[redacted]

WATER RESOURCES REPORT NUMBER SEVEN

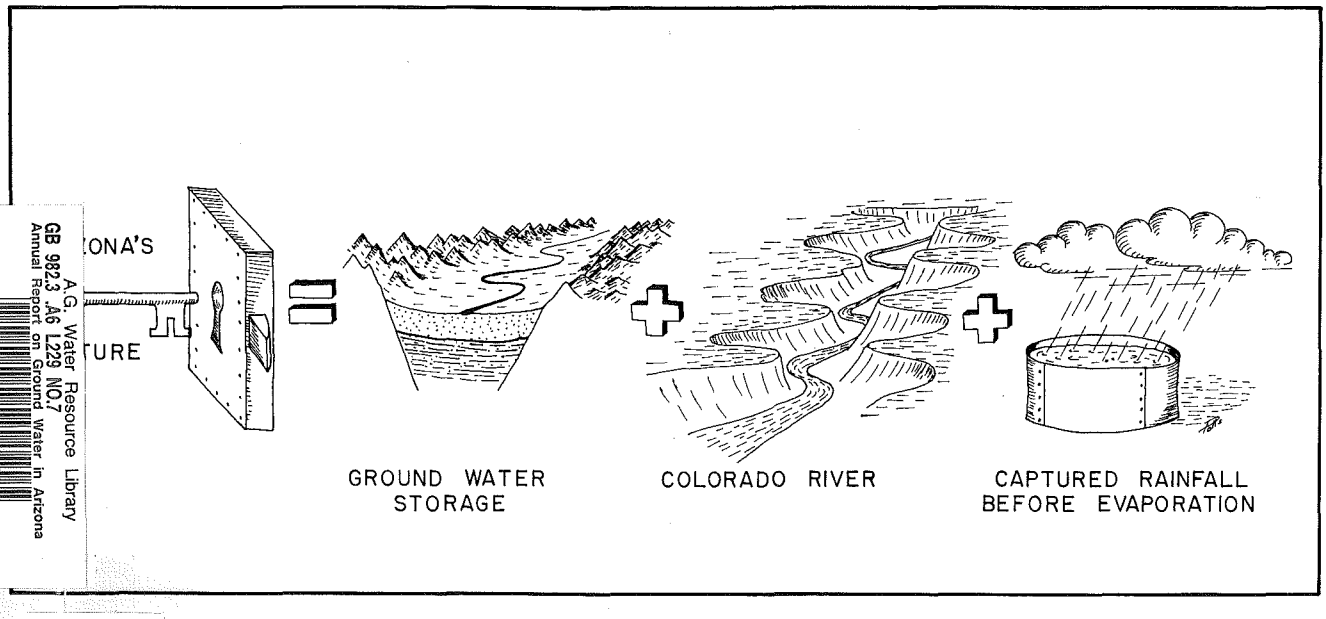
ARIZONA STATE LAND DEPARTMENT

OBED M. LASSEN, COMMISSIONER

ANNUAL REPORT ON GROUND WATER IN ARIZONA SPRING 1959 TO SPRING 1960

BY

W. F. HARDT, R. S. STULIK AND M. B. BOOHER



A.G. Water Resource Library
GB 982.3 .A6 L229 NO.7
Annual Report on Ground Water in Arizona
00000525

490
(271)
A714w
1960
no. 7

PREPARED BY THE GEOLOGICAL SURVEY,
UNITED STATES DEPARTMENT OF THE INTERIOR

Phoenix, Arizona
September 1960

WATER RESOURCES REPORT NUMBER SEVEN

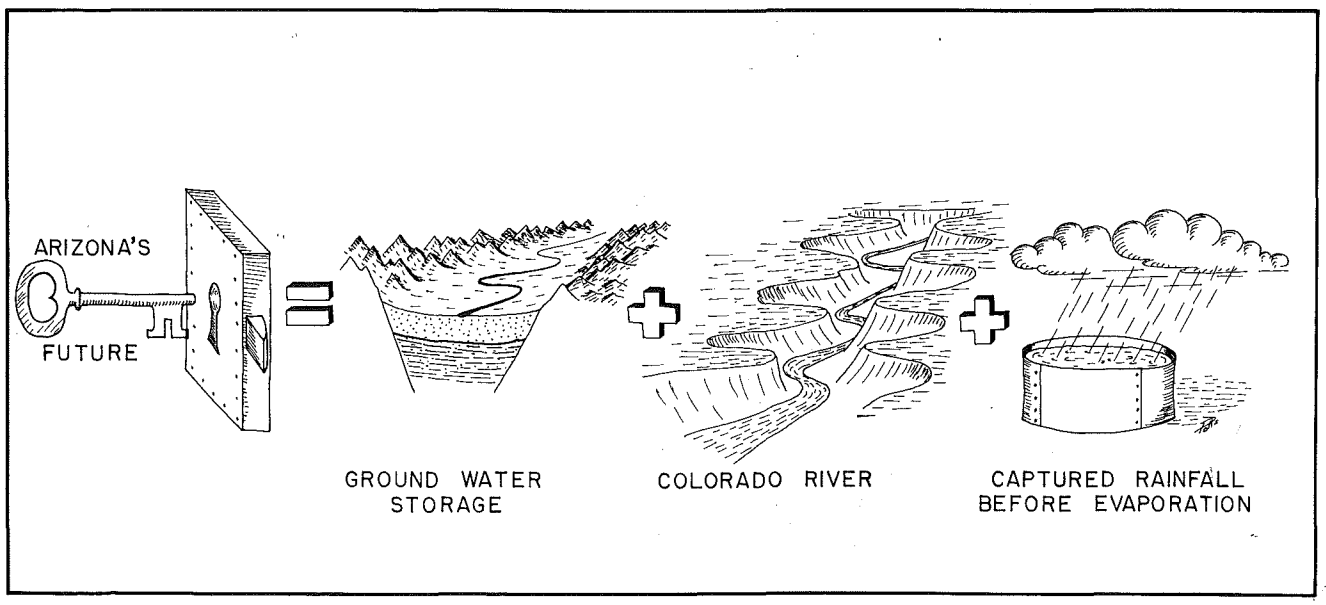
ARIZONA STATE LAND DEPARTMENT

OBED M. LASSEN, COMMISSIONER

ANNUAL REPORT ON GROUND WATER IN ARIZONA SPRING 1959 TO SPRING 1960

BY

W. F. HARDT, R. S. STULIK AND M. B. BOOHER



PREPARED BY THE GEOLOGICAL SURVEY,
UNITED STATES DEPARTMENT OF THE INTERIOR

Phoenix, Arizona
September 1960

Water Rights Adjudication Team
Civil Division
Attorney General's Office

78237

CONTENTS

	Page
Abstract	1
Introduction	2
Scope of basic-data program	4
Current projects in Arizona	5
List of publications	8
Agricultural resume for 1959	11
Precipitation	12
Surface-water runoff, storage, and diversions	13
Well-numbering system	16
Personnel	16
Acknowledgments	18
Ground-water conditions	18
Water-level fluctuations	22
Apache County	22
Cochise County	24
Willcox basin	24
Douglas basin	28
Bowie-San Simon area	30
Upper San Pedro valley	32
Coconino County	33
Gila County	33
Graham County	35
Greenlee County	36
Maricopa County	36
Salt River Valley	38
Queen Creek-Higley-Gilbert-Magma area	38
Tempe-Mesa-Chandler area	41
Phoenix-Glendale-Tolleson-Deer Valley area	43
Paradise Valley area	43
Litchfield Park-Beardsley-Marinette area	44
Liberty-Buckeye-Hassayampa area	44
Lower Hassayampa-Tonopah area	46
Lower Centennial area	46
Gila Bend area	46
Waterman Wash area	47
Harquahala Plains area	49
Mohave County	49
Navajo County	50
Pima County	51
Avra-Marana area	52
Rillito-Tucson area	54
Tucson-Continental area	54
Tanque Verde-Pantano area	54
Pinal County	55

Page

Casa Grande-Florence area 57
Maricopa-Stanfield area 59
Eloy area. 59
Santa Cruz County 59
Yavapai County. 60
Verde Valley 60
Clarkdale-Cottonwood-Camp Verde area. 60
Sedona area. 62
Chino Valley-Skull Valley-Peeples Valley. . 62
Yuma County 63
Palomas Plain area 63
Wellton-Mohawk area 63
South Gila Valley and Yuma Mesa area . . . 63
McMullen Valley area 64
Ranegras Plain area 64
Pumpage. 65
Quality of ground water in the Tucson area. 68
Quality-of-water standards for domestic and public supply. 70
Quality-of-water standards for industry. 72
Appendix A—List of published reports on geology and ground-water resources of Arizona 73
Appendix B--List of unpublished reports on the geology and ground-water resources of Arizona. 82

ILLUSTRATIONS

Figure 1. Ground water vs. funds expended for water-resources investigations in the 10 States using the most ground water 3

2. Map of Arizona showing areas of ground-water investigations 6

3. Surface-water reservoir storage and diversions in Arizona. 15

4. Sketch showing well-numbering system in Arizona . . . 17

5. Mining water in southern Arizona 20

6. Map showing ground-water areas and basins in Arizona where water levels are measured 23

7. Map of Willcox basin, Cochise and Graham Counties, Arizona, showing change in ground-water level from spring 1955 to spring 1960. 25

Page

Figure 8. Water levels in selected wells in the Willcox and Douglas basins, Cochise County 27

9. Map of Douglas basin, Cochise County, Arizona, showing change in ground-water level from spring 1955 to spring 1960. 29

10. Water levels in selected wells in the Bowie-San Simon area and upper San Pedro basin, Cochise County. . . . 31

11. Water levels in selected wells, Coconino, Graham, and Greenlee Counties 34

12. Map of Salt River Valley area, Maricopa and Pinal Counties, Arizona, showing change in ground-water level from spring 1955 to spring 1960. 37

13. Water levels in selected wells in Queen Creek-Higley-Gilbert-Magma area, Maricopa and Pinal Counties. . . 39

14. Water levels in selected wells in Tempe-Mesa and Deer Valley areas, Maricopa County 40

15. Water levels in selected wells in Tolleson, Paradise Valley, and Litchfield Park areas, Maricopa County. . 42

16. Water levels in selected wells, Maricopa County. . . . 45

17. Water levels in selected wells, Maricopa, Mohave, and Navajo Counties 48

18. Water levels in selected wells, Pima County 53

19. Map of lower Santa Cruz basin and adjacent areas, Pinal County, Arizona, showing change in ground-water level from spring 1955 to spring 1960. 56

20. Water levels in selected wells, Pinal County 58

21. Water levels in selected wells, Santa Cruz, Yavapai, and Yuma Counties. 61

22. Chemical composition of selected ground waters, Tucson area, Arizona 69

TABLES

		Page
Table 1.	Total precipitation in 1959 at selected stations and departures from long-term means	14
2.	Average depth to water in the lower Santa Cruz basin.	57
3.	Suggested water-quality tolerances in industry	71

ANNUAL REPORT ON GROUND WATER IN ARIZONA SPRING 1959 TO SPRING 1960

By

W. F. Hardt, R. S. Stulik, and M. B. Booher

ABSTRACT

This "Annual Report on Ground Water in Arizona" is a summary of the basic hydrologic data collected from the spring of 1959 to the spring of 1960. The collection and analysis of basic 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 during 1959 from all of the counties in the State. Most of the measurements were made in wells in the alluvial basins of southern Arizona where more than 80 percent of the population and 90 percent of the irrigated acreage are concentrated. The trend of water levels in the heavily pumped areas generally continued downward. Maximum declines occurred in the Salt River and lower Santa Cruz Valleys, and in the Willcox basin. Smaller declines of the water table were measured in San Simon Valley and Douglas basin in Cochise County; McMullen Valley, Harquahala Plains, Gila Bend area, and Waterman Wash area in Maricopa County; and in Avra Valley and the Tucson basin in Pima County.

Water levels in the Duncan and Safford Valleys, San Pedro River valley and upper Santa Cruz basin were about the same or slightly higher than in the previous year. Water levels continued to rise in the Yuma and Wellton-Mohawk areas. The northern half of the State had minor water-level fluctuations during 1959.

Pumpage of ground water in Arizona in 1959 was about 4,700,000 acre-feet, a slight increase in comparison to previous years. Development of ground water increased in McMullen Valley, Harquahala Plains, Willcox basin, and the Gila Bend area. More than 90 percent of the ground water used in Arizona is for irrigation, although the use of water for public supply has increased. More than 75 percent of the ground water pumped in Arizona is from the Salt River and lower Santa Cruz Valleys. Pumpage has increased considerably since 1956 in the Willcox basin, mostly in the Kansas Settlement area. In northern Arizona, ground-water pumpage was minor—about the same as in previous years. Slight increases in pumpage were noted in Yavapai, Navajo, and Apache Counties.

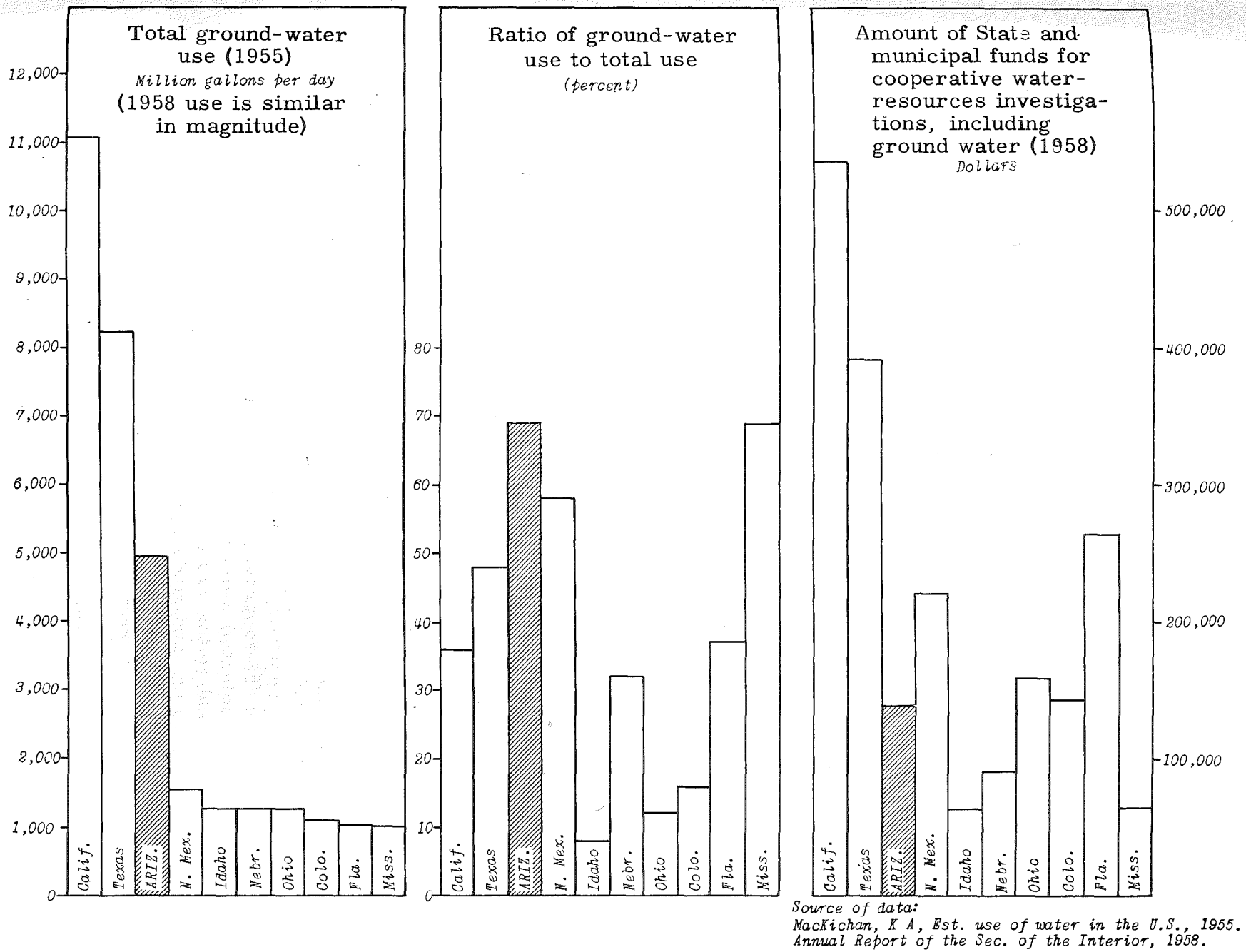
Illustrations include: (1) hydrographs showing water-level fluctuations for 10 years in selected wells; (2) maps showing change in water levels for the 5-year period spring 1955-60 for the Salt River Valley, lower Santa Cruz, Willcox, and Douglas basins; and (3) figures showing surface-water storage and diversion, the mining on ground water in southern Arizona, and the quality of water from selected wells in the Tucson area. Also, included in this report is a complete list of unpublished and published reports on the ground-water resources of Arizona by the U. S. Geological Survey.

INTRODUCTION

The future economic development of Arizona is dependent on the successful use of existing water supplies for productive benefit and on the availability of additional water 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 as a result of expanded use 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 Commissioner 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.

Ground-water problems are widespread throughout the United States and a comparison between the amount of ground water used and the expenditure of State and municipal funds for cooperative water-resources investigations for the 10 States using the greatest amounts of ground water shows the importance that the States place on water (fig. 1). Arizona uses more ground water than any other State with the exceptions of California and Texas, and it also has the second highest percentage ratio of ground-water use to total water use. Figure 1 suggests that ground water is relatively more important to the continued growth and prosperity of Arizona than it is to the other States, yet it shows that less money is spent for water-resources studies.

The ground-water studies that have been made show clearly that most of the ground water pumped from wells comes from storage and causes gradual but continuous declines in water levels. They also show that some of the ground-water reservoirs are very large, but that none of them are inexhaustible. Only by careful determination of the location and depth of the underground reservoirs and measurements of the amount of water they contain can the information be obtained that is necessary for the proper management of our ground-water resources.



Source of data:
MacKichan, K A, Est. use of water in the U.S., 1955.
Annual Report of the Sec. of the Interior, 1958.

Figure 1.--Ground water used vs. funds expended for water-resources investigations in the 10 States using the most ground water.

The cooperative program includes the collection of statewide basic hydrologic data, geologic 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 statewide basic-data-collection phase of the program in 1959.

The 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, surface-water diversion, and chemical quality of the water in the Tucson area. Hydrographs are included to show comparative changes in the stage of water levels in selected wells for the last 10 years. Maps show the changes in ground-water levels for a 5-year period (1955-60) in the Salt River Valley, lower Santa Cruz, Willcox, and Douglas basins. Figures depicting storage and diversion from the principal reservoirs, the mining of ground water in the alluvial basins of southern Arizona, and the chemical composition of selected ground waters in the Tucson area are included. In addition there is a complete list of unpublished and published reports on the ground-water resources of Arizona by the Ground Water Branch of the U. S. Geological Survey.

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 the basic-data 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 may support future development; (3) to determine the geology and hydrology of areas as related to the ground-water regimen; (4) to determine the changes in the chemical quality of water; (5) to provide continuous records of fluctuations of water levels in selected wells to study the net changes 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 basic data collected each year are used to answer hundreds of inquiries about depth to water, pumping lifts, location and yield of wells, type of rocks penetrated by wells, extent and depth of water-bearing beds, and chemical quality of water. These data are also nec-

essary to evaluate the yearly changes and trends in ground-water conditions throughout the State. As Arizona increases in economic development and population, the water problems will increase. The purpose of this annual report is to present to the people of the State some of the current data on water in a way that is informative, interesting, and helpful. An analysis of a series of these reports covering many years reveals 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 also would be revealed by such an analysis. 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 1,900 wells in 1959. The rate of discharge, in gallons per minute, was measured for about 250 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 1959 in Arizona were financed through (1) cooperative agreement with the State (Arizona State Land Department); (2) cooperative agreements with municipalities (Flagstaff), universities (University of Arizona), and others (Navajo Indian Tribe); and (3) Federal funds exclusively, including transfer of funds from other Federal agencies (Bureau of Indian Affairs and U. S. Army). The areas of new and active projects are shown on figure 2.

The cooperative program with the State includes (1) statewide 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. The information obtained may be correlated with that from a similar study of the area completed after extensive development. Projects of this type include the Snowflake-Taylor area in Navajo County, McMullen Valley and Big Sandy Valley in Mohave County, and a part of Apache County south of the Navajo Indian Reservation.

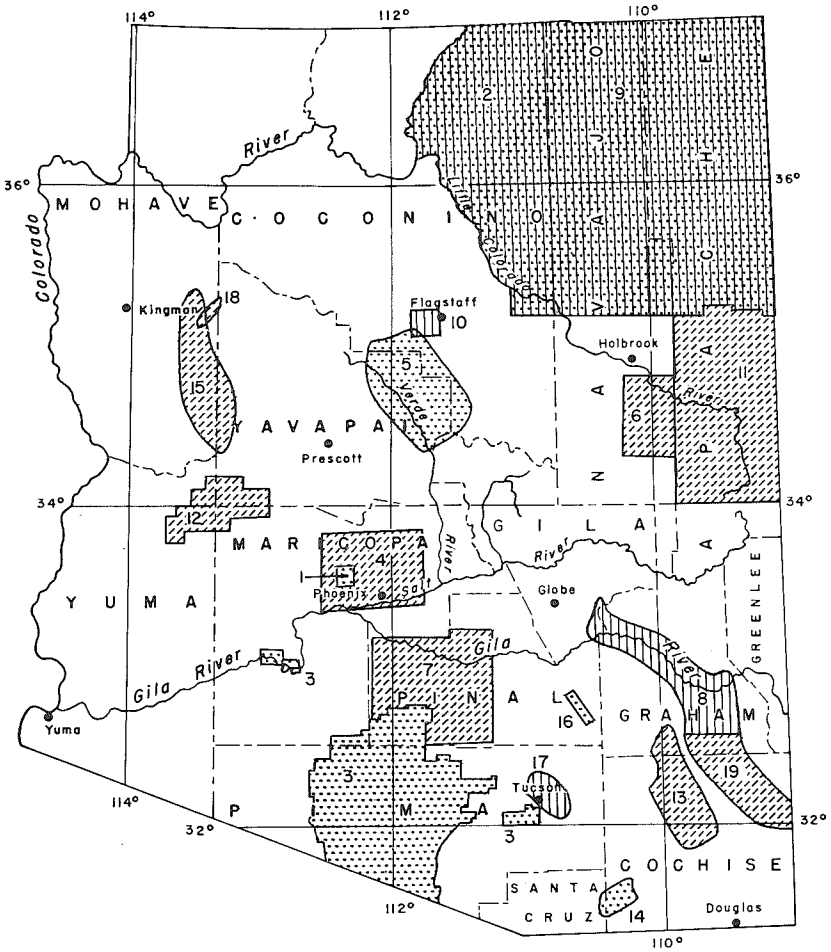


Figure 2.-- Map of Arizona showing areas of ground-water investigations.

PROJECTS BY AREA

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

Rainbow Valley + Wilkinson Wash

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

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

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

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 lower Santa Cruz basin of Pinal County, the study of water movement in the inner San Pedro Valley near Mammoth, and the geohydrologic characteristics of the Willcox and San Simon basins.

Cooperation with municipalities is exemplified by the current project with the city of Flagstaff. The Flagstaff investigation 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." Cooperative projects with the University of Arizona consist of geohydrologic studies as related to water utilization in the Safford Valley and the feasibility of capturing additional water in Rillito Creek basin near Tucson.

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, military installations, and national parks and monuments are included in this category, and the results of these investigations also are 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, the Verde Valley area of the Mogollon Rim region, and the Chiricahua National Monument in Cochise County. Water studies for the military are at Luke Air Force Base near Phoenix and at the Fort Huachuca Military Reservation south of Tucson.

New projects this year include a geohydrologic study of the San Simon basin where final quantitative analysis will be made by use of electrical analog equipment. The geometric configuration of the electrical model will be a replica of the geologic structure of the basin and the electrical model units will be in direct ratio to the transmission and storage characteristics of the aquifer. Thus future ground-water conditions can be analyzed as correctly as the geologic data the model incorporates. This is the first area in the State being analyzed by the electrical analog equipment and preliminary results are encouraging. A detailed geohydrologic study of the Willcox basin was started recently because of the increased agricultural development and the concern over the rapidly declining water table. Other new projects this year consist of developing a water supply of good quality for Luke Air Force Base near Phoenix and a geohydrologic study of the Fort Huachuca Military Reservation.

List of Publications

A complete list of unpublished and published reports on the ground-water resources of Arizona by the U. S. Geological Survey, Ground Water Branch is given in the back of this report. The list includes water studies from 1897 to May 1959. Many of the reports are out of print but they may be inspected at the U. S. Geological Survey offices in Tucson and Phoenix.

The following reports on the ground-water resources and geology of Arizona were prepared for release by the Ground Water Branch of the Geological Survey in 1959 and early 1960.

Geohydrology of arid lands (Arizona—a case study), by J. W. Harshbarger, in Proceedings of Arid Lands Colloquium: University of Arizona Press, July 1959. 29 p., 7 figs.

This paper presents a brief resume of the water conditions and the availability of water for the future growth of Arizona. Some of the major geologic features that control the occurrence, recharge, movement, storage, and discharge of water are discussed. The conclusion is that one of the most practical ways to increase the availability of water supplies is to capture liquid water and store it underground. There would be no losses by evaporation and it would be possible to recover most of the water recharged upon demand.

Annual Report on ground water in Arizona—spring 1958 to spring 1959, by W. F. Hardt, R. S. Stulik, and M. B. Booher: Arizona State Land Department Water Resources Report No. 6, September 1959. 61 p., 18 figs., 1 table.

This annual report is a summary of the basic hydrologic data collected during the period spring 1958 to spring 1959. It broadly describes the ground-water pumpage in the State and water-level fluctuations in the counties and principal basins. About 4.5 million acre-feet of ground water was pumped in 1958 and the trend of water levels in the heavily pumped areas continued downward. The work of the sediment laboratory in analyzing well cuttings and the quality of water in the Salt River Valley are discussed. Illustrations include 10-year hydrographs showing water-level fluctuations in selected wells, maps showing change in water levels for the 5-year period 1954-59 for the Salt River Valley, lower Santa Cruz, Willcox, and Douglas areas, and graphs showing laboratory analyses of well cuttings and outcrop samples.

Geology and the availability of water in the lower Bonita Creek area, Graham County, Arizona, by L. A. Heindl and R. A. McCullough: U. S. Geol. Survey open-file report, February 1960. 81 p., 14 figs., 4 tables.

The lower Bonita Creek area, about 15 miles northeast of Safford, has a drainage area of 70 square miles and supplies water to the city. Only the rocks of the upper part of the Tertiary volcanic sequence and the late Quaternary alluvium that forms the channel fill along Bonita Creek yield water in moderate quantities. The channel fill is the more important producer at the present time. The limited storage capacity of the channel and the sustained use of water suggest continuous recharge. The report includes a geologic map, cross sections, pumping-test data, and streamflow records. Tables include well and spring records and quality of water analyses.

Character and structure of volcanic rocks near Kingman, Arizona with respect to water yielding capacity, by A. M. Piper and J. F. Poland: U. S. Geol. Survey open-file report, 1959. 14 p., 2 pls.

This report, completed in 1943 for the U. S. Army Air Force, describes the water-bearing characteristics of the volcanic rocks near Kingman. The purpose of the study was to determine whether or not additional quantities of water could be developed for a gunnery school. The present water supply is from the basalts about 8 miles west of the camp which yield small amounts of water and are not capable of increased permanent production. Rapid depletion of water from the basaltic rocks would diminish the overflow from the perennial springs which constitute Kingman's water supply. The most practicable sites for new wells are in the agglomerate on the eastern flank of a former basaltic vent in the northwestern part of the Johnson Wash drainage area near the existing water supplies.

Water supply, Army Air Force Flexible Gunnery School, Kingman, Arizona, by E. R. Bowen and S. F. Turner: U. S. Geol. Survey open-file report, 1959. 7 p., 9 figs., 3 tables.

This report, completed in 1943 for the U. S. Army Air Force, describes pumping tests on the existing wells in the Johnson Spring area about 8 miles west of the gunnery school. Results of the tests indicate that a water supply from the camp area of 500,000 gpd (gallons per day) is not dependable for more than about 6 months. Three existing wells in the lower part of Hackberry Wash were examined and reportedly yielded 500 to 1,200 gpm (gallons per minute). It is suggested that future test wells be drilled along the south bank of Hackberry Wash where it turns westward toward the railroad station.

Geology and ground-water resources of McMullen Valley, Maricopa, Yavapai, and Yuma Counties, Arizona, by William Kam: Arizona State Land Department Water Resources Report and U. S. Geol. Survey Water Supply Paper (pending release). 114 p., 15 figs., 7 tables.

McMullen Valley, about 100 miles northwest of Phoenix, is one of the recently developed irrigation regions in the State. The report consists of the available information on the geology and ground-water resources of the area. The main aquifer is the valley fill that occupies the trough between the mountain ranges and exceeds 1,800 feet in thickness in some areas. The general direction of ground-water movement is southwestward from Aguila to Salome and then southeastward along Harrisburg Valley to the Harquahala Plains area. Pumpage for irrigation was about 21,000 acre-feet in 1957 with wells yielding from 150 to 3,500 gpm. In the Aguila area a relationship appears to exist between the higher specific capacity wells and the thickness of saturated alluvium. In the Wenden area wells that penetrate the coarse, alluvial deposits underlying the lake-bed material have a relatively high specific capacity. The dissolved-solids content of the water in McMullen Valley ranges from 200 to 7,410 ppm (parts per million), and most of the water contains from 200 to 400 ppm. Tables include well records, drillers' logs, chemical analyses, and pumpage. There are maps showing geology, well locations, and water-table contours.

Capturing additional water in the Tucson area, by the Rillito Creek Hydrologic Research Committee of the University of Arizona and the U. S. Geological Survey: U. S. Geol. Survey open-file report, June 1959. 68 p., 18 figs., 6 tables.

This report represents a preliminary study on the possibilities of increasing available water supplies within the Tucson basin to meet the anticipated water demand resulting from the rapid increase in population. Until disturbed by man, the amount of water in storage was essentially constant in the Tucson basin. In recent years water has been withdrawn from the basin in excess of the replenishment. Static water levels are declining and ground-water reservoirs are being depleted. Much of the runoff potential in Rillito Creek is lost to evapotranspiration and it is believed that additional water can be captured and recharged to the ground-water reservoirs. Tables include streamflow records and chemical analyses. There are maps showing geology, surface- and ground-water hydrology, and soil surveys.

Arizona Geological Society Digest, v. 3: University of Arizona, Department of Geology, March 1960. 185 p., 18 figs., 8 tables.

This annual report consists of a collection of papers, progress reports, abstracts, and notes pertaining to current geologic work in Arizona and the Southwest. Seven brief papers were written by personnel of the U. S. Geological Survey, Ground Water Branch. They are: (1) Ground Water in the Red Lake Area, Navajo Indian Reservation, Arizona and New Mexico, by J. P. Akers; (2) Current Water Well Drilling Program, Navajo Indian Reservation, Arizona and New Mexico, by J. P. Akers; (3) Cameron and Leupp Quadrangles, Arizona, by J. P. Akers;

(4) Cenozoic Geology of the Papago Indian Reservation, Pima, Maricopa, and Pinal Counties, Arizona, by L. A. Heindl; (5) Geology of the Lower Bonita Creek Area, Graham County, Arizona, by L. A. Heindl; (6) Topographic, Physiographic, and Structural Subdivisions of Arizona, by L. A. Heindl and J. F. Lance; and (7) Geology of the Eastern Part of the Safford Basin, Graham County, Arizona, by E. S. Davidson.

Agricultural Resume for 1959

According to R. E. Seltzer (Arizona Agriculture 1960: Arizona Agr. Expt. Sta. Bull. A-3, January 1960), 1,245,973 acres was irrigated in Arizona in 1959. This is an increase of about 6,400 acres from the previous year. About 6,600,000 acre-feet of water was used for irrigation during 1959, of which about 4,200,000 acre-feet was pumped from ground-water supplies. In addition an estimated 400,000 acre-feet of ground water and 50,000 acre-feet of surface water were pumped for municipal, industrial, and domestic purposes. The largest irrigated acreages under cultivation were in cotton (383,750 acres) and alfalfa (225,000 acres). The counties having the largest total irrigated acreage under cultivation were (1) Maricopa, 519,160 acres; (2) Pinal, 293,283 acres; (3) Yuma, 195,240 acres; and (4) Cochise, 75,900 acres.

There was a decrease in irrigated acreages in Pima, Graham, and Cochise Counties, no change in Mohave County, and an increase in irrigated acreage in the rest of the State. Yuma had the greatest increase of irrigated land followed by Maricopa, Yavapai, Pinal, and Navajo Counties. The greatest increase in acreages is in vegetables and alfalfa and in minor crops, such as irrigated pastures, oats, rye, flax, flowers, dry beans, peanuts, castor beans, soy beans, and grass seeds.

Seltzer (1960) stated that Arizona's cash agricultural income during 1959 was 414 million dollars. This was 7 million dollars below the record of 1958. The decreases in cotton production and price, poor vegetable markets, and late-season declines in cattle prices were the main reasons for the lower income. Cotton, cattle, and vegetables account for 73 percent of the State's total agricultural income. Agriculture is second to manufacturing as a source of income to the State despite rumors of declining importance. Cotton and vegetable receipts declined from 1958 but there was an increase in dairy products, feed grains, and hay. Citrus growers had a good year and acreages were increased in the Yuma area. Some crops are unprofitable to grow when ground-water pumping lifts exceed 300 feet, and new areas are being developed where shallow ground water or surface water is available. Such areas are the Wellton-Mohawk Valley, Gila Bend, Yuma, Snowflake, Aquila-Salome, Harquahala, and the valleys in Santa Cruz and Yavapai Counties.

Precipitation

The precipitation in 1959 was above average in Arizona for the third consecutive year, largely due to heavy rainfall in December. The only area in the State with below-average precipitation was Mohave County. The rest of northern Arizona was about average. Precipitation was about 1 inch above the long-term average in Maricopa and Pinal Counties, where 75 percent of the ground water is pumped in the State. Gila County received the most rainfall during the year and had the largest increase from the long-term average. Yavapai and Yuma Counties were slightly above average and the southeastern part of the State was well over the long-term average.

January was dry throughout the State, particularly in Gila and Yavapai Counties. In February the southern half of the State had average precipitation and the northern part above average. March was extremely dry throughout the State and April was below average. During May and June there were normal amounts of rainfall. July had varied conditions—Gila County and the southeastern part of the State were wet and Mohave, Maricopa, and Pinal Counties were deficient in rainfall. During August, the entire State was wet, with much rain in the southeastern part. September was very dry throughout the State. In October the State was relatively wet with Gila County more than 5 inches above the long-term average. November was relatively dry and December was extremely wet, with rainfall from 1 to 3 inches above the long-term average throughout the State.

Although recharge to the ground-water reservoirs comes indirectly from precipitation, most of the actual recharge to the aquifers of Arizona occurs from streamflow instead of directly from 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 rainfall (or streamflow) in 1959 will have little immediate effect on the water table in parts of the Salt River or lower Santa Cruz Valleys, or in other areas where the water table is very deep.

The plateau region in the northern part of the State is composed mostly of consolidated sedimentary rocks. The land is at a higher altitude than the basin and range country, the climate is cooler, evaporation is less, and the presence of accumulated snow on the permeable rocks probably allows more water to percolate downward.

The heaviest concentration of rainfall in 1959 was in the mountainous regions of Gila and Yavapai Counties and in the southeastern part of the State. Gila County had 23.09 inches of precipitation or 5.03 inches above the long-term average. Yavapai County had 16.23 inches of precipitation, 0.35 inches above the average. These areas are important sources of water to the Salt River Valley. The southeastern part of the county had 15.05 inches of rainfall, 1.66 inches above the average. In the intensely developed lower Santa Cruz and Salt River Valleys, the amount of precipitation in 1959 was about 1 inch above the long-term average. The driest part of the State was Yuma County with 5.25 inches of precipitation in 1959, 0.70 of an inch above the average.

Precipitation for 1959 and departures from long-term averages at various stations in Arizona are shown in table 1.

Surface-Water Runoff, Storage, and Diversions

Nearly 2,500,000 acre-feet of surface water was diverted for irrigation during the 1959 water year (October 1958 to September 1959). More than half this amount, or about 1,500,000 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, and (3) Gila Project. These projects use only surface water for irrigation. Of this total, nearly 450,000 acre-feet of water was returned to the Colorado River or discharged across the Arizona-Sonora International Boundary. The remaining 1,000,000 acre-feet of diverted surface water was used in combination with ground water for irrigation. During the 1959 water year more surface water was diverted for irrigation than in the previous four years (fig. 3).

According to the Surface Water Branch, U. S. Geological Survey, runoff during the 1959 water year varied from extremely low flows throughout the State to nearly normal runoff in the extreme southeast. This is indicated in the total yearly runoff past six key gaging stations compared with the long-term median runoff.

(1) Colorado River at Grand Canyon, 6,935,000 acre-feet
52 percent of median
(2) Little Colorado River near Cameron, 54,800 acre-feet
24 percent of median
(3) Gila River at head of Safford Valley near Solomon, 173,300 acre-feet
68 percent of median

Table 1.--Total precipitation in 1959 at selected stations and departures from long-term means (From Climatological Data, Arizona, Annual Summary 1959: U. S. Weather Bur.)

Station	Precipitation (inches)	Departure (inches)
Bowie	11.68	-
Buckeye	9.78	-
Casa Grande	8.09	+0.01
Chandler	10.30	-
Chino Valley	14.17	-
Davis Dam	6.27	-
Douglas Smelter	16.60	+4.98
Duncan	9.51	-
Eloy	10.13	-
Flagstaff	21.46	+2.99
Gila Bend	5.25	-.66
Globe	22.67	+7.27
Holbrook	9.79	+2.04
Kingman	11.54	-
Litchfield Park	12.18	+4.32
Mesa	9.75	+2.06
Nogales	17.35	-
Payson	26.29	-
Phoenix Airport	8.40	+1.24
Pinedale	24.16	+6.34
Prescott Airport	12.82	-3.16
Safford	7.63	-1.09
St. Johns	14.29	+2.92
Snowflake	13.09	+1.36
Tucson, University of Arizona	12.16	+1.73
Wellton	6.07	-
Wikieup	10.05	-.53
Willcox	11.98	-
Williams	19.46	-1.67
Yuma Airport	1.63	-1.76

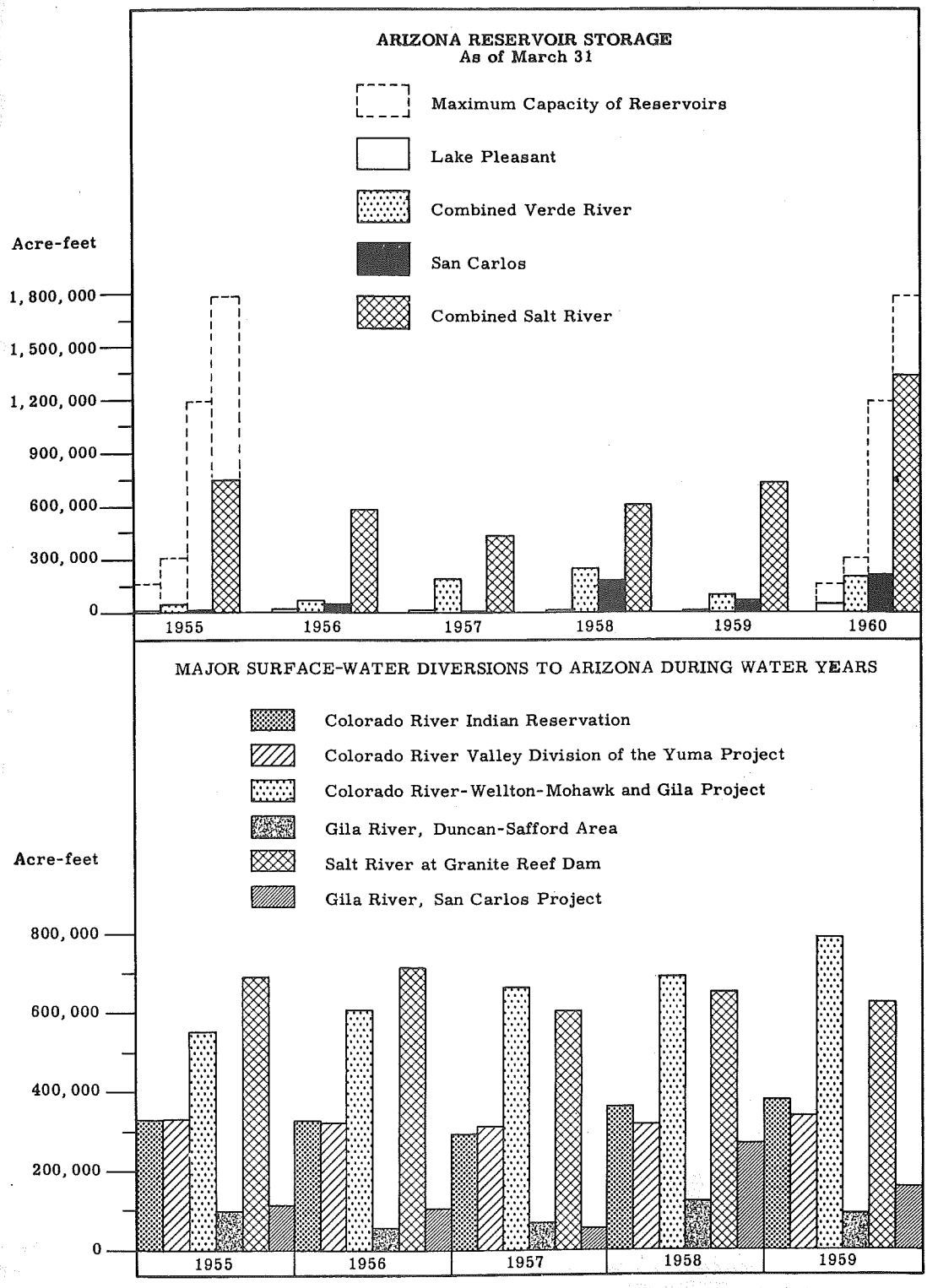


Figure 3.--Surface-water reservoir storage and diversions in Arizona.

(4) Salt River near Roosevelt, 240,400 acre-feet
49 percent median
(5) Verde River above Horseshoe Dam, 182,200 acre-feet
28 percent of median
(6) San Pedro River at Charleston, 44,230 acre-feet
102 percent of median

From October 1959 to April 1960, the runoff greatly increased and exceptionally high flows for the 6-month period were recorded on the Gila, Salt, Little Colorado, and Verde Rivers. These high flows considerably increased the amount of water in reservoir storage over the previous five years (fig. 3).

Well-Numbering System

The well numbers used by the Geological Survey in Arizona are in accordance with the Bureau of Land Management's system of land subdivision. The land survey in Arizona is based on the Gila and Salt River meridian and base line, which divide the State into four quadrants (fig. 4). These quadrants are designated counterclockwise by the capital letters A, B, C, and D. All land north and east of the point of origin is in A quadrant, that north and west in B quadrant, that south and west in C quadrant, and that south and east in D quadrant. The first digit of a well number indicates the township, the second the range, and the third the section in which the well is situated. The lowercase letters a, b, c, and d after the section number indicate the well location within the section. The first letter denotes a particular 160-acre tract (fig. 4), the second the 40-acre tract, and the third the 10-acre tract. These letters also are assigned in a counterclockwise direction, beginning in the northeast quarter. If the location is known within a 10-acre tract, three lowercase letters are shown in the well number. In the example shown, well number (D-4-5)19caa designates the well as being in the NE¼NE¼SW¼ sec. 19, T. 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 R. S. Stulik, D. G. Metzger, W. Kam, F. R. Twenter, and A. C. Hill. Personnel of the Tucson office who worked on the report are M. B. Booher, S. G. Brown, R. E. Cattany, C. S. English, E. K. Morse, N. D. White, C. L. Jenkins, M. F. Howard, W. D. Potts, L. A. Heindl, and P. W. Johnson. Those of the Holbrook office who worked on the report are J. P. Akers and E. L. Gillespie.

The project and this report were coordinated by W. F. Hardt, who wrote the introduction, the regional ground-water hydrology, and the section

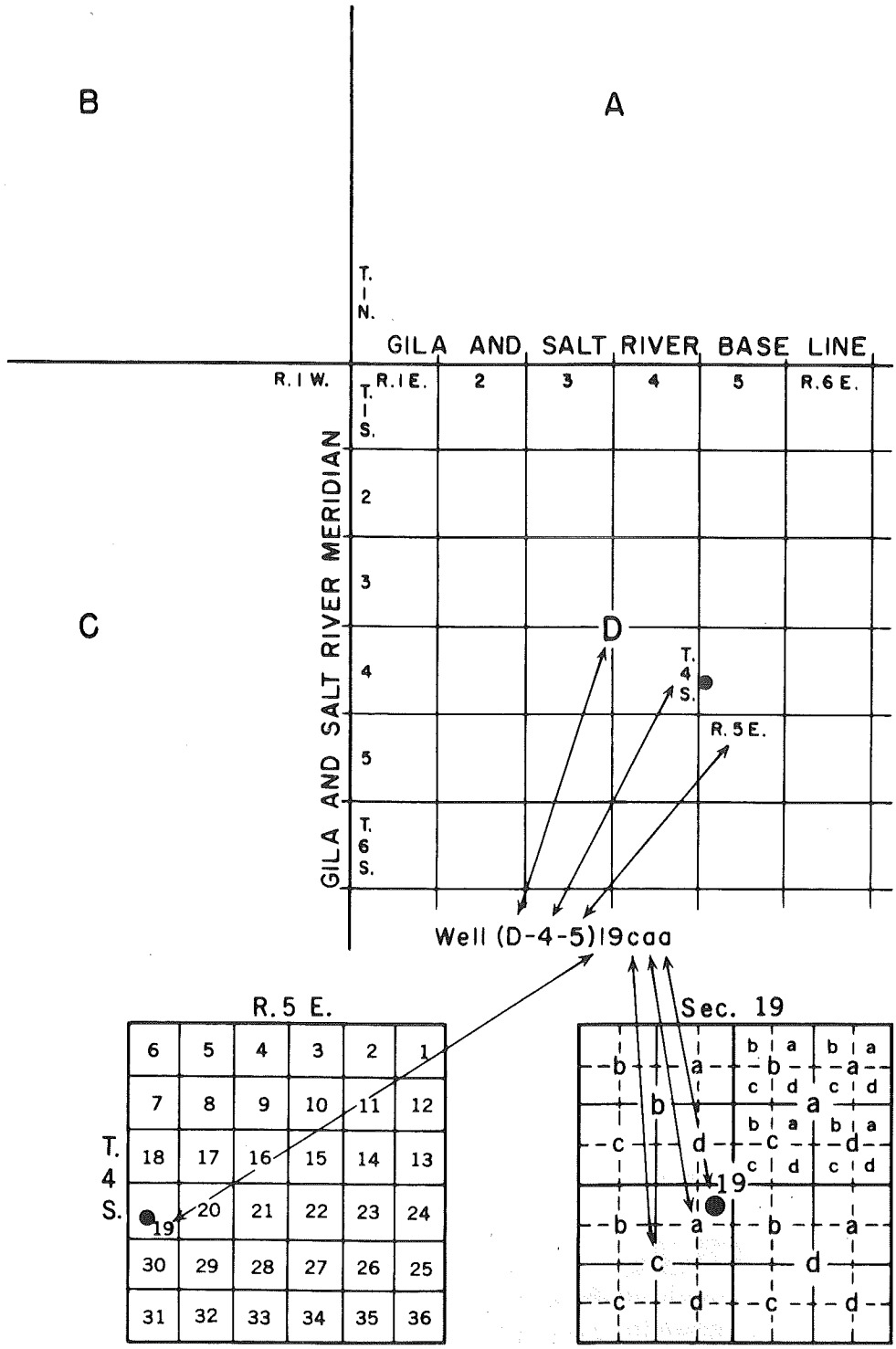


Figure 4.-- Sketch showing well-numbering system in Arizona.

on pumpage. The discussion of the ground-water conditions in the Salt River Valley and most of the northern counties was written by R. S. Stulik. Discussion of conditions in the southern part of the State was written by M. B. Booher; J. P. Akers discussed Apache and Navajo Counties. The surface-water section was written by personnel of the Surface Water Branch and 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 P. E. Dennis, district geologist.

Acknowledgments

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

GROUND-WATER CONDITIONS

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. The sedimentary deposits of the Plateau uplands store large amounts of water, but usually yield only small to moderate amounts to wells. There are exceptions where geologic conditions in local areas are favorable for high-yielding wells. The regional movement of the ground water in the northern part of the State is generally toward the Colorado River and unknown quantities of water are discharged into the river. There is little irrigation and little pumping of ground water for other purposes in the Plateau uplands. As a result, the long-term hydrographs do not show any appreciable sustained declines. However, present and future developments, such as land speculation in several parts of the area, irrigation in some of the valleys in Mohave County, increased irrigation in the Snowflake area of Navajo County, urbanization of the Flagstaff area, rural expansion in the Cottonwood-Sedona area, construction of the Glen Canyon Dam at Page, and proposed pulp mills at Snowflake and in the Red Lake area of the Navajo Indian Reservation near Window Rock, may cause future water problems.

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. Reservoir storage of water behind the dams in the spring of 1960 was the highest since 1941 when the reservoirs overflowed. There is little or no ground-water underflow in parts of the tributary valleys because the streams flow over bedrock for many miles. When the water reaches the alluvial deposits of the Salt River Valley some recharge to the ground-water reservoir occurs. To compensate for the heavy withdrawals of ground water in the Salt River Valley, it may be feasible to use surplus streamflow to recharge the area artificially, and store the water beneath the ground rather than allow it to remain on the surface where much of it is lost to the atmosphere.

The Basin and Range lowlands contain alluvial basins where at least 80 percent of the population and more than 90 percent of the irrigated acreage are concentrated. In general, the basins have similar geohydrologic characteristics, although in detail each basin is different. An understanding of the pumpage, the level of the water table, storage capacity, recharge, permeability of the subsurface sediments, and methods of proper development and management is basic to the general solution of the water problems in these areas. Quantitative solutions to the ground-water problems require more detailed studies.

The Basin and Range lowlands receive an average of about 10 inches of precipitation each year with possibly 0.1 of an inch eventually reaching the water table. Most of the natural recharge to the ground-water reservoir occurs from streamflow instead of directly from rainfall. Nearly all the precipitation is eventually returned to the atmosphere by evapotranspiration. Annually, for the last several years ground-water pumpage in the Basin and Range lowlands has been nearly 4,500,000 acre-feet, and possibly about 250,000 acre-feet of water enters the reservoirs as natural recharge derived within the area (fig. 5). The ground-water reservoirs in the alluvial basins may have as much as 700,000,000 acre-feet of water available for use in the first 1,000 feet of saturated material. At the present annual pumping rate, this stored water would last more than 100 years if it were possible to withdraw it all and it was suitable for use. Part of this stored water will never be available to wells, and part will not be used because of undesirable quality and high temperature. Increased pumping lifts, lower yields of wells, and transportation costs to places of use also will make it impossible to extract all the water. Geologic studies indicate that although some of the basins have much less than 1,000 feet of saturated thickness, other basins have 3,000 to 5,000 feet or more. It must be emphasized that the first 1,000 feet of saturated sediments is not uniform and where beds of low permeability predominate, the water levels will decline at an accelerated rate. Thus, a saturated thickness of 1,000 feet could be dewatered in much less time than 100 years in some areas. A reduction in pumpage because of economic agricultural conditions, the capturing of additional

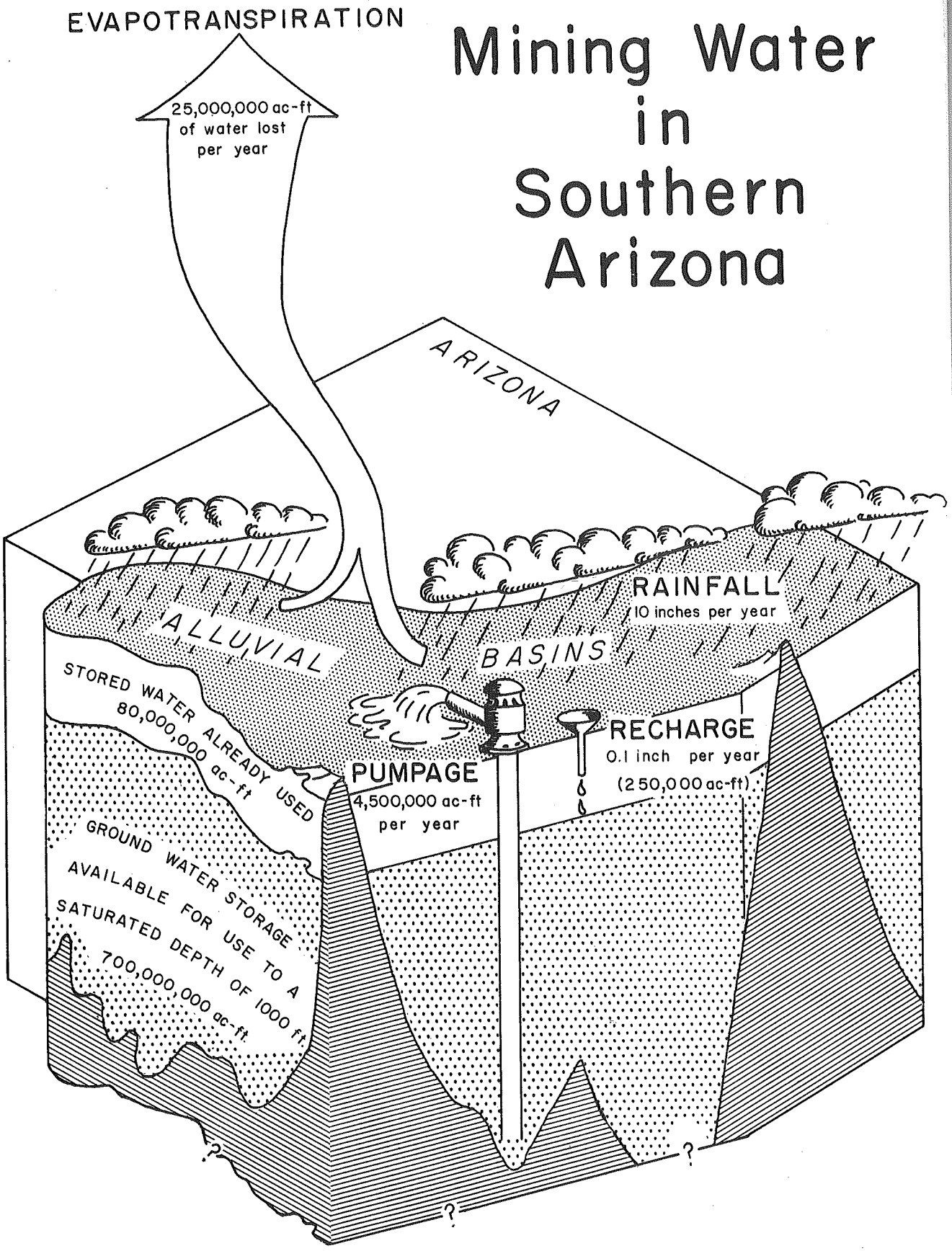


Figure 5.--Mining water in southern Arizona.

water from the Colorado River, the use of desalinized water, or reduction of evaporation losses by artificial recharge of storm runoff to underground storage would prolong the future life of these basins. Some hydrologists believe that as much as 25 percent of irrigation water applied to the land in some areas may return to the aquifer. This recirculation of ground water would also prolong the life of the basins, although eventually the quality of the water might deteriorate.

The most important drainage system in the Basin and Range lowlands is the Gila River and its tributary, the Salt River. These rivers flow west and southwest to the Colorado River. Much of the ground-water movement in the southern part of the State is north and northwest toward these rivers.

The Salt River Valley and the lower Santa Cruz basin account for about 75 percent of the ground-water pumpage; the water levels generally have continued to decline and it is obvious that the amount of water being pumped is much greater than the natural recharge.

The Phoenix area is in a fortuitous location in the State for obtaining water. It is at the confluence of the Verde and Salt Rivers, surface-water supplies are readily available, and additional water is pumped from the large ground-water reserves. The Yuma area also has a favorable water supply because of its proximity to the Colorado River. In the lower Santa Cruz basin area, which includes the towns of Eloy, Florence, Coolidge, Casa Grande, and Maricopa, the large amount of water pumped for irrigation has depressed the water table. The same amount of water generally would be more than adequate for a tremendous increase in population and industrial development. Other basins are in various stages of development and water-level measurements are essential to document the effects.

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 has resulted in as much as 80 feet of decline in the water table during the last five years in the Kansas Settlement area and as much as 20 feet in the Stewart area. The beneficial use of ground water in this basin prevents much of the water from moving into the Willcox playa. This is one area in the State where the pumping of ground water is near the point of natural discharge. During 1959, ground-water conditions in the Douglas area were about the same as the previous year.

The accelerated demand for water in the State indicates the need for intensive evaluation of the water resources. As the economic growth of Arizona increases, water interests of diversified, and often conflicting groups, will require quantitative geohydrologic answers as a basis for equitable distribution.

Water-Level Fluctuations

The general trend of water levels in Arizona in 1959 continued downward in the developed basins. The declines were caused directly by pumping. Maximum declines again occurred in Maricopa and Pinal Counties, although water levels rose in localized areas probably because of a shift in pumpage. 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. In the spring of 1960 the water levels in wells adjacent to flowing streams were higher than in previous years in the Safford Valley, upper San Pedro River valley, Duncan Valley, and parts of Pima County. 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. These areas will have serious water-logging problems if measures are not taken to remove the excess water.

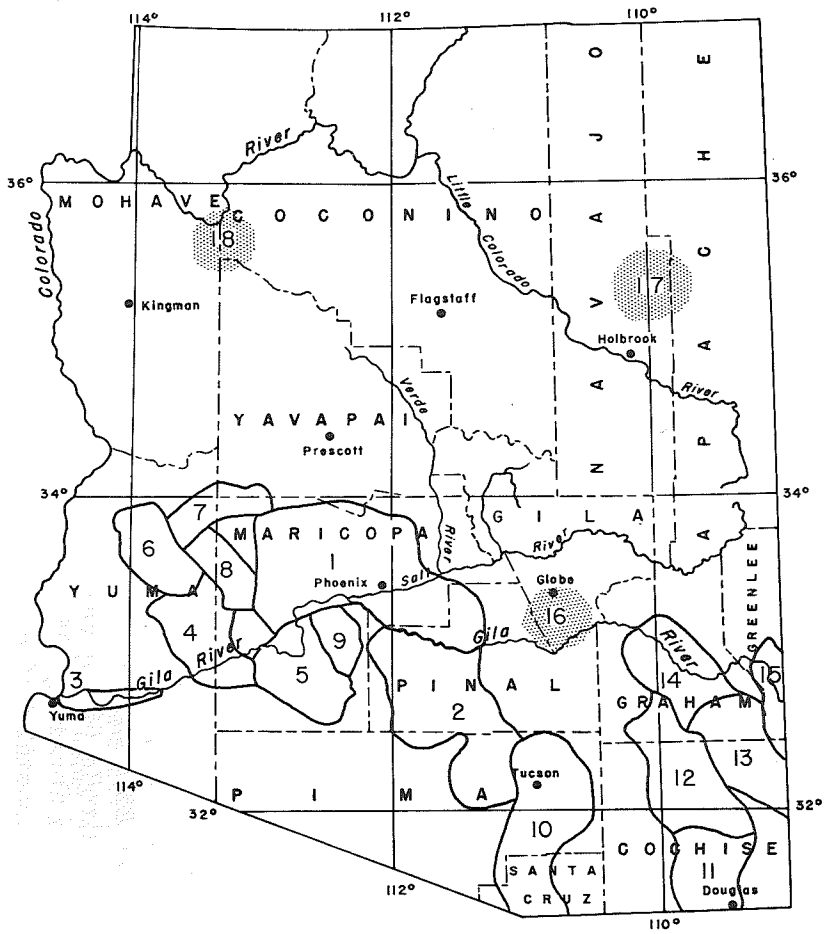
Records in the recently developed areas, such as McMullen Valley and Harquahala Plains are not long enough to establish water-level trends; but increased development and pumping will result in a declining water table. Hydrographs of selected wells in the northern half of the State show minor fluctuations.

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 January, February, and March of each year. At this time more uniform conditions prevail, and the water levels are approaching static conditions because pumping is at a minimum.

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 6 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



1. Salt River Valley
2. Lower Santa Cruz basin
3. South Gila Valley, Yuma Mesa, and Wellton-Mohawk areas
4. Palomas Plain area
5. Gila Bend-Dendora 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

Figure 6.-- Map showing ground-water areas and basins in Arizona where water levels are measured.

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 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 to more than 40 feet below the land surface, and the maximum pumping level is about 100 feet below the land surface. In other parts of the county, south of the Navajo Indian Reservation, the water levels in some of the stock wells are as much as 300 feet below the land surface. Measurements made at irregular intervals during the last 10 years indicate little overall change in the water levels, although locally, there have been both rises and declines. Discharge of flowing wells has increased considerably during the past winter in the Hunt area and water levels in some wells near Hunt have risen 3 feet.

Cochise County

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

Willcox basin

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

There are two main cultivated areas in the Willcox basin (fig. 7), the Stewart area and the Kansas Settlement area. The Stewart area, northwest of Willcox, is generally restricted to Tps. 12 and 13 S., Rs. 23 and 24 E. The irrigated area includes somewhat less than 20,000 acres. The Kansas Settlement area is about 8 miles south of Willcox and includes the eastern half of Tps. 15 and 16 S., R. 25 E., and all of T. 16 S., R. 26 E. This area includes more than 35,000 acres under

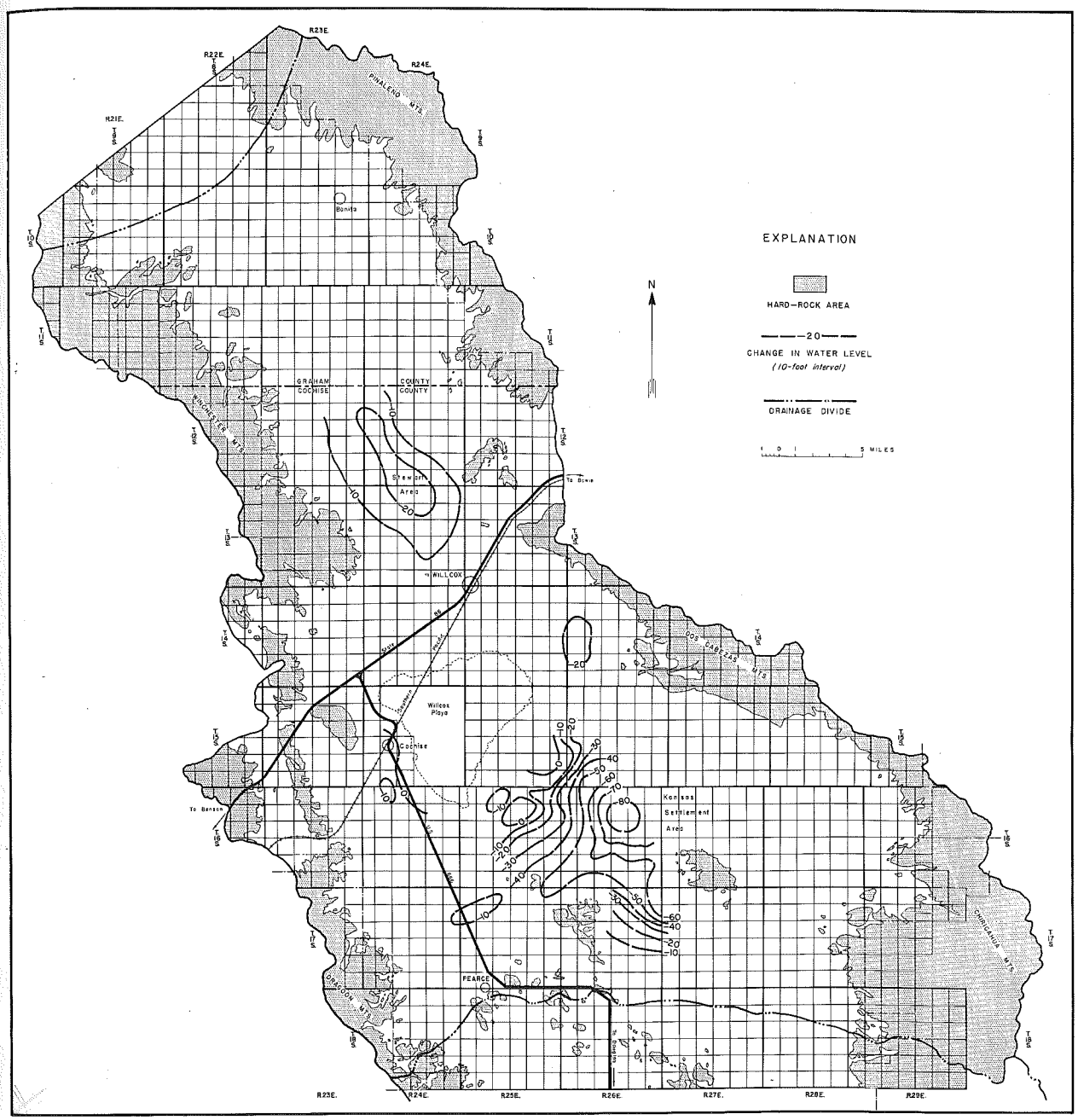


Figure 7.--Map of Willcox basin, Cochise and Graham Counties, Arizona, showing change in ground-water level from spring 1955 to spring 1960

irrigation and the irrigated acreage is expanding rapidly. There is about 5,000 acres under irrigation between Cochise and Pearce.

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

In the Stewart area, water-level fluctuations for the period spring 1959 to spring 1960, based on 40 water-level measurements, ranged from a rise of about 5 feet to a decline of about 9 feet. In the 5-year period spring 1955 to spring 1960 (fig. 7) water levels declined from about 10 feet along the fringe areas to more than 20 feet in the center of the heavily pumped areas. The water level in well (D-13-24)16 (fig. 8), in the heavily pumped area, declined about 6 feet from spring 1959 to spring 1960, about 29 feet from spring 1955 to spring 1960, and about 50 feet from spring 1950 to spring 1960. The water table is progressively deeper northwest of the Stewart area in the vicinity of Bonita. In the spring of 1960 the depth to water ranged from about 20 feet near the town of Willcox to about 130 feet on the northern edge of the irrigated area near the Graham County line and about 145 feet 6 miles southwest of Bonita.

From spring 1959 to spring 1960 fluctuations in water levels in 60 wells measured in the Kansas Settlement area ranged from a rise of about 10 feet near the playa to a decline of about 20 feet in the heavily pumped areas. In the 5-year period spring 1955 to spring 1960 water-level fluctuations ranged from a decline of about 80 feet in the recently developed areas to no change in the area along the south side of the playa (fig. 7). The water level in well (D-14-26)20 (fig. 8) northeast of the playa declined 6 feet from spring 1959 to spring 1960, about 20 feet from spring 1955 to spring 1960, and about 26 feet from spring 1950 to spring 1960. The water level in well (D-16-26)7 (fig. 8) declined 8 feet from spring 1959 to spring 1960, about 47 feet from spring 1955 to spring 1960, and about 58 feet from the summer of 1953 to the spring of 1960. This well is about 3 miles west of the area of maximum declines. Most of the agricultural development in the Kansas Settlement area has taken place since 1953. The depth to water below land surface in the Kansas Settlement area in the spring of 1960 ranged from 30 feet near the playa to about 240 feet in the eastern half of T. 16 S., R. 26 E.

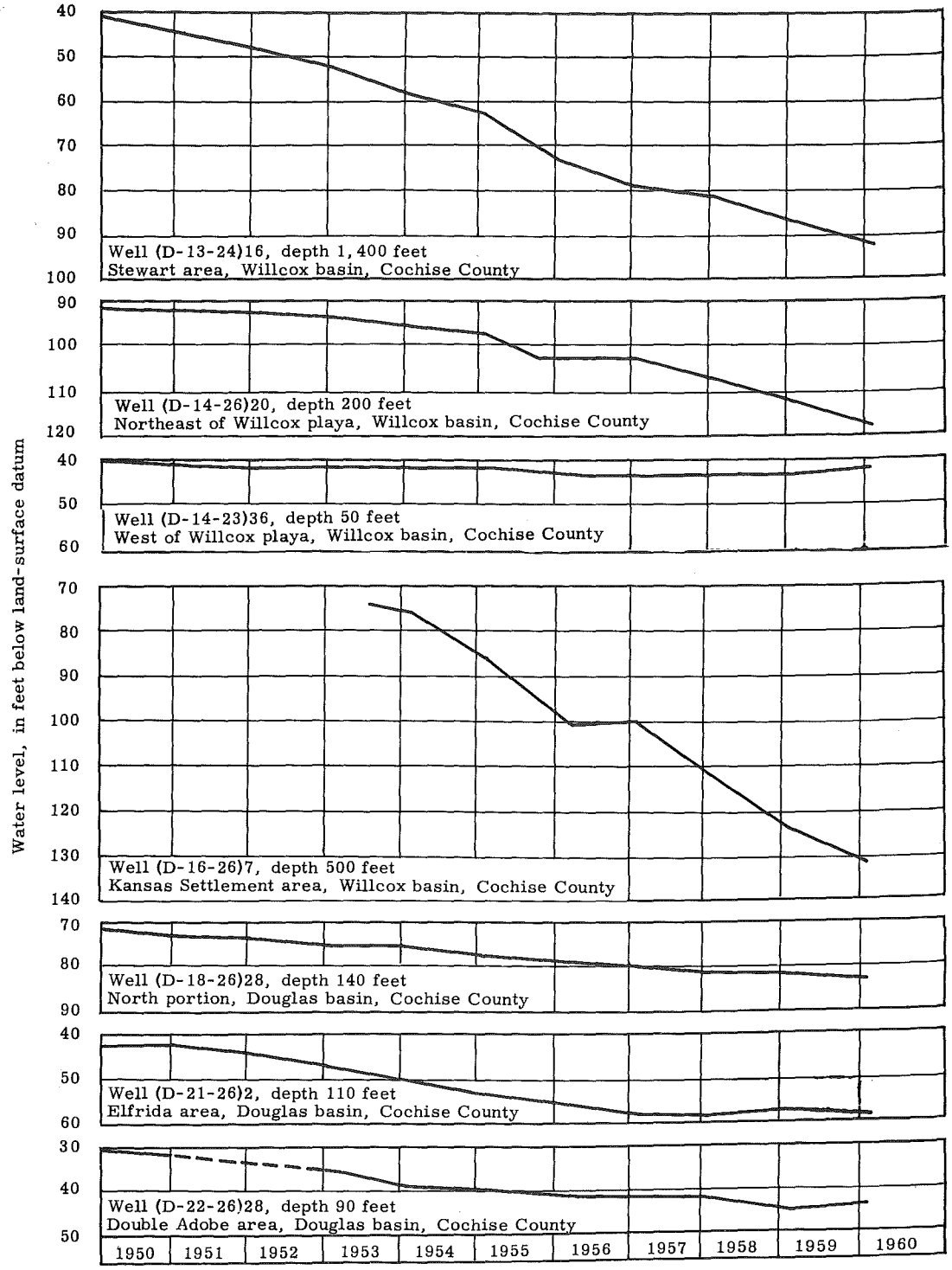


Figure 8.--Water levels in selected wells in the Willcox and Douglas basins, Cochise County.

The water level in well (D-14-23)36 (fig. 8), outside the cultivated area on the west side of the Willcox playa, has fluctuated slightly during the 18 years of record.

Douglas basin

The Douglas basin is south of the Willcox basin in the southern part of the Sulphur Spring Valley. It is separated from the Willcox basin by a common 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.

In the Douglas basin water-level fluctuations for the period spring 1959 to spring 1960 ranged from a rise of about 4 feet to a decline of nearly 9 feet, and for the 5-year period spring 1955 to spring 1960 (fig. 9) from a rise of 5 feet to a decline of 15 feet. Ground-water conditions have improved in the Douglas basin in the last few years; maps showing the change in water level for prior 5-year periods indicate substantially greater declines than for the period 1955-60. During the last 5 years (1955-60) there has been essentially no decline in the area from Douglas to about 7 miles south of McNeal; maximum declines occurred in the area about 4 miles south of McNeal. The 5-foot rise in the water table 4 miles west of McNeal is attributed to recharge from streams with headwaters in the Dragoon and Mule Mountains.

The water level in well (D-18-26)28 (fig. 8), in the northern part of the basin, declined about 1 foot from spring 1959 to spring 1960, about 6 feet from spring 1955 to spring 1960, and about 11 feet from spring 1950 to spring 1960. The water level in well (D-21-26)2 (fig. 8), near the heavily pumped Elfrida-McNeal area, declined about 2 feet from spring 1959 to spring 1960. For the 5-year period spring 1955 to spring 1960 the water level in this well declined about 6 feet, and about 17 feet from spring 1950 to spring 1960.

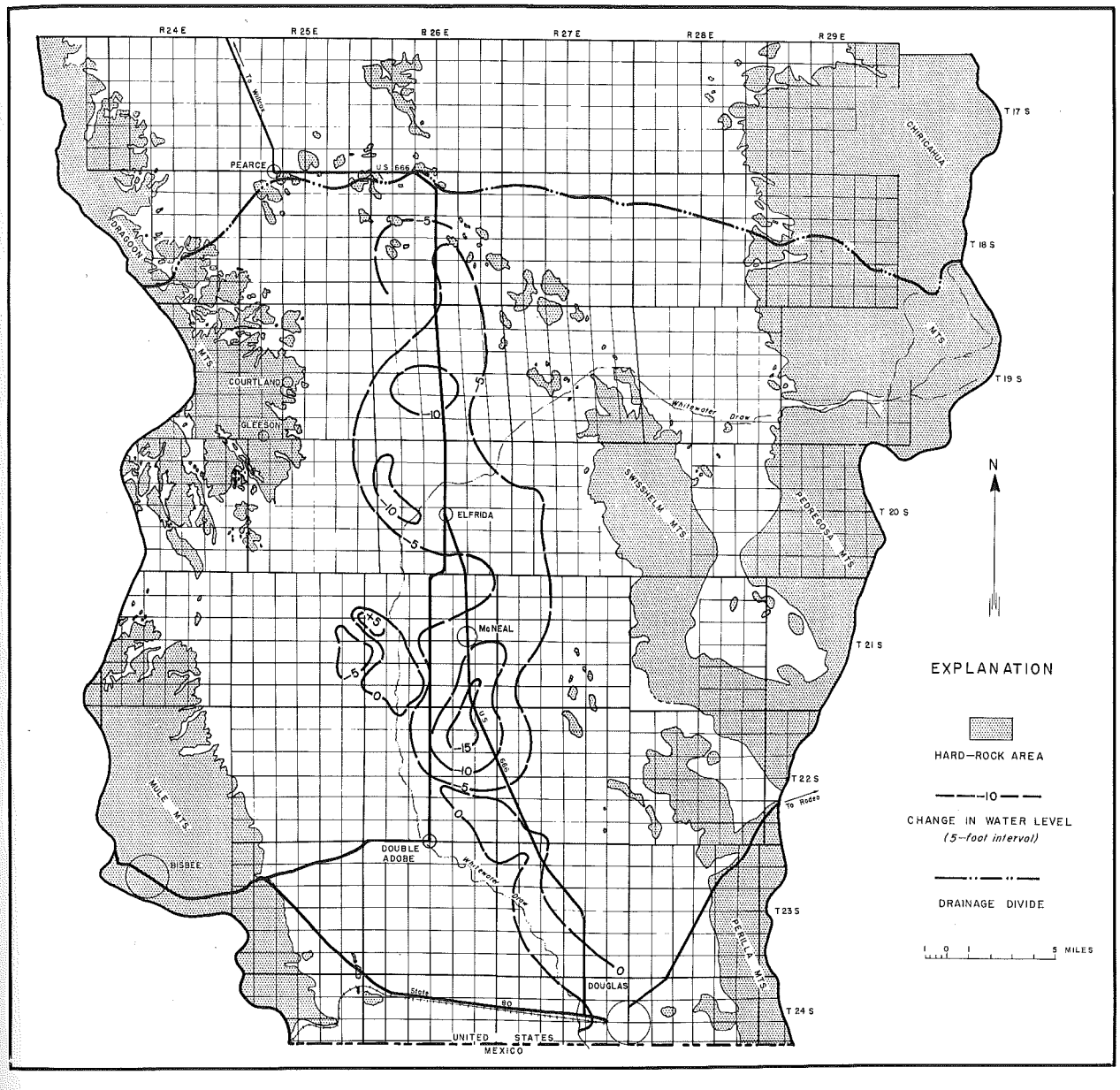


Figure 9:--Map of Douglas basin, Cochise County, Arizona, showing change in ground-water level from spring 1955 to spring 1960

The water level in well (D-22-26)28 (fig. 8), in the Double Adobe-Douglas area, rose about 1 foot from spring 1959 to spring 1960, declined about 4 feet for the 5-year period spring 1955 to spring 1960, and declined about 13 feet from spring 1950 to spring 1960. The depth to water in the Douglas basin in spring 1960 ranged from 40 to 130 feet, but in most wells the water levels were less than 100 feet below land surface.

Bowie-San Simon area

The Bowie area is on the western slope of the San Simon Valley in the vicinity of the town of Bowie, and the San Simon area is near the town of San Simon on the eastern side of the valley. The San Simon basin is a 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, New Mexico to the Safford Valley and the Gila River. There are about 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.

In the San Simon basin, ground water occurs under artesian conditions in permeable lenses of sand and gravel below an extensive blue clay that forms the confining layer and under water-table conditions in an upper permeable zone of sand and gravel. On the fringes of the basin the blue clay pinches out and the upper and lower aquifers are continuous.

Forty water-level measurements were made in this basin during the spring of 1960. In the Bowie area the water levels in the artesian wells ranged from slightly less than 100 feet to more than 150 feet below land surface in the spring of 1960. Water-level fluctuations in these wells ranged from a rise of about 10 feet to a decline of about 8 feet for the period spring 1959 to spring 1960, and for the 5-year period spring 1955 to spring 1960 declines in water level ranged from less than 35 to about 60 feet. The water level in well (D-13-29)18 (fig. 10) declined about 4 feet during the last year, about 50 feet since spring 1955, and about 90 feet during the 10-year period spring 1950 to spring 1960. The major part of the decline of the water levels in the artesian aquifer started in 1952 when irrigation pumpage was greatly increased.

In the area a few miles south of Bowie, several wells are in the zone where the upper and lower aquifers are continuous. The depth to water in these wells ranged from about 260 to 340 feet in spring 1960. There are no shallow water-table wells in the Bowie area.

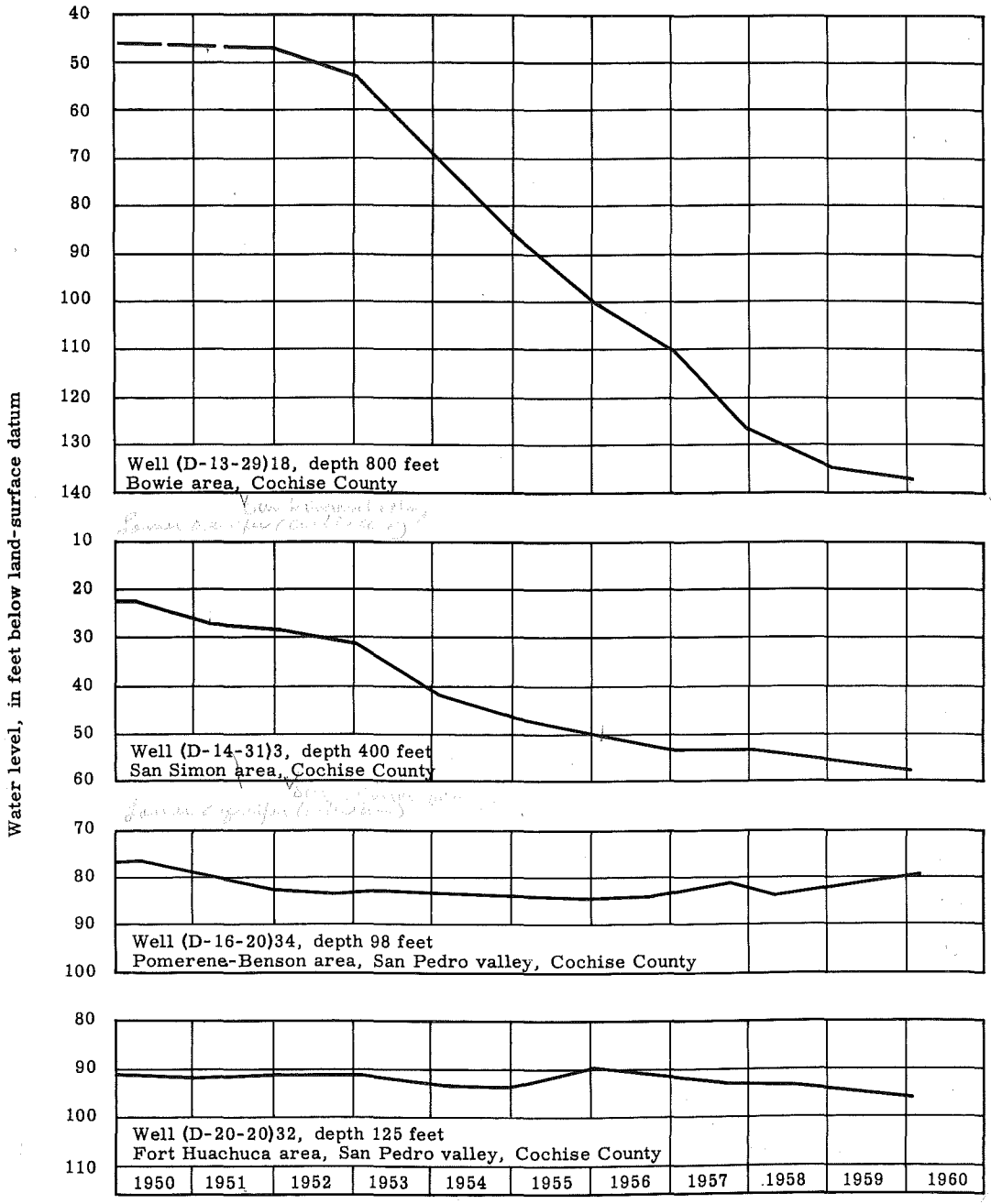


Figure 10.--Water levels in selected wells in the Bowie-San Simon area and upper San Pedro basin, Cochise County.

The water level in the artesian wells in the San Simon area ranged from about 20 to more than 100 feet below land surface in spring 1960. Water-level fluctuations in these wells ranged from a rise of about 5 feet to a decline of 7 feet for the period spring 1959 to spring 1960. For the 5-year period spring 1955 to spring 1960 water-level fluctuations ranged from a rise of about 4 feet to a decline of more than 20 feet. The water level in artesian well (D-14-31)3 (fig. 10) declined about 3 feet from spring 1959 to spring 1960. For the 5-year period spring 1955 to spring 1960 the water level in this well declined about 12 feet and more than 35 feet since spring 1950.

Only three of the shallow water-table wells in the San Simon area were measured in the spring of 1960. In these wells the depth to water was from 60 to 70 feet below land surface, and the water-level fluctuations ranged from a rise of about 8 feet to a decline of 4 feet for the period spring 1959 to spring 1960. Declines ranged from 2 to 5 feet in these wells for the 5-year period spring 1955 to spring 1960.

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 1959 to spring 1960. For the 5-year period spring 1955 to spring 1960 rises in water levels ranged from 1 foot to about 6 feet and declines ranged from 1 to 5 feet. The upper San Pedro valley is undeveloped and pumpage is at a minimum. The water level in well (D-16-20)34 (fig. 10) near Pomerene rose about 3 feet from spring 1959 to spring 1960 and declined about 3 feet since the spring of 1950. The water level in well (D-20-20)32 (fig. 10), about 6 miles north of Sierra Vista, declined about 2 feet from spring 1959 to spring 1960, and about 4 feet since the spring of 1950. The depth to water in the spring of 1960 ranged from 10 to more than 300 feet below land surface. The depths to water in the wells adjacent to the San Pedro River are less than 100 feet and many are less than 25 feet.

Coconino County

In parts of Coconino County wells less than 100 feet deep yield limited supplies of water. Water levels in these wells are readily affected by precipitation and in some localities the shallow wells are not dependable during periods of drought. In the central part of the county, particularly near Flagstaff, wells more than 1,000 feet deep may yield small to moderate amounts of water. Short distances away other wells may yield little or no water. The success of these wells depends on the local geology and structure. North of Williams and Flagstaff the Colorado River and Grand Canyon intercept the water table and possibilities of ground-water development are generally poor, with little or no yield of water to wells. However, in some parts of this region the structure may be favorable for successful wells. East of the Little Colorado River in the Tuba City area wells from 200 to 700 feet deep yield small to moderate amounts of water. The water levels in shallow wells in the vicinity of Williams and Flagstaff fluctuated slightly during the year. The hydrograph of well (A-21-6)35 (fig. 11) illustrates minor fluctuations in a deep water-table well in the Woody Mountain well field owned by the city of Flagstaff.

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 level in these wells from 1956 to 1960. The wells yield from 200 to 500 gpm and are an important 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 valley east of Globe consist of alluvial deposits. The movement of ground water is in the same direction as the surface flow—toward San Carlos Lake.

In Gila County, ground-water levels are measured in and near the city of Globe 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 Creek 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. Fifteen wells were measured in the spring of 1960 and water levels generally were higher than in previous years. Water levels rise rapidly in response to recharge of the shallow aquifers by streamflow; periods of drought are reflected in declining water levels.

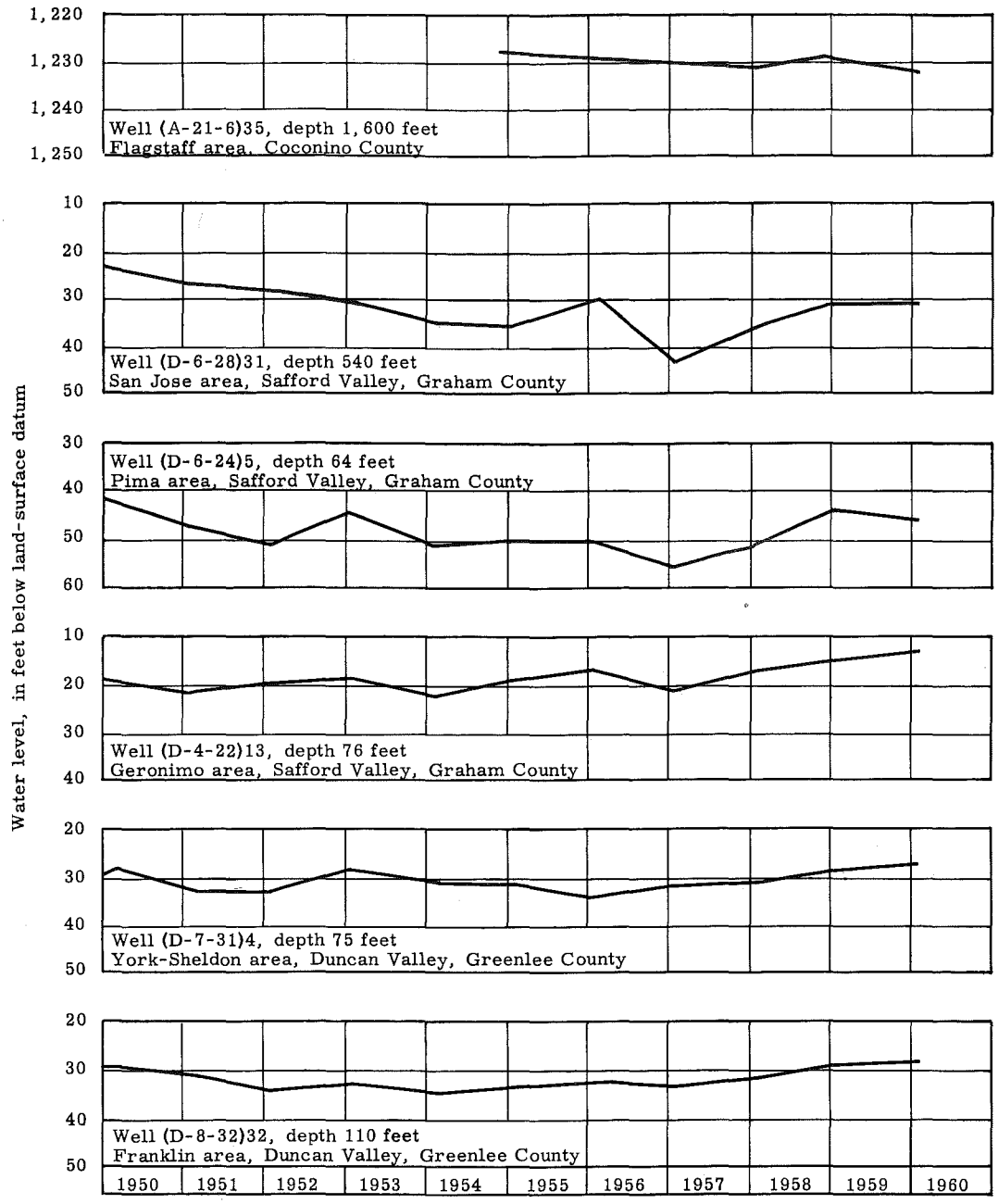


Figure 11.--Water levels in selected wells, Coconino, Graham, and Greenlee Counties.

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 in water level 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 ½ to 3-½ miles from the river.

The Safford Valley is an extension of the San Simon Valley and the ground water moves northwestward along the valley toward Coolidge Dam. Most of the recharge to the inner Safford Valley probably comes from the Gila River. Although the diversion canals take all or most of the low flow, leakage from these canals and also from applied irrigation water recharges the alluvium. During periods of high runoff, the canals divert only a small part of the surface flow and the surplus water in the river recharges the porous inner-valley fill. At the end of the valley, the ground water discharges as underflow into San Carlos Lake.

Some wells drilled recently to depths of 1,000 feet or more into the older alluvium on the sides of the valley have tapped artesian aquifers. Some hydraulic interconnection probably exists between these deeper artesian aquifers and the water table in the inner valley. The upward movement of artesian water depends on the permeability of the sediments beneath the younger inner-valley alluvium and the location of deep-seated faults that may serve as water passageways. The presence of water under artesian pressure in the basin is evidenced by the 550 gpm flow of a 2,000-foot deep well in Thatcher, surrounded by shallow wells with water levels 10 to 20 feet below the land surface. Northeast of Solomon the Gila River enters the alluvial-filled valley, and may recharge both the shallow-valley aquifer and the deeper aquifers of the Safford basin. At some periods of the year artesian water may rise to recharge the shallow river-bed alluvium, if there is hydraulic interconnection between the deeper artesian aquifers and the shallow aquifers.

From spring 1959 to early January 1960 the water levels in the Safford Valley rose about 2 feet. After excessive runoff in the Gila River, particularly in January, water levels rose as much as 10 feet in the area from the head of the valley to Thatcher, and about 3 feet in the area

from Thatcher to Geronimo. These rises are attributed to recharge from streamflow of the Gila River. Discharge of the Gila River at the entrance of Safford Valley from March 1959 to March 1960 was about 390,000 acre-feet. This is about 160,000 acre-feet greater than the average flow for the 10-year period 1949 to 1958. From November 1959 to March 1960 there was excessive streamflow, particularly in December and January; flows for these two months were 194 and 680 percent of normal, respectively. No record minimum or maximum flows occurred during the year.

The water level in well (D-6-28)31 (fig. 11) at the head of the valley, rose from 1 foot from spring 1959 to spring 1960, and declined about 8 feet from spring 1950 to spring 1960. The water level in well (D-6-24) 5 (fig. 11) in the cultivated area below Pima declined about 2 feet from spring 1959 to spring 1960, and about 4 feet from spring 1950 to spring 1960. The water level in well (D-4-22)13 (fig. 11) in the downstream part of the Safford Valley rose about 2 feet from spring 1959 to spring 1960, and about 6 feet from spring 1950 to spring 1960. In the spring of 1960 about 175 wells were measured in the Safford Valley and the depths to water ranged from about 15 to 60 feet below the land surface and were comparable to the water levels in the spring of 1952.

Greenlee County

Most of the Greenlee County consists of mountains and forests, and the developed area is in 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 northwestward 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-level rises from spring 1959 to spring 1960 ranged from about 1 foot to more than 3 feet. For the 5-year period spring 1955 to spring 1960 the water table rose from about 2 to more than 4 feet. In the spring of 1960 the water level in well (D-7-31)4 (fig. 11) in the York-Sheldon area near the Gila River was about 1 foot higher than in the spring of 1959, about 3 feet higher than in the spring of 1955, and about the same as in the spring of 1950. The water level in well (D-8-32)32 (fig. 11) in the Franklin area rose about 1 foot from spring 1959 to spring 1960, about 6 feet from spring 1955 to spring 1960, and about 1 foot from spring 1950 to spring 1960. The depth to water in the Duncan basin ranges from 10 to nearly 70 feet below the land surface, based on about 110 measurements.

Maricopa County

In 1959 about 519,160 acres was under irrigation in Maricopa County (Seltzer, 1960), 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)

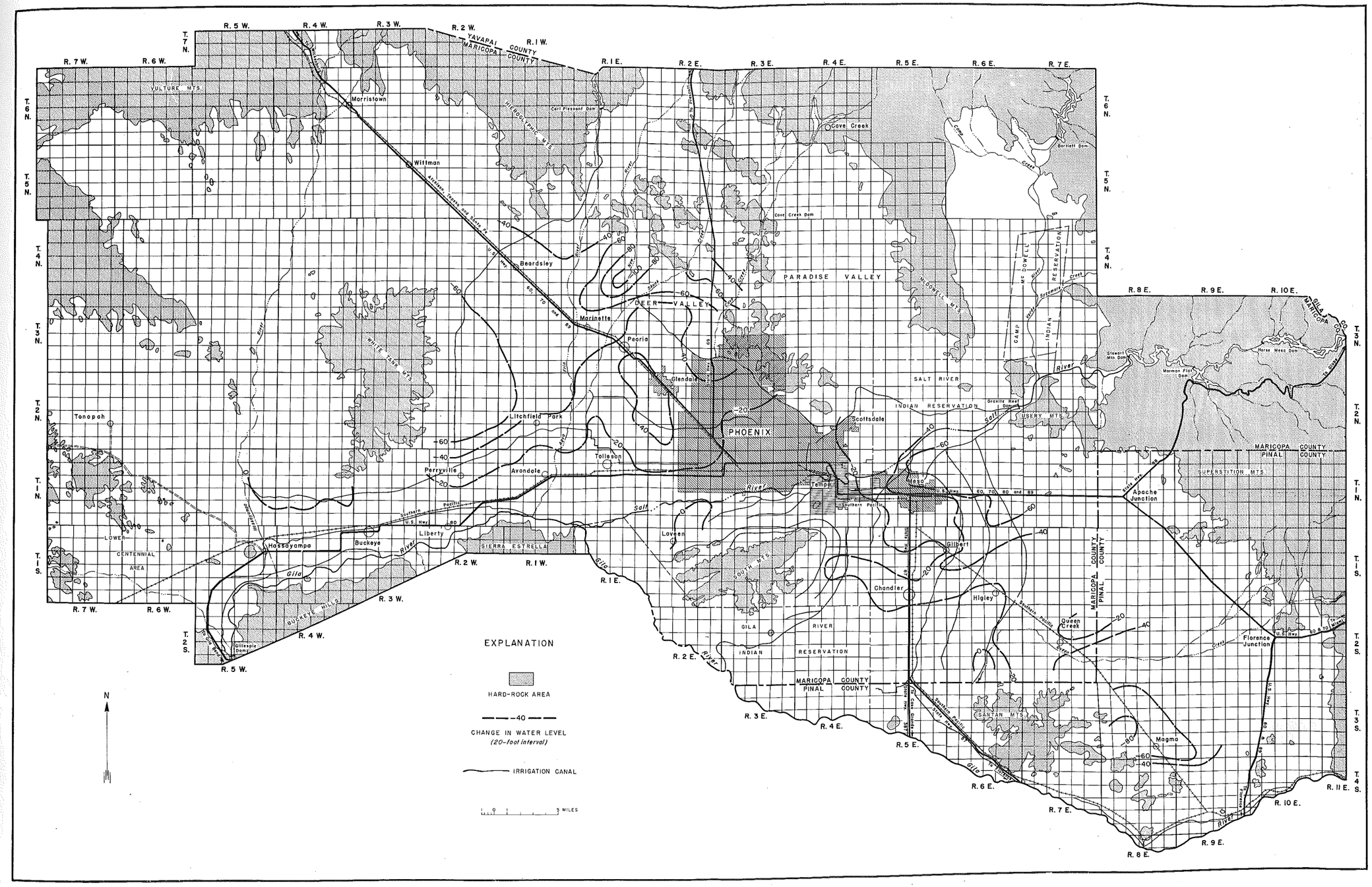


Figure 12.-- Map of Salt River Valley area, Maricopa and Pinal Counties, Arizona, showing change in ground-water level from spring 1955 to spring 1960

Waterman Wash area, (4) Harquahala Plains area, and (5) Dendora area. The Salt River Valley is by far the largest in agricultural development.

Salt River Valley

The Salt River Valley comprises the valley lands in the vicinity of Phoenix and tributary valleys such as Paradise Valley and Deer Valley, as well as lands west of the Hassayampa River and the lower reaches of Centennial Wash. Most of the area is drained by the Salt, Agua Fria, and Hassayampa Rivers, but a small part on the east and south is drained by the Gila River. The area is bounded on the north by the Hieroglyphic Mountains and Black Mountain; on the northeast and east by the McDowell, Usery, and Superstition Mountains; on the south by the Gila River to the Santan Mountains; then by the Maricopa-Pinal County line to the Sierra Estrella Mountains; and on the southwest and west by the Buckeye Hills, Gila Bend Mountains, Saddle Mountain, and an arbitrary line from the Big Horn Mountains to the Hassayampa River.

The Salt River Valley is subdivided into the following areas: (1) Queen Creek-Higley-Gilbert-Magma area, (2) Tempe-Mesa-Chandler area, (3) Phoenix-Glendale-Tolleson-Deer Valley area, (4) Paradise Valley area, (5) Litchfield-Beardsley-Marinette area, (6) Liberty-Buckeye-Hassayampa area, (7) lower Hassayampa-Tonopah area, and (8) lower Centennial area. Although the Magma subarea lies in Pinal County, it is included in the discussion of Maricopa County because it is a part of the Salt River Valley.

In the Salt River Valley the direction of ground-water movement conforms in general to the direction of slope of the land surface. In some places the natural direction of movement has been reversed and ground water is now moving toward major cones of depression that have resulted from heavy withdrawals. As of the spring of 1960 there were three such depressions in the area--northeast of Gilbert, in Deer Valley, and northwest of Litchfield Park. Most of the ground water in the eastern part of the Salt River Valley flows toward the depression northeast of Gilbert. In the central part of the valley most of the ground water flows to the west but some of it flows toward the depression in Deer Valley. In the northwestern section of the valley, the ground water generally flows southward toward the depression northwest of Litchfield Park but some water flows toward the depression in Deer Valley. In the Liberty-Buckeye-Hassayampa area the water generally flows to the southwest, but some water flows north toward the depression near Litchfield Park. In the area west of the Hassayampa River the ground water flows southward toward Gillespie Dam.

Queen Creek-Higley-Gilbert-Magma area.--During 1959 most of the water levels in wells in the Queen Creek-Higley-Gilbert-Magma area continued to follow the previously observed downward trend of the water table. In the period spring 1959 to spring 1960 water-level fluctuations

Waterman Wash area, (4) Harquahala Plains area, and (5) Dendora area. The Salt River Valley is by far the largest in agricultural development.

Salt River Valley

The Salt River Valley comprises the valley lands in the vicinity of Phoenix and tributary valleys such as Paradise Valley and Deer Valley, as well as lands west of the Hassayampa River and the lower reaches of Centennial Wash. Most of the area is drained by the Salt, Agua Fria, and Hassayampa Rivers, but a small part on the east and south is drained by the Gila River. The area is bounded on the north by the Hieroglyphic Mountains and Black Mountain; on the northeast and east by the McDowell, Usery, and Superstition Mountains; on the south by the Gila River to the Santan Mountains; then by the Maricopa-Pinal County line to the Sierra Estrella Mountains; and on the southwest and west by the Buckeye Hills, Gila Bend Mountains, Saddle Mountain, and an arbitrary line from the Big Horn Mountains to the Hassayampa River.

The Salt River Valley is subdivided into the following areas: (1) Queen Creek-Higley-Gilbert-Magma area, (2) Tempe-Mesa-Chandler area, (3) Phoenix-Glendale-Tolleson-Deer Valley area, (4) Paradise Valley area, (5) Litchfield-Beardsley-Marinette area, (6) Liberty-Buckeye-Hassayampa area, (7) lower Hassayampa-Tonopah area, and (8) lower Centennial area. Although the Magma subarea lies in Pinal County, it is included in the discussion of Maricopa County because it is a part of the Salt River Valley.

In the Salt River Valley the direction of ground-water movement conforms in general to the direction of slope of the land surface. In some places the natural direction of movement has been reversed and ground water is now moving toward major cones of depression that have resulted from heavy withdrawals. As of the spring of 1960 there were three such depressions in the area--northeast of Gilbert, in Deer Valley, and northwest of Litchfield Park. Most of the ground water in the eastern part of the Salt River Valley flows toward the depression northeast of Gilbert. In the central part of the valley most of the ground water flows to the west but some of it flows toward the depression in Deer Valley. In the northwestern section of the valley, the ground water generally flows southward toward the depression northwest of Litchfield Park but some water flows toward the depression in Deer Valley. In the Liberty-Buckeye-Hassayampa area the water generally flows to the southwest, but some water flows north toward the depression near Litchfield Park. In the area west of the Hassayampa River the ground water flows southward toward Gillespie Dam.

Queen Creek-Higley-Gilbert-Magma area.--During 1959 most of the water levels in wells in the Queen Creek-Higley-Gilbert-Magma area continued to follow the previously observed downward trend of the water table. In the period spring 1959 to spring 1960 water-level fluctuations

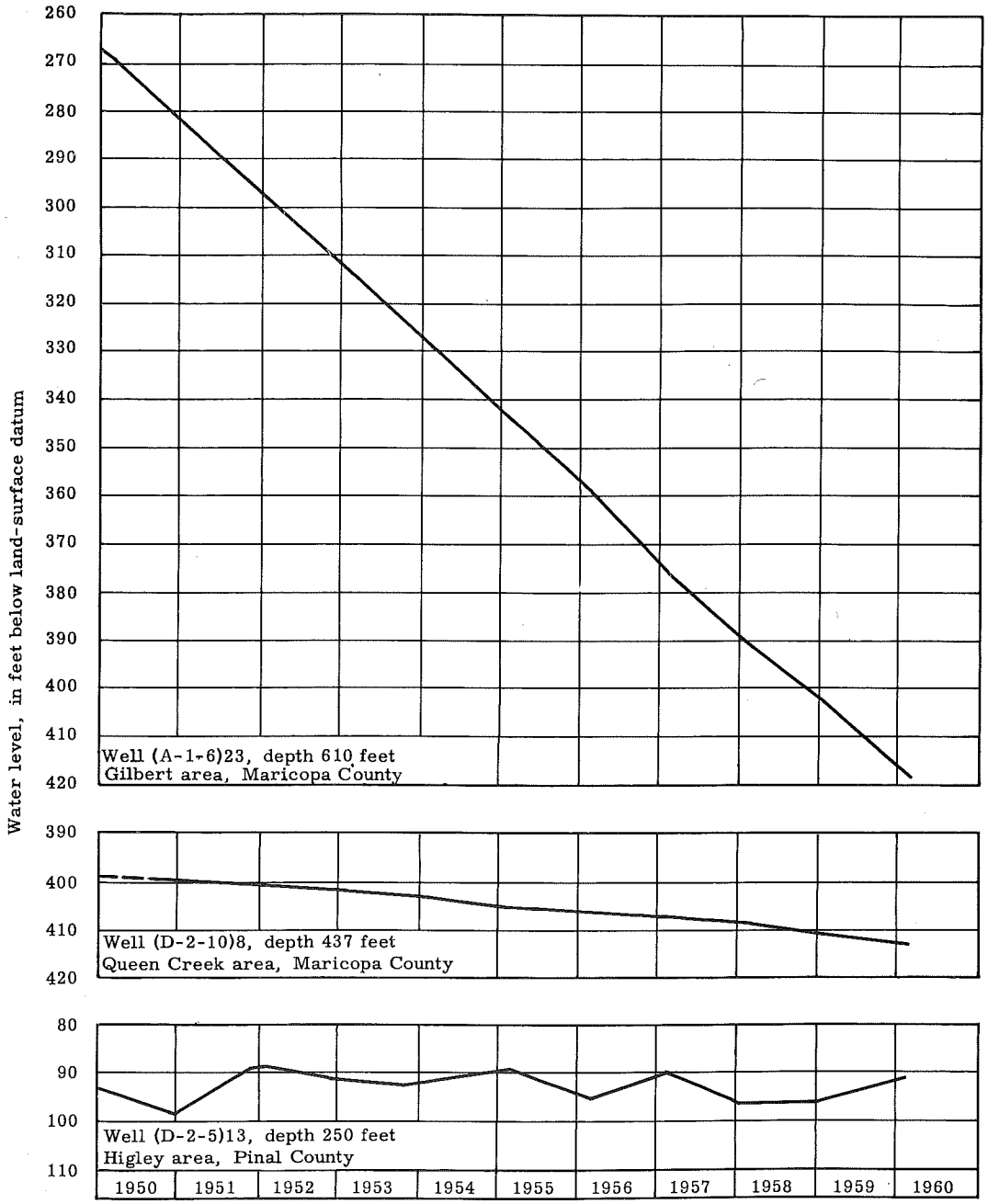


Figure 13.--Water levels in selected wells in Queen Creek-Higley-Gilbert-Magma area, Maricopa and Pinal Counties.

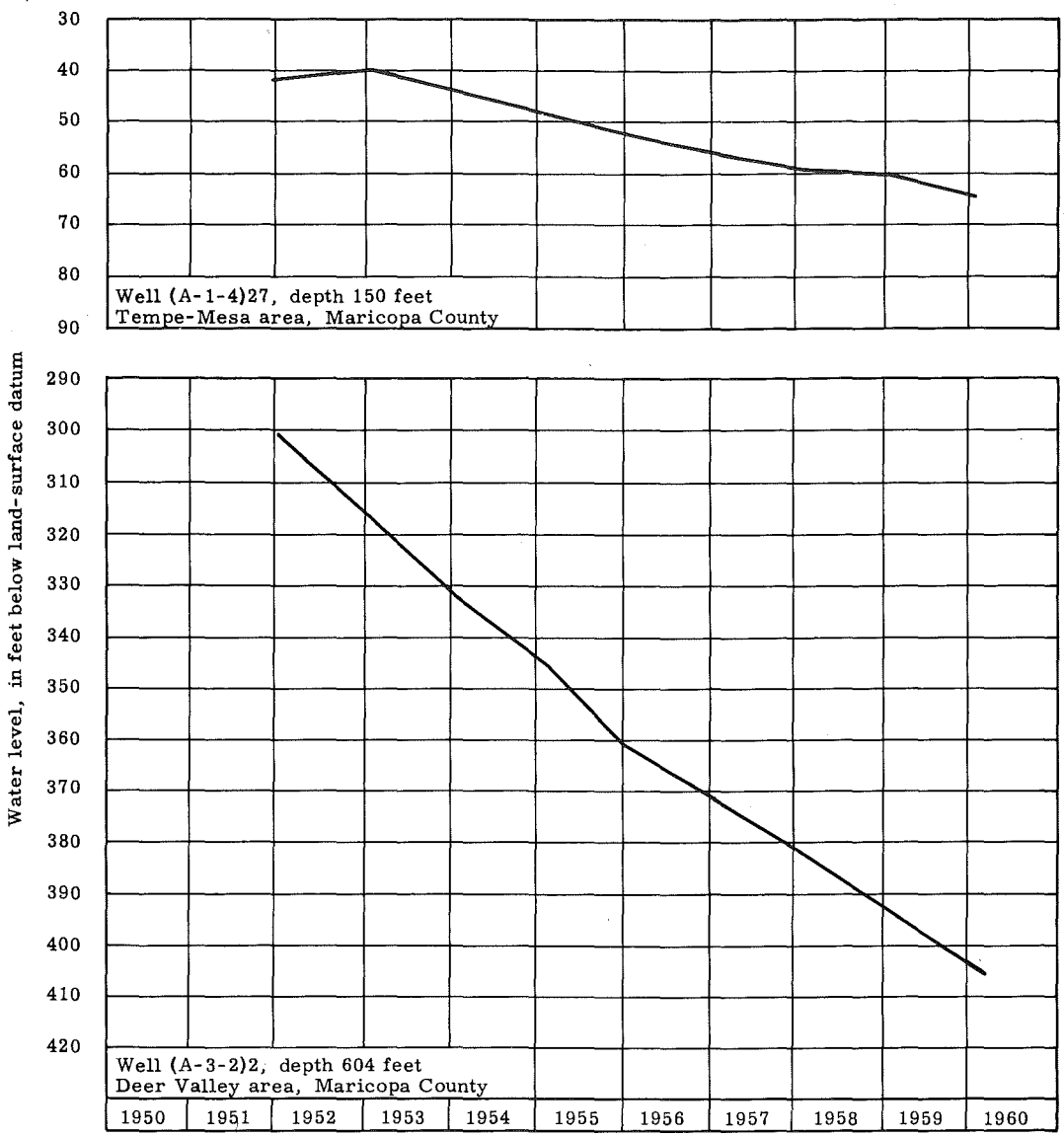


Figure 14. --Water levels in selected wells in Tempe-Mesa and Deer Valley areas, Maricopa County.

in the area ranged from a decline of 19 feet in a well near Magma to a rise of 13 feet in an abandoned irrigation well southeast of Chandler. In the 5-year period spring 1955 to spring 1960 water-level changes ranged from a small rise southeast of Chandler to a decline of more than 60 feet near Magma. Water levels declined about 30 feet at Gilbert and at Queen Creek whereas water levels in the Higley area declined about 20 feet. The minimum declines were observed in the southwestern and eastern parts of the area (fig. 12).

In the part of the area east of the Roosevelt Water Conservation District Canal, declines for the period spring 1959 to spring 1960 were as much as 16 feet, and since 1950 as much as 150 feet as shown by the hydrograph for well (A-1-6)23 (fig. 13). As in previous years the water table in the southwestern part of this area declined but little and in some places there were rises as much as 5 feet. Ground water is used only to supplement surface-water irrigation in this part of the area, and seepage from the canals influences the water-table fluctuations.

The water level in well (D-2-10)8 (fig. 13) in the extreme eastern part of the area had a minimum decline because there is no pumping of ground water for irrigation nearby. However, a steady decline amounting to 14 feet has occurred since the spring of 1950, possibly because of irrigation pumping 8 miles to the west. Little net change has occurred in the water level of well (D-2-5)13 (fig. 13) about 5 miles southwest of Higley since the spring of 1950. The water level in the well has risen about 5 feet since 1958. In the spring of 1960 water levels in observed wells in the cultivated parts of the Queen Creek-Higley-Gilbert-Magma area ranged from 427 feet below land surface in a well south of Granite Reef Dam to 91 feet in a well about 5 miles southwest of Higley. The depths to water near Magma were about 320 feet, near Higley about 160 feet, and at Queen Creek about 300 feet below land surface.

Tempe-Mesa-Chandler area.--In the period spring 1959 to spring 1960, water-level fluctuations in the Tempe-Mesa-Chandler area ranged from a rise of 11 feet to a decline of 9 feet. For the most part the larger declines occurred in the area northeast of Mesa where pumping is concentrated. In the area west of Chandler water-level declines were as great as 5 feet while south of Chandler rises of about 1 foot were recorded.

During the 5-year period spring 1955 to spring 1960 the water table declined in excess of 60 feet northeast of Mesa, from 40 to 60 feet in Mesa, and about 20 feet in Tempe. Declines throughout the rest of the area were progressively less to the south and were about 10 feet south of Chandler (fig. 12). In the spring of 1960 the depth to water below land surface was from 250 to 300 feet northeast of Mesa, about 150 feet near Chandler, about 225 feet near Mesa, and less than 100 feet at Tempe. The shallowest water level measured in the area was 65 feet below land surface in an abandoned irrigation well 1 mile south of Tempe. The hydrograph of well (A-1-4)27 (fig. 14) shows the trend of

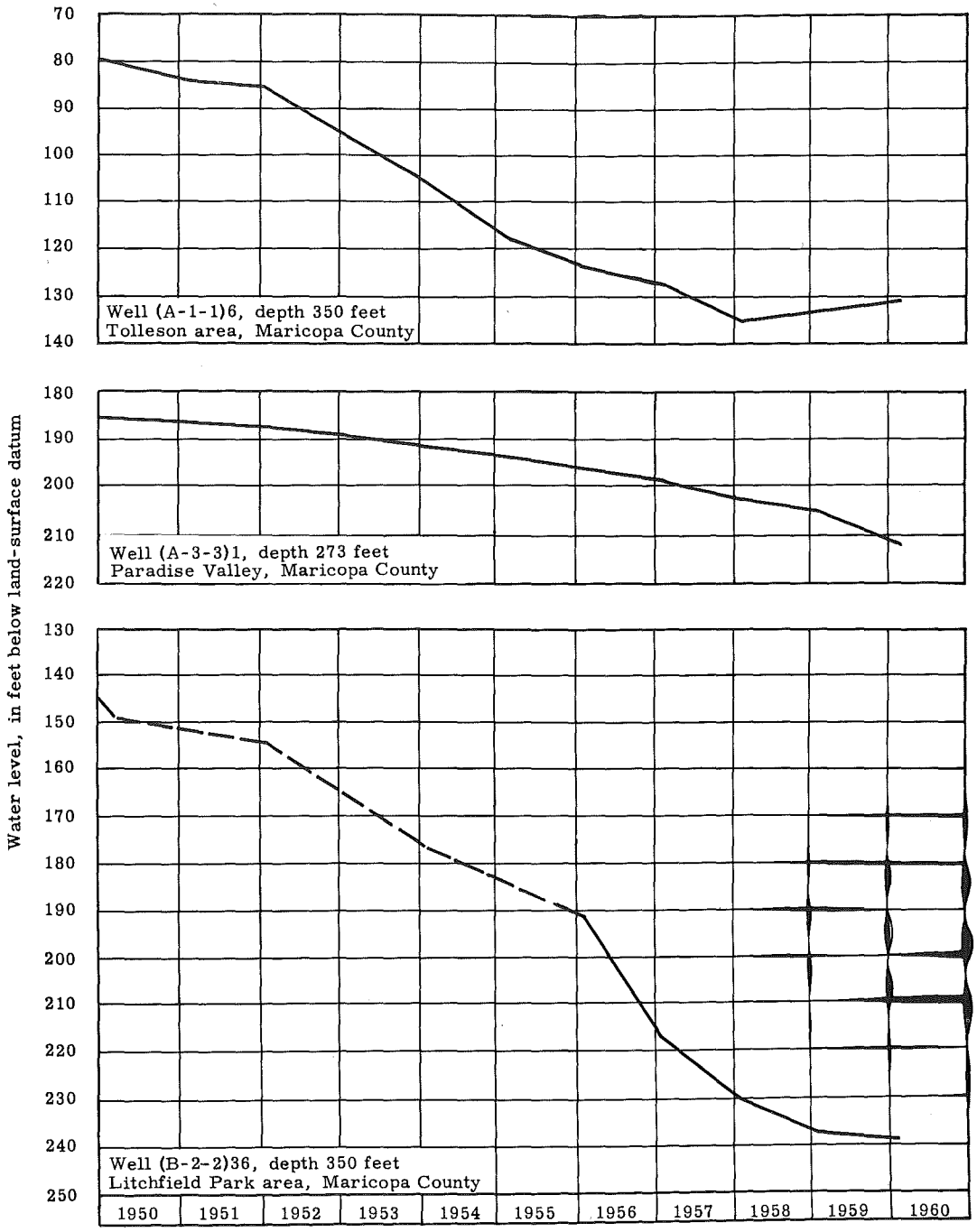


Figure 15.--Water levels in selected wells in Tolleson, Paradise Valley, and Litchfield Park areas, Maricopa County.

the continuous decline in water levels in the area between Tempe and Mesa.

Phoenix-Glendale-Tolleson-Deer Valley area.--During the period spring 1959 to spring 1960 water-level fluctuations ranged from rises of about 14 feet to declines of more than 25 feet. The greatest declines were in Deer Valley although during the last 2 years much acreage in the area has been converted from agricultural to residential and industrial development. Most of the recorded declines in Deer Valley during the period spring 1959 to spring 1960 were in excess of 12 feet and one was as great as 25 feet. The hydrograph for well (A-3-2)2 (fig. 14) shows declines typical of the Deer Valley area. In the area south of the Arizona Canal in the Salt River Project the water-table declines decreased toward Tolleson and the water level in well (A-1-1)6 (fig. 15) rose 2 feet from spring 1959 to spring 1960. From spring 1955 to spring 1960 the water level declined 14 feet and since 1950 about 50 feet. Ground water is used in the Salt River Project to supplement surface-water supplies; therefore ground-water demands within the project are not as great as elsewhere. Water-table rises were measured in wells in northern Phoenix where seepage from the Arizona Canal serves to partially replenish ground-water supplies.

During the 5-year period spring 1955 to spring 1960 water-level fluctuations ranged from almost no change to declines of more than 100 feet in Deer Valley (fig. 12). As in previous 5-year periods, the largest declines occurred in Deer Valley between Skunk Creek and New River. Along the mountains to the north and south of Phoenix the water-level declines were small because of canal seepage and lack of concentrated pumping. The 5-year declines in the center of the Phoenix-Glendale-Tolleson area were about 15 to 40 feet. In the spring of 1960 depth to water below land surface ranged from 50 to 150 feet in Phoenix, 175 to 200 feet in Glendale, 300 to 425 feet in Deer Valley, and was about 150 feet in Tolleson. In north Phoenix, adjacent to the Arizona Canal, water levels were less than 20 feet below the land surface.

Paradise Valley area.--There were minor water-table fluctuations in the Paradise Valley area in the period spring 1959 to spring 1960. Pumping of ground water for agricultural purposes in Paradise Valley has always been minor compared to other parts of the Salt River Valley. Most of the irrigation wells in the area are north of Scottsdale, and it was here that the greatest declines occurred during the period spring 1959 to spring 1960. The only observed rise in water level in the area was about 9 feet in a shallow dug well near the Cave Creek Dam, and this rise is attributed to recharge from the creek.

For the 5-year period spring 1955 to spring 1960 water-level declines ranged from 4 to 18 feet and therefore do not fall within the contour interval of the decline map (fig. 12). The hydrograph of well (A-3-3)1 (fig. 15) shows a continuous downward trend of the water table in this part of the area with an increase in the decline in the last few years.

In the spring of 1960 measured depths to water in Paradise Valley ranged from more than 440 feet below land surface in the northern part of the area to 210 feet below land surface near Scottsdale.

Litchfield Park-Beardsley-Marinette area.--Ground water constitutes the major source of water available for agriculture in the Litchfield Park-Beardsley-Marinette area. During the spring of 1960, however, the demand for ground water was less than usual because of the exceptionally heavy spring rains. The hydrograph for well (B-2-2)36 (fig. 15) shows the effects of less ground-water pumping in the spring of 1960 and lesser declines during the last 2 years. The decline from spring 1955 to spring 1960 was about 55 feet and since 1950 about 95 feet. From spring 1956 to spring 1957 the water table dropped 25 feet and since then the rate of decline has decreased. With the exception of a few wells, declines for the period spring 1959 to spring 1960 were similar to those recorded in previous years. The greatest declines were observed in the northern part of the area and were as much as 17 feet. The water level in well (B-4-1)8 (fig. 16) in the northern part of the Beardsley area declined 10 feet from spring 1959 to spring 1960, about 40 feet from spring 1955 to spring 1960, and nearly 70 feet since 1950.

During the 5-year period spring 1955 to spring 1960 water levels declined from more than 60 feet in the northeastern part of the area to more than 60 feet in the western part along the east side of the White Tank Mountains (fig. 12). In the area adjacent to the mountains water levels declined as much as 80 feet in the previous 5-year period (spring 1954 to spring 1959). The reduction in net decline is attributed to less pumpage. In the southern part of the area water levels declined about 20 feet. The maximum declines occurred in areas of deep water levels. In the spring of 1960 the depth to water in the northeastern part of the area was about 350 feet below land surface; along the White Tank Mountains the depth to water was about 415 feet. The White Tank Mountains are an effective barrier to ground-water movement from the west into the area east of the mountains and west of Litchfield Park. The maximum declines in this area are caused by the cones of depression having reached the impermeable area of the White Tank Mountains. In the spring of 1960 the minimum depth to water was about 140 feet in an irrigation well along the canal southwest of Litchfield Park. In the Litchfield Park area the depth to water ranges from about 140 to more than 300 feet below land surface; near Marinette the water level is about 300 feet below land surface, and near Beardsley about 285 feet below land surface.

Liberty-Buckeye-Hassayampa area.--Water-level fluctuations in this area from spring 1959 to spring 1960 ranged from a rise of about 3 feet in the area south of Liberty to a decline of about 5 feet west of Avondale. Water levels in most of the Liberty-Buckeye-Hassayampa area follow the same downward trend as in other areas in the Salt River Valley. However, the rate of decline is much less because the shallow water

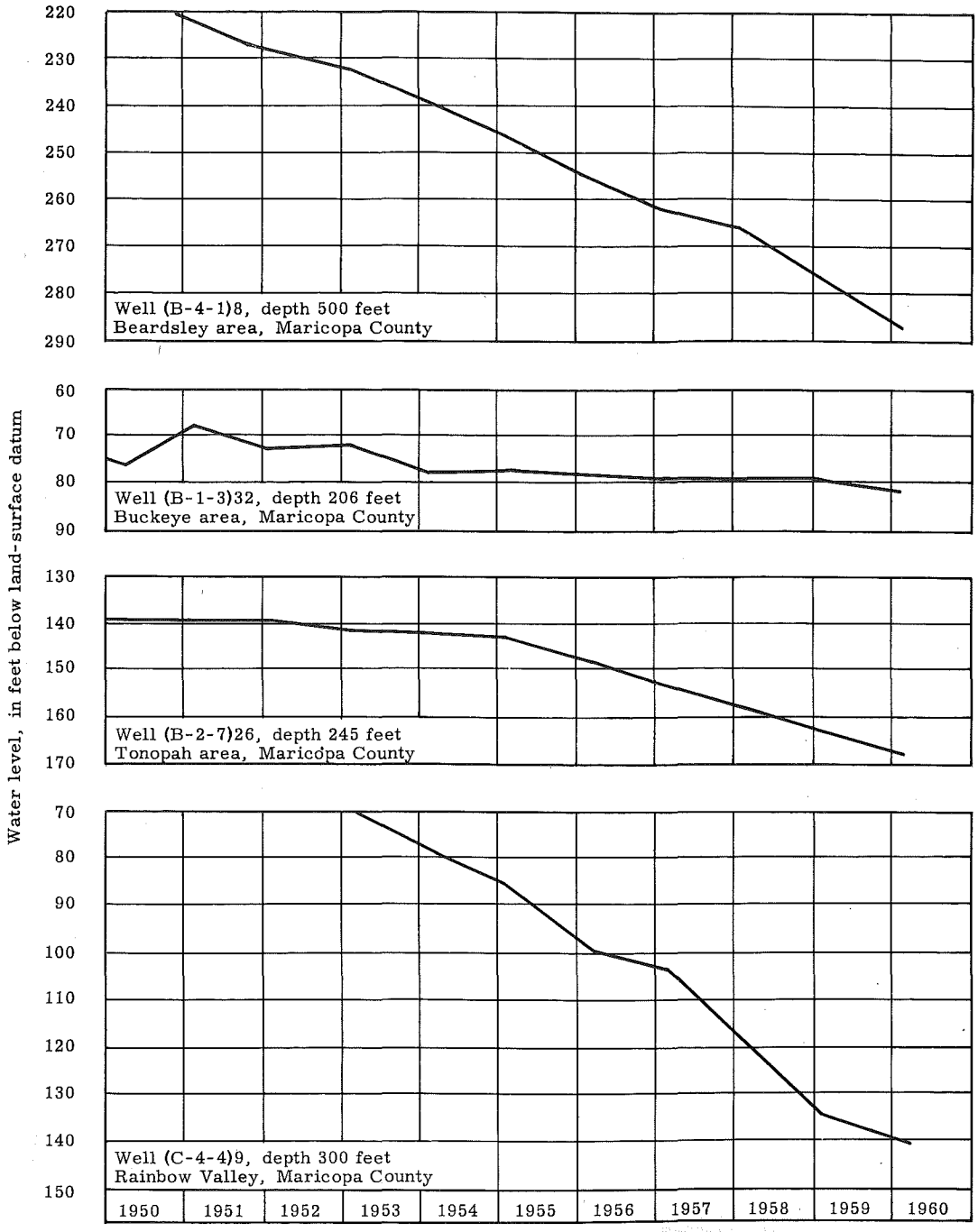


Figure 16.--Water levels in selected wells, Maricopa County.

148.05

table is continually recharged from irrigation water applied to cultivated land upstream. The hydrograph for well (B-1-3)32 (fig. 16) shows the typical water-level trend for this area. During the 5-year period spring 1955 to spring 1960 the water level in this well declined about 5 feet. The water levels in the Liberty-Buckeye-Hassayampa area fluctuated slightly during the 5-year period spring 1955 to spring 1960 (fig. 12), and all the declines were less than 20 feet. The water levels in the area west of Buckeye rose slightly but in the vicinity of Perryville water levels declined more than 20 feet. In the spring of 1960 the depths to water below land surface in the irrigation wells in the area ranged from about 30 feet southwest of Buckeye to more than 210 feet north of Perryville.

The depth to water at Hassayampa is less than 50 feet below land surface; near Buckeye the water table is about 80 feet below land surface. At Liberty and adjacent to the Gila River south of the Gillespie Dam water levels are less than 50 feet below land surface.

Lower Hassayampa-Tonopah area.--The steady decline of the water levels in the lower Hassayampa-Tonopah area began about 1955 because of the increase in the pumping of ground water for agriculture and has continued to the present time. Most of the water levels in the lower Hassayampa-Tonopah area declined from 5 to 10 feet during the period spring 1959 to spring 1960 and the greatest declines occurred near Tonopah. The hydrograph for well (B-2-7)26 (fig. 16) is a typical example of the position of the water table in the basins of Arizona before and after agricultural development. In the spring of 1960 water levels in the area ranged from about 12 feet below land surface in an abandoned well near the Hassayampa River to more than 240 feet northwest of Tonopah. Between Hassayampa and Tonopah most of the water levels ranged from 60 to 140 feet below land surface. North of Hassayampa adjacent to the canal the water table did not decline during the period spring 1955 to spring 1960 (fig. 12).

Lower Centennial area.--Ground-water levels in the lower Centennial area declined slightly during 1959. Generally, water-level declines ranged from about 2 to 9 feet during the period spring 1959 to spring 1960 although some small rises were measured in wells along the Gila River. The greater declines occurred in irrigation wells in the western part of the area. In the spring of 1960, depths to water in the area ranged from about 24 feet below land surface near the junction of Centennial Wash and the Gila River to about 225 feet below land surface in the lower part of T. 1 N., R. 6 W.

Gila Bend area

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. Since the completion of Painted Rock Dam—a flood-control structure with its base resting on bedrock—ground water no longer leaves the area through the narrows at Gila River Canyon at the north end of the Painted Rock Mountains. Ground Water has accumulated back of the dam in quantities sufficient to cause the water table to rise to the surface, and most of the water now leaving the area is flow on the surface released through the dam's flood gates.

In the spring of 1960 about 125 irrigation wells were in operation in the Gila Bend area. Most of these wells are in the northeastern part of the Gila Bend basin, known as Rainbow Valley.

During the period spring 1959 to spring 1960 the greater water-level declines were in the Rainbow Valley area and ranged from about 1 to 20 feet. The water level in well (C-4-4)9 (fig. 16) in Rainbow Valley declined about 6 feet from spring 1959 to spring 1960 and about 55 feet during the 5-year period spring 1955 to spring 1960. In the western part of the Gila Bend basin water-level fluctuations for the period spring 1959 to spring 1960 ranged from no change to rises of more than 10 feet. No declines were measured for this period, possibly due to the effect of unusually heavy spring rains resulting in minimum pumpage. In the spring of 1960 the depth to water in irrigation wells ranged from about 45 feet below land surface along the flood plains of the Gila River to about 270 feet below land surface in the Rainbow Valley area.

Waterman Wash area

The area 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, on the south by the Haley Hills, and on the southwest and west by the Maricopa Mountains, and is drained by Waterman Wash. 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.

Most of the agricultural development and water-level declines are in the northern part of the Waterman Wash area. During the period spring 1959 to spring 1960 water-level fluctuations ranged from a rise of about 5 feet in a well in Waterman Wash to a decline of about 15 feet in an irrigation well in the heavily pumped northern part of the area. The hydrograph for well (C-2-2)25 (fig. 17) shows the downward trend of the water levels in the northern part of the area. The southern part of the area has not been developed for agriculture and the principal use of ground water is for stock supplies. Development to the north has affected ground-water supplies in the southern part of the area to the extent that several of the shallow stock wells have become dry. In the Waterman Wash area the depth to water in the spring of 1960 ranged from about 130 to 360 feet below land surface.

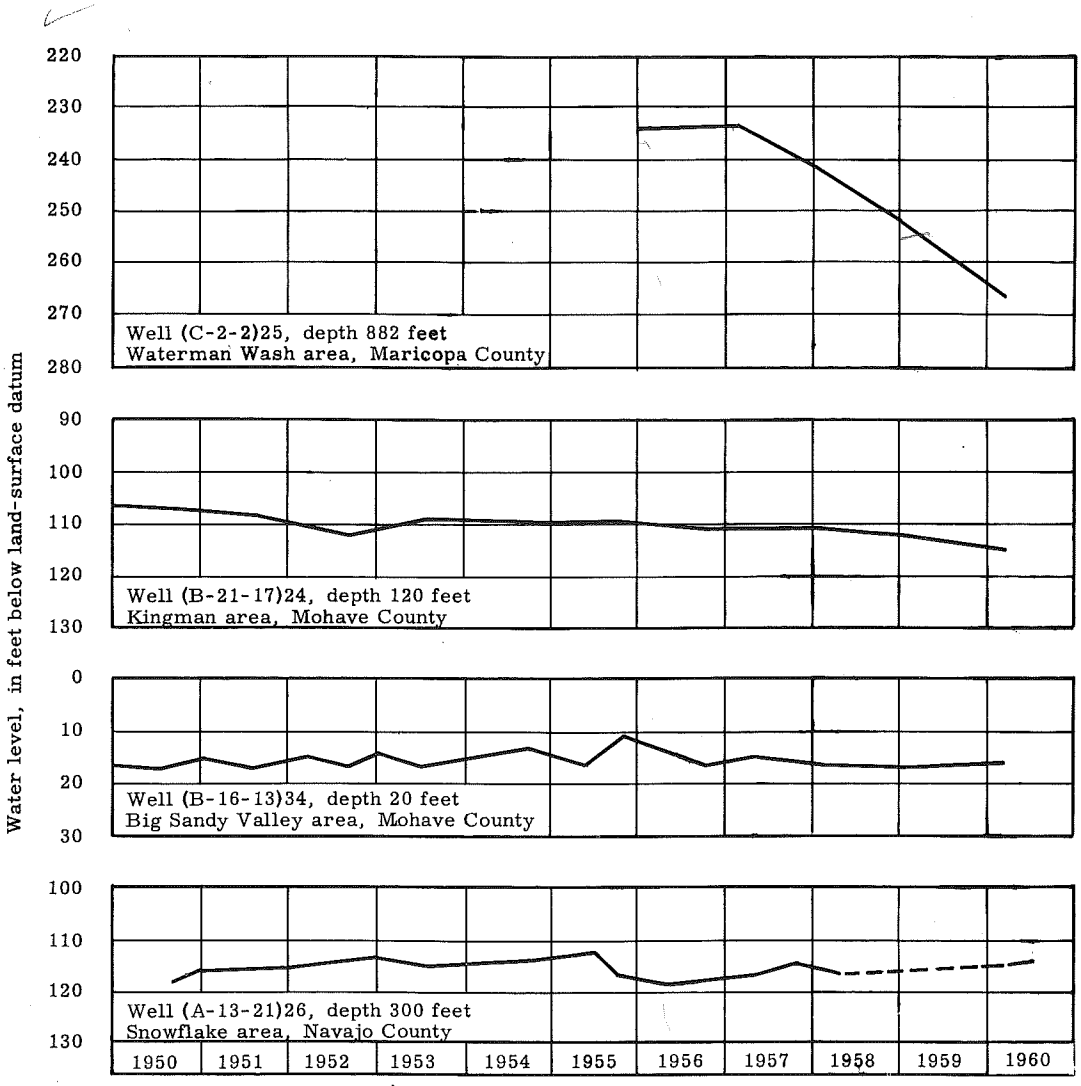


Figure 17.--Water levels in selected wells, Maricopa, Mohave, and Navajo Counties.

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 1960 more than 60 irrigation wells were in use in the Harquahala Plains area as compared to about 30 during 1956. Most of the development is in the southeastern part of the area where the yields of the wells range from about 800 to 3,200 gpm. In the northwest part of the basin wells yield about 600 to 1,200 gpm. During the period spring 1959 to spring 1960 water-level declines in the Harquahala Plains area ranged from 1 foot to about 20 feet; however, these measurements may not be indicative of the static water-level conditions in the area because of year-round pumpage. In the spring of 1960 depths to water below land surface ranged from about 31 feet in the extreme southeast to more than 370 feet in the northwestern part of the Harquahala Plains.

Mohave County

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

The Big Sandy Valley is drained by the Big Sandy River, which receives water from Trout, Burro, and Cottonwood Creeks, and Little Sandy Wash as well as many other washes. The area is more than 60 miles long and is bounded by the Hualapai, Peacock, Rawhide, and Artillery Mountains on the west, and the Cottonwood Cliffs, Aquarius Cliffs, and Aquarius Mountains on the east.

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

Water-level fluctuations in wells in the flood plain of the Big Sandy River in the period spring 1959 to spring 1960 ranged from rises of less than 1 foot to declines of about 1 foot. The hydrograph of well (B-16-13)34 (fig. 17) is typical of wells in this part of the area. The water level in this well rose about 1 foot for the 10-year period spring 1950 to spring 1960 and declined about 1 foot during the 15-year period 1945 to 1960. Depths to water below land surface ranged from 11 feet near Wickieup to about 115 feet 12 miles upstream. Outside the flood plain of the Big Sandy River the water level was 379 feet below land surface in a stock well near the extreme north end of the area.

Ground-water pumping in the Hackberry and Kingman area is mostly for public supply. Water-level fluctuations near Kingman ranged from no change to a decline of about 6 feet for the period spring 1959 to spring 1960. The water level in well (B-21-17)24 (fig. 17) indicates the trend in this area. In the wells near Hackberry during the period spring 1959 to spring 1960 the water-level fluctuations ranged from no change to a decline of about 6 feet. The depth to water below land surface in this area ranged from about 50 feet south of U. S. Highway 66 to about 510 feet near Antaris.

Three wells are used to irrigate land near Truxton. The period of records for these wells is too brief to indicate any definite trend of the water table. During the spring of 1960 the depth to water below land surface in a well at Truxton was about 145 feet--a rise of about 1 foot since the spring of 1959.

Navajo County

Most of Navajo County is 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 and the movement of ground water in the area is toward the north. Where the Coconino sandstone is not exposed, 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.

Ten irrigation wells were completed in the Snowflake-Taylor and Hay Hollow area in 1959. The increased use of ground water for irrigation has caused considerable decline in the water levels during the pumping season. However, the water levels recover completely during the winter, indicating sufficient recharge.

In the last few years increased interest in obtaining more ground water for irrigation in Navajo County has resulted in the drilling of several new wells. Recently, large-diameter gravel-packed wells about 200 feet deep and yielding 800 to 1,000 gpm have been drilled adjacent to the Little Colorado River and the Rio Puerco. Interest in agricultural expansion in the Goodwater area and in the area between Holbrook and Winslow is continuing.

At the present time water-level fluctuations in wells in the Snowflake area are minor. The hydrograph of well (A-13-21)26 (fig. 17) shows the trend. In the near future large amounts of ground water will be pumped from the Coconino sandstone for a proposed pulp mill west of Snowflake. The Coconino sandstone is present everywhere in the Hunt-Snowflake-Holbrook-Winslow area, but varies in its water-bearing characteristics. There is very little pumpage in this area and with proper development and well spacing relatively large amounts of ground water are available. Although the Coconino sandstone stores tremendous amounts of water, the specific yield and coefficient of transmissibility are much less than in the alluvial basins of southern Arizona.

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 Pima County and the central part of Santa Cruz County. The valley is arbitrarily called the upper Santa Cruz basin and extends from Mexico to the Rillito narrows (about 15 miles northwest of Tucson). The downstream part is called the lower Santa Cruz area and lies mostly in Pinal County, although the Avra-Marana area is in Pima County. The part of the upper Santa Cruz basin in Pima County is bordered on the east by the Santa Catalina, Tanque Verde, Rincon, and the northern end of the Santa Rita Mountains; on the west by the Tucson and Sierrita Mountains; and on the north by the Tortolita Mountains. The altitude ranges from 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 highly developed areas in the vicinity of Casa Grande. The Santa Cruz River forms the long axis of the basin and has an important effect on the occurrence and movement of 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. The ground-water underflow is confined to a narrow trough at this point, and only a relatively thin layer of alluvium covers the bedrock from the Tortolita Mountains to this trough. Consequently, most of the ground water moves toward the trough. Because of this constriction in cross-sectional area, the ground-water gradient is about 80 feet for 1 mile at the narrows. The average ground-water gradient from Tucson to Rillito narrows is from 20 to 30 feet per mile.

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

Avra-Marana area

In the 5-year period spring 1955 to spring 1960 water levels declined about 20 to 30 feet in the area extending from Marana to a point about 7 miles southwest. From spring 1959 to spring 1960 water-level fluctuations ranged from rises of 12 feet to declines of 14 feet, although most of the declines were less than 5 feet. The water level in well (D-11-10)32 (fig. 18) rose about 2 feet from spring 1959 to spring 1960, declined about 15 feet from spring 1955 to spring 1960, and declined about 34 feet from spring 1950 to spring 1960. The maximum declines were in the center of Avra Valley in T. 13 S. From spring 1959 to spring 1960 water levels declined from 4 to 13 feet and for the 5-year period spring 1955 to spring 1960 water levels declined as much as 40 feet. The water level in well (D-15-10)35 (fig. 18) in the southern part of Avra Valley declined about 4 feet during the 5-year period spring 1955 to spring 1960 and only 7 feet since 1950. The well is 1 mile from Three Points on the Ajo Highway and there is no nearby irrigation pumpage. The depth to water below land surface in the spring of 1960 was 190 feet in the northern part of the area and progressively deeper southward to about 330 feet near the Ajo Highway. South of the highway the water levels range from 430 to nearly 800 feet below land surface in T. 16 S., R. 10 E.

Domestic wells in the foothills on the west side of the Tucson Mountains may yield little water of doubtful quality, particularly near the Ajo Highway. Irrigation wells in the center of Avra Valley and in the Marana area yield from 1,000 to 2,000 gpm of good quality water.

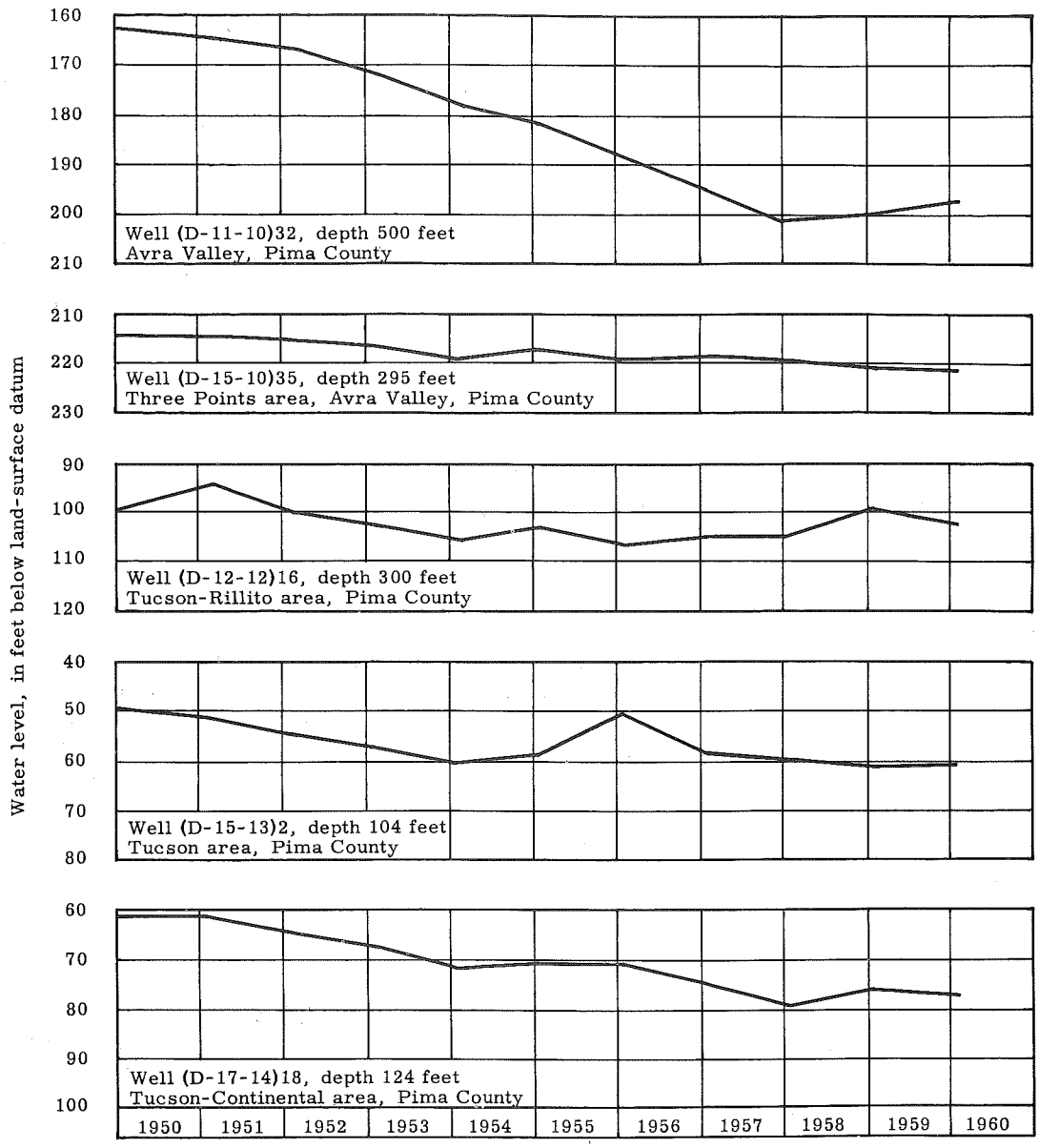


Figure 18.--Water levels in selected wells, Pima County.

Rillito-Tucson area

Water-level fluctuations in this area from spring 1959 to spring 1960 ranged from a rise of about 10 feet to a decline of about 5 feet. For the 5-year period spring 1955 to spring 1960 fluctuations ranged from a rise of about 5 feet to a decline of more than 10 feet. The water level in well (D-12-12)16 (fig. 18) in the heavily pumped area along the Santa Cruz River between Rillito and Cortaro declined about 2 feet from spring 1959 to spring 1960, and about 2 feet since 1950. The water table may be influenced by streamflow in the Santa Cruz River. In south Tucson the water level in well (D-15-13)2 (fig. 18) beside the Santa Cruz River fluctuates seasonally, rising after periods of surface flow in the river and declining when the flow ceases. From spring 1959 to spring 1960 the water level declined about 2 feet and from spring 1950 to spring 1960 about 15 feet. The water levels declined about 5 to 10 feet beneath the city of Tucson from spring 1955 to spring 1960. The declines are the result of the increase in population with correspondingly greater pumpage. The depth to water below land surface in the Tucson-Rillito area ranged from about 60 to 150 feet in the spring of 1960.

From 1952 to 1958, the average streamflow of Rillito Creek past the Oracle Highway gaging station in Tucson was about 7,000 acre-feet per year. This unused water left the Tucson area; most of it was lost to evapotranspiration, although some may have recharged the ground-water aquifers in the Cortaro-Rillito area. If all of this surface water was utilized for public supply, it would serve nearly 45,000 people. Preliminary studies indicate that the water potential of the Rillito Creek basin is greater than is shown by the records of surface-water outflow.

Tucson-Continental area

Water-level fluctuations in this area during the period spring 1959 to spring 1960 ranged from a rise of about 5 feet to a decline of about 4 feet. For the 5-year period spring 1955 to spring 1960 the declines ranged from about 2 to 15 feet. The water level in well (D-17-14)18 (fig. 18) near Sahuarita declined about 1 foot from spring 1959 to spring 1960, 6 feet from spring 1955 to spring 1960, and is about 16 feet lower than in the spring of 1950. The water levels in some wells adjacent to the Santa Cruz River rose a few feet from spring 1959 to spring 1960. The depth to water below land surface in this area in the spring of 1960 ranged from about 50 to 160 feet.

Tanque Verde-Pantano area

The water levels rose about 5 feet along Rillito Creek and Pantano Wash from spring 1959 to spring 1960. 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 1960 the depth to water below land surface ranged from about 10 feet along Tanque Verde Wash to more than 260 feet in the foothills near the Rincon Mountains. Interest in drilling domestic wells is continuing, although ground-water conditions are generally poor, except in localized areas.

In January 1960 an industrial water well was drilled to a depth of 2,500 feet in southeast Tucson. The static water level was 283 feet below land surface and the well yielded 2,000 gpm from 350 feet. The specific capacity was about 30 gpm per foot of drawdown. The water from this well is low in dissolved solids and high in fluoride content; temperature of the water is 125°F. The hydrologic significance of this well is the occurrence of permeable water-bearing sediments at depths greater than 1,000 feet.

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; about 290,000 acres are cultivated. The area 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 northwestward and toward 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.

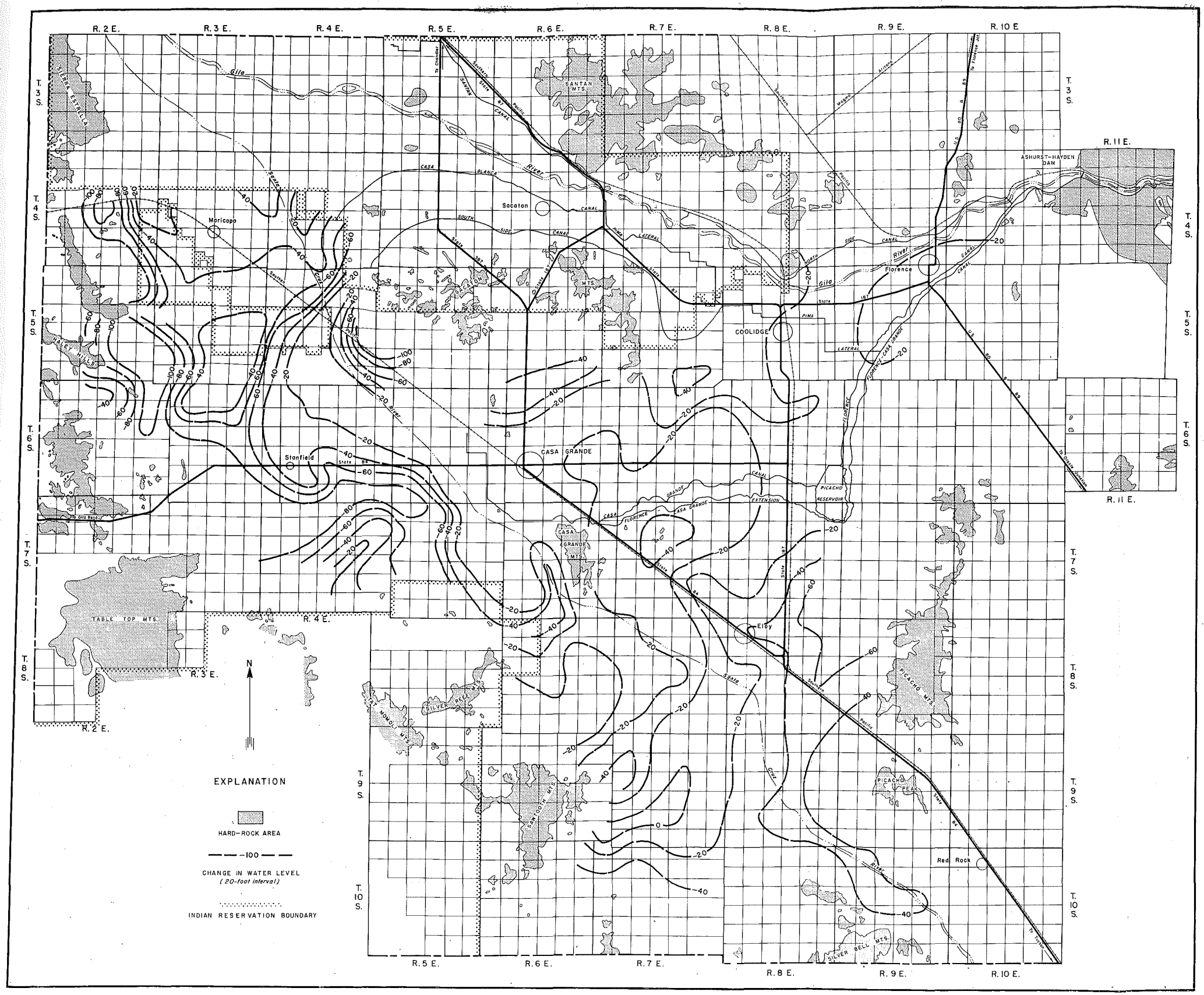


Figure 19.--Map of lower Santa Cruz basin and adjacent areas, Pinal County, Arizona, showing change in ground-water level from spring 1955 to spring 1960

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. The average depth to water in these three areas is shown in table 2. The water levels were measured in the spring. At this time more uniform conditions prevail as the water levels are approaching static conditions because pumping is at a minimum. Pumping levels during the irrigation season are much greater.

Table 2.--Average depth to water in the lower Santa Cruz basin (feet below land-surface datum)

Area	Spring 1956		Spring 1958		Spring 1960	
	Water level	Number of measurements	Water level	Number of measurements	Water level	Number of measurements
Casa Grande-Florence	123	110	133	146	132	120
Maricopa-Stanfield	191	179	191	155	210	115
Eloy	195	201	206	187	217	104

Casa Grande-Florence area

In the period spring 1959 to spring 1960 water-level fluctuations ranged from rises of 1 to 20 feet to declines of about 12 feet. Most of the rises in the water table were along the Gila River from Coolidge to Florence and in the area 2 to 7 miles west of Picacho Reservoir. Elsewhere in the Casa Grande-Florence area, many of the yearly declines were less than 5 feet. The rises in these areas during 1959 were due to less pumping than in previous years and to the availability of Gila River water. In 1959 about 154,000 acre-feet of surface water was diverted at Ashurst-Hayden Dam--about 100,000 acre-feet less than in 1958 and the largest diversion since 1952. In the 5-year period spring 1955 to spring 1960 declines ranged from about 20 to 40 feet (fig. 19). The water level in well (D-6-6)7 (fig. 20) declined about 11 feet from spring 1959 to spring 1960, about 40 feet from spring 1955 to spring 1960, and more than 70 feet from spring 1950 to spring 1960. Depths to water below land surface in the spring of 1960 were about 50 feet near Casa Grande, 115 feet along the Gila River from Florence to Coolidge, and 150 feet between Casa Grande and Coolidge. South of Florence, east of the Picacho Reservoir, water levels are 200 feet or more below land surface.

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. The average depth to water in these three areas is shown in table 2. The water levels were measured in the spring. At this time more uniform conditions prevail as the water levels are approaching static conditions because pumping is at a minimum. Pumping levels during the irrigation season are much greater.

Table 2.--Average depth to water in the lower Santa Cruz basin (feet below land-surface datum)

Area	Spring 1956		Spring 1958		Spring 1960	
	Water level	Number of measurements	Water level	Number of measurements	Water level	Number of measurements
Casa Grande-Florence	123	110	133	146	132	120
Maricopa-Stanfield	191	179	191	155	210	115
Eloy	195	201	206	187	217	104

Casa Grande-Florence area

In the period spring 1959 to spring 1960 water-level fluctuations ranged from rises of 1 to 20 feet to declines of about 12 feet. Most of the rises in the water table were along the Gila River from Coolidge to Florence and in the area 2 to 7 miles west of Picacho Reservoir. Elsewhere in the Casa Grande-Florence area, many of the yearly declines were less than 5 feet. The rises in these areas during 1959 were due to less pumping than in previous years and to the availability of Gila River water. In 1959 about 154,000 acre-feet of surface water was diverted at Ashurst-Hayden Dam--about 100,000 acre-feet less than in 1958 and the largest diversion since 1952. In the 5-year period spring 1955 to spring 1960 declines ranged from about 20 to 40 feet (fig. 19). The water level in well (D-6-6)7 (fig. 20) declined about 11 feet from spring 1959 to spring 1960, about 40 feet from spring 1955 to spring 1960, and more than 70 feet from spring 1950 to spring 1960. Depths to water below land surface in the spring of 1960 were about 50 feet near Casa Grande, 115 feet along the Gila River from Florence to Coolidge, and 150 feet between Casa Grande and Coolidge. South of Florence, east of the Picacho Reservoir, water levels are 200 feet or more below land surface.

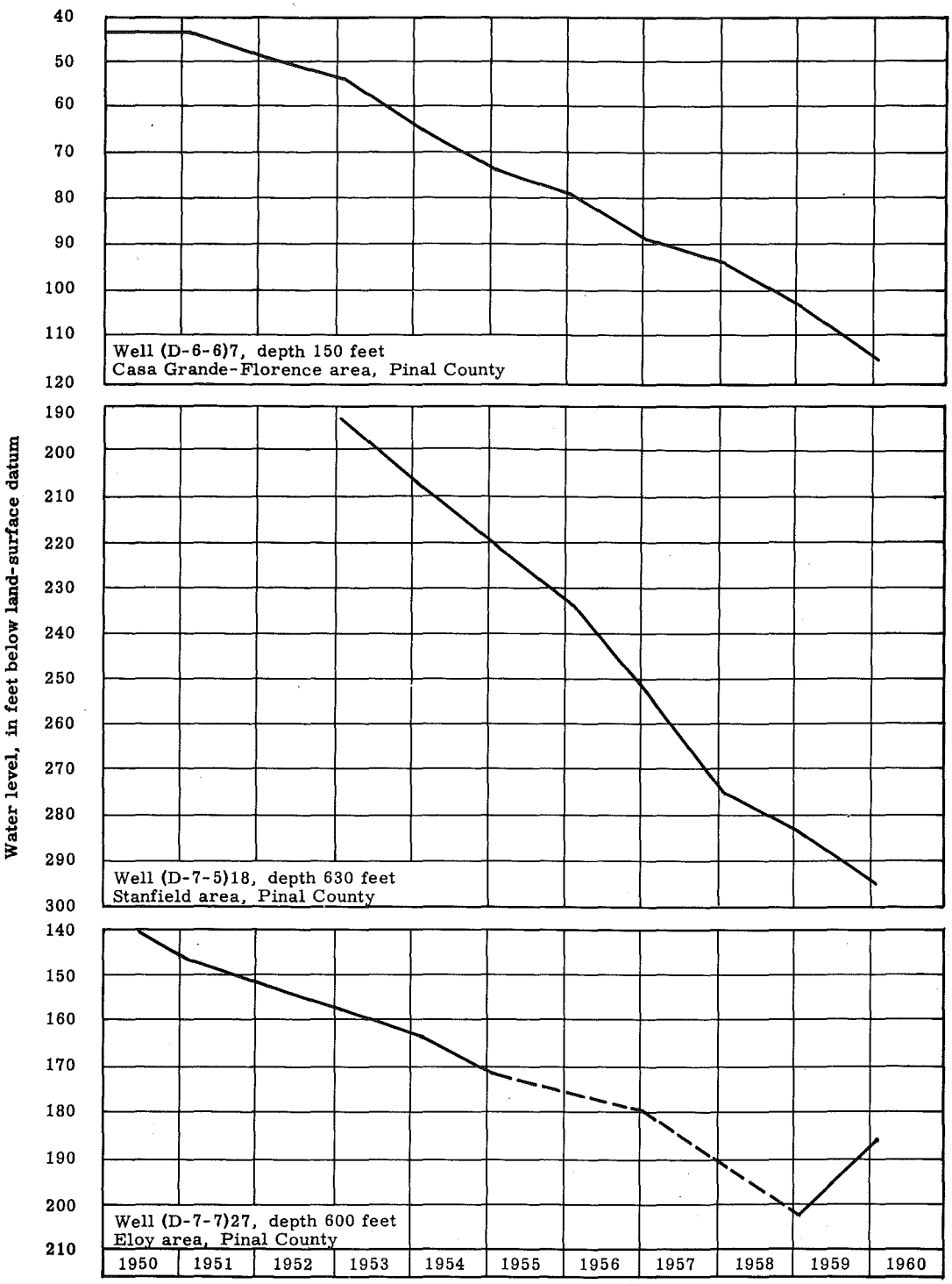


Figure 20. --Water levels in selected wells, Pinal County.

Maricopa-Stanfield area

Water-level fluctuations during the period spring 1959 to spring 1960 ranged from no change to as much as 40 feet of decline. In the areas south of Maricopa and from Maricopa southeast to Casa Grande, the water levels did not decline during the last year. Along the edges of the basin yearly declines ranged from 20 feet along the southern part of the Sacaton Mountains to as much as 40 feet near Vekol Wash and Haley Hills. South of State Highway 84 in the Stanfield area water levels declined about 10 feet. In the western part of the area along the mountains, water levels declined as much as 20 feet. In the 5-year period spring 1955 to spring 1960 declines ranged from 20 to 100 feet (fig. 19). The greatest declines were in the western part of the basin near the mountains, particularly east of Haley Hills and adjacent to the southwestern part of the Sacaton Mountains. The water level in well (D-7-5) 18 (fig. 20), about 7 miles southeast of Stanfield, declined about 10 feet from spring 1959 to spring 1960 and more than 70 feet from spring 1955 to spring 1960. The depths to water below land surface in the spring of 1960 were about 70 feet west of Casa Grande and north of Maricopa, 225 feet at Stanfield, 200 to 300 feet in the central part of the basin, and as much as 400 to 500 feet along the west side of the basin adjacent to the mountains. These are essentially static water levels measured in the spring of 1960; pumping levels are much lower during the irrigation season.

Eloy area

Water-level fluctuations in this area from spring 1959 to spring 1960 ranged from rises of about 2 to 20 feet to declines of more than 20 feet. Rises in the water table were measured in the area from Picacho Reservoir southwest to State Highway 84, in the Red Rock area, and in the area about 8 miles southwest of Eloy. Maximum yearly declines were measured along the north and east edges of the Sawtooth Mountains. In the 5-year period spring 1955 to spring 1960 water-level declines ranged from about 20 to more than 60 feet (fig. 19). The greatest declines were in the area between Eloy and the Picacho Mountains. The water level in well (D-7-7)27 (fig. 20), 3 miles northwest of Eloy, rose about 16 feet from spring 1959 to spring 1960, declined about 15 feet from spring 1955 to spring 1960, and declined more than 48 feet from spring 1950 to spring 1960. The depths to water in this area ranged from about 150 to more than 300 feet below the land surface in the spring of 1960.

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

Boundary to about 3,000 feet at the Santa Cruz-Pima County line. From spring 1959 to spring 1960 water levels rose from about 1 foot to more than 20 feet; for the 5-year period spring 1955 to spring 1960 water-level fluctuations ranged from rises of 1 to 19 feet to declines of less than 5 feet. This general rise in water level is attributed to recharge from the Santa Cruz River during the last few years. The water level in well (D-22-13)35 (fig. 21) responds rapidly to recharge from Sonita Creek and the Santa Cruz River. The water level in this well rose about 13 feet from spring 1959 to spring 1960, about 19 feet from spring 1955 to spring 1960, and about 21 feet from spring 1950 to spring 1960. The depths to water in this area in the spring of 1960 ranged from 10 to 40 feet below land surface. Ground-water levels in most of the upper Santa Cruz Valley have been rising steadily and conditions are better now than at anytime during the last 5 years. However, large pumping drafts or low runoff in the Santa Cruz River could result in declining water levels because of the small ground-water storage capacity of this part of the valley.

Yavapai County

There are four principal areas of ground-water development in Yavapai County: (1) Verde Valley; (2) Chino Valley; (3) Skull Valley; and (4) Peeples Valley.

Verde Valley

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

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

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

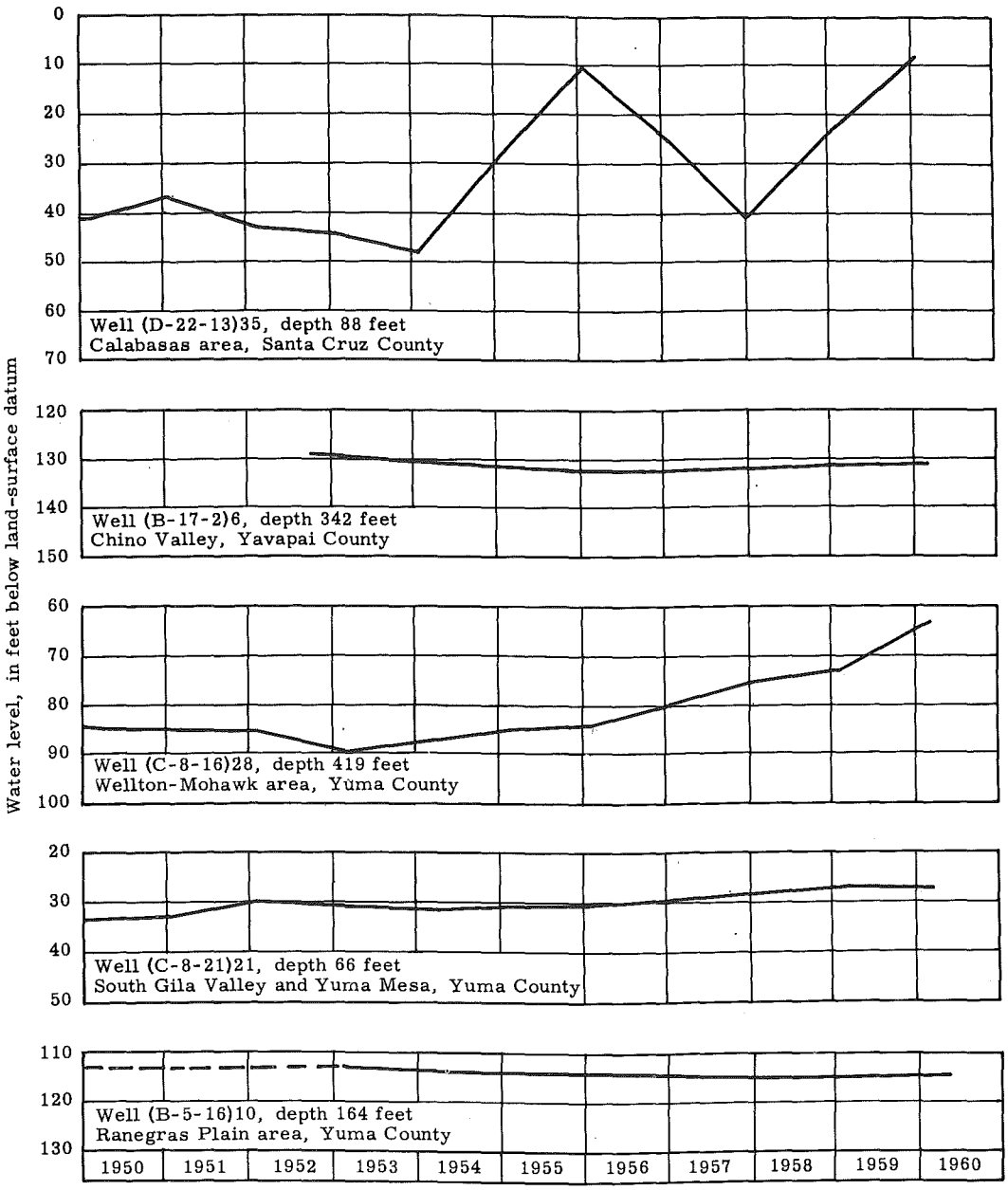


Figure 21.--Water levels in selected wells, Santa Cruz, Yavapai, and Yuma Counties.

Although most of the water used for agriculture in the valley is diverted from the Verde River, there are 10 irrigation wells in the area, an increase of 4 wells from last year. These wells range in depth from 125 feet to 800 feet—the water levels range from about 30 to 150 feet below land surface. One of the irrigation wells flows at a rate of more than 300 gpm.

More than 100 domestic wells have been drilled to depths of more than 100 feet; most of these wells have been drilled into the Verde formation. The water rose under artesian pressure in most of the wells during drilling; near Cottonwood, Page Spring, McGuireville, and Camp Verde there are about 15 flowing wells. In the nonflowing wells, depths to water ranged from a few feet to more than 200 feet below land surface. Reported data from well owners and drillers and monthly measurements of selected wells suggest that, at the present time, water-level fluctuations are influenced primarily by climatic conditions. Most of the industrial wells drilled by the mining companies in the Verde Valley were abandoned when the mines closed, although a few are being used for public supply.

Sedona area.--Prior to 1949 sufficient water supplies for the Sedona area were available from surface flow in Oak Creek and shallow wells adjacent to the creek. During the last few years, the increase in population has required the development of more convenient and dependable domestic water supplies. In 1949 a successful domestic well was drilled to a depth of 530 feet about 3 miles west of Sedona. At the present time more than 30 wells, averaging 600 feet in depth, are bottomed in the Supai formation which is the major source of domestic water supplies, exclusive of Oak Creek. The average depth to water in these wells is about 400 feet below land surface. Water for stock purposes in the area northwest of Sedona is obtained from depths as great as 800 feet below land surface.

Chino Valley-Skull Valley-Peeples Valley

Water-level fluctuations in the Chino Valley area during the period spring 1959 to spring 1960 ranged from a rise of less than 1 foot to a decline of more than 9 feet. Wells are the only source of irrigation water near Paulden and the hydrograph for well (B-17-2)6 (fig. 21) shows the water-level trend in the area. In the spring of 1960 water levels in irrigation wells in the area ranged from about 4 to 257 feet below land surface.

In Skull Valley water-level fluctuations for the period spring 1959 to spring 1960 ranged from a rise of about 3 feet to a decline of about 2 feet. The irrigation wells in this area are in shallow alluvium and are readily affected by precipitation.

During the period spring 1959 to spring 1960 ground-water levels in Peeples Valley rose about 2 feet. Small quantities of water are pumped from this area and the water-table fluctuations are only seasonal.

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.

Palomas Plain area

Palomas Plain is an alluvial area that extends northwest from the Gila River between a spur of the Gila Bend Mountains and the Palomas Mountains. The area is 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 1959 to spring 1960 water-level fluctuations in wells in the Palomas Plain area ranged from a rise of about 6 feet near Horn to a decline of about 6 feet in an abandoned well near Dateland. In the spring of 1960 the depth to water below land surface in the irrigated area ranged from about 20 feet along the Gila River to about 265 feet north of Hyder.

Wellton-Mohawk area

The Wellton-Mohawk area is a flat desert plain that extends from Dome upstream along the Gila River for a distance of about 46 miles. The area is bounded on the west by the Gila Bend 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 1959 only about 10 irrigation wells were in operation compared to about 60 during 1952. Six of the irrigation wells in operation during 1959 are in the new area of development north of Texas Hill adjacent to the boundary of the reclamation project.

Water levels in wells in the Wellton-Mohawk Irrigation District continued to rise during 1959; the rises were as great as 10 feet. The water level in well (C-8-16)28 (fig. 21) rose about 22 feet during the period 1955-1960 and about 10 feet in 1959. The rate of rise in the water table has increased during the last few years. The depth to water below land surface in the area ranged from about 4 feet in a well near the Gila River to more than 100 feet in the area north of Texas Hill.

South Gila Valley and Yuma Mesa area

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

Owing to the effects of gravity irrigation on the Yuma Mesa area, water levels continued to rise during the period spring 1959 to spring 1960; fluctuations for this period ranged from a small decline of less than 1 foot to a rise of more than 10 feet. In the south part of the valley, along the edge of Yuma Mesa, rising water levels have caused some flooding of land. The water level in well (C-8-21)21 (fig. 21) has risen slowly since 1949 and in the period spring 1955 to spring 1960 rose 4 feet. The hydrograph for this well shows conditions typical of the south Gila Valley and Yuma Mesa area. The depth to water below land surface in the spring of 1960 ranged from about 71 feet on the Yuma Mesa to about 10 feet 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 is within Yuma County, and the eastern half is in Maricopa and Yavapai Counties. As most of the area is in Yuma County, it is discussed in this section of the report.

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

Only a few wells were measured in the Aguila area in the spring of 1960 because of a year-round pumping. The water level declined about 7 feet in a domestic well on the north fringe of the cultivated area and about 2 feet in an unused irrigation well in the area northwest of Aguila during the period spring 1959 to spring 1960. During the same period water-level fluctuations ranged from no change to a decline of about 7 feet in the Salome-Wenden area. This part of McMullen Valley has not been developed as extensively as the Aguila area and water levels are nearer the land surface. Depths to water below land surface in McMullen Valley during the spring of 1960 ranged from 112 feet near Salome to 430 feet near Aguila.

Ranegras Plain area

This area is in northern Yuma County and is bounded on the north by the Bouse Hills, on the east by the Granite Wash Mountains, and on the west by the Plomosa Mountains.

Agriculture in the Ranegras Plain area has increased very little in the last 5 years. During 1959 there were about 15 irrigation wells equipped to pump water but not all of these wells were in operation.

From spring 1959 to spring 1960 water-level fluctuations in the Ranegras Plain area ranged from no change to a decline of about 5 feet. The hydrograph for well (B-5-16)10 (fig. 21) shows water-level fluctua-

tions typical of the undeveloped parts of the area. There has been essentially no change in the water table during the last 10 years in this well. The depth to water in the Ranegras Plain area in the spring of 1960 ranged from about 31 to 225 feet below land surface.

Pumpage

The amount of ground water pumped in Arizona during 1959 was nearly 4,700,000 acre-feet, a slight increase from the previous years. Development of ground water increased in McMullen Valley, Harquahala Plains, Willcox basin, and the Gila Bend area. The annual pumpage has not changed greatly the last few years despite increased pumping lifts in the developed basins, development of new irrigated areas, and a rapid growth in population. More than 90 percent of the ground-water withdrawal has been for irrigation use, and less than 400,000 acre-feet has been used for municipal, industrial, and domestic purposes.

The two main areas of ground-water pumpage in Arizona are the Salt River Valley and the lower Santa Cruz basin. About half of the total ground water pumped in the State was from the Salt River Valley and more than one-fourth from the lower Santa Cruz basin.

Pumpage in 1959 in the Salt River Valley amounted to about 2,200,000 acre-feet, which does not differ significantly from the pumpage for the last seven years. The urbanization of the greater Phoenix area has taken some agricultural land out of production, but this is balanced by an increase in population. The Salt River Valley area includes the following subareas: Queen Creek-Higley-Gilbert-Magma area, Tempe-Mesa-Chandler area, Paradise Valley, greater Phoenix, Glendale area, Deer Valley, Beardsley area, Litchfield Park area, Buckeye area, lower Centennial area, and Tonopah area.

More than 90 percent of the ground water pumped in the Salt River Valley in 1959 was for agricultural irrigation. Pumpage in the Queen Creek-Magma area was about 170,000 acre-feet. In the area east of the Agua Fria River, which includes the Glendale area, greater Phoenix, Tempe-Mesa-Chandler area, Deer Valley, and Paradise Valley, pumpage was about 1,450,000 acre-feet. West of the Agua Fria River in the Beardsley, Litchfield Park, Buckeye, and lower Centennial areas, pumpage was about 550,000 acre-feet. In the Tonopah area about 50,000 acre-feet of ground water was pumped in 1959.

Pumpage in the Pinal County part of the lower Santa Cruz basin was nearly 1,200,000 acre-feet in 1959. Most of this water was for agricultural use. Pumpage in the three areas of development in the basin includes (1) Casa Grande-Florence area, 370,000 acre-feet; (2) Maricopa-Stanfield area, 470,000 acre-feet; and (3) Eloy area, 360,000 acre feet. Wells producing about 65 percent of the total pumpage in the basin use electrical power. Electrical power is used to produce about 45 percent of the pumpage in the Maricopa-Stanfield area, 65 percent

in the Eloy area, and 85 percent in the Casa Grande-Florence area. Natural gas is the source of power for the remainder of the wells in the basin, except for a few wells with butane—or diesel-powered pumps.

About one-fourth of the total pumpage, or slightly more than 1,000,000 acre-feet, is pumped throughout the rest of the State. Smaller areas of agricultural development in the basin and range part of the State account for most of this total. Agricultural development and pumping of ground water has increased in Willcox basin, McMullen Valley, Harquahala Plains, and the Gila Bend area. The use of water for irrigation in the San Pedro River Valley, upper Santa Cruz basin, Palomas Plains, and Safford Valley remained about the same as last year. The Douglas basin has had less development and pumping in the last few years. In the Yuma and Wellton-Mohawk areas, surface water is utilized more than ground water and pumping has decreased. In northern Arizona there was a slight increase in pumpage, particularly in Yavapai, Navajo, and Apache Counties.

Pumpage in the Harquahala Plains area in western Maricopa County was about 40,000 acre-feet in 1956 and is estimated to have been 90,000 to 100,000 acre-feet in 1959. Agricultural development is increasing and many new wells have been drilled in the area. Some of the wells formerly powered by electricity have been converted to natural-gas power.

The Waterman Wash area about 25 miles southwest of Phoenix has had little increase in agricultural development. Pumpage in this area was about 40,000 acre-feet in 1956, and nearly 50,000 acre-feet in 1959.

The Gila Bend area includes about 800 square miles extending from Gillespie Dam on the Gila River downstream to the Painted Rock Mountains. The northeastern part of the basin is known locally as Rainbow Valley. Pumpage in the Gila Bend area for 1959 was about 250,000 acre-feet which includes 25,000 acre-feet pumped in Rainbow Valley. Agricultural development has increased steadily the last few years in the Gila Bend area, particularly in the vicinity of Theba.

Most of the agricultural land has been developed in the Safford Valley and total consumption of water is fairly constant. The amount of ground water pumped each year depends on the availability of surface water from the Gila River during the growing season—during periods of low flow in the river, more ground water is pumped. In 1959 about 80,000 acre-feet of surface water was diverted into the irrigation canals at the head of the valley northeast of Solomon. It is estimated that about 100,000 acre-feet of ground water was pumped in the Safford Valley in 1959.

The Willcox basin is subdivided into the Stewart area north of State Highway 84, and the Kansas Settlement area south of the highway and the playa. In the last few years agricultural development has increased around the towns of Cochise and Pearce southwest of the playa. Pumpage of ground water in the basin has increased greatly in the last three

years and in 1959 was about 180,000 acre-feet—this includes 60,000 to 70,000 acre-feet pumped in the Stewart area and 110,000 to 120,000 acre-feet pumped in the Kansas Settlement area. Most of the wells are powered by electricity in the Stewart and Cochise-Pearce areas; most of the wells in the Kansas Settlement area are powered by natural gas.

Pumpage in Pima County was about 275,000 acre-feet in 1959. About 40 percent of the county is included in the Papago Indian Reservation and pumpage on the reservation was less than 10,000 acre-feet. Most of the development is in the Papago Farms area. Pumpage for domestic and industrial purposes at Ajo was about 10,000 acre-feet. Thus, about 250,000 acre-feet of water was pumped in Avra Valley, the Tucson basin, and the Santa Cruz Valley from the Santa Cruz County line to the Marana area. About 200,000 acre-feet was pumped for irrigation and 50,000 acre-feet for public supply, domestic, and industrial use.

Although the nonirrigation use of ground water has increased because of population growth and industrial expansion, water usage for these purposes is still relatively small in comparison to agricultural needs. For example, agricultural ground-water pumpage is more than 1 million acre-feet per year in the lower Santa Cruz basin, including the Eloy, Casa Grande-Florence, Maricopa-Stanfield areas. By comparison, all the private water companies in the State and the public municipalities of Phoenix, Tucson, Bisbee, Casa Grande, Coolidge, Florence, Miami, and Superior pump less than 200,000 acre-feet of ground water per year. Total water used in the State for domestic purposes is about 250,000 acre-feet per year. Thus, large increases in population do not materially affect the total ground-water pumpage. However, any increase in pumpage in a localized area, such as a city, can present serious water problems. All the cities in Arizona can expect future growth and added demands on their water supply. The amount of ground water pumped for industrial wells, mostly in Phoenix and Tucson, is unknown, but it probably is less than 200,000 acre-feet for the State. In addition, some industries buy water from the public utilities.

The use of water for public supply has continued to increase throughout the State, particularly in Phoenix and Tucson. The Arizona Corporation Commission reports that slightly more than 12 billion gallons of water (37,000 acre-feet) was pumped in 1959 by all the private water companies in the State. This figure, which does not include the water pumped by public municipalities, is about 6 billion gallons (18,000 acre-feet) less than in 1956. This reduction in pumpage by the private water companies is due to the acquisition of many of these companies by the municipalities, particularly Phoenix and Tucson, and there is a corresponding increase in pumpage figures for the municipal water systems. During 1956 the Phoenix water department pumped 46 mgd (million gallons per day) of which 8 mgd was ground water. In 1958 it pumped 70 mgd of which 28 mgd was ground water; in 1959 more than 80 mgd was pumped, including 50 mgd (56,000 acre-feet) of ground water. Water consumption in Tucson has increased similarly. During 1957 the city ground-water pumpage was 23 mgd; in 1958, 26 mgd; and in 1959 nearly 10.5 billion gallons of water (32,200 acre-feet) or 29

mgd was used. The city supply is obtained entirely from ground-water sources. The cities of Ajo, Bisbee, Casa Grande, Coolidge, Florence, Miami, San Manuel, Superior, and Winkleman together used nearly 2.5 billion gallons of ground water (7,600 acre-feet) in 1959. Yuma used 2.8 billion gallons (8,700 acre-feet) of surface water in 1959.

QUALITY OF GROUND WATER IN THE TUCSON AREA

People in the Tucson area depend upon ground water for municipal, domestic, and industrial water supplies. The quality of this ground water varies from place to place, depending on the composition of the water-bearing sediments. It may vary also in several water-bearing horizons at the same place. Many analyses are made of composite samples of several water-bearing horizons and for this reason it is not possible to predict with certainty the quality of ground water to be found at any given location. Nevertheless, a general description of water quality in the area with respect to location may be valid.

Regionally, the ground water is satisfactory for most uses with minimum treatment. Locally, however, the water contains objectionable amounts of some constituents. The average dissolved-solids content of the ground water throughout the area is probably about 500 ppm, although some ground water contains more than 5,000 ppm. However, water of this higher concentration is not common. Sulfate in the form of gypsum ($CaSO_4$) or glauber's salts (Na_2SO_4) is the main constituent in waters containing more than about 800 ppm dissolved solids. Calcium bicarbonate is the main constituent in the less mineralized waters. Selected quality-of-water analyses from 14 wells indicate the chemical composition of ground water in the Tucson area (fig. 22).

The municipal water supply for Tucson is obtained from wells scattered through the city. Water from the shallow wells along the Santa Cruz River contains about 500 ppm of dissolved solids, 0.9 ppm fluoride, and has a hardness of about 190 ppm. Whereas the water from the deeper wells in the north and east parts of the city contains about 300 ppm dissolved solids, 0.3 ppm fluoride, and has a hardness of about 120 ppm.

Water containing more than 1,000 ppm of dissolved solids and high fluoride concentrations is found in the western part of the area between the Santa Cruz River and the Tucson Mountains, and north of Rillito Creek and Tanque Verde Wash in the foothills of the Catalina Mountains. However, excessive amounts of dissolved solids are not necessarily indicative of large amounts of fluoride. For example, a water with more than 5 ppm fluoride contained only slightly more than 300 ppm of dissolved solids.

High proportional concentrations of silica are found in the ground water throughout the area. Silica is a good cementing agent and precipitates with the calcium and magnesium salts to form an extremely hard and

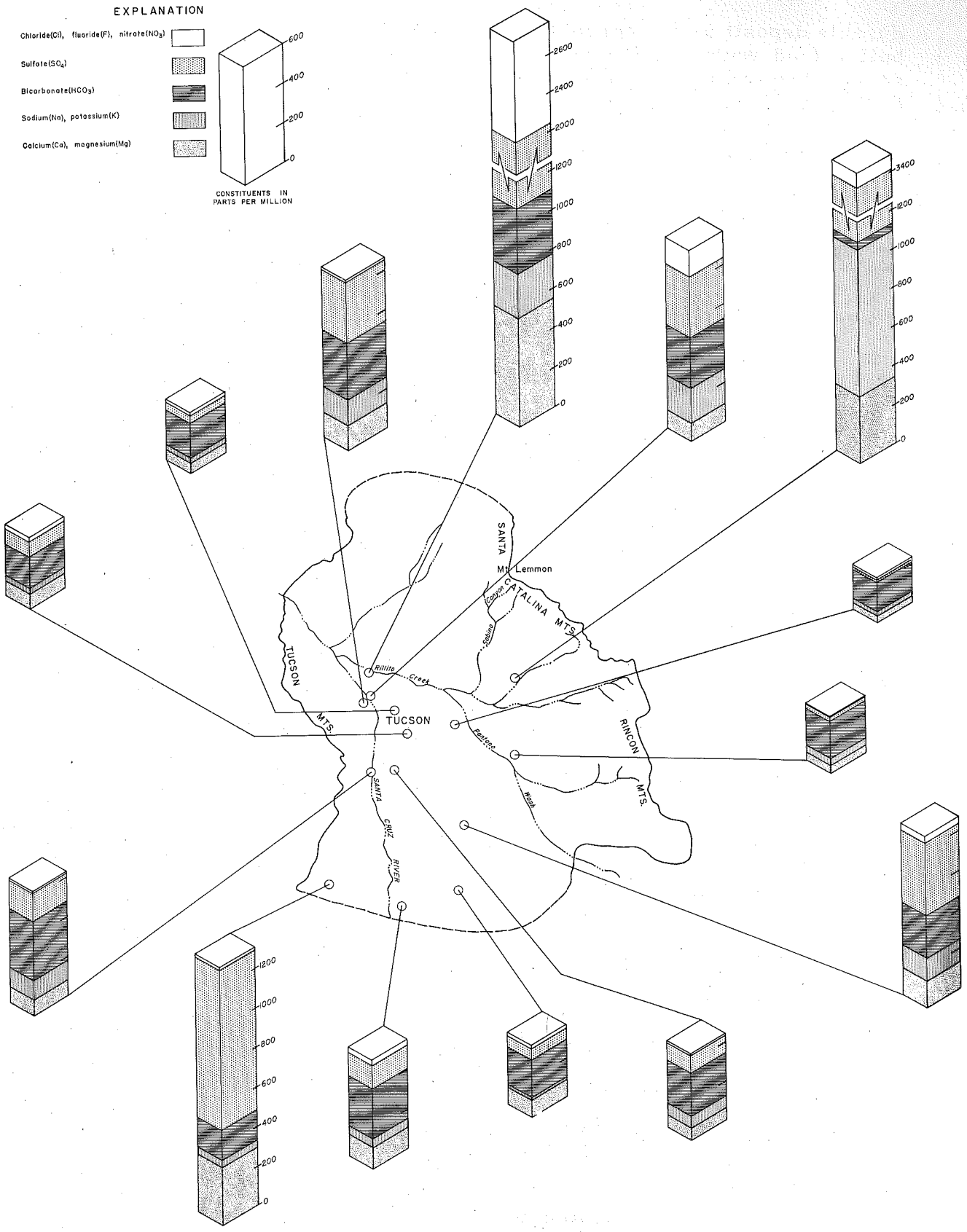


Figure 22.-- Chemical composition of selected ground waters, Tucson Area, Arizona.

durable deposit on the porcelain fixtures in the home. Its presence in boiler-feed water is also particularly troublesome for it causes boiler scale. The maximum allowable silica content in water for boilers producing more than 400 pounds per square inch is 1 ppm.

The approximate range in concentration of several constituents in the public water supplies of the Tucson area does not generally exceed the recommended limits as set forth by the U. S. Public Health Service. Other wells in the area may have excessive amounts of various constituents.

Constituent	Range of constituents (ppm) Public supply wells	All wells in area
Dissolved solids	177 -1,060	177 -5,690
Hardness	94 - 270	94 -3,000
Silica (SiO_2)	27 - 34	14 - 62
Sulfate (SO_4)	9.4- 129	9.4-3,680
Chloride (Cl)	6.0- 322	6.0-1,340
Fluoride (F)	.1- 1.0	.1- 10

Probably the most objectionable quality characteristics of ground water for public supply and indsutrial uses are high hardness properties and large concentrations of fluoride and silica. The use of these objectionable waters has been largely avoided by prudent selection of the good water that is available and the intermixing of fair quality water with good quality water.

The ground water used in Tucson meets the requirements of chemical quality for many uses. The chemical requirements for all uses are not the same, therefore certain quality criteria have been adopted for the use of water for specific purposes as follows.

Quality-of-Water Standards for Domestic and Public Supply

Drinking water should be free from unpleasant tastes, odors, color, turbidity, and harmful microorganisms, and should not contain substances in excess of the following concentrations:

	(Parts per million)
Fluoride	1.5
Lead	.1
Hexavalent chromium	.05
Arsenic	.05
Selenium	.05

These standards were adopted by the U. S. Public Health Service. A public water supply may be rejected if it contains an excess of any of the above constituents. In addition to these mandatory standards, less restrictive tolerances are suggested as follows:

Table 3.--Suggested water-quality tolerances in industry[1]
[Allowable limits in parts per million]

Industry or use	Turbidity	Color	Hardness as $CaCO_3$	Iron as Fe	Manganese	Iron and Manganese	Total solids	Alkalinity as $CaCO_3$	Odor taste	Hydrogen sulfide	Other requirements
Air conditioning	-	-	-	0.5	0.5	0.5	-	-	low	1	No corrosiveness, slime formation
Baking	10	10	-	.2	.2	.2	-	-	low	.2	Potable water[2]
Brewing:											
Light beer	10	-	-	.1	.1	.1	500	75	low	.2	Potable water.[2] NaCl less than 275 ppm (pH 6.5-7.0)
Dark beer	10	-	-	.1	.1	.1	1,000	150	low	.2	Potable water.[2] NaCl less than 275 ppm (pH 7.0 or more)
Canning:											
Legumes	10	-	25-75	.2	.2	.2	-	-	low	1	Potable water[2]
General	10	-	-	.2	.2	.2	-	-	low	1	Potable water[2]
Carbonated beverages	2	10	250	.2	.2	.4	850	50-100	low	.2	Potable water.[2] Organic color plus oxygen consumed less than 10 ppm
Confectionery	-	-	-	.2	.2	.2	100	-	low	.2	Potable water.[2] pH above 7.0 for hard candy
Cooling	50	-	50	.5	.5	.5	-	-	-	5	No corrosiveness, slime formation
Food, general	10	-	-	.2	.2	.2	-	-	low	-	Potable water[2]
Ice	5	5	-	.2	.2	.2	-	-	low	-	Potable water.[2] SiO_2 less than 10 ppm
Laundering	-	-	50	.2	.2	.2	-	-	-	-	Potable water[2]
Plastics, clear uncolored	2	2	-	.02	.02	.02	200	-	-	-	
Paper and pulp:											
Groundwood	50	20	180	1.0	.5	1.0	-	-	-	-	No grit, corrosiveness
Kraft pulp	25	15	100	.2	.1	.2	300	-	-	-	
Soda and sulfite	15	10	100	.1	.05	.1	200	-	-	-	
High-grade light papers	5	5	50	.1	.05	.1	200	-	-	-	
Rayon (viscose), pulp production	5	5	8	.05	.03	.05	100	Total 50; hydroxide 8	-	-	Al_2O_3 less than 8 ppm, SiO_2 less than 24 ppm, Cu less than 5 ppm
Manufacture	.3	-	55	.0	.0		-	-	-	-	pH 7.8 to 8.3
Tanning	20	10-100	50-135	.2	.2	.2	-	Total 135; hydroxide 8	-	-	
Textiles:											
General dyeing	5	5-20	-	.25	.25	.25	200	-	-	-	Constant composition. Residual alumina less than 0.5 ppm
Wool scouring	-	70	-	1.0	1.0	1.0	-	-	-	-	
Cotton bandage	5	5	-	.2	.2	.2	-	-	low	-	

1 Moore, E. W., 1940, Progress report of the committee on quality tolerances of water for industrial uses: Jour. New England Water Works Association, v. 54, p. 271.

2 Conforming to U. S. Public Health Service standards.

	(Parts per million)
Copper	3.0
Iron and manganese (together)	.3
Magnesium	125
Zinc	15
Chloride	250
Sulfate	250
Phenolic compounds (as Phenol)	.005
Dissolved solids	500a/

a/ 1,000 permissible where no better supply available

Hardness is probably the most troublesome constituent of water for domestic and municipal use. In addition to its wasteful soap-consuming property, hardness also causes the formation of scale in water pipes, boilers, kitchen utensils, and other containers.

Iron and manganese also are particularly troublesome when present in water to be used for laundry. Oxides of these metals cause staining of clothing and plumbing fixtures.

Many articles have been published as the result of research on the effects of fluoride in drinking water. There seems to be a relation between the amount of fluoride in drinking water and incidence of tooth decay in children. Tooth decay is apparently reduced if the drinking water contains about 1 ppm of fluoride, but concentrations in excess of 1.5 ppm may cause mottling of the tooth enamel of children who drink such water during the time their permanent teeth are forming. According to the California State Water Pollution Control Board, water containing less than 0.9 to 1.0 ppm of fluoride will seldom cause mottled enamel in children, and for adults, concentrations less than 3 or 4 ppm are not likely to cause harmful accumulations of fluoride in the body.

Quality-of-Water Standards for Industry

The quality of water required for industry varies greatly (table 3). To evaluate the quality of water for use by specific industries is not possible in this report. However, the quality of the process water is often critical and must be treated to suit the particular requirement. For example, in the manufacture of rayon, pharmaceuticals, or for pulp production the water must be very pure. On the other hand, water of almost any quality may be used for cooling or for some mining operations. Uniformity in the quality of the water is often as important as the chemical characteristics.

APPENDIX A

LIST OF PUBLISHED REPORTS ON GEOLOGY AND GROUND-WATER RESOURCES OF ARIZONA

Ground Water Branch
Tucson, Arizona

June 20, 1960

1897 Phoenix Irrigation near Phoenix, Arizona. By A. P. Davis. U. S. Geol. Survey Water-Supply Paper 2. 98 p., 31 pls.

1904 Gila Valley The underground waters of Gila Valley, Arizona. By W. T. Lee. U. S. Geol. Survey Water-Supply Paper 104. 71 p., 5 pls.

1905 Salt River Valley Underground waters of Salt River Valley, Arizona. By W. T. Lee. U. S. Geol. Survey Water-Supply Paper 136. 196 p., 23 pls.

1912 Sulphur Spring Valley Geology and water resources of Sulphur Spring Valley, Arizona. By O. E. Meinzer and F. C. Kelton, with a section on agriculture, by R. H. Forbes. U. S. Geol. Survey Water-Supply Paper 320. 231 p., 15 pls.

1916 Paradise Valley Ground water in Paradise Valley, Arizona. By O. E. Meinzer and A. J. Ellis. U. S. Geol. Survey Water-Supply Paper 375-B. p. 51-75, pls. 3-5.

1916 Navajo country The Navajo country—a geographic and hydrographic reconnaissance of parts of Arizona, New Mexico, and Utah. By H. E. Gregory. U. S. Geol. Survey Water-Supply Paper 380. 219 p., 29 pls.

1918 San Simon Valley Ground water in San Simon Valley, Arizona. By A. T. Schwennesen, with a chapter on agriculture, by R. H. Forbes. U. S. Geol. Survey Water-Supply Paper 425-A. p. 1-35, pls. 1-3.

1921 Gila and San Carlos Valleys Geology and water resources of the Gila and San Carlos Valleys in the San Carlos Indian Reservation, Arizona. By A. T. Schwennesen. U. S. Geol. Survey Water-Supply Paper 450-A. p. 1-27, pls. 1-4.

1923 Lower Gila region The lower Gila region, Arizona, a geographic, geologic, and hydrologic reconnaissance, with a guide to desert watering places. By C. P. Ross. U. S. Geol. Survey Water-Supply Paper 498. 237 p., 23 pls.

1925 Papago country The Papago country, Arizona, a geographic, geologic, and hydrologic reconnaissance with a guide to desert watering places. By Kirk Bryan. U. S. Geol. Survey Water-Supply Paper 499. 436 p., 27 pls.

1937 Avra-Altar Valley Ground water in Avra-Altar Valley, Arizona. By D. A. Andrews. U. S. Geol. Survey Water-Supply Paper 796-E. p. i-ii, 163-180, pls. 41-44.

1938 Gila River and San Simon Creek Geology and ground-water resources of the valley of Gila River and San Simon Creek, Graham County, Arizona. By M. M. Knechtel, with a section on the chemical character of the ground water, by E. W. Lohr. U. S. Geol. Survey Water-Supply Paper 796-F. p. 181-222, pls. 45-53, figs. 29-33.

1939 Holbrook region Ground-water resources of the Holbrook region Arizona. By M. A. Harrell and E. B. Eckel. U. S. Geol. Survey Water-Supply Paper 836-B. p. i-iv, 19-105, pls. 2-11.

1940 Water levels Water levels and artesian pressure in observation wells in the United States in 1939. By O. E. Meinzer, L. K. Wenzel, and others. U. S. Geol. Survey Water-Supply Paper 886. 933 p.

1941 Upper Gila River Valley Ground-water inventory in the Upper Gila River Valley, New Mexico and Arizona; scope of investigation and methods used. By S. F. Turner and L. C. Halpenny. Reprinted in Transactions of 1941 of the Am. Geophys. Union (April 1, 1941).

1941 Recharge from floods Recharge to ground water from floods in a typical desert wash, Pinal County, Arizona. By H. M. Babcock and E. M. Cushing. Reprinted from Transactions of 1942 of the Am. Geophys. Union. p. 49-56.

1941 Water level Pumpage and ground-water levels in Arizona in 1940. By S. F. Turner and others. U. S. Geol. Survey Water-Supply Paper 911. p. 7-103.

1943 Water level Pumpage and ground-water levels in Arizona in 1941. By S. F. Turner and others. U. S. Geol. Survey Water-Supply Paper 941. p. 7-85.

1944 Water level Pumpage and ground-water levels in Arizona in 1942. By S. F. Turner and others. U. S. Geol. Survey Water-Supply Paper 949. p. 7-59.

1945 Water level Pumpage and ground-water levels in Arizona in 1943. By S. F. Turner and others. U. S. Geol. Survey Water-Supply Paper 991. p. 6-71.

1947 Water level Pumpage and ground-water levels in Arizona in 1944. By S. F. Turner and others. U. S. Geol. Survey Water-Supply Paper 1021. p. 5-66.

1949 Water level Pumpage and ground-water levels in Arizona in 1945. By S. F. Turner and others. U. S. Geol. Survey Water-Supply Paper 1028. p. 5-62.

1949 Water level Pumpage and ground-water levels in Arizona in 1946. By S. F. Turner and others. U. S. Geol. Survey Water-Supply Paper 1076. p. 5-93.

1950 Phreatophytes Use of water by bottom-land vegetation in lower Safford Valley, Arizona. By J. S. Gatewood, T. W. Robinson, B. R. Colby, J. D. Hem, and L. C. Halpenny. U. S. Geol. Survey Water-Supply Paper 1103. 210 p., 5 pls.

1950 Gila River Basin Quality of water of the Gila River Basin above Coolidge Dam, Arizona. By J. D. Hem. U. S. Geol. Survey Water-Supply Paper 1104. 230 p., 2 pls., 7 figs., 18 tables.

1951 Navajo and Hopi Indian Reservations Preliminary report on the ground-water resources of the Navajo and Hopi Indian Reservations, Arizona, New Mexico, and Utah. By L. C. Halpenny. N. Mex. Geol. Soc. Guidebook of the San Juan Basin, New Mexico and Arizona. p. 147-154, illus.

1951 Water level Pumpage and ground-water levels in Arizona in 1947. By S. F. Turner and R. L. Cushman. U. S. Geol. Survey Water-Supply Paper 1101. p. 5-72.

1951 Water level Pumpage and ground-water levels in Arizona in 1948. By S. F. Turner and others. U. S. Geol. Survey Water-Supply Paper 1131. p. 5-62.

1952 Flagstaff The relation of geologic activity to the origin of parks and prairies near Flagstaff, Arizona. By J. H. Feth. Reprinted from Plateau, Museum of Northern Arizona, v. 24, no. 3. (January.) p. 104-110.

1952 Phreatophytes Use of water by phreatophytes in 2000-foot channel between Granite Reef and Gillespie dams, Maricopa County, Arizona. By S. F. Turner and H. E. Skibitzke. Reprinted from Transactions of the Am. Geophys. Union, v. 33, no. 1. p. 66-71, 9 figs.

1952 Helium Occurrence of helium in northeastern Arizona (abs.). By L. A. Heindl. Geol. Soc. America Bull., v. 63. p. 1331.

1952 Water level Pumpage and ground-water levels in Arizona in 1949. By S. F. Turner and others. U. S. Geol. Survey Water-Supply Paper 1161. p. 5-63.

1953 Black Mesa basin The Cow Springs sandstone formation of the Black Mesa basin (Arizona) and adjoining areas (abs.). By J. W. Harshbarger. Am. Assoc. Petroleum Geologists Bull., v. 36, no. 5. p. 963-964.

1953 Doney Park-Black Bill Park area A geologic and geophysical reconnaissance of the Doney Park-Black Bill Park area, Arizona, with reference to ground water. By J. H. Feth. U. S. Geol. Survey Circ. 233. 9 p., 1 pl., 1 fig.

1953 Navajo country The Navajo country, Arizona-Utah-New Mexico. By J. W. Harshbarger, C. A. Repenning, and J. T. Callahan. Printed as part of The physical and economic foundation of natural resources, Part IV, Subsurface facilities of water management and patterns of supply—Type area studies, House of Representatives, Interior and Insular Affairs Committee. p. 105-129.

1953 Water level Pumpage and ground-water levels in Arizona in 1950. By S. F. Turner and R. L. Cushman. U. S. Geol. Survey Water-Supply Paper 1170. p. 3-43.

1954 Bidahochi formation Bidahochi formation of Arizona and New Mexico. By C. A. Repenning and J. H. Irwin. Am. Assoc. Petroleum Geologists Bull., v. 38, no. 8. p. 1821-1826.

1954 Chuska Mountains area Water resources of the Chuska Mountains area, Navajo Indian Reservation, Arizona and New Mexico. By J. W. Harshbarger and C. A. Repenning. U. S. Geol. Survey Circ. 308. 16 p., 1 pl., 1 fig., 6 tables.

1954 Fort Wingate Indian School area Geology and ground-water supplies of the Fort Wingate Indian School area, McKinley County, New Mexico. By J. T. Callahan and R. L. Cushman. U. S. Geol. Survey Circ. 360. 24 p., 2 pls., 1 fig., 3 tables.

1954 Navajo country Ground water in the Navajo country. By J. W. Harshbarger. Science, v. 119. p. 421.

1954 Water level Pumpage and ground-water levels in Arizona in 1951. By L. C. Halpenny and R. L. Cushman. U. S. Geol. Survey Water-Supply Paper 1196. p. 3-40.

1955 Safford Valley Effect of western drought on the water resources of Safford Valley, Arizona, 1940-52. By R. L. Cushman and L. C. Halpenny. Reprinted from Transactions of the Am. Geophys. Union, v. 36, no. 1.

1955 Piping and Earthcracks A discussion by L. A. Heindl and J. H. Feth. Published in Transactions of the Am. Geophys. Union, v. 36, no. 2. p. 342-345.

1955 Triassic and Jurassic (correlation and nomenclature) Revisions in correlation and nomenclature of Triassic and Jurassic formations in southwestern Utah and northern Arizona. By Paul Averitt, Janis S. Detterman, J. W. Harshbarger, C. A. Repenning, and R. F. Wilson. Am. Assoc. Petroleum Geologists Bull., v. 39, no. 12. p. 2515-2524, illus.

1955 Water level Pumpage and ground-water levels in Arizona in 1952. By L. C. Halpenny and others. U. S. Geol. Survey Water-Supply Paper 1226. p. 1-42, 12 figs.

1955 Douglas basin Geology and ground-water resources of the Douglas basin, Arizona. By D. R. Coates and R. L. Cushman. U. S. Geol. Survey Water-Supply Paper 1354. 56 p., 5 pls., 5 figs., 4 tables.

1955 Conversion table Phi-millimeter conversion table. By H. G. Page. Jour. Sed. Petrology, v. 25, no. 4. p. 285-292.

1956 Black Mesa Late Cretaceous stratigraphy of Black Mesa, Navajo and Hopi Indian Reservations, Arizona. By C. A. Repenning and H. G. Page. Am. Assoc. Petroleum Geologists Bull., v. 40, no. 2.

1956 Water level Pumpage and ground-water levels in Arizona in 1953. By L. C. Halpenny and others. U. S. Geol. Survey Water-Supply Paper 1270. p. 3-41, 11 figs.

1956 Water level Pumpage and ground-water levels in Arizona in 1955. By P. W. Johnson, N. D. White, and J. M. Cahill. Arizona State Land Dept. Water Resources Rept. 1. 69 p., 30 figs., 1 table.

1956 Bill Williams River valley Water resources of the Bill Williams River valley near Alamo, Arizona. By H. N. Wolcott, H. E. Skibitzke, and L. C. Halpenny. U. S. Geol. Survey Water-Supply Paper 1360-D. 28 p., 1 pl., 5 figs., 5 tables.

1957 Triassic and Jurassic (stratigraphy) Stratigraphy of the uppermost Triassic and the Jurassic rocks of the Navajo country. By J. W. Harshbarger, C. A. Repenning, and J. H. Irwin. U. S. Geol. Survey Prof. Paper 291. 74 p., 3 pls., 38 figs.

1957 Water level Pumpage and ground-water levels in Arizona in 1954. By P. W. Johnson, N. D. White, and H. N. Wolcott. U. S. Geol. Survey Water-Supply Paper 1326. p. 3-43, 24 figs.

1957 Water level Annual report on ground water in Arizona—spring 1956 to spring 1957. By J. W. Harshbarger and others. Arizona State Land Dept. Water Resources Rept. 2. 42 p., 18 figs., 1 table.

1957 Harquahala Plains area Geology and ground-water resources of the Harquahala Plains area, Maricopa and Yuma Counties, Arizona. By D. G. Metzger. Arizona State Land Dept. Water Resources Rept. 3. 40 p., 2 pls., 7 figs., 4 tables.

1957 Arizona Use of ground water in Arizona. By J. W. Harshbarger. In Climate and Man in the Southwest. Univ. Arizona Bull., v. XXVIII, no. 4. p. 51-68.

1958 Water level Pumpage and ground-water levels in Arizona in 1955. By P. W. Johnson, N. D. White, and J. M. Cahill. U. S. Geol. Survey Water-Supply Paper 1409. p. 3-61, 44 figs.

1958 Palomas Plain-Dendora Valley area 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 Dept. Water Resources Rept. 4. 49 p., 3 pls., 4 figs., 5 tables.

1958 Black Mesa basin Ground water in Black Mesa basin and adjacent areas. By J. P. Akers and J. W. Harshbarger. New Mexico Geol. Soc. Guidebook, 9th Field Conf. p. 173-183, 8 figs.

1958 Black Mesa basin Moenkopi and Chinle formations of Black Mesa basin and adjacent areas. By J. P. Akers, M. E. Cooley, and C. A. Repenning. New Mexico Geol. Soc. Guidebook, 9th Field Conf. p. 88-94, 4 figs.

1958 Water level Annual report on ground water in Arizona—spring 1957 to spring 1958. By W. F. Hardt, J. M. Cahill, and M. B. Booher. Arizona State Land Dept. Water Resources Rept. 5. 60 p., 19 figs., 1 table.

1959 Papago Indian Reservation Precambrian and Paleozoic sedimentary rocks on the Papago Indian Reservation, Arizona. By N. E. McClymonds. Arizona Geol. Soc. Southern Arizona Guidebook II. p. 77-84, 1 fig.

1959 San Xavier Indian Reservation Geology of the San Xavier Indian Reservation, Arizona. By L. A. Heindl. Arizona Geol. Soc. Southern Arizona Guidebook II. p. 153-159, 1 fig.

1959 Southern Arizona valleys Test holes in southern Arizona valleys. By P. W. Johnson. Arizona Geol. Soc. Southern Arizona Guidebook II. p. 62-65, 1 table, 1 fig.

1959 Waterman Mountains Paleozoic stratigraphy of the Waterman Mountains, Pima County, Arizona. By N. E. McClymonds. Arizona Geol. Soc. Southern Arizona Guidebook II. p. 67-76, 2 figs.

1959 Water level Annual report on ground water in Arizona—spring 1958 to spring 1959. By W. F. Hardt, R. S. Stulik, and M. B. Booher. Arizona State Land Dept. Water Resources Rept. 6. 61 p., 18 figs., 1 table.

1960 Arizona Topographic, physiographic, and structural subdivisions of Arizona. By L. A. Heindl and J. F. Lance. Arizona Geol. Soc. Digest, v. III. p. 12-18, 2 figs.

1960 Bonita Creek area Geology of the lower Bonita Creek area (A preliminary report). By L. A. Heindl. Arizona Geol. Soc. Digest, v. III. p. 35-39, 1 fig.

1960 Cameron and Leupp Geology of the Cameron and Leupp quadrangles, Arizona. By J. P. Akers. Arizona Geol. Soc. Digest, v. III. p. 43-44.

1960 Navajo Indian Reservation Current assistance in water-development program of Navajo Tribe, Arizona and New Mexico. By J. P. Akers. Arizona Geol. Soc. Digest, v. III. p. 45.

1960 Papago Indian Reservation Cenozoic geology of the Papago Indian Reservation, Pima, Maricopa, and Pinal Counties, Arizona (A preliminary summary). By L. A. Heindl. Arizona Geol. Soc. Digest, v. III. p. 31-34.

1960 Red Lake area Ground water in the Red Lake area, Navajo Indian Reservation, Arizona and New Mexico. By J. P. Akers. Arizona Geol. Soc. Digest, v. III. p. 41-42.

1960 Safford basin Geology of the eastern part of the Safford basin, Graham County, Arizona (A preliminary report). By E. S. Davidson. Arizona Geol. Soc. Digest, v. III. p. 123-126, 1 fig.

APPENDIX B

LIST OF UNPUBLISHED REPORTS ON THE GEOLOGY AND GROUND-WATER RESOURCES OF ARIZONA

Ground Water Branch
U. S. Geological Survey
Tucson, Arizona

June 20, 1960

ARIZONA GENERAL

c/ Arid Lands Physical phenomena in arid-zone hydrology. By H. E. Skibitzke and N. D. White. April 4, 1959. 19 p., 5 figs.

b/ Arid Lands Geohydrology of arid lands (Arizona—a case study). By J. W. Harshbarger. September 1959. 28 p., 7 figs.

a/ Arizona (central) Water supply of the central Arizona area. Answers to 24 questions by J. Richard Queen, Staff Consultant, Committee of Interior and Insular Affairs, House of Representatives. August 1951. 18 p., 1 pl.

a/ Arizona (central) Answers to 24 questions asked by the Honorable John R. Murdock, Member of Congress from Arizona, by letter of December 7, 1951 to the Director, U. S. Geological Survey. Answers prepared by L. C. Halpenny, R. L. Cushman, and J. H. Feth. February 1952. 13 p.

c/ Big Sandy Valley Ground-water resources of the Big Sandy Valley, Mohave County, Arizona. By R. B. Morrison. December 30, 1940. 6 p., 1 map.

c/ Big Sandy Valley Records of wells and springs, well logs, water analyses and maps showing locations of wells and springs in Big Sandy Valley, Mohave County, Arizona. By R. B. Morrison. July 21, 1941. 16 tables, 3 figs.

c/ Cactus Flat-Artesia area Ground-water resources and problems of the Cactus Flat-Artesia area, San Simon Basin, Arizona. By L. C. Halpenny, R. L. Cushman, and J. D. Hem. January 21, 1947. 14 p., 3 pls., 2 figs.

---

a/ Available for distribution.

b/ Open-file inspection, Tucson office only.

c/ Loan copy available.

c/ Bonita Creek area Geology and the availability of water in the lower Bonita Creek area, Graham County, Arizona. By L. A. Heindl and R. A. McCullough. February 1960. 81 p., 14 figs., 4 tables.

a/ Date Creek area Water supply of Date Creek area, Yavapai County, Arizona. By H. M. Babcock and S. C. Brown. January 20, 1948. 2 p., 2 figs., 3 tables.

a/ Deer Valley Ground-water resources of Deer Valley, Maricopa County, Arizona. By F. I. Bluhm and H. N. Wolcott. October 15, 1949. 34 p., 3 pls., 2 figs.

c/ Dripping Springs basin Memorandum on the geology and ground-water resources of Dripping Springs basin, Gila and Pinal Counties, Arizona. By D. R. Coates. May 1955. 11 p., 2 figs., 1 pl., 4 tables.

c/ Duncan Basin Ground-water resources of the Duncan Basin, Arizona. By L. C. Halpenny, H. M. Babcock, R. B. Morrison, and J. D. Hem. January 4, 1947. 21 p., 2 pls., 2 figs., 3 tables.

c/ Duncan-Virden Valley Records of wells and springs, well logs, water analyses and map showing locations of wells and springs in Duncan-Virden Valley, Greenlee County, Arizona, and Hidalgo County, New Mexico. By R. B. Morrison and H. M. Babcock. September 1, 1942. 29 p., 1 map.

c/ Gila Bend Basin Geology and ground-water resources of the Gila Bend Basin, Maricopa County, Arizona. By H. M. Babcock and K. K. Kendall, with a section on quality of water by J. D. Hem. February 18, 1948. 26 p., 3 pls.

b/ Gila Bend and Dendora area Ground-water resources and geology of the Gila Bend and Dendora areas, Maricopa County, Arizona. By P. W. Johnson and J. M. Cahill. March 1955. 43 p., 4 pls., 6 figs., 5 tables.

c/ Gila River basin Ground water in the Gila River basin and adjacent area, Arizona—a summary. By L. C. Halpenny and others. October 1952. 224 p., 32 pls., 24 figs.

b/ Gila River (upper) Stratigraphic relationships within Cenozoic alluvial deposits of the upper Gila River drainage (abs.). By L. A. Heindl. 1957. 1 p.

c/ Gila and Salt Rivers Safe yield of the ground-water reservoirs in the drainage basins of the Gila and Salt Rivers, near Phoenix. By S. F. Turner, H. R. McDonald, and R. L. Cushman. 1945. 11 p., 1 pl., 2 figs., 3 tables.

c/ Graham and Greenlee Counties Analyses of samples from ground-water sources, Graham and Greenlee Counties, Arizona. 1940-42. 10 p.

c/ Grand Canyon Availability of water along the south rim, Grand Canyon National Park, Arizona. By D. G. Metzger. October 1959. 81 p., 5 figs., 2 tables.

c/ Holbrook area Ground-water resources of the Holbrook area, Navajo County, Arizona. By H. M. Babcock and C. T. Snyder. February 21, 1947. 27 p., 3 pls.

a/ Joseph City Irrigation District Memorandum on ground-water supply of the Joseph City Irrigation District. By H. M. Babcock. August 1948. 8 p., 1 fig.

c/ Kingman area Letter regarding an investigation to determine the possibilities of an additional water supply for the Army Air Force Flexible Gunnery School near Kingman, Arizona. By S. F. Turner and J. F. Poland. April 19, 1943 (released to the open file June 19, 1959). 10 p., 1 table, 1 map.

c/ Kingman area Letter regarding a further investigation to determine the possibilities of an additional water supply for the Army Air Force Flexible Gunnery School near Kingman, Arizona. By S. F. Turner. July 30, 1943 (released to the open file June 19, 1959). 5 p., 2 maps, 1 diagram.

c/ Kingman area Water supply, Army Air Force Flexible Gunnery School, Kingman, Arizona. By E. R. Bowen and S. F. Turner. August 31, 1943 (released to the open file June 19, 1959). 7 p., 3 tables, 9 diagrams.

c/ Kingman area Character and structure of volcanic rocks near Kingman, Ariz., with respect to water-yielding capacity. By A. M. Piper and J. F. Poland. September 14, 1943 (released to the open file June 19, 1959). 14 p., 2 pls.

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

b/ Mammoth Cenozoic alluvial deposits in the vicinity of Mammoth. Pinal County, Arizona (abs.). By L. A. Heindl. 1957. 2 p.

c/ McMullen Valley area 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.

a/ Mogollon Rim region Preliminary report of investigations of springs in the Mogollon Rim region, Arizona. By J. H. Feth, with sections on base flow of streams by N. D. White and quality of water by J. D. Hem. June 1954. 77 p., 5 pls., 24 figs., 10 tables.

c/ Oracle Memorandum on geology and ground-water resources in the vicinity of Oracle, Pinal County, Arizona. By L. A. Heindl. February 1955. 11 p., 2 figs., 2 tables.

c/ Oracle and Oracle Junction Ground-water conditions between Oracle and Oracle Junction, Pinal County, Arizona. By L. A. Heindl. April 1955. 5 p., 1 fig., 2 tables. (A supplement to "Memorandum on geology and ground-water resources in the vicinity of Oracle, Pinal County, Arizona.")

c/ Organ Pipe Cactus National Monument Memorandum of geology of ground water in Organ Pipe Cactus National Monument. By D. R. Coates. 1951. 10 p., 1 map.

a/ Paradise Valley Geology and ground-water resources of Paradise Valley, Maricopa County, Arizona. By H. R. McDonald, H. N. Wolcott, F. I. Bluhm, and J. D. Hem. January 8, 1947. 34 p., 1 pl., 1 fig.

c/ Patagonia area Geologic and ground-water reconnaissance of the Patagonia area, Arizona. By J. H. Feth. 1954. 12 p., 1 fig.

c/ Peeples Valley Ground-water resources of Peeples Valley, Arizona. By H. M. Babcock and S. C. Brown. January 8, 1947. 13 p., 1 pl.

c/ Pinal Creek (upper) Geology and ground-water resources of the upper Pinal Creek area, Arizona. By G. E. Hazen and S. F. Turner. December 18, 1946. 55 p., 12 pls., 3 figs.

c/ Queen Creek area Records of wells, well logs, water analyses and a map showing locations of wells of Queen Creek area, Maricopa and Pinal Counties, Arizona. By H. M. Babcock and L. C. Halpenny. September 1942. 39 p.

c/ Queen Creek area Records of wells and springs in the Queen Creek area, Maricopa and Pinal Counties, Arizona. By H. E. Skibitzke, C. B. Yost, Jr., A. D. Pulido, and others. 1950. 73 p.

c/ Rainbow Valley-Waterman Wash area Memorandum on ground-water resources and geology of Rainbow Valley-Waterman Wash area, Arizona. By H. N. Wolcott. 1953. 13 p., 1 pl.

c/ Ranegras Plain area Geology and ground-water resources of the northern part of the Ranegras Plain area, Yuma County, Arizona. By D. G. Metzger. February 1951. 47 p., 4 pls.

c/ Red Rock quadrangle Structural reconnaissance of the Red Rock quadrangle, Arizona. By J. H. Feth. February 1951. 34 p., 2 pls., 6 figs.

a/ Rillito Creek Capturing additional water in the Tucson area. By the Rillito Creek Hydrol. Research Comm. of the Univ. Arizona and the U. S. Geol. Survey. June 1959. 59 p., 18 figs., 6 tables.

c/ Safford Basin Ground-water resources and problems of Safford Basin, Arizona. By S. F. Turner and others. December 9, 1946. 28 p., 3 pls., 4 figs.

c/ Safford Valley Records of wells and springs, well logs, water analyses and map showing locations of wells and springs in Safford Valley, Graham County, Arizona. By R. B. Morrison, H. R. McDonald, and W. T. Stuart. July 10, 1942. 102 p., 1 map.

c/ Safford and Duncan-Virden Valleys Water resources of Safford and Duncan-Virden Valleys, Arizona and New Mexico. By S. F. Turner and others. August 15, 1941. 49 p., 28 tables, 15 figs., 2 pls.

a/ Salt River Valley area Geology and ground-water resources of the Salt River Valley area, Maricopa and Pinal Counties, Arizona. By H. R. McDonald, H. N. Wolcott, and J. D. Hem. February 4, 1947. 45 p., 4 pls., 3 figs.

b/ San Manuel Letter from Acting Director, U. S. Geological Survey, to Administrator, Reconstruction Finance Corporation, giving available data on ground water in the vicinity of the San Manuel copper mine, Pinal County, Arizona. By Acting Director, U. S. Geol. Survey. September 1952. 6 p.

c/ San Simon Basin Geology and ground-water resources of the San Simon Basin, Cochise and Graham Counties, Arizona. By R. L. Cushman and R. S. Jones, with a section on quality of water by J. D. Hem. March 11, 1947. 27 p., 2 pls., 2 figs.

c/ Santa Cruz Basin Ground-water resources of the Santa Cruz Basin, Arizona. By S. F. Turner and others. May 1, 1943. 84 p., 3 pls., 4 figs.

a/ Santa Cruz Basin Further investigations of the ground-water resources of the Santa Cruz Basin, Arizona. By S. F. Turner and others. March 11, 1947. 7 p., 4 figs., 4 tables.

c/ Tucson quadrangle Geology of the Tucson quadrangel, Arizona. By B. N. Moore, C. F. Tolman, Jr., B. S. Butler, and R. M. Hernen. 1941. 20 p.

b/ Tucson quadrangle Ground water in the Tucson quadrangle, Arizona. By S. F. Turner. 1946. 15 p., 4 illus., 2 maps.

c/ Tucson to Nogales Ground-water field trip, Tucson to Nogales, Arizona. By D. R. Coates and L. C. Halpenny. April 1954. 20 p., 1 pl.

c/ Verde River Valley Geology and ground-water resources of the Verde River Valley near Fort McDowell, Arizona. By H. R. McDonald and H. D. Padgett, Jr. November 1, 1945. 86 p., 5 pls., 14 figs., 11 tables.

b/ Verde River Valley Further investigations of the ground-water resources of the Verde River Valley near Fort McDowell, Arizona. By H. R. McDonald and F. I. Bluhm. May 20, 1946. 12 p., 2 pls., 3 tables.

a/ Verde River Valley Geophysical investigation of possible aquifers in the vicinity of Williams and Moore Ranches, Verde River Valley, Arizona. By H. R. McDonald, H. N. Wolcott, and R. I. Bluhm. 1948. 3 p., 1 pl., 2 figs., 1 table.

a/ Wellton-Mohawk area Geology and ground-water resources of the Wellton-Mohawk area, Yuma County, Arizona. By H. M. Babcock, S. C. Brown, and J. D. Hem. April 15, 1947. 22 p., 2 pls., 2 figs.

a/ Wellton-Mohawk area Records of wells, well logs, water analyses, and maps showing location of wells in Wellton-Mohawk area, Yuma County, Arizona. By H. M. Babcock and A. M. Sourdry. 1948. 39 p., 1 pl.

a/ Willcox Basin Geology and ground-water resources of the Willcox Basin, Cochise and Graham Counties, Arizona. By R. S. Jones, R. L. Cushman, and J. D. Hem. May 1, 1947. 35 p., 4 tables, 1 pl., 1 fig.

b/ Williams River and Kirkland Creek Geology of dam sites on Williams River and Kirkland Creek, Arizona. By Edwin B. Eckel. November 23, 1940. 14 p., 6 figs., 2 maps.

b/ Wupatki and Sunset Crater National Monuments Ground water in the Wupatki and Sunset Crater National Monuments, Coconino County, Arizona. By O. J. Cosner. August 1955. 19 p., 1 pl., 3 figs., 4 tables.

c/ Yuma area Analysis of basic data concerning ground water in the Yuma area, Arizona. By R. H. Brown, J. W. Harshbarger, and H. E. Thomas. 1956. 117 p., 2 pls., 43 figs., 2 tables, 2 apps.

b/ Yuma County Memorandum on ground-water conditions in parts of Tps. 10 and 11 S., Rs. 23 and 24 W., Yuma County, Arizona. By P. W. Johnson. January 1954. 5 p.

INDIAN RESERVATIONS

Hopi Indian Reservation

b/ Keams Canyon area Water-supply investigation of Keams Canyon area, Hopi Indian Reservation, Navajo County, Arizona. By C. A. Repenning, L. C. Halpenny, and J. D. Hem. January 1951. 42 p., 1 pl., 2 figs.

Hualapai Indian Reservation

c/ Hualapai Indian Reservation Geology and promising areas for ground-water development in the Hualapai Indian Reservation, Arizona. By F. R. Twenter. October 1959. 95 p., 9 figs., 1 table.

Navajo Indian Reservation

a/ Black Mesa basin Ground water in Black Mesa basin and adjacent areas. By J. P. Akers and J. W. Harshbarger. July 1958. 19 p., 8 figs.

b/ Buell Park-Sawmill area Water-supply investigation of the Buell Park-Sawmill area, Navajo Indian Reservation, Apache County, Arizona. By H. A. Whitcomb, L. C. Halpenny, and J. D. Hem. August 12, 1950. 20 p., 1 pl., 3 tables.

c/ Chinle Water-supply investigation at Chinle, Navajo Indian Reservation, Arizona. By L. C. Halpenny and S. C. Brown. March 17, 1948. 10 p., 1 pl.

c/ Fort Defiance Water-supply investigation at Fort Defiance area, Apache County, Navajo Indian Reservation, Arizona. By L. C. Halpenny, S. C. Brown, and J. D. Hem. March 1949. 10 p., 2 pls., 1 table.

b/ Hopi Buttes area The occurrence of ground water in diatremes of the Hopi Buttes area, Arizona. By J. T. Callahan, William Kam, and J. P. Akers. 1958. 17 p., 2 figs., 2 tables.

a/ Lukachukai Water-supply investigation at Lukachukai, Navajo Indian Reservation, Arizona. By S. C. Brown and L. C. Halpenny, February 25, 1949. 8 p., 1 fig.

b/ Navajo Mountain Water-supply investigation at Navajo Mountain, Navajo Indian Reservation, San Juan County, Utah. By S. C. Brown, L. C. Halpenny, and H. A. Whitcomb. September 12, 1949. 9 p., 1 fig., 2 tables.

c/ Red Lake area Preliminary report on the availability of water in the Red Lake area, Navajo Indian Reservation, Arizona and New Mexico. By J. P. Akers, N. E. McClymonds, and J. W. Harshbarger. February 1959. 22 p., 4 tables, 2 maps.

c/ Tuba City Water-supply investigation at Tuba City, Navajo Indian Reservation, Arizona. By S. C. Brown and L. C. Halpenny. March 19, 1948. 14 p., 1 pl., 1 fig.

Papago Indian Reservation

b/ Chiu Chuischu Location of sites for irrigation wells near Chiu Chuischu, Papago Indian Reservation, Pinal County, Arizona. By H. E. Skibitzke and C. B. Yost, Jr. 1951. 6 p., 3 figs.

a/ Chiu Chuischu area Geophysical and geological reconnaissance to determine ground-water resources of Chiu Chuischu area, Papago Indian Reservation, Arizona. By C. B. Yost, Jr. July 1953. 25 p., 3 pls., 3 figs.

b/ Sells Memorandum on ground-water investigations in the Sells area, Papago Indian Reservation, Pima County, Arizona. By D. R. Coates. November 1954. 6 p., 1 pl.