# Ground-Water Conditions in the Rainbow Valley and Waterman Wash Areas Maricopa and Pinal Counties Arizona

*By* NATALIE D. WHITE

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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# GROUND-WATER CONDITIONS IN THE RAINBOW VALLEY AND WATERMAN WASH AREAS, MARICOPA AND PINAL COUNTIES, ARIZONA

By Natalie D. White


## ABSTRACT

The area discussed in this report is in south-central Arizona and includes two valleys—the Rainbow Valley and Waterman Wash areas—where ground water is used for irrigation. The two valleys are separated by a low saddle cut on granite that has been partly covered by alluvium. The granite is exposed across the saddle in small hills and in the bottoms of dry washes, and it effectively separates the Rainbow Valley and Waterman Wash areas into two distinct ground-water basins. The valleys, consisting largely of piedmont slopes extending from the foot of the mountains to the center of each valley, are typical of the Basin and Range province in Arizona. Tertiary and Quarternary alluvial material, consisting of lenticular deposits of gravel, sand, silt, and clay of variable thickness, occupies the intermontane troughs.

In the Rainbow Valley area ground water is under water-table conditions in the sand and gravel lenses of the alluvial fill and to some extent in lavas near the Gila River south of Gillespie Dam. The general pattern of movement of ground water is southwestward toward the Gila River and from north to south along the river. Water levels in the area are declining in response to the discharge of ground water in excess of replenishment. In the center of the irrigated area, the water table declined more than 100 feet in the 9-year period 1952–61.

For the most part, the ground water in the Waterman Wash area is under water-table conditions although some water may be under artesian conditions locally. Medium to high water-yielding materials of the alluvial fill, composed mostly of sand and gravel with lesser amounts of silt and clay, constitute the major aquifer in the area. In 1960, about 60,000 acre-feet of ground water was pumped from the aquifer in the Waterman Wash area. It is estimated that more than 80 percent of this water was removed from storage. Water-level declines for the period 1952–61 ranged from about 20 feet on the edge of the irrigated area to more than 80 feet in the center. Seven million acre-feet of ground water is estimated to be available from storage in the area from a depth of about 300 to 800 feet below the land surface. By definition, this is the amount of water in storage that will drain by gravity to wells. The ability to actually

withdraw the full amount is contingent upon several factors, such as the depth and distribution of wells and operation of the ground-water reservoir at optimum rates and schedules of pumping. The quality of the ground water at depth will also affect the amount of water that can be used.

## INTRODUCTION

The investigation of the ground-water conditions in the Rainbow Valley and Waterman Wash areas was undertaken by the U.S. Geological Survey at the request of the U.S. Bureau of Land Management. Information was needed regarding the availability of ground water as a basis for controlling additional agricultural development.

### LOCATION AND GENERAL FEATURES OF THE AREA

The area discussed in this report is in the southeastern part of Maricopa County and the northwestern part of Pinal County in south-central Arizona (fig. 1) and includes two irrigated valleys. On most maps both valleys are called Rainbow Valley; however, in this report the northwestward-trending valley lying between the Sierra Estrella and the Maricopa Mountains and drained by Waterman Wash is called the Waterman Wash area (pl. 1). The smaller southwestward-trending valley lying between the Buckeye Hills and the north edge of the Maricopa Mountains, which drains into the Gila River, is called the Rainbow Valley area.

The Rainbow Valley area is hydrologically a part of the Gila River valley, and the data given on the maps and in the report extend south of the area of Rainbow Valley as defined herein. No attempt has been made, however, to include detailed data for the extended area. The Rainbow Valley area is bounded on the northwest by the Buckeye Hills, on the southwest by the Gila River, and on the southeast by the northern part of the Maricopa Mountains and an arbitrary line extending westward through T. 3 S., R. 4 W. to the Gila River. It is separated on the east from the Waterman Wash area by the surface-drainage divide extending through T. 2 S., R. 3 W.

The Waterman Wash area is bounded on the north by outliers of the Sierra Estrella and the Buckeye Hills and on the east by the Sierra Estrella and Palo Verde Mountains. On the south the area is bounded by the southern part of the Maricopa Mountains and the Booth and Haley Hills and on the west by the Maricopa Mountains.

### PURPOSE AND SCOPE

The purposes of the investigation were to determine and to describe the ground-water conditions in the Rainbow Valley and Waterman Wash areas with special emphasis on the effect of increased development of the water resources. The source and movement of the ground

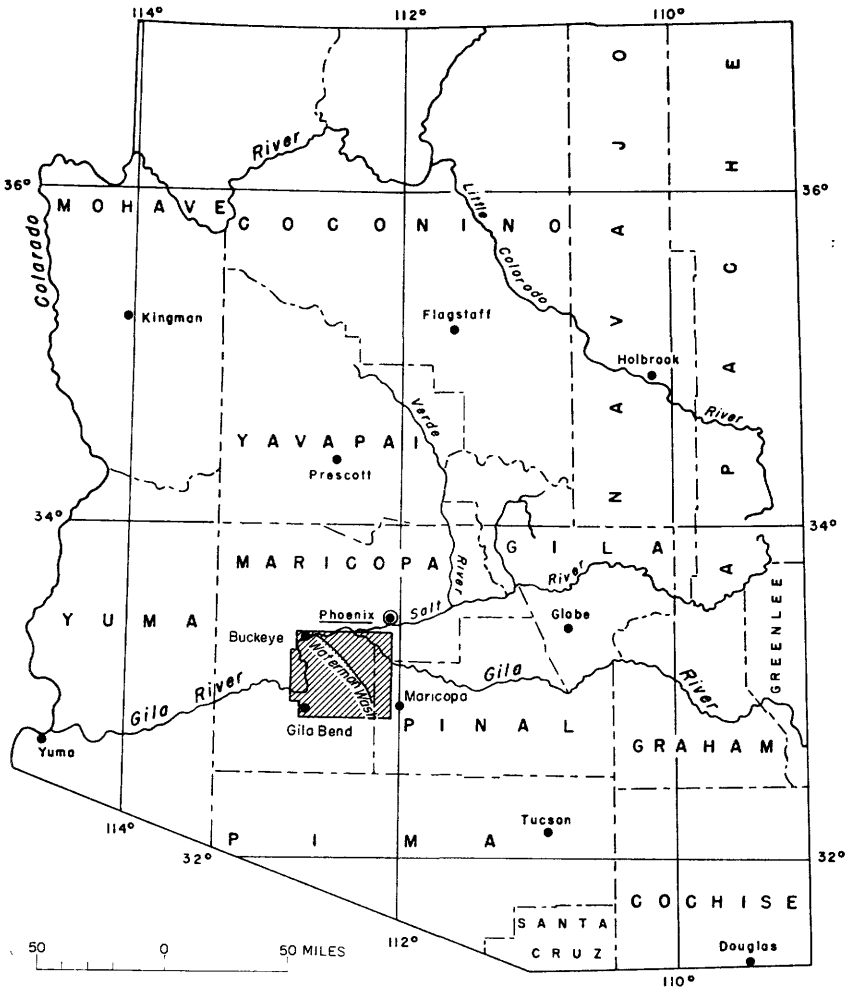


FIGURE 1.—Map of Arizona showing area of report.

water, the recharge and discharge relations, and the effects of present and proposed future pumping on the water levels are described in the report for each area separately. The determination of the amount of ground water available from storage in the aquifer is a significant part of the overall evaluation of the water resources of the Waterman Wash area. For the Rainbow Valley area, no attempt was made to determine the amount of ground water available from storage because the area is only part of the much larger Gila River valley.

The investigation included a general geologic reconnaissance and a field inventory of existing wells. Water levels were measured in September 1960 during the pumping season and again in January

1961 after the water levels had recovered from the seasonal drawdown caused by pumping.

## CLIMATE

The climate of the Rainbow Valley and Waterman Wash areas is typically arid and is characterized by low precipitation and high summer temperatures, which, combined with the low humidity, cause high evaporation rates. The arid conditions result in a large percentage of the precipitation being evaporated before it can be used beneficially by crops or as recharge to the ground-water reservoir.

There are no climatological stations within the two areas of this study, but data are shown in table 1 for several nearby stations having similar conditions and altitudes. Data from these stations indicate that the average annual precipitation is about 6½ inches in the Rainbow Valley area and 7½ inches in the Waterman Wash area. The mean annual temperature is about 70°F for both areas. The data were taken from a compilation by the staff of the Institute of Atmospheric Physics, University of Arizona (Sellers, 1960). The period of record from which the averages were computed is: Maricopa 9 SSW, 1899–1957; Buckeye, 1893–1957; and Gila Bend, 1893–1957.

In arid climates the amount of water that evaporates and transpires is much less than that which would evaporate and transpire if it were available. Thornthwaite (1948) has devised a method for computing the so-called potential evapotranspiration based on temperature and the latitude of the station. For the Rainbow Valley area, the temperatures at Buckeye and at Gila Bend were averaged, and this figure was used to compute the potential evapotranspiration. For the Waterman Wash area, data for Buckeye and Maricopa were used. These potential evapotranspiration rates are shown graphically in figure 2 where they are compared with the monthly precipitation. In both the Rainbow Valley and the Waterman Wash areas, precipitation is slightly greater than potential evapotranspiration in January and December. During the other months of the year, potential evapotranspiration is greatly in excess of precipitation.

## ACKNOWLEDGMENTS

The author wishes to acknowledge the assistance of those who provided some of the information for this investigation. Several landowners, well drillers, and other individuals provided information about wells in the areas. Several water-level measurements, logs of wells, sample cuttings, and electric logs were furnished to the Geological Survey by Samuel F. Turner, consulting engineer, Phoenix.

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TABLE 1.—*Climatic data for stations near the Rainbow Valley and Waterman Wash areas*

[Upper figures refer to precipitation, in inches; lower figures refer to temperature, in degrees Fahrenheit. Mean for period of record indicated. Data from Sellers (1960)]

| Station | Altitude (feet above mean sea level) | Period of record [1] | Average length of record (years) | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Maricopa, 9 SSW. 32°55′ | 1,400 | 1899–1957 | 51 | 0.64 | 0.68 | 0.51 | 0.30 | 0.13 | 0.12 | 1.16 | 1.20 | 0.88 | 0.44 | 0.56 | 0.87 | 7.49 |
| | | | 45 | 48.6 | 53.5 | 58.9 | 66.6 | 75.0 | 84.9 | 91.2 | 89.6 | 83.1 | 70.5 | 57.3 | 49.7 | 69.1 |
| Buckeye, 33°22′ | 888 | 1893–1957 | 62 | .89 | .74 | .70 | .31 | .10 | .08 | 1.01 | 1.14 | .63 | .45 | .62 | .85 | 7.52 |
| | | | 60 | 50.5 | 54.7 | 59.7 | 66.6 | 74.2 | 82.7 | 89.6 | 88.6 | 82.4 | 70.0 | 58.3 | 51.0 | 69.0 |
| Gila Bend, 32°57′ | 737 | 1893–1957 | 55 | .60 | .47 | .62 | .22 | .11 | .07 | .82 | .91 | .47 | .36 | .45 | .59 | 5.69 |
| | | | 47 | 53.0 | 56.9 | 62.4 | 69.4 | 77.0 | 86.3 | 92.8 | 91.2 | 86.2 | 74.2 | 61.2 | 53.5 | 72.0 |

[1] Period of years during which records were reported; not necessarily continuous.

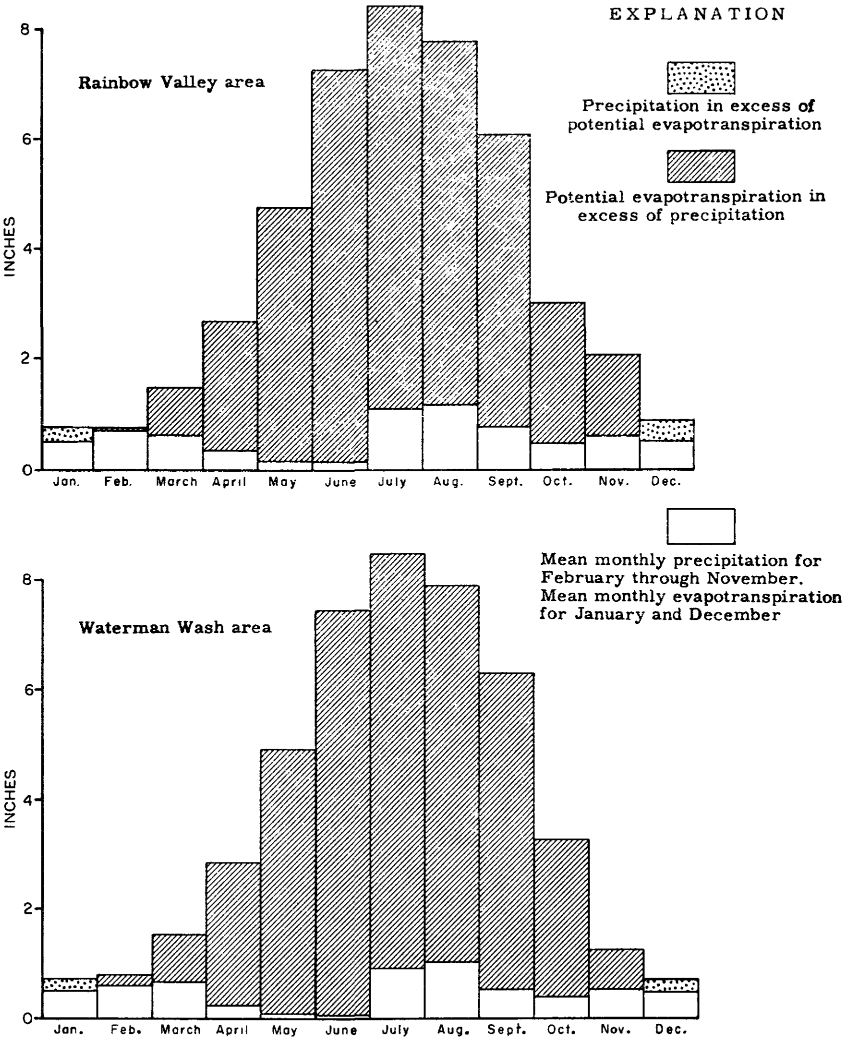


FIGURE 2.—Precipitation and potential evapotranspiration, Rainbow Valley and Waterman Wash areas.

## WELL-NUMBERING SYSTEM

The well numbers used by the U.S. Geological Survey in Arizona are in accordance with the U.S. 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 divides the State into four quadrants (fig. 3). 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

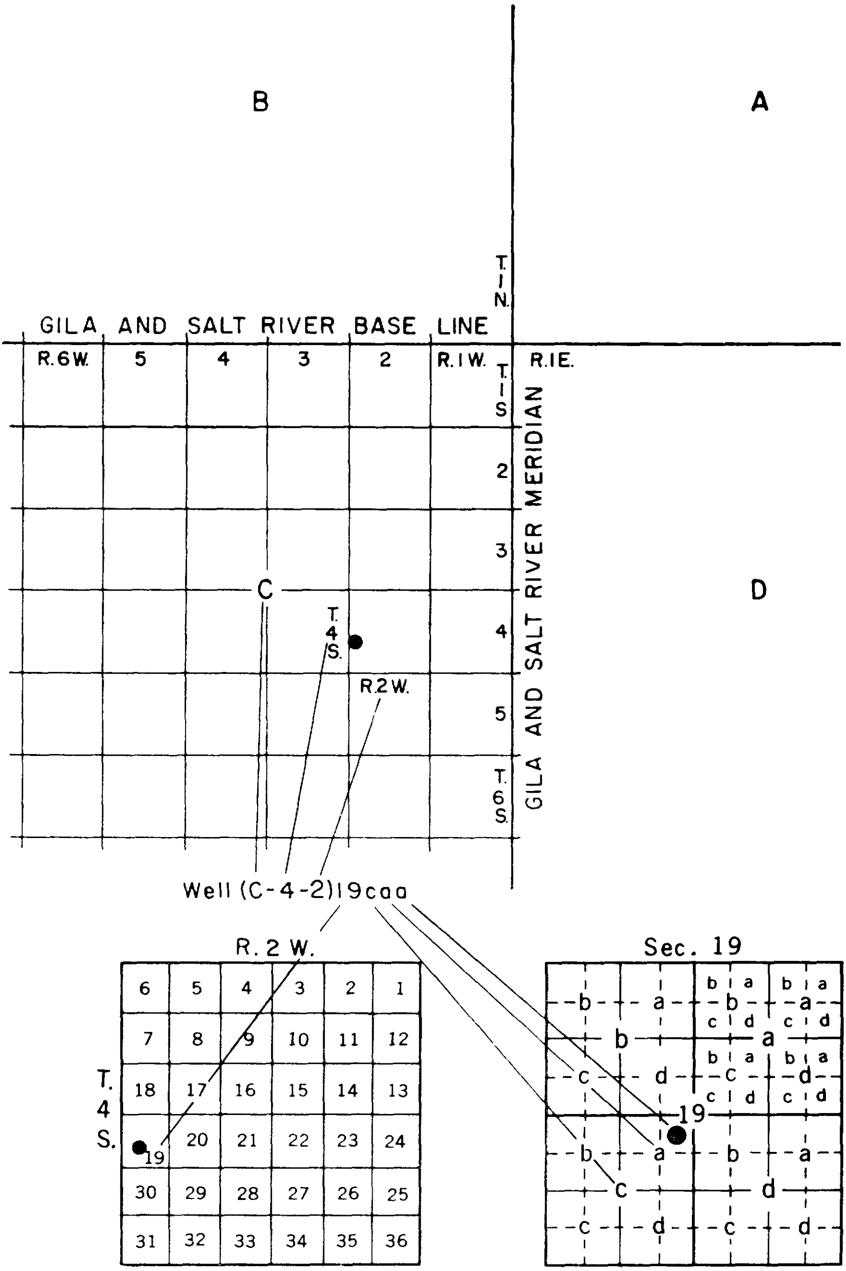


**Figure 3.**—Sketch showing well-numbering system in Arizona.

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. 3), 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 (C-4-2)19caa designates the well as being in the NE¼NE¼SW¼ sec. 19, T. 4 S., R. 2 W. Where there is more than one well within a 10-acre tract, consecutive numbers beginning with 1 are added as suffixes.

## GEOLOGY IN RELATION TO GROUND WATER

### LANDFORMS AND DRAINAGE

The mountains that form the boundaries of the Rainbow Valley and Waterman Wash areas rise above the valley floors to heights as great as 4,000 feet above mean sea level. The altitude of the valley floors ranges from about 1,000 to 1,400 feet in the Waterman Wash area and from about 700 to 950 feet in the Rainbow Valley area. The mountains are rugged and are dissected by streams having steep gradients. Except for the Buckeye Hills on the north, the mountains are roughly parallel and trend northwestward. The two valleys are separated by a low, broad saddle extending through T. 2 S., R. 3 W. from the Maricopa Mountains to the Buckeye Hills. This saddle is cut on granite that has been covered partly by alluvium of various thickness; a low ridge of this alluvium forms the surface divide between the two valleys. However, the granite, which is exposed across the saddle in small hills and in the bottoms of dry washes about 2 miles west of the surface-drainage divide, effectively separates the Rainbow Valley and Waterman Wash areas into two distinct ground-water basins.

The valleys are typical of the Basin and Range province in Arizona. They consist largely of piedmont slopes extending from the foot of the mountains to the center of each valley. Only a part of these piedmont slopes are underlain by deep alluvium; the part nearest the mountains is cut on hard rock overlain by only a thin veneer of alluvium and is called a pediment area. Wolcott (1953) showed the approximate extent of these pediments in part of the area. The pediment areas effectively limit the ground-water storage capacity of the valley and must be excluded when computing the area of sediments available for the storage of ground water in an alluvial basin, because the bedrock surface of the pediments is generally above the water table. The pediment areas also act as barriers which limit or prevent ground-water movement between basins.

The surface drainage of both valleys is toward the Gila River. Rainbow Valley is a small tributary of the larger Gila River valley, trends southwestward, and joins the Gila River about 4½ miles below Gillespie Dam. The area ranges from about 3 to 8 miles in width and averages about 5 miles in width; it is about 10 miles long. The total drainage area is about 80 square miles.

Waterman Wash, which drains the Waterman Wash area, flows northwestward through a narrow gap in outliers of the Sierra Estrella and Buckeye Hills and joins the Gila River at a point about 4 miles east of the town of Buckeye. The axis of the valley has an average slope of about 20 feet per mile; from the foot of the mountains toward the axis, the slopes are much greater—as much as 60 feet per mile in some places. The average width of the valley is about 8 miles, and it is about 25 miles along. The total drainage area is about 400 square miles.

## ROCKS OF THE AREA

### CRYSTALLINE AND METAMORPHIC ROCKS

Crystalline and metamorphic rocks of probable Precambrian age predominate in the mountain ranges that border the two valley areas discussed in this report. In the Sierra Estrella and Palo Verde Mountains, granite-gneiss is the predominant rock; in the Haley Hills and Maricopa Mountains, granite and schist are the principal rock types. The granite-gneiss and granite of the Buckeye Hills have been intruded by younger granite of possible Laramide age. Where these rocks are highly fractured, they yield small amounts of water to domestic and stock wells. Inasmuch as these hard rocks do not constitute an important source of ground water, they were not studied in detail during the present investigation.

### VOLCANIC ROCKS

Younger volcanic rocks of Quaternary age are exposed as basaltic lava flows at the southwest edge of the Buckeye Hills. Drillers' logs of wells (table 2) in the area just south of Gillespie Dam indicate that the lava and interbedded tuff and breccia occur in the valley at depths from about 40 to more than 600 feet below the land surface. Some of these volcanic rocks yield small amounts of water to wells in the area.

### SEDIMENTARY ROCKS

No consolidated sedimentary rocks are exposed in the Rainbow Valley and Waterman Wash areas. However, sedimentary rocks of probable Tertiary age crop out in the Gila Bend Mountains north of Gila Bend outside the area of this study.

TABLE 2.—*Drillers' logs of wells in and near the Rainbow Valley area*

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| *(C-2-4)31daa* | | |
| Surface soil with streaks of gravel | 170 | 170 |
| Gravel | 86 | 256 |
| Clay | 34 | 290 |
| Gravel with streaks of clay | 145 | 435 |
| Hard clay and gravel mix | 17 | 452 |
| Total | | 452 |
| *(C-2-4)32caa* | | |
| Surface soil | 140 | 140 |
| Dry gravel and rocks | 25 | 165 |
| Gravel with streaks of clay | 295 | 460 |
| Total | | 460 |
| *(C-2-5)28aab* | | |
| River sand and gravel, salty water | 45 | 45 |
| Alternating hard and soft lava layers | 645 | 690 |
| Granitic fill and rounded gravel | 240 | 930 |
| Granite | 50 | 980 |
| Total | | 980 |
| *(C-2-5)28caa* | | |
| Sand | 12 | 12 |
| Gravel and boulders | 58 | 70 |
| Clay and gravel | 115 | 185 |
| Clay and malapai | 30 | 215 |
| Clay and gravel | 60 | 275 |
| Clay and malapai | 28 | 303 |
| Clay and gravel | 151 | 454 |
| Clay | 29 | 483 |
| Clay and gravel | 60 | 543 |
| Clay, gravel and boulders | 30 | 573 |
| Clay and gravel | 61 | 634 |
| Clay, gravel and malapai | 30 | 664 |
| Clay and malapai | 30 | 694 |
| Malapai | 31 | 725 |
| Clay and malapai | 78 | 803 |
| Malapai | 7 | 810 |
| Sand and gravel | 72 | 882 |
| Clay and boulders | 29 | 911 |
| Boulders | 4 | 915 |
| Clay and boulders | 26 | 941 |
| Quartz | 9 | 950 |
| Clay and boulders | 21 | 971 |
| Quartz | 10 | 981 |
| Quartz and basement | 10 | 991 |
| Total | | 991 |
| *(C-3-4)4cab* | | |
| Top soil | 8 | 8 |
| Clay | 32 | 40 |
| Caliche and gravel | 10 | 50 |
| Clay and gravel | 23 | 73 |
| Gravel and streaks of clay | 17 | 90 |
| Gravel | 54 | 144 |
| Clay | 4 | 148 |
| Gravel, streaks hard sand | 26 | 174 |
| Gravel and small boulders | 34 | 208 |
| Gravel | 29 | 237 |
| Rock | 3 | 240 |
| Total | | 240 |

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| *(C-3-4)6caa* | | |
| Sandy silt | 39 | 39 |
| Gravel to 8 inches | 31 | 70 |
| Clay sand gravel to 6 inches | 20 | 90 |
| Clay and small gravel | 130 | 220 |
| Hard clay and gravel | 276 | 496 |
| Cemented gravel | 34 | 530 |
| Total | | 530 |
| *(C-3-4)9baa* | | |
| Surface sand and clay | 130 | 130 |
| Sand and gravel | 46 | 176 |
| Clay with streaks of gravel | 29 | 205 |
| Gravel | 49 | 254 |
| Tight gravel with streaks of clay | 71 | 325 |
| Clay | 55 | 380 |
| Gravel | 46 | 426 |
| Clay and gravel mix | 64 | 490 |
| Total | | 490 |
| *(C-3-4)15daa* | | |
| Sand and gravel | 20 | 20 |
| Sand | 25 | 45 |
| Tight sand | 70 | 115 |
| Sand, gravel | 85 | 200 |
| Sand, boulders | 70 | 270 |
| Sand, gray | 140 | 410 |
| Granitic formation | 10 | 420 |
| Total | | 420 |
| *(C-3-4)19bbb* | | |
| Silt soil | 6 | 6 |
| Gravel (Gila), first water at 56 feet | 58 | 64 |
| Gravel (granite) | 16 | 80 |
| Shows of gravel | 22 | 102 |
| Gravel | 8 | 110 |
| Shell | 2 | 112 |
| Gravel in clay | 112 | 224 |
| Gravel | 4 | 228 |
| Gravel in clay | 22 | 250 |
| Shell | 4 | 254 |
| Gravel in clay | 28 | 282 |
| Gravel | 40 | 322 |
| Gravel in clay and shells | 68 | 390 |
| Gravel in clay | 60 | 450 |
| Shell | 4 | 454 |
| Gravel in clay | 6 | 460 |
| Total | | 460 |
| *(C-3-4)22ddd* | | |
| Surface sand | 35 | 35 |
| Sand, gravel | 45 | 80 |
| Boulders, gravel | 65 | 145 |
| Sand, gravel with some boulders | 25 | 170 |
| Sand with streaks of clay | 105 | 275 |
| Sand, clay | 55 | 330 |
| Sand, gravel | 13 | 343 |
| Gray sand | 107 | 450 |
| Hard granite formation | 15 | 465 |
| Total | | 465 |

### ALLUVIAL DEPOSITS

Tertiary and Quaternary alluvial material occupies both of the intermontane troughs—Rainbow Valley area and Waterman Wash area—discussed in this report. The material is similar to that of many basins in southern Arizona and in particular to the area north of Gila Bend and south of the Gila Bend Mountains (Heindl and Armstrong, 1960). The alluvial deposits, in general, consist of lenticular beds of poorly sorted gravel, sand, silt, and clay of variable thickness, as suggested by drillers' logs of wells in the areas (tables 2 and 3). Although the alluvial deposits probably represent two or more cycles of deposition separated by intervals of erosion, they are hydrologically interconnected and act as a single aquifer in each of the areas.

In the Rainbow Valley area the alluvium probably was deposited largely by short streams within the drainage area of the valley and in part by a tributary to the ancestral Gila River. Lenticular clay layers at various depths throughout the valley probably indicate that through drainage was intermittent during deposition of the alluvium. The thickness of the alluvial deposits, including interbedded volcanic flows, is about 1,000 feet near the Gila River (table 2) and thins eastward.

TABLE 3.—*Interpretations of selected logs indicating water-yielding properties of subsurface materials in the Waterman Wash area*

[Water-yielding category: X, Medium to high water-yielding material, where saturated; Y, Low water-yielding material, where saturated]

| Description of material | Thickness (feet) | Depth (feet) | Water-yielding category |
|---|---|---|---|
| **(C-2-1)18aaa** | | | |
| Surface sand and gravel | 100 | 100 | X |
| Clay and streaks of sand | 180 | 280 | Y |
| Sand and gravel | 70 | 350 | X |
| Hard conglomerate and quartz rocks | 70 | 420 | Y |
| Firm sand and gravel with hard streaks | 80 | 500 | |
| Streaks of shells and hard coarse gravel | 80 | 580 | |
| Fine sand and streaks of coarse gravel | 40 | 620 | X |
| | 200 | | |
| Hard quartz shells and streaks of sand and gravel | 130 | 750 | |
| Streaks of sand and gravel, thin shells | 50 | 800 | |
| Hard shells and streaks of hard sand and gravel | 110 | 910 | |
| Broken streaks of shells and hard sand | 30 | 940 | |
| Hard rock | 13 | 953 | Y |
| | 333 | | |

TABLE 3.—*Interpretations of selected logs indicating water-yielding properties of subsurface materials in the Waterman Wash area*—Continued

| Description of material | Thickness (feet) | Depth (feet) | Water-yielding category |
|---|---|---|---|
| **(C-2-1)19aad** | | | |
| Top soil | 5 | 5 | |
| Clay | 26 | 31 | |
| Clay and sand | 49 | 80 | |
| Clay and sand streaks | 113 | 193 | |
| Gray clay and sand | 36 | 229 | |
| Clay and sand | 11 | 240 | Y |
| | 240 | | |
| Granite wash—water at 240 feet | 11 | 251 | |
| Granite wash and clay streaks | 61 | 312 | |
| Granite wash and some clay | 38 | 350 | |
| Decomposed granite | 95 | 445 | |
| Decomposed granite, hard and soft spots | 357 | 802 | X |
| | 562 | | |
| **(C-2-1)19baa** | | | |
| Sand and clay | 166 | 166 | X |
| Clay, sand streaks | 231 | 397 | Y |
| Sand—hard streaks | 211 | 608 | X |
| Hard sand shells | 41 | 649 | |
| Hard rock, streaks sand | 15 | 664 | |
| Hard sand, shells | 70 | 734 | |
| Hard sand, soft streaks | 28 | 762 | Y |
| | 154 | | |
| Sand, shells | 44 | 806 | X |
| Hard sand | 19 | 825 | Y |
| Sand, hard rock | 39 | 864 | X |
| Cemented sand | 32 | 896 | Y |
| Sand, cemented streaks | 53 | 949 | X |
| Malapai | 160 | 1,109 | |
| Malapai and hard sand | 30 | 1,139 | Y |
| | 190 | | |

TABLE 3.—*Interpretations of selected logs indicating water-yielding properties of subsurface materials in the Waterman Wash area*—Continued

| Description of material | Thickness (feet) | Depth (feet) | Water-yielding category |
|---|---|---|---|
| **(C-2-1)20dba** | | | |
| Surface soil | 45 | 45 | |
| Sand and gravel | 33 | 78 | X |
| | 78 | | |
| Clay with streaks of sand | 42 | 120 | Y |
| Sand | 15 | 135 | X |
| Clay with streaks of sand | 69 | 204 | |
| Clay | 56 | 260 | |
| Clay, sand and boulders | 24 | 284 | |
| Clay with streaks of sand | 86 | 370 | Y |
| | 235 | | |
| Sand, gravel, and boulders | 60 | 430 | X |
| Clay with streaks of sand | 34 | 464 | Y |
| Sand | 186 | 650 | X |
| Tight sand | 67 | 717 | Y |
| **(C-2-1)29bab** | | | |
| Sand clay | 95 | 95 | X |
| Clay | 105 | 200 | Y |
| Sand | 15 | 215 | X |
| Clay | 85 | 300 | Y |
| Gray sand | 60 | 360 | |
| Gray and white sand | 35 | 395 | |
| Coarse sand | 105 | 500 | |
| Sand and streaks of boulders | 200 | 700 | |
| Light gray sand | 100 | 800 | X |
| | 500 | | |
| Hard gray sand | 9 | 809 | Y |

TABLE 3.—*Interpretations of selected logs indicating water-yielding properties of subsurface materials in the Waterman Wash area*—Continued

| Description of material | Thickness (feet) | Depth (feet) | Water-yielding category |
|---|---|---|---|
| **(C-2-1)29caa** | | | |
| Sand and clay | 100 | 100 | X |
| Clay | 100 | 200 | Y |
| Sand | 15 | 215 | X |
| Clay | 35 | 250 | Y |
| Gray sand | 60 | 310 | |
| Gray and white sand | 50 | 360 | |
| White sand | 35 | 395 | |
| Coarse gray sand | 105 | 500 | |
| Coarse gray sand and boulders | 200 | 700 | X |
| | 450 | | |
| Hard gray tight sand | 109 | 809 | Y |
| **(C-2-1)29daa** | | | |
| Surface sand | 20 | 20 | |
| Gray sand with streaks of gravel | 160 | 180 | X |
| | 180 | | |
| Sand with streaks of clay | 220 | 400 | |
| Do | 80 | 480 | Y |
| | 300 | | |
| Gray sand and gravel | 40 | 520 | |
| Loose sand and gravel | 120 | 640 | |
| Sand and gravel | 240 | 880 | X |
| | 400 | | |
| Hard tight gray sand | 40 | 920 | |
| Hard tight gray sand with showing of granite | 16 | 936 | Y |
| | 56 | | |

TABLE 3.—*Interpretations of selected logs indicating water-yielding properties of subsurface materials in the Waterman Wash area*—Continued

| Description of material | Thickness (feet) | Depth (feet) | Water-yielding category |
|---|---|---|---|
| **(C-2-1)32ada** | | | |
| Surface sand and silt | 50 | 50 | |
| Sand and gravel | 70 | 120 | |
| Gravel with streaks of clay | 40 | 160 | X |
| | 160 | | |
| Clay with small streaks of gravel | 248 | 408 | Y |
| Boulders and gravel | 84 | 492 | |
| Sand and gravel with streaks of clay | 58 | 550 | |
| Boulders embedded in coarse sand | 130 | 680 | |
| Sand, gray | 40 | 720 | X |
| | 312 | | |
| Tight gray sand | 160 | 880 | Y |
| **(C-2-1)33dcc** | | | |
| Gravelly sand | 200 | 200 | |
| Muddy gravelly sand | 80 | 280 | X |
| | 280 | | |
| Gravelly sandy mud | 20 | 300 | |
| Sandy mud | 20 | 320 | |
| Gravelly sandy mud | 40 | 360 | |
| Sandy mud | 20 | 380 | |
| Gravelly sandy mud | 80 | 460 | |
| Sandy mud | 40 | 500 | Y |
| | 220 | | |
| Muddy sand | 40 | 540 | |
| Muddy gravelly sand | 20 | 560 | |
| Gravelly sand | 120 | 680 | |
| Gravelly sand mud | 20 | 700 | |
| Muddy sand | 20 | 720 | |
| Gravelly sand | 80 | 800 | |
| Muddy gravelly sand | 40 | 840 | |
| Gravelly sand | 40 | 880 | |
| Sand | 120 | 1, 000 | X |
| | 500 | | |
| Sand cemented | 80 | 1, 080 | Y |

TABLE 3.—*Interpretations of selected logs indicating water-yielding properties of subsurface materials in the Waterman Wash area*—Continued

| Description of material | Thickness (feet) | Depth (feet) | Water-yielding category |
|---|---|---|---|
| **(C-2-2)5ccc** | | | |
| Geohydrologic units as interpreted from electric log | 190 | 190 | X |
| | 295 | 485 | Y |
| | 230 | 715 | X |
| | 14 | 729 | Y |
| **(C-2-2)5ddc** | | | |
| Geohydrologic units as interpreted from electric log and driller's log | 200 | 200 | X |
| | 260 | 460 | Y |
| | 90 | 550 | X |
| | 572 | 1,122 | Y |
| **(C-2-2)9cdd** | | | |
| Soil | 16 | 16 | |
| Caliche | 4 | 20 | |
| Silt and mountain fill | 120 | 140 | Y |
| | 140 | | |
| Mountain wash and sand, water | 350 | 490 | X |
| Hard granite | 17 | 507 | |
| Hard conglomerate | 8 | 515 | Y |
| | 25 | | |
| **(C-2-2)10dda** | | | |
| Surface sand and clay | 200 | 200 | Y |
| Sand fine gravel with cemented streaks | 160 | 360 | |
| Sand clay with streaks cut gravel | 80 | 440 | |
| Gravel and fine sand | 120 | 560 | |
| Fine sand streaks clay and malapai | 80 | 640 | |
| Sand and fine gravel | 60 | 700 | |
| Sand and hard streaks of sand | 100 | 800 | |
| Sand gravel with hard streaks sand | 80 | 880 | X |
| | 680 | | |
| Sand clay and cemented streaks | 60 | 940 | |
| Hard sand streaks of coarse gravel streaks of malapai | 60 | 1,000 | Y |
| | 120 | | |

TABLE 3.—*Interpretations of selected logs indicating water-yielding properties of subsurface materials in the Waterman Wash area*—Continued

| Description of material | Thickness (feet) | Depth (feet) | Water-yielding category |
|---|---|---|---|
| **(C-2-2)23ccc** | | | |
| Surface silt, clay and caliche | 144 | 144 | Y |
| Fine gravel, traces of clay | 88 | 232 | |
| Coarse gravel, streaks of clay | 22 | 254 | X |
| | 100 | | |
| Caliche and fine sand | 22 | 276 | |
| Fine gravel and caliche | 12 | 288 | Y |
| | 34 | | |
| Fine gravel, very thin streaks of clay | 76 | 364 | |
| Coarse sand | 88 | 452 | |
| Fine gravel with sand | 20 | 472 | X |
| | 184 | | |
| Cemented sand and gravel | 56 | 528 | |
| Hard sand and gravel | 108 | 636 | |
| Fine hard sand | 22 | 658 | |
| Hard sand and gravel | 62 | 720 | |
| Coarse conglomerate sand | 22 | 742 | |
| Cemented sand and gravel | 227 | 969 | |
| Fine cemented sand | 96 | 1, 065 | |
| Fine sand and hard gravel | 66 | 1, 131 | |
| Cemented sand and some cemented gravel | 66 | 1, 197 | |
| Fine hard sand | 44 | 1, 241 | |
| Coarse sand and gravel | 22 | 1, 263 | Y |
| | 791 | | |
| Last 200 ft. hard brown rust-colored sand | -------- | -------- | -------- |
| **(C-2-2)24aaa** | | | |
| Silt | 6 | 6 | |
| Caliche | 26 | 32 | |
| Clay, streaks of sand | 124 | 156 | Y |
| | 156 | | |
| Coarse sand, thin streaks small gravel and shells | 494 | 650 | X |
| Hard cemented sand | 140 | 790 | |
| Quartz, rocks with streaks hard sand cemented | 140 | 930 | Y |
| | 280 | | |

TABLE 3.—*Interpretations of selected logs indicating water-yielding properties of subsurface materials in the Waterman Wash area*—Continued

| Description of material | Thickness (feet) | Depth (feet) | Water-yielding category |
|---|---|---|---|
| **(C-2-2)27ccc** | | | |
| Surface sand and clay | 150 | 150 | Y |
| Sand and fine gravel | 105 | 255 | |
| Sand with streaks coarse gravel | 38 | 293 | |
| Gravel | 43 | 336 | |
| Coarse gravel and sand | 54 | 390 | |
| Gravel with clay streaks and sand streaks | 90 | 480 | |
| Sand | 20 | 500 | |
| Streaks sand and gravel | 70 | 570 | |
| Fine sand and gravel | 60 | 630 | |
| Gravel and sand | 60 | 690 | |
| Sand | 80 | 770 | X |
| | 620 | | |
| Streaks fine sand clay and fine gravel | 120 | 890 | |
| Malapai with sand and gravel streaks | 50 | 940 | Y |
| | 170 | | |
| **(C-3-1)21dcc** | | | |
| Surface sand | 40 | 40 | |
| Fine sand | 60 | 100 | |
| Sand and gravel | 120 | 220 | |
| Gravel with sand and light clay streaks | 180 | 400 | X |
| | 400 | | |
| Clay with gravel streaks | 120 | 520 | Y |
| Coarse gravel with sand streaks | 100 | 620 | X |
| Fine decomposed granite with light showing of malpais | 120 | 740 | Y |
| Gray sand with streaks malpais | 60 | 800 | |
| Coarse gravel and sand with showing of malpais | 40 | 840 | |
| Fine gray sand and gravel | 160 | 1,000 | |
| Very fine gray sand | 20 | 1,020 | |
| Small gravel with heavy sand streaks | 100 | 1,120 | X |
| | 380 | | |
| Very fine gray sand with malpais showing | 55 | 1,175 | Y |

The alluvial material in the Waterman Wash area probably was derived from the erosion of the surrounding mountains. The lack of laterally extensive clay deposits or other evidence of lake beds suggests that some through drainage may have existed in the area during part of the period of alluvial deposition. The area probably is a downfaulted block between the Sierra Estrella and Maricopa Mountains (Wolcott, 1953). The alluvial materials, which are as much as 1,263 feet thick and may be thicker locally, appear to represent deposition that both predates and postdates the deformation that gave the valley its present form. The generally well-indurated material below depths of about 600 to 800 feet is reported to contain very little clay and may represent deposition before the existing structural elements were elevated to their present position and when drainage was well integrated. Above a depth of about 600 feet, the material is largely poorly consolidated and is reported to contain clay at many horizons. This material probably represents deposition within the basin until such time as when the shallow bedrock barriers between the Buckeye Hills and the Sierra Estrella were topped. The interval between 200 feet and the surface in many parts of the area contains abundant clay and is composed of fine-grained materials.

The water-bearing characteristics of the subsurface materials of the Waterman Wash area have been interpreted from scant information consisting of a set of well cuttings, 3 electric logs, and about 25 drillers' logs. A longitudinal section, *A–A′*, and 2 cross sections, *B–B′* and *C–C′*, are shown in figure 4. The categories shown in the sections (fig. 4) represent an interpretation and a grouping of drillers' descriptions of lithology into two general units based upon their water-yielding properties (table 3). In general, the materials assigned to category "X" are capable of medium to high yields; the materials assigned to category "Y" can yield only small amounts of water. The materials of category "X," where saturated, constitute the major aquifer, although their capacity to yield water to wells is not uniform throughout the area.

Figure 4 shows that in some wells, the material assigned to the "X" category is overlain and underlain by material of the "Y" category. This condition is shown along the central 5 miles of the longitudinal section *A–A′* and along most of section *B–B′*. The "X" material overlies the "Y" material at the northwest and southeast ends of section *A–A′*, at the extreme northeast end of section *B–B′*, and throughout the entire length of section *C–C′*.

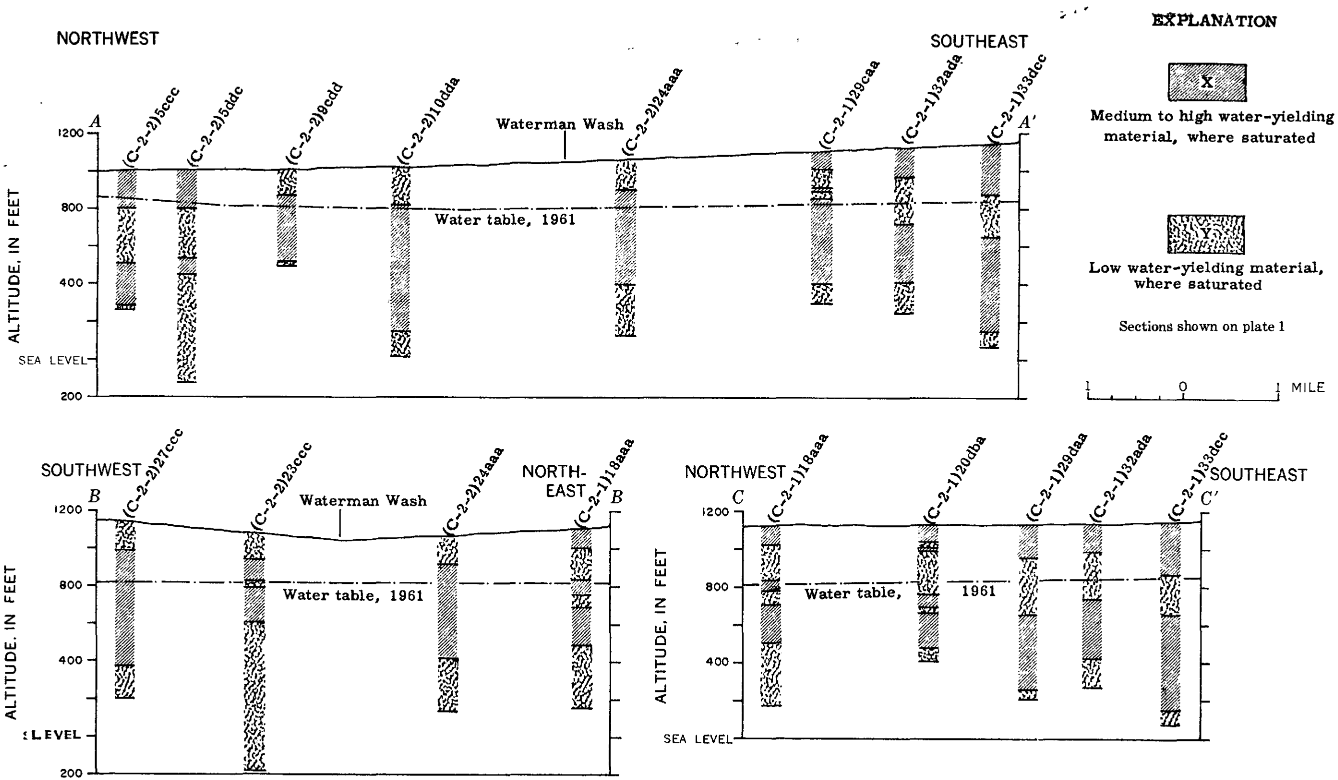


FIGURE 4.—Sections in the Waterman Wash area, indicating water-yielding properties of subsurface materials based on interpretations of selected logs.

## GROUND-WATER CONDITIONS

The Rainbow Valley and Waterman Wash areas are two distinct ground-water basins. Granite is exposed in low hills and in the bottoms of dry washes between the two areas as described in the section on geology. Although some of the characteristics of the ground-water reservoirs of the two areas are similar, each also has some characteristics distinct from the other; accordingly, the ground-water conditions of the basins are discussed separately. Table 4 gives descriptions of all wells in both areas.

### RAINBOW VALLEY AREA

#### OCCURRENCE AND MOVEMENT OF GROUND WATER

In the Rainbow Valley area ground water occurs in the sand and gravel lenses of the alluvial fill and to some extent in lavas along the Gila River near Gillespie Dam. Well (C–2–5)28aab, for example, produced about 300 gpm (gallons per minute) from lavas occurring from 45 to 690 feet below the land surface (table 2). In deepening the well to 980 feet, "granitic fill" was found below the lava at 690 feet and "granite" was reported at 930 feet. The well produced about 1,500 gpm of water of poor quality from the granitic fill.

The saturated thickness of the alluvial fill is unknown in most of the area; a few well logs indicate that bedrock or granite was penetrated at depths ranging from less than 500 to nearly 1,000 feet. For the most part, the wells in this area are less than 500 feet deep, and the materials penetrated consist of fairly coarse gravel intermixed with silt and clay. No extensive clay deposits are present to confine the water under pressure, and the ground water in the area is, therefore, under water-table conditions. The depth to water in the area ranged from less than 100 to more than 300 feet in the spring of 1961.

The general pattern of movement of ground water in the Rainbow Valley area is from the head of the basin in T. 2 S., R. 3 W. southwestward toward the Gila River and from north to south along the river. However, the water-table contours (pl. 2) indicate that a substantial cone of depression due to pumping had formed in the developed area as early as 1952. By 1961 the general pattern of movement was dominated by the depression, which had deepened more than 100 feet in places and had expanded in all directions (pl. 3). This cone of depression intercepts water that normally would have moved down the Gila River valley toward Gila Bend. As more water is pumped in the Rainbow Valley area, the cone of depression will deepen and expand still farther and presumably will intercept more water from the Gila River.

690-149—63——4

TABLE 4.—*Description of wells in the Rainbow Valley and Waterman Wash areas*

Well: See p. F6 for description of well-numbering system.
Perforated interval: OH, open hole.
Water level: R, reported.
Type of lift: Pump—C, cylinder; J, jack; Je, jet; N, none; S, submersible; T, turbine. Power—D, diesel; E, electric; G, gasoline; NG, natural gas; W, windmill.
Use of water: D, domestic; I, irrigation; N, none; O, observation well; PS, public supply; S, stock.
Yield: E, estimated; R, reported.
Remarks: C, chemical analysis in table 5; H, hydrologic characteristics in table 8; L, log in table 2 or 3.

| Well | Year completed | Reported depth (feet) | Casing diameter (inches) | Perforated interval (feet below land surface) | Land-surface altitude (feet above mean sea level) | Water level | | Type of lift | Use of water | Yield | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Depth below land surface (feet) | Date measured | | | Gallons per minute | Date measured | |
| **Rainbow Valley area** | | | | | | | | | | | | |
| (C-2-4)25bcc | | | | | 925 | 302.16 | 1-19-61 | T, NG | I | | | |
| 25ccc | | | | | 945 | 349.18 | 1-19-61 | T, NG | I | | | |
| 26bdd | | 428 | 10 | | 900 | 268.60 | 3- 2-60 | T, NG | I | 140 | 9-26-55 | C. |
| 29dda | 1956 | 424 | 16 | | 845 | 260.02 | 1-24-61 | T, D | I | | | |
| 31daa | 1952 | 452 | 20 | 150-452 | 787 | 219.26 | 1-24-61 | T, E | I | 1,104 | 10- 6-55 | L, C. |
| 32ada | | 450 | 20 | | 820 | 188.15 | 4- 1-52 | T, E | I | 1,900 | 5- 6-53 | C. |
| | | | | | | 246.58 | 1-24-61 | | | 773 | 8-22-56 | |
| 32caa | 1952 | 460 | 20 | 210-440 | 800 | 241.09 | 1-24-61 | T, E | I | 2,260R | 4- -52 | L, C. |
| | | | | | | | | | | 1,700 | 5- 6-53 | |
| | | | | | | | | | | 1,300 | 8-22-56 | |
| 33abb | | | 16 | | 838 | | | T, NG | I | | | |
| 33acc | | 169 | 6 | | 828 | 166.40 | 2-13-51 | N | N | | | |
| | | | | | | Dry | 4- 1-52 | | | | | |
| 33bca | | | | | 824 | 249.42 | 1-24-61 | T, E | I | | | |
| (C-2-5)26cba | | | | | 756 | | | T, E | I | | | |
| 27daa | | | | | 760 | 95.03 | 9-15-55 | T, E | I | | | |
| 28aab | 1954 | 980 | 18 | OH 490-980 | 775 | 48.58 | 1-24-61 | N | N | 300-1,500 | 12- -54 | Produced 300 gpm from lavas; shallow water cased off; L. |
| 28acc | | 45 | 96 | | 730 | | | T, NG | I | 528 | 9-10-52 | C |
| 28bcd | 1952 | 51 | 6 | | 750 | 17.10 | 9-23-52 | Je | O | 22R | 9- -52 | |
| 28caa | 1957 | 991 | 16 | OH 70-991 | 740 | 25.59 | 1-24-61 | | | | | L. |
| 33baa | | 576 | | | 740 | | | | | | | |
| 35adb | 1938 | 386 | 20 | 50-372 | 750 | | | T, E | I | 1,950 | 4-9-46 | C. |
| | | | | | | | | | | 1,825 | 6-16-55 | |
| 35baa | | 345 | 20 | 174-314 | 748 | 124.94 | 1-24-61 | T, E | I | | | |
| 36cbd | | 400 | 20 | | 750 | | | T, E | I | 2,160 | 4-9-46 | |
| | | | | | | | | | | 1,640 | 9-15-55 | |
| 36daa | | | | | 780 | 195.05 | 10-27-58 | T, E | I | 1,920 | 8-22-56 | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (C-3-4)4baa | | 250 | 18 | 150–250 | 815 | 159.68 | 2–15–51 | T, E | I | | | C. |
| | | | | | | 203.11 | 9–21–60 | | | | | |
| 4bdd | | 492 | 20 | 170–492 | 810 | 186.35 | 12–28–53 | T, E | I | 2,984 | 8–16–51 | C. |
| | | | | | | | | | | 2,460 | 8–22–56 | L. |
| 4cab | 1953 | 240 | 16 | 155–240 | 800 | 246.04 | 1–24–61 | T, E | I | 1,840 | 10–6–55 | |
| 6bab | 1940 | 545 | 20 | | 748 | 62.52 | 12–18–45 | T, E | I | 1,570 | 4– 9–46 | |
| | | | | | | 164.30 | 1–24–61 | | | 1,470 | 5– 6–53 | |
| | | | | | | | | | | 1,295 | 9–15–55 | |
| 6caa | 1940 | 530 | 20 | 100–484 | 750 | 172.68 | 9–19–60 | T, E | I | 3,020 | 5–29–46 | L, C. |
| | | | | | | | | | | 1,895 | 9–15–55 | |
| 6dab | | | | | 760 | 188.70 | 1–24–61 | T, E | I | 1,300 | 8–22–56 | |
| $7aaa_1$ | 1938 | 332 | 20 | 60–308 | 750 | 179.67 | 1–24–61 | T, E | I | 2,670 | 5–27–46 | |
| $7aaa_2$ | 1936 | 153 | 8 | | 745 | 63.73 | 4–10–46 | N | N | | | |
| 7aab | 1936 | 176 | 20 | | 748 | 100.25 | 4– 1–52 | N | N | | | |
| 8baa | 1951 | 406 | 14 | 130–400 | 760 | 113.13 | 2–15–51 | T, E | I | 1,570 | 8–27–56 | C. |
| | | | | | | 192.50 | 1–24–61 | | | | | |
| 8caa | 1938 | 370 | 20 | 135–356 | 749 | 67.81 | 12–18–45 | T, E | I | 2,275 | 5–27–46 | |
| | | | | | | 181.05 | 1–25–61 | | | 1,940 | 9–15–55 | |
| 8dcb | | 780 | 20 | 120–755 | 746 | 67.08 | 12–18–45 | T, E | I | 2,675 | 4–10–46 | |
| | | | | | | 182.45 | 1–25–61 | | | 1,750 | 8–27–56 | |
| 9aad | 1952 | 474 | 20 | 190–404 | 825 | 276.30 | 9–21–60 | | D | | | |
| 9baa | | 490 | 20 | 135–490 | 807 | 154.95 | 2–13–51 | T, E | I | 1,935 | 8–22–56 | L, C. |
| | | | | | | 324.14 | 1–20–61 | | | | | |
| 9caa | | 500 | 20 | 135–500 | 795 | 210.19 | 12–14–54 | T, E | I | 2,490 | 5– 8–53 | |
| | | | | | | | | | | 1,670 | 9–27–55 | |
| 9dda | 1954 | | | | 818 | 222.37 | 12–14–54 | T, E | I | 2,400 | 9–26–55 | |
| | | | | | | 259.53 | 1–20–61 | | | | | |
| 10caa | | | | | 859 | 251.54 | 12–28–53 | T, E | N | 2,570 | 5– 5–53 | C. |
| | | | | | | 298.61 | 1–20–61 | | | 1,660 | 9–26–55 | |
| 14aad | | 600 | | | 945 | | | T, E | I | | | |
| 15bdd | 1951 | 465 | 20 | 128–465 | 830 | 225.64 | 12–29–53 | T, E | I | 3,180 | 8–16–51 | C. |
| | | | | | | 271.40 | 2–16–61 | | | 2,690 | 9–28–55 | |
| 15daa | 1951 | 420 | 20–16 | 154–420 | 860 | 259.24 | 12–29–53 | T, E | I | 2,490 | 9–28–55 | L. |
| | | | | | | | | | | 1,310 | 9–21–60 | |
| 16daa | | | | | 806 | 159.30 | 4– 1–52 | T, E | I | 2,170 | 9–27–55 | |
| | | | | | | 251.33 | 1–19–61 | | | | | |
| 17aab | | 745 | 20 | 120–755 | 745 | | | T, E | I | | | |
| 17add | | 302 | 20 | 115–288 | 745 | 196.94 | 1–25–61 | T- E | I | | | |
| 19bbb | 1951 | 460 | 20 | 200–440 | 710 | 78.28 | 12–30–53 | T, E | I | | | L. |
| | | | | | | 133.35 | 1–24–61 | | | | | |
| 20aaa | | | | | 735 | 143.86 | 12– 4–54 | T, E | I | 3,380 | 9–21–60 | |
| 20dba | | | 6 | | 718 | 107.60 | 12–30–53 | T, E | D | | | |
| 21bba | 1937 | 300 | 20 | | 748 | 104.80 | 1–28–52 | T, E | I | 1,900 | 9–15–55 | |
| 21bdb | | | 20 | | 746 | | | T. E | I | 2,660 | 5– 8–53 | C. |
| | | | | | | | | | | 1,640 | 9–22–55 | |
| 21caa | 1937 | 550 | 20–16 | | 750 | 70.38 | 12–18–45 | T, E | I | 2,820 | 8–30–50 | |
| | | | | | | 208.70 | 9–19–60 | | | 2,120 | 9–22–55 | |
| 21cdd | 1947 | 812 | 20 | 140–800 | 750 | | | T, E | I | 2,160 | 9–22–55 | |
| 22ddd | 1951 | 465 | 20–16 | 45–465 | 854 | 284.33 | 5– 6–53 | T, E | I | 2,590 | 9–28–55 | L, C. |
| | | | | | | 327.14 | 1–19–61 | | | 2,540 | 8–27–56 | |
| | | | | | | | | | | 1,100 | 9–20–60 | |
| 23bba | 1951 | 372 | 20–18 | 141–360 | 872 | 318.50 | 1–19–61 | T, E | I | 2,415 | 9–28–55 | To be deepened. |
| 26bcc | | 317 | 6 | | 865 | Dry | 9–20–60 | N | N | | | |

TABLE 4.—*Description of wells in the Rainbow Valley and Waterman Wash areas*—Continued

| Well | Year completed | Reported depth (feet) | Casing diameter (inches) | Perforated interval (feet below land surface) | Land-surface altitude (feet above mean sea level) | Water level: Depth below land surface (feet) | Water level: Date measured | Type of lift | Use of water | Yield: Gallons per minute | Yield: Date measured | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Rainbow Valley area—Continued** | | | | | | | | | | | | |
| (C-3-4)27baa | | | | | 812 | 204.03 | 5-6-53 | T, E | I | 3,500 | 9- -53 | |
| | | | | | | 324.02 | 1-19-61 | | | | | |
| 28abb | | 918 | 20 | 160-906 | 745 | | | | | 1,745 | 9-22-55 | |
| 28acc | | 1,000 | 20 | 130-985 | 744 | | | T, E | I | 1,800 | 9-22-55 | |
| 28dbb | | 332 | 20 | 60-308 | 742 | 164.13 | 12-30-53 | T, E | I | 1,945 | 8-22-56 | |
| 30aba | | | 8 | | 700 | 76.82 | 12-30-53 | T, E | D | | | |
| | | | | | | 136.43 | 9-19-60 | | | | | |
| 33aba | | 800 | 20 | 100-780 | 743 | | | T, E | I | 2,885 | 5-27-46 | C. |
| | | | | | | | | | | 2,400 | 9-22-55 | |
| 33adb | | 775 | 20 | 125-760 | 742 | | | T, E | I | 1,975 | 9-21-55 | |
| 33adc | 1945 | 800 | 20 | 100-780 | 740 | | | T, E | I | | | |
| 34dcc | | | | | 796 | 240.80 | 10-30-58 | T, E | I | | | |
| (C-3-5)1aaa | | 490 | 20 | 200-458 | 743 | 156.54 | 1-24-61 | T, E | I | 2,920 | 9- -60 | |
| 2bbc | 1957 | 1,500 | | | 720 | | | | | | | Log by S. F. Turner from 1,010 to 1,500 ft. |
| 2cbb | | 320 | 24 | 60-245 | 735 | 108.45 | 1-24-61 | S,E | D | | | |
| 36add | | 353 | 20 | 155-342 | 720 | | | T, E | I | | | |
| **Waterman Wash area** | | | | | | | | | | | | |
| (C-1-2)16bcd | 1952 | 225 | 16 | | 935 | 75.50 | 5-23-52 | N | N | | | |
| | | | | | | 84.59 | 9-28-60 | | | | | |
| 17aac | 1937 | 200 | 20 | | 913 | 80.00 | 6-26-51 | T, E | D | | | |
| 17cba | | | | | 906 | 58.75 | 4-18-49 | Je, G | D | 5E | 4- -49 | |
| | | | | | | 60.69 | 9-28-60 | | | | | |
| 22bcb | | 200 | 12 | | 980 | 83.35 | 4-18-49 | N | N | | | |
| | | | | | | 86.65 | 9-28-60 | | | | | |
| 30dbc | | 75 | 6 | | 940 | 59.75 | 6-30-49 | N | N | | | Well has been destroyed. |
| 31adc | | 33 | | | 950 | 24.10 | 6-5-52 | N | N | | | |
| | | | | | | 20.10 | 1-19-61 | | | | | |
| (C-2-1)15cdc | | | | | 1,236 | 312.61 | 2-6-51 | N | N | | | |
| | | | | | | 313.50 | 11-12-53 | | | | | |
| 16add | | | 6 | | 1,210 | 315.80 | 6-3-52 | J | N | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 18aaa | 1953 | 953 | 20–16 | | 1,120 | 299.66 | 1–18–61 | N | N | | | L. |
| 18daa | 1953 | 958 | 20–16 | | 1,117 | 295.21 | 1–18–61 | T, E | I | 1,210 | 9–10–57 | |
| 19aad | 1955 | 802 | 20–16 | 297–621<br>639–802 | 1,106 | 271.60 | 2–29–60 | N | N | | | L. |
| 19baa | 1952 | 1,139 | 20–16 | 295–1,125 | 1,095 | 278.93 | 1–18–61 | T, E | I | 2,935R | 5– –52 | L, H. |
| 20baa | | 800 | 20 | | 1,130 | 300.39 | 1–18–61 | N | N | | | |
| 20dba | 1954 | 717 | 20–16 | 200–650 | 1,135 | 260R | 8– –54 | T, NG | I | 2,200R | 8– –54 | L, H. |
| 28bab | 1959 | 870 | 16 | 176–870 | 1,156 | 326.85 | 9–27–60 | T, NG | I | | | |
| 28dad | 1959 | 805 | 20–16 | 176–805 | 1,175 | | | T, NG | I | | | |
| 29bab | 1952 | 809 | 20–16 | 120–809 | 1,120 | 218R | 10– –52 | T, E | I | 12,800R<br>2,420 | 10– –52<br>3–19–54 | L, H. |
| 29caa | 1952 | 809 | 20–16 | 200–809 | 1,115 | 206.62 | 1–18–61 | T, NG | I | 2,800R<br>2,830 | 11– –52<br>3–19–54 | L, C, H. |
| 29daa | 1959 | 936 | 20–16 | 256–936 | 1,138 | 295.22 | 1–18–61 | T, NG | I | | | L. |
| 30cdd | | | | | 1,080 | | | C, W | S | | | |
| 30dba | 1955 | 600 | 20 | 300–590 | 1,090 | 202R | 1955 | T, E | I | 1,000E | 9–20–60 | |
| 32ada | 1959 | 880 | 20–16 | 400–880 | 1,128 | 284.33 | 1–18–61 | T, NG | I | | | L. |
| 33aaa | 1950 | 1,030 | 20–16 | 240–1,000 | 1,169 | 266.30 | 6– 2–52 | T, NG | I | 2,000E | 9–20–60 | |
| 33dcc | 1961 | 1,080 | 16 | | 1,142 | 296.76 | 2–15–61 | T, NG | I | | | L. |
| (C-2-2)1ccc | 1950 | 585 | Uncased | | 1,049 | 186.00 | 4– 2–52 | N | N | | | Well has been destroyed. |
| 3dcd | | 136 | Uncased | | 992 | 107.88 | 2– 1–51 | N | N | | | Do. |
| 5ccc | 1953 | 725 | 20 | | 991 | 102.10 | 2–24–54 | N | N | | | Well has been destroyed; electric log; L. |
| 5ccd | 1954 | | | | 990 | 142.63 | 1–19–61 | T, E | I | | | |
| 5cdd | | | | | 990 | 146.11 | 1–19–61 | T, NG | I | | | |
| 5ddc | 1950 | 1,122 | 20–16 | 100–600 | 985 | 95.25 | 2– 7–51 | N | N | | | Well has been destroyed; electric log; L. |
| 8cad | 1959 | 605 | 16 | 300–605 | 1,015 | | | T, NG | I | | | |
| 8dad | | | | | 1,015 | 198.19 | 1–19–61 | T, NG | I | 1,925 | 9–28–60 | C. |
| 9bdd | 1958 | 815 | 20–16 | 160–815 | 1,000 | | | T, NG | I | | | |
| 9cbb | | | | | 1,007 | 233.73 | 9–28–60 | T, NG | I | | | |
| 9cdd | 1951 | 515 | 20 | 200–485 | 1,020 | 132.48<br>222.85 | 4– 2–52<br>1–19–61 | T, NG | I | | | L. |
| 10ccc | | | | | 1,015 | 186.33 | 1–19–61 | T, E | I | | | |
| 10dda | 1953 | 1,000 | 20 | 312–985 | 1,010 | 134.50<br>192.12 | 11–12–53<br>1–19–61 | T, E | I | 3,450R<br>3,270 | 2– –53<br>10– 6–55 | L, C, H. |
| 12acc | | | | | 1,070 | 258.16 | 1–18–61 | T, E | I | | | |
| 12add | | | | | 1,085 | 281.44 | 1–18–61 | T, E | I | 1,120 | 9–10–57 | |
| 12cdc | | | | | 1,053 | 240.19 | 1–18–61 | T, NG | I | | | |
| 12ddd | | 188 | 6 | | 1,078 | 185.36 | 2– 1–51 | N | N | | | |
| 13aaa | | | | | 1,078 | | | T, E | I | | | |
| 13acb | | | | | 1,063 | | | T, E | I | 1,354 | 9–27–60 | |
| 13daa | 1952 | 680 | 20–16 | 200–639 | 1,080 | 180.82 | 4– 2–52 | T, E | I | 658 | 8–27–57 | |
| 14add | 1958 | 992 | 20–16 | 300–930 | 1,015 | 225.02 | 1–18–61 | T, NG | I | 1,668 | 9–27–60 | |
| 14daa | | | 6 | | 1,042 | 143.50 | 6– 1–49 | C, G | S | | | |
| 17adc | | | | | 1,039 | | | T, NG | I | 2,830 | 10– 6–55 | |
| 22dcc | 1950 | 1,250 | 20–16 | 241–1,236 | 1,082 | 272.27 | 1–19–61 | T, NG | I | | | |
| 23aba | | | | | 1,037 | 142.05<br>156.81 | 2– 1–51<br>1–14–59 | N | N | | | |
| 23ccc | | 1,263 | 20 | 205–1,200 | 1,074 | 252.70 | 1–19–61 | T, NG | I | 3,475R | | L, C. |

TABLE 4.—*Description of wells in the Rainbow Valley and Waterman Wash areas*—Continued

| Well | Year completed | Reported depth (feet) | Casing diameter (inches) | Perforated interval (feet below land surface) | Land-surface altitude (feet above mean sea level) | Water level: Depth below land surface (feet) | Water level: Date measured | Type of lift | Use of water | Yield: Gallons per minute | Yield: Date measured | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Waterman Wash area—Continued** | | | | | | | | | | | | |
| (C-2-2)23dcb | ---- | 174 | ---- | ---- | 1,054 | 168.50 | 4- 7-52 | N | N | ---- | ---- | Well has been destroyed. |
| 24aaa | 1951 | 930 | 20-16 | 214-785 | 1,077 | 194.11 | 2-18-54 | T, NG | I | 2,920R | 12- -51 | L, H. |
| | | | | | | 260.47 | 1-18-61 | | I | 1,967 | 8-27-57 | |
| 25ccc | 1955 | 882 | 20 | 290-868 | 1,078 | 251.70 | 1-18-61 | T, E | | 3,198 | 8-27-57 | |
| 26ccc | 1952 | 1,031 | 20-16 | 240-1,000 | 1,100 | ---- | ---- | T, NG | I | 2,165 | 3-19-54 | |
| 27cbb | 1951 | 1,055 | 20-16 | 250-1,028 | 1,115 | ---- | ---- | T, NG | I | ---- | ---- | |
| 27ccc | 1953 | 940 | 20-16 | 295-895 | 1,135 | 260.15 | 2-18-54 | T, NG | I | ---- | ---- | L. |
| | | | | | | 311.64 | 1-19-61 | | | | | |
| 27cdd | 1951 | 1,084 | 20-16 | 243-1,082 | 1,120 | 200R | 11- -51 | T, NG | I | 3,400R | 11- -51 | H. |
| | | | | | | | | | | 1,990 | 10- 6-55 | |
| 35dcc | 1951 | 1,037 | 20-16 | 202-806 | 1,105 | 212.61 | 4- 3-52 | T, NG | I | 3,020 | 3-19-54 | |
| 36dcc | ---- | ---- | ---- | ---- | 1,100 | ---- | ---- | T, NG | I | ---- | ---- | |
| (C-3-1)1bca | ---- | 350 | 8 | ---- | 1,258 | 329.67 | 6- 2-49 | J | N | ---- | ---- | |
| | | | | | | 330.20 | 11-12-53 | | | | | |
| | | | | | | 343.52 | 2-15-61 | | | | | |
| 9dcb | ---- | ---- | ---- | ---- | 1,135 | 211.30 | 6- 3-49 | C, W | S | ---- | ---- | C |
| 21dcc | 1958 | 1,175 | 20-16 | 200-1,020 | 1,182 | 293.40 | 1-14-59 | T, NG | I | ---- | ---- | L. |
| | | | | | | 316.21 | 10-25-60 | | | | | |
| 34ddb | ---- | 368 | 12 | ---- | 1,240 | 342.60 | 10-10-53 | N | N | ---- | ---- | Dry at 349 ft, 3/1/60. |
| | | | | | | 346.45 | 1-14-59 | | | | | |
| 36aaa | ---- | ---- | 6 | ---- | 1,203 | 291.40 | 2-25-54 | C, W | S | ---- | ---- | |
| | | | | | | 291.74 | 1-27-55 | | | | | |
| (C-3-2)1cbb | 1935 | 237 | 8-20 | ---- | 1,120 | ---- | ---- | N | N | ---- | ---- | |
| (D-4-1)21ada | ---- | ---- | 20 | ---- | 1,288 | 367.51 | 1-28-55 | N | N | ---- | ---- | |
| | | | | | | 367.94 | 1-26-61 | | | | | |
| 23aba | ---- | 176 | Uncased | ---- | 1,280 | Dry | 8- 2-49 | N | N | ---- | ---- | Dry hole, granite in drill cuttings. |
| 26bac | 1948 | 370 | 6 | ---- | 1,312 | 330R | 8- -49 | J, G | D, S | 10E | 8- -49 | C. |
| 28bbc | 1940 | 504 | 12 | ---- | 1,320 | 440R | 10- -41 | T, G | D, PS | 100R | 10- -41 | C. |
| 28dcc | 1951 | 750 | 20 | 300-750 | 1,338 | 398.52 | 4- 3-52 | N | N | ---- | ---- | |
| | | | | | | 399.95 | 4-24-61 | | | | | |
| 29abd | 1918 | 452 | 12 | ---- | 1,328 | 400.60 | 4- 3-52 | N | N | ---- | ---- | |
| (D-5-1)1dca | ---- | 352 | 20 | ---- | 1,375 | 282.36 | 5-13-53 | N | N | ---- | ---- | |
| | | | | | | 299.15 | 1-28-58 | | | | | |
| (D-5-2)7ccd | ---- | ---- | ---- | ---- | 1,390 | 274.90 | 5-14-53 | N | N | ---- | ---- | |

### RECHARGE

The ground-water reservoir in the Rainbow Valley area is recharged from several sources: (1) runoff from rainfall in the adjacent mountain ranges; (2) seepage from canals and irrigated lands; (3) surface flow and underflow along the Gila River; and (4) direct penetration of precipitation.

#### RUNOFF FROM RAINFALL IN THE ADJACENT MOUNTAIN RANGES

Part of the rainfall in the mountain areas tributary to Rainbow Valley runs off and some of the runoff reaches the ground-water reservoir of the valley through the coarse alluvial materials along the mountain fronts. The total mountain area tributary to the valley is only about 20 square miles or 13,000 acres. By use of a figure of 6 inches for average annual precipitation, it is estimated that a total of about 6,500 acre-feet of water falls on the mountainous area annually. Coates and Cushman (1955) estimated that in the Douglas basin about 10 percent of the precipitation on mountain areas becomes runoff. Because of the differences in altitude and in the terrain of the mountains surrounding the two basins, the figure of 10 percent may be high for the Rainbow Valley area; however, the percentage is probably within a reasonable order of magnitude for the area. Earlier work by Babcock and Cushing (1942) indicates that about half of the runoff probably infiltrates into the coarse-grained sediments at the mountain front and percolates to the ground-water reservoir. Thus, by use of these percentages, it is estimated that a maximum of about 300 acre-feet of water reaches the ground-water reservoir in the Rainbow Valley area from this source each year.

#### SEEPAGE FROM CANALS AND IRRIGATED LANDS

About 8 miles of the unlined Gila Bend Canal traverses the west edge of the Rainbow Valley area, and part of the water that is diverted or pumped into this canal recharges the ground-water reservoir along the area that the canal traverses. Johnson and Cahill (1955) estimated that an average of about 22,000 acre-feet of water reaches the ground-water reservoir from this source annually in the entire reach of about 52 miles of canals extending from Gillespie Dam to the Painted Rock narrows (about 10 miles west of the mapped area). On the basis of a direct ratio of the miles traversed by the canal, about 3,400 acre-feet of water is recharged to the ground-water reservoir in the Rainbow Valley area annually from this source.

In 1960, about 9,000 acres of land was under cultivation in the area. Based on 4 acre-feet per acre average application (Blaney and Harris, 1951), about 35,000 acre-feet of water was applied to the land in the 1960 growing season. Johnson and Cahill (1955) estimated that about

20 percent of the water applied to the irrigated land in the Gila Bend area may be returned to the ground-water reservoir. As the Rainbow Valley area is similar to the Gila Bend area, this percentage has been used here. Thus, the annual recharge to the ground-water reservoir in this area from this source is estimated at about 7,000 acre-feet.

#### SURFACE FLOW AND UNDERFLOW ALONG THE GILA RIVER

Some water is recharged to the ground-water reservoir of the Rainbow Valley area by infiltration from the Gila River in the reach that forms the southwestern boundary of the area. Johnson and Cahill (1955) estimated that in the reach of the Gila River from Gillespie Dam to the Painted Rock narrows, a distance of about 40 miles, about 10,000 acre-feet of water infiltrated to the ground-water reservoir from surface flow in the Gila River. Their calculations were based on the assumption that about 50 percent of the total flow of the stream is recharged to the ground-water reservoir. Based on this same assumption, it is estimated that about 2,000 acre-feet infiltrates in the 8-mile reach of the river that traverses the Rainbow Valley area.

Some water may enter the area as underflow at the narrows at Gillespie Dam; the amount is unknown but probably is negligible.

#### DIRECT PENETRATION OF PRECIPITATION

Most of the precipitation that falls directly on the valley floors in arid areas, such as the Rainbow Valley area, is lost by evaporation and transpiration before it can penetrate below the soil zone. The only recharge to the ground-water reservoir from direct penetration of precipitation is the small amount that may occur where rain falls directly on the coarse materials in washes and minor drainages that traverse the valley floors. In the Rainbow Valley area, this recharge is negligible.

### DISCHARGE

Ground water is discharged from the Rainbow Valley area by natural means and by pumping from wells. Because the Rainbow Valley area is hydrologically a part of the Gila River valley, it is difficult to determine the amount of water that is discharged from the area.

#### DISCHARGE BY NATURAL MEANS

The only possible means of the natural discharge of ground water from the Rainbow Valley area are (1) underflow to the Gila River and (2) evaporation and transpiration.

Before the development of ground water for irrigation in the Rainbow Valley area, there was undoubtedly some discharge of water to the Gila River, at least during periods of low flow in the river. However, contours of the water table for 1961 (pl. 3) indicate that the water moving from the upper end of the Gila River valley is drawn into the cone of depression created by pumping in the approximate center of the area.

There is no discharge of water from the ground-water reservoir by evaporation in the Rainbow Valley area, because the water table is sufficiently below the land surface to prevent the loss of water in this manner. White (1932) indicates that as the depth to water approaches 10 feet the loss of water by evaporation is negligible. At the present time the depth to water in the Rainbow Valley area is more than 100 feet, except in a small area just below Gillespie Dam where it is about 30 feet.

The loss of water through transpiration by phreatophytes is negligible in the Rainbow Valley area. The basin does not support any large areas of phreatophytes, because the water table is too far below the land surface. Small amounts of water may be lost by transpiration in a few areas along washes or along the channel of the river where there are minor amounts of vegetation.

### PUMPING FROM WELLS

The amount of ground water pumped for irrigation in the Rainbow Valley area never has been calculated separately from the total amount pumped in the entire Gila River valley below Gillespie Dam. In the spring of 1961, a little less than 9,000 acres of land was under irrigation in the Rainbow Valley area. A pumpage estimate based entirely on cultivated acreage is not feasible, however, because part of the water pumped from wells in the Rainbow Valley area is transported out of the area in the Gila Bend Canal to irrigate land downstream. Johnson and Cahill (1955) state that 21 wells pumped a total of 68,000 acre-feet of ground water directly into the canal in 1953. Of these wells, 17 are within the limits of the Rainbow Valley area as described in this report and were still in operation in the 1960 pumping season. If it is assumed that the wells pumped at about the same rate as in 1953, about 55,000 acre-feet of water would have been pumped into the Gila Bend Canal from the Rainbow Valley area in 1960. If an additional 4 acre-feet of water per acre was pumped from other wells in the area to apply to the 9,000 acres irrigated, the total amount of ground water pumped in the Rainbow Valley area in 1960 was about 90,000 acre-feet.

The discharge rates of wells in the area range from about 500 to about 3,000 gpm. In the 1960 pumping season, there were about 60 irrigation wells in use in the area.

## WATER-LEVEL FLUCTUATIONS

Water levels in the Rainbow Valley area have declined markedly from 1952 to 1961. This decline suggests that the total withdrawal of ground water exceeds the total replenishment. Plate 4 shows lines of equal decline of the water table for the period 1952–61. The lines of equal decline are based on values obtained by superimposing maps showing water-table contours for the years 1952 and 1961, respectively (pls. 2 and 3). The map (pl. 4) shows that the water level has declined more than 100 feet in the center of the pumped area and near the mountain boundary on the southeast edge of the area. As the cone of depression approaches the mountain boundary, the water table will decline even more rapidly because no ground water can enter the cone from this side. Along the Gila River and in the northeastern part of the pumped area the water table declined only about 70 feet during the period 1952–61.

The hydrograph for well (C–3–4)9baa (fig. 5) shows that the water level in this well declined 154 feet in the period 1952–61; 70 feet of this decline was in the period 1960–61. The water level in well (C–2–4)32ada (fig. 5) declined only 58 feet in the 9-year period. Other miscellaneous measurements corroborate the pattern of the decline contours as shown on the map (pl. 4). The water level in well (C–3–4)16daa declined 92 feet in the period 1952–61, and in well (C–3–4)27baa the water level declined 120 feet in the 8-year period 1953–61 (table 4).

## CHEMICAL QUALITY OF THE WATER

Chemical analyses of water from wells in the Rainbow Valley area show that the water is highly mineralized—the specific conductances generally range from 1,650 to 4,160 micromhos (table 5). Specific conductance, expressed in micromhos at 25°C, indicates dissolved-solids content of the water; dissolved-solids content is approximately equal to 0.6 of the value for specific conductance. The most concentrated ground water sampled in the area was from a shallow well near the Gila River, which had a specific conductance of more than 10,000 micromhos. The sodium content of the ground water in the Rainbow Valley area is high and makes the water "doubtful to unsuitable" for irrigation use according to the standards of the U.S. Department of Agriculture (Wilcox, 1948). The boron content of the water from some wells in the Rainbow Valley area is higher than the permissible limits for boron-sensitive crops. However, semitolerant and tolerant crops, such as alfalfa and cotton, may be irrigated successfully with water containing from 2.00 to 3.00 ppm (parts per million) boron (U.S. Salinity Laboratory Staff, 1954).

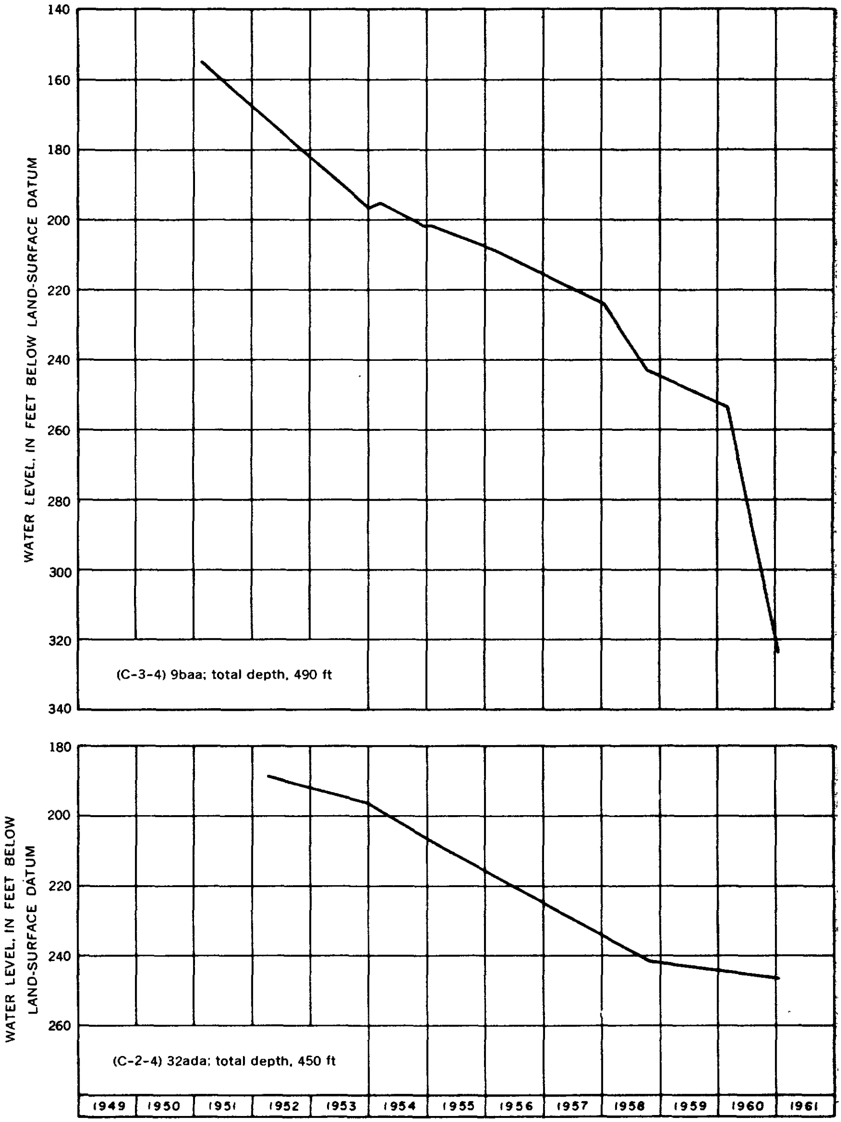


FIGURE 5.—Water levels in selected wells in the Rainbow Valley area.

The analyses show that the dissolved-solids content of the water decreases from northwest to southeast along the Gila Bend Canal and increases northeastward from the vicinity of the canal. For example, the dissolved-solids content of the water from well (C–2–5)35adb was 1,930 ppm, that from well (C–3–4)21bdb was 1,370 ppm, and that from well (C–3–4)4bdd was 1,900 ppm according to analyses of samples collected in 1953 (table 5).

TABLE 5.—*Chemical analyses of water from wells in the Rainbow Valley and Waterman Wash areas*

[Analyses by U.S. Geological Survey. Results in parts per million, except as indicated]

| Well location | Date of collection | Depth (feet) | Temperature (°F) | Silica ($SiO_2$) | Calcium (Ca) | Magnesium (Mg) | Sodium and potassium (Na+K) | Bicarbonate ($HCO_3$) | Carbonate ($CO_3$) | Sulfate ($SO_4$) | Chloride (Cl) | Fluoride (F) | Nitrate ($NO_3$) | Boron (B) | Dissolved solids | | Hardness as $CaCO_3$ | | Percent sodium | Sodium-adsorption ratio (SAR) | Specific conductance (micromhos at 25°C) | pH | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | Parts per million | Tons per acre-foot | Calcium, magnesium | Noncarbonate | | | | | |
| **Rainbow Valley area** | | | | | | | | | | | | | | | | | | | | | | | |
| (C-2-4)26bdd | 9-26-55 | 428 | 89 | 31 | 54 | 5.7 | 279 | 110 | 0 | 116 | 370 | 7.0 | 15 | ------ | 932 | 1.27 | 158 | 68 | 79 | 9.6 | 1,650 | 7.4 | |
| | 9-26-60 | ----- | ---- | 36 | 64 | 2.6 | 373 | 143 | 0 | 132 | 498 | 4.3 | 16 | ------ | 1,200 | 1.63 | 170 | 53 | 83 | 12 | 2,110 | 6.6 | |
| 31daa | 5- 6-53 | 452 | 82 | 30 | 96 | 28 | 352 | 237 | 0 | 139 | 550 | 1.2 | 4.0 | 0.90 | 1,320 | 1.80 | 354 | 160 | 68 | ------ | 2,330 | ----- | |
| 32ada | 5- 6-53 | 450 | 92 | 29 | 80 | 6.1 | 482 | 95 | 0 | 181 | 702 | 5.0 | 2.6 | 1.8 | 1,530 | 2.08 | 224 | 146 | 82 | ------ | 2,730 | ----- | |
| 32caa | 5- 6-53 | 460 | 91 | 29 | 92 | 18 | 411 | 162 | 0 | 163 | 628 | 3.0 | 3.2 | 2.0 | 1,430 | 1.94 | 304 | 171 | 75 | ------ | 2,520 | ----- | |
| (C-2-5)28acc | 9-10-52 | 45 | 72 | 37 | 510 | 210 | 1,800 | 666 | 0 | 1,080 | 3,090 | 3.1 | 5.7 | ------ | 7,060 | 9.60 | 2,140 | 1,590 | 65 | ------ | 10,900 | ----- | Shallow well, near river channel. |
| 35adb | 4- 9-46 | 386 | 74 | ---- | 202 | 71 | 503 | 257 | 0 | 327 | 945 | .7 | 5.7 | ------ | 2,180 | 2.96 | 796 | 586 | ---- | ------ | 3,770 | ----- | |
| | 5- 6-53 | ----- | 74 | 26 | 224 | 70 | 377 | 226 | 0 | 268 | 850 | .4 | 4.1 | 1.2 | 1,930 | 2.62 | 847 | 662 | 49 | ------ | 3,370 | ----- | |
| | 6-16-55 | ----- | 74 | 38 | 171 | 72 | 339 | 190 | 5 | 230 | 745 | .6 | 4.1 | ------ | 1,700 | 2.31 | 722 | 558 | 50 | 5.5 | 2,930 | 8.4 | |
| | 9-11-57 | ----- | ---- | ---- | ----- | ------ | ----- | 199 | 0 | ------- | 630 | ----- | ------ | .32 | ------- | ------ | 526 | 363 | ---- | ------ | 2,610 | 7.1 | |
| | 9-26-60 | ----- | 73 | 34 | 482 | 165 | 684 | 280 | 0 | 690 | 1,710 | .7 | 6.6 | ------ | 3,910 | 5.32 | 1,880 | 1,650 | 44 | 6.9 | 6,400 | 7.2 | Well had not been pumped for some time. |
| (C-3-4)4baa | 5- 6-53 | 250 | 89 | 29 | 92 | 7.4 | 524 | 134 | 0 | 180 | 770 | 4.0 | 5.8 | 1.2 | 1,680 | 2.28 | 260 | 150 | 81 | ------ | 2,950 | ----- | |
| 4bdd | 5- 6-53 | 492 | 88 | 29 | 134 | 18 | 535 | 126 | 0 | 275 | 820 | 4.0 | 19 | 1.2 | 1,900 | 2.58 | 408 | 306 | 74 | ------ | 3,270 | ----- | |
| 6caa | 5-27-46 | 530 | 75 | ---- | ----- | ------ | ----- | 233 | 0 | ------- | 645 | ----- | ------ | ------ | ------- | ------ | ------- | ------- | ---- | ------ | 2,680 | ----- | |
| | 5- 6-53 | ----- | 75 | ---- | ----- | ------ | ----- | 218 | 0 | ------- | 602 | ----- | ------ | .90 | ------- | ------ | ------- | ------- | ---- | ------ | 2,550 | ----- | |
| 8baa | 5- 8-53 | 406 | 78 | 30 | 105 | 38 | 293 | 238 | 18 | 124 | 515 | .8 | 2.7 | .28 | 1,230 | 1.67 | 418 | 223 | 60 | ------ | 2,140 | ----- | |
| 9baa | 2-15-51 | 490 | 70 | 25 | 104 | 16 | 477 | 126 | 0 | 190 | 735 | 8.0 | 4.2 | ------ | 1,620 | 2.20 | 326 | 222 | 76 | ------ | 2,880 | ----- | Sample from pressure tank. |
| | 5- 5-53 | ----- | 87 | ---- | ----- | ------ | ----- | 143 | 0 | ------- | 680 | ----- | ------ | .55 | ------- | ------ | ------- | ------- | ---- | ------ | 2,710 | ----- | |
| | 6- 4-54 | ----- | 86 | ---- | ----- | ------ | ----- | 134 | 5 | ------- | 670 | ----- | ------ | ------ | ------- | ------ | ------- | ------- | ---- | ------ | 2,700 | ----- | |
| | 6-16-55 | ----- | 86 | ---- | ----- | ------ | ----- | 142 | 0 | ------- | 705 | ----- | ------ | ------ | ------- | ------ | ------- | ------- | ---- | ------ | 2,760 | 6.8 | |
| | 8-22-56 | ----- | 87 | ---- | ----- | ------ | ----- | 140 | 0 | ------- | 705 | ----- | ------ | ------ | ------- | ------ | 332 | 218 | ---- | ------ | 2,770 | 7.1 | |
| | 9-11-57 | ----- | ---- | ---- | ----- | ------ | ----- | 140 | 15 | ------- | 677 | ----- | ------ | .89 | ------- | ------ | 310 | 170 | ---- | ------ | 2,730 | 8.7 | |
| 10caa | 4- 1-52 | ----- | ---- | 29 | 99 | 8.3 | 530 | 117 | 0 | 191 | 795 | 4.8 | 6.7 | ------ | 1,720 | 2.34 | 281 | 185 | 80 | ------ | 3,030 | ----- | |
| | 5- 5-53 | ----- | 83 | ---- | ----- | ------ | ----- | 118 | 0 | ------- | 805 | ----- | ------ | .86 | ------- | ------ | ------- | ------- | ---- | ------ | 3,060 | ----- | |
| 15bdd | 5- 5-53 | 465 | 82 | 28 | 114 | 14 | 469 | 138 | 0 | 179 | 740 | 3.6 | 10 | 0.31 | 1,630 | 2.22 | 342 | 229 | 75 | ------ | 2,870 | ----- | |
| 21bdb | 5-27-46 | ----- | 78 | ---- | ----- | ------ | ----- | 246 | 0 | ------- | 620 | ----- | ------ | ------ | ------- | ------ | ------- | ------- | ---- | ------ | 2,660 | ----- | |

| | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5- 8-53 | ----- | 77 | 27 | 132 | 39 | 315 | 248 | 0 | 176 | 555 | .9 | 4.8 | .17 | 1,370 | 1.86 | 490 | 287 | 58 | ----- | 2,400 | ----- |
| 29ddd | 4- 1-52 | 465 | 83 | 25 | 76 | 6.3 | 444 | 128 | 0 | 179 | 615 | 4.4 | 14 | ----- | 1,430 | 1.94 | 216 | 110 | 82 | ----- | 2,500 | ----- |
| | 9- 9-53 | ----- | 83 | ---- | ----- | ----- | ----- | 127 | 0 | ----- | 585 | ---- | ----- | ----- | ----- | ----- | ----- | ----- | ---- | ----- | 2,420 | ----- |
| 35aba | 9-26-60 | 800 | 82 | 37 | 173 | 34 | 393 | 221 | 0 | 205 | 725 | 1.4 | 6.6 | ----- | 1,680 | 2.28 | 572 | 391 | 60 | 7.2 | 2,910 | 7.1 |
| **Waterman Wash area** | | | | | | | | | | | | | | | | | | | | | |
| (C-2-1)29caa | 9-26-60 | 809 | ---- | 23 | 32 | 3.4 | 384 | 70 | 0 | 138 | 498 | 3.9 | 18 | ----- | 1,130 | 1.54 | 94 | 36 | 90 | 17 | 2,050 | 6.6 |
| (C-2-2)8dad | 9-28-60 | ----- | ---- | 27 | 6.0 | 1.2 | 172 | 322 | 0 | 19 | 56 | 7.3 | 16 | ----- | 462 | .63 | 20 | 0 | 95 | 17 | 766 | 7.6 |
| 10dda | 9-30-60 | 1,000 | ---- | 32 | 28 | 1.7 | 213 | 196 | 0 | 65 | 199 | 6.6 | 18 | ----- | 659 | .90 | 77 | 0 | 86 | 11 | 1,140 | 7.3 |
| 14daa | 6- 1-49 | ----- | ---- | ---- | ----- | ----- | ----- | 160 | 0 | ----- | 760 | ---- | ----- | ----- | ----- | ----- | ----- | ----- | ---- | ----- | 3,030 | ----- |
| 23ccc | 4- 7-52 | 1,263 | 87 | 20 | 17 | 3.4 | 264 | 101 | 0 | 116 | 282 | 2.6 | 28 | ----- | 783 | 1.06 | 56 | 0 | 91 | ----- | 1,370 | ----- |
| (C-3-1)9dcb | 8-25-49 | ----- | 77 | 28 | 51 | 14 | 41 | 321 | 0 | 3.7 | 3 | .2 | 3.2 | ----- | 302 | .41 | 184 | 0 | 33 | ----- | 493 | ----- |
| (D-4-1)26bac | 8-12-49 | 370 | 75 | 39 | 55 | 16 | 227 | 195 | 0 | 223 | 206 | 1.2 | 13 | ----- | 876 | 1.19 | 203 | 43 | 71 | ----- | 1,420 | ----- |
| 28bbc | 8-12-49 | 504 | ---- | 33 | 48 | 13 | 131 | 209 | 0 | 109 | 111 | .5 | 20 | ----- | 568 | .77 | 174 | 2 | 62 | ----- | 923 | ----- |

The fluoride content of the ground water in the Rainbow Valley area, in general, is higher than the upper limit of 1.5 ppm recommended by the U.S. Public Health Service (1946) for drinking water. The water from wells along the canal is lower in fluoride than is the water from the wells to the east. The water from several wells along the canal contains less than 1.5 ppm of fluoride.

Analyses of the water from a few wells sampled periodically indicate that between 1946 and 1953 there was a slight reduction in the dissolved-solids content of the ground water in the Rainbow Valley area (table 5). Since 1953, an insufficient number of samples have been taken to establish a trend, but from the few that are available, it seems that there may be an increase in mineralization of the water. As more ground water is pumped and more data are collected, the time-quality relationship may be established.

## WATERMAN WASH AREA

### OCCURRENCE AND MOVEMENT OF GROUND WATER

The Waterman Wash area is underlain by alluvial fill similar in character to that of other basins in southern Arizona. Ground water is in the sand and gravel to a depth of 1,263 feet at well (C-2-2)23ccc—the deepest well in the area. Logs of wells indicate bedrock at much shallower depths along the margins of the basin (table 3). For the most part the ground water in the area is under water-table conditions, although some water may be under artesian pressure locally.

Before any development of ground water in a basin, the ground-water system is in approximate hydrologic equilibrium—the natural discharge is balanced by the natural recharge to the system. Under equilibrium conditions small amounts of ground water probably moved northward and discharged from the basin through the shallow, alluvial-covered opening between outliers of the Buckeye Hills where Waterman Wash leaves the area. As there is no evidence that ground water discharged as effluent seepage, it probably moved out of the basin as underflow.

The total amount of water that could be discharged from the basin as underflow is limited by the cross-sectional area of the opening, which here is only about half a mile wide and probably less than 200 feet deep.

Contours of the water table for 1952 (pl. 2), when only a small amount of ground water had been developed in the basin, indicate that ground water was moving from nearly all directions toward the center of pumping. A small amount of water may have moved northward through the Waterman Wash opening, but water levels north and south of the opening suggest that any such movement was limited to ground water that accumulated on the crest of the barrier in the vicinity of the well in sec. 31, T. 1 S., R. 1 W. The gradient of the water table toward the developed area was slight in 1952, but by 1961 (pl. 3) it had steepened owing to pumping. In 1961, the slope of the water table from the bedrock boundaries toward the center of the developed area averaged about 15 to 20 feet per mile.

### RECHARGE

The possible sources of recharge to the ground-water reservoir in the Waterman Wash area are (1) runoff from rainfall in the adjacent mountain ranges, (2) infiltration of excess irrigation water, (3) direct penetration of precipitation, and (4) underflow into the area.

#### RUNOFF FROM RAINFALL IN THE ADJACENT MOUNTAIN RANGES

Although most of the rainfall on the mountains adjacent to the valley is lost to the atmosphere by evaporation or transpiration, a part becomes runoff and reaches the coarse alluvial materials at the mountain fronts where it may recharge the ground-water reservoir.

It has been estimated (Coates and others, 1955) that about 10 percent of the rainfall on mountain terrain adjacent to a valley area becomes runoff, and Babcock and Cushing (1942) estimate that perhaps as much as 50 percent of the runoff is recharged to the ground-water reservoir at the mountain fronts. The figure of 10 percent may be high for the Waterman Wash area for the same reasons discussed in the section on the Rainbow Valley area, and the calculated runoff would thus be greater than the actual runoff. However, no data are available by which to revise the figure and it will be used here. The total mountain area in the Waterman Wash drainage is about 50,000 acres; the average annual precipitation, based on data for the Buckeye and Maricopa climatological stations (table 1), is about 7½ inches. Thus, about 30,000 acre-feet of precipitation per year falls on the mountain drainage area tributary to the Waterman Wash area, of which a maximum of about 3,000 acre-feet may become runoff. Of this amount as much as 1,500 acre-feet, but probably considerably less because the calculated runoff is excessive, may be recharged to the ground-water reservoir in the area.

#### INFILTRATION OF EXCESS IRRIGATION WATER

Wolcott (1953) estimated that about 15 percent of the water applied to the land for irrigation in the Waterman Wash area was returned to the ground-water reservoir by infiltration. No further data are available with which to refine this estimate. The amount of water pumped in the area and, hence, the amount of recharge from this source vary each year. However, as the recharge for any given time interval is a function, not only of the amount of water pumped, but also of the rate at which the water percolates toward the zone of saturation, the quantity of water that reaches the ground-water reservoir cannot be evaluated with current methods. In 1960, about 60,000 acre-feet of water was applied to the land for irrigation in the Waterman Wash area. Thus, about 9,000 acre-feet of water may be recharged to the ground-water reservoir from this amount of pumpage. In the 9-year period, 1952 through 1960, about 350,000 acre-feet of water was pumped. Of this amount about 52,000 acre-feet of water probably infiltrated toward the zone of saturation. The time required for any of the water to reach the water table and thus become recharge to the ground-water reservoir is unknown. The process described is a recirculation of water from storage within the basin and should not be considered a gain to the ground-water storage.

###### DIRECT PENETRATION OF PRECIPITATION

Most of the rain that falls on the valley floor evaporates directly from the soil zone or is transpired by vegetation before it can percolate downward to the ground-water reservoir. Some recharge may occur where the precipitation falls directly on the coarse-grained materials along the washes, but the amount probably is negligible.

###### UNDERFLOW INTO THE AREA

The possible avenues of underflow into the Waterman Wash area are (1) from the Vekol Wash area between the Booth Hills and the Haley Hills and (2) from the Hidden Valley area between the Haley Hills and the Palo Verde Mountains.

Water-table contours for 1953 (pl. 2) indicate a gradient of the water table of more than 50 feet per mile from well (D-6-1)3add in the Vekol Wash drainage to well (D-5-1)1dca in the Waterman Wash drainage. However, whether the water table is continuous and, hence, whether any underflow moves across this area are not known. No water-level records are available for the 5-mile stretch between the two wells mentioned. Possibly there is a ground-water divide or a bedrock barrier that would preclude any ground-water movement.

If any underflow from the Vekol Wash drains into the Waterman Wash area, the amount would be limited by the small size of the opening through which it could move and probably would not be more than 2,000 acre-feet per year. Considering the overall size of the Waterman Wash area, the gentle slope of the water table from the southeastern part toward the irrigated area, and the amount of water pumped from the area, this amount of recharge would not be significant.

Before development of the ground-water resources, some water may have moved from the lower Santa Cruz basin into the Waterman

Wash area through Hidden Valley. However, owing to extensive pumping of ground water in the Maricopa-Stanfield area of the lower Santa Cruz basin, a ground-water divide has been created and the flow reversed so that water now moves from Hidden Valley into the lower Santa Cruz basin. In 1953 (pl. 2), the ground-water divide was in the vicinity of sec. 17, T. 5 S., R. 2 E. Although water-level measurements are not available for wells in the extreme south end of the Waterman Wash area for 1961, continued lowering of water levels in the lower Santa Cruz basin probably has caused the divide to move toward the Waterman Wash area (pl. 3).

No ground water moves southward into the Waterman Wash area from the Gila River, as shown by the water-table altitudes (pls. 2 and 3).

### DISCHARGE

Before the development of irrigation wells in the area, a small amount of ground water may have discharged as underflow northward through the opening between the hard-rock outliers of the Buckeye Hills and the Sierra Estrella. There is no underflow out of the basin as of 1961, as indicated by the water-table contours and water levels north of the barrier (pl. 3). Water-table contours for 1952 (pl. 2) indicate that pumping had created a cone of depression and that the ground-water divide between water moving southward into the cone and water moving northward as underflow was already near the northern limits of the alluvial basin. The cone of depression for 1961 is larger and deeper and the ground-water divide probably lies within the narrow neck of alluvium between the hard-rock outliers of the Buckeye Hills and the Sierra Estrella.

The possibility of the underflow of ground water from the Waterman Wash area into the Rainbow Valley area to the west has been discussed. Bedrock is exposed in this area, thus preventing the discharge of ground water as underflow.

Some water may discharge from the basin by transpiration but the amount is negligible, as evidenced by the sparse vegetation along the washes.

The major means of discharge of ground water from the Waterman Wash area is by pumping from wells. In 1960, about 60,000 acre-feet of ground water was pumped from wells in the Waterman Wash area as compared to only 17,000 acre-feet in 1952 (table 6). About 40 irrigation wells were in operation during the 1960 irrigation season (table 4 and pl. 1).

### SUMMARY OF RECHARGE AND DISCHARGE

It is possible that as much as 3,500 acre-feet of water may be recharged to the ground-water reservoir in the Waterman Wash area

TABLE 6.—*Amount of ground water pumped from wells in the Waterman Wash area, 1952–60*

| Year | Pumpage (acre-feet) | Year | Pumpage (acre-feet) |
|---|---|---|---|
| 1952 | 17, 000 | 1958 | 45, 000 |
| 1953 | 28, 000 | 1959 | 50, 000 |
| 1954 | 30, 000 | 1960 | 60, 000 |
| 1955 | 40, 000 | | |
| 1956 | 40, 000 | Total | 350, 000 |
| 1957 | 40, 000 | | |

from underflow and precipitation each year. The amount that may be recirculated and available for reuse by infiltration of excess irrigation water varies with the amount of water pumped. In 1960, about 60,000 acre-feet of ground water was pumped from the aquifer in the Waterman Wash area. Of this amount about 9,000 acre-feet may be returned to the ground-water reservoir. Thus, a total of about 12,500 acre-feet of water may be recharged to the aquifer at the 1960 rate of pumping. The natural discharge is negligible; therefore, the difference between the pumpage (60,000 acre-ft) and the total recharge (12,500 acre-ft) or 47,500 acre-feet (nearly 80 percent) was removed from storage. However, as all estimates of recharge probably are excessive, more than 80 percent of the amount pumped may have been removed from storage.

## SOURCE OF THE GROUND WATER WITHDRAWN

Natural recharge to the ground-water reservoir of the Waterman Wash area is small when compared to the amount of ground water pumped, and natural discharge from the aquifer that could be converted to man's use is negligible. Hence, it is evident that most of the water pumped in the basin must be removed from storage—that is, ground water that has accumulated in the basin during geologic time. For proper management of the basin it is important to ascertain the hydrologic characteristics that control the storage capacity of the aquifer, the amount of the stored water that can be extracted, and the transmission of water through the aquifer.

The storage capacity of an aquifer is defined as the volume of space available to contain water; that is, the total volume of saturated sediments multiplied by their porosity. The porosity of a rock or soil is its property of containing interstices (Meinzer, 1923, p. 19) and is expressed as the percentage of the aggregate volume of its interstices to its total volume. However, because a large part of this stored water will be held in the aquifer by molecular attraction and other forces of retention, the amount that can be extracted from the aquifer is much less than the total storage capacity. The volume of water that is theoretically available for man's use from an aquifer is a function of the total volume of saturated sediments in which the ground water is stored and the specific yield of these sediments. The specific yield of a rock is defined as the ratio of the volume of water which the rock, after being saturated, will yield by gravity to its own volume (Meinzer, 1923, p. 28). The volume of recoverable water is defined here as that amount determined by multiplying the total volume of saturated sediments within specified depth limits by the specific yield. The ability to withdraw by pumping the optimum amount of recoverable water from storage depends on several factors which are discussed in the section "Volume of recoverable water."

Other terms used to describe the hydrologic characteristics that control the occurrence and movement of ground water in the aquifer are (Ferris, 1955): (1) the coefficient of permeability of the aquifer, which is defined as the rate of flow of water, in gallons per day, through a cross-sectional area of 1 square foot under a hydraulic gradient of 1 foot per foot; (2) the coefficient of transmissibility of the aquifer, which is defined as the rate of flow of water, in gallons per day, through a vertical strip of the aquifer 1 foot wide extending the full saturated height of the aquifer under a hydraulic gradient of 100 percent—transmissibility is equal to permeability multiplied by the saturated thickness of the aquifer; and (3) the coefficient of storage of the aquifer, which is defined as the volume of water it releases from or takes into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface. For water-table conditions, the coefficient of storage is virtually equivalent to the specific yield, which was described in the preceding paragraph.

The coefficients of transmissibility and permeability of the aquifer may be thought of as the characteristics of the aquifer that determine the rate at which the aquifer will yield water to wells if sufficient water is available. The coefficient of storage or the specific yield is the characteristic that controls the amount of regional drawdown or dewatering caused by a given amount of withdrawal of water from the aquifer.

A determination of all these characteristics makes possible an understanding of the physics of the ground-water system and helps evaluate the ground-water resources of an area in relation to the development of these resources.

### VOLUME OF RECOVERABLE WATER

A method has been devised for computing the average specific yield and the amount of water that, under optimum conditions, can be withdrawn from storage by pumping in a basin. The method consists of assigning values of specific yield to the several categories of materials penetrated during drilling, as described in the logs of wells

(Davis and others, 1959). The values assigned by Davis were based on test drilling and laboratory analysis of data. The method used in the present investigation is a modification of the one used by Davis (1959) and includes the following steps: (1) delineation of the storage area (pl. 1), (2) selection of depth zones, (3) grouping of materials described in the well logs into several categories, (4) assignment of specific-yield values to the several categories of material, and (5) computation of the average specific yield and volume of recoverable water.

The area of the approximate storage reservoir (pl. 1) was computed at about 120,000 acres. However, the delineation of the storage area and, hence, the total volume of sediments available that will store ground water are only approximate. No data are available on the total depth of saturated sediments for distances of several miles along the mountain fronts. Possibly part of this area is underlain by bedrock at a depth shallower than that for which the volume is calculated. If so, the overall volume of saturated sediments and, hence, the computed amount of water available from storage would be less than calculated. The depth zones selected were from about 300 to 500 feet, 500 to 800 feet, and 800 to 1,000 feet. The selection of these zones was based on the following factors: (1) The upper limit was dictated by the position of the water table, (2) the 1,000-foot depth was arbitrarily selected as a probable limit of pumping lift for agricultural purposes, and (3) the intermediate depths were chosen for flexibility of computation.

The materials described in well logs were grouped into categories and specific yields were assigned as follows: (1) Primarily sand and gravel with lesser amounts of silt and clay, 15 percent ("X" category, table 3); (2) primarily silt and clay with lesser amounts of sand and gravel and all hard or tight materials, 5 percent ("Y" category, table 3); and (3) bedrock, 0 percent. The grouping of the materials into categories and the values of specific yield assigned to the several categories will influence greatly the final value for specific yield and, hence, the determination of the volume of water available from storage. Both the grouping and the values assigned here probably are reasonable for the types of material penetrated and are based on comparison with similarly described materials and values in other areas. The reliability of the results of the final computation must be evaluated on the basis of the data available. Most of the logs were for wells in the cultivated part of the area; only two logs were available for wells in the southern, undeveloped part of the area, and one of these wells was only 750 feet deep. The two logs that were available for wells in the southern part of the area showed materials similar in character to those in the cultivated part of the basin, and the extrapolation made on this basis probably is valid.

The computation of the volume of recoverable water for the area included the following steps: (1) Each well log was examined and the material described was classified into the three categories for each of the three depth zones; (2) for each depth zone, the footage in each of the categories of material was added, and tabulations of total footage are shown in table 7; (3) the percentage of the total footage contained in each category was calculated; (4) by use of the specific yields assigned to each category of material, the weighted average specific yield was computed for each depth zone; (5) by use of the total volume (area multiplied by thickness of depth zone), multiplied by the average specific yield, the volume of water available from each depth zone was computed (table 7); and (6) the volumes for the three depth zones were added to obtain the total volume of ground water available for the area (table 7).

The total volume of recoverable water, as shown in table 7, from the water table (about 300 ft deep) to a depth of 1,000 feet was calculated to be about 9.5 million acre-feet. However, perhaps only the storage capacity to a depth of 800 feet should be considered. As indicated in the table, the specific yield of the sediments in the depth

TABLE 7.—*Computation of average specific yield and volume of recoverable water, Waterman Wash area*

[Category of material: X, Medium to high-water-yielding material, where saturated; Y, Low water-yielding material, where saturated]

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| Depth zone (feet) | Category of material | Estimated specific yield (percent) | Footage of logs examined [1] | Percent of total footage | Weighted average specific yield [2] (percent) | Average thickness of zone [3] (feet) | Area (acres) | Total volume of sediments [4] (acre-feet) | Volume of recoverable water [5] [6] (acre-feet) |
| Water level-500 [3] | X | 15 | 2,390 | 69.3 | 10.4 | | | | |
| | Y | 5 | 1,060 | 30.7 | 1.5 | | | | |
| Sum | | | 3,450 | 100.0 | 11.9 | 200 | 120,000 | 24,000,000 | 2,800,000 |
| 500-800 | X | 15 | 4,963 | 76.3 | 11.4 | | | | |
| | Y | 5 | 1,547 | 23.7 | 1.2 | | | | |
| Sum | | | 6,510 | 100.0 | 12.6 | 300 | 120,000 | 36,000,000 | 4,500,000 |
| 800-1,000 | X | 15 | 1,243 | 42.0 | 6.3 | | | | |
| | Y | 5 | 1,713 | 58.0 | 2.9 | | | | |
| Sum | | | 2,956 | 100.0 | 9.2 | 200 | 120,000 | 24,000,000 | 2,200,000 |
| Total | | | | | | | | | 9,500,000 |

[1] Total footage in each of the categories of material for all logs examined.
[2] Multiply column 3 by column 5.
[3] To compute thickness of zone, average water level was taken as 300 feet.
[4] Multiply column 7 by column 8.
[5] Multiply column 6 by column 9.
[6] All figures are rounded to nearest 100,000.

zone 800–1,000 feet is somewhat less than in the upper two zones and, therefore, materials probably are tighter. Thus, less water would be available per unit volume of saturated sediments than in the upper zones of higher specific yields. Also, pumping from these levels may not prove to be economically feasible.

Theoretically, the total volume of recoverable water to a depth of 800 feet is slightly more than 7 million acre-feet; the average specific yield of the upper two depth zones is about 12 percent. However, the actual volume of water that can be pumped from the ground-water reservoir in the Waterman Wash area will be less than the computed volume depending upon the effectiveness of the removal of the water from storage. The ability to withdraw the full amount of the volume of water that is available in a basin is contingent upon several physical factors such as the depth of the wells, distribution of wells, and operation of the ground-water reservoir at optimum rates and schedules of pumping. The pattern of the cone of depression created by pumping and the quality of the ground water at depth also will affect the amount of water that can be used.

When a well is pumped, the water levels are lowered in the vicinity of the well, and water is removed from storage concurrently with the lowering of water levels; thus a cone of depression is formed in the water table. Continued pumping causes the cone to deepen and broaden. Expansion of the cone and removal of water from storage must continue until recharge is increased, natural discharge decreased, or a combination of both by an amount equal to the rate of pumping the well. The shape of the cone is determined chiefly by the rate at which water moves through the aquifer (coefficient of transmissibility), by the specific yield of the aquifer materials, and by the aquifer boundaries. The radius of the cone is dependent on a quantity involving distance, time, transmissibility, and the ability of the material to store water; thus, it is inversely proportional to the coefficient of storage because of its relation to time (Theis, 1938). The rate of discharge of a single well or closely spaced group of wells affects the depth of the cone but not its rate of lateral growth. Thus, uniform areal distribution of wells over the area is necessary in order to withdraw the optimum amount of recoverable water from storage. As of 1961, the cone of depression created by pumping in the cultivated part of the Waterman Wash area covered about 45,000 acres, indicating that all the water withdrawn so far has come from this much of the total area. The concentration of pumping in the comparatively small irrigated area as compared to the basin as a whole has caused the cone of depression to deepen rapidly rather than to expand to the southern, undeveloped part of the basin. Future development to the south will spread the cone of depression and withdraw water from the ground-water storage reservoir in this part of the area but probably would not alter the pattern of rapid deepening of the cone in the presently cultivated area. Thus, continued pumping in the cultivated area will result in excessive lowering of the water table, which may limit the life of this area while ground water may be still available from storage in other parts of the basin. Most efficient utilization of the available water requires that wells be spaced as uniformly as possible throughout the area so that the lowering of the water level in any one place will be kept at a minimum and the life of the storage reservoir will be extended.

The quality of the water at depth in the area may be such that not all the water available to a depth of 800 feet is usable. In many of the areas studied in Arizona, the dissolved-solids content of the ground water increases greatly with depth. No data are available to determine whether this is true in the Waterman Wash area, but it is, nevertheless, a factor that must be considered in evaluating the overall water resources of the area.

#### TRANSMISSION CHARACTERISTICS OF THE AQUIFER

The coefficients of transmissibility and permeability of the aquifer in the Waterman Wash area have been estimated in the present study in several ways. In general, the methods used herein fall into two categories: (1) "spot" determinations, by well-data analysis; and (2) regional determinations, by flow-net analysis and by an expression based on Darcy's law.

The computations based on well data consisted of estimating the coefficient of transmissibility from the specific capacity of individual wells by two methods and of determining a yield factor for these wells from which the coefficient of permeability can be estimated. The specific capacity of a well is the relation of drawdown to discharge—that is, its yield in gallons per minute per foot of drawdown caused by the pumping. The yield factor of a well has been defined (Poland, 1959) as the specific capacity divided by the saturated thickness of sediments from which the well draws water, multiplied by 100. Multiplication by the factor of 100 is for convenience of units only and has no significance in the evaluation of the characteristic. Both the specific capacity and the yield factor are dependent not only on the hydrologic characteristics of the aquifer material penetrated by the well but also on the construction of the well itself and particularly on the condition of the perforations in the casing and their distribution within the saturated zone. Wenzel (1942, p. 147–151) has pointed out that the drawdown-discharge relation or specific capacity of a well may be a poor index of the permeability of the water-bearing zone surrounding the well. In view of the lack of better data, however, these indices of the coefficients of transmissibility and permeability of the aquifer have been used in the present study to give, at least, a rough estimate of these characteristics. Where it can be shown that the values obtained for these characteristics are within the same order of magnitude when derived from the several methods described, the results probably are indicative of the actual conditions.

Data were available with which to compute the specific capacity and yield factor for only seven wells widely spaced over the irrigated area. Table 8 shows the computed values of specific capacity and yield factor to be within a reasonable order of magnitude.

The first method used to compute the coefficient of transmissibility was described by Meyer (Theis and others, 1954); when the specific capacity and the coefficient of storage are known, the transmissibility may be read from a graph based on the Theis (1935, p. 520) nonequilibrium formula. The coefficient of storage (specific yield) was estimated to be about 12 percent, as shown in the computation for the volume of water available from storage in the aquifer. The second method used was described by Thomasson and others (1960, p. 222); the specific capacity of the well is multiplied by an empirical factor to obtain an approximate value for the coefficient of transmissibility. The average value for the coefficient of transmissibility derived from the two methods is about 65,000 gpd (gallons per day) per ft. Thomasson (1960) also suggested an empirical relationship between the yield factor and permeability, which was used to obtain approximate values for the coefficient of permeability (table 8).

The flow-net method for determining the coefficient of transmissibility of an aquifer has been described in several publications; the

TABLE 8.—*Hydrologic characteristics estimated from well data, Waterman Wash area*

Saturated thickness: Based on water levels reported at time well was completed.
Specific capacity: Gallons per minute per foot of drawdown. Data from well completion tests.
Yield factor:

$$\frac{\text{Specific capacity x 100}}{\text{Saturated thickness penetrated by well, in feet}}.$$

Transmissibility: Estimated from specific capacity.
Permeability: Estimated from yield factor. After Thomasson and other (1960).

| Well location | Total depth (feet) | Perforated zone (feet) | Saturated thickness (feet) | Discharge (gpm) | Drawdown (feet) | Specific capacity | Yield factor | Transmissibility (gpd per ft) | | Permeability (gpd per sq ft) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | After Theis and others (1954) | After Thomasson and others (1960) | |
| (C-2-1)19baa | 1,139 | 295–1,125 | 830 | 2,935 | 110 | 27 | 3.2 | 40,000 | 45,000 | 55 |
| 20dba | 717 | 200–650 | 390 | 2,200 | 45 | 49 | 12.5 | 80,000 | 85,000 | 210 |
| 29bab | 809 | 120–809 | 591 | 2,800 | 72 | 39 | 6.6 | 60,000 | 65,000 | 110 |
| 29caa | 809 | 200–809 | 564 | 2,800 | 50 | 56 | 10.0 | 90,000 | 95,000 | 170 |
| (C-2-2)10dda | 1,000 | 312–985 | 673 | 3,450 | 89 | 39 | 5.8 | 60,000 | 65,000 | 100 |
| 24aaa | 930 | 214–785 | 571 | 2,920 | 130 | 22 | 3.8 | 30,000 | 35,000 | 65 |
| 27cdd | 1,084 | 243–1,082 | 839 | 3,400 | 65 | 52 | 6.2 | 80,000 | 85,000 | 105 |

details of the method used depend upon the data available. For a complete discussion of flow-net analysis see Taylor (1948). Although the water-bearing materials in the Waterman Wash area are not uniform (table 3, fig. 4, and accompanying discussion) and, hence, the transmissibility is not uniform, an estimate of transmissibility can be obtained from a generalized water-table contour map by adjusting the position of flow lines relative to the equipotential lines. The present analysis is based on the generalized configuration of the water table for spring 1961 (pl. 3 and fig. 6). Thus, the dashed lines on figure 6 are equipotential lines and represent the contours connecting points of equal altitude of the water table in feet above mean sea level; the dotted lines are flow lines and represent the path that a particle of water would follow to the point of discharge.

If the permeability and transmissibility of the water-bearing material were uniform throughout the area of the flow net, the quantity of water flowing into the discharge area would be equally distributed over the net and the intersecting flow and equipotential lines would form "squares." Construction of a flow net is principally a trial-and-error process, and admittedly the net for the Waterman Wash area probably could be modified within the scope of the data available. Further refinement of the net, however, probably would not appreciably change the overall aspect or the computed value for the coefficient of transmissibility. The density and pattern of the flow paths into the discharge area are controlled by both the amount of discharge and the coefficient of transmissibility of the aquifer in the area. The amount of discharge for the 1960 pumping season is known, and the coefficient of transmissibility of the aquifer can be determined from the following relation:

$$T=\frac{Q}{Nh}$$

in which

$T$=Coefficient of transmissibility, in gallons per day per foot.
$Q$=Discharge, in gallons per day.
$N$=Number of flow channels.
$h$=Difference in head between two equipotential lines.

The total pumpage from 44 wells in the irrigated area was about 60,000 acre-feet for the 1960 irrigation season. The computations will be based on the discharge area enclosed by the 820-foot contour; 17 wells are within this area. On the basis of the ratio of the 17 wells to the total of 44 wells in the entire irrigated area, about 23,000 acre-feet of water per year, or about 20 million gpd, was discharged

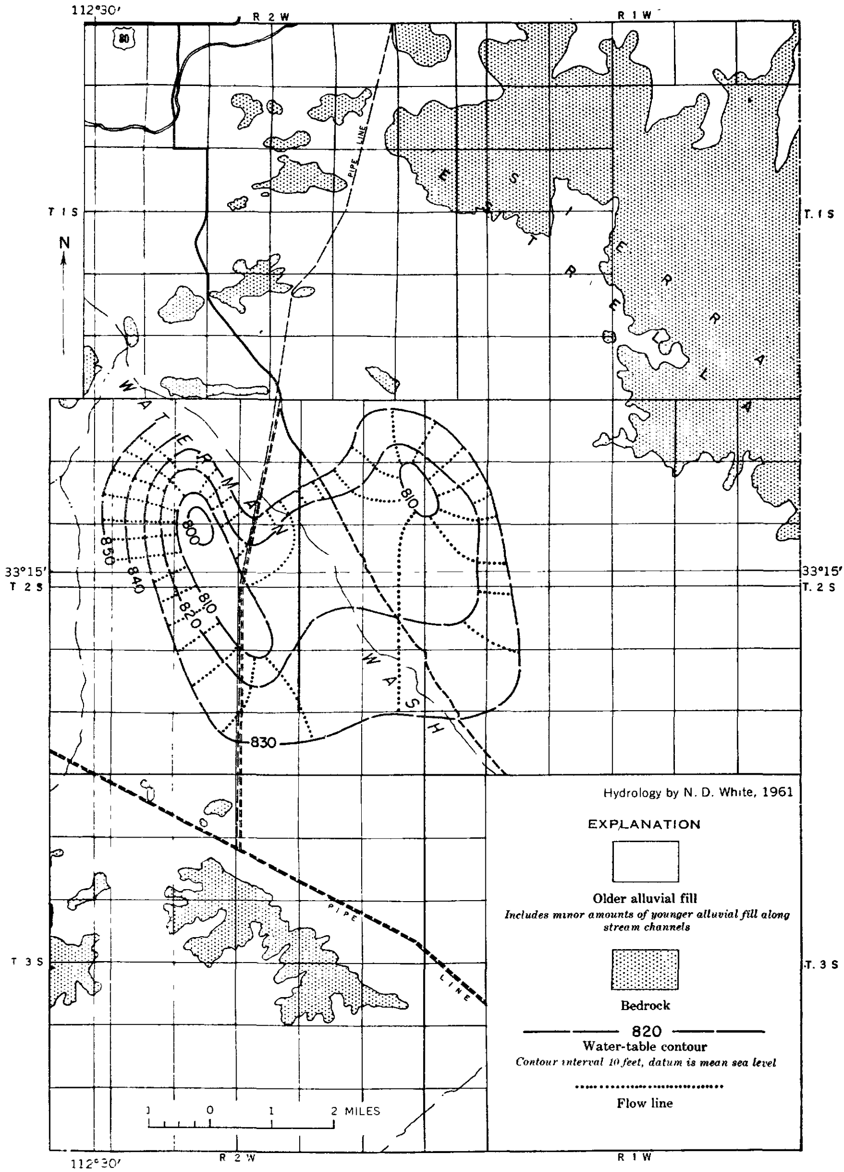


FIGURE 6.—Generalized flow net for the Waterman Wash area, based on 1961 water-table contours

from the area within the 820-foot contour. The number of flow paths entering the area is 37, and the difference in head is 10. Thus,

$$T=\frac{2\times10^7}{37\times10}=54{,}000 \text{ gpd per ft}$$

This value is in the same order of magnitude as that obtained by the methods based on well data.

An additional method for computing transmissibility is based on Darcy's law. A useful and convenient form of the law is the expression,

$$Q=TIL$$

in which

$Q$=Discharge, in gallons per day.
$T$=Coefficient of transmissibility, in gallons per day per foot.
$I$=Hydraulic gradient, in feet per foot.
$L$=Width of the cross section through which the discharge takes place.

For the problem here: $I$ is the average hydraulic gradient from the 830- to the 820-foot contour and equals about 20 feet per mile; $L$ is the distance around the 820-foot contour and equals 16.8 miles; and $Q$ is the discharge within the 820-foot contour as computed for the flow-net method and equals $2\times10^7$ gpd. Thus,

$$T=\frac{Q}{IL}$$

$$=\frac{2\times10^7}{20\times16.8}$$

$$=60,000 \text{ gpd per ft}$$

The coefficient of transmissibility for the irrigated area of the Waterman Wash basin probably is between 55,000 and 65,000 gpd per ft. The same value probably would be approximately correct for the entire basin.

## WATER-LEVEL FLUCTUATIONS

Ground-water levels in the Waterman Wash area, as in many other areas in the arid parts of Arizona, are declining in response to the withdrawal of water in excess of replenishment. Water-table contours for the years 1952 and 1961, respectively, were superimposed to determine the amount of decline in the water table for the period shown in plate 4, which indicates that declines ranged from about 20 feet on the east edge of the irrigated area to more than 80 feet in the center. The water level in well (C–2–2)9cdd declined about 90 feet in the period 1952–61 and that in well (C–3–1)1bca, about 2½ miles from the edge of the irrigated area, declined about 13 feet in the period 1953–61 (table 4).

In the southern part of the Waterman Wash area, where there is little or no pumping for irrigation, declines for the period 1952–61 were less than 20 feet and, for the most part, were less than 5 feet. Development of ground water in the southern part of the basin probably will cause the water table to decline at a rate similar to that in the presently irrigated area. As of the spring of 1961, about 16,000 acres was irrigated and the cone of depression created by pumping covered about 45,000 acres. Small cones of depression also have formed around pumped wells in other parts of the area. For example, the water level in well (D-5-1)1dca, in the southern part of the area, declined about 17 feet in the period 1953-58. The water level in well (D-4-1)21ada declined less than half a foot in the period 1955-61 and that in well (C-3-1)34ddb declined less than 4 feet from October 1953 to January 1959 (table 4).

### CHEMICAL QUALITY OF THE WATER

The few available chemical analyses of water from wells in the Waterman Wash area indicate that, in general, the water is suitable for irrigation use according to the standards of the U.S. Department of Agriculture (Wilcox, 1948). The data are insufficient to establish a definite pattern, but the water from wells in the southern part of the area may be slightly lower in dissolved-solids content than that from the developed area at the north end of the basin; the water from wells east of Waterman Wash in the irrigated area may be higher in dissolved solids than that from wells in the western part (table 5). The fluoride content of the water from wells in the southern part of the area is much lower than that from the irrigated area. Samples of the water from wells in the cultivated area of the basin showed a fluoride content greatly in excess of the upper limit of 1.5 ppm recommended for drinking water by the U.S. Public Health Service (1946). For example, the water from well (C-2-2)8dad, sampled in 1960, contained 7.3 ppm of fluoride, although the dissolved-solids content was only 462 ppm. The water from well (C-2-2)29caa had a fluoride content of 3.9 ppm and a dissolved-solids content of 1,130 ppm when sampled in 1960. In contrast, the water from well (C-3-1)9dcb, in the undeveloped part of the basin, contained only 0.2 ppm of fluoride and 302 ppm dissolved solids.

Plant uptake and evaporation remove most of the water from the soil and leave the dissolved minerals in the root zone. Subsequent irrigation may leach these minerals downward toward the water table, and the quality of the ground water eventually may deteriorate and become unusable for some purposes. Data are insufficient to establish any definite trends in the chemical quality of the ground water with time.

## CONCLUSIONS

The study has shown that the geologic and hydrologic data available are sufficient only for rough quantitative analysis of the water resources of the two areas. The quantitative estimates that have been given are as good as can be made with the information available and probably are in the correct order of magnitude.

The report points out several facts concerning the water resources of the two areas. Water levels in the Rainbow Valley and Waterman Wash areas have declined fairly rapidly in response to the withdrawal of ground water in excess of replenishment. Ground water is being mined in both areas—that is, water that had accumulated during a long period of time is being progressively depleted. The length of time that this process can continue without depleting the ground-water reservoir to an extent that it will be no longer economically feasible to pump ground water for some purposes is unknown.

Additional agricultural development in the areas undoubtedly will increase the withdrawal of ground water from storage and will result in further lowering of water levels. In the Rainbow Valley area, future agricultural development is limited by the small amount of additional land that could be farmed. Any additional development, however, probably will increase the rate of decline of the water table in the area. In the Waterman Wash area, less than 15 percent of the available land is being cultivated. Thus, future development in the basin beyond the presently cultivated area would require properly spaced wells in order to make the most efficient use of the ground water from storage. Such development would cause an increase in the rate of depletion of the ground water in storage.

As more and more ground water is pumped and applied to the land for irrigation in the areas, the quality of the water may deteriorate. Recharge of "new" water to the areas is negligible, but some applied irrigation water is returned to the ground-water reservoir by infiltration. The quality of this water may be influenced by the leaching of the materials through which it flows and, in time, the water may become unusable for some purposes.

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