligible.

Willcox Basin

The Willcox basin, in the northern part of Sulphur Spring Valley, has three main areas of agricultural development---the Stewart area, the Kansas Settlement area, and the Pearce-Cochise area. A total of about 60,000 acres of land was under cultivation in 1962; all irrigation was with ground water. About 160,000 acre-feet of ground water was pumped in the basin with the distribution among the areas as follows: Stewart area, about 60,000 acre-feet; Kansas Settlement area, about 80,000 acre-feet; and Pearce-Cochise area, about 20,000 acre-feet. Most of this water was used to irrigate crops, and only a minor amount was used for domestic and industrial purposes.

San Simon Basin

Pumpage of ground water in the San Simon basin was nearly 65,000 acre-feet in 1962. Only ground water is used to irrigate the 21,000 acres under cultivation in the basin. There are three main areas of agricultural development in the San Simon basin. Total acreage cultivated and ground water pumped in these areas in 1962 is as follows: Bowie area, 8,000 acres irrigated with 25,000 acre-feet of ground water; San Simon area, 6,000 acres irrigated with 22,500 acre-feet of ground water; and Rodeo-Cienaga area (Arizona and New Mexico), 7,400 acres irrigated with about 15,000 acre-feet of ground water.

Harquahala Plains Area

During 1962 an estimated 30,000 acres was irrigated in the Harquahala Plains area. The pumpage in this area in the past has been estimated on the basis of the number of irrigated acres and an average use of about 4 acre-feet of water per acre.

In 1962, through the cooperation of Arizona Public Service, it was possible to improve the estimate of the pumpage in this area. In a study of about 50 percent of the wells in the area, Arizona Public Service concluded that the average pumping rate was 2,376 gpm, and the average operating time for each well was 4,344 hours per year, or that the average annual production per well was about 1,900 acre-feet. There are about 105 operating wells in the Harquahala Plains area; therefore, pumpage for 1962 was computed to be 200,000 acre-feet.

Other Areas

In the Safford basin ground water is used to supplement surface water for the irrigation of crops; thus, the amount of ground water pumped is contingent upon the availability of surface water from the Gila River during the irrigation season. In 1962 nearly 135,000 acre-feet of surface water was diverted for irrigation in the Safford basin---about 100,000 acre-feet more than in 1961. Consequently, less ground water was needed and only about 60,000 acre-feet was pumped in 1962.

In the Gila Bend area, which includes Rainbow Valley in its northeastern part, nearly 45,000 acres was irrigated in 1962. Analysis of power-consumption records for this area indicated a decrease in pumpage during 1962. Based on the decrease of power consumption during 1962, the pumpage for this period is estimated to have been about 170,000 acre-feet.

Data obtained from the Maricopa County Agricultural Extension Service indicate that about 18,000 acres of land was cultivated in McMullen Valley in 1962. Thus, it is estimated that about 75,000 acre-feet of ground water was pumped to irrigate this land.

About 4,000 acres of land was irrigated in the Palomas Plain area and an estimated 15,000 acre-feet of ground water was pumped to meet irrigation needs in 1962.

About 22,000 acres of land was cultivated in the Douglas basin in 1962, requiring about 65,000 acre-feet of ground water.

It is estimated that perhaps an additional 150,000 to 200,000 acre-feet of ground water was used for irrigation of small areas of farmland and by private water companies and individuals in places scattered throughout the State. These areas include the pumpage in nearly all the Plateau uplands and Central highlands provinces and many areas not mentioned previously in the Basin and Range provinces.

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