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ANNUAL REPORT ON GROUND WATER IN ARIZONA SPRING 1957 TO SPRING 1958

BY

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ANNUAL REPORT ON GROUND WATER IN ARIZONA SPRING 1957 TO SPRING 1958

By

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ABSTRACT

The collection and analysis of basic hydrologic data are integral parts of the investigation of the ground-water resources of Arizona, conducted by the U. S. Geological Survey in cooperation with the State Land Department. About 3,000 water-level measurements were made in 1,900 wells during 1957. Most of the measurements were made in the Salt River and lower Santa Cruz Valleys. Development of ground water increased in McMullen Valley, Harquahala Plains, Willcox basin, and parts of Mohave County. This report is a summary of the basic hydrologic data collected during the year, spring 1957 to spring 1958.

Pumpage of ground water in Arizona in 1957 was about the same as in 1956, about 4,500,000 acre-feet. More than 90 percent of this ground water was used for irrigation, although there was an increase in use for public supply. The trend of water levels in the heavily pumped areas continued downward, although in the Yuma and Wellton-Mohawk areas and parts of upper Santa Cruz basin some rises did occur. Illustrations include: (1) Hydrographs showing fluctuations in selected wells; (2) maps showing change in water levels for the 5-year period 1953-58 for the Salt River Valley, lower Santa Cruz, Willcox, and Douglas basins; (3) selected well logs; and (4) map showing location of annual water-sampling program.

INTRODUCTION

The future economic development of Arizona is dependent on the successful use of existing water supplies for productive benefit, and the availability of water supplies for an expanding economy. Pumping of ground water in large quantities in Arizona began in the 1920's. At that time most of the pumpage was from drainage wells used to reclaim waterlogged land. In the 1930's the pumping of ground water increased, owing primarily to the utilization of water for irrigation. The State Legislature observed this increase in the development of ground water for irrigation and recognized the need for information on the occurrence and storage of ground water. In 1939 it appropriated funds for investigations of the ground-water resources of the State,

and a cooperative agreement providing for the studies was made between the State Water Commission and the U. S. Geological Survey. Succeeding State Legislatures have appropriated funds for a continuation of these investigations, and these State funds are matched by Federal funds. Since 1942 the State Land Department has been the cooperating agency.

The work done under the cooperative program includes the collection of basic hydrologic data, geological and ground-water investigations of specific areas, and studies related to the solution of specific hydrologic problems. This report is a compilation and analysis of the basic-data-collection part of the program in 1957.

This report contains a discussion of the ground-water hydrology and summary statements of changes or trends in the ground-water conditions throughout the State by counties and areas. Sections are presented on ground-water pumpage, logs of wells in important irrigation areas, and chemical quality of the water. Hydrographs are included to show comparative changes in the stage of water levels in selected wells. Maps show the changes in ground-water levels for a 5-year period (1953-58) in the Salt River Valley, lower Santa Cruz, Willcox, and Douglas basins. There is a graph showing the type of subsurface material encountered in drilling wells in seven different areas, and a map showing the location of wells where water samples are collected periodically for chemical analysis.

Scope of Basic-Data Program

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. Because of the economic value to the State and Nation, particular emphasis is directed toward studies in areas of extensive irrigational and industrial development. This work includes a well inventory, periodic water-level measurements, collection of water samples for chemical analysis, and collection and cataloguing of drill cuttings from recently completed wells.

The objectives of this part of the program are (1) to evaluate the trends 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 conditions may support future development; (3) to determine the geologic and hydrologic characteristics of areas as related to the ground-water regimen; (4) to determine the changes in the chemical quality of water; (5) to provide continuous records of fluctuations of water levels in selected wells in order to study the net change in ground-water storage; (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 collect pumpage records from specific areas, when applicable.

The collection of basic data provides a foundation for ground-water research and a framework for the compilation of records in any detailed regional investigation. The data are necessary for the evaluation of the yearly changes and trends in ground-water conditions throughout the State. During the year water-level measurements and other related information are collected, tabulated, and analyzed, and the results are published in an annual report. The purpose of this report is to present the data to the people of the State in a way that is informative, interesting, and helpful. An analysis of a series of these reports covering a number of years would reveal the effects of heavy pumping in the developed basins throughout the State. The conditions in the lesser known and undeveloped areas, the possible areas for industrial and irrigational development, the possible range in depth and yield of contemplated wells, and the areas in which the Geological Survey is making more detailed ground-water studies would also be revealed. Additional information not published in reports is on file in Phoenix and Tucson for inspection by interested parties.

Under the cooperative program, about 3,000 water-level measurements were made in 1957 in 1,900 wells. The rate of discharge, in gallons per minute, was measured in about 1,300 wells. Water-level measurements and chemical analyses of water samples are available for inspection in the offices of the Geological Survey, Ground Water Branch, at Phoenix and Tucson.

Current Projects in Arizona

Ground-water studies made by the U. S. Geological Survey in Arizona are financed by means of the following: (1) cooperative agreement with the State; (2) cooperative agreements with municipalities and water districts; (3) Geological Survey noncooperative funds; and (4) transfer of federal funds from other federal agencies. The areas of new and active projects are shown on figure 1.

The cooperative program with the State includes (1) collection of basic hydrologic data (discussed under "Scope of Basic-Data Program"); (2) geologic and ground-water investigations of specific areas; and (3) studies related to the solution of specific hydrologic problems.

Ground-water investigations of specific areas consist of geologic studies, complete well inventories, measurements of pumpage or natural discharge, and descriptions of hydrologic conditions. The preliminary work, preferably done before extensive development, is invaluable as a basis for long-range study of the ground-water resources.

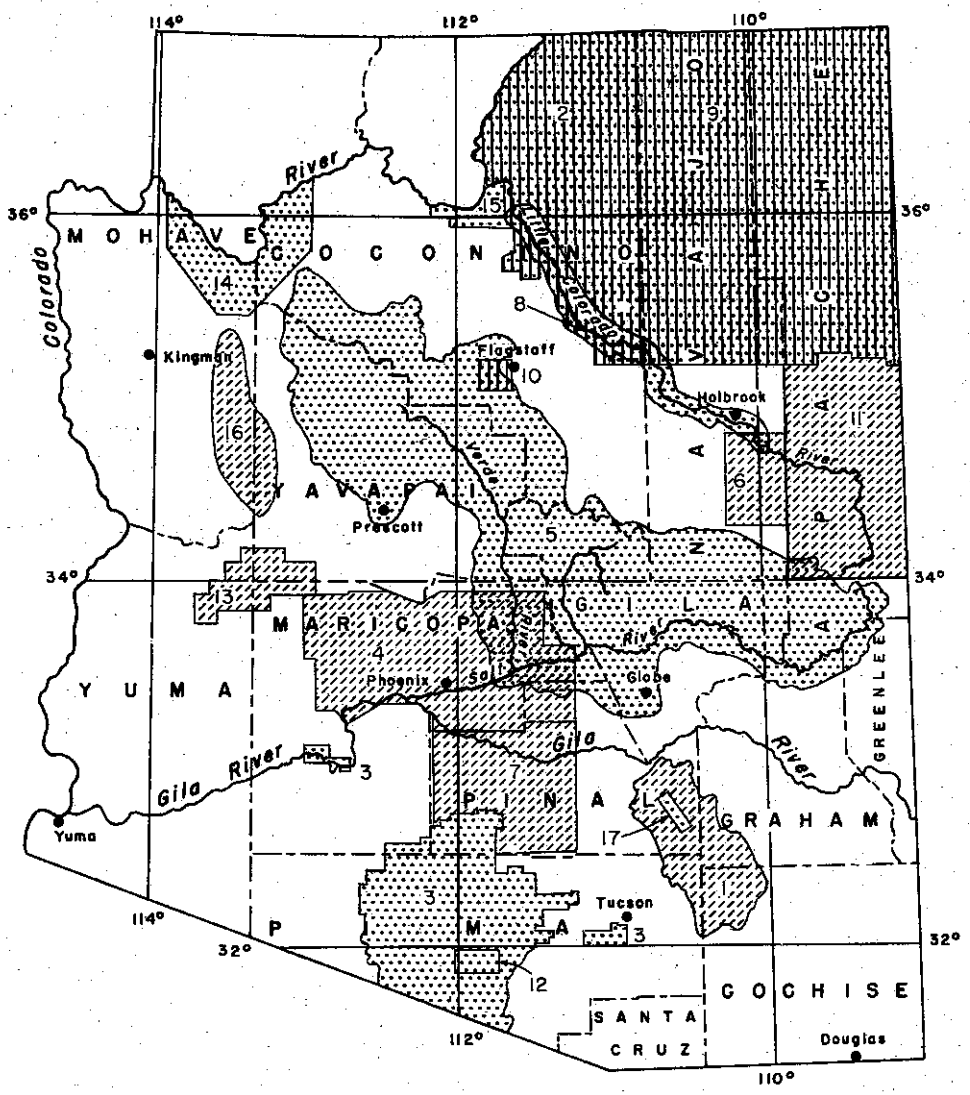

Figure 1.-- Map of Arizona showing areas of ground-water investigations.

PROJECTS BY AREAS

1. Lower San Pedro River basin
2. Navajo-Hopi Indian Reservations
3. Papago Indian Reservation
4. Salt River Valley
5. Mogollon Rim region
6. Snowflake-Taylor area
7. Northwestern Pinal County
8. Little Colorado River basin
9. Navajo Tribal well-development program
10. City of Flagstaff
11. Apache County
12. Sells Hospital site
13. McMullen Valley
14. Hualapai Indian Reservation
15. Grand Canyon National Park
16. Big Sandy
17. San Pedro-Mammoth area

Basic hydrologic data part of State cooperative program covers entire State

Investigations financed jointly with State and Federal funds

Investigations financed jointly with other non-Federal and Federal funds

Investigations financed with noncooperative Federal funds and Federal funds transferred from other Government agencies

The information obtained may be correlated with that from a similar study of the area completed after extensive development. Projects of this type include those in the lower San Pedro basin, Snowflake-Taylor area, McMullen Valley, Mogollon Rim region, and a part of Apache County south of the Navajo Indian Reservation.

Studies related to the solution of specific hydrologic problems provide a more accurate quantitative determination of the ground-water resources of the State. These studies have been undertaken because of the necessity for obtaining more specific information on the occurrence, movement, recharge, storage, discharge, and chemical quality of ground water in areas of present or prospective development. The studies involve an analysis of available basic geologic and hydrologic data and the collection of basic data related specifically to these problems. Current projects of this nature are the determination of the productivity of deep aquifers in the Salt River Valley and of changes in the chemical quality of ground water at depth, the analysis of geologic and hydrologic data collected since 1903 in the Florence-Casa Grande-Maricopa area in Pinal County, and the study of water movement in the inner San Pedro Valley near Mammoth.

Cooperation with municipalities is exemplified by the current project with the city of Flagstaff and the recently completed project with the city of Safford. The cooperation with the city of Safford consisted of an investigation of the Bonita Creek area for obtaining additional water for the city. The Flagstaff cooperation consists of determining the feasibility of developing ground water as a supply for the city; the success of the deep wells to date is discussed in this report under "Coconino County."

Work financed entirely with federal funds is done in areas where the Federal Government has a specific interest not related solely to that of the State and local cooperating agencies. Studies of the several Indian reservations are included in this arrangement, and the results of these investigations are also beneficial to the State. Projects of this type include the Navajo-Hopi country in the northeastern part of the State, the Papago reservation west of Tucson, and the Hualapai reservation in the northern part of Mohave and Coconino Counties. A new project on the ground-water resources of the Grand Canyon National Park and Monument has been started. The purpose of this investigation is to appraise the ground-water regimen in order that the water supply for the National Park facilities may be increased to meet present demands. Other federal projects are the Little Colorado River basin study, the Sells (Papago) Hospital site, and the Mogollon Rim region.

List of Publications

The following reports on the ground-water resources and geology of Arizona were prepared and released to the open file by the Ground Water Branch of the Geological Survey in 1957 and early 1958:

Use of ground water in Arizona, by J. W. Harshbarger, in Contribution No. 6, Climate and Man in the Southwest, Program in Geochronology: University of Arizona Bull., May 1957. 34 p., 5 figs., 1 table.

This paper presents a brief résumé of the ground-water conditions in the State. Some of the major geologic features that control the occurrence, recharge, movement, storage, and discharge of water in the ground are discussed. There is a comparison between the ground-water reservoirs prior to extensive development and the current water-table conditions. The decline of the water table in some of the heavily pumped basins has resulted in a depletion of the ground-water reservoirs.

Geology and ground-water resources of the Harquahala Plains area, Maricopa and Yuma Counties, Arizona, by D. G. Metzger: Arizona State Land Department Water Resources Report No. 3, September 1957. 40 p., 2 pls., 7 figs., 4 tables.

This report describes a reconnaissance study of the ground-water resources of the Harquahala Plains area in the west-central part of the State. The ground-water hydrology, including occurrence, recharge, movement, storage, and discharge, and the geology are discussed qualitatively. Most of the ground water is being pumped from storage, and if pumping remains at the present rate or increases, the water levels will continue to decline. There is a section on the chemical quality of the water and various tables include well records, drillers' logs, and chemical analyses.

Interim report on the ground-water resources of the McMullen Valley area, Maricopa, Yavapai, and Yuma Counties, Arizona, by William Kam, October 1957. 27 p., 1 pl., 2 figs., 3 tables.

McMullen Valley is one of the newly developed irrigation regions in the State. This preliminary report consists of the available information on the geology and ground-water resources of the area. The subsurface geology of the Aguila, Wenden, and Salome-Harrisburg Valley areas is described. There is a general discussion of the ground-water hydrology and a section on the quality of water. Tables include well records, drillers' logs, and chemical analyses. A comprehensive report of this valley is being written by the author at the present time.

Annual report on ground water in Arizona—spring 1956 to spring 1957, by J. W. Harshbarger and others: Arizona State Land Department Water Resources Report No. 2, September 1957. 42 p., 18 figs., 1 table.

This annual report is a summary of the basic hydrologic data collected during the spring 1956 to the spring 1957. It broadly describes the ground-water pumpage from the principal basins in the State and water-level fluctuations in these basins. Approximately 4.5 million acre-feet of ground water was pumped in 1956 and the trend of water levels in the heavily pumped areas continued downward. Illustrations include 10-year hydrographs showing water-level fluctuations in selected wells, maps showing change in water levels for the 5-year period 1952-57 for the Salt River Valley, lower Santa Cruz, Willcox, and Douglas areas, and a graph showing ground-water pumpage from basins in Arizona.

Geology and ground-water resources of the Palomas Plain-Dendora Valley area, Maricopa and Yuma Counties, Arizona, by C. A. Armstrong and C. B. Yost, Jr.: Arizona State Land Department Water Resources Report No. 4, January 1958. 49 p., 3 pls., 4 figs., 5 tables.

The Palomas Plain-Dendora Valley area is midway between Phoenix and Yuma. This report describes the geology and ground-water resources of the area. The most important aquifers are sand and gravel lenses within the alluvium-filled valleys. The drainage is intermittent and controlled largely by the Gila River. The aquifers are recharged by streamflow within the area. The ground-water hydrology is broadly discussed and there is a section on the quality of water. Tables include well records, drillers' logs, and chemical analyses.

Reconnaissance of the water resources of the Lonesome Valley area, Yavapai County, Arizona, by D. G. Metzger, March 1957. 4 p., 1 map.

A brief reconnaissance of the water resources of the Lonesome Valley area was made to determine the probable hydrologic effects of a proposed dam on Lynx Creek. It was concluded that the dam would have little effect on water levels in the wells along the Agua Fria River. Most of the ground water in the valley is pumped from storage and the construction of the dam would effect only a small change in the amount of recharge to the valley.

Should the term Gila conglomerate be abandoned? by L. A. Heindl, in Contribution No. 7, Program in Geochronology: University of Arizona Bull., January 1958. 34 p., 3 illus.

As the term Gila conglomerate refers to diverse units, the author believes that it should be abandoned. He does not consider it feasible to raise the Gila conglomerate to group status because the deposits now referred to as the Gila conglomerate do not represent a succession of units in a single basin.

Agricultural Résumé for 1957

According to R. E. Seltzer (Arizona Agriculture 1958: Arizona Agr. Expt. Sta. Bull. 292, January 1958), about 1,150,000 acres were irrigated in Arizona in 1957, the same as in the previous year. About 6,100,000 acre-feet of water was used for irrigation during 1957, of which 4,000,000 acre-feet was pumped from ground-water supplies. The largest irrigated acreages under cultivation were in cotton (350,000 acres) and alfalfa (192,000 acres). The counties having the largest acreage under cultivation were: (1) Maricopa, 479,000 acres; (2) Pinal, 264,000 acres; (3) Yuma, 175,000 acres; and (4) Cochise, 82,000 acres.

There was a decrease in the irrigated acreage in the southeastern part of the State, including Pinal, Pima, Graham, Santa Cruz, and Greenlee Counties. This decrease probably resulted from participation in the soil-bank program, and from deep pumping lifts in certain basins. Cochise County had an increase of 2,000 acres under cultivation, due principally to the lettuce industry in the Willcox area. Maricopa County had the greatest increase of irrigated land, and Mohave, Coconino, and Navajo Counties had smaller increases.

Seltzer (1958) states that Arizona's cash agricultural income was the second highest of record. It amounted to 398 million dollars, and income from cotton (166 million dollars) and from cattle (85 million dollars) accounted for slightly over 50 percent of this amount. Higher prices for cotton, cattle, and citrus, and increased government payments under the soil-bank program provided the increase over the 1956 income. Although less cotton was grown than in the previous year, 1957 was the 11th year in which it was the principal money crop in the State. The income from vegetables and commercial feed grains was lower than in 1956, and the prices of milk and eggs were about the same.

The trend toward the development of new vegetable-producing areas in Arizona is continuing. The development in the Willcox basin is encouraging because the high altitude and low temperatures prolong the spring season into May and June. The water table in this area is much closer to the surface than in areas where extensive pumping is taking place. Increased development is also taking place in McMullen Valley and the Harquahala Plains. Of course, increased production in the new areas could result in overpumping and declining water levels.

Precipitation

The precipitation in 1957 was above the average in Arizona. During the first half of the year, precipitation was helpful in restoring the condition of the range, and during the latter part of the year conditions were similar to the long-term average.

January was wet throughout the State. February, March, and April were relatively dry, although individual stations received above-average precipitation. There was a large amount of rain in May, particularly in and near the mountains. June and July had above-average precipitation. August was relatively wet and September was very dry. October was wet and the precipitation continued throughout November in the northern part of the State, but practically ceased in the southern part. December was dry throughout the State.

Although recharge to the ground-water reservoirs comes originally from precipitation, most of the actual recharge to the aquifers of Arizona occurs from streamflow instead of from direct rainfall. In arid climates, such as Arizona, the small amount of precipitation usually falls in sudden short bursts. In the southern part of the State, in the Basin and Range province, the precipitation from these short-duration storms runs off quickly into the streams because of the relatively high topographic relief and the soil conditions. Evaporation losses are extremely high and only very small amounts of water percolate downward to the water table. After the rainfall enters the streams as runoff and reaches the alluvial valleys, recharge to the ground-water

aquifers is enhanced. However, adjacent to the streams abundant water-loving vegetation uses tremendous amounts of water and much of the infiltrating water never reaches the water table.

The rate of movement of water through sediments is very slow, and the time it takes for water to reach the water table depends on the thickness, the permeability, and the soil-moisture capacity of the unsaturated sediments. Therefore, it must be emphasized that the excess rainfall (or streamflow) in 1957 will have little immediate effect on the water table in the Salt River or Santa Cruz Valleys, or in other areas where the water table is very deep.

The plateau regions in the northern part of the State are composed mostly of consolidated sedimentary rocks. The land is at a higher altitude than the basin country, temperatures are lower, evaporation is less, and the presence of accumulated snow on permeable forest cover probably allows more precipitation to percolate downward.

The heaviest concentration of rainfall during 1957 was in the mountainous regions of Gila, Yavapai, Coconino, Navajo, and Apache Counties. Gila County had an average of 21.79 inches of precipitation, or 3.73 inches above the long-term average. Yavapai County had 18.47 inches of rainfall, 2.59 inches above the average. These areas are an important source of water to the Salt River Valley. In the lower Santa Cruz and Salt River Valleys, the amount of precipitation in 1957 was about half an inch above the long-term average. The major benefit of the increased rainfall in these extensively developed basins was an indirect one—a slight reduction of the ground-water pumpage.

The heavy precipitation during January was a fortunate occurrence. In January, vegetation is dormant, temperatures are near the minimum for the year, and evapotranspiration losses, therefore, are near the minimum. Thus a larger portion of the precipitation became streamflow or ground water than would have if the precipitation had occurred in some other season of the year. Precipitation for 1957 and departures from long-term averages at various stations in Arizona are shown in table 1.

Surface-Water Diversions

About 2,100,000 acre-feet of surface water was diverted for irrigation in 1957. More than half this amount, or about 1,300,000 acre-feet, was diverted from the Colorado River for use by (1) Colorado River Indian Reservation below Parker, (2) Valley Division of the Yuma Project, (3) Yuma Mesa Auxiliary Project, and (4) Wellton-Mohawk Project. These projects use only surface water for irrigation. Of this total, about 300,000 acre-feet is returned to the Colorado River or discharged across the Arizona-Sonora International Boundary.

Table 1.--Total precipitation in 1957 at selected stations and departures from long-term means (From Climatological Data, Arizona, Annual Summary 1957: U. S. Weather Bur.)

Station	Precipitation (inches)	Departure (inches)
Bowie	10.88	-
Buckeye	7.26	-
Casa Grande	9.72	+1.64
Chandler	8.25	-
Chino Valley	10.71	-
Davis Dam	6.41	-
Douglas Smelter	11.45	-0.17
Duncan	10.98	-
Eloy	10.04	-
Flagstaff	24.59	+6.12
Gila Bend	7.30	+1.39
Globe	16.49	+1.09
Holbrook	10.96	+3.21
Kingman	10.72	-
Litchfield Park	9.27	+1.41
Mesa	7.90	+0.21
Nogales	15.67	-
Payson	29.24	-
Phoenix Airport	7.60	+0.44
Pinedale	20.71	+2.89
Prescott Airport	14.90	-1.08
Safford	10.28	+1.56
St. Johns	15.06	+3.69
Snowflake	12.52	+0.79
Tucson, University of Arizona	13.35	+2.92
Wellton	3.71	-
Wikieup	10.63	-
Willcox	10.02	-
Williams	28.16	+7.03
Yuma Airport	4.84	+1.45

According to the Surface Water Branch, U. S. Geological Survey, the remaining 800,000 acre-feet of diverted surface water was used in combination with ground water for irrigation. Almost 600,000 acre-feet was diverted at Granite Reef Dam for use in the Salt River Valley. About 78,000 acre-feet from the Ashurst-Hayden Dam was diverted to the San Carlos Project, and about 70,000 acre-feet was diverted from the Gila River for use in the Safford basin. Smaller diversions included those from the Gila River for the Buckeye Irrigation District, Agua Fria River at Carl Pleasant Dam, Salt and Verde Rivers above the dams, and Little Colorado River. The runoff to the reservoirs in the central part of the State was below normal and surface flow throughout the State was 10 to 15 percent below average. Although the total annual precipitation was above average, and that for the spring months was below average the storms were not "flashy," and there was less surface flow than might have been expected.

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. 2). These quadrants are designated counterclockwise by the capital letters A, B, C, and D. All land north and east of the point of origin is in A quadrant, that north and west in B quadrant, that south and west in C quadrant, and that south and east in D quadrant. The first digit of a well number indicates the township, the second the range, and the third the section in which the well is situated. The lowercase letters a, b, c, and d after the section number indicate the well location within the section. The first letter denotes a particular 160-acre tract (fig. 2), 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 NE$\frac{1}{4}$NE$\frac{1}{4}$SW$\frac{1}{4}$ 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

Personnel of the Phoenix office who worked on this report are J. M. Cahill, D. G. Metzger, W. Kam, F. R. Twenter, R. S. Stulik, and Ann C. Hill. Personnel of the Tucson office who worked on the report are M. B. Booher, C. S. English, E. K. Morse, N. D. White, C. L. Jenkins, M. F. Howard, L. A. Heindl, P. W. Johnson, and N. A. Tilghman. Those of the Holbrook office who worked on the report are J. P. Akers and E. L. Gillespie.

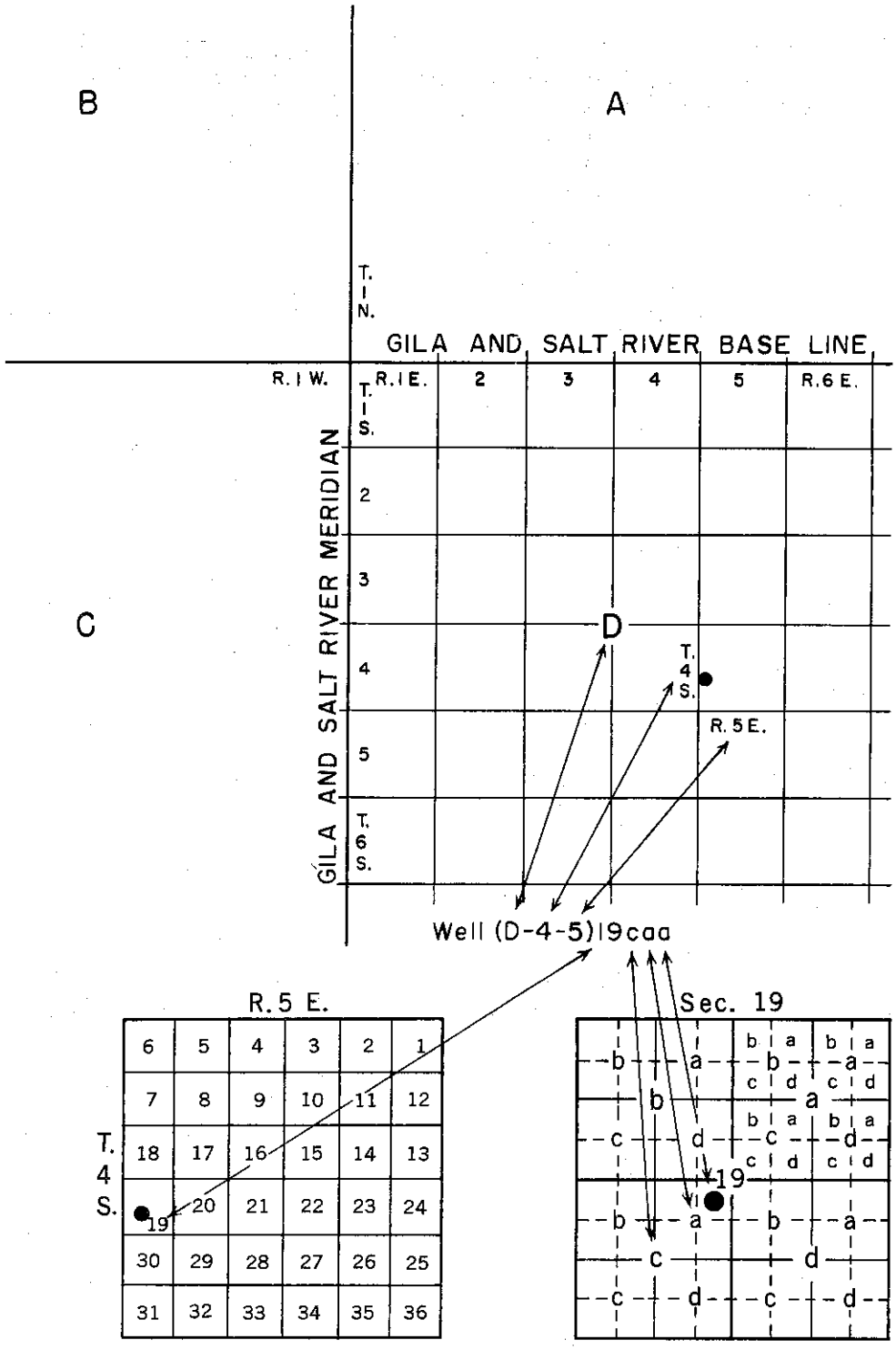

Figure 2.-- Sketch showing well-numbering system in Arizona.

The project and this report were coordinated by W. F. Hardt, who wrote the introduction, the regional ground-water hydrology, and the section on pumpage. The discussion of the ground-water conditions in the Salt River Valley and most of the northern counties was written by J. M. Cahill. Discussion of conditions in the southern part of the State was written by M. B. Booher; and J. P. Akers discussed Apache and Navajo Counties. The quality of water section was written by L. R. Kister, chemist, Quality of Water Branch of the U. S. Geological Survey; and the illustrations were prepared by G. S. Smith. The report was prepared under the supervision of J. W. Harshbarger, district geologist.

Acknowledgments

Many irrigation districts, cities, well drillers, water companies, government agencies, and individuals provided splendid cooperation in furnishing information. The following organizations were particularly helpful: Arizona Corporation Commission, Arizona Water Company, Buckeye Irrigation District, City of Douglas, City of Nogales, City of Phoenix, City of Tucson, Cortaro Farms, Gila Water Commissioner, Goodyear Farms, Maricopa County Municipal Water Conservation District, Salt River Valley Water Users' Association, San Carlos Irrigation District, U. S. Bureau of Indian Affairs, U. S. Bureau of Reclamation, U. S. Weather Bureau, and Surface Water and Quality of Water Branches of the U. S. Geological Survey.

GROUND-WATER HYDROLOGY

To develop the ground-water reserves of Arizona intelligently, a comprehensive understanding of the hydrology and geology is essential. The work necessary to achieve this understanding includes the periodic measurement of ground-water levels in wells. The accumulation of this information over a period of years is plotted on charts called hydrographs. The interpretation of these hydrographs is an important step in evaluating the ground-water resources of the State. From the results of these data, additional quantitative studies can be outlined.

The State has been divided into three water provinces: (1) the Plateau uplands in the northern part of the State; (2) the Central highlands; and (3) the Basin and Range lowlands in the southern part of the State. In the northern half of the State, there is little irrigation and ground-water pumping. As a result, the long-term hydrographs do not show any appreciable sustained declines. Future developments in localized areas, such as in some of the valleys of Mohave County or in parts of the Little Colorado River drainage, would cause a cone of

depression or lowering of the water table in the vicinity of the pumped wells. The regional movement of the ground water in the northern part of the State is generally toward the Colorado River, and large but unknown quantities are discharged into the river.

The Central highlands lie mostly in Yavapai, Gila, and Greenlee Counties. High precipitation, rapid runoff, and low evaporation is characteristic of the water resources in this area. The direction of movement of the surface water is toward the Salt River Valley. Before the water reaches the valley, it is impounded in the mountains by Bartlett, Roosevelt, and Coolidge Dams. There is little or no ground-water underflow in these tributary valleys because the streams flow over bedrock for many miles. When the water reaches the alluvial deposits of the Salt River Valley there may be some recharge to the ground-water reservoir. To compensate for the heavy withdrawals in the Salt River Valley, it may be feasible to recharge the area artificially with surplus streamflow. It may be desirable to store the water beneath the ground rather than allow it to remain on the surface where much of it is lost to the atmosphere.

In the Salt River Valley and the lower Santa Cruz basin the water levels have continued to decline and it is obvious that the amount of water being pumped is much greater than the natural recharge. Other basins are in various stages of development and water-level measurements are essential to document the effects. At the present time there is little ground-water pumping or decline in water levels in the Sacramento Valley, Hualapai Valley, the Big Sandy area of Mohave County, Mohawk Valley in Yuma County, Santa Rosa and San Simon Valleys in the Papago Indian Reservation, and other smaller valleys. To develop these new areas properly, detailed geologic and hydrologic studies are needed.

The most important drainage system in the Basin and Range lowlands is the Gila River and its tributary, the Salt River. Much of the ground-water movement in the southern part of the State is toward these rivers. In the Douglas basin in Sulphur Spring Valley and San Simon Valley in the Papago Indian Reservation, ground water moves toward Mexico.

Movement of ground water in the San Simon (Rodeo, New Mexico, to Safford) and San Pedro Valleys is northward toward the Gila River. In the Safford Valley area most of the available agricultural land is being used and the pumpage varies with the amount of precipitation and the streamflow in the Gila River.

The Sulphur Spring Valley is divided into the Willcox and Douglas basins. Pumping in this area has increased during the last 10 years and water levels have declined. The increased development in the Willcox basin during 1957 will result in greater pumping and the water levels in the area will decline; however, the beneficial use of the

ground water in this basin prevents it from moving into the Willcox playa and being lost by evaporation. This is one area in the State where the pumpage is adjacent to the point of natural discharge.

Ground water in the Santa Cruz Valley moves northward from Nogales, past Tucson, and toward the Gila River. Heavy pumping over a period of years in the Eloy, Casa Grande, and Maricopa areas has depressed the water table and reduced the amount of underflow to the Gila River. Declining water levels and increasing pumping costs may result in a reduction in the amount of farming in the developed basins. A partial solution to the situation in these critical areas may be a change to industrial developments and housing projects, which ordinarily use less water than farming. The application of artificial recharge, if feasible, may be helpful. The accelerated demand for water in the State indicates the need for intensive evaluation of the water resources.

Water-Level Fluctuations

The general trend of water levels in Arizona in 1957 continued downward in the developed basins. These declines are caused directly by pumping. Maximum declines again occurred in Maricopa and Pinal Counties. Smaller declines of the water table were measured in the Sulphur Spring and San Simon Valleys of Cochise County, and in parts of Pima County, particularly the Avra-Marana and Tucson areas. The only places in the State where the water table is rising consistently is in the Wellton-Mohawk area and Yuma Mesa of Yuma County. The rise in water level is attributed to recharge from Colorado River water diverted onto the irrigated areas.

Records in the recently developed areas, such as McMullen Valley, are not long enough to establish water-level trends; but increased development and pumpage will result in a declining water table. Hydrographs of selected wells in the northern half of the State show minor fluctuations.

The periodic measurement of water levels throughout the State is necessary to maintain current appraisals of the ground-water conditions and to compute the amount of water stored in the various basins. A rise or decline of water levels in an area will show a net gain or loss of water stored for that period of time. A steady decline in the water table of a basin over a period of years indicates that ground water is being depleted. It is important to measure the water levels in wells about the same time each year to obtain consistent results. The Geological Survey makes measurements during the early months of each year. At this time pumping is at a minimum, more uniform conditions prevail, and the water levels are approaching static conditions.

Most of the water-level measurements are made in the developed areas of southern Arizona where fluctuations in the ground-water reservoir are of prime importance to a large number of people. The increase in industrial development and the growth in population could affect the ground-water storage in different areas. In this event the Survey would increase the number of water-level measurements in new areas. Figure 3 is a map showing the areas in the State where ground-water levels are measured.

Apache County

Most of the ground-water development for irrigation is confined to the central part of Apache County, along the Little Colorado River near St. Johns and Hunt. The land surface in this area slopes gently toward the northwest from an altitude of about 5,700 feet at St. Johns to about 5,400 feet at Hunt. A large part of the country to the south of this area is covered by lava flows, but the irrigated lands are in broad alluvial valleys formed in sedimentary rock by the Little Colorado River. The regional dip of the rock is to the north, so that exposed strata are, in general, successively older toward the south. This regional dip is an important factor in the movement of ground water from the southeast to the northwest. The controlling factor in this movement is the difference in head of the ground-water surface between the mountain regions south and west of St. Johns and the lower discharge areas. This is the reason for artesian rise of water in most wells drilled in the area.

The depths of wells in these areas range from 200 to more than 700 feet. The static water levels range from several feet above the land surface to 40 feet below the ground, and the maximum pumping level is about 100 feet below the land surface. In other parts of the country, just south of the Navajo reservation, the water levels in some of the stock wells are as much as 300 feet below the ground. No trend of decline or rise in water levels has been observed in Apache County because no water-level-measurement program is in progress. However, farmers in the Hunt Valley area report higher water levels (spring 1958) than for the past several years.

Cochise County

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

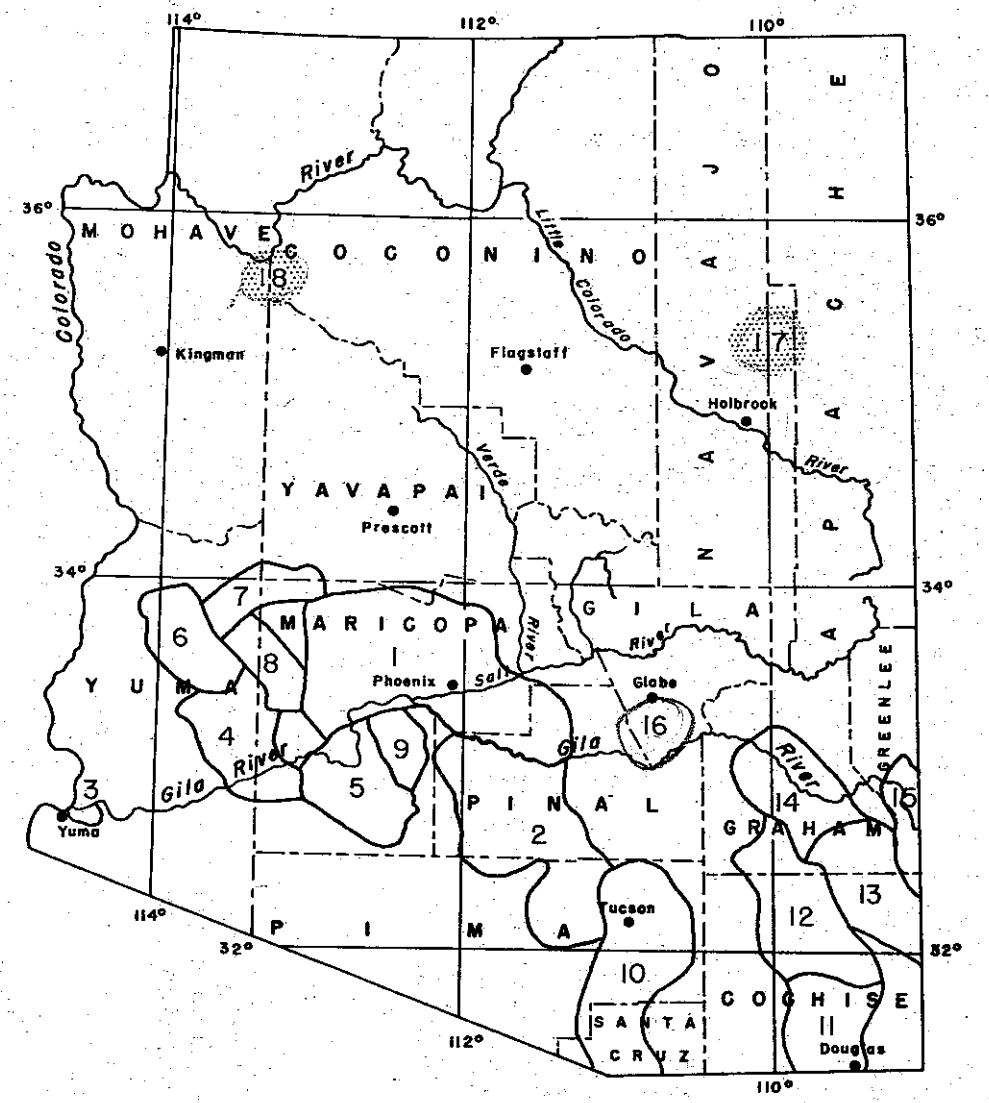

Figure 3.-- Map showing ground-water areas and basins in Arizona where water levels are measured.

1. Salt River Valley
2. Lower Santa Cruz basin
3. South Gila Valley
4. Palomas Plain area
5. Gila Bend area
6. Ranegras Plain area
7. McMullen Valley
8. Harquahala Plains area
9. Waterman Wash area
10. Upper Santa Cruz basin
11. Douglas basin
12. Willcox basin
13. Bowie-San Simon area
14. Safford Valley
15. Duncan Valley
16. Gila County (City of Globe, San Carlos Valley)
17. Navajo and Apache Counties
18. Coconino, Yavapai, and Mohave Counties

Willcox basin. --The Willcox basin lies 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 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 ranges from about 15 to 30 miles in width, is about 50 miles long, and covers about 1,500 square miles. Although most of the basin is within Cochise County, approximately 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. 4), 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 about 27,500 acres. The Kansas Settlement area lies 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 about 30,000 acres under irrigation and is expanding rapidly.

The natural ground-water gradient in the Willcox basin is toward the playa. North of the playa the ground-water movement is southward from the divide near Aravaipa Creek, and south of the playa it is northward in the vicinity of Pearce. At times the playa is dry and partly encrusted with white salts; at other times a shallow body of water derived from runoff covers the flat. Many years ago, this playa probably intersected the surface of the ground-water table. A water-table contour map, based on water-level measurements made in the spring of 1958, shows that the pumping of ground water for irrigation intercepts some of the underflow and is making a 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.

In the Stewart area, water-level fluctuations for the period spring 1957 to spring 1958, based on 65 water-level measurements, ranged from a rise of about 4 feet to a decline of about 7 feet and indicated an average decline of about 4 feet. In the 5-year period, spring 1953 to spring 1958, water levels in wells in the area declined from about 10 feet along the fringe areas to nearly 30 feet in the center of the heavily pumped areas (fig. 4). The water level in well (D-13-24)16 (fig. 5), in the heavily pumped area, declined less than 5 feet from spring 1957 to spring 1958 and nearly 30 feet for the 5-year period. In the spring of 1958, the depth to water in the Stewart area ranged from about 20 feet near the town of Willcox to about 120 feet on the northern edge of the irrigated area.

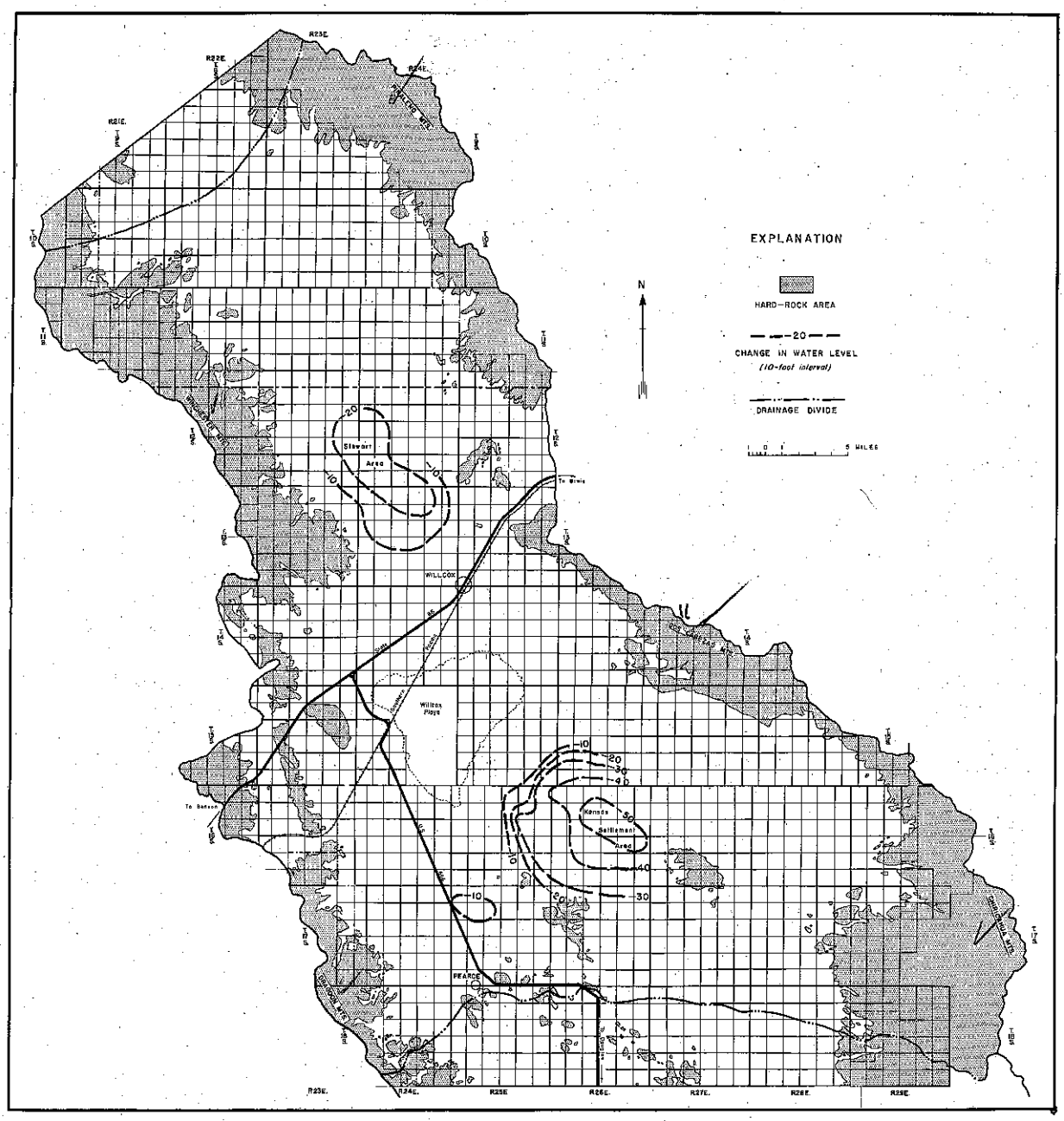

Figure 4.--Map of Willcox basin, Cochise County, Arizona, showing change in ground-water level from spring 1953 to spring 1958

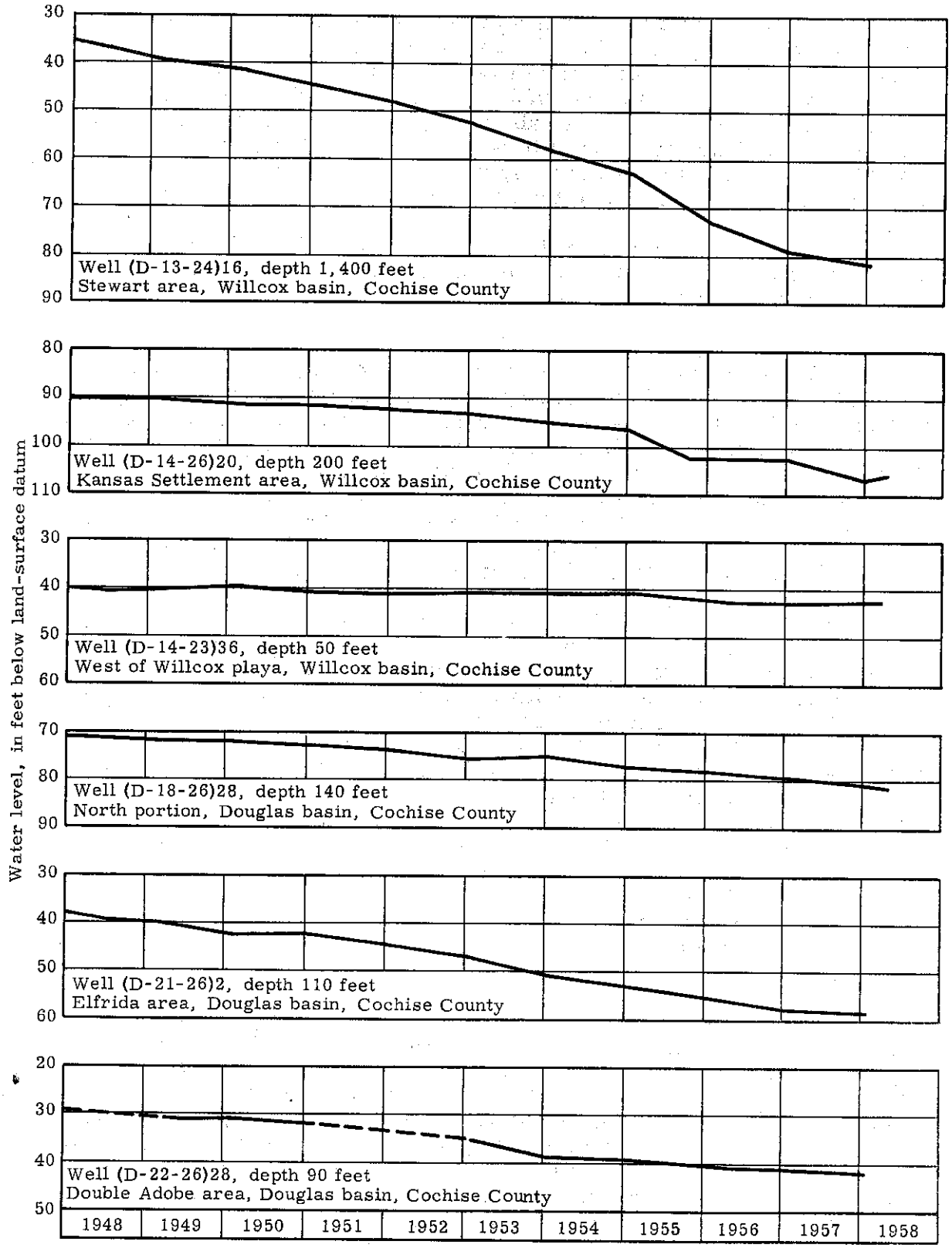

Figure 5.--Water levels in selected wells in the Willcox and Douglas basins, Cochise County.

Fluctuations in water levels in 44 wells in the Kansas Settlement area ranged from a rise of about 4 feet near the playa to a decline of more than 21 feet in the heavily pumped areas. In the 5-year period, spring 1953 to spring 1958, declines ranged from about 50 feet in the newly developed areas to about 10 feet along the west side of the playa (fig. 4). The water level in well (D-14-26)20 (fig. 5) declined 4 feet during the last year. In the spring of 1958 the depth to the water table ranged from 30 to more than 200 feet below the land surface.

The water level in well (D-14-23)36 (fig. 5), outside the cultivated area on the west side of the Willcox playa, has fluctuated slightly during the 16 years of record.

Douglas basin.--This area is south of the Willcox basin in the southern part of the Sulphur Spring Valley. It is separated from the Willcox basin by the 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 fluctuations for the period spring 1957 to spring 1958 ranged from a rise of about 2 feet west of McNeal to a decline of nearly 4 feet north of Elfrida. About 6 miles north of Elfrida, declines ranged from 2 to 3 feet; north of Elfrida the declines ranged from 3 to 4 feet; and between McNeal and Double Adobe the declines ranged from 2 to 3 feet. For the 5-year period spring 1953 to spring 1958 (fig. 6) water levels in the Elfrida area declined from 10 to 15 feet. Between McNeal and Double Adobe the declines were from 5 to 10 feet. The water level in well (D-18-26)28 (fig. 5), in the northern part of the basin, has continued to decline slightly since 1948. Well (D-21-26)2

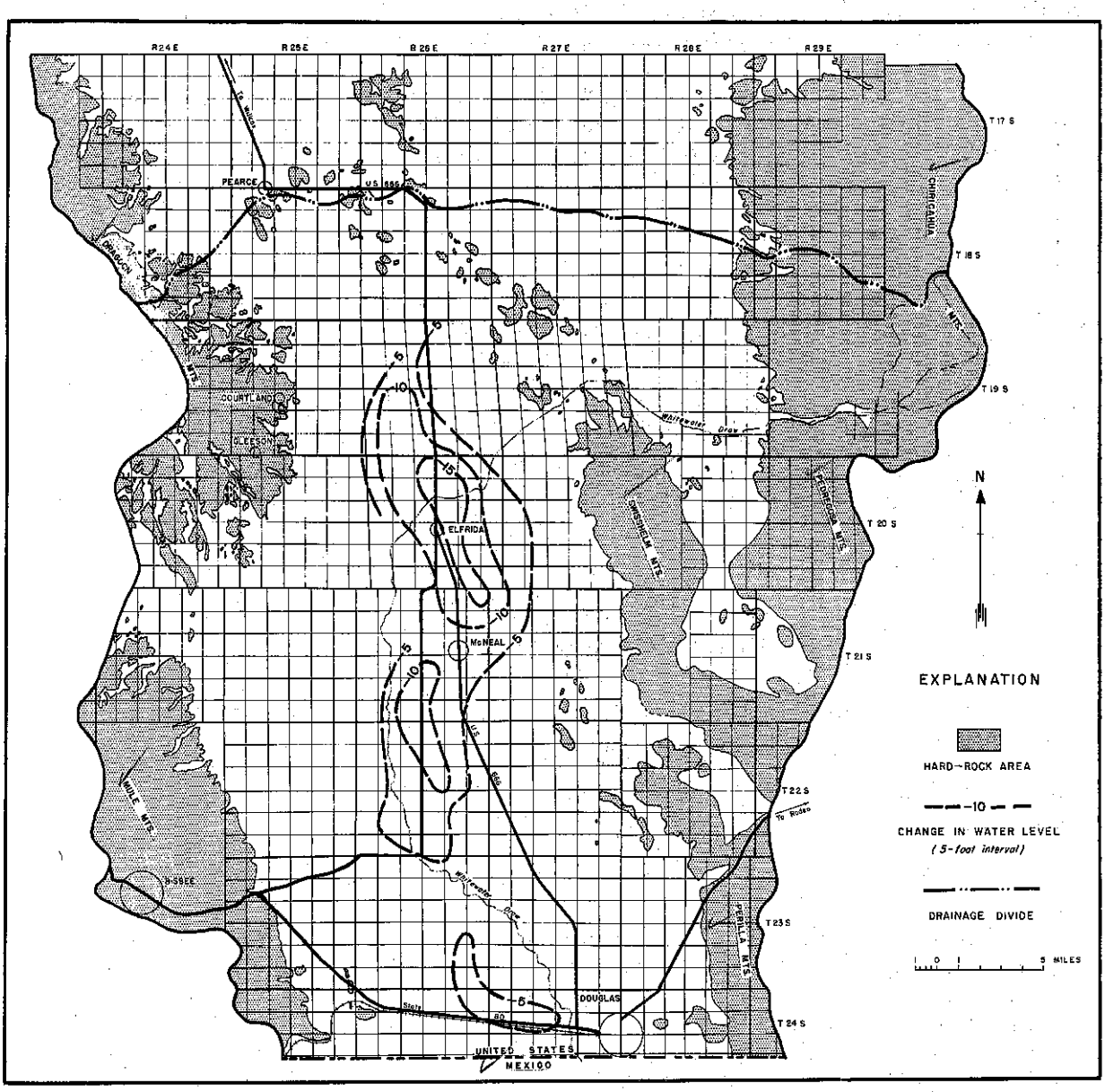

Figure 6.--Map of Douglas basin, Cochise County, Arizona, showing change in ground-water level from spring 1953 to spring 1958

(fig. 5), in the center of the heavily pumped Elfrida-McNeal area, declined about 10 feet during the 5-year period ending in the spring of 1958, and more than 20 feet during the period 1948 to 1958. The water level in well (D-22-26)28 (fig. 5), in the Double Adobe-Douglas area, declined about 7 feet during the 5-year period ending in the spring of 1958, and about 14 feet from spring 1948 to spring 1958.

One hundred and ten water-level measurements were made in the Douglas basin during 1957. The depth to water in these wells ranged from 40 to 130 feet but in most wells the levels were less than 100 feet.

Bowie-San Simon area.--This area is in the central part of the San Simon Valley. The Bowie area is on the western slope of the basin in the vicinity of the town of Bowie. The San Simon area is near the town of San Simon in the eastern side of the basin. The San Simon basin is part of a structural trough lying between two parallel chains of mountains. The Peloncillo Mountains lie to the east and the Chiricahua, Dos Cabezas, and Pinaleno Mountains to the west. This valley trends northwest, and extends from the vicinity of Rodeo, N. Mex. to the Safford Valley and the Gila River. There are approximately 1,200 square miles in the Bowie-San Simon area of this valley. Altitudes range from 3,350 to 4,000 feet.

The general movement of ground water in this valley is from the divide near Rodeo, N. Mex., northwestward down the valley, to Safford and the Gila River. Ground water moves also from the bordering mountain ranges toward the axis of the valley. In the Bowie area, the movement is influenced by the Dos Cabezas Mountains and is northeastward toward the center of the valley. San Simon is at the axis of the valley adjacent to the main surface drainage of San Simon Creek, and the ground-water movement is toward the northwest.

Sixty water-level measurements were made in this basin during the spring of 1958. The depth to water ranged from 100 to 325 feet in the vicinity of Bowie and from about 20 to 60 feet in the artesian aquifers near San Simon. In the Bowie area, water-level fluctuations for the period spring 1957 to spring 1958 ranged from a rise of about 2 feet to a decline of nearly 18 feet. For the 5-year period, spring 1953 to spring 1958, declines ranged from about 3 feet to more than 80 feet in the irrigated areas. The water level in well (D-13-29)18 (fig. 7) declined about 20 feet during the last year. For the 5-year period the decline was about 80 feet. The major part of the decline in the water table started in 1952 when irrigation pumping was greatly increased.

In the San Simon area water-level fluctuations for the period spring 1957 to spring 1958 ranged from a rise of about 3 feet to a decline of more than 9 feet. For the 5-year period, spring 1953 to spring 1958, declines ranged from about 3 to more than 25 feet. The water

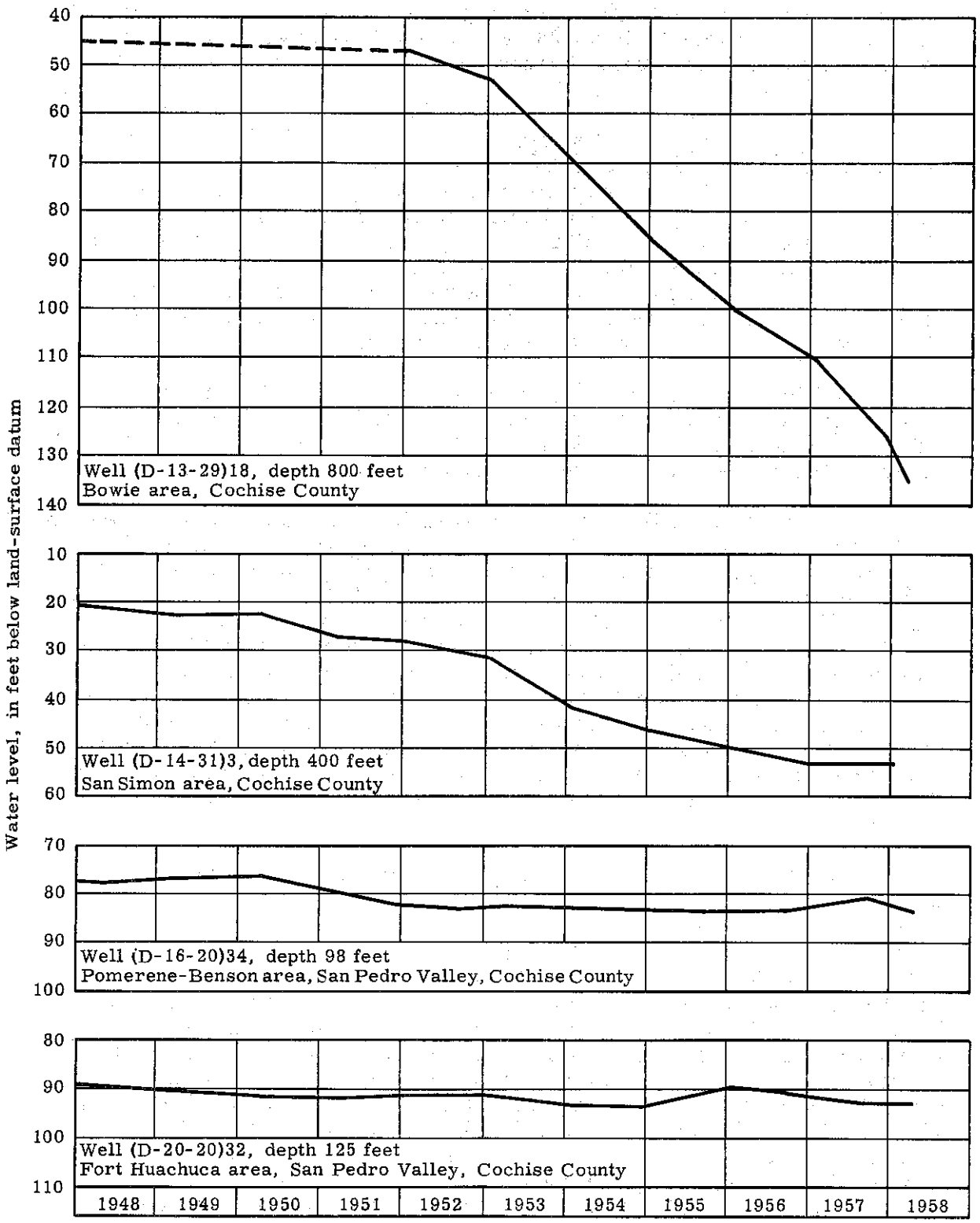

Figure 7.--Water levels in selected wells in the Bowie-San Simon area and upper San Pedro basin, Cochise County.

level in well (D-14-31)3 (fig. 7) changed but little in 1957. Since 1946 it has declined about 35 feet, 28 feet of which has been since 1950, when pumping for irrigation in this area increased substantially.

Upper San Pedro Valley.--The upper San Pedro basin is defined as the drainage area of the north-flowing San Pedro River between the International Boundary on the south and the narrows at the Tres Alamos dam site, about 8 miles north of the town of Pomerene, Ariz. The east boundary is the drainage divide extending from the southern end of the Winchester Mountains, southward through the Little Dragoon, Dragoon, and Mule Mountains. The west boundary is the drainage divide between the San Pedro and Santa Cruz Rivers along the Rincon, Whetstone, and Huachuca Mountains.

The direction of the ground-water movement is similar to the land-surface drainage—the ground-water divide is in Mexico and the water moves to the north, similar to the San Pedro River. Water also moves toward the center of the valley from the bordering mountains.

Water-level fluctuations ranged from a rise of about 4 feet to a decline of nearly 5 feet for the period spring 1957 to spring 1958, and for the 5-year period, spring 1953 to spring 1958, there were rises from 2 to 3 feet and declines from 1 to 5 feet. The water level in well (D-16-20)34 (fig. 7) near Pomerene declined about 2 feet from spring 1957 to spring 1958 and 9 feet since the spring of 1946. The water level in well (D-20-20)32 (fig. 7) did not change from spring 1957 to spring 1958, declined about 1 foot in the 5-year period spring 1953 to spring 1958, and has declined about 3 feet since spring 1946. The depth to water in the spring of 1958 ranged from 10 to more than 300 feet below the ground. The depths to water in the wells adjacent to the San Pedro River are less than 100 feet.

Coconino County

In Coconino County, limited supplies of water are obtained from relatively shallow wells. Most of these wells are less than 100 feet deep, and are readily affected by precipitation and in some localities are not dependable during periods of drought. Water levels in shallow wells in the vicinity of Williams rose from about half a foot to more than 1 foot during 1957. The depth to water in these wells ranged from about 2 to 6 feet below land surface at the end of 1957. In the Flagstaff area, the water levels in shallow wells changed but little—in one well the water level rose about 2 feet. The hydrograph for well (A-22-6)26 (fig. 8) shows that there have been minor fluctuations in the water table in some of the deeper wells at Fort Valley.

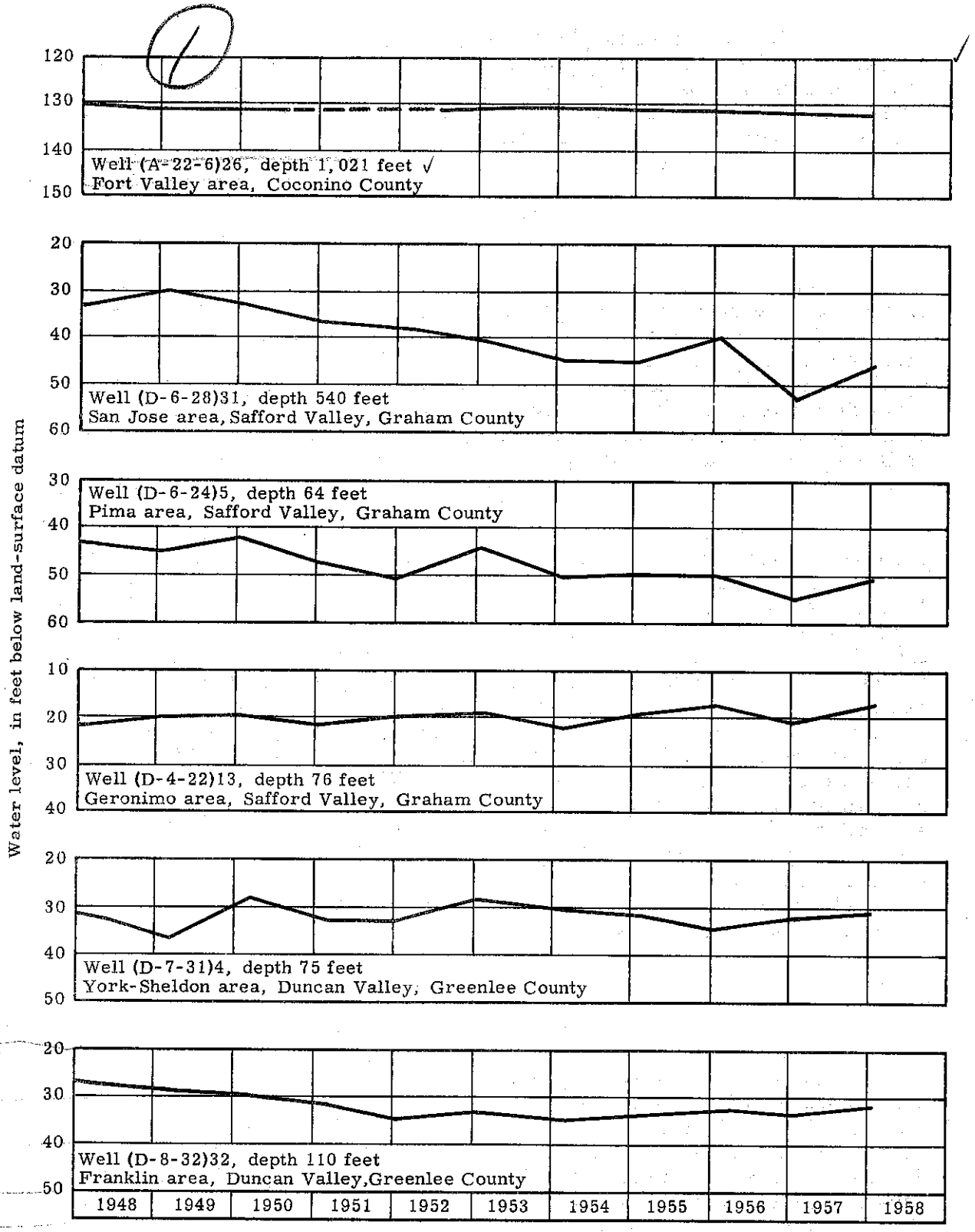

Figure 8.--Water levels in selected wells, Coconino, Graham, and Greenlee Counties.

Water levels in the four deep wells drilled for the city of Flagstaff are between 1,050 and 1,250 feet below land surface. There has been little fluctuation in the water table from 1956 to 1958. The wells yield between 200 and 500 gpm (gallons per minute) and are the primary source of water for the city.

Gila County

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 Roosevelt 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 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 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 Icehouse Canyon are the two major streams in this area. Most of the wells are shallow, and the water levels fluctuate in response to surface flow and local domestic pumping. No particular pattern of rise or decline could be determined. Above-average precipitation occurred in the winter of 1957-58 and the water levels were above average in the spring of 1958. 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 have been developed for irrigation. The wells are shallow in depth and are recharged by the summer floods of June and July. No decline has been recorded.

Graham County

Most of the water-level measurements made in Graham County were in the Safford Valley, which lies entirely within the county. This valley is bounded on the north by the Gila Mountains, on the east by the Peloncillo Mountains, and on the southwest by the Pinaleno and Santa Teresa Mountains. The basin is about 50 miles long and 15 to 20 miles wide. The cultivated lands lie along the Gila River and are 1/2 to 3-1/2 miles from the river.

The Safford Valley is an extension of the San Simon Valley and the ground water moves in a northwestward direction along the valley toward Coolidge Dam. Most of the recharge to the Safford Valley probably comes from the Gila River where it enters the alluvial-filled valley about 15 miles east of Safford. Although the diversion canals take all or most of the low flow, leakage from these canals recharges the alluvium. During periods of high runoff, the canals divert only a small portion of the surface flow and the surplus water in the river recharges the porous valley fill. At the end of the valley, this underflow discharges into San Carlos Lake.

From spring 1957 to spring 1958 the water levels rose from 1 to more than 30 feet. This rise in the water table is attributed to recharge from streamflow of the Gila River. The depth to the water table below the surface of Safford Valley is about the same as it was in 1955. The water level in well (D-6-28)31 (fig. 8), at the head of the valley, rose about 7 feet from spring 1957 to spring 1958, although it was about 14 feet lower than in 1946. The water level in well (D-6-24)5 (fig. 8) in the cultivated area below Pima rose about 4 feet from spring 1957 to spring 1958, but had declined about 10 feet since spring 1946. The water level in well (D-4-22)13 (fig. 8) in the downstream part of the Safford Valley rose about 4 feet from spring 1957 to spring 1958, and was about 2 feet higher than in 1946. In the spring of 1958, the depths to water ranged from about 15 to 60 feet below the land surface.

Greenlee County

Most of Greenlee County consists of mountains and forests, and the developed area is in the southern part of the county. This area is adjacent to the Gila River and is called the Duncan basin. The basin is a part of a structural trough that extends northwest from the vicinity of Lordsburg, N. Mex. The eastern margin of the Duncan basin is set arbitrarily at the Arizona-New Mexico State line where the Gila River enters Arizona, and on the west the basin terminates about a mile upstream from the junction of the San Francisco and Gila Rivers. The basin is enclosed on the northeast by the Steeple Rock Mountains and on the southwest by the Peloncillo Mountains. Water levels from spring 1957 to spring 1958 rose about 1 foot to more than 10 feet. For the 5-year period, spring 1953 to spring 1958, the water table declined about 2 feet. During the winter of 1952-53 the recharge to this area was greater than it was for the 1951-52 period and the water levels were above average. During the early months of 1958 there was a large amount of precipitation and stream runoff, and hence recharge to this area from the Gila River probably will be above average in 1958. In the spring of 1958 the water level in well (D-7-31)4 (fig. 8) in the York-Sheldon area near the Gila River was about 1 foot higher than in the spring of 1957, but about 3 feet lower than in the spring of 1950 and about 2 feet lower than in the spring of 1946. The water level in well

(D-8-32)32 (fig. 8) in the Franklin area rose about 2 feet from spring 1957 to spring 1958 but had declined about 8 feet since spring 1946. The depth to water in the Duncan basin ranges from about 16 to nearly 70 feet below the land surface.

Maricopa County

In 1957 about 480,000 acres were under irrigation in Maricopa County (Seltzer, 1958), which accounted for about 40 percent of the total irrigated acreage in Arizona. The five principal areas of irrigation in Maricopa County are (1) Salt River Valley, (2) Gila Bend area, (3) Waterman Wash area, (4) Harquahala Plains area, and (5) Dendora area. The Salt River Valley is by far the largest in agricultural development.

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: Queen Creek-Higley-Gilbert-Magma area; Tempe-Mesa-Chandler area; Phoenix-Glendale-Tolleson area; Paradise Valley area; Litchfield-Beardsley-Marinette area; Liberty-Buckeye-Hassayampa area; lower Hassayampa-Tonapah area; and lower Centennial-Arlington 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.

In the Salt River Valley the direction of ground-water movement conforms in general to the slope of the land surface. In some instances 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 1958 there are 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 northwest 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 a part flows north toward the depression near Litchfield Park. In the area west of the Hassayampa River the ground water flows south toward Gillespie Dam.

Queen Creek-Higley-Gilbert-Magma area. --During 1957 the majority of water levels in wells in the Queen Creek-Higley-Gilbert-Magma area continued to decline at about the same rate as in previous years. The change in water levels from spring 1957 to spring 1958 ranged from a rise of about 9 feet in an unused irrigation well 1 mile east of Higley to a decline of about 22 feet in a well 1-1/2 miles south of the town of Queen Creek. The levels in most of the wells east of the Roosevelt Conservation District Canal declined about 9 feet or more during this period. In the 5-year period spring 1953 to spring 1958, water-table fluctuations ranged from almost nothing to about 80 feet of decline (fig. 9). The greatest declines occurred in the northern part of this area, where pumping is heavy. There was little or no change in the 5-year period on the southwest edge of the area, where ground-water storage receives recharge by seepage from canals and irrigated lands. Hydrographs for selected wells in the Queen Creek-Higley-Gilbert-Magma area (fig. 10) show water-table fluctuations in this area. The hydrograph for well (A-1-6)23 shows that the water table has declined at a fairly consistent rate of almost 15 feet per year for the past 10 years. The total decline for that period was about 145 feet. This well is in the northern part of the area where irrigation water is obtained solely from ground-water storage. The water level in well (D-2-10)8, has declined less than in wells closer to the area of heavy pumping. The water level in well (D-2-6)31 is affected by seepage from canals. This well is in the southwestern part of the area where ground water is used to supplement surface water for irrigation. In the spring of 1958, depths to water in wells in the cultivated area ranged from about 240 feet to 330 feet in the vicinity of Magma, and from approximately 250 to 330 feet near Queen Creek. The shallowest depth to water measured in the entire area in the spring of 1958 was 60 feet below the land surface in a well 9 miles south of Higley and the deepest was 413 feet in a well south of Granite Reef Dam.

Tempe-Mesa-Chandler area. --In the period spring 1957 to spring 1958, water-level fluctuations in this area ranged from a rise of about 8 feet to a decline of about 15 feet. The greatest declines in the Tempe-Mesa-Chandler area during this period ranged from about 4 to 15 feet and occurred north of Mesa. In the area west of Chandler declines in water level in most wells were about 4 feet during this period, whereas south of Chandler water-table fluctuations ranged from rises of about 8 feet to declines of about 4 feet. The hydrograph for

well (A-2-4)26 (fig. 11) shows the continued downward trend of the water level typical of this area north of Chandler. During the 5-year period, spring 1953 to spring 1958, the water table declined from 80 feet north of Mesa to less than 20 feet south of Chandler (fig. 9). In the spring of 1958 depths to water in wells ranged from about 240 feet near Mesa to about 60 feet south of Tempe.

Phoenix-Glendale-Tolleson area. --During the period spring 1953 to spring 1958 (fig. 9) water-table fluctuations ranged from almost no change to 80-foot declines. The greatest decline occurred in Deer Valley between Skunk Creek and New River. Fluctuations of the water table in the areas near Camelback Mountain and the Salt River Mountains were slight, owing to light pumping and to recharge from canal seepage. In the area south of the Arizona Canal in the Salt River Project, during this period, water levels generally declined 20 to 40 feet, and the maximum decline was less than 60 feet. During the year from spring 1957 to spring 1958 the water-table fluctuations ranged from no appreciable change to declines of more than 20 feet. The largest decline occurred in Deer Valley where most of the water levels in wells declined 10 feet or more. In the area between Glendale and the Arizona Canal, water-level declines ranged from 6 to 12 feet and were somewhat less in the vicinity of Phoenix. A hydrograph of well (A-3-2)12 (fig. 11) in Deer Valley shows the downward trend in the water level in this area where wells are the only source of irrigation water. In the Salt River Project where surface water is supplemented by ground water, levels declined at a lesser rate, as shown in the hydrograph of well (A-1-1)6 (fig. 12). In the spring of 1958, depths to water below land surface ranged from about 13 feet northeast of Phoenix to about 420 feet in Deer Valley.

Paradise Valley. --Changes in water levels during the period spring 1957 to spring 1958 ranged from a rise of about 1 foot in the center of Paradise Valley to a decline of about 8 feet in the area approximately 3 miles north of Scottsdale. Pumping for irrigation in this area has continued to be light compared to other areas in the Salt River Valley, and most of the declines for a 5-year period, spring 1953 to spring 1958, ranged from about 3 to 14 feet. The hydrograph for well (A-3-3)1 (fig. 12), in the area of largest decline, shows fluctuations in the water level for a 10-year period. The declines are slight but have a continuous downward trend. The depth to water below land surface in the spring of 1958 ranged from about 283 feet in the northern part of the cultivated area to about 165 feet in the southern section of Paradise Valley.

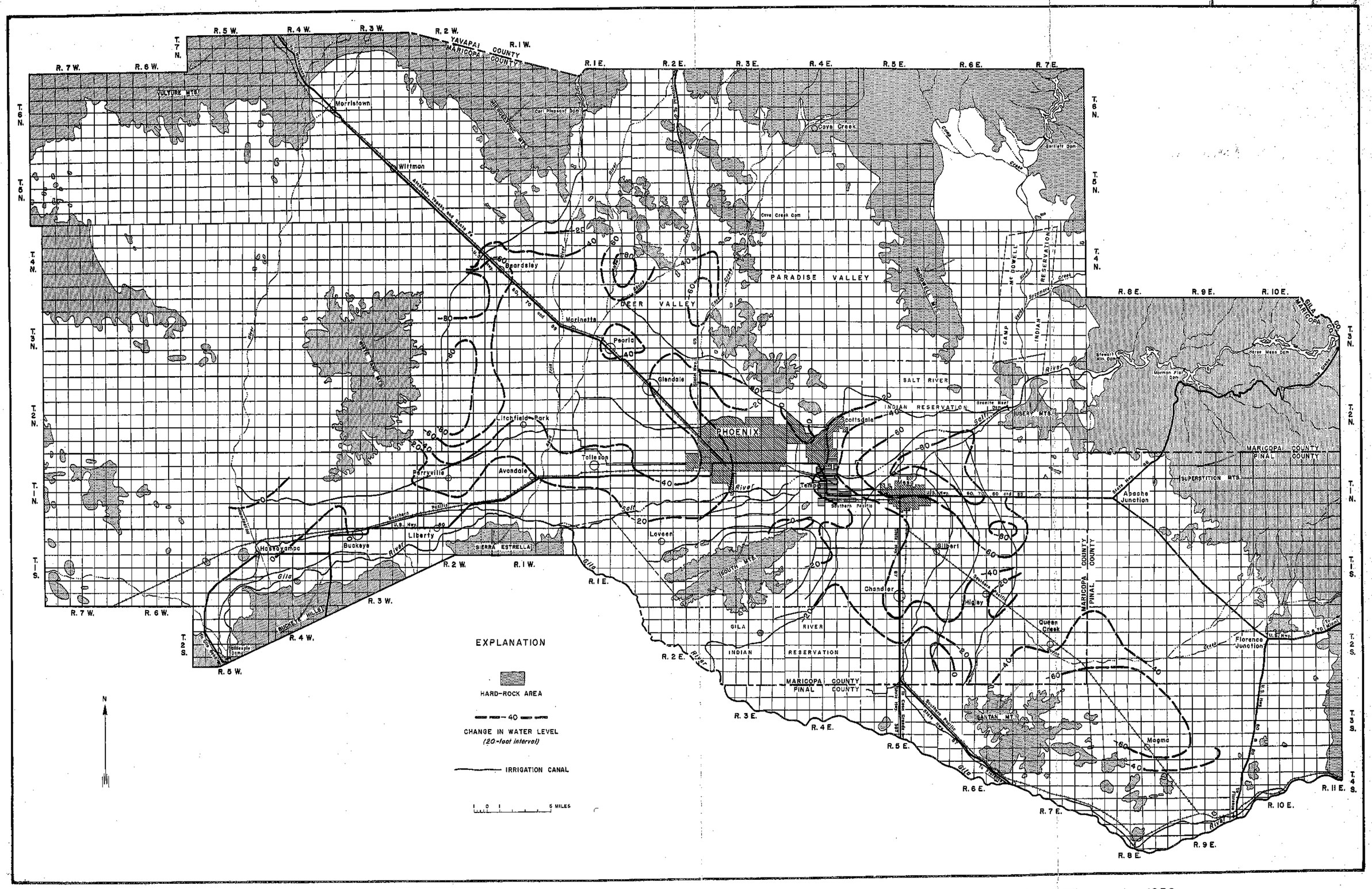

Figure 9.--Map of Salt River Valley area, Maricopa and Pinal Counties, Arizona, showing change in ground-water level from spring 1953 to spring 1958

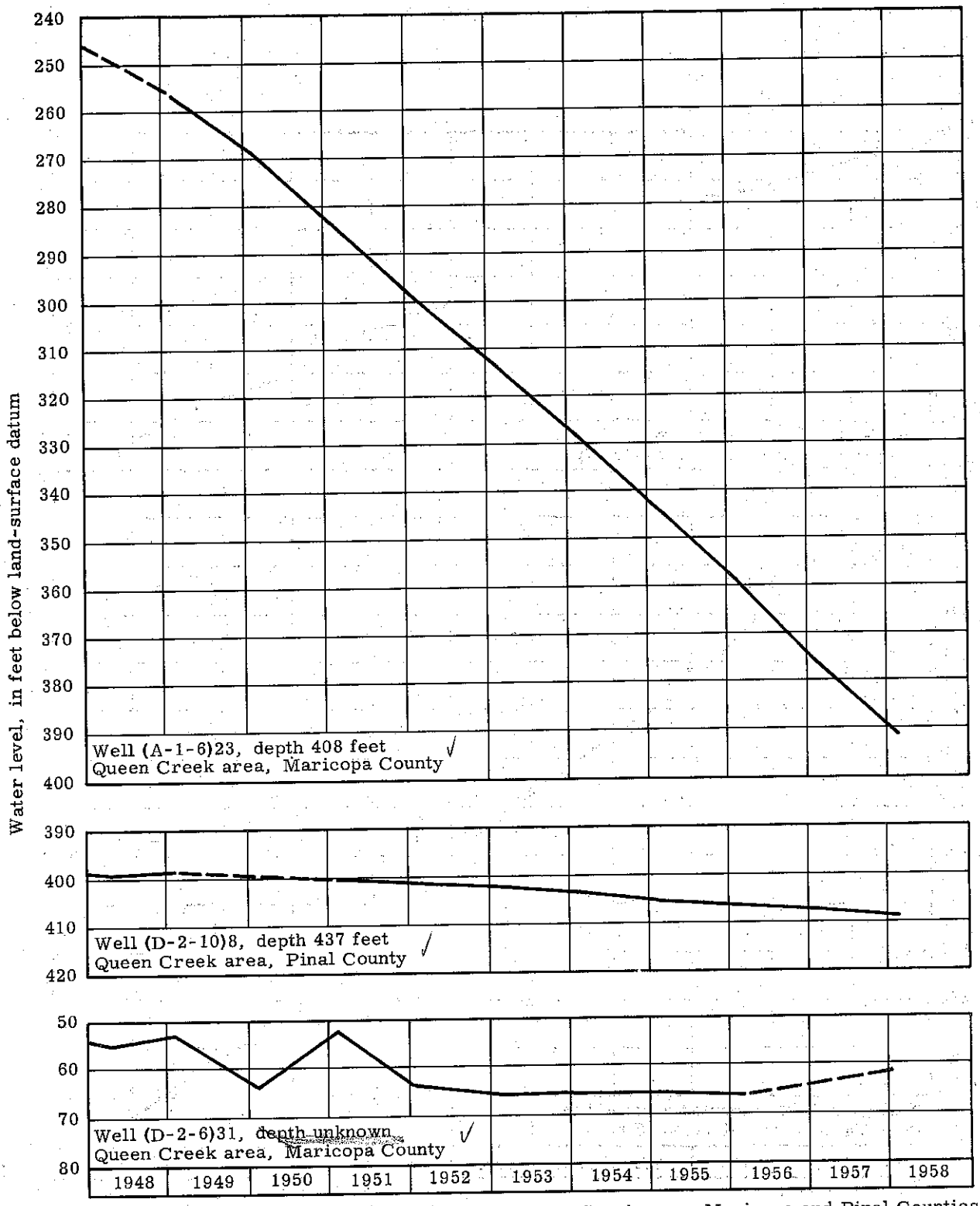

Figure 10.--Water levels in selected wells in Queen Creek area, Maricopa and Pinal Counties.

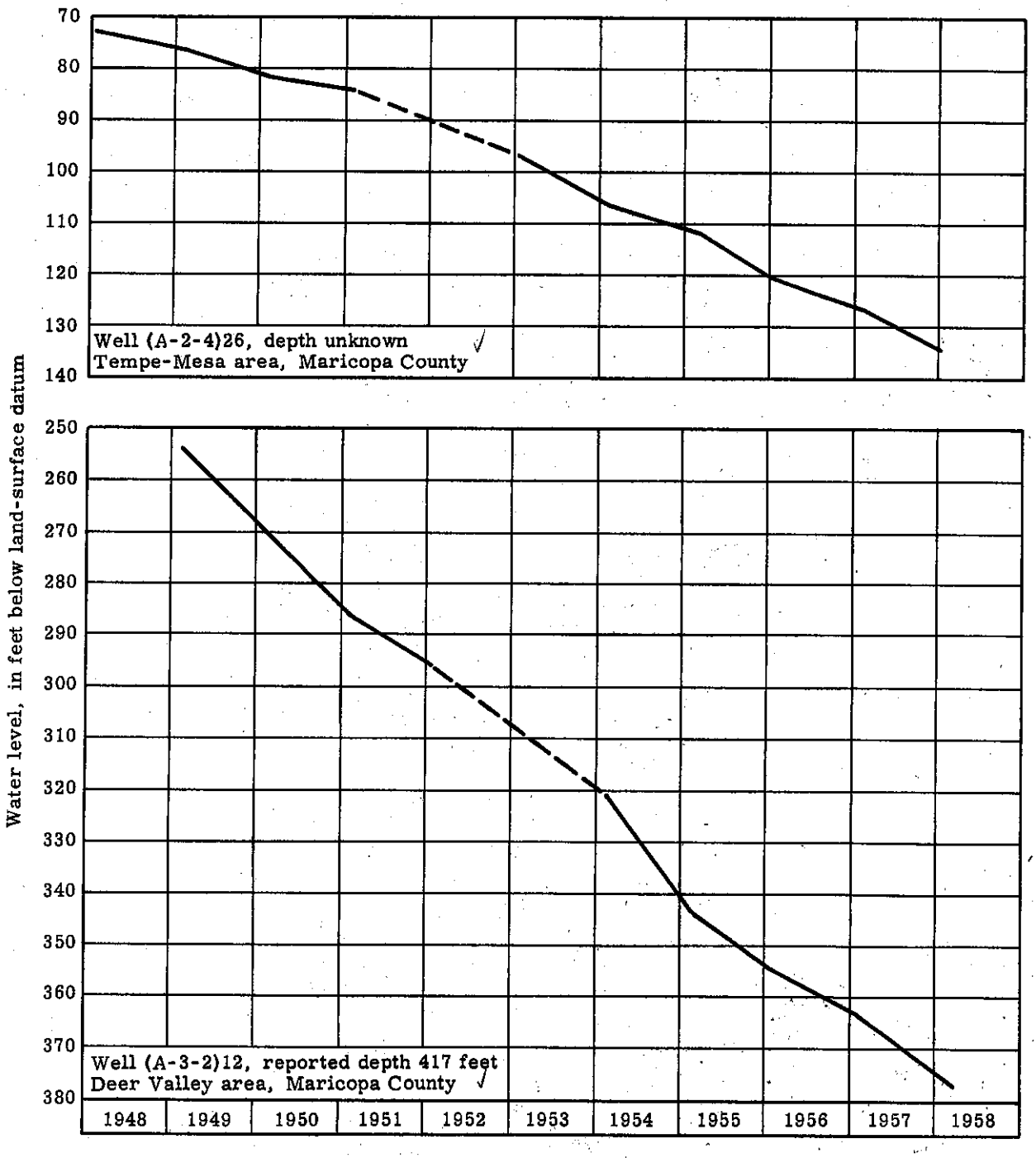

Figure 11.--Water levels in selected wells in Tempe-Mesa and Deer Valley areas, Maricopa County.

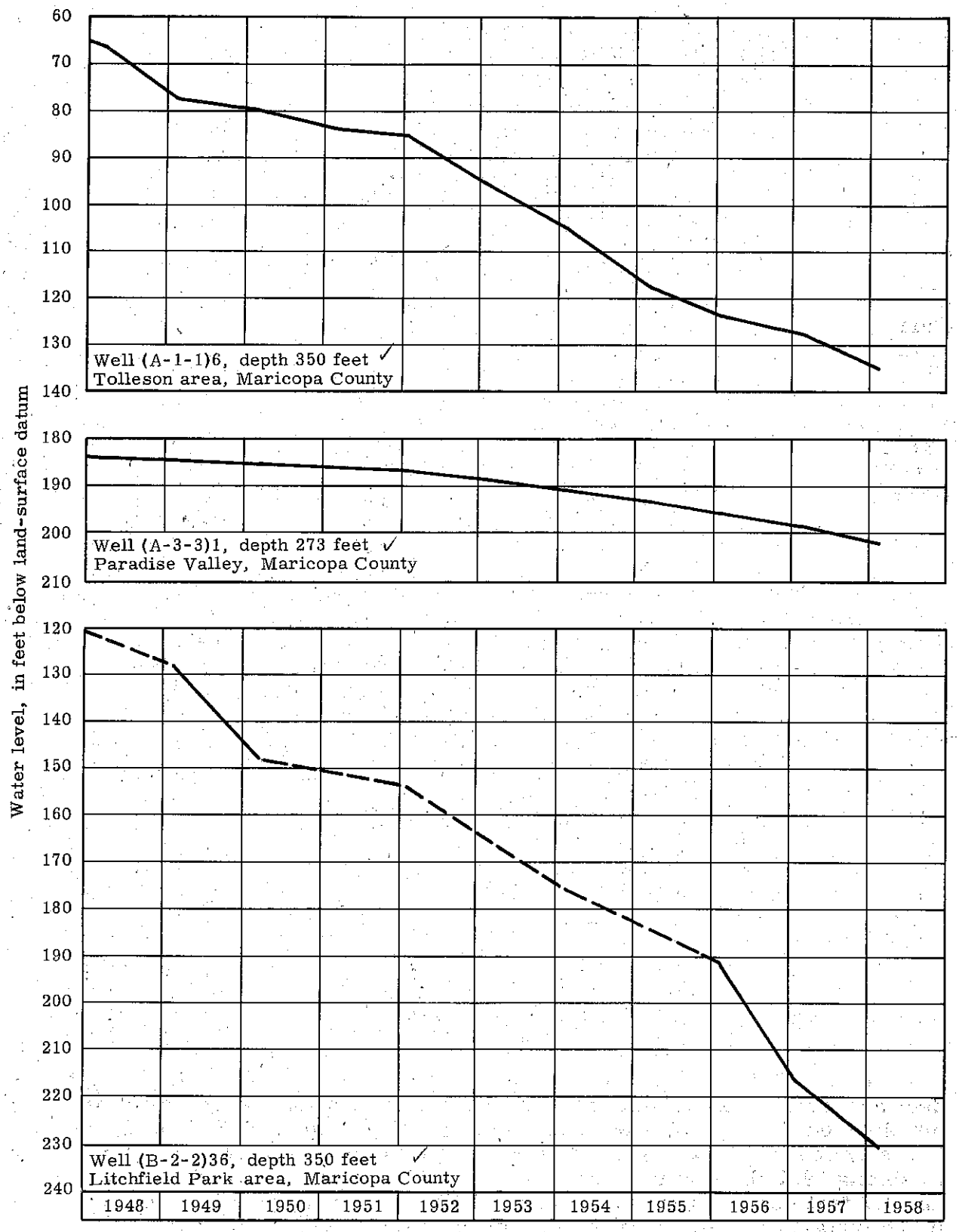

Figure 12.--Water levels in selected wells in Tolleson, Paradise Valley, and Litchfield Park areas, Maricopa County.

Litchfield Park-Beardsley-Marinette area. --Ground-water levels in the Litchfield Park-Beardsley-Marinette area continued to decline during the period spring 1957 to spring 1958, because of continual withdrawal of ground water from storage. Some surface water, diverted from Carl Pleasant Dam on the Agua Fria River, is used for irrigation in this area but most irrigation water is obtained from wells. The water-level declines ranged from about 2 feet, in a well about 2 miles south of Litchfield Park, to more than 25 feet in a well southwest of Beardsley. The water level in well (B-2-2)36 (fig. 12) has declined continuously in an area where the ground-water table is influenced by a large number of irrigation wells. The water level in this well has declined about 110 feet from 1948 to the spring of 1958. During the 5-year period spring 1953 to spring 1958, the water table in this area has declined about 40 feet to as much as 80 feet (fig. 9). The greatest decline occurred near the east end of the White Tank Mountains along the Maricopa Municipal Water District Canal. In the spring of 1958 the depth to water in irrigation wells ranged from about 137 to 420 feet below land surface in the vicinity of Beardsley, whereas it ranged from about 122 feet to more than 300 feet in the area near Litchfield Park.

Liberty-Buckeye-Hassayampa area. --Water-level fluctuations in this area during 1957 ranged from a rise of about 1 foot along the Hassayampa River to a decline of about 7 feet north of Perryville. Water levels in most of the Liberty-Buckeye-Hassayampa area follow the same downward trend as in other areas in the Salt River Valley basin. However, the rate of decline is much less, owing to the continual recharge from irrigation water applied to cultivated land upstream. The hydrograph for well (B-1-3)32 (fig. 13) shows the typical water-level trend for this area. During the 5-year period spring 1953 to spring 1958 the water level in this well declined about 7 feet, and during the 10-year period spring 1948 to spring 1958 it declined 15 feet. Figure 9 shows the water-level fluctuations in the area during the 5-year period. The water levels in the area west of Buckeye rose slightly, while in the vicinity of Perryville they declined more than 20 feet. In the spring of 1958 the depths to water below land surface in irrigation wells ranged from about 11 feet along the lower end of the Hassayampa River to about 204 feet north of Perryville.

Lower Hassayampa-Tonopah area. --During the period spring 1957 to spring 1958 the water-level fluctuations in this area ranged from a rise of about 2 feet to a decline of about 19 feet, and the greatest declines were in the vicinity of Tonopah where most of the agricultural development is concentrated. The hydrograph for well (B-2-7)26 (fig. 13) is typical of the wells in this area. During the period spring 1948 to spring 1952 the water level fluctuated very little, but it declined about 3 feet during the next 3 years. After the spring of 1955 when more irrigation wells were put into production the rate of decline

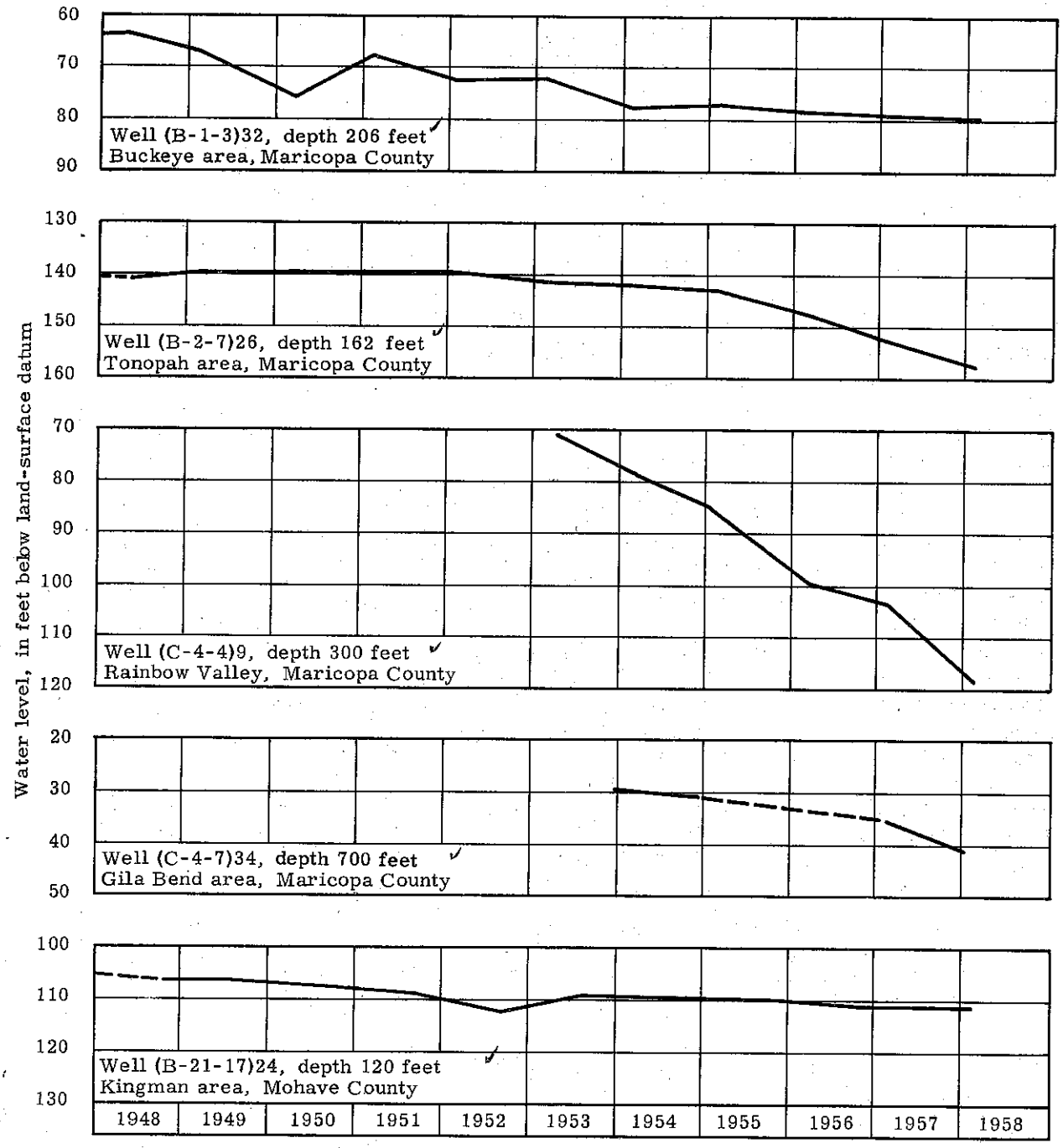

Figure 13.--Water levels in selected wells, Maricopa and Mohave Counties.

increased, and by the spring of 1958 the water level had declined an additional 15 feet. At this time the water level in wells in the cultivated area ranged from about 75 to 208 feet below land surface.

Lower Centennial-Arlington area. --Ground-water levels in the lower Centennial-Arlington area rose during 1957 in the cultivated area because of a decrease in pumping. In the undeveloped parts of the area the levels continued to decline as a result of the movement of water to the pumped areas. The water-table fluctuations ranged from a rise of about 4 feet approximately 4 miles west of Arlington, to a decline of about 2 feet in the west end of the area. The rate of decline is not known, because of the limited number of water-level measurements. In the spring of 1958 depths to water in wells within the cultivated area ranged from about 23 feet below land surface near the junction of Centennial Wash and the Gila River to more than 220 feet in the lower end of T. 1 N., R. 6 W.

Gila Bend basin. --The Gila Bend area extends irregularly from Gillespie Dam on the Gila River to a point 36 miles downstream. 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 basin a depression exists where continual pumping is diverting water into the Gillespie Canal. This water is used to irrigate land downstream near Theba. Ground water leaves the area in the western part of the basin through the narrows at Gila River Canyon at the north end of the Painted Rock Mountains, and beneath the Sentinel lava flows at the southwestern end of the basin.

In the spring of 1958 about 115 irrigation wells were in operation. This is an increase of about 25 wells over 1957. Most of the wells are in the northeastern part of the Gila Bend basin, known as Rainbow Valley.

During the period spring 1957 to spring 1958 the greatest water-level declines were in the Rainbow Valley area, where they ranged from about 4 to 15 feet. The water level in well (C-4-4)9 (fig. 13) in Rainbow Valley declined about 15 feet from spring 1957 to spring 1958. During the 5-year period, spring 1953 to spring 1958, the water level declined about 48 feet in this well. In the western part of the Gila Bend basin, water-level fluctuations during the period spring 1957 to spring 1958 ranged from a rise of about 2 feet to a decline of about 13 feet. During the last 2 years additional irrigation wells have been drilled in the area north of Theba and the operation of these wells has caused the water table to decline. The water level in well (C-4-7)34

(fig. 13) declined about 5 feet from the spring of 1957 to the spring of 1958. In the spring of 1958 the depth to water in irrigation wells ranged from about 40 feet below land surface along the flood plains of the Gila River in the western part of the basin to slightly more than 300 feet below land surface in the Rainbow Valley area.

Waterman Wash area.--This area, drained by Waterman Wash, is bounded on the north by the Buckeye Hills and outliers of the Sierra Estrella, on the northeast and east by the Sierra Estrella and Palo Verde Mountains, no the south by the Haley Hills, and on the southwest and west by the Maricopa Mountains. The physiographic division between the Waterman Wash area and Rainbow Valley is a low alluvial ridge that extends northward from the Maricopa Mountains to the Buckeye Hills.

In the Waterman Wash area most of the water-level declines have occurred in the northern part of the basin where agricultural development has taken place. During the period spring 1957 to spring 1958 water-level fluctuations ranged from substantially no change in the southern end of the area where there is no development to about 6 to 10 feet of decline in the irrigated area. In the spring of 1958 the depths to water ranged from about 163 feet to more than 300 feet below land surface in active irrigation wells.

Harquahala Plains area.--This 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 1958 about 50 irrigation wells were pumped in the Harquahala Plains area, as compared to about 30 in use during 1956. Most of the development is concentrated in the southeastern part of the area where the discharges range from about 800 to 3,200 gpm. Discharges from wells in the northwest end of the basin ranged from about 600 to 1,200 gpm.

During the period spring 1957 to spring 1958 water-level declines in the Harquahala Plains area ranged from less than a foot to more than 10 feet. In the spring of 1958, depths to water below land surface in the cultivated area ranged from about 26 feet at the extreme southeast end of the basin to more than 344 feet in the northwestern part of the area.

Dendora area.--The Dendora area lies west of the Gila Bend basin and is drained principally by the Gila River. It is bounded on the north by the Gila Bend Mountains, on the west by Face and Oatman Mountain, on the east by Painted Rock and Gila Bend Mountains, and on the south by the Sentinel lava flows.

Water levels in the Dendora area have remained nearly constant. Most wells were drilled and the land put under cultivation prior to 1948. Most of the irrigated land lies along the Gila River flood plains and the aquifer receives recharge from the Gila River. During the period spring 1957 to spring 1958 little change in the water table was observed in well (C-4-8)23. The depth to water below land surface in the cultivated area is fairly slight, rarely exceeding 60 feet.

Mohave County

The areas of ground-water withdrawal in Mohave County are: (1) Along the Big Sandy River; (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. Most of the agricultural development in the area is along the flood plains of the Big Sandy River.

Water levels in wells in the Big Sandy Valley fluctuated little from the spring of 1957 to the spring of 1958. These wells are shallow and water levels are readily affected by recharge from the Big Sandy River. In the spring of 1958, depths to water below land surface in this area ranged from about 11 feet near Wickieup to slightly more than 115 feet about 12 miles upstream.

Ground-water pumping in the Hackberry and Kingman area is mostly for public supply. Water-level fluctuations near Kingman ranged from a rise of about a foot to a decline of less than half a foot. The water level in well (B-21-17)24 (fig. 13) indicates the overall trend in this area. In wells near Hackberry the water-level fluctuations ranged from a rise of about 1 foot to a decline of about 1 foot. The depths to water below land surface in this area range from about 53 feet south of U. S. Highway 66 to about 510 feet north of the highway near Antaris.

Three wells are used to irrigate land near Truxton. The period of record for these wells is too brief to indicate any definite trend of the water table. In spring 1958 the depth to water in well (B-24-12)18 was about 146 feet below the land surface.

In the Red Lake area, about 30 miles north of Kingman, two 14-inch-diameter wells were drilled during 1957. The water levels in these wells were about 262 and 266 feet below the land surface.

Navajo County

Most of Navajo County lies within the Navajo and Hopi Indian Reservations. The principal crop in this area is corn, and irrigation water is usually obtained from small streams or springs. Only small amounts of ground water are pumped from wells. South of the Indian reservations, most of the ground water used for irrigation is from wells and the development is confined to the area along the Little Colorado River between Hay Hollow and Joseph City, and to the Snowflake-Taylor area. Nearly all the ground water used for irrigation in this area is obtained from the Coconino sandstone. South of the Little Colorado River, the quality of water from this aquifer is generally good but to the north the water is likely to be salty.

The regional dip of strata in the area is toward the north and movement of ground water is toward the north. Where the Coconino sandstone is not exposed at the surface, the water may be under artesian pressure and in topographically low areas, wells penetrating the Coconino sandstone may flow. In other areas, water levels may be as much as 160 feet below the land surface. The yields of 37 irrigation wells are reported to range from 400 to more than 3,000 gpm. According to a driller's report, a well 200 feet deep about 4 miles northwest of Woodruff produced 1,800 gpm with only 6 feet of drawdown from a static water level of 16 feet below the land surface. A well completed in April 1958 at Woodruff produces 1,800 gpm with 26 feet of drawdown from a static level of 45 feet below the land surface.

No trend in fluctuation of water levels has been established in the area, but during the drier part of the growing season of 1957, pump bowls were lowered in some wells in Hay Hollow because the water levels declined.

In the last year or two there has been an increased interest in obtaining more ground water for irrigation in Navajo County and several new wells have been drilled.

Pima County

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 the county. This 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 area and lies mostly in Pinal County, although the Avra-Marana area lies in Pima County. In Pima County, the upper Santa Cruz basin is bordered on the east by the Santa Catalina, Tanque Verde, Rincon, and 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 about 3,000 feet at the Pima-Santa Cruz County line to about 1,900 feet at the Pima-Pinal County line.

The movement of the ground water in the upper Santa Cruz basin is northward toward the extremely 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 the ground water because the river recharges the ground-water reservoir in Santa Cruz County. 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 the Tortolita Mountains at Rillito narrows. Much of 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 steep and was steep under natural conditions before large-scale pumping took place in the Casa Grande area.

Water-level fluctuations in Pima County are discussed as follows: (1) Avra-Marana area, (2) Rillito-Tucson area, (3) Tucson-Continental area, and (4) Tanque Verde-Pantano area.

Avra-Marana area.--Water-level fluctuations for the period spring 1957 to spring 1958 ranged from a rise of about 2 feet to a decline of nearly 12 feet. In the 5-year period spring 1953 to spring 1958 the water levels declined about 30 to 50 feet in the area extending from Marana to a point about 7 miles southwest. In the same period,

the levels declined about 30 to 40 feet in the area of Tps. 12 and 13 S., R. 10 E. The water level in well (D-11-10)32 (fig. 14) declined about 7 feet from spring 1957 to spring 1958, about 29 feet from spring 1953 to spring 1958, and about 40 feet from spring 1947 to spring 1958. The water level in well (D-15-10)35 (fig. 14) in the southern part of Avra Valley declined about half a foot from spring 1957 to spring 1958 and about 3 feet from spring 1953 to spring 1958. From spring 1946 to spring 1958 the level declined about 6 feet. The range in depth to water below land surface during the spring of 1958 was from about 180 to 320 feet in the Avra-Marana area.

Rillito-Tucson area.--Water-level fluctuations in this area from spring 1957 to spring 1958 ranged from a rise of about 2 feet to a decline of about 10 feet. The water level in wells along the Santa Cruz River changed very little. For the 5-year period spring 1953 to spring 1958, fluctuations ranged from a rise of about 2 feet to a decline of more than 20 feet. The water level in well (D-12-12)16 (fig. 14) in the heavily pumped area along the Santa Cruz River declined about 1 foot from spring 1957 to spring 1958. It declined about 3 feet from spring 1953 to spring 1958, and about 14 feet from spring 1946 to spring 1958. The water level in well (D-15-13)2 (fig. 14), beside the Santa Cruz River near Tucson, fluctuates seasonally, rising after periods of surface flow in the river and declining when the flow ceases. From the spring of 1957 to the spring of 1958 the level declined about 2 feet to about the stage it was in the spring of 1953. From spring 1947 to spring 1958 the water level in this well declined about 24 feet. The depth to water below land surface in the Tucson-Rillito area ranged from 40 to 200 feet in early 1958.

Tucson-Continental area.--Water levels in this area during the period spring 1957 to spring 1958 continued to decline. From Sahuarita northward for about 6 miles, the levels declined about 4 to 6 feet and between Sahuarita and Continental they declined 2 to 8 feet. For the 5-year period spring 1953 to spring 1958, the declines were about 5 to 25 feet. The greatest declines were in the area between Sahuarita and Continental. The water level in well (D-17-14)18 (fig. 14) declined about 5 feet from spring 1957 to spring 1958, nearly 12 feet from spring 1953 to spring 1958, and about 23 feet from spring 1946 to spring 1958. The depth to water below land surface in this area in the spring of 1958 ranged from about 40 to 125 feet.

Tanque Verde-Pantano area.--The water-level fluctuations in this area during 1957 ranged from a rise of about 4 feet along Rillito Creek to a decline of about 7 feet along Pantano Wash. The rises along Rillito Creek and also along Tanque Verde Wash were due to the recharge of the ground-water reservoir from surface runoff from the mountain areas. In the spring of 1958 the depth to water below land

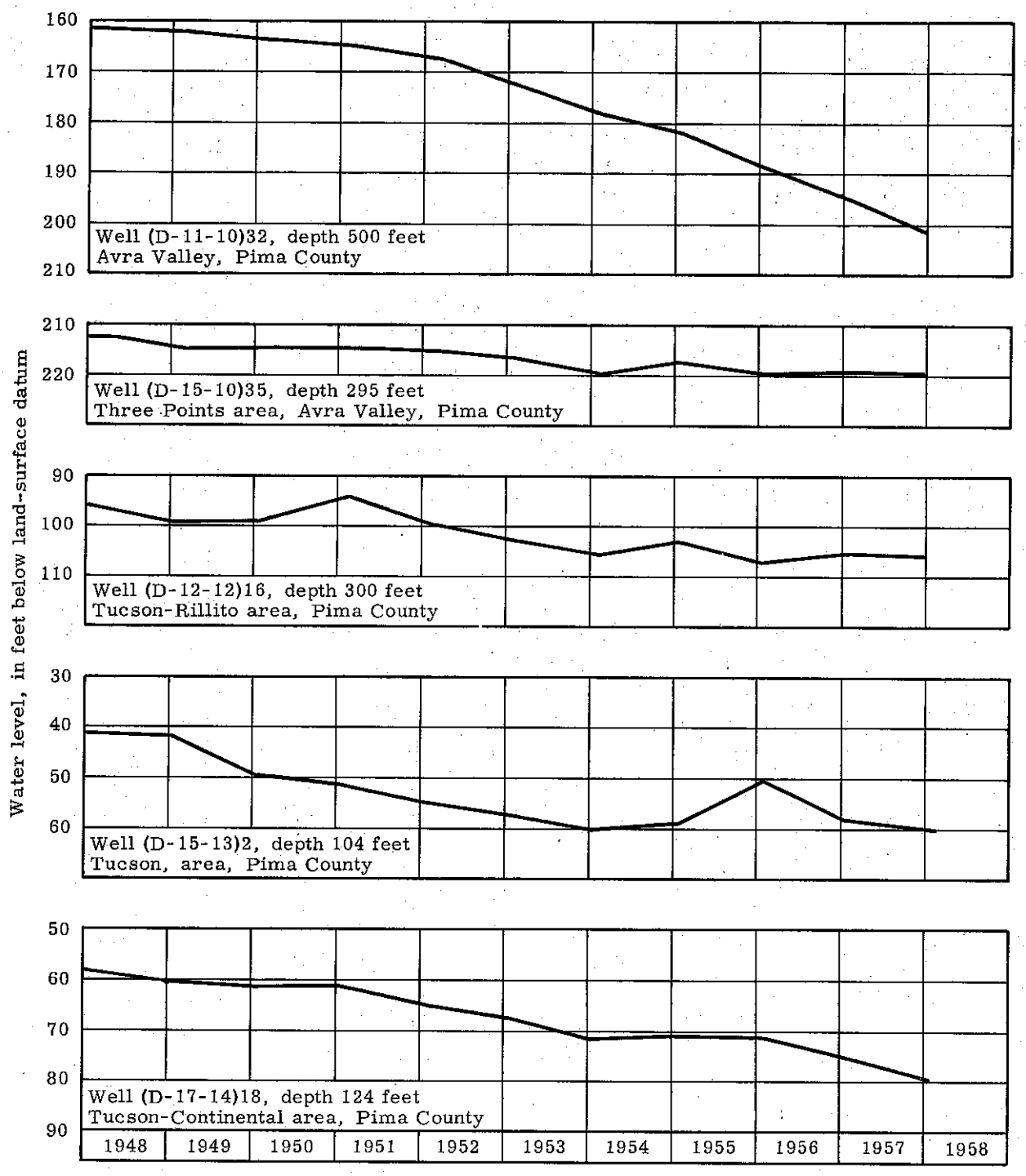

Figure 14.--Water levels in selected wells, Pima County.

surface ranged from about 10 feet along Tanque Verde Wash to more than 260 feet in the foothills near the Rincon Mountains.

Pinal County

About 90 percent of the lower Santa Cruz basin is within Pinal County and the remainder is in Pima County. The lower Santa Cruz area is part of a large drainage basin of the Gila River and is the second largest irrigation area in the State. The area is roughly triangular in shape, and is bounded on the east by the Tucson and Tortolita Mountains. The northern boundary follows an arbitrary line westward from Ashurst-Hayden Dam to the Santan Mountains, thence northward to the Pinal-Maricopa County line, thence westward along the county line to the Gila River, and thence northwestward along the river to the line between Rs. 1 and 2 E. The western boundary is formed by the Sierra Estrella, Palo Verde, Table Top, Tat Momoli, Silver Reef, Sawtooth, Silver Bell, Waterman, and Roskruge Mountains. The southern boundary is an arbitrary line between Tps. 15 and 16 S. The common boundary of the lower Santa Cruz area and the upper Santa Cruz basin is the Rillito narrows between the Tucson and Tortolita Mountains. The valley floor of the area covers about 2,200 square miles and ranges in altitude from about 2,500 feet at the southern boundary to about 1,000 feet at the northwest corner. The broad valley south of the Pinal-Pima County line is referred to as the Avra-Marana area, as reported in the Pima County section of this report.

The movement of ground water in the lower Santa Cruz basin is toward the northwest and the Gila River. The subsurface flow is influenced by heavy pumping, which causes areas of depression in the water table. In the Eloy area, the flow is from the Red Rock area, parallel to the Santa Cruz River and toward the Casa Grande and Coolidge areas. In the vicinity of the Casa Grande area, the ground-water movement is in two directions, a diversion caused by the Sacaton Mountains. Part of the flow is toward Coolidge and thence to the Gila River, and part of the flow is to the west toward Stanfield. Between Stanfield and Maricopa there is a ground-water depression and water is moving toward it from all sides. There probably is little discharge of water to the Gila River in the Maricopa area.

About 4 miles west of Casa Grande and 6 miles east of Stanfield the ground-water gradient is more than 75 feet per mile. This drop in the water table is similar to that observed at the Rillito narrows.

The areas of irrigation development in Pinal County are: (1) the Casa Grande-Florence area; (2) the Maricopa-Stanfield area; and (3) the Eloy area.

Casa Grande-Florence area. --In the period spring 1957 to spring 1958, water-level fluctuations ranged from small rises to declines of about 10 to 30 feet. The greatest declines were along the Casa Grande Canal. In the 5-year period spring 1953 to spring 1958 (fig. 15), declines ranged from about 20 to 40 feet. The water level in well (D-6-6)7 (fig. 16) declined about 5 feet from spring 1957 to spring 1958, about 40 feet from spring 1953 to spring 1958, and more than 60 feet from spring 1946 to spring 1958. Depths to water below land surface in the spring of 1958 ranged from 60 to more than 230 feet in the Casa Grande-Florence area.

Maricopa-Stanfield area. --Water levels during the period spring 1957 to spring 1958 rose about 5 to 10 feet in a part of this area. The water levels are deeper in the Maricopa-Stanfield area than in other areas in the basin and some reduction in pumping in 1957 may have caused the rise in the water table. In the western part of this area, along the mountains, water levels declined about 30 to 40 feet. In the 5-year period spring 1953 to spring 1958 (fig. 15) the levels west of Stanfield declined about 120 feet and near the mountains in the western part of this area they declined about 140 feet. The water level in well (D-7-5)22 (fig. 16) declined about 2 feet from spring 1957 to spring 1958, about 10 feet from spring 1953 to spring 1958, and nearly 48 feet from spring 1946 to spring 1958. The depths to water below land surface in the spring of 1958 ranged from 70 to 440 feet.

Eloy area. --Water-level fluctuations in this area from spring 1957 to spring 1958 ranged from a rise of about 7 feet to a decline of more than 20 feet. In the 5-year period, spring 1953 to spring 1958, water-level declines ranged from about 20 to more than 60 feet (fig. 15). The greatest declines were in an area southeast of Eloy and near the Papago Indian Reservation west of Eloy. Well (D-7-7)27 (fig. 16) is in one of the areas where the water table rose from spring 1957 to spring 1958 and the hydrograph for this well shows a rise of about 3 feet in the water level. For the 5-year period spring 1953 to spring 1958 the water level declined about 20 feet, and for the 12-year period spring 1946 to spring 1958 it declined nearly 73 feet. The depths to water in this area ranged from about 150 to more than 300 feet below the ground in the spring of 1958.

Santa Cruz County

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

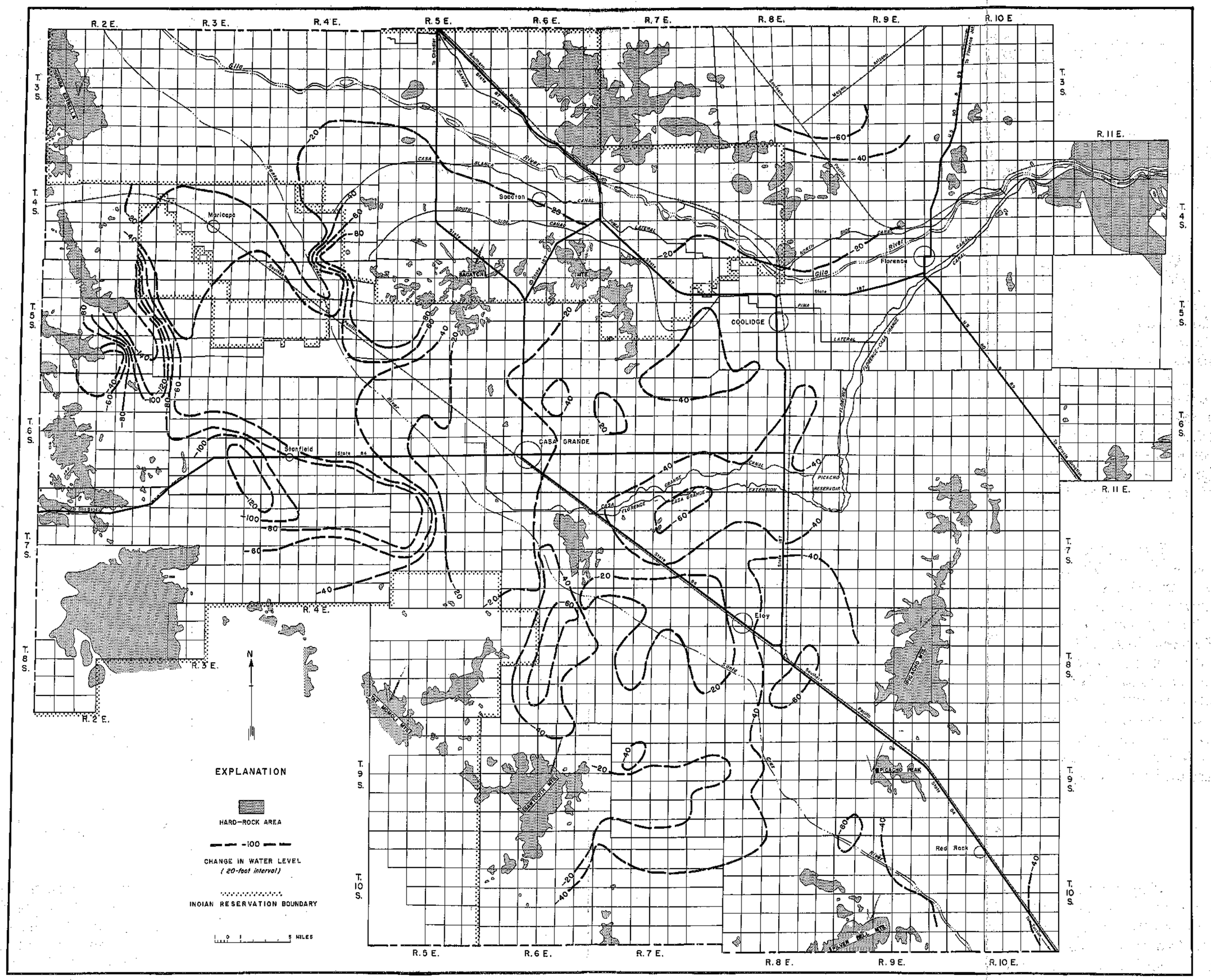

Figure 15.--Map of lower Santa Cruz basin and adjacent areas, Pinal County, Arizona, showing change in ground-water level from spring 1953 to spring 1958

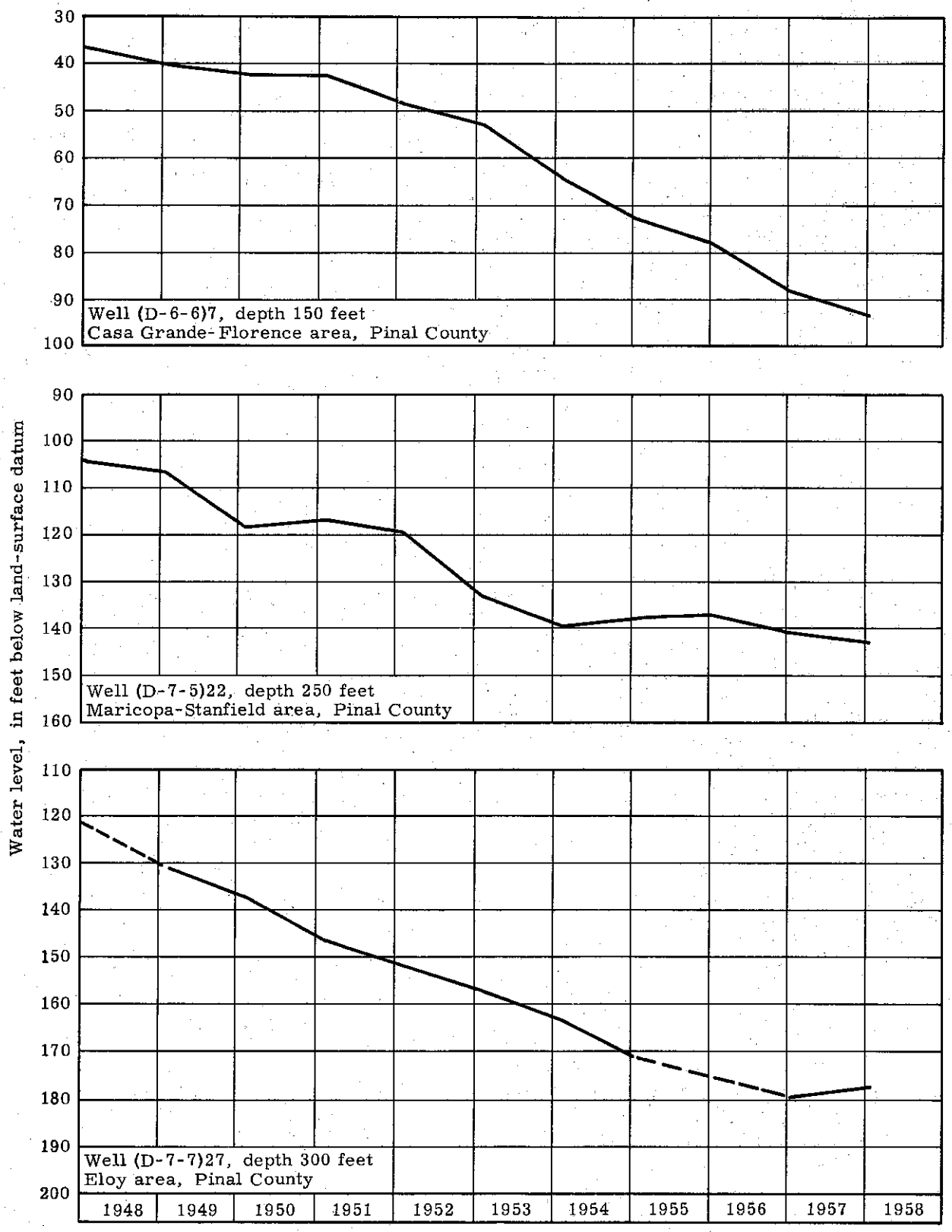

Figure 16.--Water levels in selected wells, Pinal County.

Boundary to about 3,000 feet at the Santa Cruz-Pima County line. In 1957 about 6,000 acres were irrigated (Seltzer, 1958). From spring 1957 to spring 1958 water-level fluctuations in wells from Amado to Carmen ranged from a rise of about 1 foot to a decline of a little more than 1 foot. Water levels in the Carmen-Nogales area declined from about 2 to 10 feet. However, the water-level fluctuations in the county during the 5-year period spring 1953 to spring 1958 ranged from no change to small rises. This is attributed to recharge from the Santa Cruz River during the past few years. The water level in well (D-22-13)35 (fig. 17) responds rapidly to recharge from the Santa Cruz River and Sonoita Creek, and may possibly have been influenced by a reduction in pumping from nearby wells since 1954. The water level in this well declined about 16 feet from spring 1957 to spring 1958, but in the spring of 1958 the level was about 3 feet higher than it was in the spring of 1953 and about 11 feet higher than in the spring of 1946. The depths to water in this area in the spring of 1958 ranged from about 10 to 50 feet below the ground.

Yavapai County

Water-level fluctuations in the Chino Valley area during the period spring 1957 to spring 1958 ranged from a rise of about 7 feet in the lower end of Chino Valley to a decline of less than 1 foot in the upper end of the area. The hydrograph for well (B-17-2)6 (fig. 17) shows the water-level trend in the area near Paulden where wells are the only source of irrigation water. The water levels in nonflowing irrigation wells ranged from about 5 to 258 feet below land surface at the end of 1957. In Skull Valley, water-level fluctuations ranged from a rise of about 3 feet to a decline of less than 1 foot. The depth to water below land surface in this area ranged from about 12 to 20 feet at the end of 1957. The largest declines last year in Yavapai County were in Skull Valley along Kirkland Creek. The irrigation wells in this area are in shallow alluvium and are readily affected by precipitation. Ground-water levels in Peeples Valley declined about 1 foot during 1957. Small quantities of water are pumped in this area and the water-table fluctuations are only seasonal.

Yuma County

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

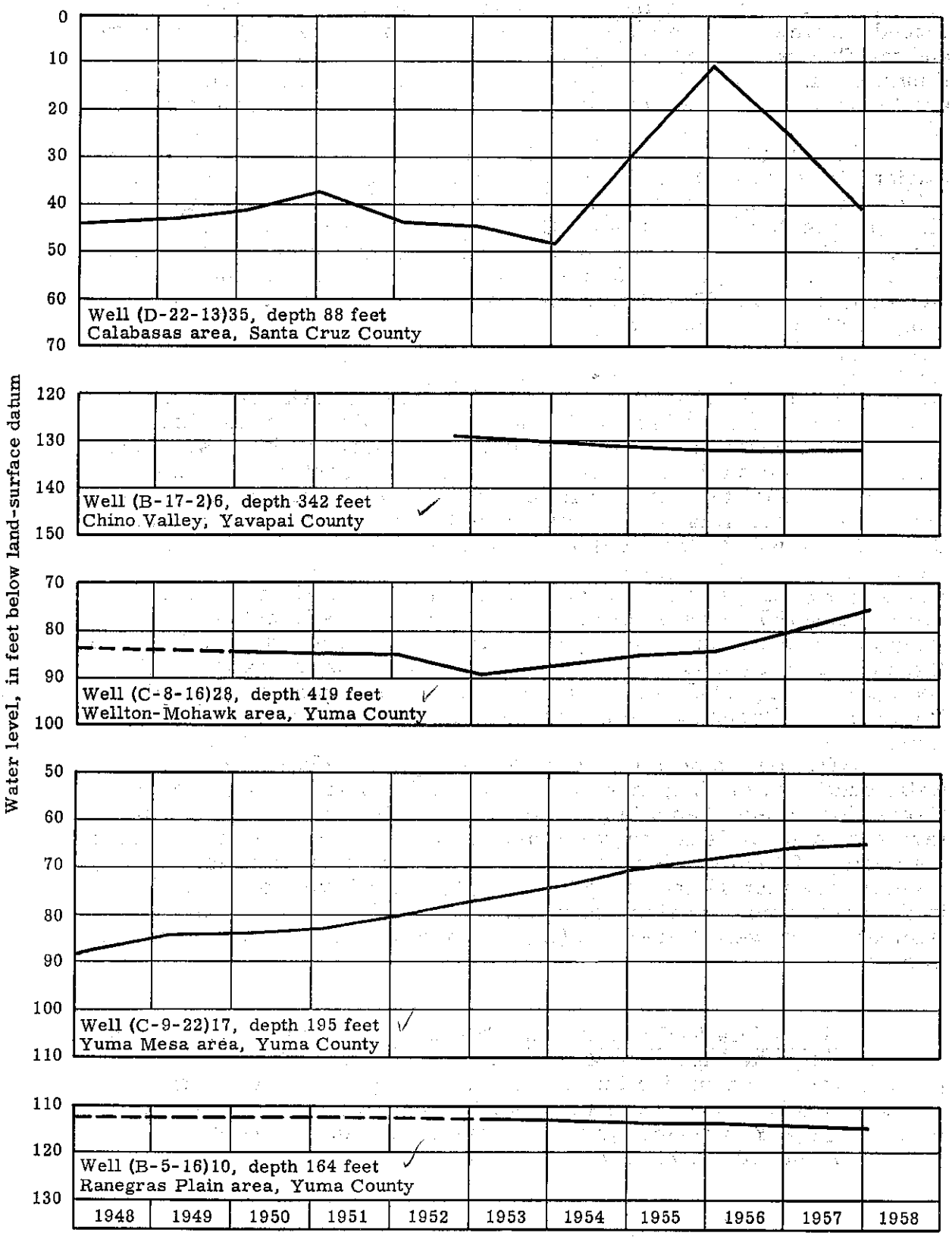

Figure 17.--Water levels in selected wells, Santa Cruz, Yavapai, and Yuma Counties.

Palomas Plain area. --Palomas Plain is an alluvial area that extends northwest from the Gila River between a spur of the Gila Bend and the Palomas Mountains. The area lies in 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 1957 to spring 1958 water-level fluctuations in wells in the Palomas Plain area ranged from a rise of about 2 feet near Horn, a station on the Southern Pacific Railroad, to a decline of less than 3 feet in well (C-4-10)6. There was little or no change in the water levels in most of the wells in the area during this same period. In spring 1958 the depth to water in the irrigated area ranged from about 20 feet along the Gila River to more than 280 feet near Turtle Back Mountain.

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. In 1957 only about 10 irrigation wells were in operation compared to about 60 during 1952. Five of the irrigation wells in operation during 1957 are in the new area of development north of Texas Hill, adjacent to the reclamation-project boundary.

During the period spring 1957 to spring 1958 water levels in wells continued to rise; these rises ranged from about 6 feet north of Texas Hill to less than a foot 9 miles east of Texas Hill. The water levels in most wells in the Wellton-Mohawk area rose about 3 feet. In the spring of 1958 the depth to water below land surface ranged from slightly less than 12 feet in wells along the Gila River to about 86 feet in the area of new development north of Texas Hill. The water-level fluctuations in well (C-8-16)28 (fig. 17) are indicative of conditions in this area.

South Gila Valley and Yuma Mesa area. --The south Gila Valley lies along the Gila River flood plains 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 "A" Canal.

Water levels in wells in the south Gila Valley and Yuma Mesa areas continued to rise from spring 1957 to spring 1958. The rises in water level ranged from about half a foot to slightly more than 1 foot. The water level in well (C-9-22)17 (fig. 17), typical for this area, rose about 23 feet during the period 1948-58. The depths to water in spring 1958 ranged from 64 to more than 72 feet below the land surface in the Yuma Mesa area and from about 12 to 29 feet below the land surface in the south Gila Valley.

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 lies within Yuma County, and the eastern half lies 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. More than half the present irrigation wells in McMullen Valley, however, have been drilled since 1955. The two areas of most recent development are near the towns of Wenden and Aguila.

During the period spring 1957 to spring 1958 water levels in wells in McMullen Valley continued their downward trend and the declines ranged from less than 1 foot to about 10 feet. The greatest declines were near the town of Aguila where 14 irrigation wells supply water for about 8 sections of land. Near Wenden and Salome the water-table declines ranged from about half a foot to 2 feet. In the spring of 1958, the depths to water in irrigation wells ranged from about 330 to 417 feet below the land surface in the Aguila area, from about 169 to 245 feet below the land surface in the Wenden area, and from about 87 to 210 feet below the land surface in the Salome-Harrisburg Valley area.

Ranegras Plain area. --This area lies 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.

Agriculture in the Ranegras Plain area has increased very little in the past 5 years. During 1957 there were about 15 irrigation wells equipped to pump water but not all of these wells were in operation during the year.

From spring 1957 to spring 1958 water-level fluctuations in the Ranegras Plain area ranged from a rise of about 1 foot to a decline of nearly 3 feet. Water levels in most wells in the area declined 1 foot

or less. The water level in well (B-5-16)10 (fig. 17), in the undeveloped portion of the area, declined slightly. The depths to water in spring 1958 ranged from about 67 to more than 224 feet below the land surface.

Pumpage

The amount of ground water pumped in Arizona during 1957 was about 4,500,000 acre-feet; this amount is not significantly different from that pumped in 1955 and 1956. For the last few years, the annual pumpage has been nearly constant despite increased pumping lifts. Most of this ground water withdrawal has been for irrigation use; only about 300,000 acre-feet has been used for municipal, industrial, and domestic purposes.

Irrigation pumpage has decreased in the basins in the southeastern part of the State, with the exception of Cochise County, and increased in Maricopa and some of the northern counties. This pumpage is related to the amount of increase or decrease of the irrigated acreage. The two principal areas of ground-water pumping are the Salt River Valley and the lower Santa Cruz basin. There has been increased development and pumping in the Willcox basin, McMullen Valley, Harquahala Plains area, and parts of Mohave County. The use of water for irrigation in the upper Santa Cruz basin (Nogales to Tucson), Safford area, and Douglas basin remained about the same as last year. Pumping has increased in the Gila Bend area because of recent developments. In the Yuma and Wellton-Mohawk areas, surface water is utilized more than ground water. Wells in Apache County, near St. Johns and Hunt, yield moderate amounts of water and some wells southwest of Hunt flow in the winter months. In Navajo County, most of the pumping is along the Little Colorado River in the vicinity of Winslow and Holbrook, and in the Snowflake-Taylor area.

The use of water for public supply has continued to increase throughout the State, particularly in Phoenix and Tucson. The increase in the number of housing developments has resulted in additional water franchises. The Arizona Corporation Commission had a list of 245 private water franchises as of January 1, 1957. This does not include the public municipalities. Many of these companies have less than 25 meters and service a very small area. These private companies pumped about 18 billion gallons of water in 1956. Tucson had about 90 and Phoenix about 50 water franchises. In 1957, the public municipalities extended their service and acquired many of these franchises. In 1947 the public water company for Phoenix sold 22 mgd (million gallons per day) of water, of which 7 mgd was ground water. At the end of 1957, an average of 46 mgd was being used, the increase coming from surface water. The average depth of the city wells is 300-500 feet; the average pumping lift is 200 feet; and the average yield is about 2,300 gpm. The public water company serves about 70 percent of greater Phoenix.

Water consumption in Tucson has grown at a similar rate. In 1947 the city pumped about 10-1/2 mgd; during 1957 the pumpage was 23 mgd or nearly 8-1/2 billion gallons of water. The city supply is obtained from 124 wells producing entirely from ground-water sources.

The demand for water by industry has become more important and will increase in the future. In the Phoenix area, 59 wells were inventoried as industrial recharge wells. They are primarily used for the air conditioning of department stores and for factories. The depths of these wells ranged from 90 to 400 feet, and averaged 225 feet. The static water levels were from 50 to 100 feet below the ground, and the average pumping rate was approximately 550 gpm.

Inspection of the pumpage records and maps showing the yearly and 5-year declines indicates that the sediments in the various basins differ in the amount of water they are capable of storing. Preliminary evaluations indicate that the sediments in the Salt River Valley have a larger capacity to store water than the material in the lower Santa Cruz basin. The sediments in the Douglas basin may have a larger coefficient of storage than the material in the Willcox basin. The effects of irrigation recharge may be one reason for the apparent higher storage coefficient in the Salt River Valley. The chemical quality of the irrigation water that percolates in the soil is one of the more important problems to be studied. Much of this water is high in dissolved solids, particularly chlorides. Any water that is put into an aquifer should be of such chemical quality that it will not impair the use of the existing water in the ground-water reservoir.

SELECTED WELL LOGS

Well logs are an important aid in the studies of subsurface geology and hydrology. A library of well logs is of great value to the exploration geologist, and helpful also to the well drillers, farmers, private companies, and individuals in estimating the cost, depth, and yield of a future well. Figure 18 shows graphic logs of 7 wells in selected areas of Arizona. These areas are as follows:

1. Willcox basin. Well (D-13-24) was drilled in 1932 to a depth of 1,356 feet. This well was a test hole for obtaining flowing water. The static water level came within 28 feet of the land surface in 1932, but was about 81 feet below the ground in the spring of 1958. The well-construction record shows that 16-inch-diameter casing was used from the surface to 460 feet, 10-inch from 460 to 777 feet, and 8-1/4-inch from 777 to 1,356 feet. There is no record of a pumping test.

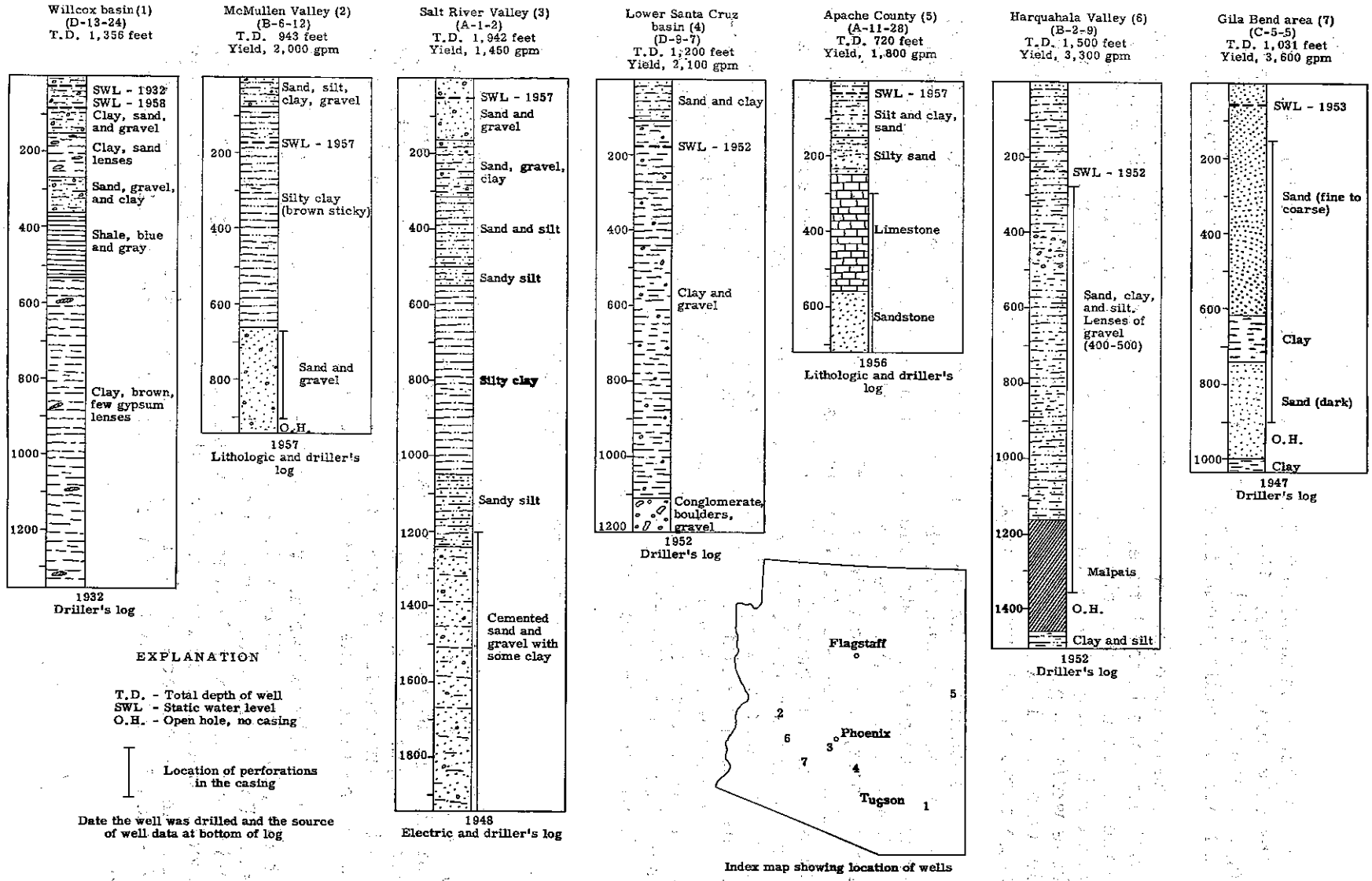

Figure 18.--Graphic logs of 7 wells in selected areas of Arizona.

2. McMullen Valley. Well (B-6-12) was drilled to a total depth of 943 feet and the static water level was about 172 feet below land surface in June 1957. Water from this well is obtained from the sand and gravel which lies below the silty clay unit. The well was reported to produce 2,000 gpm with a drawdown of about 130 feet. The specific capacity of this well, based on information obtained during a 2-hour test, was 15.4 gpm per foot of drawdown. This well was initially tested in fine-grained material at a depth of 446 feet. The test showed a 332-foot drawdown in 4 minutes of pumping at a rate of 400 gpm. The low permeability of this silty clay was also indicated in the reported test data obtained in a nearby well. Two chemical analyses of water were obtained from well (B-6-12)—one at a depth of 800 feet and a second at the completed depth of the well. The first analysis shows the total dissolved solids to be 792 ppm (parts per million) in contrast to 386 ppm in the second sample. This contrast is probably due to the lithology or composition of the material penetrated by the well bore.

Well construction in McMullen Valley depends upon the type of drilling equipment used. Well (B-6-12) was drilled with a cable-tool rig. Three sizes of casing were used which included 535 feet of 22-inch diameter, 206 feet of 20-inch diameter, and 232 feet of 16-inch diameter. The 20-inch casing was set at 705 feet and perforated in the lower 30 feet, 8 cuts every 2 feet. The 16-inch casing was set at 902 feet and perforated its entire length. The lower 41 feet of the well is open hole.

3. Salt River Valley. Well (A-1-2) was drilled in 1948 to a depth of 1,942 feet. Two sizes of casing were used: 20-inch from the surface to a depth of 650 feet; and 16-inch from 650 to 1,942 feet. In July 1947, the well was reported to yield 1,400 to 1,500 gpm with a drawdown of 193 feet from a static level of 47 feet. The specific capacity of this well is more than 7 gpm per foot of drawdown. The water contained 653 ppm dissolved solids and 306 ppm chloride. The temperature was 94°F in July 1957.

4. Lower Santa Cruz basin. Well (D-9-7) was drilled in 1952 to a depth of 1,200 feet and has a 20-inch-diameter casing. The original pump-test record indicates a static water level of 175 feet below the ground in 1952 and a discharge of 2,100 gpm with a drawdown of 272 feet. Thus, the specific capacity is 7.7 gpm per foot of drawdown. The water level in the spring of 1958 was about 228 feet below the land surface.

5. Apache County. Well (A-13-28) was drilled to a depth of 720 feet and had a static water level of nearly 29 feet in the spring of 1957. In 1956 during a pumping test, the well yielded an average of 1,800 gpm with a drawdown of nearly 56 feet. The specific capacity of the well was 32.5 gpm per foot of drawdown after 72 hours of pumping. A calculated transmissibility of the formation from the pumped well

was 24,000 gpd (gallons per day) per foot of aquifer. The aquifers include the Moenkopi formation, Kaibab limestone, and the Coconino sandstone.

6. Harquahala Plains area. Well (B-2-9) was drilled to a total depth of 1,500 feet in 1952. It was cased with 20-inch-diameter casing from the surface to 580 feet, 16-inch from 580 to 1,355 feet, and open hole to 1,500 feet. The perforations in the casing are from 275 to 1,335 feet. In January 1952 the static water level was 235 feet below the ground and the reported yield was 3,300 gpm. In 1957 the measured yield was 1,600 gpm. In August 1956 the water contained approximately 500 ppm of dissolved solids, 94 ppm chloride, and its temperature was 94°F.

7. Gila Bend area. Well (C-5-5) was drilled in 1947 to a total depth of 1,031 feet. It has a 20-inch-diameter casing from the surface to 1,000 feet with perforations from 150 to 900 feet. During the pump test, the well is reported to have yielded 3,600 gpm with 40 feet of drawdown with a specific capacity of 90 gpm per foot of drawdown. In August 1956 the yield was 2,900 gpm. The static water level in June 1949 was 69 feet below the surface; in December 1953 it was 57 feet below the surface. In September 1950 the water contained 2,230 ppm of dissolved solids, 1,020 ppm chloride, and 2 ppm fluoride.

CHEMICAL QUALITY OF WATER

The Ground Water Branch has supported a well-sampling program to obtain data on the chemical quality of the water yielded to wells in Arizona. Some of these wells are sampled periodically to observe chemical changes in the ground water. Most of the wells are in the southern part of the State in the Basin and Range lowlands. Figure 19 shows the location of wells that are sampled annually. This work is part of the program for the collection of basic data. In addition to this annual program, water samples are collected and analyzed and the results are published as part of special reports on the ground-water resources of specific areas.

Evaporation of water from the soil surface and transpiration by plants increase the mineral content of the soil and the soil water. The minerals left on the surface of the ground and in the plant-root zone may accumulate in the shallow ground water when leached by further applications of irrigation water or by precipitation. Evidence of this is seen in many shallow wells throughout the State in the irrigated areas (fig. 19). The water in a 75-foot well in the Buckeye irrigation district increased in dissolved solids from 4,500 ppm in 1952 to 5,000 ppm in 1955; the concentration increased from 2,460 ppm in 1952 to 3,600 ppm in 1956 in a 58-foot well in the Safford Valley. Similar increases in concentration of dissolved solids occur in other areas. In

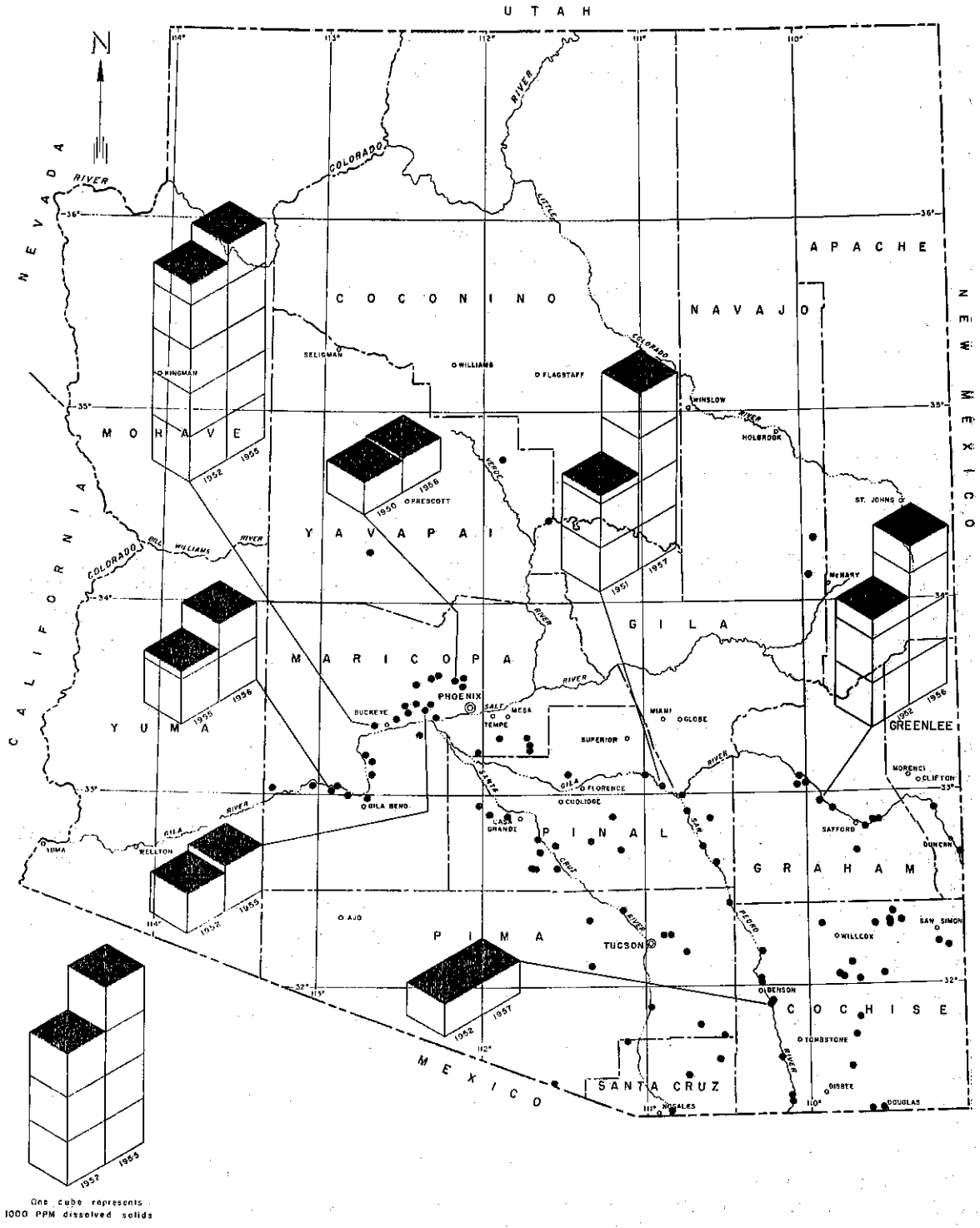

Figure 19.--Location of wells and springs in the annual water-sampling program, and selected analyses showing increased mineralization of the water.

parts of the Safford Valley, Salt River Valley, and the Gila Bend area, the shallow ground water is more mineralized than the water in deeper aquifers. The quality of the ground water is becoming progressively worse in some parts of the State and additional analyses of water are necessary to determine where the salts are accumulating.

About 1,000 chemical analyses of water from wells in the State are in the open files of the Tucson and Phoenix offices. Some of the wells have been sampled periodically because of increased mineralization of the water in extensively developed areas, and others have been sampled only once.

The water in the Douglas basin ranges from 100 to 500 ppm in dissolved solids and is generally hard except west of Douglas. The water in the Willcox basin is low in dissolved solids but is hard, and has a high fluoride content. The more mineralized water is near the playa. The water in the Ranegras Plain area of Yuma County ranges from 400 to 3,700 ppm in dissolved solids and is high in fluoride; the water in the Wellton-Mohawk area is highly mineralized. The Gila Bend area contains water that is increasing in salt content and is hard. The Santa Cruz basin contains water with 100 to 1,000 ppm of dissolved solids and hardness of 75 to 350 ppm. The dissolved solids do not increase consistently downstream until it reaches the lower Santa Cruz area at Cortaro. Within the developed areas of Eloy, Casa Grande, Coolidge, and Maricopa, the water is highly mineralized in specific localities. The ground water in the San Pedro Valley is generally of good quality and low in dissolved solids, although in local areas the water may have as much as 9,000 ppm of dissolved solids. Water is relatively soft in the Bowie area and moderately hard in the San Simon area of the San Simon Valley. The quality of the water in the Safford area is related to the flow of the Gila River. The river water normally is low in mineral content and, during a high stage, recharges the alluvium. When the river is at a low stage, most of the recharge to the valley is from the canals and irrigated fields. The ground water from these sources is higher in mineral content than river water. The Duncan basin contains water with 250 to 5,000 ppm of dissolved solids, the higher concentrations at the upstream end of the basin near the State line. The Salt River Valley contains ground water of generally good quality, although the salt content is increasing, probably owing to recharge from irrigation.

The use of water for irrigation is an important part of the economy of Arizona. With the increase in industrial development and the trend in the population growth of the Southwest, the chemical quality of the ground water in all areas of the State is of prime importance.