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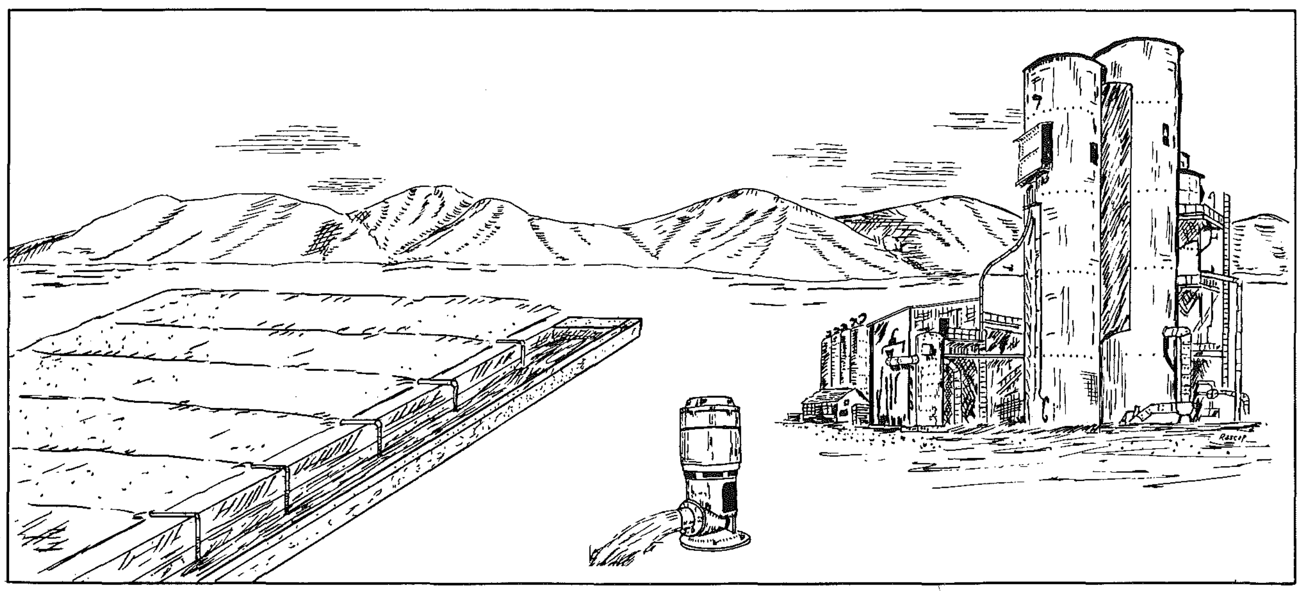
ANNUAL REPORT ON GROUND WATER IN ARIZONA SPRING 1960 TO SPRING 1961

BY

NATALIE D. WHITE, R.S. STULIK, E.K. MORSE, AND OTHERS



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ABSTRACT

By

Natalie D. White

Since 1939, when a district office of the U.S. Geological Survey, Ground Water Branch was established in Tucson, a planned program of ground-water studies has been carried on by the Survey in cooperation with the State; since 1942, the State has been represented by the State Land Department. 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 1960 to spring 1961.

The climate of Arizona, especially in the southern part of the State, is semiarid, and thus conducive to the loss of water to the atmosphere. Roughly half the State receives less than 10 inches of rainfall annually, and nearly 95 percent of the precipitation is consumed by evaporation or transpired from natural vegetation, largely nonbeneficial. An illustration is given in this report to show the relation between precipitation and the potential evapotranspiration at Phoenix. Throughout most of the year the potential evapotranspiration is greatly in excess of the precipitation.

In Arizona ground water occurs under both artesian (confined) and water-table (unconfined) conditions, and in several types of aquifer materials. Arizona may be divided into three water provinces which are synonymous with the physiographic subdivisions: (1) the Plateau uplands in the northern part of the State; (2) the Basin and Range lowlands in the southern part of the State; and (3) the Central highlands which, in part, are transitional between the other two provinces. In the Plateau uplands the water-bearing sandstones store large amounts of ground water but, because they are fine grained, well yields are small. In the Central highlands the rocks contain little space for the storage of ground water except in areas where they are fractured and faulted. In the Basin and Range lowlands ground water occurs in large

quantities in the unconsolidated sediments of the alluvial basins. About 80 percent of the population and more than 90 percent of the irrigated acreage of Arizona are concentrated in this province; hence, it is here that water is in greatest demand.

The data contained in this report and other ground-water studies in the State indicate that in most developed areas ground water is being removed from storage in excess of the rate of replenishment, resulting in the continuous decline of water levels. The trend of the water levels in nearly all the developed basins in southern Arizona continued downward in 1960. Maximum declines again occurred in Maricopa and Pinal Counties; lesser declines occurred in other areas throughout the State. Water levels are rising in the Yuma and Wellton-Mohawk areas as a result of recharge from Colorado River water diverted onto the irrigated areas.

Pumpage of ground water in Arizona in 1960 amounted to about 4-½ million acre-feet, slightly less than in 1959. Most of the decrease was in the Salt River Valley and in the Pinal County part of the lower Santa Cruz basin, but was offset in part by an increase in pumpage in other parts of the State. More than 90 percent of the ground water used in Arizona is for irrigation and more than 75 percent of it is pumped from aquifers in the Salt River Valley and lower Santa Cruz basin.

INTRODUCTION

By

Natalie D. White

The future development of Arizona is largely dependent on the availability of adequate water supplies and the proficient use of these supplies for the most productive benefit to the expanding economy. Although it is not recognized generally, the underground reservoirs are the chief source of water in Arizona. As an ever-increasing demand for water logically accompanies an expanding economy and increasing population, the need for comprehensive evaluation of the water resources also is more pressing. Quantitative solutions to the ground-water problems require detailed, and sometimes costly, geologic and hydrologic studies. Adequate knowledge of the geologic and hydrologic characteristics that govern the storage capacity and the transmission of water through the subsurface sediments is essential for long-range planning and development of the ground-water resources in Arizona. Efficient management of the available water supply cannot be accomplished without adequate scientific information on the occurrence, movement, and chemical quality of ground water and the effects of withdrawal and replenishment on the ground-water reservoirs.

The U. S. Geological Survey has made investigations of ground-water conditions in Arizona intermittently since the 1890's although the pumping of ground water in large quantities did not begin in Arizona until the 1920's. At that time most of the pumpage was from drainage wells used to reclaim land that had become waterlogged owing to the application of excess surface water. Expanded use of ground water for irrigation began in the 1930's. In July 1939, a district office of the U. S. Geological Survey, Ground Water Branch, was established in Tucson, Ariz., and a cooperative agreement between the Geological Survey and the State Water Commissioner provided 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. In the early years, the program was concerned mostly with the collection of basic data—well inventory, periodic water-level measurements, water samples for chemical analysis, and drill cuttings for cataloguing and analysis. During the period 1956 to the present, the cooperative program has been enlarged to include more comprehensive compilation and analysis of the hydrologic and geologic data. Particular emphasis has been given to studies of the subsurface controls on the ground-water reservoirs in order that quantitative answers may be obtained on the amount of water available, the effects of withdrawal, and the chemical character of the water. This report shows the trend toward more comprehensive analysis of the geologic and hydrologic data collected during the year.

The report discusses the changes or trends in ground-water conditions throughout the State by counties and areas, ground-water pumpage in the principal areas of agricultural development, surface-water diversions, climate, chemical quality of water, and some principles of ground-water hydrology. Illustrations include: (1) hydrographs showing comparative changes in the stage of water levels in selected wells for the last 10 years; (2) graphs showing cumulative changes in the water level and pumpage in the Salt River Valley, 1930-61, and in Pinal County, 1940-61; (3) maps showing contours of the change in ground-water levels for the 5-year period 1956-61 in the Salt River Valley, lower Santa Cruz, Willcox, and Douglas basins; and (4) maps showing contours of the altitude of the water level in three aquifer systems in parts of Apache, Coconino, and Navajo Counties.

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

Studies Related to Specific Hydrologic Problems

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

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

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

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

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

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

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

Current Projects in Arizona

The following investigations were being conducted and were in various stages of completion under the three phases of the Federal-State cooperative ground-water program in Arizona during 1960. (1) The collection of basic geologic and hydrologic data under the statewide ground-water survey; (2) Geohydrology and utilization of water in Willcox basin, Cochise County; (3) Subsurface geologic and hydrologic studies of northwestern Pinal County; (4) Geology and ground-water resources of Big Sandy Valley, Mohave County; (5) Geology and ground-water resources of the central part of Apache County; (6) Determination of the productivity of aquifers at depth in Salt River Valley, Maricopa County; (7) Change in water yield by defoliation and vegetation removal, Cottonwood Wash, Mohave County; and (8) Analysis and evaluation of available hydrologic data for San Simon basin, Cochise and Graham Counties.

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

Work is also done by the Geological Survey for other Federal agencies. Ground-water investigations in cooperation with the U.S. Army are at Luke Air Force Base near Phoenix and at the Fort Huachuca Military Reservation south of Tucson. The ground-water study of the Rainbow Valley and Waterman Wash areas, Maricopa County, was in cooperation with the Bureau of Land Management. Projects in cooperation with the Bureau of Indian Affairs include the Navajo-Hopi country in the northeastern part of the State and the Papago Indian Reservation west of Tucson.

The study of ground-water conditions in the Verde Valley area of the Mogollon Rim region is a Federal Geological Survey project.

The areas of new and active projects for 1960 are shown on figure 1.

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 late 1960 and the first half of 1961.

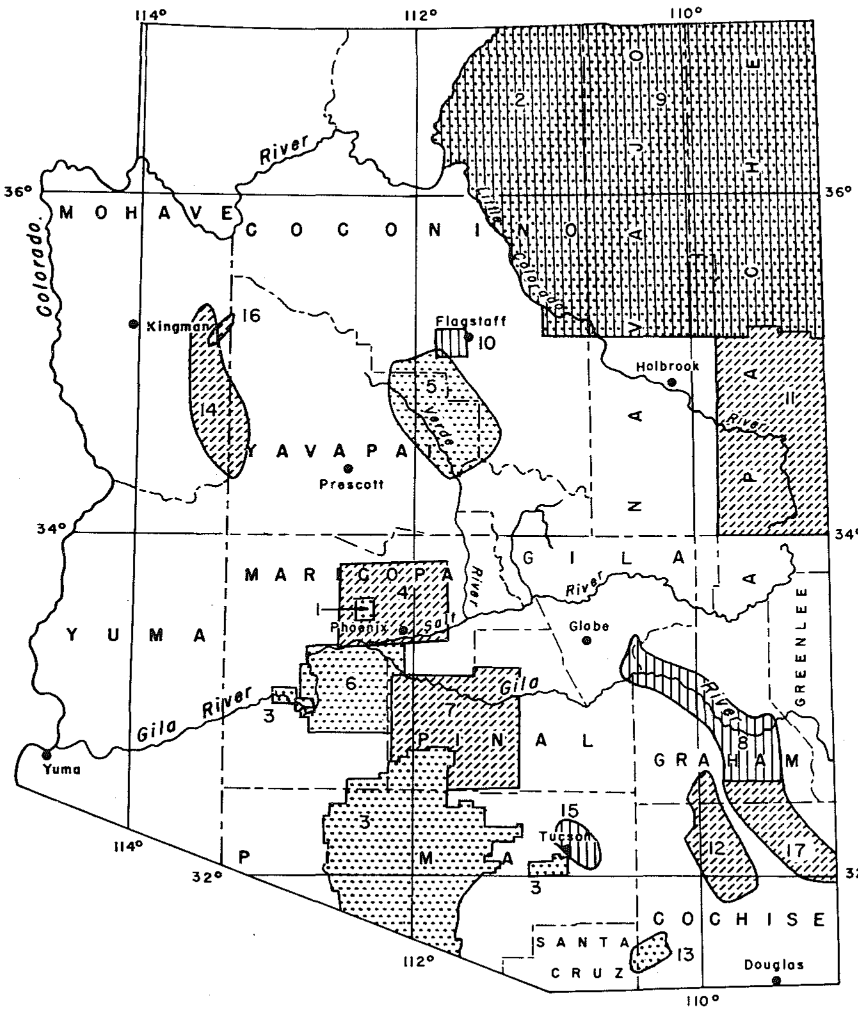

Figure I.-- Map of Arizona showing areas of ground-water investigations.

PROJECTS BY AREA

1. Luke Air Force Base
2. Navajo-Hopi Indian Reservations
3. Papago Indian Reservation
4. Salt River Valley
5. Verde Valley area (Modification of Mogollon Rim region)
6. Rainbow Valley and Waterman Wash areas
7. Northwestern Pinal County
8. Arid Lands Study (Safford Valley)
9. Navajo Tribal well-development program
10. City of Flagstaff
11. Apache County
12. Willcox basin
13. Fort Huachuca
14. Big Sandy
15. Rillito Creek
16. Cottonwood Wash
17. San Simon basin

Cooperative projects with State Land Department financed jointly with State and Federal funds. Part of this program is the statewide geologic and hydrologic survey

Other cooperative projects financed jointly with non-Federal and Federal funds

Projects financed with Federal funds only, including funds transferred from other Federal agencies

Availability of additional water for Chiricahua National Monument, Cochise County, Arizona, by P. W. Johnson: U.S. Geol. Survey open-file report, August 1960. 15 p., 2 figs. For publication as a U.S. Geol. Survey water-supply paper.

The Chiricahua National Monument, in the eastern part of Cochise County, is in an area drained by two intermittent washes—Bonita and Rhyolite Canyons. The present source of water for the Chiricahua National Monument is Shake Spring, which is inadequate during dry periods for the requirements of the monument. This report outlines several sources of available water—undeveloped springs or seeps, capture of runoff from canyons, and wells drilled in the alluvium—combinations of which may provide ample water to meet the present and future needs of the Chiricahua National Monument.

Annual report on ground water in Arizona—spring 1959 to spring 1960, by W. F. Hardt, R. S. Stulik, and M. B. Booher: Arizona State Land Dept. Water Resources Rept. No. 7, September 1960. 81 p., 22 figs., 3 tables.

This annual report is a summary of the basic hydrologic data collected during the period spring 1959 to spring 1960. It broadly describes the ground-water pumpage in the State and water-level fluctuations in the counties and principal basins. About 4.7 million acre-feet of ground water was pumped in 1959 and the trend of water levels in the heavily pumped areas continued downward. The quality of the water in the Tucson area for domestic and industrial supplies is discussed. Illustrations include 10-year hydrographs showing water-level fluctuations in selected wells, maps showing change in water levels for the 5-year period 1955-60 for the Salt River Valley, lower Santa Cruz, Willcox, and Douglas areas, and graphs showing laboratory analyses of well cuttings and outcrop samples. The process of ground-water mining in Arizona is shown pictorially. An appendix to the report gives a complete list of published and unpublished reports on the ground-water resources of Arizona by the U. S. Geological Survey. A supplement to the report shows the cumulative net changes in water levels and total annual pumpage in parts of Maricopa County and the Santa Cruz basin, Pinal County, for the period 1940-59.

Progress report on use of water by riparian vegetation, Cottonwood Wash, Arizona, by E. L. Hendricks, William Kam, and James E. Bowie: U. S. Geol. Survey Circ. 434, 1960. 18 p., 6 figs.

The report describes the current progress of the project which is designed to determine whether a water savings for beneficial use can be accomplished by reducing transpiration losses through the modification of the vegetation in Cottonwood Wash, Ariz. The geology of the area, the results obtained from the study to date, and the future phases of the investigation are discussed.

Further investigations of the ground-water resources of the Gila Bend and Dendora areas, Maricopa County, Arizona, by J. M. Cahill and H. N. Wolcott: U.S. Geol. Survey open-file report, August 1960. 14 p., 2 pls., 4 figs., 2 tables.

The report is a supplement to one on the same area submitted to the U.S. Corps of Engineers in 1954 and released to the open file in 1955 by the U.S. Geological Survey. The initial report sets forth the results of an investigation of the geology and ground-water resources of the Gila Bend and Dendora areas, Maricopa County, Ariz. The supplemental report includes additional information on the wells, electric logs, and the chemical quality of water. A map showing the ground-water contours of the area as of December 1954 accompanies the report.

The geology and ground-water conditions in the Gila Bend Indian Reservation, Maricopa County, Arizona, by L. A. Heindl and C. A. Armstrong: U. S. Geol. Survey open-file report, November 1960. 68 p., 14 figs., 3 tables. For publication as a U.S. Geol. Survey water-supply paper.

The geology and hydrology of the Gila Bend Indian Reservation and adjacent areas are discussed. The investigation shows that sufficient ground water is available to irrigate, for at least 25 years, the 1,200 acres of arable reservation land that is not now under cultivation. The chemical quality of the water is discussed, and illustrations include a map showing geology and the location of the wells, and a block diagram showing the geologic relationships of the rocks.

Geology of the Leupp quadrangle, Arizona, by J. H. Irwin, J. P. Akers, and M. E. Cooley: U.S. Geol. Survey open-file report, May 1961. 24 p., 2 figs. For publication in the U.S. Geol. Survey miscellaneous investigations series.

This report describes the stratigraphy, structure, physiography, and the sources of ground water of the Leupp quadrangle, in the Navajo Indian Reservation. The occurrence of the ground water and chemical quality are discussed. A location map, geologic map, and section of the quadrangle are included.

Cenozoic geology in the Mammoth area, Pinal County, Arizona, by L. A. Heindl: U.S. Geol. Survey open-file report, April 1961. 97 p., 6 figs. For publication as a U.S. Geol. Survey bulletin.

A revised interpretation of the Cenozoic history of the lower San Pedro Valley in the vicinity of Mammoth, Ariz., based on mapping and stratigraphic analysis of separate alluvial units, is set forth in this report. Detailed study provides information about environments of deposition, particularly source areas, and this information is used to interpret the sedimentary and structural history of the area during the Cenozoic Era. Descriptions of geologic formations and their syntheses are followed by the conclusions upon which the author bases his revised interpretation of the Cenozoic Era.

Supplemental memorandum on ground water in vicinity of Painted Rock damsite, by J. M. Cahill: U.S. Geol. Survey open-file report, August 1960. 7 p., 1 table.

The report is the result of further investigations of the ground-water hydrology in the Gila Bend and Dendora areas by the U.S. Geological Survey in cooperation with the U.S. Corps of Engineers, and supplements the reports of ground-water resources in the Gila Bend and Dendora areas, Maricopa County, Ariz., released in 1954 and 1955. Further evaluation of the well data and chemical quality of the water of the area are included.

Hydrologic data and drillers' logs, Papago Indian Reservation, Arizona, by L. A. Heindl and O. J. Cosner, with a section on chemical quality of the water, by L. R. Kister: Arizona State Land Dept. Water Resources Rept. No. 9, July 1961. 116 p., 3 figs., 3 tables.

The well records for the Papago Indian Reservation have been compiled and summarize well construction and hydrologic data, chemical analyses, and drillers' logs. Included are records of about 375 wells, 225 chemical analyses of water from 150 wells, and about 140 drillers' logs. A brief explanation and a location map accompany the report.

Summary of occurrence of ground water on the Papago Indian Reservation, Arizona, by L. A. Heindl and O. J. Cosner: U.S. Geol. Survey open-file report, June 1961. 24 p., 3 figs. For publication as a U.S. Geol. Survey hydrologic atlas.

The atlas summarizes information obtained during the ground-water investigation of the Papago Indian Reservation made by the U.S. Geological Survey in cooperation with the Bureau of Indian Affairs. It also refers to small-area studies made under separate cooperative agreements with the U. S. Public Health Service for local water supplies. The atlas is a summary in graphic form of information that supplements "Hydrologic Data and Drillers' Logs, Papago Indian Reservation, Arizona." The atlas describes in general the ground-water occurrence on the Papago Indian Reservation.

Water in the Coconino sandstone for the Snowflake-Hay Hollow area, Navajo County, Arizona, by Phillip W. Johnson: U.S. Geol. Survey open-file report, November 1960. 77 p., 12 figs., 4 tables. For publication as a U.S. Geol. Survey water-supply paper.

The investigation was conducted in cooperation with the State Land Department and the report summarizes the geologic and hydrologic facts as follows: (1) The principal aquifer (the Coconino sandstone) is present everywhere in the area but varies greatly in its water-bearing characteristics; (2) a map of the water table shows that the ground water moves northward at a rate of less than 1 foot per day under a gradient of about 28 feet per mile; (3) the Coconino sandstone crops out extensively south and west of the area, where it may be recharged; (4) natural discharge from the principal aquifer is chiefly from springs and seeps, and artificial discharge is from flowing wells and pumped wells; and (5) the amount of ground water in storage that can be pumped by wells for man's use in 500 feet of saturated thickness of the principal aquifer in 1 square mile is less than the assumed specific yield of 16,000 acre-feet. The report includes illustrations showing geology, contour of the altitude of the water surface, chemical quality, and tables of wells and drillers' logs.

Agricultural Resume for 1960

According to R. E. Seltzer (Arizona Agriculture 1961: Arizona Agr. Expt. Sta. Bull. a-10, February 1961), a total of 1,253,972 acres was irrigated in Arizona in 1960 (total obtained by adding figures for counties—State total as shown is a misprint). This is an increase of about 8,000 acres over 1959. Increases of several thousand acres occurred in Cochise, Graham, Maricopa, Yavapai, and Yuma Counties; lesser increases occurred in Apache and Santa Cruz Counties. These increases were partially offset by decreases in acreage in the remaining counties. According to the report, western Maricopa and eastern Yuma Counties were the areas of major land development during 1960. The counties having the largest total irrigated acreage under cultivation were: (1) Maricopa, 523,863 acres; (2) Pinal, 285,900 acres; (3) Yuma, 201,202 acres; and (4) Cochise, 80,150 acres. Cotton continued to occupy the largest amount of irrigated acreage in the State. A total of 426,095 acres of cotton was under cultivation in 1960, an increase of more than 42,000 acres over 1959. Acreagewise, alfalfa was the second largest crop with 231,000 acres cultivated. The pumping of ground water continued to be the major source for irrigation of the cultivated acreage in the State; thus declining ground-water levels are a major problem in Arizona's water picture.

The net value of sales from agricultural products was 416.9 million dollars in 1960 (Seltzer, op. cit.); this represents an increase of 12.5 million dollars over 1959. Seltzer (op. cit.) states: "Increases in grain, cotton, and cattle production, and higher prices for hay, milk, eggs, and vegetables accounted for the higher income figure, while lower prices for cattle and grain were restricting factors." Agriculture continues to be one of the major sources of income in Arizona; cotton, cattle, and vegetables account for 75 percent of the total agricultural income.

Agriculture in Arizona is largely dependent on the availability of ground water. Figure 2 gives a comparison of the amount of ground water pumped and the acreage irrigated for the years 1946-60.

Climate

In 1960 precipitation was below average throughout Arizona for the first time since 1956; it was more than 4 inches below the long-term average in Maricopa and Pinal Counties where the greatest amount of ground water is pumped in the State, and also in Yavapai County which is relatively undeveloped. Precipitation was nearly 2 inches below average in the southwestern and southeastern parts of the State, nearly 3 inches below average in Mohave County, and about 3-½ inches below average in Gila County.

A summary of the precipitation pattern throughout the State shows that in January rainfall was slightly below average in the northern part but somewhat above average in the southern part. February, March, and April had considerably below-average precipitation throughout the State, and May was about average. Rainfall was again deficient throughout the State in June, July, and August, and in September it was below average except in Mohave and Yuma Counties where it was slightly more than half an inch above normal. Above-average precipitation occurred in all parts of the State during October, except in Yuma County where it was slightly below average. November had slightly below-average rainfall except in Mohave County. December was dry throughout the State.

One of the most distinctive characteristics of Arizona's climate is the wide range in temperatures occurring over the State. The extremes in temperature are caused by differences in altitude and the wide range in latitude. Thus, the highest temperatures occur along the lower Colorado and Gila River drainages and the lowest at high altitudes in north-central Arizona. The lowest mean monthly temperatures throughout the State are usually recorded in January and the highest in July. Average annual temperatures in 1960 were within 1-½° of the long-term means throughout the State, although the average temperatures for individual months showed large departures from the long-term means. In January and February average temperatures were considerably below the long-term means throughout the State; in June, July, August, and September the average temperatures were several degrees above the long-term means. The highest temperature recorded in the State during 1960 was 120°F at Parker on July 16; the lowest was -25°F at Maverick and Alpine on January 2 and January 18, respectively.

About half of the State receives less than 10 inches of rainfall annually and nearly 95 percent of the precipitation is consumed by evaporation or transpired from natural vegetation, largely nonbeneficial. The major process by which this water is lost to the atmosphere probably is evaporation. Evaporation, a nearly continuous process, is a func-

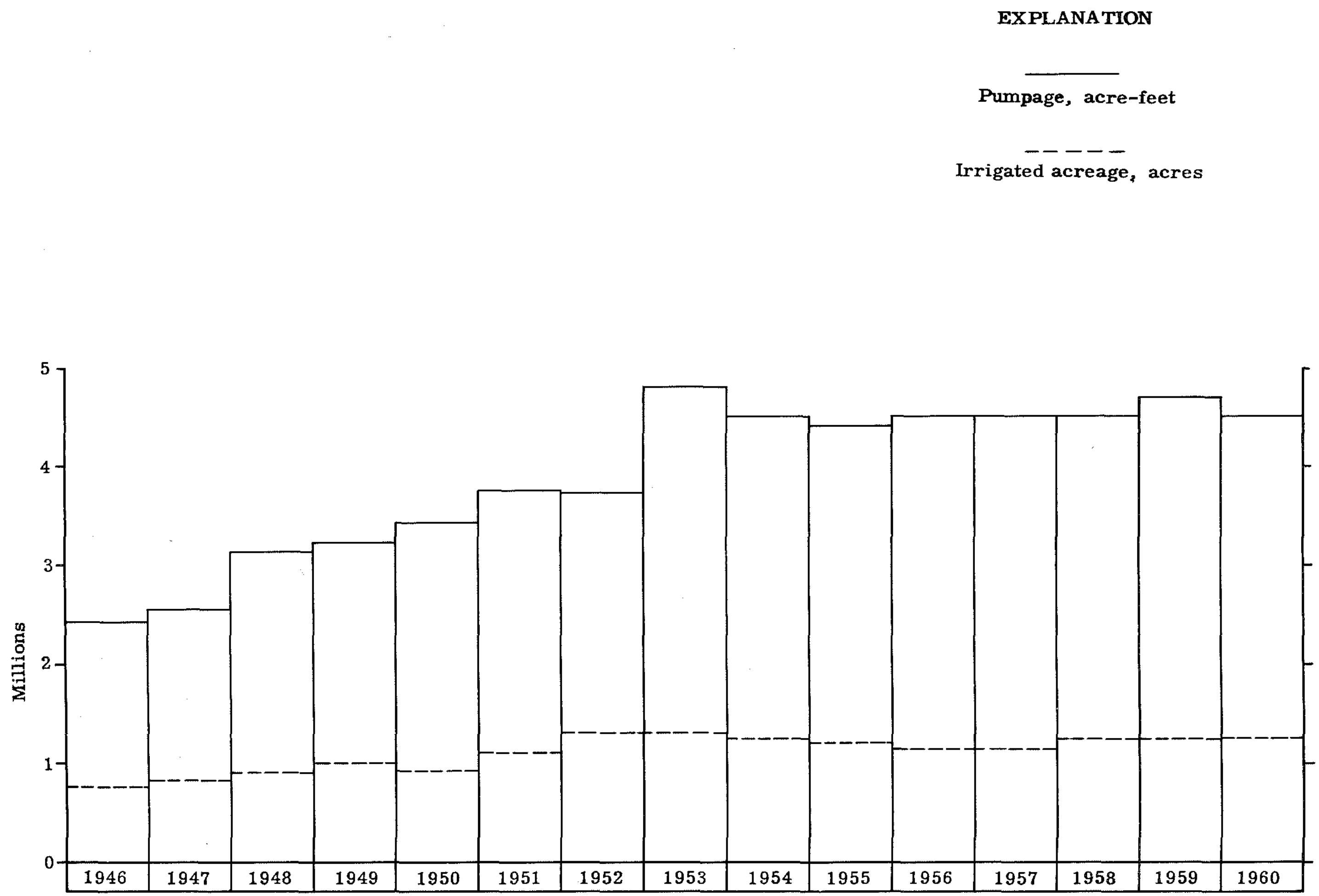

Figure 2.--Pumpage of ground water compared to irrigated acreage, 1946-60.

tion of temperature, wind movement, humidity, and barometric pressure. The U.S. Weather Bureau measured evaporation in a standard shallow 4-foot-diameter pan at several stations in Arizona. Such measurements do not represent the evapotranspiration potential from land areas, but they provide an index to a characteristic of the climate that acts to limit the quantity of water available. The records available show that evaporation in Arizona ranges from about 6 to more than 10 feet per year; it is highest in the desert regions in the southern part of the state.

In semiarid regions such as southern Arizona, the amount of water that evaporates and transpires is less than that which would evaporate and transpire if it were available. Thornthwaite (1948, An appraoch toward a rational classification of climate: Geog. Rev., v. 38, no. 1, p. 55-94) devised a method for computing potential evapotranspiration based on mean monthly temperatures and the latitude of the area. In southern Arizona throughout most of the year, the potential evapotranspiration is greatly in excess of precipitation. Figure 3 shows a comparison of monthly precipitation and potential evapotranspiration computed by the Thornthwaite method for the city of Phoenix. The graph shows that in January and December the precipitation is slightly in excess of the potential evapotranspiration, but throughout the rest of the year the potential evapotranspiration is greatly in excess of the precipitation. The high evapotranspiration potential causes most of the precipitation to be returned to the atmosphere before it can reach the ground-water reservoir as recharge. If a method could be devised for capturing this water before it is evaporated it could be used for recharging the ground-water reservoir. Under present conditions there is little recharge to the ground-water reservoir directly from precipitation and most of the recharge in Arizona is by runoff from the mountainous regions surrounding the alluvial valleys.

Table 1 shows the total precipitation and average temperature and departures from the long-term means for several weather stations in Arizona for 1960.

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

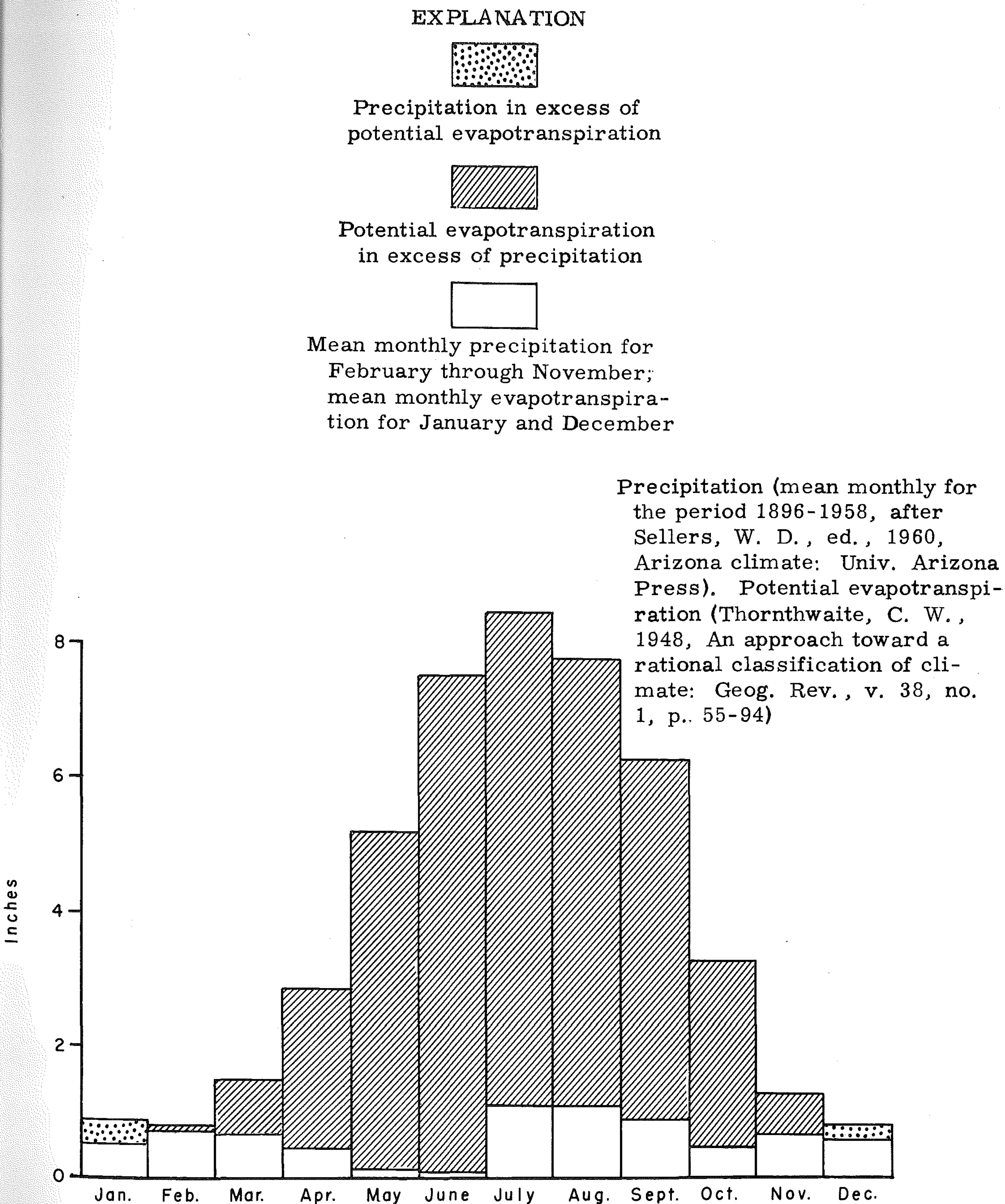

Figure 3.—Precipitation and potential evapotranspiration at Phoenix, Ariz.

Table 1. --Total precipitation and average temperature in 1960 at selected stations and departures from long-term means. (From Climatological Data, Arizona, Annual Summary 1960: U. S. Weather Bur.)

Station	Precipitation (inches)	Departure (inches)	Temperature (°F)	Departure (°F)
Bowie	9.24	-	63.0	-
Buckeye	3.91	-2.57	69.9	-
Casa Grande	5.51	-	71.0	1.3
Chandler	5.11	-	69.9	-
Chino Valley	9.86	-	54.0	-
Davis Dam	4.71	-	72.9	-
Douglas Smelter	12.20	.58	62.7	-.4
Duncan	9.72	-	58.9	-
Eloy	6.10	-	70.7	-
Flagstaff	16.60	-1.93	45.6	1.0
Gila Bend	2.39	-3.52	73.2	-
Globe	10.75	-4.65	62.4	.6
Holbrook	5.88	-1.87	54.0	-1.2
Kingman	7.68	-	62.5	-
Litchfield Park	3.85	-4.01	70.9	.7
Mesa	6.72	.97	69.4	1.2
Nogales	12.91	-	60.0	-
Payson	14.74	-	55.5	-
Phoenix Airport	3.39	-3.80	71.1	1.7
Pinedale	10.84	-6.98	48.4	-
Prescott Airport	8.33	-7.70	56.0	.8
Safford	7.65	-1.07	64.6	.7
St. Johns	8.44	-2.93	52.6	.2
Snowflake	7.37	-4.36	51.0	-
Tucson, University of Arizona	9.34	-1.09	69.6	1.8
Wellton	2.97	-	70.4	-
Wikieup	9.54	-1.04	66.0	-
Willcox	8.08	-	-	-
Williams	23.09	1.96	50.0	1.0
Yuma Airport	1.42	-1.98	75.4	.7

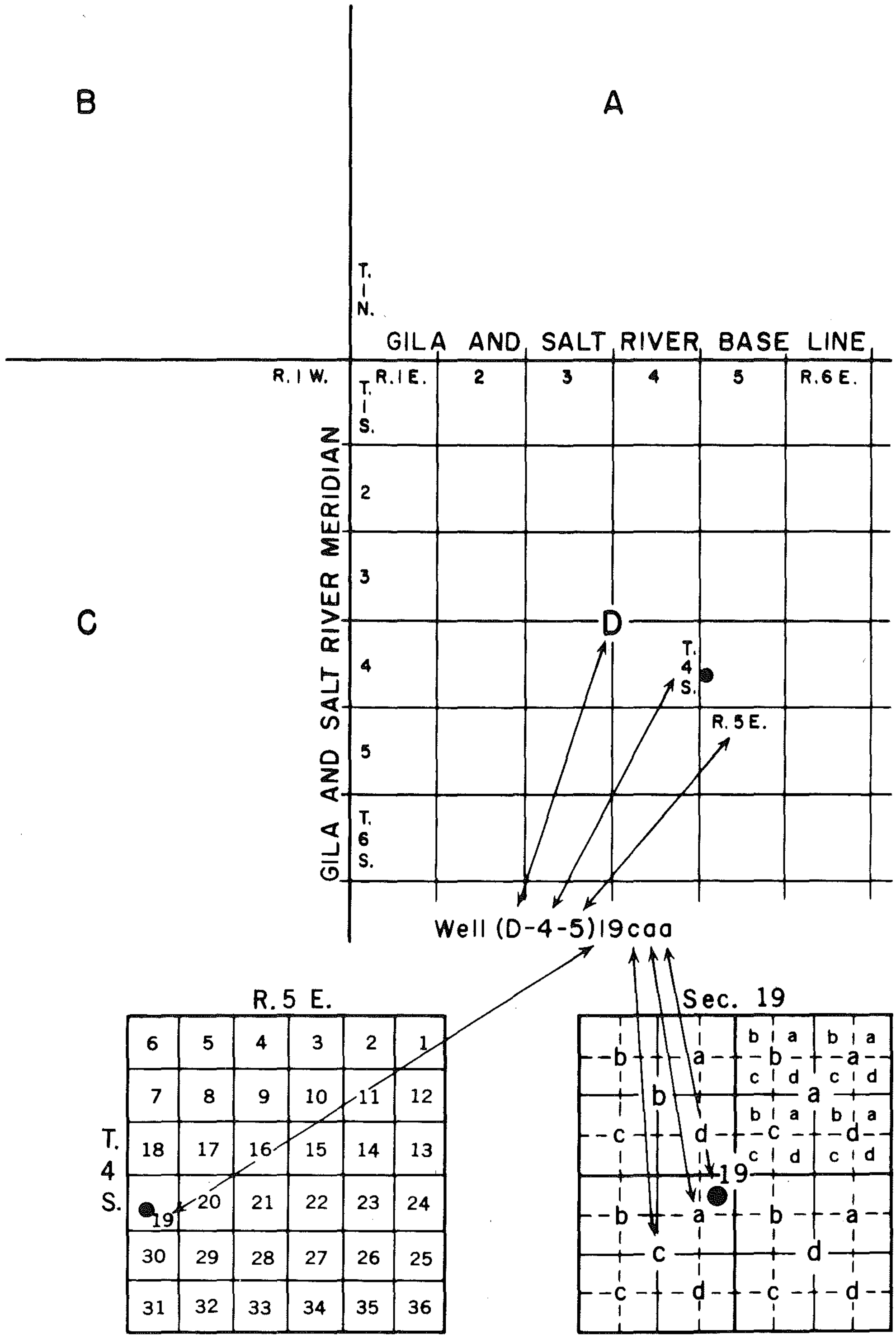

Figure 4.-- Sketch showing well-numbering system in Arizona.

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. 4 S., R. 5 E. Where there is more than one well within a 10-acre tract, consecutive numbers beginning with 1 are added as suffixes.

Personnel

This report is prepared by the combined efforts of most members of the staff in the Arizona district. The sections that discuss ground-water conditions by areas were, in general, prepared by the person most familiar with the particular area. Authorship of the individual sections is shown in the table of contents. In addition to those persons listed as authors, several other people contributed substantially to the preparation of the report. E. K. Morse prepared the hydrographs and the table showing precipitation and temperature; W. D. Potts prepared the drawing showing the hydrologic cycle; and G. S. Smith and F. H. Rascop prepared the illustrations. Others who worked on the report include: William Kam, F. R. Twenter, A. C. Hill, R. E. Cattany, C. L. Jenkins, M. E. Kambitsch, and M. F. Smith. The report was compiled and coordinated by N. D. White and P. W. Johnson.

Acknowledgments

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REGIONAL HYDROLOGY

By

Natalie D. White

One of the most important physical processes described by man is the hydrologic cycle—the earth's circulatory system. Water is one of our most valuable natural resources without which no form of life can exist. Although water in some form occurs everywhere, the amount varies widely—from the abundant supply in the oceans to the meager supplies in the arid desert regions as in parts of Arizona. Nearly all water is in a constant process of circulation. The process involves the transfer of water from the sea or large inland bodies of water by evaporation, the release of the collected vapor from the clouds as precipitation, and the runoff and underground movement of the water back to the sea or water vapor. Much of the water, especially in the arid regions, never completes the full cycle because it is returned to the vapor state before reaching any large body of water. In Arizona most of the water is lost either by evaporation or transpiration (fig. 5). Probably only about 1.0 percent per year of the water derived from precipitation reaches the ground-water reservoirs—the chief source of water supplies.

Ground water is one phase of the hydrologic cycle—nearly all ground water originates as precipitation. It occurs in permeable geologic formations—consolidated and unconsolidated rock materials—that act as conduits for transmission or as reservoirs for the storage of water. Water from the surface infiltrates into these formations, travels slowly through them for varying distances, and, in part, returns to the surface by some means. The formations with appreciable quantities of water moving through them are called aquifers. The amount of water that an aquifer will store or the rate at which it will transmit water are functions of the porosity and the permeability of the aquifer materials. The porosity of a rock or soil is its property of containing interstices or void spaces in which water can be stored. It is expressed quantitatively as the percentage of void space to the total volume. 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. It should be noted here that rocks may have high porosities but yield little or no water because the permeability is so small that water cannot move freely.

In Arizona ground water occurs under both artesian (confined) and water-table (unconfined) conditions, and in several types of aquifer materials. In the northern part of Arizona, ground water occurs, for the most part, in fine-grained sandstone and limestone formations which, in places, are separated by confining layers composed of shale and claystone. In the southern part of the State ground water occurs in the alluvial fill, which consists chiefly of gravel, sand, silt, and clay.

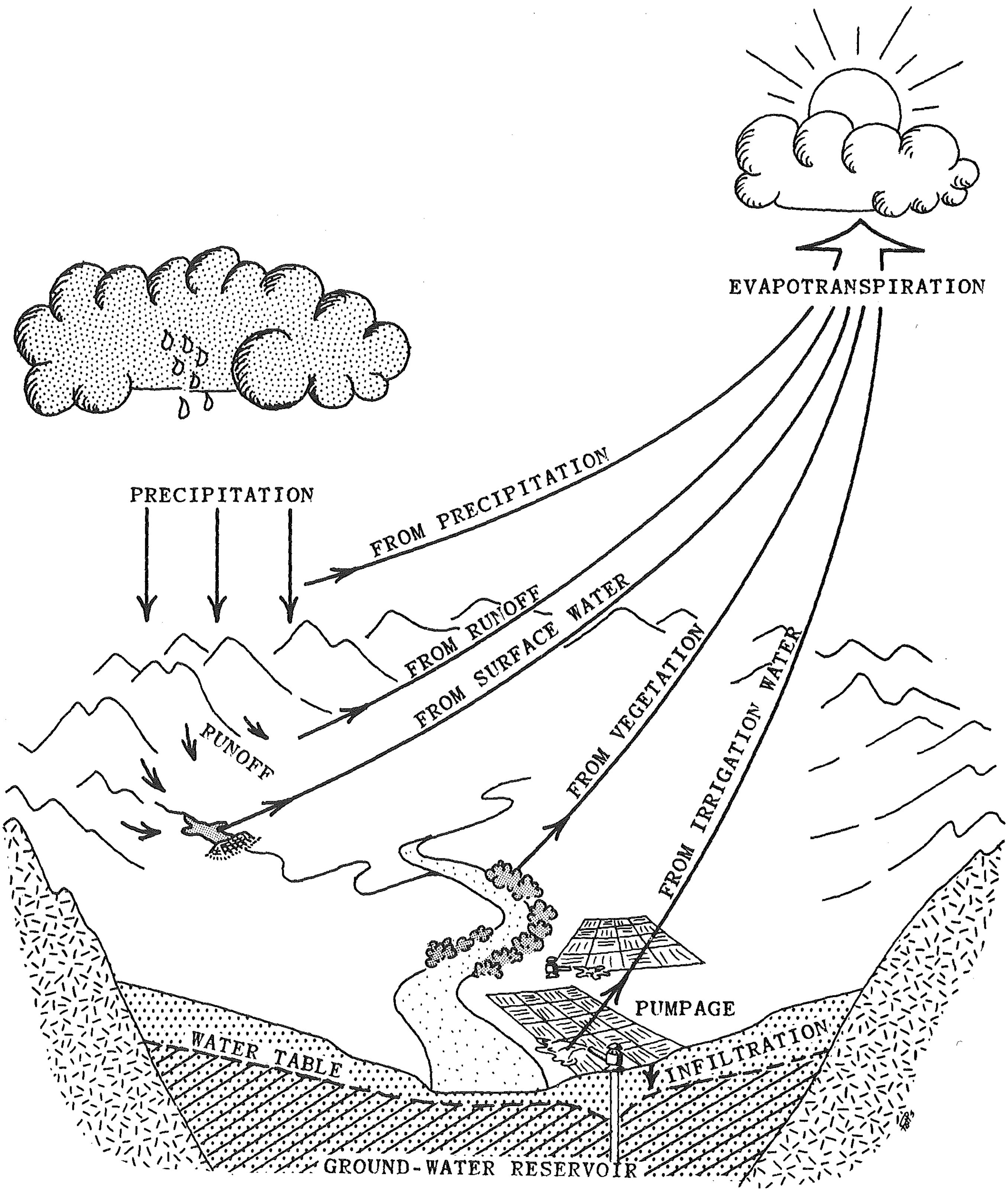

Figure 5. --The hydrologic cycle in Arizona.

Water Provinces in Arizona

Arizona may be divided into three water provinces which are synonomous with the physiographic subdivisions (fig. 6): (1) the Plateau uplands in the northern part of the State; (2) the Basin and Range lowlands in the southern part of the State; and (3) the Central highlands which, in part, are transitional between the other two provinces.

Plateau Uplands Province

The Plateau uplands constitute nearly 40 percent of the total area of the State. The topography is one of gently sloping surfaces ranging in altitude from about 4,000 to 13,000 feet above mean sea level, but lying mostly between 5,000 and 7,000 feet; the soil covering is thin, and vegetation is usually sparse but may be moderately heavy in parts above 7,000 feet. The climate is generally hot and dry in areas below 4,500 feet and relatively cool and humid in regions above 7,000 feet.

Although several water-bearing sandstones constitute a large storage reservoir for ground water, well yields generally are small because the rocks are fine grained and do not transmit water freely. There are several exceptions, however, in areas where faults and fractures increase the permeability of the formation and permit water to move more freely, thus increasing well yields considerably. In places faults and fractures also provide means of recharging the ground water from precipitation.

The regional movement of ground water in the Plateau uplands province is toward the Colorado, Little Colorado, and San Juan Rivers. The canyons of both the Colorado and Little Colorado Rivers have cut through the aquifers and the ground water discharges into the rivers through springs and seeps. A more complete discussion of the aquifers in the Plateau uplands is given in the sections on Apache, Coconino, and Navajo Counties.

Basin and Range Lowlands Province

About 80 percent of the population and more than 90 percent of the irrigated acreage of Arizona are concentrated in the Basin and Range lowlands province, which constitutes more than 45 percent of the total area of the State. Hence, it is here that the demand for water is greatest.

The topography of the area is characterized by isolated parallel mountain ranges rising sharply above the broad alluviated valleys and basins. The alluvial basins are filled with unconsolidated sediments up to several thousand feet in thickness. These sediments store large amounts

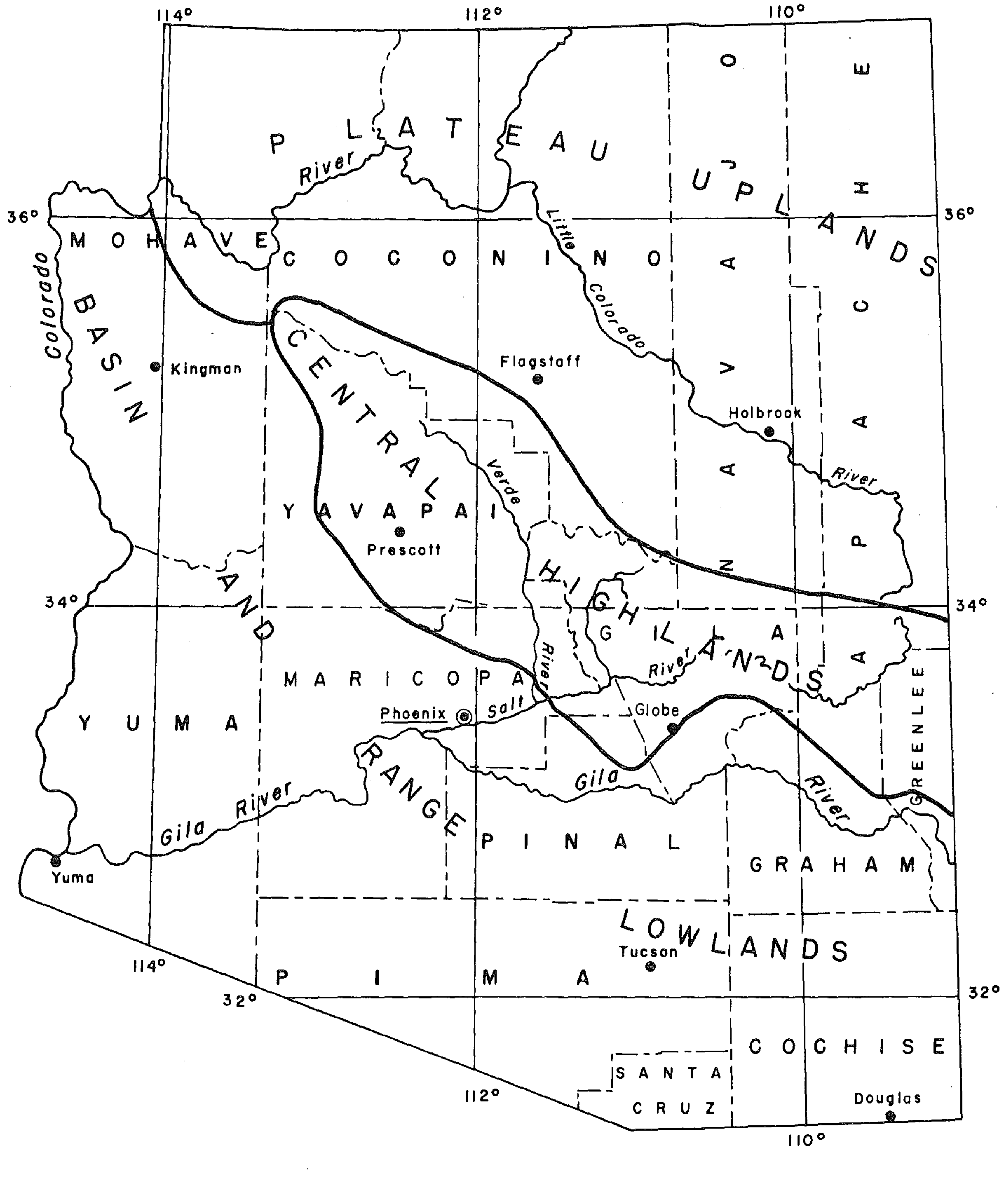

Figure 6. --Map of Arizona showing water provinces.

of ground water that have accumulated during geologic time. However, the current annual rate of recharge to the ground-water reservoirs in the basins is negligible and conservation of water is essential in this arid zone. The water-bearing materials in each alluvial basin and in different parts of the same basin vary widely in their ability to store and transmit ground water resulting in a wide range in the amount of water yielded to wells. The intertonguing of lenticular beds of sand, gravel, and clay forming complex sedimentary sequences has a major effect on water development in specific areas. In general, the occurrence of clay or silt beds decreases the amount of storage, restricts movement, and decreases the yield. In many heavily pumped areas, the presence of these beds is reflected in the accelerated decline of the water table.

Most valleys slope northwestward and ground-water movement within them follows the same pattern. A notable exception is the Douglas basin in the Sulphur Spring Valley which drains southward toward Mexico; a few other smaller and less-developed valleys also drain southward. When wells are pumped and ground water is removed from the alluvial sediments of the basins, the water table is drawn down in the vicinity of the wells and a cone of depression is formed. Continued pumping in an area causes these cones to expand and deepen. Thus, the regional pattern of ground-water movement is gradually changed and water moves into the cones from all directions. The regional pattern of ground-water movement has been altered by such cones in areas throughout the Basin and Range lowlands. These cones are particularly well developed in the areas of greatest agricultural development where the pumping of ground water is greatly in excess of the rate of replenishment. As more water is removed from the ground-water reservoirs and the cones expand and deepen to intercept water from larger areas, the regional dewatering which results will be indicated by the downward trend of the water levels.

Central Highlands Province

The Central highlands province is areally the smallest of the water provinces and constitutes a transitional zone between the Plateau uplands and the Basin and Range lowlands. For the most part, the highlands consist of rugged mountain masses rising to altitudes several thousand feet higher than the adjoining alluviated valleys of the Basin and Range lowlands. The Mogollon Rim approximates the ground-water divide and the surface-water drainage divide between the Little Colorado River system and the Gila River system. The Central highlands receive the largest amount of precipitation in Arizona; summer thundershowers are common and winter snowfalls are heavy. This relatively heavy precipitation is the chief source of water for perennial streamflow in the Gila, Salt, and Verde Rivers, and other streams. The surface water that flows southward toward the Basin and Range lowlands province is impounded in reservoirs for use in the alluvial valleys.

The subsurface materials in the mountain ranges of the Central highlands, for the most part, are indurated igneous, metamorphic, and crystalline rocks, and well-consolidated sedimentary rocks; these rocks contain little space for the storage of ground water. However, the rocks are extensively fractured and faulted and small amounts of water are stored in these zones. In places the fractures are at the surface and ground water issues as springs. Alluvial sediments in the small valleys between the mountains in the Central highlands vary greatly in thickness and composition which influence the amount of ground-water storage and yield.

Surface-Water Runoff, Storage, and Diversions

By

D. D. Lewis

Total diversion of streamflow to Arizona lands during the 1960 water year (October 1959 to September 1960) was in excess of 2,700,000 acre-feet. About 1,500,000 acre-feet was diverted from the Colorado River for use by the Colorado River Indian Reservation, the Valley Diversion of the Yuma Project, and the Gila Project. These projects use only surface water for irrigation. About 450,000 acre-feet of the water diverted from the Colorado River is returned to the river or discharged across the Arizona-Sonora boundary.

About 1,180,000 acre-feet of water was diverted from the Gila River basin during the 1960 water year. Diversions from the Salt River at Granite Reef Dam were 781,400 acre-feet. The other significant surface-water diversions are in the Duncan-Safford areas and for the San Carlos Project. Each of these is used in combination with ground water (fig. 7).

The Surface Water Branch, U. S. Geological Survey, reports varying conditions of runoff during the 1960 water year. During the first half of the year streamflow in Arizona was generally above normal as a result of heavy rains and a deep snow pack. As the year progressed the situation deteriorated and streamflow for the last 6 months of the year was below normal at all key stations.

Following is a list of key stations with discharge for the 1960 water year and its relation to normal or median discharge.

(1) Colorado River at Grand Canyon, 9,584,000 acre-feet
85 percent of median

(2) Little Colorado River near Cameron, 194,200 acre-feet
114 percent of median

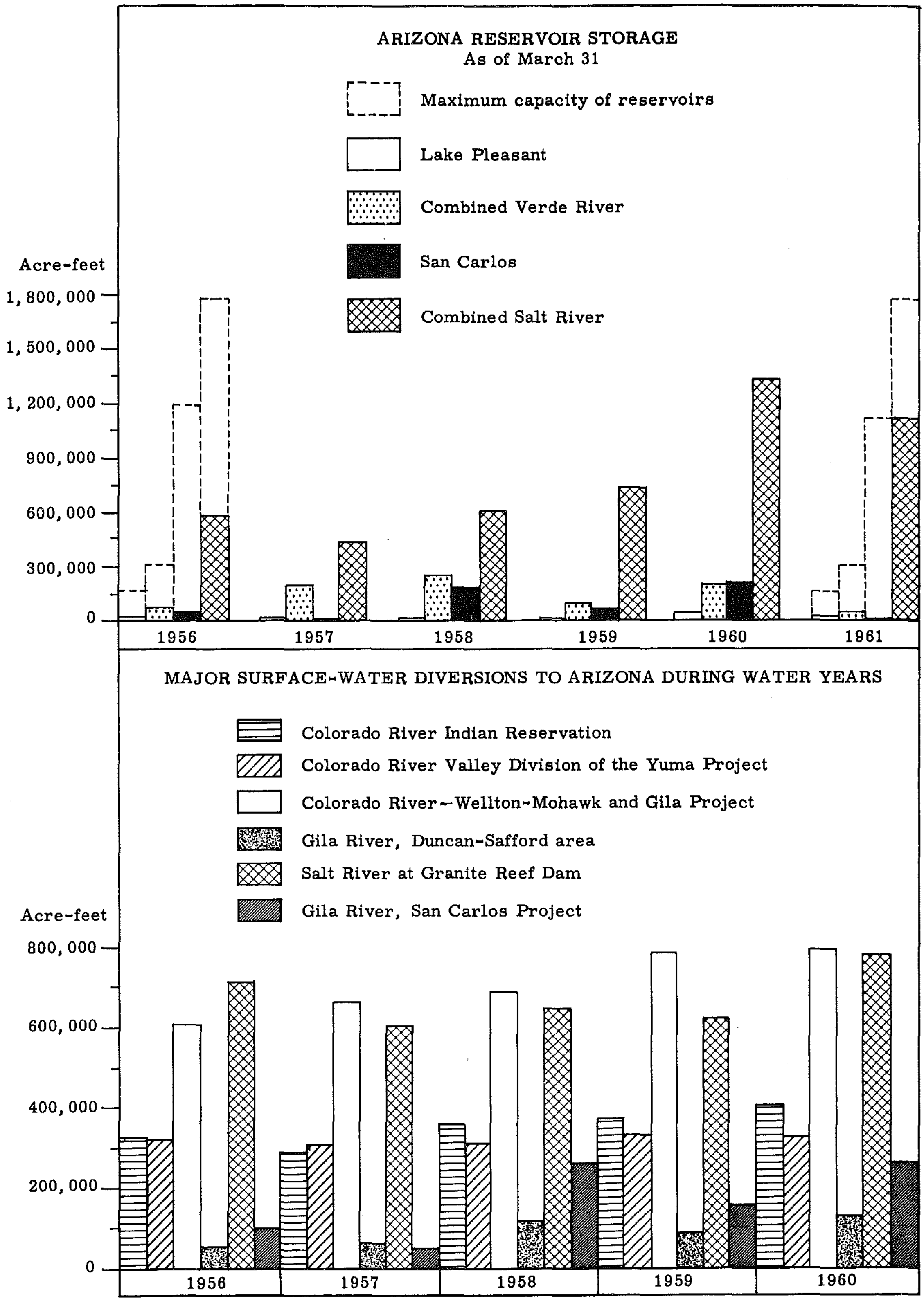

Figure 7.--Surface-water reservoir storage and diversions in Arizona.

(3) Gila River at head of Safford Valley near Solomon, 319,600 acre-feet
157 percent of median

(4) Salt River near Roosevelt, 856,100 acre-feet
210 percent of median

(5) Verde River above Horseshoe Dam, 394,800 acre-feet
138 percent of median

(6) San Pedro River at Charleston, 24,300 acre-feet
67 percent of median

GROUND-WATER CONDITIONS BY AREAS

By

Natalie D. White

The trend of the ground-water surface in an area is an indication of the gain or loss of water from storage in the aquifer. In the natural state, before the use of any water by man in an area, the aquifer was in approximate hydrologic balance; that is, the average recharge from all sources equals the average discharge, and ground-water storage was at a maximum. In this state the water levels were relatively stable and would be affected only by severe changes in natural conditions. With the development of the water resources by man in an area, the balance is disturbed and water levels are no longer stable but fluctuate in response to the artificial removal or addition of water. In the highly developed areas of Arizona, the chief factor affecting the trend of the water levels is the pumping of ground water in large quantities. A steady decline of the water levels over a period of years indicates that ground water is being mined and the aquifer is being depleted.

The periodic measurement of water levels and an analysis of the trend are necessary parts of an overall appraisal of the ground-water conditions in a basin. In order to obtain consistent results in the analysis of water-level trends, it is important to measure the water levels in wells about the same time each year. The Geological Survey makes extensive measurements during the first 3 months of each year when pumping is at a minimum and water levels are approaching more stable conditions. Other measurements made throughout the year help to establish the trend of the water levels in relation to the pumping regimen.

The trend of the water levels in nearly all the developed basins in southern Arizona continued downward in 1960. Maximum declines again occurred in Maricopa and Pinal Counties; lesser declines occurred in other areas throughout the State. The current ground-water conditions for all the major areas in the State are discussed in the following paragraphs by counties.

Apache County

By

J. P. Akers

Ground water in Apache County occurs under both water-table (unconfined) and artesian (confined) conditions mostly in consolidated sedimentary formations which extend for hundreds of square miles. However, several scattered small lava flows in the Navajo Indian Reservation and some rather extensive flows in the southern part of the county contain water. Water also commonly occurs in the alluvium along the rivers and the larger washes. Brief descriptions of the water-bearing characteristics of the sedimentary rocks that are present in Apache County and adjoining areas are given in table 2.

In the southern part of the county, wells obtain water mostly from the lava. Water from rainfall and from snowmelt enters the lava through fractures and moves downward until it is stopped or slowed by underlying relatively impermeable rocks. Locally, the downward movement may be stopped or slowed by ancient, impermeable soil zones between lava flows resulting in perched water. However, in general, the water occurs near the base of the lava under water-table conditions.

In the area between the southern lava fields and the northern end of the Defiance uplift, most wells obtain water from the Coconino Sandstone (or its equivalent, the De Chelly Sandstone), the Bidahochi Formation, or the alluvium along washes or rivers. Water enters the Coconino Sandstone where it is exposed in the structurally high areas and moves downdip into structurally low areas where the Coconino usually is buried beneath younger formations. One such low area trends northwestward in central Apache County, and is reflected in the altitude of the water level as shown in figure 8. In the low areas the water in the Coconino generally is under artesian conditions; in the high areas where the Coconino is exposed it occurs under water-table conditions.

Water enters the Bidahochi Formation directly from precipitation and surface runoff and moves downward until it is stopped by underlying impermeable rocks. The movement of water along the contact of the Bidahochi and the underlying rocks is controlled mainly by the large ancient valley in which the Bidahochi was deposited and by irregularities in the contact (fig. 9). Water-level contours (fig. 9) indicate that water in the Bidahochi moves in about the same direction as the present surface drainage. Underflow provides most of the water in the alluvium along the streams.

Ground water in the northern part of Apache County is mostly in aquifers younger than the Coconino Sandstone—the Navajo Sandstone (fig. 10), the Bluff Sandstone, and sandstone members of the Morrison Formation. A few wells obtain water from formations of Cretaceous age in widely scattered areas throughout the county. The Supai Formation,

Table 2.--Brief descriptions of the water-bearing characteristics of sedimentary rocks in Apache, Coconino, and Navajo Counties, and adjoining regions, Arizona

System	Series	Group	Stratigraphic unit	Brief lithologic description and thickness (feet)	Water-bearing characteristics: General hydrologic description	Water-bearing characteristics: Depth of wells (feet)	Water-bearing characteristics: Depth to water (feet)	Chemical quality of water: General characteristics	Chemical quality of water: Total dissolved solids (ppm)
QUATERNARY	PLEISTOCENE AND RECENT		Alluvium	Chiefly sand, silt, and gravel; 200	Yields small amounts of water to wells along the Little Colorado River and larger tributaries; alluvium is more than 200 feet thick in Aubrey and Chino Valleys	50- >300	10- >200	Good to poor depending upon local geohydrologic conditions	<500- >10,000
TERTIARY AND QUATERNARY	PLIOCENE AND PLEISTOCENE		Volcanic rocks and interbedded sediments	Chiefly basalt flows, cinder beds, and sediments composed of volcanic materials; 50-1,000	Yields small amounts of water to springs in most areas and locally to a few wells on the San Francisco Plateau, Mount Floyd area, and in the White Mountains	<600	50-300	Generally good to fair depending on the composition of the rocks and sediments locally	<1,000
TERTIARY	PLIOCENE		Bidahochi Formation	Siltstone, sandy siltstone, sandstone, tuff, and basalt flows;<800	Yields small amounts of water to wells in central Navajo and Apache Counties; small springs issue from tuff in the Hopi Buttes	<700	100-600	Usually fair in sediments; fair to poor in tuff beds	500- >3,000
TERTIARY	PLIOCENE(?)		Chuska Sandstone	Chiefly sandstone; 1,000	Yields water to springs in Chuska Mountains; it is the source of water in the perennial reaches of Tsaile, Wheatfields, and Whiskey Creeks; no wells penetrate the formation	-	-	Generally good	<500
CRETACEOUS	UPPER	MESAVERDE	Yale Point Sandstone, Wepo Formation, and Toreva Formation of Black Mesa basin and undifferentiated Cretaceous rocks in the southern part of Apache County	Interbedded shale, sandstone, and coal; 200-<1,600	Yields small amounts of water to springs and to wells drilled in the sandstone beds	-	-	Fair to good	500-1,500
CRETACEOUS	UPPER		Mancos Shale	Shale; 300-700	Essentially nonwater bearing	-	-	Reported to be salty	-
CRETACEOUS	LOWER(?) AND UPPER		Dakota Sandstone	Sandstone, siltstone, and coal; 100	Yields small amounts of water to wells in the southern part of Black Mesa basin; some of the wells flow; locally, it is hydrologically interconnected with the Cow Springs Sandstone and Morrison Formation	200-1,000	flow-500	Fair to poor; contains high fluoride locally in Black Mesa basin	600- >1,500
JURASSIC	UPPER		Morrison Formation	Alternating sandstone and siltstone beds; 200-600	Sandstone units yield small amounts of water to wells in northern Apache and Navajo Counties	200-700	150-600	Generally fair to poor	500-2,000
JURASSIC	UPPER		Bluff (of San Rafael Group) and Cow Springs Sandstones	Sandstone; 100-300	Yields small amounts of water in Chinle Valley area and in the southern and eastern parts of Black Mesa basin	200-500	100-400	Generally of slightly better quality than water in overlying and underlying units	500-1,500

Table 2. --Brief descriptions of the water-bearing characteristics of sedimentary rocks in Apache, Coconino, and Navajo Counties, and adjoining regions, Arizona—Continued

SYSTEM	SERIES	GROUP	Stratigraphic unit	Brief lithologic description and thickness (feet)	Water-bearing characteristics: General hydrologic description	Water-bearing characteristics: Depth of wells (feet)	Water-bearing characteristics: Depth to water (feet)	Chemical quality of water: General characteristics	Chemical quality of water: Total dissolved solids (ppm)
JURASSIC	UPPER	SAN RAFAEL	Summerville Formation	Siltstone and some sandstone; 100-200	Usually nonwater bearing; sandy facies of the formation yields some water to springs in the Chuska Mountains	-	-	Fair quality in Chuska Mountains	-
JURASSIC	UPPER	SAN RAFAEL	Entrada Sandstone	Sandstone and some siltstone; 50-350	Yields water to a few springs in the northern part of the Navajo Indian Reservation; yields small amounts to wells in Chinle Valley area and in southern part of Black Mesa basin	200-600	150-500	Fair to poor; unless cased out of well, water contaminates water withdrawn from the other aquifers	1,000-5,000
JURASSIC	MIDDLE	SAN RAFAEL	Carmel Formation	Siltstone and some sandstone; 0-300	Yields water to a few small springs in northeastern Coconino County	-	-	-	-
JURASSIC AND TRIASSIC(?)		GLEN CANYON	Navajo Sandstone	Sandstone; 0-1,800; thickens northwestward	Yields small to medium amounts of water principally in the northern part of the Navajo Indian Reservation; base of formation is prominent spring horizon; forms a multiple aquifer with the Kayenta Formation and Wingate Sandstone	100-1,500	50-1,400	Good to fair	<1,000
TRIASSIC(?)	UPPER	GLEN CANYON	Kayenta Formation	Chiefly a sandstone in the northern part of the Navajo Indian Reservation; chiefly a siltstone in southwestern part of the reservation; 100-700	Yields water to a few springs; tongues of the Navajo Sandstone in the upper part of the formation yield small amounts of water to wells near Tuba City; a few of these wells flow	<200	flow-50	Good to fair	<1,000
TRIASSIC(?)	UPPER	GLEN CANYON	Moenave Formation	Silty sandstone and sandy siltstone; 0-500	Essentially nonwater bearing	-	-	-	-
TRIASSIC	UPPER	GLEN CANYON	Wingate Sandstone	Upper member is a sandstone; 0-300. Lower member is a siltstone and silty sandstone; 0-900	Upper member: yields small and moderate amounts of water to springs and wells in northern Apache and Navajo Counties. Lower member: yields some water to springs; unit generally does not yield sufficient water to drilled wells	300-800	100-700	Upper member: good to fair. Lower member: fair to poor	200-3,000
TRIASSIC	UPPER		Chinle Formation (excluding Shinarump Member)	Alternating shaly units, 200-400 feet thick with sandstone beds 50-100 feet thick; formation between 850 and 1,500 feet thick	Shaly units are essentially nonwater bearing; sandstone beds yield small amounts of water to springs and wells in the Defiance uplift area	-	-	Generally good to fair in the Defiance uplift; locally contains high amounts of sulfate, chloride, and fluoride in Black Mesa basin	200->50,000

Table 2.--Brief descriptions of the water-bearing characteristics of sedimentary rocks in Apache, Coconino, and Navajo Counties, and adjoining regions, Arizona—Continued

SYSTEM	SERIES	GROUP	Stratigraphic unit	Brief lithologic description and thickness (feet)	Water-bearing characteristics: General hydrologic description	Water-bearing characteristics: Depth of wells (feet)	Water-bearing characteristics: Depth to water (feet)	Chemical quality of water: General characteristics	Chemical quality of water: Total dissolved solids (ppm)
TRIASSIC	UPPER		Shinarump Member of the Chinle Formation	Sandstone and some conglomerate and mudstone; 30-200	Locally, yields small amounts of water to wells and springs throughout northeastern Arizona; it is connected hydrologically with the Coconino (De Chelly) Sandstone of Permian age in the Defiance uplift area	100-2,500	flow-800	Generally good to fair on Defiance uplift but fair to poor in other areas	200-<2,000
TRIASSIC	MIDDLE(?) LOWER		Moenkopi Formation	Siltstone and some sandstone; 0-400	Yields a small amount of water to a few wells scattered throughout northern Arizona; water is generally salty; basal conglomerate of formation yields water to wells in northern Mohave and Coconino Counties	100-300	30-200	Locally where the formation is flushed the quality is fair; in the subsurface in Black Mesa basin it is poor being high in chloride and sulfate	500-30,000
PERMIAN			Kaibab Limestone	Limestone and some limy sandstone; 0-300	Yields small amounts of water to a few wells in southern Navajo and Coconino Counties; yields moderate amounts of water to wells in southern Apache County where the limestone is connected hydrologically with the Coconino Sandstone	100-300	100-250	Same as Coconino Sandstone	
PERMIAN		AUBREY	Coconino Sandstone (De Chelly Sandstone of the Defiance uplift and De Chelly Sandstone Member of Cutler Formation in Monument upwarp)	Sandstone; 300-800	Unit is the chief aquifer of northeastern Arizona; yields small to large amounts of water to wells in Apache, Navajo, and the southeastern part of Coconino County; locally in Apache County aquifer is utilized for irrigation; wedge-out of unit restricts ground-water development in northern Coconino and Mohave Counties	100-1,500	flow-1,000	Good to fair near areas of recharge in the Mogollon Rim and Defiance uplift; the aquifer is contaminated by water from Supai and Moenkopi Formations	200-60,000
PERMIAN		AUBREY	Supai Formation	Chiefly siltstone and sandstone, some gypsum present in southern Apache and Navajo Counties	Uppermost sandstone beds of formation interconnect hydrologically with the Coconino Sandstone; lowermost beds yield some water to wells in Coconino County and northeastern part of Verde Valley	150->2,000	100-2,000	Uppermost and lowermost sandstone beds contain water of good and fair quality in the San Francisco Plateau and Verde Valley areas; in Apache County it contains strongly mineralized water	200->60,000

Table 2.--Brief descriptions of the water-bearing characteristics of sedimentary rocks in Apache, Coconino, and Navajo Counties, and adjoining regions, Arizona—Continued

SYSTEM	SERIES	GROUP	Stratigraphic unit	Brief lithologic description and thickness (feet)	Water-bearing characteristics: General hydrologic description	Water-bearing characteristics: Depth of wells (feet)	Water-bearing characteristics: Depth to water (feet)	Chemical quality of water: General characteristics	Chemical quality of water: Total dissolved solids (ppm)
MISSISSIPPIAN			Redwall Limestone	Limestone; 0-500	Yields some water to wells in northeastern part of Verde Valley; yields large amounts of water to Blue Springs in canyon of the Little Colorado River and springs in Havasu Canyon	200->2,000	150-2,000	Usually good to fair; water in Havasu Canyon precipitates calcium carbonate	200-1,000
CAMBRIAN	MIDDLE	TONTO	Muav Limestone	Limestone; 0-300	Yields small amounts of water to a few springs in Marble and Grand Canyons; most of the water moves into the formation from the Redwall Limestone	-	-	-	-
CAMBRIAN	MIDDLE	TONTO	Bright Angel Shale	Shale; 0-600	Nonwater bearing	-	-	-	-
CAMBRIAN	MIDDLE and LOWER	TONTO	Tapeats Sandstone	Sandstone and some conglomerate; partly quartzitic; 0-250	Yields small amounts of water to springs in Grand Canyon	-	-	Generally poor; source of "Hopi Salt Springs" near mouth of the Little Colorado River	-

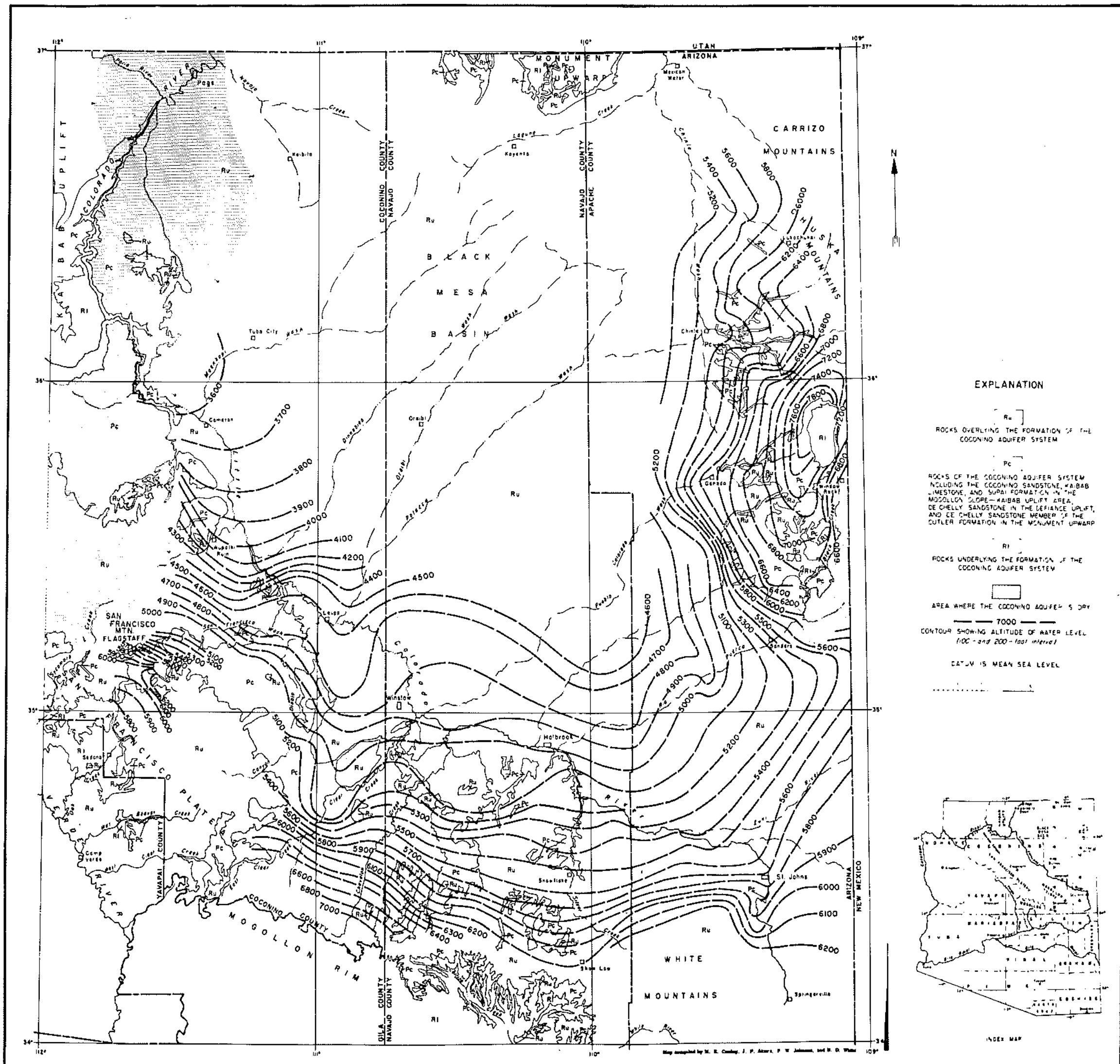

Figure 8.—Map showing altitudes of water levels, 1961, in the Coconino Sandstone aquifer system in Apache, Coconino, and Navajo Counties, Ariz.

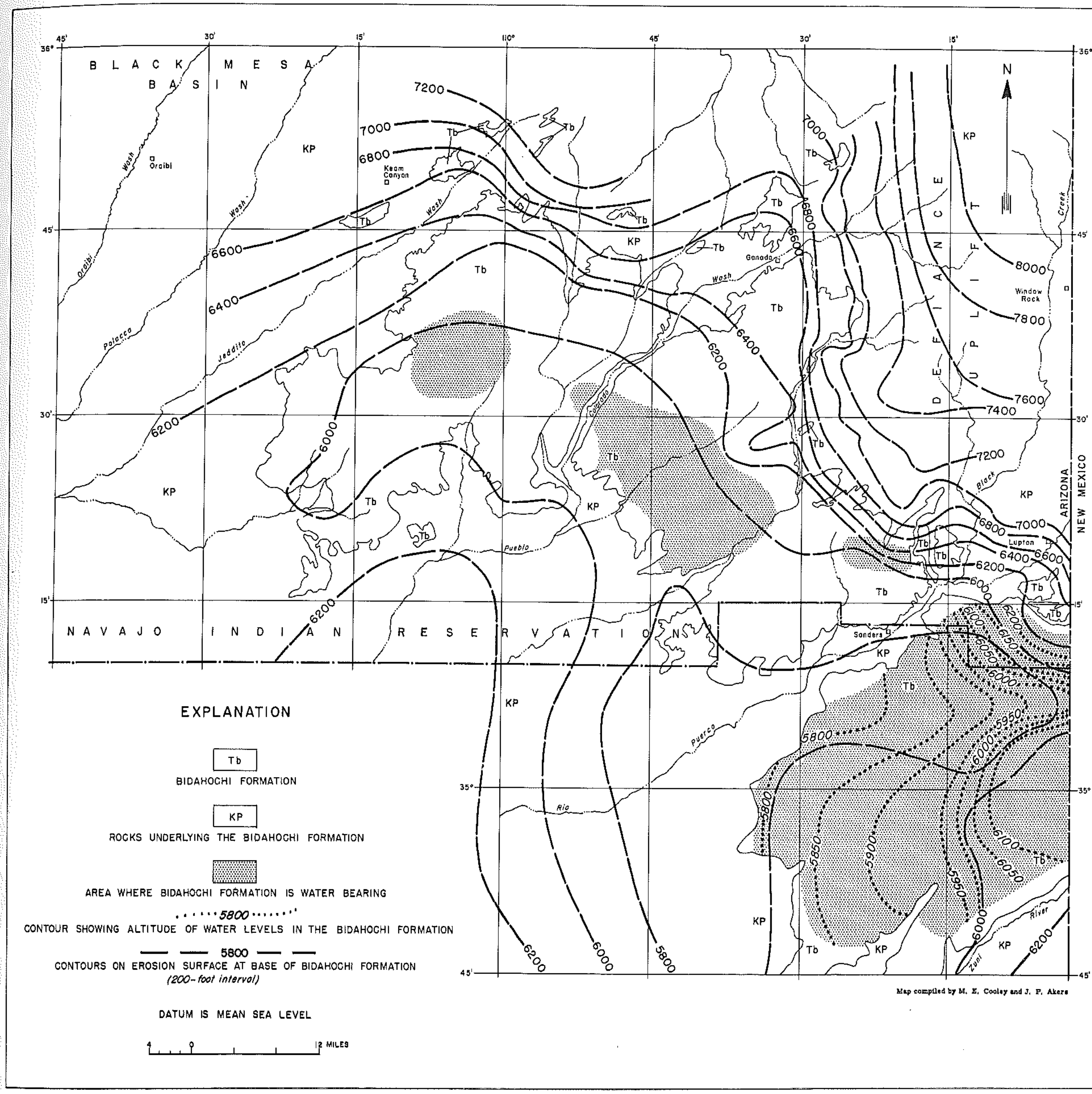

Figure 9.-- Map showing configuration of the base of the Bidahochi Formation and altitudes of water levels, 1961, in the Bidahochi Formation in Apache and Navajo Counties, Ariz.

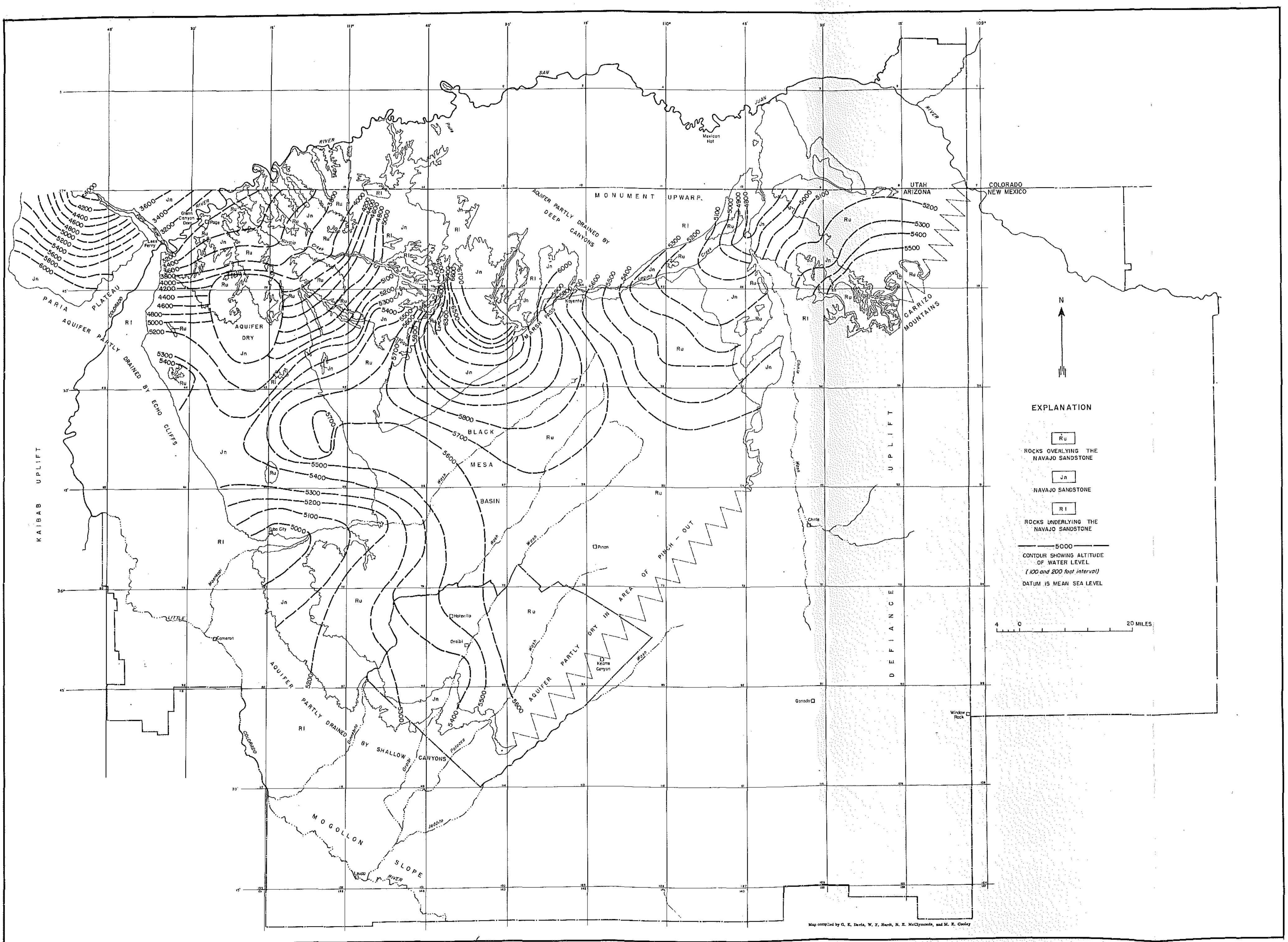

Figure 10.-- Map showing altitudes of water levels, 1961, in the Navajo Sandstone in Apache, Coconino, and Navajo Counties, Ariz.

which is older than the Coconino, yields water to several wells on the Defiance uplift.

Most of the wells in Apache County furnish water for domestic and stock use and yield from 5 to 50 gpm (gallons per minute) from depths of as much as 1,000 feet below the land surface. A few wells flow at the surface. Several wells developed in the alluvium near Red Lake about 20 miles north of Window Rock produce from 100 to 200 gpm. These wells were drilled for use by a wood-products mill being built at Navajo, New Mexico, by the Navajo Tribe. Irrigation wells in the Hunt and St. Johns areas yield from 800 to 2,000 gpm.

The chemical quality of the water in the aquifers in most of Apache County is fair to good. The most notable exception is the water of poor to very poor quality in the Coconino Sandstone in the structurally low area north of St. Johns. The water in the Coconino is of poor quality in most of the area bounded on the south by the Little Colorado River and Carrizo Wash and on the north by the Rio Puerco. The water from the Entrada and Bluff Sandstones in the northern part of the county is also of poor quality.

The available records are inadequate to show any significant fluctuations in the water levels in Apache County. However, several artesian wells in the Coconino Sandstone in the heavily pumped area near Hunt have ceased to flow. In general, water levels decline during the heavy pumping season but recover during the winter. The water levels in wells in the Hunt and St. Johns areas (fig. 11) show considerable seasonal fluctuation but no long-term trends are discernible.

Several continuous water-level recorders have been installed recently in Apache County, and these may help to establish trends of the decline or rise of the water level.

Cochise County

By

S. G. Brown and Natalie D. White

There are four principal areas of irrigation development in Cochise County: (1) Willcox Basin, (2) Douglas basin, (3) San Simon basin, and (4) upper San Pedro Valley.

Willcox Basin

The Willcox basin is in the northern part of the Sulphur Spring Valley. The basin extends from a drainage divide at the headwaters of Aravaipa Creek southward to a drainage divide among the buttes and ridges near

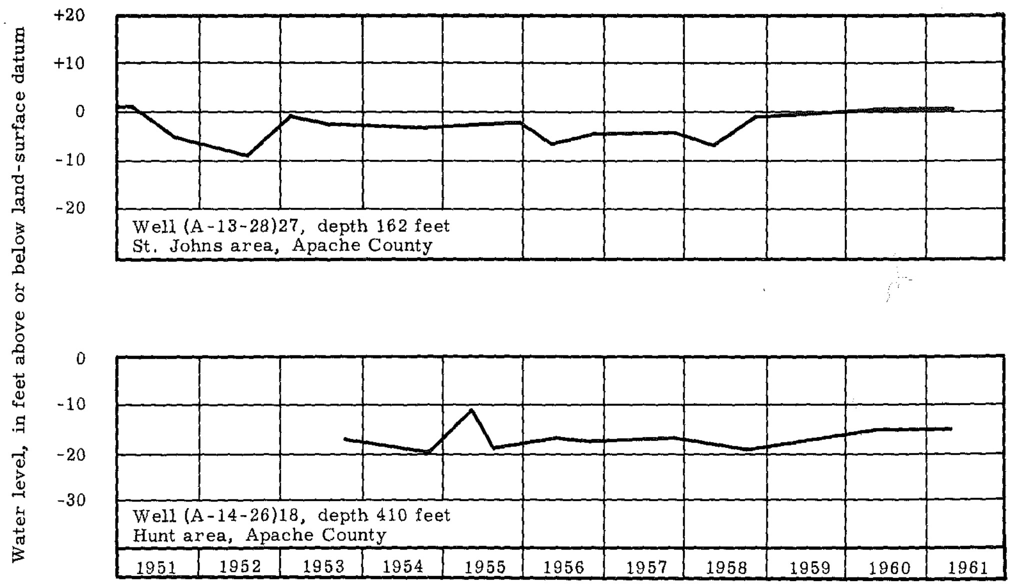

Figure 11.--Water levels in selected wells in Apache County.

the town of Pearce. Along the eastern side of the basin are the Pinaleno, Dos Cabezas, and Chiricahua Mountains, and along the western side are the Winchester, Little Dragoon, and Dragoon Mountains. The basin is about 30 miles wide, about 50 miles long, and covers about 1,500 square miles. Although most of the basin is within Cochise County, about 250 square miles in the northern part is in Graham County. The altitude of the valley floor ranges from 4,135 feet, at the Willcox playa, to about 4,500 feet at the lowest point of the drainage divide at the headwaters of Aravaipa Creek.

There are two main cultivated areas in the Willcox basin (fig. 12), the Stewart area and the Kansas Settlement area. The Stewart area, northwest of Willcox, is generally restricted to Tps. 12 and 13 S., Rs. 23 and 24 E. The irrigated area includes somewhat less than 20,000 acres. The Kansas Settlement area is about 8 miles south of Willcox and includes the eastern half of Tps. 15 and 16 S., R. 25 E. and all of T. 16 S., R. 26 E. This area includes more than 35,000 acres under irrigation and the irrigated acreage is expanding rapidly. There is about 5,000 acres under irrigation between Cochise and Pearce.

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

Infiltration of excess irrigation water has caused the levels of the shallow ground water in the eastern half of T. 15 S., R. 25 E. to rise more than 10 feet during the period spring 1956 to spring 1961.

In the Stewart area, water-level fluctuations for the period spring 1956 to spring 1961 (fig. 12) ranged from declines of 2 to 12 feet in the fringe areas to as much as 27 feet in the central part of the heavily pumped area. The water level in well (D-13-24)16 (fig. 13) in the heavily pumped area declined more than 9 feet from spring 1960 to spring 1961 and more than 26 feet from spring 1956 to spring 1961. In the spring of 1961 the depth to water below the land surface ranged from 20 feet near the town of Willcox to about 130 feet on the northern edge of the irrigated area near the Graham County line and about 145 feet 6 miles southwest of Bonita.

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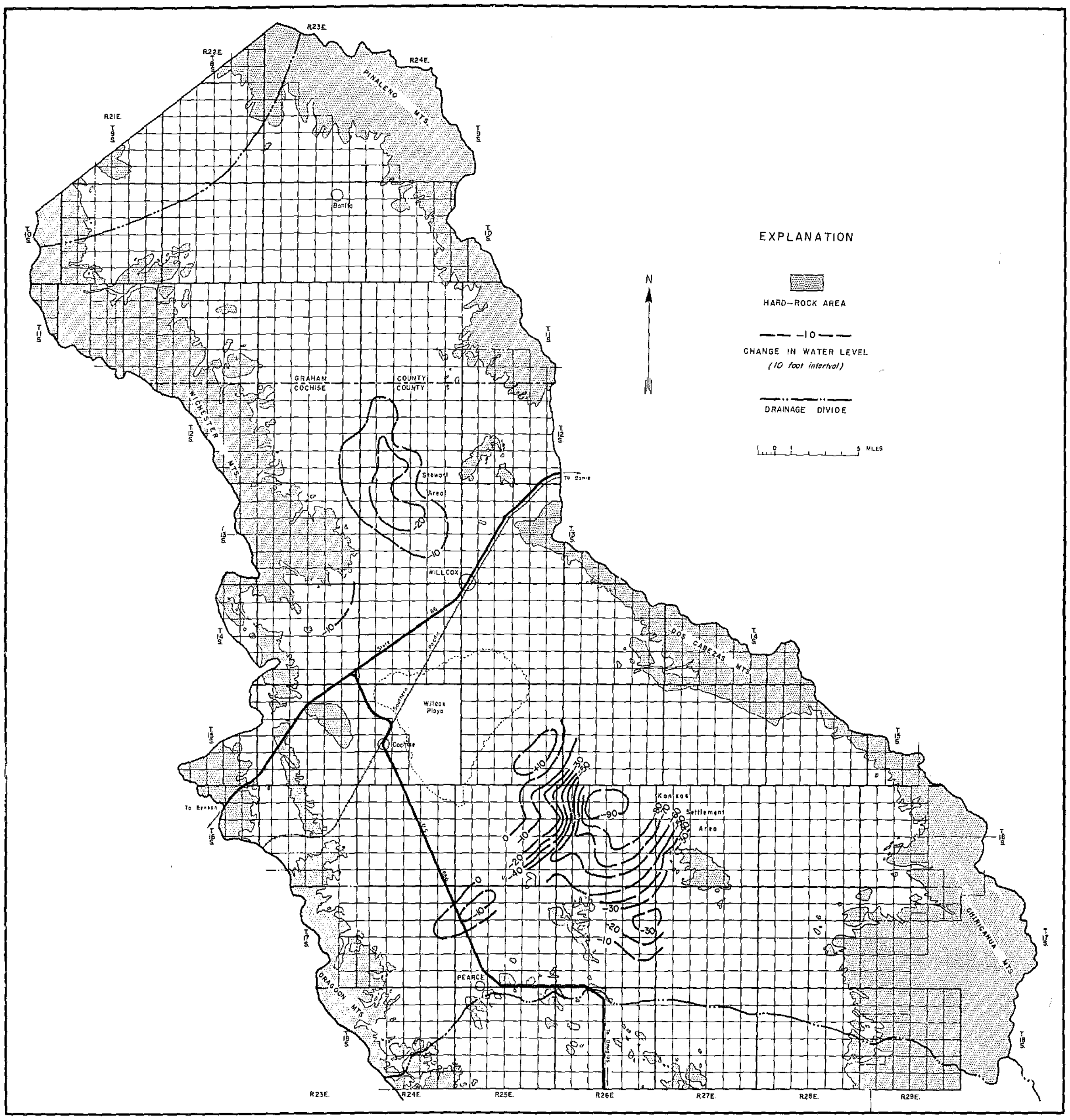

Figure 12.--Map of Willcox basin, Cochise and Graham Counties, Ariz. showing change in ground-water level from spring 1956 to spring 1961.

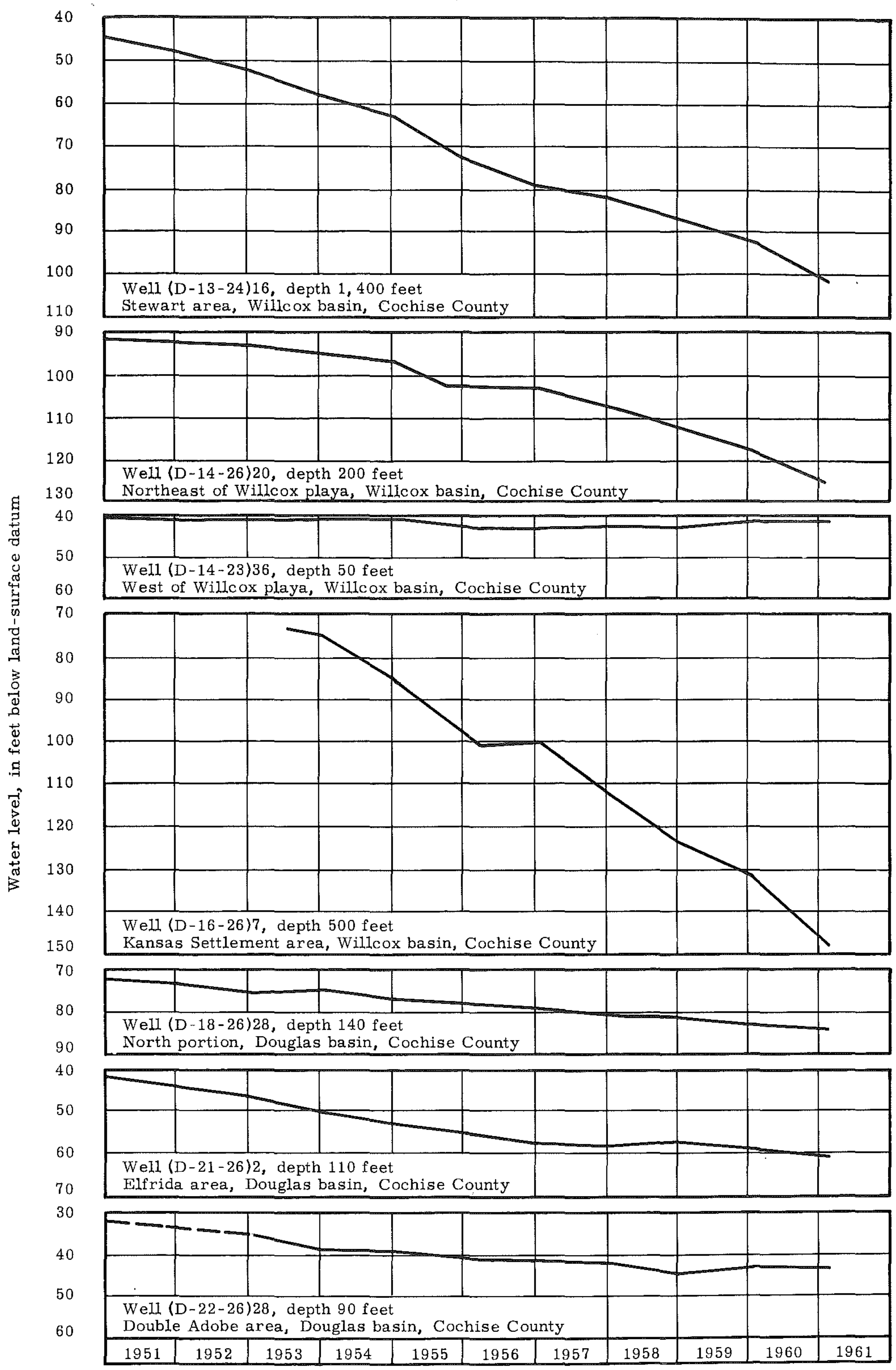

Figure 13.--Water levels in selected wells in the Willcox and Douglas basins, Cochise County.

From spring 1956 to spring 1961 water-level fluctuations in the Kansas Settlement area ranged from rises of about 3 to 14 feet in the lowlying area west of the Kansas Settlement road to declines of more than 96 feet in the center of the area of heavy withdrawal in the north-central part of T. 16 S., R. 26 E. Of special interest is the fact that water levels in the north-central part of T. 16 S., R. 26 E. have declined from 14 to 37 feet since the spring of 1960, while farther west in the eastern half of Tps. 15 and 16 S., R. 25 E. water levels have risen from 1 to 5 feet since the spring of 1960.

Water-level fluctuations in the Pearce area ranged from rises of about 6 feet to declines of more than 15 feet for the period spring 1956 to spring 1961. Water levels 1-½ miles southwest of Cochise have declined as much as 11 feet and risen slightly more than 3 feet in the Cochise cemetary well.

Douglas Basin

The Douglas basin is south of the Willcox basin in the southern part of the Sulphur Spring Valley. It is separated from the Willcox basin by a surface-water drainage divide formed by a series of buttes and ridges; Six-Mile Hill, Township Butte, and Turkey Creek Ridge are the most prominent. Along the east side are the Chiricahua, Pedregosa, and Perilla Mountains; on the south is the International Boundary; and on the west are the Mule and Dragoon Mountains. The basin is about 40 miles long, 30 miles wide, and includes an area of about 1,200 square miles. The altitude ranges from 4,400 feet in the vicinity of the drainage divide in the north to about 3,900 feet at the International Boundary. The cultivated areas are centered along Whitewater Draw which heads in the Chiricahua Mountains and enters the main part of the valley around the northern end of the Swisshelm Mountains. The channel loses its identity in the cultivated lands northeast of Elfrida, but reappears southwest of McNeal and trends southward into Mexico. Whitewater Draw is a perennial stream in the 2-mile reach immediately north of the International Boundary. This surface flow is caused by the stream channel intersecting the water table. The direction of ground-water movement in this basin is southward toward Douglas and Mexico. The gradient from Pearce to Douglas, a distance of about 40 miles, averages slightly less than 10 feet per mile. In the area near Douglas the gradient is a little steeper and is influenced by Whitewater Draw. The pumping in the basin has not greatly influenced the ground-water movement, although there is a slight flattening of the water table about 15 miles northwest of Douglas.

Water-level rises in the Douglas basin for the period spring 1956 to spring 1961 occurred only in the southern and eastern parts of the basin. Two areas of no decline exist—one just south of Double Adobe and the other 3 miles west of Douglas along State Highway 80. The remainder of this area is one of general water-level declines ranging from about 1 to 6 feet for the period spring 1956 to spring 1961 (fig. 14). Two

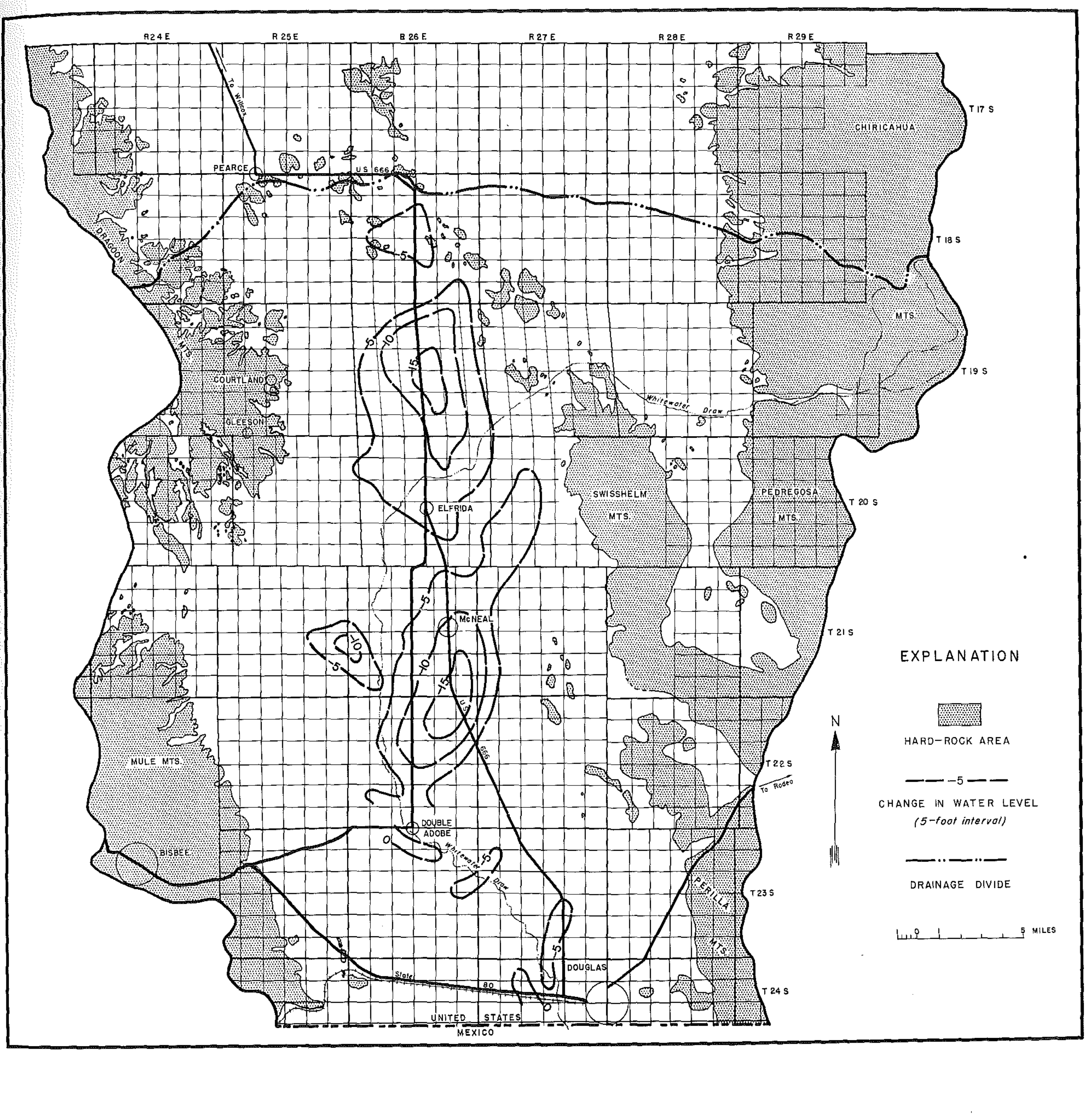

Figure 14.--Map of Douglas basin, Cochise County, Ariz. showing change in ground-water level from spring 1956 to spring 1961.

distinct areas of water-level decline are apparent. The area of decline south of McNeal has expanded rapidly from spring 1960 to spring 1961. Annual declines in Tps. 21 and 22 S., R. 26 E. range from zero in sec. 21, T. 21 S., R. 26 E. to about 10 feet in sec. 18, T. 21 S., R. 26 E. Water-level declines from spring 1956 to spring 1961 in the McNeal area range from zero to 19 feet. In the area north of Elfrida water-level declines have increased; for the 5-year period spring 1956 to spring 1961 the maximum decline in this area was nearly 16 feet at a point about 5 miles north of Elfrida. The water level in well (D-21-26) 2 (fig. 13) in the heavily pumped area between Elfrida and McNeal declined about 2 feet from spring 1960 to spring 1961. Water-level declines in the area west of McNeal for the period 1956 to 1961 ranged from 1 to 10 feet.

The depth to water in the Douglas basin ranges from 40 to 130 feet and in most of the area is less than 100 feet below the land surface. In general, water-level declines in the basin have been less than in similarly developed areas in the State.

San Simon Basin

The San Simon basin is part of a northwest-trending structural trough that extends from near Rodeo, N. Mex. to Globe, Ariz. It is bounded by two nearly parallel chains of mountains—the Peloncillo Mountains to the east and the Chiricahua, Dos Cabezas, and Pinaleno Mountains to the northwest and west. To the north, the San Simon basin merges with the Safford Valley. The area is drained by San Simon Creek and the gradient of the valley is about 20 feet per mile. On the sides of the valley the slopes are much greater and gradients of more than 100 feet per mile are common.

Nearly all the deposits in the San Simon basin are classified as older alluvial fill and have been divided into four geologic units—the "lower unit," the "blue clay unit," the "upper unit," and the "marginal zone." Hydrologically, the lower unit constitutes the "lower aquifer" and the saturated part of the upper unit constitutes the "upper aquifer." Ground water is under artesian conditions in the lower aquifer and under water-table conditions in the upper aquifer and in the marginal zone where the lower and upper aquifers form a hydrologic unit.

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

Bowie area.--In the Bowie area, the water levels in the artesian wells ranged from slightly more than 100 to about 180 feet below the land surface in the spring of 1961. Water-level fluctuations in these wells ranged from a rise of about 5 feet to a decline of about 14 feet for the period spring 1960 to spring 1961; for the 5-year period spring 1956 to spring 1961, declines in the water level ranged from about 20 to 60 feet. The water level in well (D-13-29)18 (fig. 15) declined about 5 feet from spring 1960 to spring 1961, about 38 feet since spring 1956, and about 95 feet during the 10-year period spring 1951 to spring 1961.

Several wells have been drilled in the marginal zone in the area a few miles south of Bowie. The water level, measured in four of these wells in the spring of 1961, ranged from about 260 to 340 feet below the land surface. Water-level declines in these wells ranged from about 20 to 30 feet from spring 1960 to spring 1961, and for the 5-year period spring 1956 to spring 1961, the water-level declines ranged from about 40 to more than 60 feet. The water level in well (D-13-28)16 (fig. 15) declined about 30 feet from spring 1960 to spring 1961, about 50 feet from spring 1956 to spring 1961, and about 115 feet since 1953 when the first measurement was made. The hydrograph shows that the water level in this well fluctuates erratically; this pattern seems to predominate in the wells in this area. There are no shallow water-table wells in the Bowie area.

San Simon area.--The depth to water in the artesian wells in the San Simon area ranged from less than 30 to more than 100 feet below the land surface in the spring of 1961. Water-level fluctuations ranged from a rise of about 9 feet to a decline of about 9 feet in the period spring 1960 to spring 1961. In the 5-year period spring 1956 to spring 1961, water-level fluctuations ranged from a rise of about 8 feet to a decline of about 23 feet. The water level in artesian well (D-14-31)3 (fig. 15) declined about 7 feet from spring 1960 to spring 1961, about 15 feet in the 5-year period spring 1956 to spring 1961, and more than 35 feet since the spring of 1951.

The water level was measured in only three of the shallow water-table wells in the San Simon area in the spring of 1961. The depth to water in these wells averaged about 65 feet below the land surface, and water-level declines ranged from zero to about 2 feet from spring 1960 to spring 1961. For the 5-year period spring 1956 to spring 1961, declines ranged from less than a foot to about 2 feet. The water level in well (D-13-31)30 (fig. 15) declined less than half a foot from spring 1960 to spring 1961, about 2 feet from spring 1956 to spring 1961, and about 4 feet since spring 1951.

Upper San Pedro Valley

The upper San Pedro Valley is defined as the drainage area of the north-flowing San Pedro River between the International Boundary on the south and the narrows at Tres Alamos, about 8 miles north of Pomerene, Ariz. The east boundary is the drainage divide extending from the southern end of the Winchester Mountains, southward through

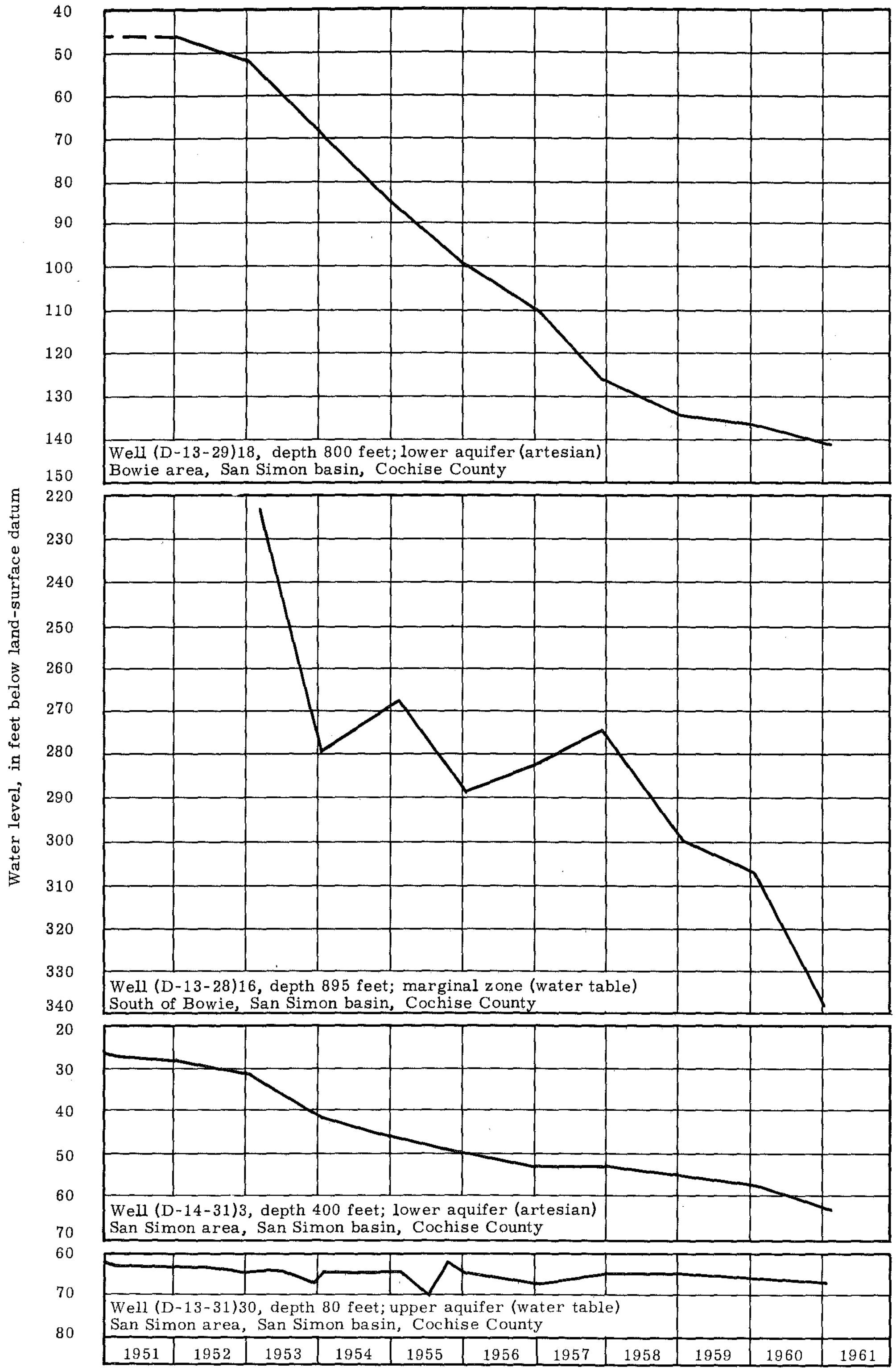

Figure 15.--Water levels in selected wells in the San Simon basin, Cochise County.

the Little Dragoon, Dragoon, and Mule Mountains. The west boundary is the drainage divide between the San Pedro and Santa Cruz Rivers along the Rincon, Whetstone, and Huachuca Mountains. The upper San Pedro Valley is about 58 miles long and ranges from 15 to 35 miles wide. The drainage area of the San Pedro River above the narrows is about 2,500 square miles, of which about 1,850 is in the United States and the remainder is in Mexico.

Nearly all the ground water in the upper San Pedro Valley is in the alluvial fills; it is under water-table conditions in the Recent alluvium and under artesian conditions in the older alluvium. The chief source of the ground water in the basin is runoff from precipitation in the mountains and surface flow in the San Pedro River. The movement of ground water in the basin is similar to the land-surface drainage—the ground-water divide is in Mexico and the water moves from south to north along the axis of the valley, similar to the San Pedro River. Water also moves toward the center of the valley from the bordering mountains.

For the period spring 1960 to spring 1961, water-level fluctuations ranged from rises of about 2 feet to declines of about 4 feet. For the 5-year period spring 1956 to spring 1961, water-level rises ranged from less than half a foot to nearly 6 feet and water-level declines ranged from less than 3 to nearly 6 feet. The upper San Pedro Valley is not extensively developed and the pumping of ground water is at a minimum. The hydrograph for well (D-16-20)34 (fig. 16) shows that the water level in this well declined about 2 feet from spring 1960 to spring 1961, rose nearly 3 feet in the 5-year period spring 1956 to spring 1961, and declined slightly more than a foot since 1951. The water level in well (D-20-20)27 (fig. 16) has been measured only for a few years and no trend is discernible; the water level in this well rose about 4 feet from March 1960 to March 1961. The depths to water in wells adjacent to the San Pedro River are less than 100 feet and some are less than 25 feet below the land surface, although water levels in wells a few miles distant from the river are more than 300 feet below the land surface.

Coconino County

By

M. E. Cooley

All ground-water movement in Coconino County is controlled by the broad structural arch formed by the Kaibab uplift and the Mormon Mountain anticline. The arch trends northward and northwestward across the San Francisco Plateau and the Grand Canyon. All the precipitation that enters the rocks as ground water moves from this arch northeastward into the Black Mesa basin or it moves westward or southwestward, and is discharged eventually into the tributaries of the Colorado and Verde Rivers (fig. 8).

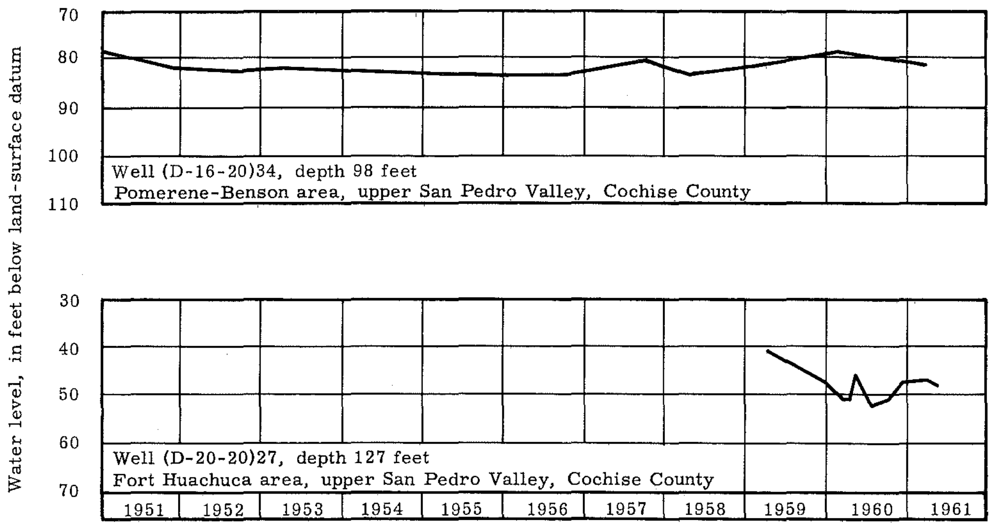

Figure 16.--Water levels in selected wells in the upper San Pedro Valley, Cochise County.

The chief aquifer is the Coconino Sandstone which is present in the subsurface throughout most of the county (table 2). About 50 deep wells withdraw small to moderate amounts of ground water from the aquifer in the central and southeastern parts of the county. The largest yields are from 200 to 500 gpm from wells drilled for the city of Flagstaff in the Woody Mountain well field; wells in the vicinity of Leupp yield about 200 gpm. Throughout the western and northern parts of the county, the Coconino Sandstone generally is dry (fig. 8). Locally, southeast of Flagstaff, the Coconino either is dry or contains extremely small amounts of water. Successful wells drilled in these areas must withdraw water from the Coconino in combination with the uppermost sandstone beds of the underlying Supai Formation. Water levels in wells in the Coconino Sandstone range from 100 to 400 feet in the area near the Little Colorado River and to more than 1,000 feet in the vicinity of Flagstaff.

Fracturing of the Coconino Sandstone aquifer by faults and joints has increased its permeability. Many of the fractures serve as conduits to intercept ground water moving through the aquifer, and they divert it downward into the underlying Supai Formation and Redwall Limestone. In the northwestern part of the county the Coconino Sandstone has been drained by these fractures and by incising of the Grand Canyon and its deep tributary canyons. However, in some places in this area the underlying Supai Formation and Redwall Limestone contain water at depths of more than 1,500 feet below the land surface. The large-yielding springs of Havasu Canyon issue principally from the Redwall Limestone. All the springs in and near Havasu Canyon have a total discharge of about 65 cfs, or about 47,500 acre-feet per year, which represents the total discharge of northward-moving ground water in Coconino County west of Flagstaff and south of Grand Canyon. Although Blue Springs issue from the Redwall Limestone in the canyon of the Little Colorado River, their water is originally derived principally from the Coconino Sandstone. The yield is 123 cfs or about 89,000 acre-feet per year, and is most of the ground-water discharge from all water-bearing rocks of the Black Mesa basin and adjoining regions in Coconino, Navajo, and Apache Counties. The approximate ground-water discharge of the Kaibab uplift, represented chiefly by the base flows of Tapeats and Bright Angel Creeks, is 75 cfs. The sum of the ground-water discharge into the Colorado River system from the Coconino Sandstone, including the Supai Formation and Redwall Limestone, in Coconino County and the adjoining Black Mesa basin area in Navajo and Apache Counties is more than 275 cfs or nearly 200,000 acre-feet per year. Additional water is discharged from these aquifers southward into the Verde River system.

In the northeastern part of Coconino County, the Navajo Sandstone generally yields from 10 to 30 gpm of water to stock wells in the Navajo Indian Reservation. However, wells near Tuba City yield as much as 200 gpm, a well at the Cow Springs School yields 130 gpm, and wells north of the Colorado River at the Glen Canyon Dam yield between 100 and 1,000 gpm. The depth to water in wells in the Navajo Sandstone ranges from 50 to 1,400 feet below the land surface. Locally, in an area south of Page, the Navajo Sandstone is dry. Movement of water within the Navajo Sandstone in the Kaiparowits basin is toward the Colorado River and locally toward the Paria River (fig. 10); in Black Mesa basin, the movement is principally toward Moenkopi Wash. The perennial stretches of Moenkopi Wash, the Paria River, and Navajo Creek are maintained by this ground-water discharge.

Volcanic rocks and associated sediments in the southern part of Coconino County contain zones of perched water that are hundreds of feet above the regional water table in the Coconino Sandstone (table 2). The largest yield is from sediments laid down by glaciers on San Francisco Mountain. A substantial part of this water is utilized by a system of collection galleries, and forms most of the supply for the city of Flagstaff. Locally, some water is withdrawn by shallow wells drilled into the alluvium within the city limits in the northwestern part of Flagstaff. A few wells drilled in the volcanics and sediments elsewhere in the county yield some water, but because of complex hydrogeologic conditions within this area, a large number of dry holes have been drilled.

Most of the wells and small springs in Coconino County show minor fluctuations of water level, which may be due partly to seasonal variation and partly to variations in the amount of annual precipitation. Because most of the county is in the recharge area of the several aquifers, short-term variations in the amount of precipitation cause fluctuation of the water table. The fluctuations are greatest in the water levels in shallow wells in the volcanic rocks and alluvial sediments and in yields of springs. The yields of springs issuing from the Navajo Sandstone near the Colorado River fluctuate seasonally. Little or no fluctuation of the water levels occurs in deep wells in the Coconino and Navajo Sandstones or in the discharge of the large springs in Havasu Canyon and at Blue Springs.

The water in the collection galleries in the glacial sediments on San Francisco Mountain fluctuates seasonally, depending primarily on winter snowfall and secondarily on precipitation during July and August (fig. 17). During the 2-year period 1955-56, the galleries discharged a minimum of 99,409,964 gallons per year, and in the period 1958-60 the average discharge was 221,688,670 gallons per year. The discharge in 1960 was 178,444,497 gallons which is considered about a normal year. Data above were furnished by the city of Flagstaff.

Gila County

By

Natalie D. White and P. W. Johnson

The mountainous terrain of Gila County is probably unfavorable for the storage of large amounts of ground water. The principal streams in the county are the Salt River and Tonto Creek, which drain into Roose-

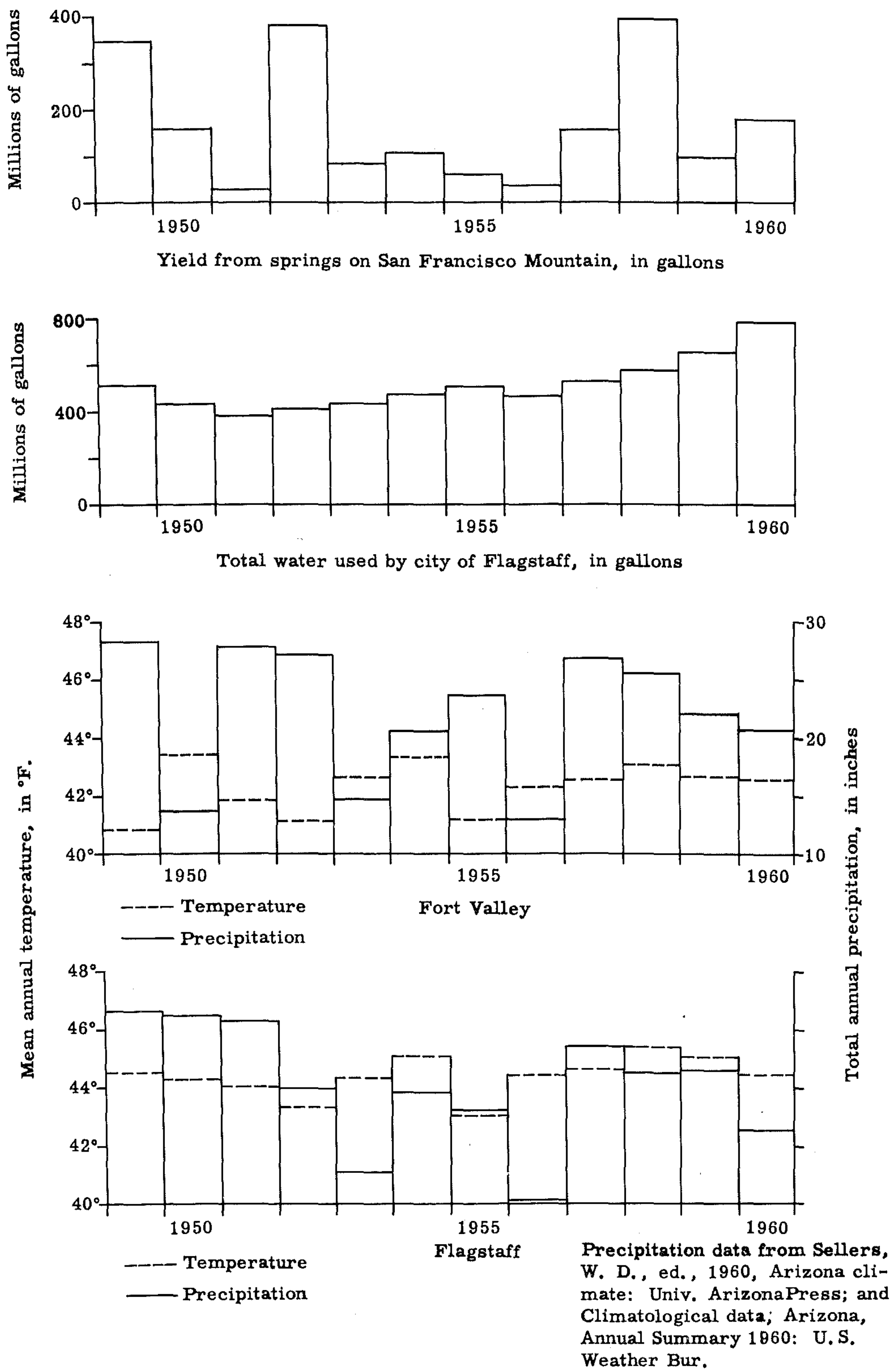

Figure 17.--Chart showing water used by the city of Flagstaff, and correlation of the yield from springs on San Francisco Mountain with annual precipitation at Flagstaff and Fort Valley.

velt Lake. The lake and parts of Tonto Creek are underlain by alluvial deposits which store ground water. The only outlet for water from this lake is by regulated surface flow at Roosevelt Dam. In the southern part of the county, the tributaries of the San Carlos River valley east of Globe consist of alluvial deposits. The movement of ground water is in the same direction as the surface flow—toward San Carlos Lake.

In Gila County, ground-water levels are measured in and near the city of Globe, in the Dripping Springs Valley, and in the San Carlos Valley of the San Carlos Indian Reservation. The Globe area is on the northern slope of the Pinal Mountains; Pinal Creek and its tributaries drain the area and flow northward into the Salt River. Most of the wells are shallow, and the water levels fluctuate in response to surface flow and local domestic pumping. In general, the water levels in wells measured in the spring of 1961 were higher than in previous years; some of the water levels, however, were lower than in spring 1960, probably owing to lack of surface flow.

The Dripping Springs Valley lies between the Pinal and Mescal Mountains on the north and the Dripping Springs Mountains on the south, and drains southward into the Gila River. Most of the water levels are shallow and fluctuate in response to surface flow along the valley. Water levels are generally rising in the area, although from spring 1960 to spring 1961, the water level in some of the wells measured declined as a result of lack of surface flow.

The San Carlos Valley is in a trough traversed by the San Carlos River, which flows southward to the San Carlos Reservoir. The basin is bounded on the east by Natanes Mountain; on the south by the Turnball Range; on the west by the eastern ridges of the Mescal, Pinal, and Apache Mountains; and on the north, in part, by the Gila Range. Along the flood plain of the San Carlos River about 1,000 acres has been developed for irrigation. The water levels are shallow and the ground water is recharged by summer floods. No decline in water level has been recorded.

Graham County

By

W. D. Potts and E. S. Davidson

More than 90 percent of the irrigated area in Graham County is in the Safford basin. The remaining cultivated area near Bonita is mentioned in the section on the "Willcox Basin," Cochise County. The Safford basin bounded by the Gila Mountains to the northeast and the Pinaleno and Santa Teresa Mountains to the southwest, is about 50 miles long and 15 to 20 miles wide; however, most of the agricultural and ground-water development is within the ½- to 3-½-mile-wide flood plain of the Gila River.

The principal developed aquifer in the Safford basin is the alluvial fill, which underlies the present flood plain of the Gila River. This very permeable aquifer is as much as 110 feet and averages 60 to 70 feet in thickness in the vicinity of Safford. The alluvial fill receives ground-water recharge from surface flow and underflow of the Gila River and tributary drainage, from precipitation, and from return irrigation water. Discharge from the aquifer takes place by pumping from wells, underflow out of the basin, evaporation, and transpiration.

Measurements of water levels in the alluvial fill show that there has been an overall decline in the area of about 2 feet from spring 1960 to spring 1961. The water level in well (D-4-22)13 near Geronimo and in well (D-6-28)31 near San Jose (fig. 18) declined nearly 4 feet from spring 1960 to spring 1961. The water level in well (D-6-24)5 (fig. 18) declined more than 1-½ feet in the same period. Water levels near Solomon rose nearly 2 feet and a slight rise was measured near Fort Thomas during the period spring 1960 to spring 1961. During the 5-year period spring 1956 to spring 1961, the water level rose in nearly all the wells measured. The measured rise in water levels during the 5-year period ranged from about ½ foot to nearly 22 feet. The depth to water below the land surface in spring 1961 ranged from about 17 to nearly 60 feet.

Measurements of water levels in the nonflowing wells in the Cactus Flat-Artesia area show declines ranging from nearly 3 feet to more than 7 feet from spring 1960 to spring 1961. During the 5-year period spring 1956 to spring 1961 these water levels declined from a foot to more than 7 feet. Flowing wells in this area usually continue to flow until spring and summer pumping lowers the head sufficiently to cause a cessation of natural flow.

Deep aquifers yield water under flowing and nonflowing artesian conditions in the Cactus Flat-Artesia area, Bear Spring Flat, Cottonwood Wash, and to a few wells along the Gila River. The water contains moderate to very high amounts of total solids. Sodium, chloride, bicarbonate, and sulfate are the principal constituents of these solids; therefore, the water from the artesian aquifers is moderately to highly injurious for irrigation use and is not used extensively in the area.

A continuation of below-average precipitation and streamflow may result in a continued and perhaps increased decline of the water levels during the 1961 growing season because more ground water must be pumped to supply irrigation demands.

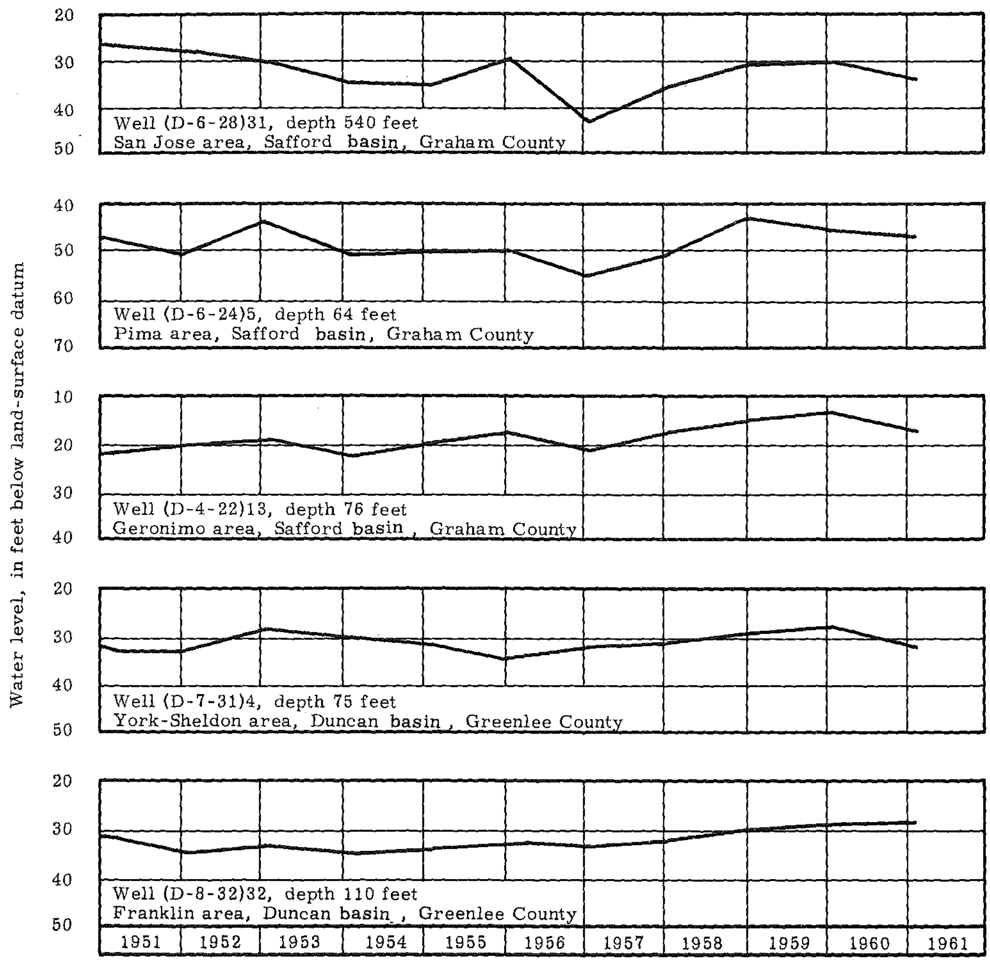

Figure 18. --Water levels in selected wells, Graham and Greenlee Counties.

Greenlee County

By

W. D. Potts and E. S. Davidson

Nearly all the agricultural and ground-water development in Greenlee County is in the Duncan basin, a northwest-trending alluvial basin extending into New Mexico. The basin is bounded by the Steeple Rock Mountains on the northeast and by the Peloncillo Mountains on the southwest. The rest of Greenlee County is predominantly mountainous and heavily forested, and, except for some development in the Eagle Creek drainage, the amount of ground water pumped is insignificant.

Measurements of 8 observation wells in this area show that there has been a slight decline in the water levels from spring 1960 to spring 1961. The water level in well (D-8-32)32 (fig. 18) near Duncan rose about a quarter of a foot in this period, and in well (D-7-31)4 (fig. 18) about 12 miles down the valley from well (D-8-32)32 the water level declined about 3 feet. However, the overall decline in the area was probably less than 2 feet. During the 5-year period spring 1956 to spring 1961, the water level rose from 1/4 of a foot to more than 17 feet in the observed wells. The depth to water in spring 1961 ranged from 10 feet to more than 65 feet below the land surface.

About 8,100 acres of land was irrigated in Greenlee County in 1960. From March 1960 to February 1961 about 15,000 acre-feet of surface water was diverted from the Gila River for irrigation. Additional water was pumped from the ground-water reservoir to supply the demands.

The usage of ground water in the Duncan basin during the 1961 growing season probably will result in an additional general water-level decline because of deficient Gila River flow and deficient rainfall. Such a condition necessitates increased pumping of ground water and decreases the amount of water that ordinarily is available to recharge the basin ground-water reservoir.

Maricopa County

By

R. S. Stulik

In 1960, 523,863 acres (Arizona Agriculture 1961: Arizona Agr. Expt. Sta. Bull. A-10, February, 1961) was under irrigation in Maricopa County, which accounted for about 40 percent of the total irrigated acreage in Arizona. The four principal areas of irrigation in Maricopa County are (1) Salt River Valley, (2) Gila Bend area, (3) Waterman

Wash area, and (4) Harquahala Plains area. The Salt River Valley is by far the largest area of agricultural development.

Salt River Valley

The Salt River Valley comprises the valley lands in the vicinity of Phoenix and tributary valleys such as Paradise Valley and Deer Valley, as well as lands west of the Hassayampa River and the lower reaches of Centennial Wash. Most of the area is drained by the Salt, Agua Fria, and Hassayampa Rivers, but a small part on the east and south is drained by the Gila River. The area is bounded on the north by the Hieroglyphic Mountains and Black Mountain; on the northeast and east by the McDowell, Usery, and Superstition Mountains; on the south by the Gila River to the Santan Mountains; then by the Maricopa-Pinal County line to the Sierra Estrella Mountains; 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. Although the Magma subarea lies in Pinal County, it is included in the discussion of Maricopa County because it is a part of the Salt River Valley. These areas are delineated and named on the map showing declines of the water level in the Salt River Valley area (fig. 19). Figures 20, 21, and 22 show the cumulative net changes in water levels in various parts of the Salt River Valley since 1930. Figure 21 also shows the total pumpage for the Salt River Valley area.

In the Salt River Valley the direction of ground-water movement conforms, in general, to the direction of slope of the land surface. In some places the natural direction of movement has been reversed and ground water is now moving toward major cones of depression that have resulted from heavy withdrawals. As of the spring of 1961, there were three such depressions in the area—northeast of Gilbert, in Deer Valley, and northwest of Litchfield Park. Most of the ground water in the eastern part of the Salt River Valley flows toward the depression northeast of Gilbert. In the central part of the valley most of the ground water flows to the west, but some of it flows toward the depression in Deer Valley. In the northwestern section of the valley, the ground water generally flows southward toward the depression northwest of Litchfield Park, but some water flows toward the depression in Deer Valley. In the Liberty-Buckeye-Hassayampa area the water generally flows to the southwest, but some water flows north toward the depression near Litchfield Park. In the area west of the Hassayampa River the ground water flows southward toward Gillespie Dam.

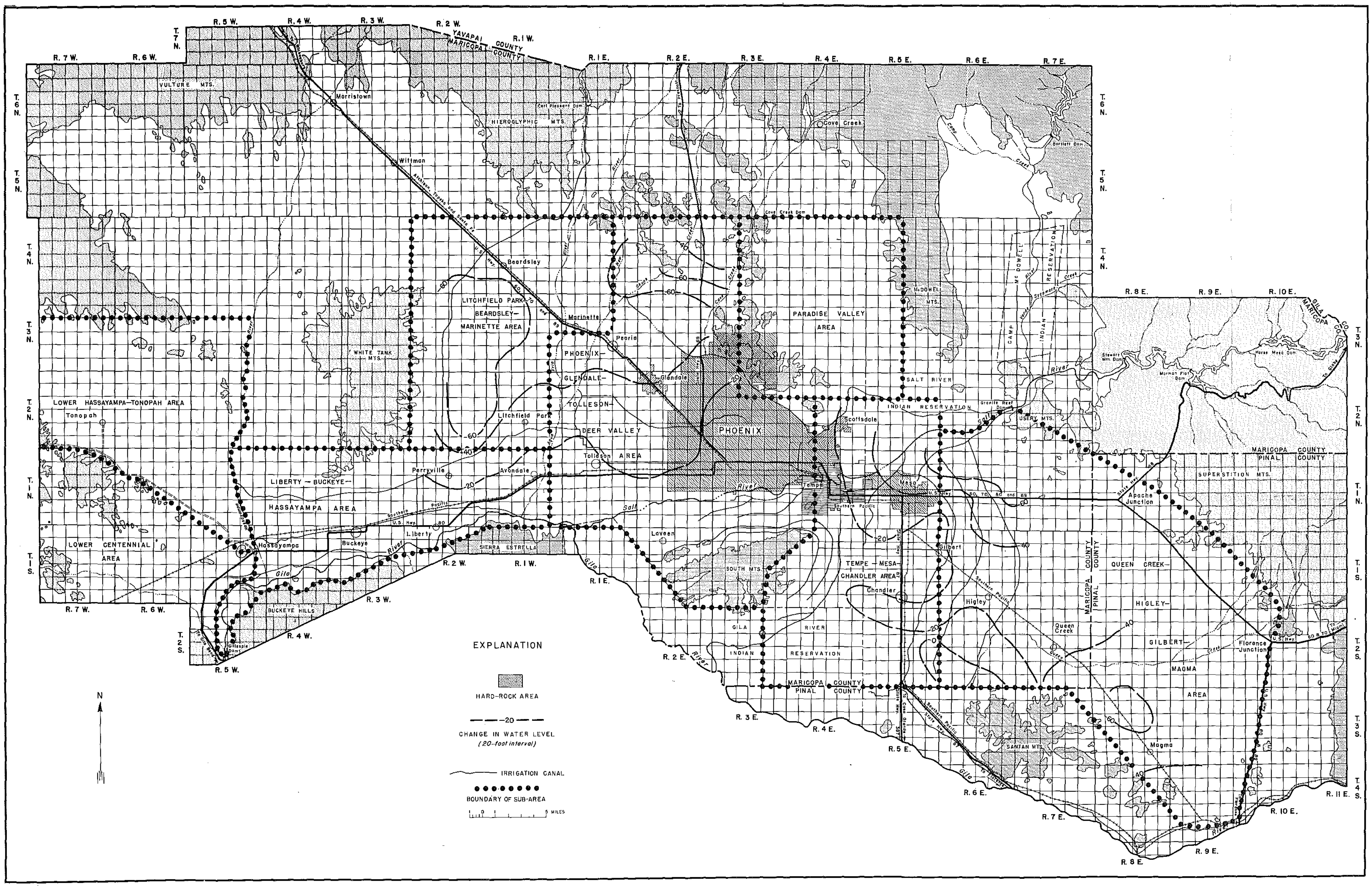

Figure 19.--Map of Salt River Valley area, Maricopa and Pinal Counties, Ariz. showing change in ground-water level from spring 1956 to spring 1961.

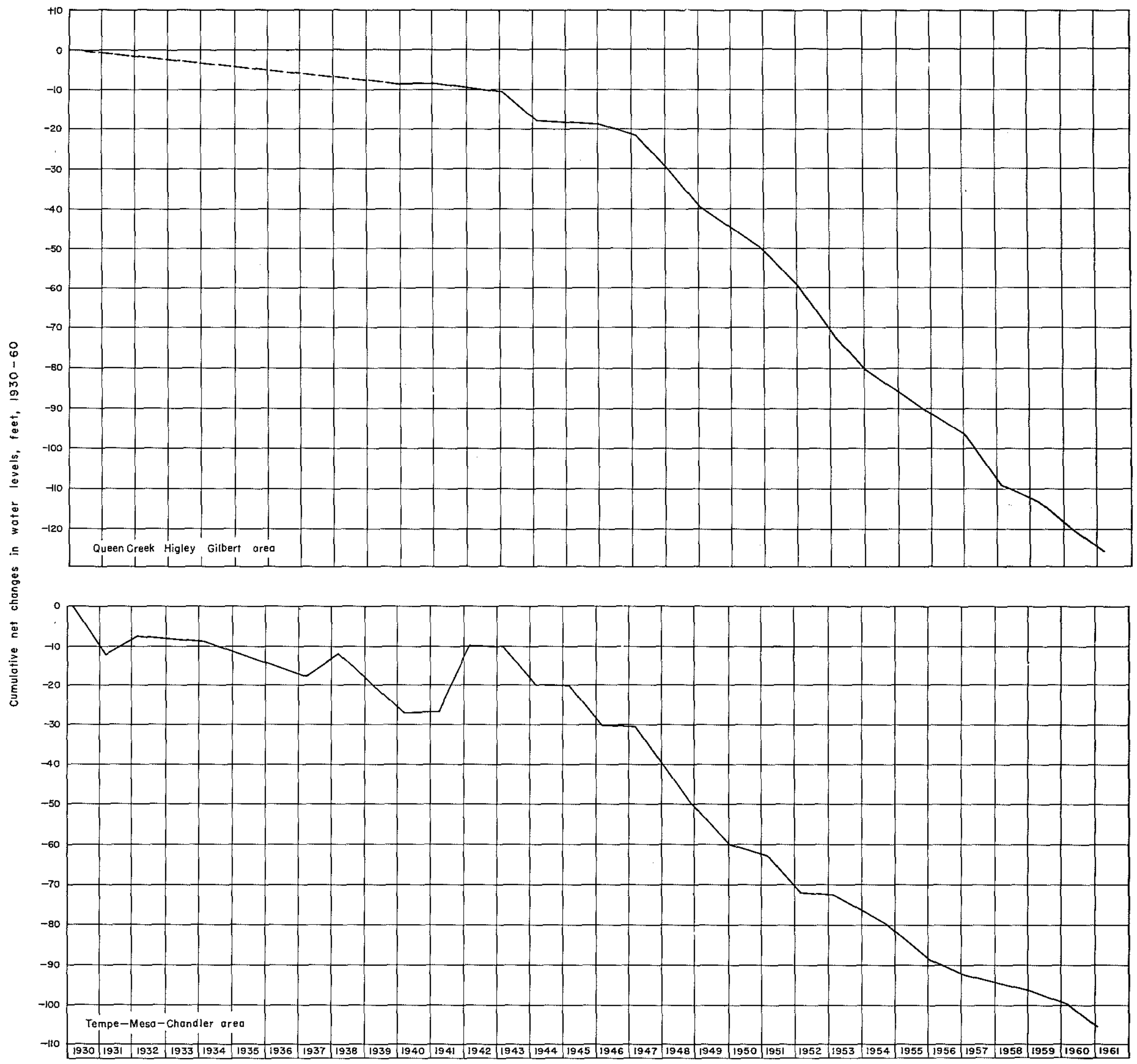

Figure 20.--Cumulative net changes in water levels in the Queen Creek-Higley-Gilbert and Tempe-Mesa-Chandler areas of the Salt River Valley, Maricopa County.

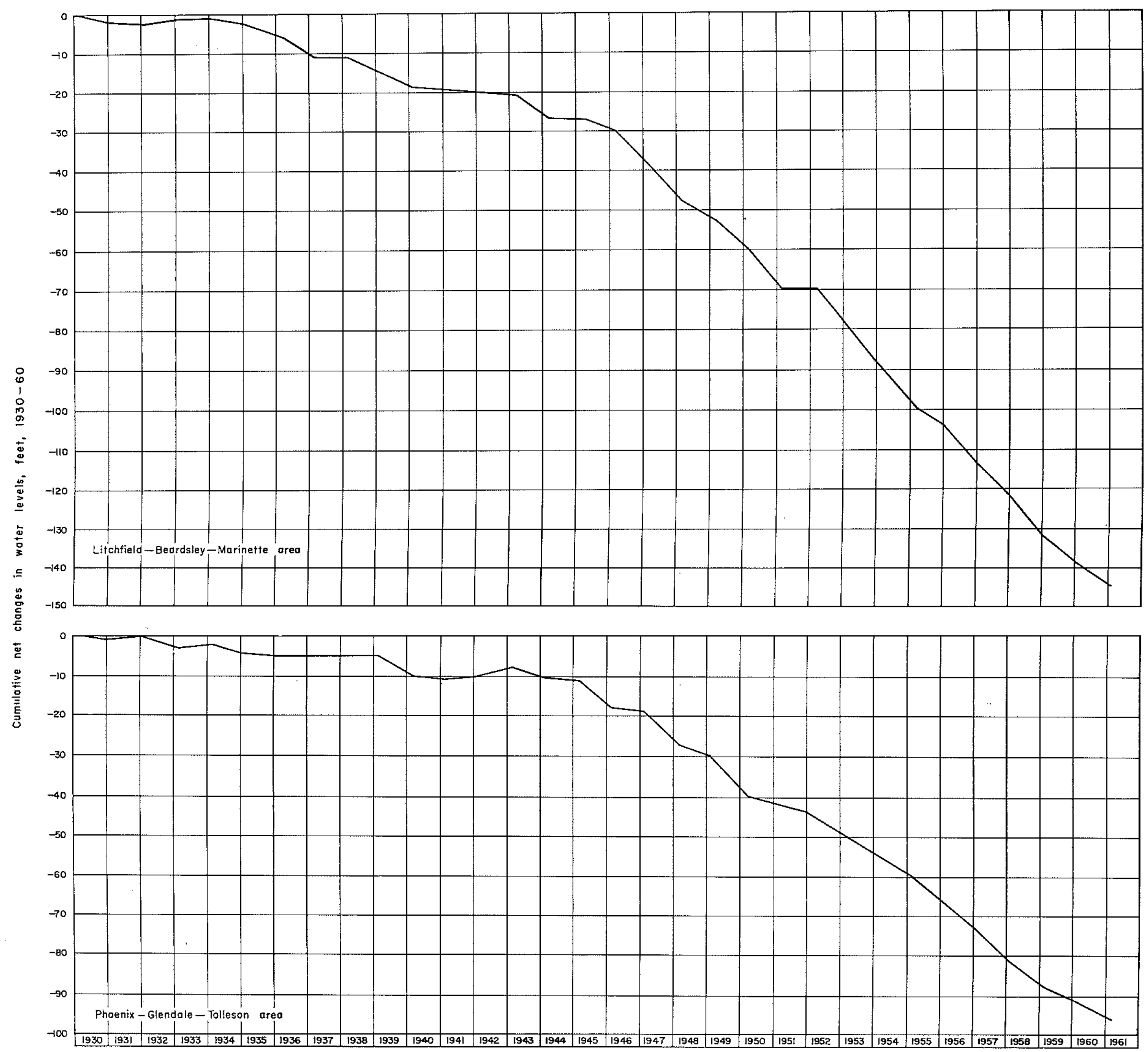

Figure 21.--Cumulative net changes in water levels in the Litchfield-Beardsley-Marinette and Phoenix-Glendale-Tolleson areas of the Salt River Valley, Maricopa County.

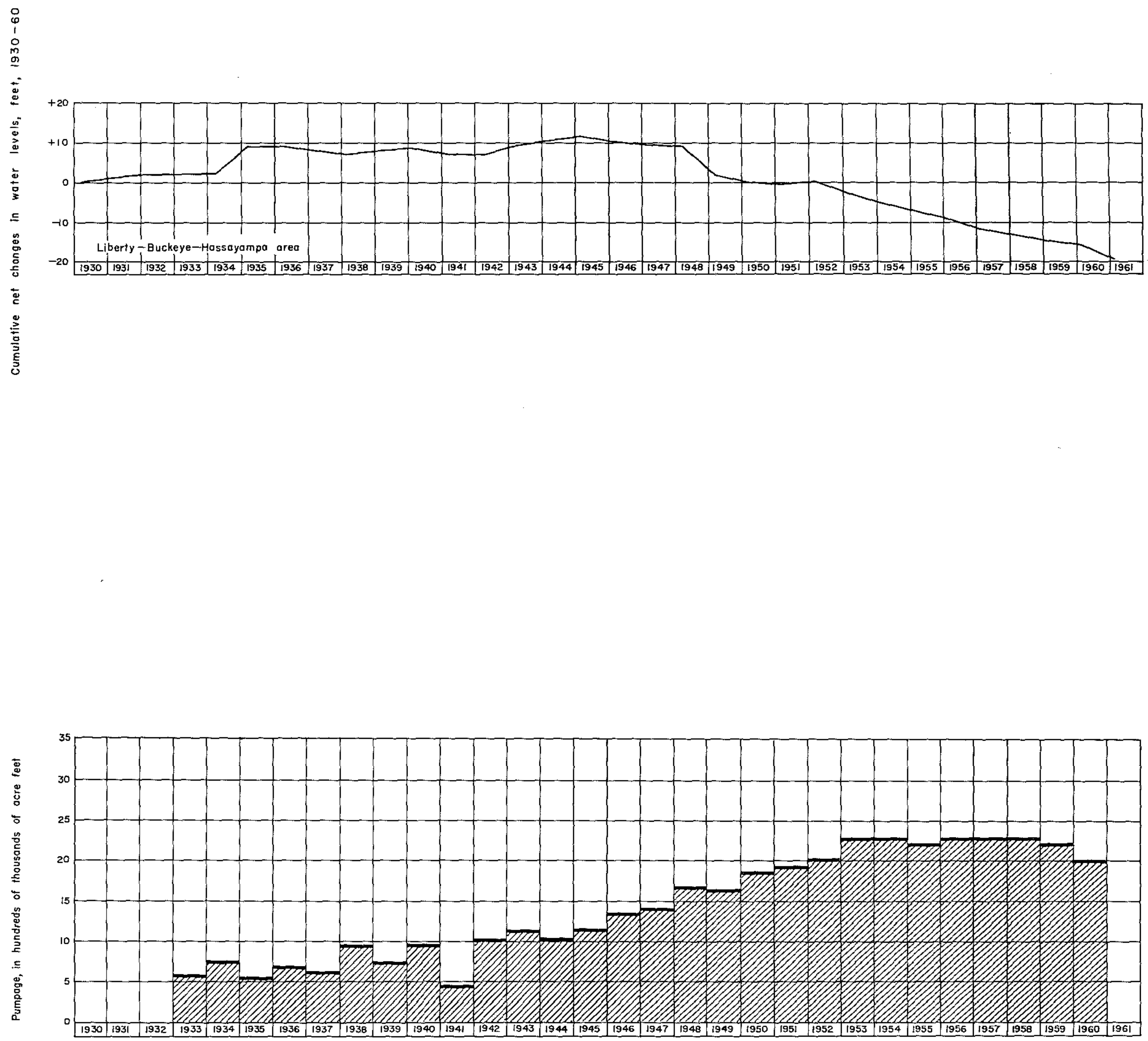

Figure 22.--Cumulative net changes in water levels in the Liberty-Buckeye-Hassayampa area and total annual pumpage in the Salt River Valley, Maricopa County.

Queen Creek-Higley-Gilbert-Magma area.--During 1960 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. 20). In the period spring 1960 to spring 1961, water-level fluctuations in the area ranged from a decline of 18 feet in a well near Magma to a rise of about 2 feet in a well near Gilbert. In the 5-year period spring 1956 to spring 1961, water-level changes ranged from small rises southeast of Chandler to a decline of more than 60 feet near Magma. Declines of more than 60 feet also occurred in the northwestern corner of the area, northeast of Mesa. The minimum declines were observed in the southwestern and eastern part of the area (fig. 19).

In the part of the area east of the Roosevelt Water Conservation District Canal, declines for the period spring 1960 to spring 1961 were as much as 12 feet. The water level in well (A-1-6)23 (fig. 23) declined about 3 feet from spring 1960 to spring 1961, more than 60 feet from spring 1956 to spring 1961, and since 1951 nearly 140 feet. As in previous years, the water table in the southwestern part of this area declined but little and in some places there were rises of several feet. Ground water is used only to supplement surface-water irrigation in this part of the area, and seepage from the canals influences the water-table fluctuations.

The water level in well (D-2-10)8 (fig. 23) 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 14 feet has occurred since the spring of 1951, possibly because of irrigation pumping 8 miles to the west. Little net change has occurred in the water level of well (D-2-5)13 (fig. 23) about 5 miles southwest of Higley since the spring of 1951. The water level in the well has risen about 5 feet since 1958. In the spring of 1961 water levels in observed wells in the cultivated parts of the Queen Creek-Higley-Gilbert-Magma area ranged from 438 feet below the land surface in a well south of Granite Reef Dam to 56 feet in an abandoned irrigation well about 7 miles southwest of Higley. The depths to water below the land surface near Magma were about 325 feet, near Higley about 160 feet, and at Queen Creek about 310 feet.

Tempe-Mesa-Chandler area.--In the period spring 1960 to spring 1961 water-level fluctuations in the Tempe-Mesa-Chandler area ranged from a rise of 3 feet to a decline of 15 feet. For the most part, the larger declines occurred in the area northeast of Mesa where pumping is concentrated. Declines of 10 feet or more also were observed in the area west of Chandler. The declines were least near Tempe and south of Chandler. The downward trend of the water levels in this area has continued since the early 1940's (fig. 20).

During the 5-year period spring 1956 to spring 1961 the water table declined more than 60 feet northeast of Mesa, from 40 to 60 feet in Mesa, and about 20 feet in Tempe. Declines throughout the rest of the area were progressively less to the south and were about 10 feet south

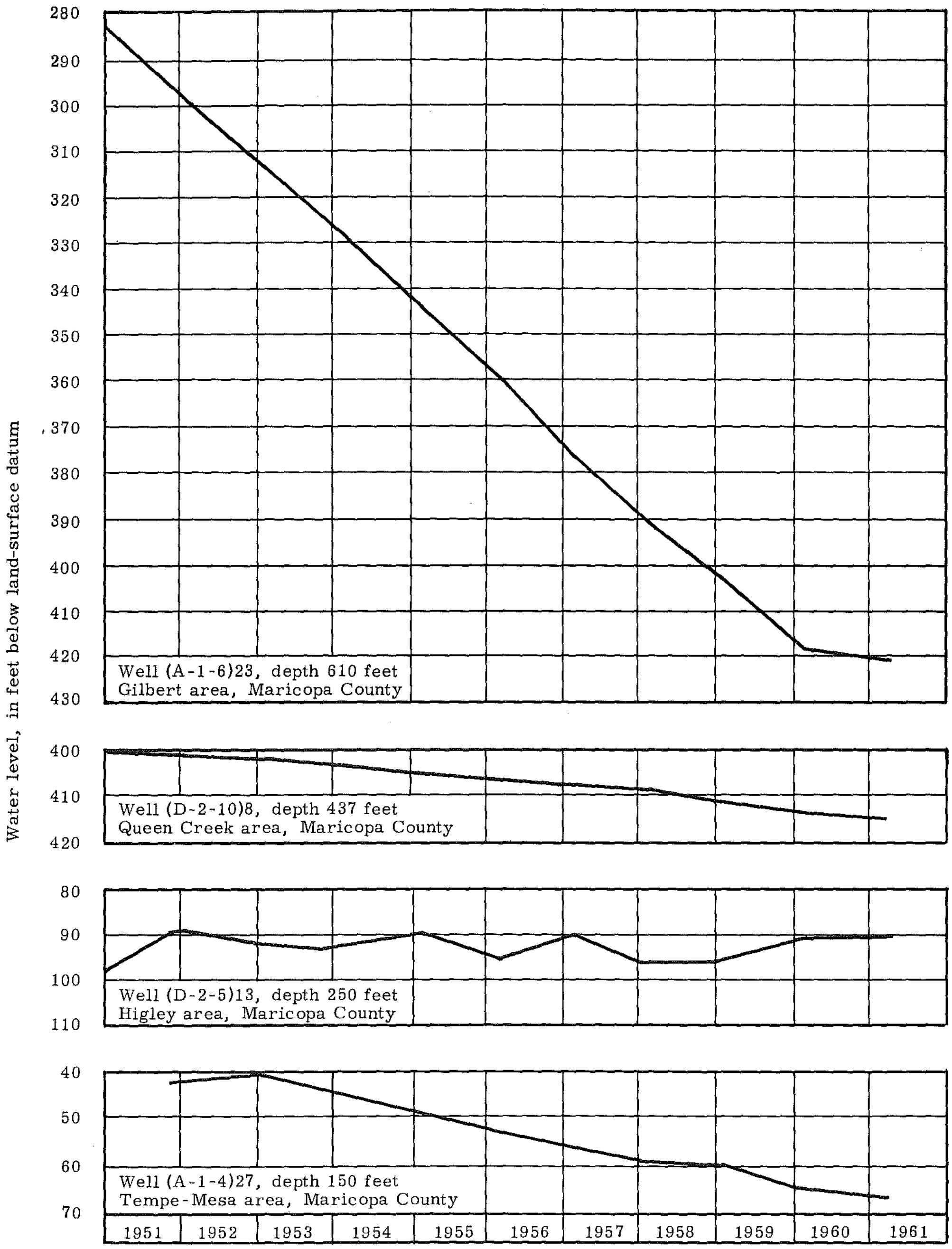

Figure 23.--Water levels in selected wells in Queen Creek-Higley-Gilbert-Magma and Tempe-Mesa areas, Maricopa and Pinal Counties.

of Chandler (fig. 19). In the spring of 1961, the depth to water below the land surface was from 260 to 300 feet northeast of Mesa, about 150 feet near Chandler, about 225 feet at Mesa, and less than 70 feet at Tempe. The shallowest water level measured in the area was 67 feet below the land surface in an abandoned irrigation well a mile south of Tempe. The hydrograph of well (A-1-4)27 (fig. 23) shows the trend of the continuous decline in water levels in the area between Tempe and Mesa.

Phoenix - Glendale - Tolleson - Deer Valley area. --During the period spring 1960 to spring 1961 water-level fluctuations ranged from rises of about 5 feet to declines of more than 25 feet. Most of the greater declines occurred in Deer Valley. However, the declines for the period spring 1960 to spring 1961 were generally slightly less than those observed during the period spring 1959 to spring 1960. This may be a result of the recent conversion of much acreage from agricultural to residential and industrial use. The hydrograph for well (A-3-2)2 (fig. 24) shows declines typical of the Deer Valley area. In the area south of the Arizona Canal in the Salt River Project the water-level declines decreased toward Tolleson. In the 11 years since 1950 the water level in this part of the area has declined only about 50 feet. The cumulative net changes in water levels in this area (fig. 21) 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. Some water-level rises were measured in wells in northern Phoenix where seepage from the Arizona Canal serves to partially replenish ground-water supplies.

During the 5-year period spring 1956 to spring 1961 water-level fluctuations ranged from almost no change to declines of more than 60 feet in Deer Valley (fig. 19). As in previous periods, the largest declines occurred in Deer Valley between 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 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 1960 depth to water below the land surface was about 50 feet in central Phoenix, 200 feet in Glendale, 300 to 440 feet in Deer Valley, and about 150 feet in Tolleson. In north Phoenix, adjacent to the Arizona Canal, water levels were less than 20 feet below the land surface.

Paradise Valley area. --There were minor water-level fluctuations in the Paradise Valley area in the period spring 1960 to spring 1961. Pumping of ground water for agricultural purposes in Paradise Valley has always 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 greatest declines occurred during the period spring 1960 to spring 1961.

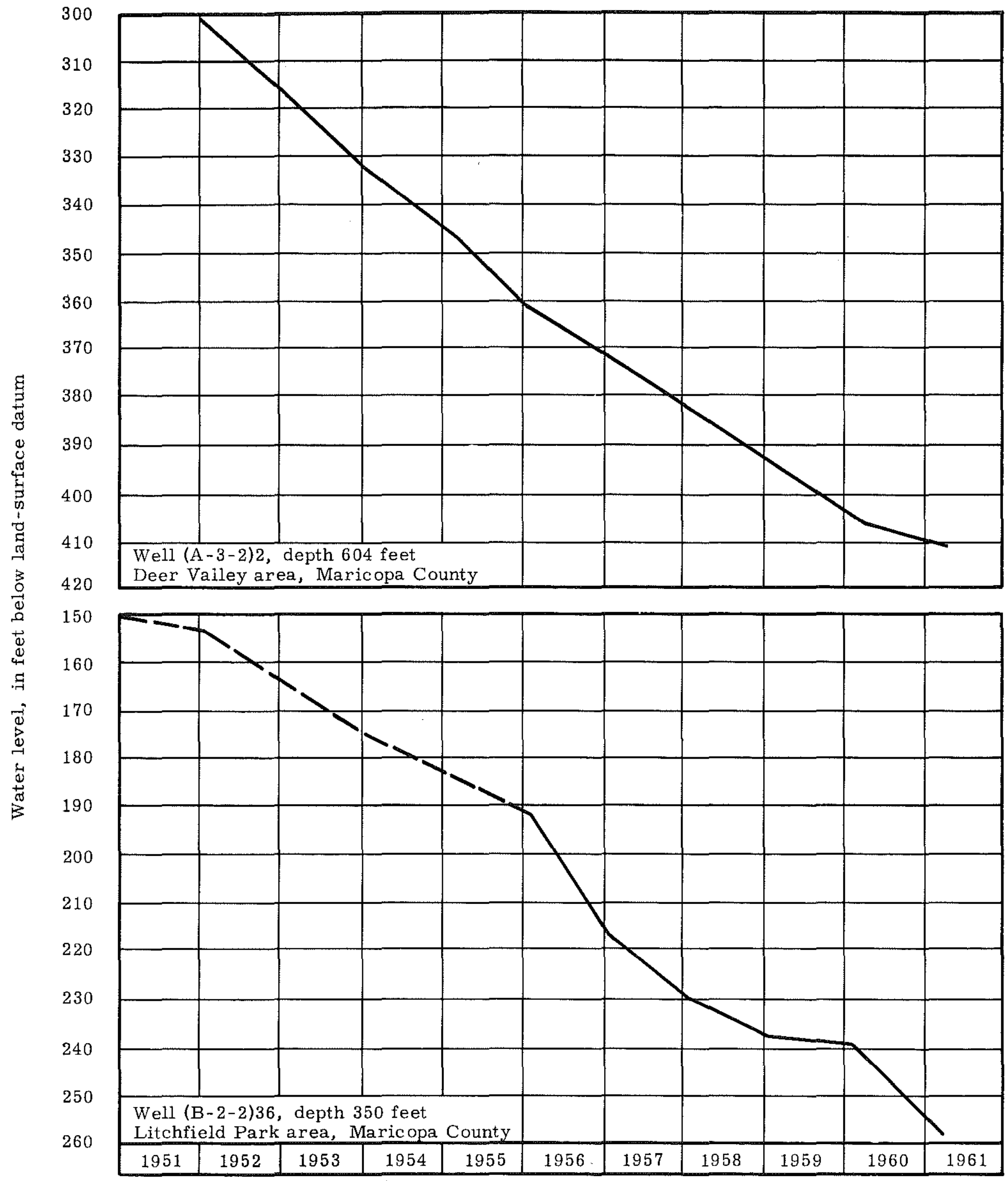

Figure 24. --Water levels in selected wells in Deer Valley and Litchfield Park areas, Maricopa County.

For the 5-year period spring 1956 to spring 1961 water-level declines in the area were less than 20 feet and, therefore, do not fall within the contour interval of the decline map (fig. 19). In the spring of 1961 measured depths to water in Paradise Valley ranged from more than 440 feet below the land surface in the northern part of the area to 230 feet below the land surface near Scottsdale.

Litchfield Park-Beardsley-Marinette area.--Ground water constitutes the major source of water available for agriculture in the Litchfield Park-Beardsley-Marinette area. Figure 21 shows the cumulative net changes in the water levels and indicates the effect of increased pumping beginning in the early 1940's. The hydrograph for well (B-2-2)36 (fig. 24) shows the effects of pumping in this area during the last 10 years. The hydrograph indicates that during the period spring 1960 to spring 1961 the rate of decline increased. For the period spring 1951 to spring 1961 the water level in the well declined more than 100 feet.

In the northern part of the area, where the greatest declines usually occur, most of the wells were pumping during the spring of 1961 and measurements were difficult to obtain. However, the hydrograph for well (B-4-1)8 in the Beardsley area (fig. 25) indicates that the water level in this part of the area is following the trend of previous years and shows a decline in excess of 70 feet for the 10-year period spring 1951 to spring 1961.

During the 5-year period spring 1956 to spring 1961 water levels declined from more than 60 feet in the northeastern and western parts of the area to less than 20 feet in the southern part of the area (fig. 19). The maximum declines occurred in areas of deep water levels. In the spring of 1961 the depth to water in the northeastern part of the area was about 350 feet below the land surface; along the northeast edge of the White Tank Mountains the depth to water was more than 400 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. The maximum declines in this area probably are caused by the cones of depression having reached the impermeable area of the White Tank Mountains. In the spring of 1961 the minimum depth to water was about 145 feet in an irrigation well along the canal southwest of Litchfield Park. In the vicinity of Litchfield Park the depth to water ranged from about 145 to 300 feet below the land surface; near Marinette the water level was about 300 feet, and near Beardsley about 295 feet.

Liberty-Buckeye-Hassayampa area.--Water-level fluctuations in this area from spring 1960 to spring 1961 ranged from small rises in some parts of the area to declines of more than 5 feet in the vicinity of Avondale. 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. 22). However, the rate of decline is much less because the shallow water table probably is recharged by irrigation water applied

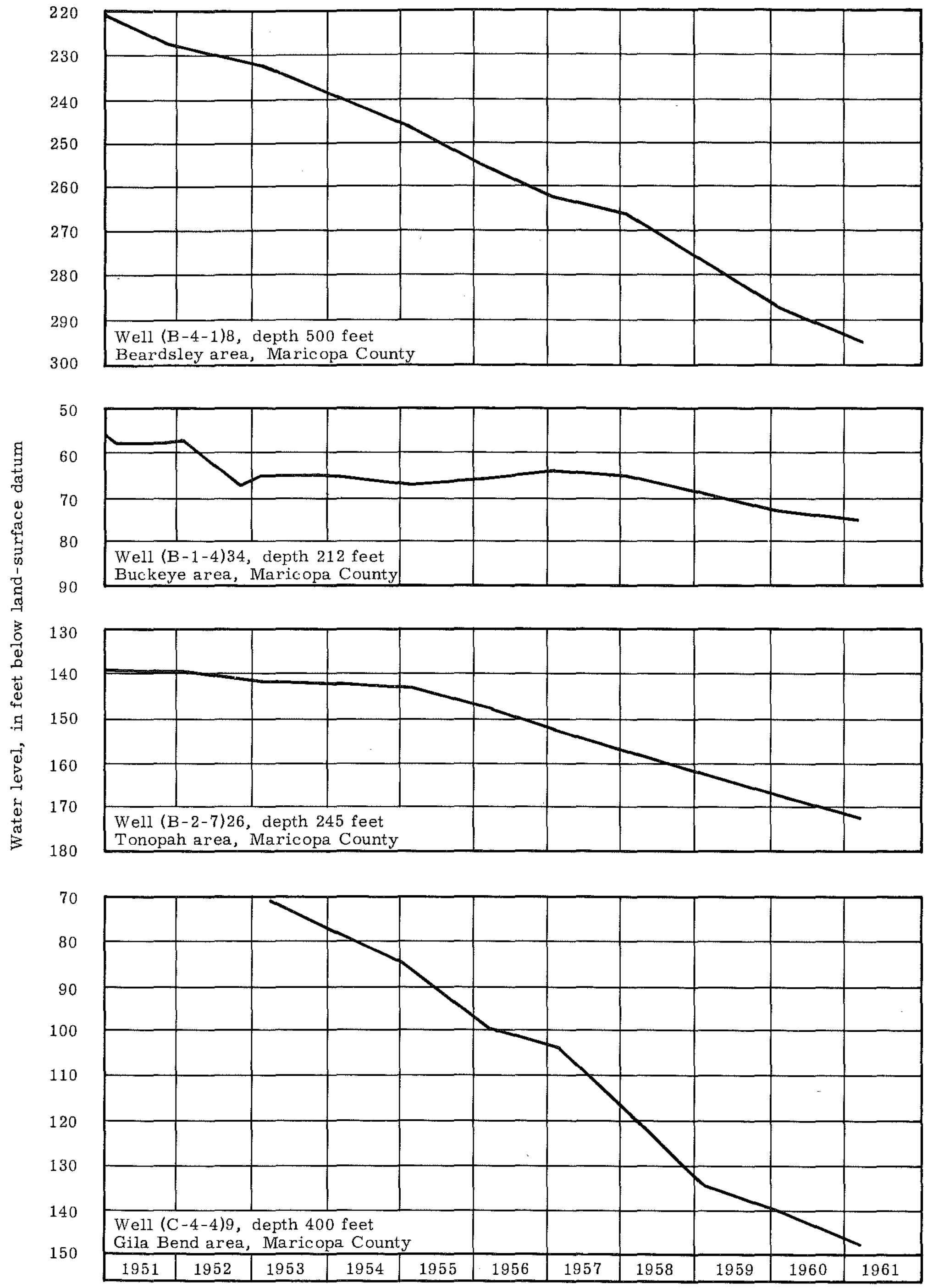

Figure 25.--Water levels in selected wells, Maricopa County.

to cultivated land upstream. The hydrograph for well (B-1-4)34 (fig. 25) shows the typical water-level trend for this area. During the 5-year period spring 1956 to spring 1961 water levels in the Liberty-Buckeye-Hassayampa area fluctuated slightly and most of the declines were less than 20 feet. The water levels in the area west of Buckeye rose slightly, but in the vicinity of Perryville water levels declined slightly more than 20 feet. In the spring of 1961 the depth to water below the land surface in the irrigation wells in the area ranged from about 30 feet southwest of Buckeye to more than 215 feet north of Perryville.

The depth to water at Hassayampa is less than 50 feet below the land surface; near Buckeye the water table is about 80 feet below the land surface. At Liberty and adjacent to the Gila River south to the Gillespie Dam water levels are about 50 feet below the 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 the pumping of ground water for agriculture. During the last 2 years about 30 new irrigation wells have been constructed in the area mostly near Tonopah. Most of the water levels in the lower Hassayampa-Tonopah area declined during the period spring 1960 to spring 1961 and the greatest declines were near Tonopah. The hydrograph for well (B-2-7)26 (fig. 25) shows the fluctuation of the water level in a well before and after irrigational development in a typical alluvial basin in southern Arizona. During the period spring 1956 to spring 1961 the water table near Tonopah declined more than 15 feet but less than 20 feet, and therefore did not fall within the contour interval of the decline map (fig. 19). In several wells declines in excess of 20 feet for this 5-year period were measured, but data were insufficient to accurately depict a contour line. However, increased pumping from the new wells may cause greater declines throughout the area. In the spring of 1961 water levels in the area ranged from about 20 feet below the land surface in an abandoned well near the Hassayampa River to more than 240 feet northwest of Tonopah. Between Hassayampa and Tonopah the measured depths to water ranged from 60 to 145 feet below the land surface.

Lower Centennial area.--Ground-water levels in the lower Centennial area declined slightly during 1960. Generally, water-level fluctuations ranged from no change to a decline of about 4 feet during the period spring 1960 to spring 1961 although several small rises were measured in wells along the Gila River. The greater declines occurred in irrigation wells in the western part of the area. In the spring of 1961 depths to water in the area ranged from about 24 feet below the land surface near the junction of Centennial Wash and the Gila River to more than 225 feet in the lower part of T. 1 N., R. 6 W.

Gila Bend Area

The Gila Bend area is that part of the Gila River Valley extending from Gillespie Dam on the Gila River to a point 36 miles downstream near the Painted Rock narrows. The area is bounded by the Gila Bend Mountains and the Buckeye Hills on the north, the Maricopa and Sand Tank Mountains on the east, the Sauceda Mountains on the south, and the Painted Rock Mountains on the west.

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

In the spring of 1961 more than 125 irrigation wells were in operation in the Gila Bend area. About 60 of these wells are in the northeastern part of the Gila Bend basin, known as Rainbow Valley.

The Rainbow Valley area is a southwest-trending valley lying between the Buckeye Hills and the northern edge of the Maricopa Mountains which drains into the Gila River about 4-½ miles below Gillespie Dam. It is hydrologically a part of the Gila Bend area and is separated from it on the south by an arbitrary line that forms an extension of the drainage divide in the northern part of the Maricopa Mountains. Ground-water movement in the area is southwestward toward the Gila River and from north to south along the river. In the spring of 1961, the depth to water in the Rainbow Valley area ranged from about 30 feet below the land surface just south of Gillespie Dam to about 350 feet at the northeast edge of the area. Water-level declines in the Rainbow Valley area ranged from a few feet to more than 100 feet for the 5-year period 1956-61.

In the western part of the Gila Bend basin, water-level fluctuations for the period spring 1960 to spring 1961 ranged from a rise of about 5 feet to a decline of more than 7 feet. The water level in well (C-4-4)9 (fig. 25) declined about 48 feet in the 5-year period 1956-61.

Waterman Wash Area

The Waterman Wash area is bounded on the north by outliers of the Sierra Estrella and the Buckeye Hills, and on the east by the Sierra Estrella and Palo Verde Mountains. On the south the area is bounded by the southern range of the Maricopa Mountains, and the Booth and Haley Hills. On the west the Waterman Wash area is separated from the Rainbow Valley area by the Maricopa Mountains and a low alluvial ridge extending northward from the Maricopa Mountains to the Buckeye Hills. The area of about 400 square miles is drained by Waterman Wash, a northwest-trending intermittent stream.

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

Only the northern part of the Waterman Wash area has been developed for agriculture, and it is in this part that most of the water-level declines have taken place. For the 5-year period spring 1956 to spring 1961, declines ranged from less than a foot in the undeveloped southern part of the valley to more than 40 feet in the irrigated area in the northern part. The water level in well (C-2-2)25 (fig. 26) in the irrigated area declined about 29 feet in the 5-year period spring 1956 to spring 1961; the hydrograph shows that the water level in this well rose about 5 feet from spring 1960 to spring 1961, but the apparent rise is due to the fact that the well had been pumped just prior to the time of the 1960 measurement, causing the water level to be deeper than a normal static level unaffected by recent pumping. The water level in well (C-3-1)1 (fig. 26), south of the irrigated area, declined about 8 feet in the period spring 1956 to spring 1961. The depth to water in the Waterman Wash area ranged from about 145 to more than 360 feet below the land surface in the spring of 1961.

Harquahala Plains Area

The Harquahala Plains area 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 Eagletail Mountains, and on the southeast by Saddle Mountain and the Gila Bend Mountains.

In the spring of 1961 more than 75 irrigation wells were in use in the Harquahala Plains area as compared to about 30 during 1956. Most of the development is in the southeastern part of the area where the yields of the wells range from about 800 to 3,000 gpm. Data pertaining to the decline of water levels in the area has been difficult to obtain during previous years because of year-round pumping. During the spring of 1961 measurements in several wells in the center of the cultivated area indicated average yearly declines of more than 20 feet.

In the spring of 1961 measured depths to water below the land surface ranged from about 18 feet in the extreme southeast to more than 310 feet in the center of the cultivated area.

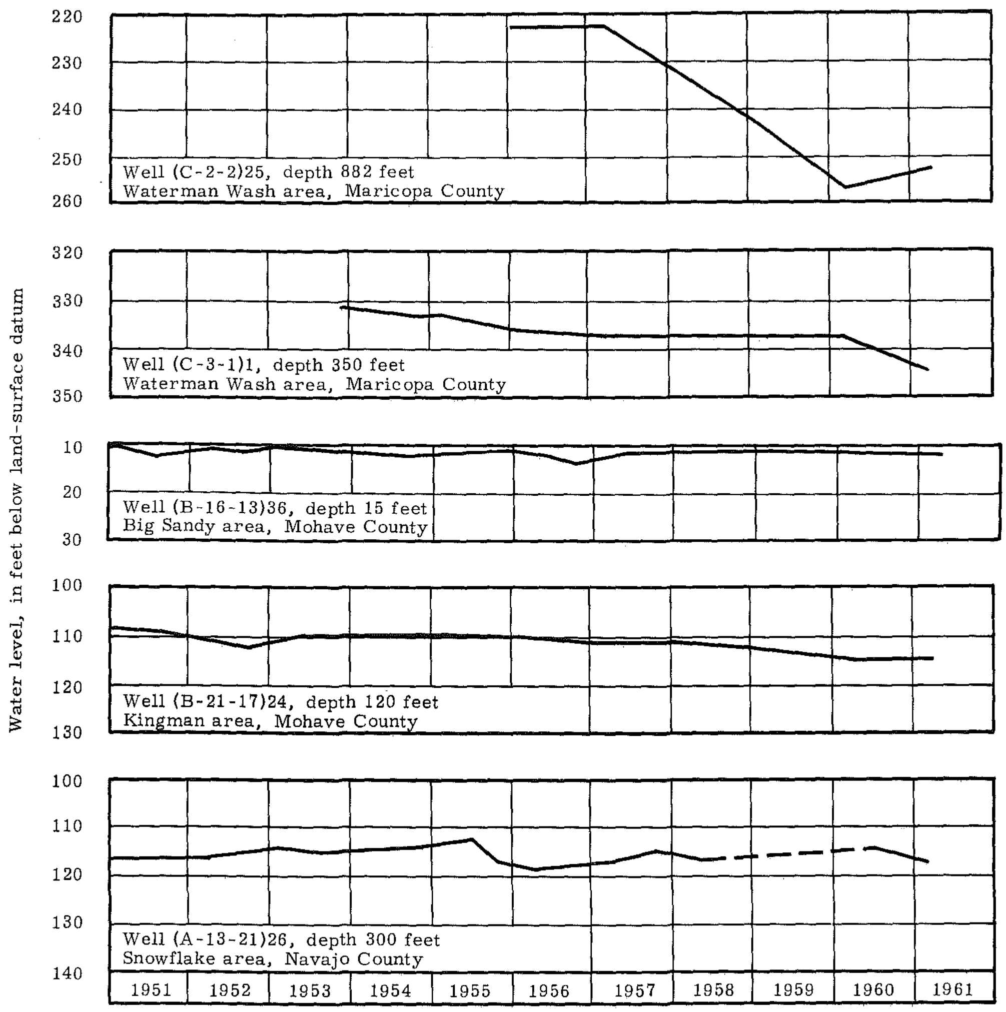

Figure 26.--Water levels in selected wells, Maricopa, Mohave, and Navajo Counties.

Mohave County

By

R. S. Stulik

The areas of ground-water withdrawal in Mohave County are: (1) the Big Sandy Valley; (2) in the vicinity of Hackberry and Kingman; and (3) near Truxton. Some withdrawal of ground water occurs along the Colorado River south of Davis Dam but not enough data are available to permit any estimate of the amount of water used.

The Big Sandy Valley is drained by the Big Sandy River which receives water from Trout, Burro, and Cottonwood Creeks and Little Sandy Wash 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, Aquarius Cliffs, and Aquarius Mountains on the east.

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

Water-level fluctuations in wells in the flood plain of the Big Sandy River during the period spring 1960 to spring 1961 ranged from small rises to declines of slightly more than a foot. The hydrograph of well (B-16-13)36 (fig. 26) shows water-level fluctuations typical for this part of the area. The water level in this well declined slightly more than a foot during the 10-year period spring 1951 to spring 1961. Depth to water below the land surface ranged from 11 feet near Wickieup to about 115 feet 12 miles upstream. Outside the flood plain of the Big Sandy River the water level was 375 feet below the land surface in a stock well near the extreme north end of the area.

Ground-water pumping in the Hackberry and Kingman area is mostly for public supply. Water-level fluctuations near Kingman ranged from a small rise to a decline of less than a foot during the period spring 1960 to spring 1961. The water level in well (B-21-17)24 (fig. 26) indicates the trend in this area. During the period spring 1960 to spring

1961 the water-level fluctuations ranged from no change to a decline of about a foot in the wells near Hackberry. The depth to water below the land surface in this area ranged from about 50 feet in a stock well near Hackberry to about 510 feet in an abandoned well near Antaris.

Three wells are used to irrigate land near Truxton. The depth to water below the land surface in one of these wells was about 146 feet in the spring of 1961. The water table in this area did not fluctuate appreciably during the period spring 1953 to spring 1961.

Navajo County

By

M. E. Cooley

Ground water in Navajo County is withdrawn principally from wells penetrating the Coconino Sandstone in the area south of the Little Colorado River, the Navajo Sandstone in the Kayenta-Marsh Pass area in the extreme northern part of the county, and the Dakota Sandstone and Toreva Formation in the Black Mesa area (table 2). Springs discharge ground water from volcanic rocks and associated sediments near Shumway and in the Hopi Buttes area. Water is present in the alluvium along the Little Colorado River and along some of the tributary drainages.

The Coconino Sandstone is in the subsurface in most of the area between the Mogollon Rim and the Little Colorado River and is recharged principally by water that enters the sandstone by downward percolation through the overlying Kaibab Limestone and younger sediments. However, where the Coconino is exposed in the Snowflake-Winslow area it is recharged by direct precipitation. South of the Little Colorado River ground water is under water-table and artesian conditions and north of the river it is under artesian conditions. Movement of water in the Coconino is northward in the southern part of the county and northwestward in the central part along the southern flank of Black Mesa basin (fig. 8). Natural discharge from the Coconino Sandstone is to the Little Colorado River near Holbrook, to the lower 3 or 4 miles of East Clear and Chevelon Creeks, to Silver Creek, and to springs south of the Little Colorado River between Holbrook and Winslow. Wells developed in the Coconino yield from 25 to 2,000 gpm depending upon their location with respect to the recharge areas, to structure, and to fracturing. Most water levels range from a few feet to more than 500 feet below the land surface but locally some wells flow. In most of the area south of the Little Colorado River the water contains less than 1,000 ppm (parts per million) total dissolved solids and locally less than 200 ppm. However, near the Little Colorado River and north of it, the total-solids concentration may exceed 30,000 ppm.

In the area of Navajo County north of Black Mesa, wells drilled into the

Navajo Sandstone yield small amounts of water, which supply the needs of the Navajo Indians. The water is utilized chiefly for stock and domestic purposes, for schools, and for the town of Kayenta. Discharge from the Navajo Sandstone in combination with the underlying Wingate Sandstone maintains perennial flow in Laguna Creek in the Kayenta-Marsh Pass area. The depth to water ranges from a few feet to more than 500 feet below the land surface. The sandstone is recharged locally from direct precipitation, and ground-water movement is generally southward away from the Monument upwarp which forms a structural highland bounding the Black Mesa basin on the north (fig. 10). The water in the Navajo Sandstone usually contains from 200 to 500 ppm of total dissolved solids.

In the Black Mesa area of north-central Navajo County, the Dakota Sandstone and Toreva Formation supply most of the water used by the Navajo and Hopi Indians. Some water is withdrawn locally from the Wepo Formation on Black Mesa and from the Cow Springs Sandstone which, in the southern part of Black Mesa, underlies and is hydrologically connected with the Dakota Sandstone. Along Polacca Wash some water is withdrawn from the alluvium. The yields from all the wells are small, generally from 5 to 25 gpm. A few wells drilled in the Dakota Sandstone flow in the eastern part of the Hopi Indian Reservation. Depth to water in the Toreva Formation ranges from 200 to 400 feet and in the alluvium it is less than 50 feet below the land surface. In much of southern Black Mesa, the Toreva Formation is dry where it forms the caprock of mesas and platforms, but water can be obtained from wells in the Dakota Sandstone at depths of as much as 1,000 feet. Several such wells furnish a dependable water supply at Pinon and Hotevilla. The chemical quality of the water ranges from fair to poor and the best water in the Black Mesa area is from the Toreva Formation. In places, the water from the Dakota Sandstone contains more than 3 ppm of fluoride, making the water undesirable for domestic use.

Many springs yielding less than 5 gpm are in the lavas and tuffs of the volcanic member of the Bidahochi Formation in the Hopi Buttes. Only a few wells have been drilled into the volcanic rocks because of low yield and variation in the chemical quality of the water. Ground water is more plentiful and of excellent quality in the lavas and associated sediments south of Shumway. Within this area numerous springs yield substantial amounts of water; the largest is Silver Spring which discharges about 2,000 gpm.

Fluctuations of the water levels in most of Navajo County are slight and show no long-term trends. Water-level fluctuations in the Snowflake-Hay Hollow area are caused by drawdown resulting from seasonal use of the water in summer for irrigation and the recovery after the pumping season. The hydrograph of well (A-13-21)26 (fig. 26) shows these fluctuations. At the present time recharge is sufficient to replace the water withdrawn, although drilling of new wells in the area, eventually will result in a decline in water levels. In parts of the county where there is little pumping, water-level fluctuations reflect seasonal and annual differences in precipitation. Throughout the county many springs having local recharge areas are dry or yields are reduced during periods of drought.

Pima County

By

E. F. Pashley

Pima County consists of a series of alluvial valleys divided by several mountain ranges. The general trend of these physiographic features is in a north-south direction. The most important basins in the county are Altar, Avra, San Simon (Papago Indian Reservation), and Santa Cruz Valleys. At present, most of the development is in the Santa Cruz Valley in the eastern part of Pima County and the central part of Santa Cruz County. The upstream part of the valley is arbitrarily called the upper Santa Cruz basin and extends from Mexico to the Rillito narrows about 15 miles northwest of Tucson. The downstream part is called the lower Santa Cruz basin and is mostly in Pinal County, although the Avra-Marana area is in Pima County. The part of the upper Santa Cruz basin that is in Pima County is bordered on the east by the Santa Catalina, Tanque Verde, Rincon, and the northern end of the Santa Rita Mountains; on the west by the Tucson and Sierrita Mountains; and on the north by the Tortolita Mountains. The altitude ranges from 3,000 feet at the Pima-Santa Cruz County line to about 1,900 feet at the Pima-Pinal County line.

The movement of ground water in the upper Santa Cruz basin is northward toward the highly developed areas in the vicinity of Casa Grande. The Santa Cruz River forms the long axis of the basin and has an important effect on the occurrence and movement of ground water because the river recharges the ground-water reservoir. From Calabasas 9 miles north of Nogales to Tucson, a distance of about 55 miles, the average ground-water gradient is about 20 feet per mile. This is about the same gradient as the Santa Cruz River.

About 15 miles northwest of Tucson the basin is constricted between the Tucson and Tortolita Mountains at the Rillito narrows. The ground-water underflow is confined to a narrow trough at this point, and only a relatively thin layer of alluvium covers the bedrock from the Tortolita Mountains to this trough. Consequently, most of the ground water moves toward the trough. Because of this constriction in cross-sectional area, the ground-water gradient is about 80 feet per mile at the narrows. The average ground-water gradient from Tucson to the Rillito narrows is from 20 to 30 feet per mile.

Water-level fluctuations in Pima County are discussed as follows: (1) Avra-Marana area, (2) Tucson area, and (3) Continental-Sahuarita area.

Avra-Marana Area

In the 5-year period spring 1956 to spring 1961 water-level declines in the wells measured southwest of the Casa Grande Highway and within a 9-mile radius of Marana ranged from about 10 to 55 feet. The average 5-year decline was about 24 feet. From spring 1960 to spring 1961 water-level fluctuations ranged from rises of 12 feet, recorded in 2 wells, to declines of about 20 feet; the average decline was about 10 feet. The depth to water in this area in the spring of 1961 ranged from 190 to 280 feet. The water level in well (D-11-10)32 (fig. 27) declined about 12 feet from spring 1960 to spring 1961, about 20 feet from spring 1956 to spring 1961, and about 45 feet from spring 1951 to spring 1961.

Along the axis of the Avra Valley the water levels declined from 2 to 15 feet during the period spring 1960 to spring 1961. During the 5-year period spring 1956 to spring 1961, declines ranged from about 20 to 45 feet. In the spring of 1961 the depth to water ranged from about 280 feet at the north end to 330 feet at the south end of the valley.

The water level in well (D-15-10)35 (fig. 27) in the southern part of Avra Valley near Three Points declined about 3 feet during the 5-year period spring 1956 to spring 1961 and about 7 feet since 1951. The well is a mile from Three Points on the Ajo Highway where there is little pumping of ground water.

Tucson Area

Variable geologic and hydrologic conditions make it necessary to divide the Tucson area into several subareas and to describe the water-level rises and declines in each one independently.

Four wells were measured along Canada del Oro between its junction with the Santa Cruz River and a point 3 miles upstream. The fluctuations of the water levels in these wells from spring 1960 to spring 1961 ranged from a rise of a foot to a decline of 4 feet. Depth to water ranged from about 110 to 160 feet in the spring of 1961.

Water - level declines in wells measured along the Santa Cruz River from its junction with Canada del Oro to the town of Rillito, a distance of slightly more than 7 miles, averaged about 3 feet, but rises of as much as 6 feet and declines of as much as 9 feet were measured. Depth to water in spring 1961 ranged from about 75 to 145 feet and averaged about 100 feet. The water level in well (D-12-12)16 (fig. 27) in the heavily pumped area along the Santa Cruz River between Rillito and Cortaro declined about 2 feet from spring 1960 to spring 1961 and about 10 feet since spring 1951. Water levels in this well are influenced by streamflow in the Santa Cruz River and by the amount of pumping in the area.

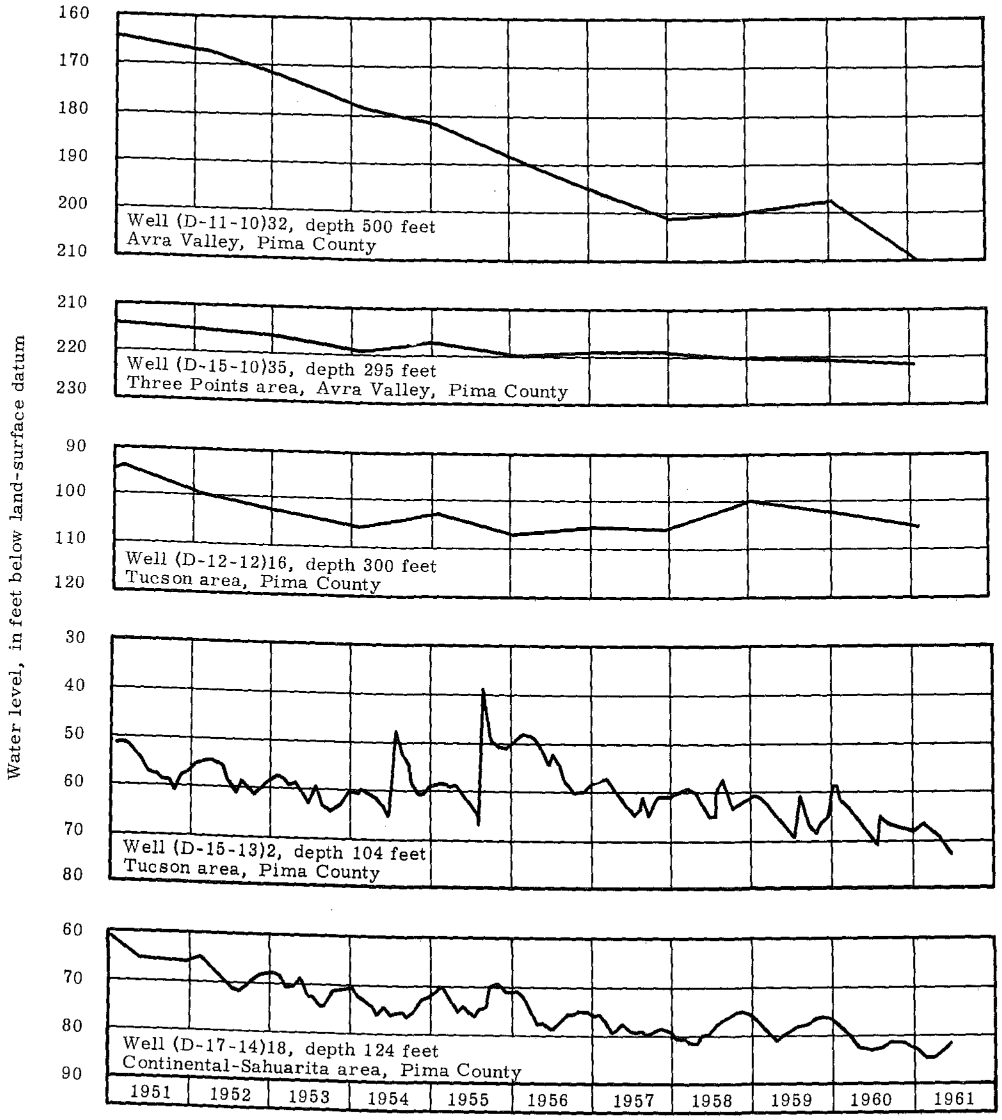

Figure 27.--Water levels in selected wells, Pima County.

Streamflow also affects the water level in wells along the Santa Cruz River from its junction with Canada del Oro upstream to Black Mountain, a distance of about 18 miles. In south Tucson the water level in well (D-15-13)2 (fig. 27) beside the Santa Cruz River fluctuates seasonally, rising after periods of surface flow in the river and declining when flow ceases. The hydrograph shows that the water level in February 1961 had declined about 9 feet from its high in January 1960. The 1960 high was caused by streamflow in the Santa Cruz River while the 1961 decline reflected lack of streamflow.

The water levels in wells on the flood plain of Rillito Creek and Tanque Verde Wash respond quickly to the recharge effects of streamflow. This response to streamflow has been documented by the Department of Agricultural Engineering, College of Agriculture of the University of Arizona (Schwalen, H. C., and Shaw, R. J., Water in the Santa Cruz Valley: Univ. Arizona, Agr. Exp. Sta. Bull. 288). Their analysis of a large number of spring water-level measurements made in this area showed that as a result of heavy streamflow water levels in wells on the flood plain rose from 4 to 24 feet between spring 1959 and spring 1960. From spring 1960 to spring 1961 their records show that water levels in the same area declined from 1 to 29 feet as a result of an almost complete lack of streamflow since spring 1960. A few wells in a small area south of the flood plain showed rises of as much as 2 feet in the period spring 1960 to spring 1961.

The water levels in wells in the Tucson area south of Rillito Creek and east of the Santa Cruz River generally are unaffected by streamflow. The water levels in this area generally decline as a result of pumping of ground water. From spring 1960 to spring 1961 water levels in these wells declined from 1 to 18 feet; the average decline was about 4 feet.

Continental-Sahuarita Area

The Continental-Sahuarita area is defined as the narrow strip of land including the flood plain of the Santa Cruz River extending from the Santa Cruz County line on the south to about 6 miles north of Sahuarita, a total distance of about 22 miles; the area is from 2-½ to 3 miles wide.

From spring 1960 to spring 1961 water-level declines in this area ranged from zero to 45 feet. The average water-level decline was about 11 feet. During the 5-year period spring 1956 to spring 1961 declines ranged from about 5 to 35 feet. Depth to water below the land surface in the spring of 1961 ranged from about 45 feet in a well near the Santa Cruz River to 185 feet in a well about 3 miles east of the river. The average depth to water in the area was about 105 feet below the land surface.

The hydrograph for well (D-17-14)18 (fig. 27) near Sahuarita shows that the water level fluctuates in response to pumping and to natural recharge from the Santa Cruz River. The water level in well (D-17-14) 18 (fig. 27) generally is highest in the winter or spring and lowest in the summer as the result of pumping. The hydrograph shows that the long-term trend of the water level in this well is downward despite the seasonal recoveries. The water level declined about 20 feet from January 1951 to January 1961.

Pinal County

By

W. F. Hardt

The principal area of irrigation development in Pinal County is the lower Santa Cruz basin. More than 90 percent of the 286, 000 irrigated acres in the county is in this basin. Small acreages are irrigated by pumping in the Queen Creek - Mammoth areas, chiefly near the San Pedro River. The lower Santa Cruz basin of nearly 2,000 square miles consists of the lower part of the Santa Cruz River drainage which is a part of the Gila River drainage. The area is bounded on the north by the Gila River from Ashurst-Hayden Dam westward to the Santan Mountains, and thence to the Pinal-Maricopa County line near the confluence of the Santa Cruz and Gila Rivers adjacent to the Sierra Estrella. The western boundary is formed by the Sierra Estrella, Palo Verde, Table Top, Tat Momoli, Silver Reef, and Sawtooth Mountains. The southern boundary of the basin is arbitrarily set at the Pinal-Pima County line for this section of the report. The eastern boundary of the basin in Pinal County is a line extending north from the Tortolita Mountains to the Gila River. The common boundary of the lower Santa Cruz basin and the upper Santa Cruz basin is the Rillito narrows between the Tucson and Tortolita Mountains in Pima County about 10 miles south of the Pinal County line.

Most of the irrigated acreage in the lower Santa Cruz basin is concentrated northwest of Red Rock and west of the Picacho Mountains to the Gila River; it is the second largest agricultural area in the State. This intensively developed area consists of 1, 000 square miles of valley floor of low relief surrounded by mountain masses. The valley floor slopes gently from about 1, 800 feet above sea level a few miles north 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 the county between the Sierra Estrella and Salt River Mountains.

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

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

The area of irrigation development in the lower Santa Cruz basin of Pinal County is arbitrarily divided into three subareas (fig. 28): (1) the Eloy area; (2) the Casa Grande-Florence area; and (3) the Stanfield-Maricopa area. Cumulative net changes in water level from 1940-61 in the three areas (fig. 29) show the tremendous decline of the water table in the alluvial-basin reservoir.

Eloy Area

The depth to water in the Eloy area ranged from about 150 to more than 300 feet below the land surface in the spring of 1961. The shallower water levels are south of the Casa Grande Mountains and adjacent to the Sawtooth Mountains. Water-level fluctuations from spring 1960 to spring 1961 ranged from rises of about 4 to 20 feet to declines of about 30 feet. Many of the yearly declines were less than 10 feet. Rises in the water table were measured in the area from Picacho Reservoir south to the Santa Cruz River between Picacho Peak and the Silver Bell Mountains, and in the area a few miles southeast of the Sawtooth Mountains. Maximum yearly declines were measured about 10 miles south of Eloy and north of Eloy to the Casa Grande Canal. In the 5-year period spring 1956 to spring 1961 water-level declines were as great as 60 feet (fig. 28). There was essentially no decline along the southeastern edge of the Sawtooth Mountains and in a small area 8 miles south of Eloy. The lack of water-table decline in the two areas may be due to recharge from underflow, or it may be the result of different lithologic characteristics of the subsurface sediments. The greatest water-level decline during the last 5 years was about 60 feet in the area between Eloy and the Picacho Mountains. In the central part of the area declines ranged from 20 to 40 feet. The water level in well (D-7-7)27 (fig. 30), 3 miles northwest of Eloy, declined about 5 feet from spring 1960 to spring 1961, about 16 feet from spring 1956 to spring 1961, and about 45 feet from spring 1951 to spring 1961. The hydrograph shows a fairly uniform yearly decline in the water table of 6 feet from spring 1951 to spring 1957. The water-level measurement

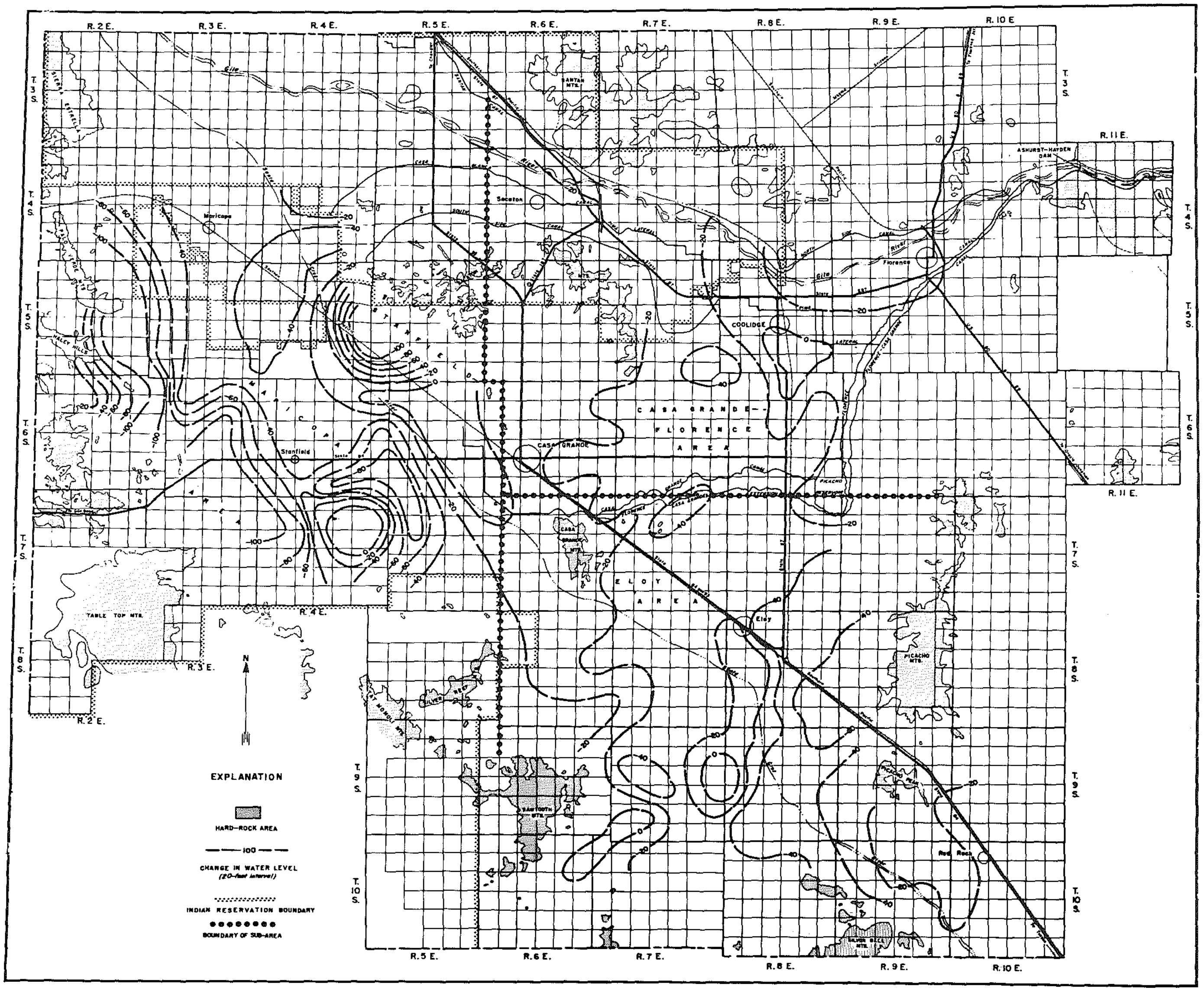

Figure 28.—Map of lower Santa Cruz basin and adjacent areas, Pinal County, Ariz. showing change in ground-water level from spring 1956 to spring 1961

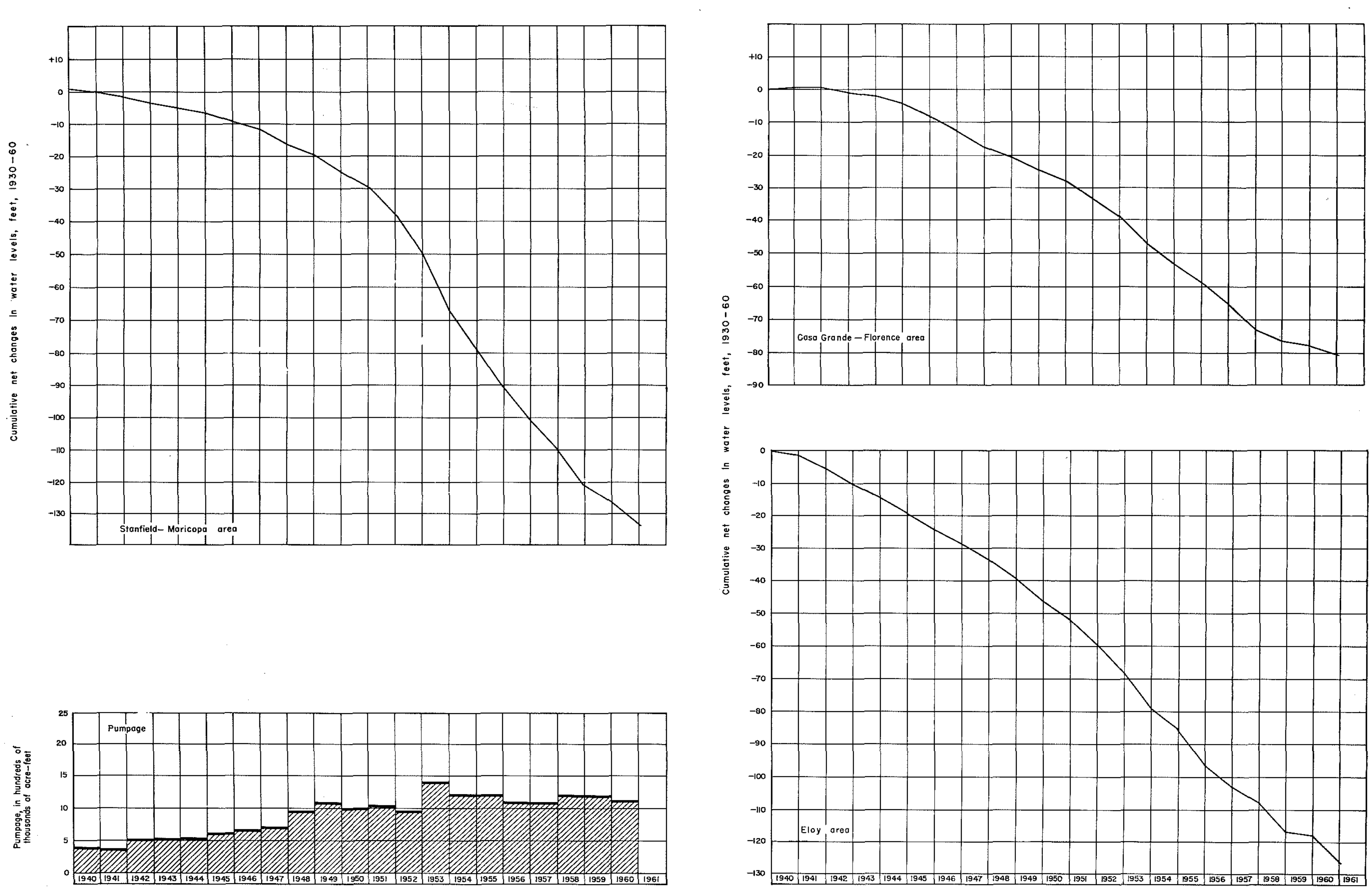

Figure 29.--Cumulative net changes in water levels by areas and total annual pumpage in the lower Santa Cruz basin within Pinal County.

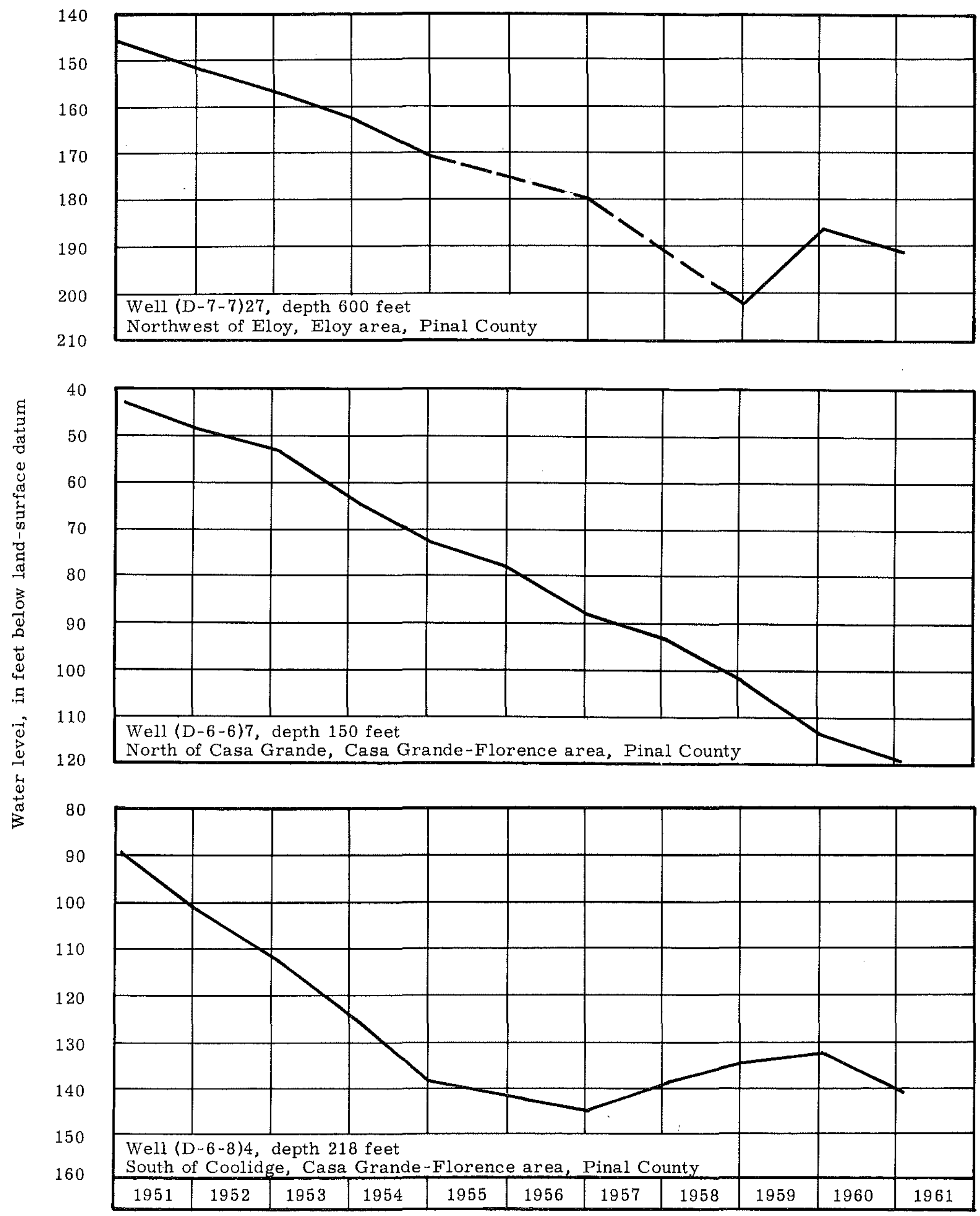

Figure 30. --Water levels in selected wells in the Eloy and Casa Grande-Florence areas, Pinal County.

in spring 1959 may have been influenced by pumping. The rate of decline from spring 1957 to spring 1961 appears to be slightly reduced.

Casa Grande-Florence Area

The depth to water below the land surface in the spring of 1961 ranged from 50 to 100 feet near Casa Grande, was about 150 feet between Casa Grande and Coolidge, and about 120 feet along the Gila River from Florence to Coolidge. In the undeveloped area south of Florence and east of the Florence-Casa Grande Canal, water levels are more than 200 feet below the land surface. Water levels in wells near the Gila River in the vicinity of Sacaton are less than 100 feet below the land surface. In the period spring 1960 to spring 1961 water-level fluctuations ranged from rises of 1 to 20 feet to declines of 30 feet. Many of the yearly declines were less than 5 feet. Most of the rises in the water table were along the Florence Canal from the Gila River to the Picacho Reservoir and along the Pima Lateral near Coolidge. Elsewhere in the Casa Grande-Florence area rises in the water table are attributed partly to the availability of Gila River water. In 1960, 240,000 to 250,000 acre-feet of surface water was diverted from the Gila River at Ashurst-Hayden Dam. This is about 90,000 acre-feet more than was diverted in 1959, and is the second largest diversion since 1949. In the 5-year period spring 1956 to spring 1961 declines ranged from 20 to 40 feet (fig. 28), except in the area adjacent to the Picacho Reservoir and in Casa Grande and Coolidge. Along the Gila River from Sacaton to Florence, the declines were about 20 feet, and in a small area 3 miles southwest of Coolidge the decline was about 40 feet for the 5-year period. The smaller declines generally were along the canals. The water level in well (D-6-6)7 (fig. 30) near Casa Grande declined about 5 feet from spring 1960 to spring 1961, about 41 feet from spring 1956 to spring 1961, and more than 75 feet since spring 1951. The hydrograph shows a fairly uniform yearly decline of the water table of about 7 to 8 feet. The water level in well (D-6-8)4 (fig. 30) 3 miles south of Coolidge declined about 7 feet from spring 1960 to spring 1961, rose about 2 feet from spring 1956 to spring 1961, and declined 50 feet since spring 1951. The hydrograph shows a uniform decline in the water table of about 12 feet annually from spring 1951 to spring 1955 and smaller annual declines from spring 1955 to spring 1957. From spring 1957 to spring 1960, the water level rose a few feet due to unknown geohydrologic conditions. The trend of the water table is downward from spring 1960 to spring 1961.

Stanfield-Maricopa Area

The depth to water below the land surface in the spring of 1961 varied considerably throughout the area, ranging from 40 feet 2 miles west of Casa Grande to nearly 500 feet 5 to 10 miles west of Stanfield. There are shallow water levels of 40 to 100 feet in an area 2 to 5 miles west of Casa Grande. A few miles to the west, the depth to water ranges from 200 to 300 feet below the land surface. The ground-water gradient in this area is more than 75 feet per mile. Elsewhere in the Stanfield-Maricopa area, the depth to water below the land surface is about 125 feet at Maricopa and 225 feet at Stanfield, although it varies considerably short distances away; it is from 200 to 300 feet below the land surface in the central part of the basin, and as much as 400 to 500 feet along the west side of the basin adjacent to the mountains south of Haley Hills. West of Maricopa toward the mountains, the water levels range from less than 100 to nearly 300 feet below the land surface. These are essentially static water levels measured in the spring of 1961; pumping levels are much lower during the irrigation season.

Water-level fluctuations from spring 1960 to spring 1961 ranged from rises of 30 feet to declines of 40 feet. The wide variation in net change in the water table is due partly to local pumping schedules related to the time of the water-level measurement. A few miles west of Casa Grande the water levels rose as much as 5 feet during the year, in the vicinity of Stanfield yearly declines ranged from 5 to 25 feet, and at Maricopa from 5 to 15 feet. Along the mountains on the west side of the basin, the yearly fluctuations ranged from rises of 25 feet to declines of nearly 40 feet. In the central part of the area the water levels generally declined from a few feet to about 40 feet. South of Stanfield, yearly declines ranged from 10 to 25 feet.

In the 5-year period spring 1956 to spring 1961 declines were as great as 100 feet (fig. 28). The greatest declines were in the western part of the basin near the mountains, particularly southeast of the Haley Hills and adjacent to the southwestern part of the Sacaton Mountains. Large declines also were measured in the area 5 miles east of Stanfield near State Highway 84. In the central part of the area from Maricopa to Stanfield, the 5-year declines generally ranged from 20 to 40 feet. Four miles southeast of Stanfield a small area of lesser declines is flanked by areas of large declines. The geohydrologic characteristics of this small region are not fully understood, but apparently recharge is available in sufficient quantities to minimize declines. A few miles west of Casa Grande no declines in the water table have taken place during the last 5 years. Only a small amount of ground water is pumped in this area. Some surface water from a canal may be recharged to the aquifer.

The water level in well (D-7-5)18 (fig. 31) about 7 miles southeast of Stanfield declined about 17 feet from spring 1960 to spring 1961, about 77 feet from spring 1956 to spring 1961, and more than 115 feet since spring 1953. The hydrograph shows a uniform decline of about 15 feet per year. The water level in well (D-4-3)32 (fig. 31) about 2 miles southwest of Maricopa declined about 9 feet from spring 1960 to spring 1961, about 39 feet from spring 1956 to spring 1961, and more than 75 feet since spring 1951. The hydrograph shows yearly declines of about 15 feet from spring 1952 to spring 1954. From spring 1954 to spring 1959, the declines decreased to 4 feet per year and increased again from spring 1959 to spring 1961.

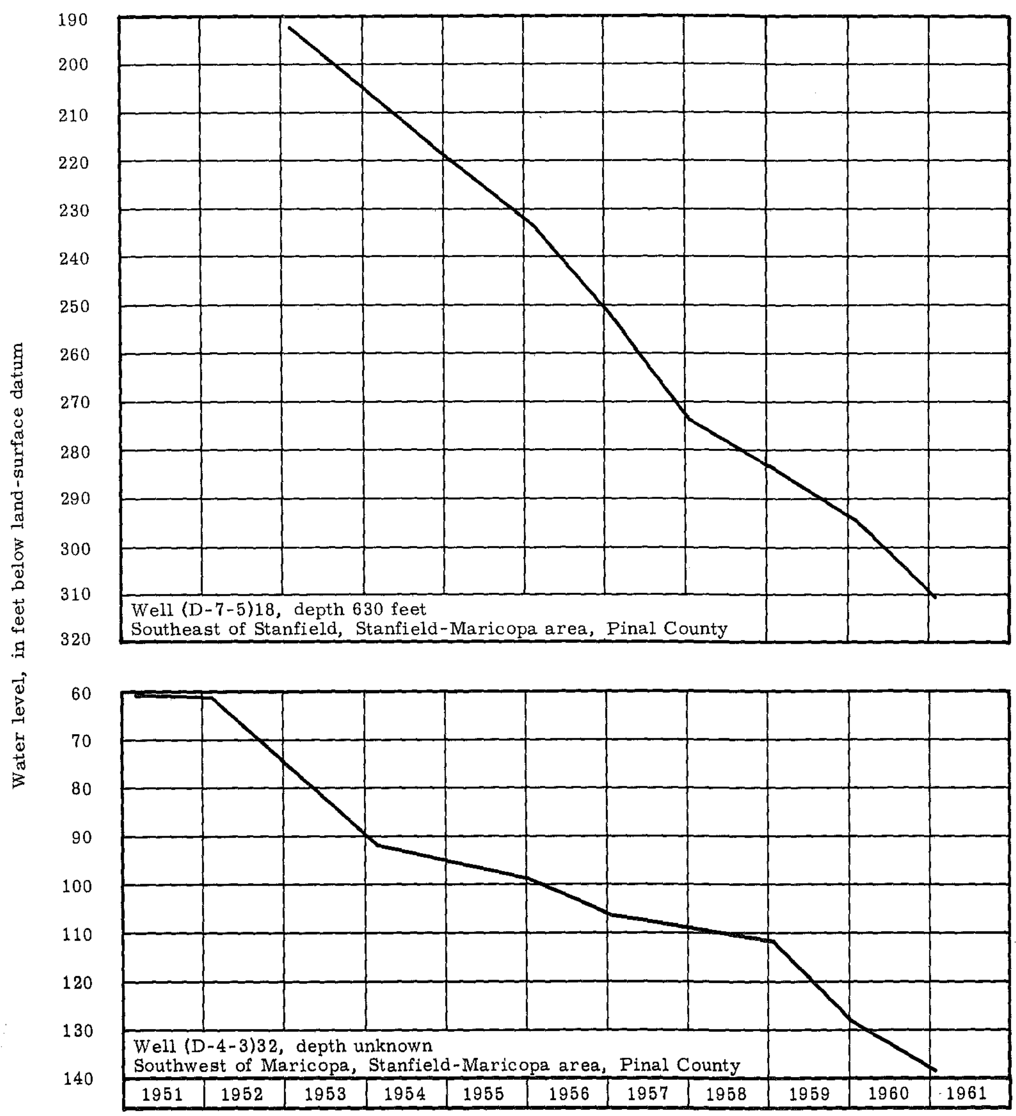

Figure 31.--Water levels in selected wells in the Stanfield-Maricopa area, Pinal County.

Santa Cruz County

By

E. F. Pashley

The southern part of the upper Santa Cruz basin lies in Santa Cruz County. It is bounded on the north by the Pima County line, on the east by the Santa Rita and Patagonia Mountains, on the south by the International Boundary, and on the west by the Tumacacori and Atascosa Mountains. Altitudes range from about 3,700 feet at the International Boundary to about 3,000 feet at the Santa Cruz-Pima County line.

From spring 1960 to spring 1961 the water-level fluctuations in this area ranged from a decline of 18 feet to a rise of nearly 19 feet. Near the Santa Cruz River the water level in many wells rose from spring 1959 to spring 1960 but declined from spring 1960 to spring 1961, as a result of less recharge from the Santa Cruz River during the latter period. The water level in well (D-22-13)35 (fig. 32) responds to recharge from Sonoita Creek and the Santa Cruz River. The water level in this well declined about 8 feet from spring 1960 to spring 1961 as a result of the lack of recharge from the river. Depth to water in wells on the flood plain of the Santa Cruz River ranged from 10 to 50 feet below the land surface in spring 1961.

Yavapai County

By

R. S. Stulik

There are three principal areas of ground-water development in Yavapai County: (1) Verde Valley; (2) Chino Valley; and (3) Skull Valley.

Verde Valley

The Verde Valley is a northwest-trending valley extending from the junction of Fossil Creek and Verde River to Perkinsville. It is bounded on the west by the Black Hills and on the east by the Mogollon Rim. Verde River, Oak Creek, West Clear Creek, and Beaver Creek are the main streams in the valley. The towns of Clarkdale, Cottonwood, Camp Verde, and Sedona lie within the area.

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

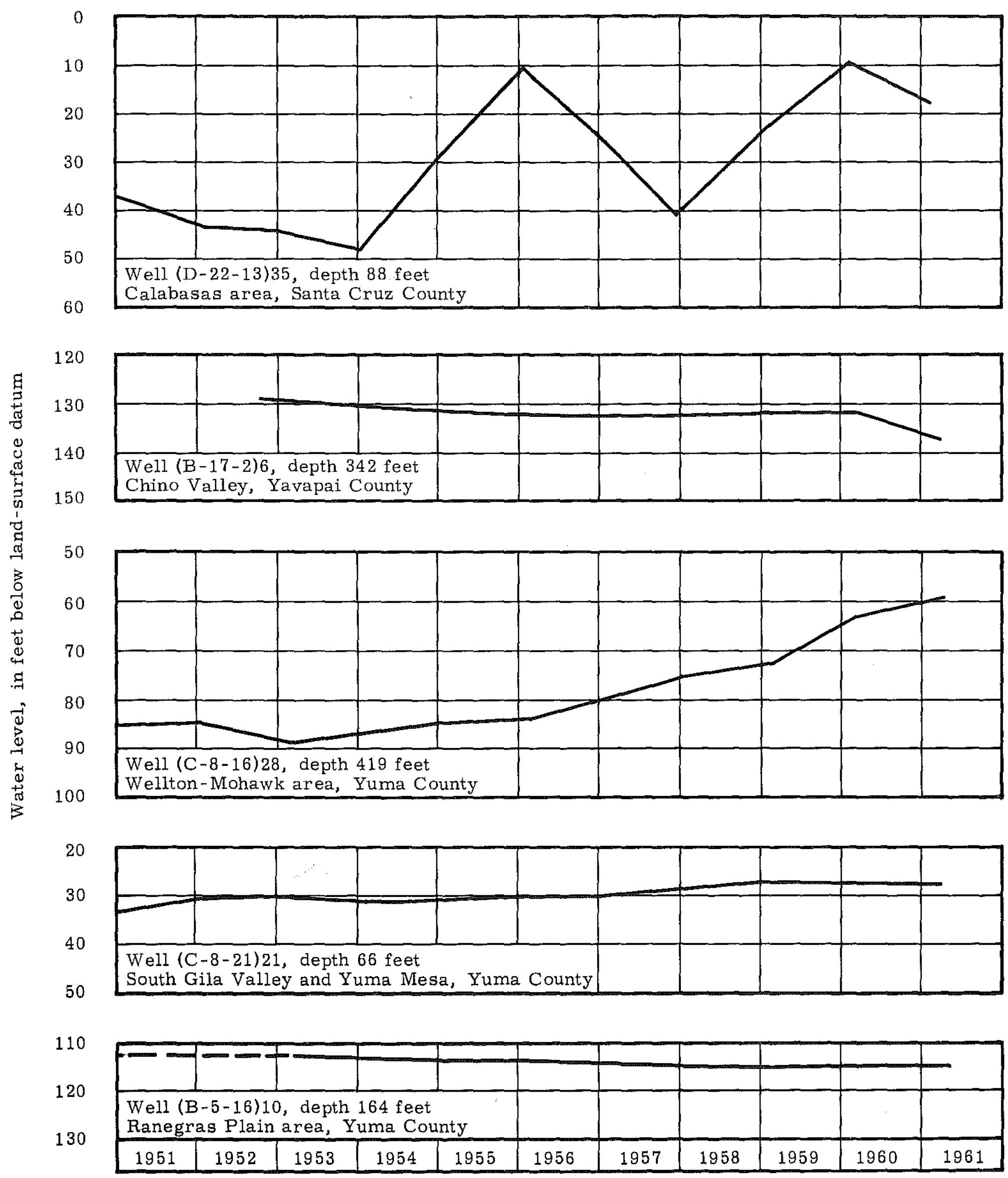

Figure 32.--Water levels in selected wells, Santa Cruz, Yavapai, and Yuma Counties.

principal source of ground water is the Supai Formation of Pennsylvanian and Permian age.

Clarkdale-Cottonwood-Camp Verde area.--In this area water is used mainly for farming, domestic, and industrial purposes. The three major sources of water supplies in the Clarkdale-Cottonwood-Camp Verde area are (1) the Verde River and its tributaries, (2) shallow wells near the river, and (3) deeper wells that penetrate the Verde Formation. The Verde Formation is a lake-bed deposit composed of alternating strata of limestone, sandstone, conglomerate, siltstone, and claystone. In some parts of the valley there is sufficient artesian pressure to cause the wells to flow. Although most of the water used for agriculture in the valley is diverted from the Verde River, there are 11 irrigation wells in the area. One of the wells is reported to flow at a rate of more than 300 gpm. The nonflowing wells range in depth from 125 to 800 feet and the water levels range from about 30 to 150 feet below the land surface.

More than 150 domestic wells have been drilled to depths of more than 100 feet; most of the wells are in the Verde Formation. The water rose under artesian pressure in most of the wells during drilling; near Cottonwood, Page Springs, McGuireville, and Camp Verde there are about 15 flowing wells. In the nonflowing wells, depths to water ranged from a few feet to more than 200 feet below the land surface. Monthly measurements of selected wells and reported data from well owners and drillers suggest that water-level fluctuations are caused primarily by recharge from precipitation and runoff and not by the effect 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.

Sedona area.--Prior to 1949 water supplies for the Sedona area were limited to use of surface flow in Oak Creek and shallow wells adjacent to the creek. During the last few years the increase in population has required the development of more convenient and dependable domestic water supplies. During 1949 a successful domestic well was drilled to a depth of 530 feet about 3 miles west of Sedona. Since that time more than 40 wells have been drilled and bottomed in the Supai Formation which is the major source of domestic water supplies, exclusive of Oak Creek. Measured depths to water in selected wells in this area ranged from 168 to 575 feet below the land surface. The altitude of the water surface in the Supai Formation throughout the area ranged from about 3,500 feet along the west edge to about 4,000 feet along the east edge, and the depth to water at any given site will be influenced by the altitude of the land surface at the site. There are several major faults and structures within the area that probably also affect the depth to water. Water-level fluctuations during the period spring 1959 to spring 1961 do not seem to indicate that the present amount of pumping is causing any significant decline in the water table.

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

Chino Valley-Skull Valley

Water-level fluctuations in the Chino Valley area during the period spring 1960 to spring 1961 ranged from a rise of about 4 feet to a decline of about 8 feet. Wells are the only source of irrigation water near Paulden, and the hydrograph for well (B-17-2)6 (fig. 32) shows the water-level trend in the area. In the spring of 1961 depths to water in the area ranged from about 5 feet to more than 300 feet below the land surface.

In Skull Valley water-level fluctuations for the period spring 1960 to spring 1961 ranged from no change to a decline of about 3 feet. The wells in this area are in shallow alluvium and are readily affected by precipitation.

Yuma County

By

R. S. Stulik

There are five principal areas of irrigation development in Yuma County: (1) Palomas Plain area; (2) Wellton-Mohawk area; (3) McMullen Valley area; (4) Ranegras Plain area; and (5) south Gila Valley and Yuma Mesa area.

Palomas Plain Area

Palomas Plain is an alluvial area that extends northwest from the Gila River between a spur of the Gila Bend Mountains and the Palomas Mountains. The area lies within both Yuma and Maricopa Counties but most of the agricultural development is in Yuma County, and the discussion is therefore included in this section of the report.

During the period spring 1960 to spring 1961 water-level fluctuations in wells in the Palomas Plain area ranged from a rise of about 10 feet in an abandoned well southeast of Horn to a decline of about 3 feet in an abandoned well near Dateland. The majority of data in the area showed little change in the water levels. In the spring of 1961 the depth to water below the land surface in the irrigated areas ranged from about 21 feet along the Gila River to about 266 feet north of Hyder.

Wellton-Mohawk Area

The Wellton-Mohawk area is a flat desert plain that extends from Dome upstream along the Gila River for a distance of about 46 miles. The area is bounded on the west by the Gila Mountains; on the north by the Muggins and Castle Dome Mountains; on the east by Texas Hill; 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 nearly ceased in the area during 1957 because of the operation of the Wellton-Mohawk reclamation project. The few irrigation wells which were still in operation in 1960 were, for the most part, in the new area of development north of Texas Hill adjacent to the boundary of the reclamation project.

For the most part, water levels in the wells in the Wellton-Mohawk Irrigation District continued to rise during 1960.

The water level in well (C-8-16)28 (fig. 32) rose about 24 feet during the period spring 1956 to spring 1961 and about 4 feet from spring 1960 to spring 1961. The depth to water below the land surface ranged from about 4 feet in a well near the Gila River to more than 75 feet in the area north of Texas Hill.

McMullen Valley Area

The McMullen Valley area 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. As most of the area is in Yuma County, it is discussed in this section of the report.

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

During the period spring 1960 to spring 1961 measured water-level fluctuations near Aguila ranged from a decline of about 3 feet northwest of Aguila to a decline of more than 7 feet in a domestic well north of Aguila. Both of these wells are on the fringe of the cultivated area and therefore are not indicative of the decline within the pumped area. Records of water-level fluctuations in an irrigation well within the pumped area showed a decline of 28 feet during the period spring 1958 to spring 1961. Because of year-round pumping in the area it is difficult to obtain more detailed data.

During the period spring 1960 to spring 1961 water-level fluctuations in the vicinity of Salome ranged from no change to a decline of about 5 feet. This part of 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 1961 ranged from about 112 feet near Salome to 453 feet near Aguila.

Ranegras Plain Area

The Ranegras Plain area is in northern Yuma County and is bounded on the north by the Bouse Hills, 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 1960 to spring 1961 water-level fluctuations in the Ranegras Plain area ranged from no change to a decline of more than 10 feet. The hydrograph for well (B-5-16)10 (fig. 32) shows water-level fluctuations typical of the undeveloped parts of the area. Essentially no change has occurred 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 1961 ranged from about 31 feet to more than 225 feet below the land surface.

South Gila Valley and Yuma Mesa Area

By

G. E. Hendrickson

The south Gila Valley is along the Gila River flood plain where ground water is the principal source of irrigation water. The area is bounded on the north by the Gila River and on the east, west, and south by the Gila River terrace. The Yuma Mesa area consists of the land between the south terrace of the Gila River and the "A" Canal.

The rising trend in water levels continued in both the south Gila Valley and the Yuma Mesa area during the period spring 1960 to spring 1961. Although the water level in a few wells declined slightly, the water levels in most wells in the valley rose a few tenths of a foot to about 2 feet during the period March 1960 to June 1961. Water levels in wells on the mesa rose during the same period from about 1 to 4 feet. The water level in well (C-8-21)21 (fig. 32) showed no change from spring 1960 to spring 1961.

Depth to water below land surface in June 1961 ranged from about 50 to 80 feet on the mesa. A few wells on the mesa had depths to water of less than 10 feet under semiperched conditions. In the valley depths to water in most wells were about 10 feet in June 1961, but water levels in a few of the deeper wells near the toe of the mesa were above the land surface.

USE OF GROUND WATER

By

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

In 1960 water pumped from underground storage was again the principal source of supply to meet Arizona's requirements. The total ground-water pumpage and surface-water diversion during 1960 was about 7.2 million acre-feet. Of this amount about 4.5 million acre-feet was ground water and about 2.7 million acre-feet was surface water. Thus, ground water made up nearly two-thirds of all water used in Arizona during 1960. This larger use of ground water compared to surface water has prevailed since 1945 when for the first time more than 50 percent of the total amount of water used came from ground-water supplies, according to records of the U.S. Geological Survey.

In addition to the greater use of ground water over surface water, two other characteristics are notable. First, almost all the ground water pumped is used to grow crops in Arizona's semiarid intermontane basins. In 1960, as well as in 1959, more than 90 percent of the water withdrawn from underground storage was used to irrigate cultivated lands. Secondly, about three-fourths of Arizona's total ground-water production is from wells in two principal areas. The Salt River Valley accounts for about half, and the lower Santa Cruz basin for about a fourth of the total annual pumpage in the State. The remainder of the total annual pumpage is principally from wells in smaller irrigation areas in other parts of Arizona. Compared to the amount of ground water pumped to meet agricultural needs, the pumpage required to satisfy domestic, industrial, and municipal needs in the State is very small.

The total amount of ground water pumped in Arizona in 1960 was only slightly less than the amount pumped in 1959; most of the decrease was in the Salt River Valley and in the Pinal County part of the lower Santa Cruz basin. The decrease was offset in part, however, by increased pumpage in other parts of the State, such as Harquahala Plains, Willcox basin, and McMullen Valley.

Pumpage from wells in the Salt River Valley was about 2,000,000 acre-feet in 1960, about 200,000 acre-feet less than in 1959. The total annual pumpage of ground water in the Salt River Valley for the years 1933-60 is shown graphically in figure 22. The decrease in pumpage in

1960, in part, was due to the conversion of agricultural land to residential use. A large part of the decrease in the amount of ground water pumped can be accounted for, however, by the large volume of surface water in reservoir storage, available prior to the start of the 1960 growing season. This additional surface water, which accumulated from rains occurring in December 1959 and January 1960, was used until the latter part of May 1960. Heavy pumping in 1960 did not begin until June, whereas in 1959 heavy pumping began early in March.

In the Salt River Valley most of the ground water pumped is used to irrigate crops and less than 10 percent is used for municipal, industrial, and domestic purposes. In the Queen Creek - Higley - Gilbert-Magma subarea of the Salt River Valley, pumpage during 1960 was about 155,000 acre-feet, about 15,000 acre-feet less than in 1959. East of the Agua Fria River, in the Phoenix-Glendale-Tolleson-Deer Valley, the Tempe-Mesa-Chandler, and the Paradise Valley subareas, slightly more than 1,175,000 acre-feet of ground water was pumped in 1960, about 275,000 acre-feet less than in 1959. West of the Agua Fria River the total pumpage during 1960 in the Litchfield Park-Beardsley-Marinette, the Liberty-Buckeye-Hassayampa, the lower Centennial, and the Tonopah subareas was about 675,000 acre-feet. In the Tonopah subarea, alone, 55,000 acre-feet was pumped in 1960, about the same as in 1959.

Pumpage in the Pinal County part of the lower Santa Cruz basin totaled about 1,100,000 acre-feet in 1960. This water was used mainly to irrigate crops in three principal areas of development. The total annual pumpage in the lower Santa Cruz basin for the years 1940-60 is shown graphically in figure 29. In the Casa Grande - Florence area 370,000 acre-feet of ground water was pumped in 1960, the same as in 1959; in the Stanfield-Maricopa area 400,000 acre-feet was pumped in 1960, about 70,000 acre-feet less than in 1959; and, in the Eloy area 330,000 acre-feet was pumped in 1960, about 30,000 acre-feet less than in 1959. Thus, the total pumpage in 1960 for the three major areas in the Pinal County part of the lower Santa Cruz basin was about 100,000 acre-feet less than in 1959. A significant part of the decrease in pumpage probably is due to increased pumping lifts resulting from the continued decline in water levels.

Pumpage in Pima County, including that part of the county in the lower Santa Cruz basin, was about 285,000 acre-feet in 1960, about the same as in 1959. About 225,000 acre-feet of the total pumpage in Pima County in 1960 was used to irrigate crops. The rest of the pumpage was used for industrial, municipal, and domestic purposes. Only a small part of the Papago Indian Reservation uses ground water for irrigating crops, although the reservation includes an area of about 1,200 square miles or 40 percent of Pima County. In 1960, as in 1959, pumpage in the Papago Farms area was less than 10,000 acre-feet.

Ground water pumped in Pima County in 1960 to satisfy irrigation needs in Avra Valley and in Santa Cruz Valley from the Santa Cruz County line to and including the Cortaro-Marana area was about 215,000 acre-feet.

Pumpage in the Cortaro-Marana area in the lower Santa Cruz basin was about 40, 000 acre-feet in 1960, slightly more than in 1959.

Ground water pumped for municipal, industrial, and domestic use in Pima County in 1960 was about 60, 000 acre-feet, about the same as in 1959. In the Ajo area in western Pima County, industrial, public supply, and domestic use amounted to about 10, 000 acre-feet in 1960, the same as in 1959. Only a very small part of this pumpage was for domestic use. In the Tucson basin, about 50,000 acre-feet was pumped for municipal, industrial, and domestic uses.

The Willcox basin in Cochise County includes three principal agricultural areas: (1) the Kansas Settlement area east and south of the playa, (2) the Stewart area north of State Highway 86, and (3) the Cochise-Pearce area southwest of the playa. Pumpage in these areas of the basin in 1960 totaled between 180, 000 and 200, 000 acre-feet, about the same as in 1959.

The increase in agricultural development in the Harquahala Plains area continued in 1960 when nearly 32, 000 acres was placed under cultivation. It is estimated that from about 120, 000 to 130, 000 acre-feet of ground water was pumped in 1960, about 30, 000 acre-feet more than was pumped in 1959. Since 1956, the amount of ground water pumped in this area has increased about three times.

Pumpage of ground water in the Waterman Wash area in Maricopa County amounted to about 60, 000 acre-feet in 1960, slightly more than in 1959. Pumpage in this area has increased about 1-½ times since 1956.

About 16,000 acres was under irrigation in the Aguila part of McMullen Valley in 1960, and it is estimated that from about 55, 000 to 65, 000 acre-feet of ground water was pumped. Development in the Aguila area began in 1954 when the first deep well was drilled. In 1955 pumpage in this part of McMullen Valley was 2, 000 acre-feet and in 1957 pumpage totaled 13, 000 acre-feet.

In Safford Valley ground water and surface water are used to irrigate crops. As the crop acreage is limited by decree, and most of the arable land in the area is already under cultivation, the amount of supplemental ground water pumped each growing season depends mainly on the amount of Gila River flow available for diversion. In 1960 surface-water diversion into the canals was about 93, 000 acre-feet, and it is estimated that about 90,000 acre-feet of supplemental ground water was pumped in Safford Valley. This amount of ground water was about 10, 000 acre-feet less than in 1959 when only 80, 000 acre-feet of surface flow from the Gila River was available.

The pumpage of ground water in the Cactus Flat-Artesia area on the eastern slope of the Pinaleno (Graham) Mountains in Graham County is estimated to have been from about 15, 000 to 25, 000 acre-feet in 1960.

Pumpage in both the Bonita area in Sulphur Spring Valley and in the Klondyke area in Aravaipa Valley in Graham County is estimated to have been about 8,000 to 10,000 acre-feet in 1960.

In the Gila Bend area pumpage of ground water in 1960 is estimated to have been about the same as in 1959. Surface water and ground water are used to irrigate crops in the Gila Bend area which includes about 800 square miles along the Gila River from Gillespie Dam to the Painted Rock Mountains. Currently available data are insufficient to present a more detailed inventory of ground-water pumpage in the Gila Bend area.