Geology and Ground-Water System in the Gila River Phreatophyte Project Area, Graham County, Arizona

GEOLOGICAL SURVEY PROFESSIONAL PAPER 655-D

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By WILLIAM G. WEIST, JR.

GILA RIVER PHREATOPHYTE PROJECT

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A study of the geology and ground water in the Gila River flood plain and the adjacent terraces

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By WILLIAM G. WEIST, JR.

ABSTRACT

The Gila River Phreatophyte Project is along a 15-mile reach of the Gila River at the head of San Carlos Reservoir in the San Carlos Indian Reservation. The area is underlain by two major water-bearing units—the basin-fill deposits and the alluvial deposits. The basin-fill deposits are divided into a silt and sand facies and a limestone facies; the alluvial deposits are divided into terrace alluvium and flood-plain alluvium. The silt and sand facies of the basin fill consists principally of very fine sand and silt; the limestone facies contains fresh-water limestone, tuff, marl, silt, and sand. The terrace and flood-plain alluvium consist of poorly sorted lenticular deposits of clay, silt, sand, and gravel; in general, the flood-plain alluvium is coarser than the terrace alluvium.

Because the basin-fill deposits are fine grained, they yield only a few gallons of water per minute to wells. An aquifer test made at one of the wells that tap the basin fill indicates a coefficient of transmissivity of about 50 square feet per day and a storage coefficient of 0.00043. Water enters the basin fill near the edge of the project area and moves toward the center of the area and downstream. Some water is discharged horizontally and vertically into the overlying alluvial deposits in the central part of the area.

Wells drilled into the alluvial deposits yield as much as 600 gallons per minute of water. Results of an aquifer test indicate an average coefficient of transmissivity of 10,700 square feet per day and an average storage coefficient of 0.12. The alluvial deposits are recharged by flow from the basin-fill deposits, by underflow from upstream, and by percolation from streamflow. Water levels in wells near the Gila River respond rapidly to increases in streamflow.

INTRODUCTION

The Gila River Phreatophyte Project is along a 15-mile reach of the Gila River at the head of the San Carlos Reservoir in the San Carlos Indian Reservation, Graham County, Ariz. (fig. 1). This area along the Gila River covers about 60 square miles of flood plain and terraces.

The flood plains of many of the rivers in the Southwestern United States are choked with dense growths of phreatophytes, mainly saltcedar (*Tamarix pentandra* Pall.). In 1962 an investigation was begun along a 15-mile reach of the Gila River to determine how much water was being lost through consumptive use by phreatophytes and how much water could be saved by replacing the phreatophytes with a more beneficial vegetation, such as Bermuda grass. The results of the study are being published in a series of U.S. Geological Survey professional papers; this report is the fourth in the series and describes the geology and the ground-water system in the Gila River Phreatophyte Project area.

METHODS OF INVESTIGATION

The geology was mapped by E. S. Davidson on a semidetailed basis in 1964–65 and was modified by photogrammetric methods by the author in the fall and winter of 1966–67. No attempt was made to place exact ages on the geologic units.

The collection of ground-water data was begun in November 1962, when the first in a network of 72 observation wells was drilled in the alluvial deposits. The wells were equipped with digital recorders set to record the altitude of the water table at 30-minute intervals; in 1966, the recorders were reset to record the altitude of the water table at hourly intervals. During March and April 1966, about 35 additional observation wells were installed. Most of the additional wells consist of a 1- or 2-inch pipe in which the water level is measured monthly; however, four of the wells are 4 inches in diameter and are equipped with digital recorders.

In March 1965 a network of observation wells was established using the existing stock and domestic wells

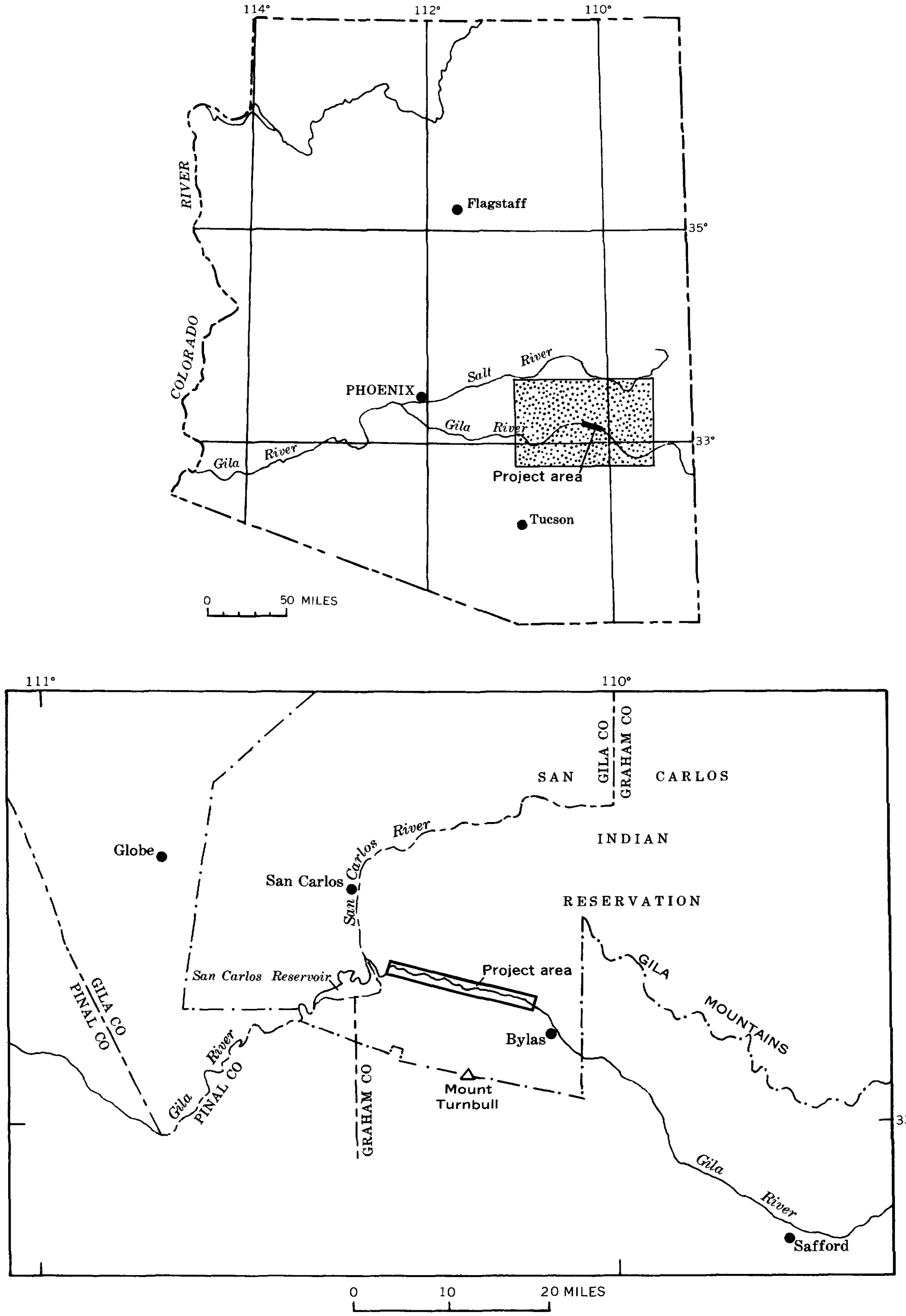

FIGURE 1.—Location of project area.

that tap the basin-fill deposits. The network has been expanded gradually; at the present time (1966), water levels are being measured in 20 wells on a monthly basis.

Well-cutting samples were collected from the observation wells drilled in 1966, and size analyses were made by the author in the sedimentation laboratory of the University of Arizona. E. S. Davidson measured five stratigraphic sections in the area, and cores were collected from two wells drilled in the basin fill (pl. 1).

Data collected during the Gila River Phreatophyte Project study will be analyzed by use of a digital computer, and the results will be discussed in other chapters of the professional-paper series. Only the analyses of the sedimentation studies of the alluvial deposits are given in this report.

WELL-NUMBERING SYSTEM

The 72 observation wells drilled in the alluvial deposits between 1962 and 1963 are arranged in lines or cross sections spaced about 2 miles apart perpendicular to the Gila River. Each cross section has six wells, and the cross sections are numbered with odd numbers—1, 3, 5, etc.—starting with the most upstream cross section (pl. 1). In 1966 cross section 12, having six wells, was added about midway between cross sections 11 and 13. These cross sections are the basis for the well-numbering system in the project area.

Each well has a unique 4-digit number; the first two digits represent the cross section at or immediately downstream from the well, and the last two digits are an arbitrary but unique number. For example, well 0102 is the second well from the left (facing downstream) in cross section 1; well 0532 is between cross sections 3 and 5. In general, the numbers increase from south to north and in downstream order.

ACKNOWLEDGMENTS

Messrs. C. S. English, W. M. Fogarty, T. E. Eisenhuth, and R. D. Dale aided in the collection of the ground-water data. An aquifer test on a well tapping the alluvial deposits was made under the supervision of S. G. Brown. Mr. C. S. Huzzen gave assistance in the preparation of data for computer analysis and wrote or modified the computer programs.

GEOLOGIC UNITS

Two sedimentary rock units underlie the project area—the basin-fill deposits and the alluvial deposits. The basin-fill deposits are divided into a silt and sand facies and a limestone facies; the alluvial deposits are divided into terrace alluvium and flood-plain alluvium (pl. 1). The basin fill is the most widespread unit in the area; it underlies the alluvium along the river and crops out on the slopes beyond the outer edges of the present river flood plain. Although terrace gravel overlies the basin fill at different levels that are higher than the Gila River (Davidson, 1960, p. 125), these deposits are mainly outside the project area and are not significant to this investigation; therefore, they are not mapped or described in this report. The alluvial deposits along the Gila River are in a wide trough carved into the basin fill. The terrace alluvium covers the entire width of the trough and forms terraces about 20–100 feet above the bed of the Gila River and its major tributaries. In most places the terrace alluvium is separated from the flood-plain alluvium by a 5–20-foot escarpment. The flood-plain alluvium underlies the bed and flood plain of the Gila River and its tributaries (pl. 1).

BASIN-FILL DEPOSITS

In general, the following discussion of the basin-fill deposits is based on work done by E. S. Davidson (written commun., 1966). The basin-fill deposits are divided into a silt and sand facies and a limestone facies. In most of the area the basin-fill deposits consist of thin-bedded to very thin bedded reddish-brown to light-brown silt and sand. The silt and sand facies grades into the limestone facies, which crops out in the western part of the project area. The limestone facies consists of thin-bedded white limestone and minor amounts of silt and tuff. Five stratigraphic sections were measured and two drill cores were collected in widely separated places in the study area (pl. 1) and are representative of the lithologic characteristics of the basin fill. (See the sections entitled "Stratigraphic Sections" and "Drill-Core Descriptions.") The lithology of the basin fill probably is similar to that in the sections and core descriptions to depths of at least a few hundred feet. The basin-fill deposits extend to a depth of about 1,000 feet below the land surface, and several hundred feet of the deposits is exposed in ridges along the tributaries of the Gila River.

The beds in the basin fill dip gently from the north and south into the poorly defined axial area slightly south of the Gila River. A few horizontal and southward-dipping beds occur at the south boundary of the alluvial deposits.

The oldest unit exposed is the limestone facies, which crops out in the western part of the area. Although individual beds cannot be traced very far, the westward-sloping stream gradient intersects nearly horizontal strata throughout most of the area and indicates that the siltstone beds in the eastern part of the area are about 100 feet higher in the stratigraphic sequence.

The hydraulic conductivity of the basin-fill deposits is very low in most of the project area. Some wells penetrate from 200 to 500 feet of the unit and yield from 3 gpm (gallons per minute) to a reported 20 gpm of water; the drawdown is as much as 50 feet. The water is obtained from the thin sand beds intercalated in the unit, and the most productive of these beds have a grain size at least as coarse as fine. Although the pore spaces are very small, a major factor in allowing the sand to yield water to wells is that the grains are well sorted. In places, the limestone facies is more permeable than the silt and sand facies, because some beds contain abundant interconnected vugs and because the limestone is fractured along and across the bedding planes. Although no large caverns were observed, ground water seeping along the openings dissolves the rock of the fracture walls and increases the overall hydraulic conductivity of the limestone.

SILT AND SAND FACIES

The silt and sand facies of the basin-fill deposits consists of very thin to thinly laminated intergradational beds of silt and sand and small amounts of clay. The material was derived largely from rocks in the surrounding mountains. The sand is well sorted and is fine to very fine. Locally, medium and coarse grains are scattered throughout the sand beds or are concentrated along parting planes and constitute as much as 5 percent of the unit. The sand is arkosic and micaceous. Some of the sand beds occur in small thin discontinuous lenticular deposits (fig. 2), but the thicker beds may be traced for more than a mile in outcrop. A few beds are firmly cemented by calcium carbonate and form resistant ledges, but more commonly, the beds are weakly consolidated and weather to smooth slopes. The silty beds are not resistant and weather to gentle slopes and rounded ridges and knobs. The clay beds that are interlaminated in the silt and sand facies are less than a foot thick. The clay is reddish brown to light brown and in places contains flecks of green; a few beds are greenish gray. The clay generally is silty to sandy. White salt effloresces on the exposed surface of the clay, particularly following rainstorms, when the clay beds are wetter than the enclosing silt or sand beds. Some of the beds show ripple laminations and small-scale cross-bedding, and these sedimentary features dip steeply toward the structural axis of the basin.

A small volcanic neck intrudes the silt and sand facies in the western part of the area (fig. 3). The neck is about 400 feet in diameter and consists of andesitic agglomerate, tuff, and breccia; andesitic dikes closely parallel the borders of the neck. Another vent occurs slightly more than 2 miles south of the area mapped during this investigation, and several vents and other volcanic intrusive and extrusive bodies occur north of the mapped area (Marlowe, 1961, p. 50–68).

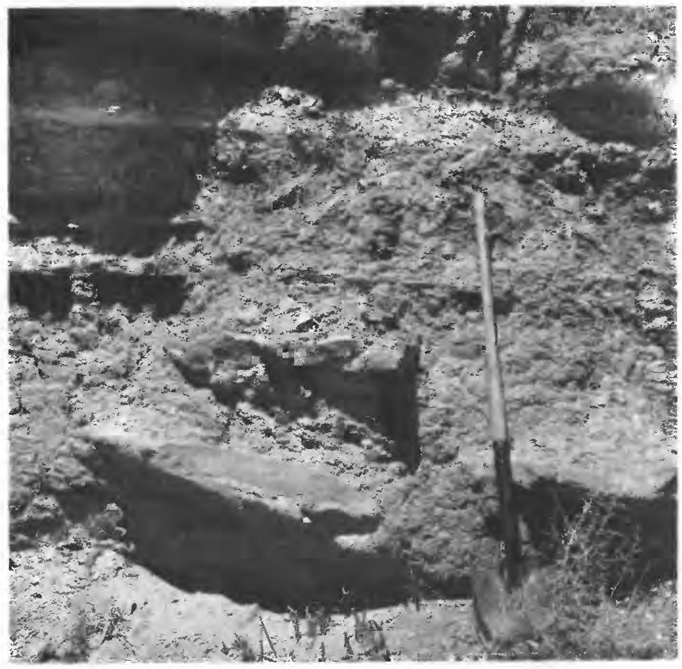

FIGURE 2.—Silt and sand facies of the basin-fill deposits exposed along the Coolidge Dam road south of cross section 15.

The silt and sand facies grades into the limestone facies north of the Gila River about 2 miles downstream from Salt Creek and in the extreme west end

FIGURE 3.—Volcanic neck intruding the silt and sand facies of the basin-fill deposits in western part of project area.

of the area. The uppermost limestone beds that crop out in the west end of the area grade southward and eastward into silt and probably are equivalent to the beds that crop out west of Salt Creek. The lowermost limestone beds in the west end of the area are overlain by beds of the silt and sand facies on the south side of the Gila River.

The amount of sand and sandstone in the silt and sand facies in the measured sections and drill cores ranges from 15 to 88 percent and averages 54 percent. Even the sand and sandstone, however, rarely contain grains coarser than medium in size, and most of them are of silt size. The fine-grained nature of the deposits is indicative of low hydraulic conductivity. Wenzel (1942, p. 13) listed the physical properties of 35 samples taken from representative unconsolidated material in the United States; 12 of the samples were composed predominantly of very fine to medium sand. As determined in the laboratory, the hydraulic conductivity of these samples ranges from 4 to 125 feet per day. Stearns (1927) reported similar results (3–135 feet per day) from tests made on about 30 samples that were predominantly very fine to medium grained.

The large amounts of silt, siltstone, and clay in and interbedded with the sand and sandstone reduce the overall hydraulic conductivity of the acquifer. This "dirty" nature of the sand indicates that the hydraulic conductivity is probably less than 10 feet per day. Generally, it is necessary to penetrate 100 feet or more of saturated basin fill to obtain a well yield of from 3 to 10 gpm. The wells that tap the basin fill in the project area are not known to yield more than about 20 gpm.

Drillers' logs of two stock wells are given in table 1. Although the logs are not very detailed, they give some indication of the materials penetrated. Most of the gravel mentioned in the logs probably is coarse sand. House well (well 2169) is about 4 miles south of cross section 21, and Randall well (well 0731) is north of U.S. Highway 70 opposite cross section 9 (fig. 8). The stratigraphic units were added to the logs by the author.

On September 20, 1966, an aquifer test was made on Calva Tribal well 1 (well 0531), and water-level measurements were made in Calva Tribal well 2 (well 0532), 62 feet from well 1. The wells are south of the railroad tracks at the stockpens near Calva (pl. 1). The wells are 6 inches in diameter and are reported to be 200 feet deep. The water levels in the wells were about 45 feet below the land surface before the start of the test. Unfortunately, logs are not available for either well, and the amount of sand and sandstone penetrated by them is not known. Well 1 was pumped for 24 hours at an average rate of 8.7 gpm; the water level was measured periodically for 10 hours and again before

TABLE 1.—*Drillers' logs of stock wells in the Gila River Phreatophyte Project area*

House well (well 2169)

[Alt 3,112 ft; lat 33°09′14″ N.; long 110°20′47″ W. The last 50 ft of casing was perforated with a cutting torch. In July 1966 the water level was about 256 ft below land surface]

	Thickness (ft)	*Depth (ft)*
Alluvial deposits:		
Terrace alluvium:		
Boulders and gravel	14	14
Red conglomerate	8	22
Basin-fill deposits:		
Yellow clay and gravel	33	55
Yellow clay	40	95
Gray clay and gravel	40	135
Blue shale	15	150
Yellow clay	15	165
Yellow clay and gravel	30	195
Gray clay	50	245
Blue shale	15	260
Yellow clay and gravel	50	310
Blue clay and gravel	10	320
Gray clay and gravel	10	330
Blue shale	25	355
Yellow clay and gravel	25	380
Gray clay and gravel	85	465
Red, black, and gray gravel	27	492

Randall well (well 0731)

[Alt 2,816 ft; lat 33°13′03″ N.; long 110°12′16″ W. The last 50 ft of casing was perforated with a cutting torch. In July 1966 the water level was about 116 ft below the surface]

	Thickness (ft)	*Depth (ft)*
Alluvial deposits:		
Terrace alluvium:		
Clay, gravel, and boulders	70	70
Basin-fill deposits:		
Clay	50	120
Sandy clay, some gravel	86	206

the pump was shut off. The water level in the pumped well declined more than 55 feet during pumping; the water level in the observation well declined about 25 feet. Water levels also were measured during the first 4 hours of the recovery period. Data collected during pumping indicate a transmissivity of 18 sq ft (square feet) per day, and recovery data indicate a transmissivity of 20 sq ft per day. As determined from the pumping-test data the storage coefficient is 3.7×10^{-4}.

The data collected during the pumping test are plotted in figure 4, which shows a definite break in slope at the 80-minute mark. It is possible that the break is caused by boundary effects, because the well is near the edge of the valley. The data points to the 80-minute mark define a transmissivity of 50 sq ft per day and a storage coefficient of 4.3×10^{-4}. If 100 feet of basin fill is contributing to the well, the average hydraulic conductivity is 0.5 ft. per day.

The water in the silt and sand facies is of good chemical quality. The dissolved-solids content generally is not more than 500 mg/l (milligrams per liter) and may be as low as 100–200 mg/l.

LIMESTONE FACIES

The limestone facies consists of thinly laminated to thinly bedded limestone in addition to calcareous silt

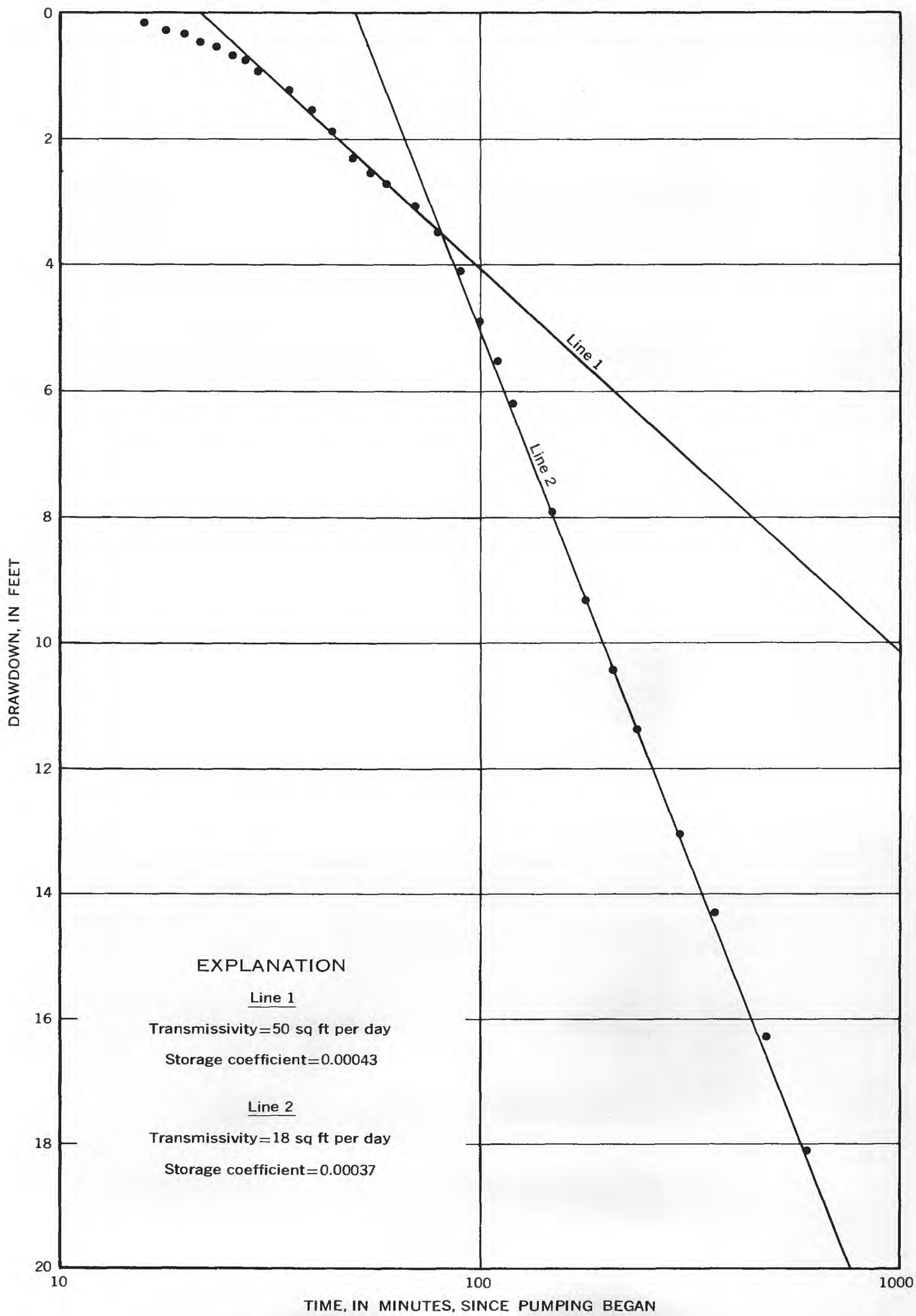

FIGURE 4.—Drawdown in Calva Tribal well 1 (well 0531) during aquifer test.

and sandstone. Tuff beds and disseminated tuff fragments are a minor constituent, but increase in quantity north of the project area. The limestone is white to light gray, is fine to medium crystalline, and commonly contains abundant small vugs, some of which are lined with calcite crystals. The limestone generally is laminated, but the rock splits into layers 1–5 feet thick. The layers form cliffs and ledges on exposed surfaces (fig. 5). The laminae are contorted, crinkly bedded, and in gently undulating planes; some show ripple lamination. In places ⅛-inch veins of white calcite cross or parallel the bedding planes.

The sandstone beds included in the limestone facies are light colored, calcareous, and very fine to fine grained. The sandstone is well sorted; the very fine grained units contain abundant silt and grade into siltstone. The sandstone has horizontal laminations to small-scale crossbeds, is even bedded to lenticular, and splits into 6-inch- to 1-foot-thick beds that form ledgy slopes. The siltstone beds are light brown and thinly laminated. Many beds contain few to abundant nodules of limestone and probably grade laterally into limestone. The siltstone forms gentle smooth slopes.

The sediment of the limestone facies grades laterally into light-brown sediment of the silt and sand facies. The edge of the facies is gradational and is placed at the point in the exposed section where most of the light-colored limestone is replaced by light-brown silt and sand.

The only recognizable faults in the project area offset beds in the limestone facies. The strike length of the faults is as great as a few hundred feet, and the vertical displacement ranges from a few feet to about 100 feet. The faults offset the beds in the westernmost exposure of the limestone facies, trend northwest, and generally are vertical (pl. 1). The beds on the southwest side of the faults are displaced downward, and the displacement along the faults ranges from 10 to 30 feet, except for the southwesternmost fault, where the displacement is more than 50 feet. The limestone beds are fractured along the faults and are considerably more permeable than they are elsewhere.

Very little is known about the occurrence of water in the limestone facies of the basin-fill deposits. Well 2374, about 1½ miles northwest of the Gila River near cross-section 23 (pl. 1), is the only well that is believed to obtain water from the facies. The water from the well is of the sodium chloride type and is the poorest in chemical quality of any water from the basin-fill deposits. The dissolved-solids content is about 5,000 mg/l.

The sand beds in the limestone facies are capable of transmitting water, and the bedding planes and fractures in the dense limestone and marl are other potential water-bearing zones. It is possible that water flowing along bedding planes and fractures has dissolved some of the limestone and has thus created solution channels and increased the hydraulic conductivity.

FIGURE 5.—Limestone facies of the basin-fill deposits exposed in an old railroad-cut at the west end of the project area.

ALLUVIAL DEPOSITS

The alluvial deposits bound and underlie the flood plain of the Gila River and its tributaries and fill the channels that have been incised into the basin-fill deposits. Along the Gila River, the channel is 4,000–8,000 feet wide, and drilling indicates that it is filled with alluvial deposits to a maximum depth of about 85 feet. Along the tributaries, a few alluvial channels range from 1,000 to 3,000 feet wide, but most of the channels are only a few hundred feet wide. The alluvium in the tributary channels probably is less than 40 feet thick.

The alluvial deposits are distinguished from the basin-fill deposits chiefly by their greater content of coarse material, poorer sorting, and greater lenticularity. In some places the basin fill is darker than the alluvium, but in general, drill cuttings and outcrops show similar colors in both units.

The alluvial deposits are divided into terrace alluvium and flood-plain alluvium mainly on the basis of their topographic position. The flood-plain alluvium (pl. 1) occupies the central part of the alluvial channels, supports most of the saltcedar along the Gila River system, and is frequently flooded by the flows of the Gila River and its tributaries. The uppermost surface of the flood-plain alluvium is 5–20 feet below the surface of the terrace alluvium and generally is 5 feet or less above the bed of the Gila River. The terrace alluvium is the principal channel-filling deposit along the Gila River system, although it is incised and filled with a channel deposit of flood-plain alluvium along the Gila River. Mappable deposits of flood-plain alluvium underlie only the streambeds of the largest tributaries. The channel in which the flood-plain alluvium was deposited represents a period of erosion in which the carrying power of the Gila River was sufficient to remove the material being brought in by the tributaries and to lower the base level of the river. Since the middle and late 1800's, the Gila River has again increased its carrying power, and the stream now flows in a channel or arroyo incised in the flood-plain alluvium. The cutting probably has been stabilized by the San Carlos Reservoir.

The alluvial deposits are moderately permeable, although some of the beds of fine material penetrated during drilling were almost impermeable. Some water may be under artesian pressure in the beds of coarse material in and underlying the fine material. In most places, the terrace alluvium and the flood-plain alluvium form a continuous aquifer.

TERRACE ALLUVIUM

The terrace alluvium consists of very poorly sorted beds and lenses of light- to dark-brown silty sand and gravelly sand and some sandy gravel (fig. 6). Although cementation is rare, the terrace alluvium is generally firmer than the flood-plain alluvium and is noticeably tougher to drill. Test drilling in the early spring of 1966 indicated that the terrace alluvium underlies the entire area. The terrace alluvium is as much as 74 feet thick, but where it underlies the flood-plain alluvium, the unit generally is not more than 40 feet thick. Several terraces border the channels of the Gila River and its tributaries, and only deposits associated with the lowest two terraces yield water.

The lower part of the terrace alluvium, especially where it underlies the flood plain, consists of 5–10-foot-thick beds of light-brown sandy clayey silt interbedded with sandy silty gravel beds as much as 3 feet thick. When brought to the surface by an auger, the mixture of these gravel deposits with the clayey silt has the consistency of pea soup.

Size analyses were made of 214 samples of terrace alluvium collected during the installation of the observation wells in 1966. A computer program prepared by Pierce and Good (1966) was modified and used to compute weight percentages, mean, standard deviation, skewness, and kurtosis for each sample. The phi (ϕ) grade scale for particle diameter is based on the negative logarithm to the base 2 of the particle diameter and is used in most of the recent sedimentation studies. In this scale the negative values represent very coarse sand and gravel, 0ϕ is the dividing line between coarse and very coarse sand, and 4ϕ is the dividing line between very fine sand and silt. The amount of gravel in the samples ranged from 0 to 98 percent and averaged 33 percent. The mean diameter of the particles ranged from -4.132ϕ to 5.609ϕ. The values given show that particle diameters ranged from pebble to silt size. That the standard deviation of the diameters ranged from 1.120ϕ to 4.246ϕ indicates the very poor sorted nature of the material. Most of the samples contained more fine than coarse particles, but in 25 samples the coarse particles were predominant. Because of the poor-sorted nature of the samples, the distribution curves were generally quite flat. When the curves did show a preponderance of 1 or 2 diameters, they were either unimodel fine (79 samples) or bimodal coarse (66 samples). The predominant coarse material was usually in the range of -2ϕ to -3ϕ (small pebbles). It is interesting that when there were two peaks in the distribution curve, the predominant fine material was usually 1.5ϕ–2ϕ (medium sand), whereas when there was only a fine peak, the predominant material was usually 3ϕ–3.5ϕ (very fine sand). The predominance of fine material throughout most of the samples greatly reduces the

FIGURE 6.—Terrace alluvium exposed in a streamcut 2,200 feet northeast of the west end of the highway bridge across the Gila River.

ability of the terrace alluvium to store and transmit water.

Water in the terrace alluvium occurs under unconfined conditions. Some of the wells drilled in 1966, however, penetrated alternating dry tight clay and silt beds and sandy gravel beds. The clay and silt beds are as much as 10 feet thick, and the gravel beds are 1–3 feet thick. The sequence of alternating beds is as much as 47 feet thick. Because the beds of very fine grained material seem to be dry, it is assumed that the water in the coarser grained beds is under artesian or semiartesian pressure. It should be emphasized that the water in the terrace alluvium is generally unconfined and that the occurrence of water under artesian pressure is a local phenomenon.

The chemical composition of the water from the terrace alluvium and from the flood-plain alluvium is similar. The water is very hard and contains from about 1,000 mg/l to more than 15,000 mg/l of total dissolved solids. The wells closest to the river generally yield water with the lowest total dissolved-solids content. The principal ions are sodium and chloride, which are present in about equal amounts.

FLOOD-PLAIN ALLUVIUM

The flood-plain alluvium is quite similar to the terrace alluvium except that it is less well compacted and cemented and may be somewhat coarser. The flood-plain alluvium may be as much as 50 feet thick, although the greatest thickness penetrated during drilling was 48 feet. The contact between the flood-plain alluvium and the terrace alluvium was placed at the depth where the drill bit went from very coarse material (as large as cobbles and boulders) into appreciably finer material; the change in grain size was evidenced by a decrease in the rate of drilling and by the amount of bit "chatter." Although additional gravel was present below the contact, the change in drill performance at this depth was pronounced enough to leave little doubt of a change in formation. Size analyses of the samples and gamma-ray logs made on some of the wells substantiated the placement of the contact.

The flood-plain alluvium consists of 10–20 feet of predominantly fine material (silt and sand), which overlies coarser deposits (gravel and cobbles). Size analyses were made of 55 samples collected from the flood-plain alluvium. The amount of gravel in the samples ranged from 0 to 95 percent and averaged 37 percent. The mean size ranged from 5.456ϕ (silt) to -4.190ϕ (pebbles); however, the mean size of the material in the upper 10–20 feet ranged from 5.456ϕ (silt) to -0.608ϕ (very coarse sand), and that of the lower part of the deposits ranged from 0.974ϕ (coarse sand) to -4.190ϕ (pebbles). The standard deviation of the diameters is 0.701ϕ–3.681ϕ, a range which indicates that the material is slightly better sorted than the terrace alluvium. No difference in sorting was apparent between the upper 10–20 feet and the lower part of the flood-plain alluvium. Distribution curves show that 22 of the samples had a single peak in the fine range, 12 had a single peak in the coarse range, and 10 had two peaks with the dominant peak in the coarse range. The remainder of the curves were fairly flat. The peaks generally occurred in the same phi groups as those for the terrace alluvium.

The data from the analyses of the terrace and flood-plain alluvium have been combined in a map showing the percentage of gravel in the alluvial deposits below the water table (pl. 2). More wells are needed for a better definition of the pattern, but in general, the coarsest material is in the central part of the trough. In the lower part of the area flooding and dense vegetation prevented drilling of wells near the river.

Water in the flood-plain alluvium is unconfined. Because the materials become coarser with depth, the hydraulic conductivity of the flood-plain alluvium increases with depth. The water table is at or near the bottom of the fine sediments, and most of the ground water is in the coarser sand and gravel beds.

The Bureau of Indian Affairs drilled eight 16-inch wells on the right bank of the Gila River near cross sections 1 and 3. The wells penetrated from 23 to 40 feet of saturated sand and gravel; well yields ranged from 60 to 600 gpm "with air." The drawdown in these wells is not known.

An aquifer test was made by using a well drilled specifically for this test near the east (upstream) margin of the project area near well 0105 (pl. 1). The well was 8 inches in diameter and penetrated 39 feet of saturated sand, gravel, and silt. A wire-wrapped screen, 6 inches in diameter and 30 feet long, was set in the well; the bottom of the screen was about 2 feet above the base of the alluvium. Sixteen observation wells were installed radially from the pumped well (fig. 7). Eight of the wells were 4 inches in diameter and were equipped with digital water-level recorders, and eight of the wells were 2 inches in diameter. Water levels in the latter observation wells were measured by using a chalked steel tape. The water level in the pumped well was measured by using an air line and a mercury manometer.

The well was pumped at 152 gpm from 1400 hours on April 2, 1964, until it was accidentally shut off during the repair of a leaky fuel line at 0141 on April 6—a period of 5,021 minutes. The data from the test were analyzed by using the modified nonequilibrium formula (Ferris and others, 1962, p. 98–100), and the results are

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given in table 2. The modified nonequilibrium formula may be written as

$$T=\frac{35.3Q\left(\log_{10}\frac{t_2}{t_1}\right)}{s_2-s_1},$$

where

T=transmissivity, in square feet per day;
Q=discharge of a well, in gallons per minute;
t_1 and t_2=selected times, in days, since pumping started or stopped; and
s_1 and s_2=respective drawdowns or recoveries at the selected times, in feet.

TABLE 2.—*Results of aquifer test*

Well	Radius from pumped well (ft.)	Transmissivity (sq. ft. per day)	Apparent storage coefficient	Time at which $u\geq0.02$ (minutes)
C-1	0	9,250		
C-2	6	11,700		
C-3	7	10,000		
E-1	41	10,200	0.06	193
E-2	100	10,300	.10	1,685
E-3	200	10,700	.10	6,667
E-4	399	9,930	.08	24,106
N-1	34	11,000	.10	190
N-2	70	11,400	.07	560
N-3	100	12,500	.08	1,123
0105	31	10,300	.23	386
S-1	37	10,900	.10	217
S-2	74	10,900	.14	1,238
S-3	99	10,100	.11	1,944
W-1	30	9,760	.31	521
W-2	60	9,410	.19	1,296
W-3	90	11,200	.04	477
W-4	125	11,200	.07	1,728
Average		10,700	.12	
Maximum		12,500	.31	
Minimum		9,250	.04	

To use the modified nonequilibrium formula, the value $u=\frac{0.25r^2S}{Tt}$ must be equal to or less than 0.02 (J. G. Ferris, oral commun., 1963), where r is distance, in feet, from the discharging well to a point of observation and S is storage coefficient expressed as a decimal fraction. The aquifer test was not of sufficient duration to satisfy this condition at the two farthest wells, E-3 and E-4. The transmissivity and storage values for these wells are included in table 2, but were not used to calculate the average. The data for wells C-1 (the pumped well), C-2, and C-3 plotted poorly; although the coefficients of transmissivity for these wells are included in the table, they were not used in determining the average.

The average coefficient of transmissivity of 10,700 sq ft per day is reasonable (table 2) and can be used with confidence in this part of the project area. The average saturated thickness of the aquifer at the test site is 39 feet; therefore, the average hydraulic conductivity is 10,700/39 or about 275 feet per day. This value is reasonable when compared with the yields of the Bureau of Indian Affairs' wells and the values of conductivity expected for sand and gravel (Wenzel, 1942, p. 13).

The test site is in a part of the alluvial trough that contains 25-50 percent gravel below the water table (pl. 2), a range which is average for the project area. Because the flood-plain and terrace alluvium have similar water-bearing characteristics, 275 feet per day can be used as the average value for the hydraulic conductivity of the alluvial aquifer. Where the gravel content is more than 50 percent, however, the hydraulic conductivity will be greater.

The average value of 0.12 is low for the storage coefficient, and the range is great enough to indicate that the true value was not approached for many of the wells. The storage coefficient is very sensitive to local changes in lithology and to the length of time that the well is pumped. An aquifer test of a well in the alluvial deposits along the Arkansas River in eastern Colorado gave an average storage coefficient of 0.17 after 4 days of pumping and an extrapolated value of 0.25 for 20 days of pumping (Weist, 1965, p. 25). Similar conditions probably exist along the Gila River, and the true storage coefficient may be about 0.20. Preliminary soil-moisture studies indicate a value of about 0.25 in the project area (R. M. Myrick, oral commun., 1966).

An attempt was made to estimate the storage coefficient by using cyclic water-level fluctuations (Ferris, 1952), but the results were inconclusive because there are no true cyclic fluctuations in the flow of the Gila River. One value obtained was 0.29, and the other was 0.04. The divergence of the fluctuations from a true cycle probably accounts for the poor results. The constant head, nonsteady state, no recharge method (Ferris and others, 1962, p. 126-131) was also applied, but poor results were obtained.

A directional variation in transmissivity appears to take place at the aquifer-test site. The average value for wells E-1, E-2, 0105, W-1, W-2, W-3, and W-4 is 10,300 sq. ft. per day. The average value for wells N-1, N-2, N-3, S-1, S-2, and S-3 is 11,100 sq. ft. per day, an increase of 800 sq. ft. per day or 8 percent. The difference in transmissivity, or more specifically in hydraulic conductivity, is probably due to the mode of deposition of the gravel. When deposited by a stream, gravel is imbricated—that is, the pebbles are inclined so that they overlap, and the upstream pebbles rest on the downstream pebbles. This overlapping reduces the hydraulic conductivity in the direction of streamflow, which is east to west in the project area, and allows easier flow perpendicular to the direction of the streamflow.

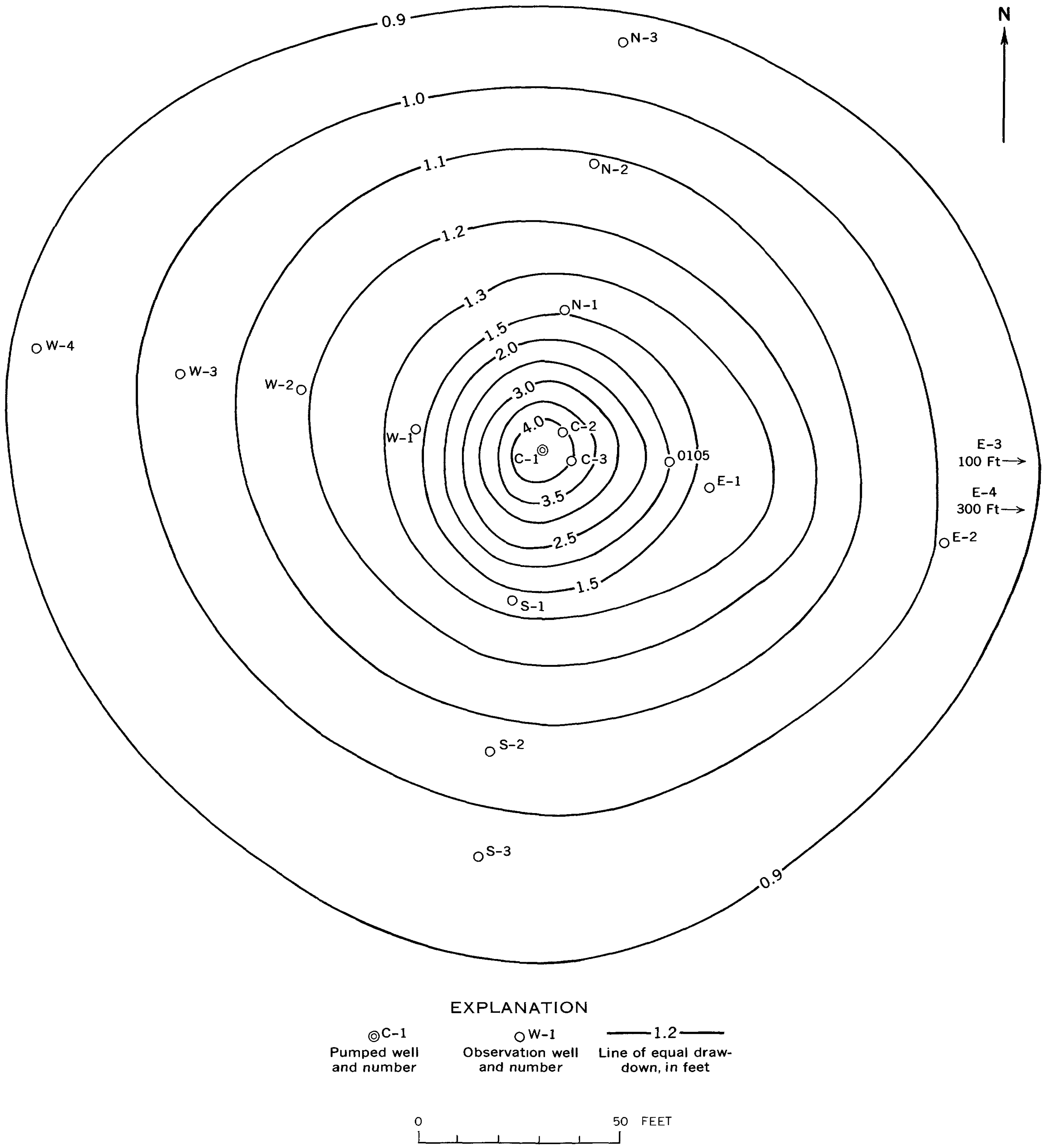

FIGURE 7.—Drawdown near well C–1 after pumping for 5,000 minutes.

Figure 7 shows the cone of depression in the aquifer-test area after pumping for 5,000 minutes. The cone is steeper near the pumped well on the west side, but farther from the pumped well the cone becomes elliptical. (See well W–4 in Fig. 7.) Before pumping was started the water table had a regional west-northwest gradient of about 11.5 feet per mile, and this gradient influenced the outer part of the cone, as indicated by the elliptical shape.

THE GROUND-WATER SYSTEM

Water in the basin-fill deposits occurs under artesian conditions, although there are small areas having non-artesian or unconfined conditions (mainly where recharge occurs). In general, water in the alluvial deposits is unconfined, but in places lenses of fine-grained material cause semiconfined or confined conditions. Some interchange of water occurs between the basin fill and the alluvium.

OCCURRENCE OF WATER IN THE BASIN-FILL DEPOSITS

Ground-water recharge to the basin-fill deposits occurs mainly along the contact of the basin fill and the older rocks along the slopes of the surrounding mountains. Recharge originates from precipitation falling directly on the deposits and from runoff and snowmelt. The main areas of recharge are the coarse permeable sediments that were deposited by ancient tributaries that entered the area. Davidson (1961, fig. 204.1) showed coarse deposits on the south and north sides of the project area, and recharge to the basin fill probably occurs in these areas.

MOVEMENT

Contours of the potentiometric surface in the basin-fill deposits were prepared by using water-level measurements made in 20 wells in August 1966 (fig. 8). Ground-water movement in the basin fill is downslope toward the Gila River and slightly downstream to the west. The potentiometric surface is subparallel to the land surface and is steeper south of the river and more gentle north of the river. In the basin fill beneath the alluvial deposits, water in wells generally is under sufficient artesian pressure to rise above the level of the adjacent water table in the alluvial deposits. A well drilled on the right bank between cross sections 19 and 21 penetrated 103 feet of the basin fill, and in 1966 water in the well was flowing at a rate of about 0.5 gpm. The water level in a nearby observation well that taps the alluvial deposits is about 12 feet below the land surface.

In the project area most of the water moving through the basin fill is discharged into the alluvial deposits along the Gila River. The few springs in the area generally go dry or their flow diminishes greatly in the summer. A few scattered stock and domestic wells are the only other means of discharge from the basin fill.

Ground water moves from the basin fill into the alluvial deposits were the water-bearing beds in the basin fill have been cut by channels of alluvial deposits. Because water in the basin fill is under sufficient artesian pressure to rise several feet above the water table, movement is from the basin fill into the alluvium rather than vice versa.

Some water may move vertically through the basin fill into the overlying alluvial deposits, as shown by temperature-gradient measurements made by R. W. Stallman in March 1965 in two wells drilled on the south bank at Dewey Flat (well 1141) and at cross section 17 (well 1756). An analysis of these data, using a method developed by Bredehoeft and Papadopulos (1965), indicate a vertical flow of 0.78 foot per year at Dewey Flat and 1.08 feet per year at cross section 17. The results are based on the following assumed conditions: (1) The heat conductivity of the profiles is uniform, (2) the velocity and heat-flow vectors are vertical, and (3) the heat and fluid flow are in a steady state. None of the conditions were met exactly in the field. Stallman (written commun., 1965) stated that variations in heat conductivity with depth can be expected, but the magnitude of the variations and their effect on the computations are not known. He further stated that the flow will be variable depending on location with respect to the river. Stallman recommended that a line of deeper wells (about 200 ft. deep) be drilled across the area to obtain a more complete picture of the vertical-velocity profile, but it was not possible to carry out this recommendation. The closeness of the results indicates that the method is feasible and that the results probably are in the correct order of magnitude—that is, about 0.9 acre-foot per acre per year of water is moving from the basin fill into the overlying alluvial deposits. The project area covers about 6,000 acres; therefore, about 5,400 acre-feet of water per year moves into the alluvial deposits from the basin fill.

WATER-LEVEL FLUCTUATIONS

Monthly water-level measurements have been made for about 2 years in several wells drilled into the basin fill in and near the project area. The period of record is not sufficient to determine a trend in water-level fluctuations. Hydrographs for five of the wells show high peaks in 1966 (fig. 9). The peaks probably reflect the large amount of runoff from the extremely wet winter of 1965–66. The peak occurred earlier in well 0523 because the well is on the south side of the river, which is

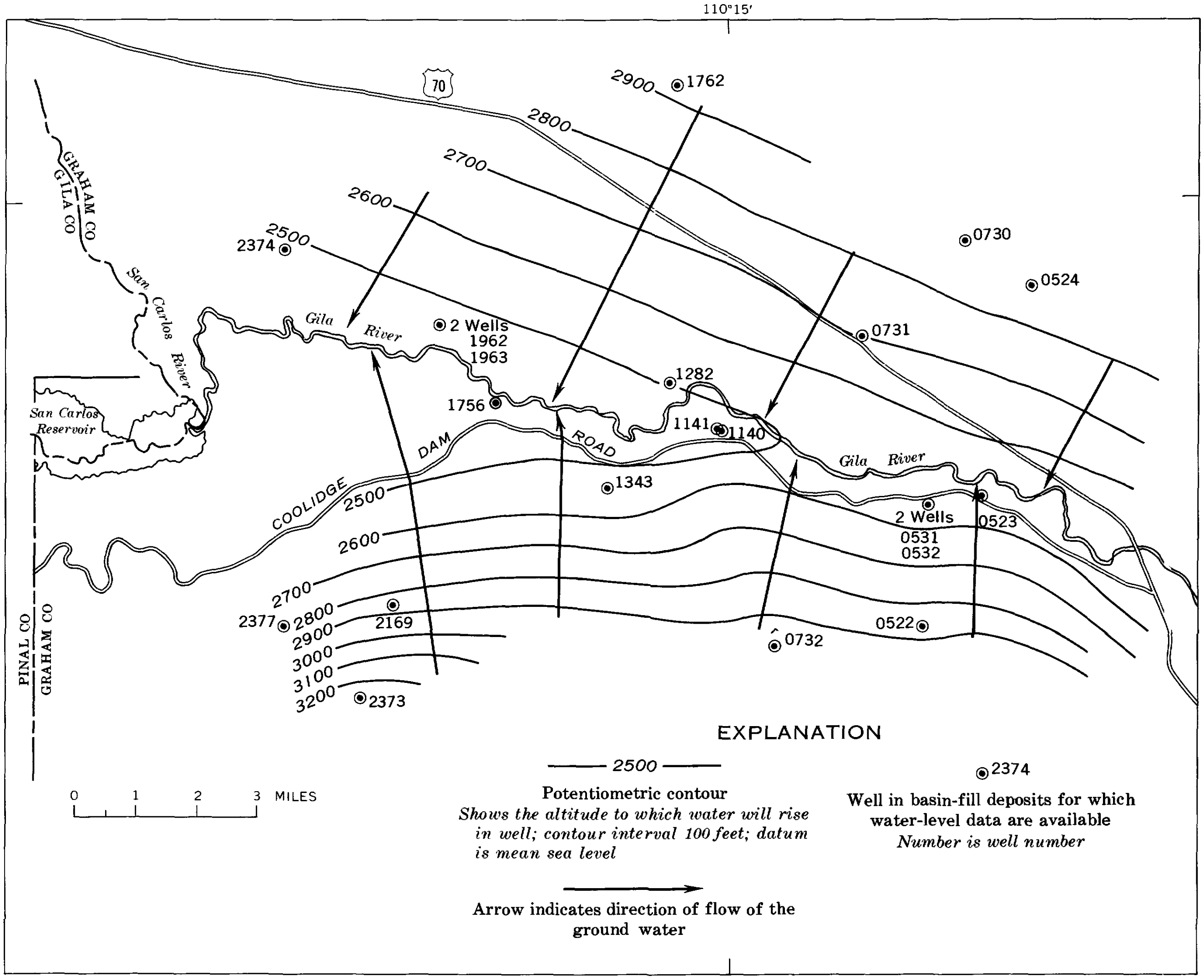

FIGURE 8.—Potentiometric surface in the basin-fill deposits, August 1966.

closer to the recharge area and where the potentiometric surface is steeper (fig. 8); the other four wells are north of the river, where the areas of recharge are more remote. That wells 0731, 0730, and 0524 are in or adjacent to tributaries of the Gila River may explain why their changes in water levels were greater than those in the other two wells.

OCCURRENCE OF WATER IN THE ALLUVIAL DEPOSITS

The main source of water in the alluvial deposits is recharge from the basin fill, about 5,400 acre-feet per year. Another source of water in the alluvium is underflow into the project area from the alluvial deposits upstream along the Gila River. The amount of underflow can be estimated by using Darcy's equation,

$$Q=KIA,$$

in which

Q=underflow,
K=hydraulic conductivity,
I=gradient, and
A=area.

By using an average saturated thickness of 35 feet, an average gradient of 8 feet per mile, and a hydraulic conductivity of 275 feet per day, the amount of underflow into the project area along the Gila River through a water-bearing channel about 5,000 feet wide is estimated to be 73,000 cubic feet per day, or 610 acre-feet per year. Some ground water may enter the area as underflow along the tributaries to the Gila River; how-

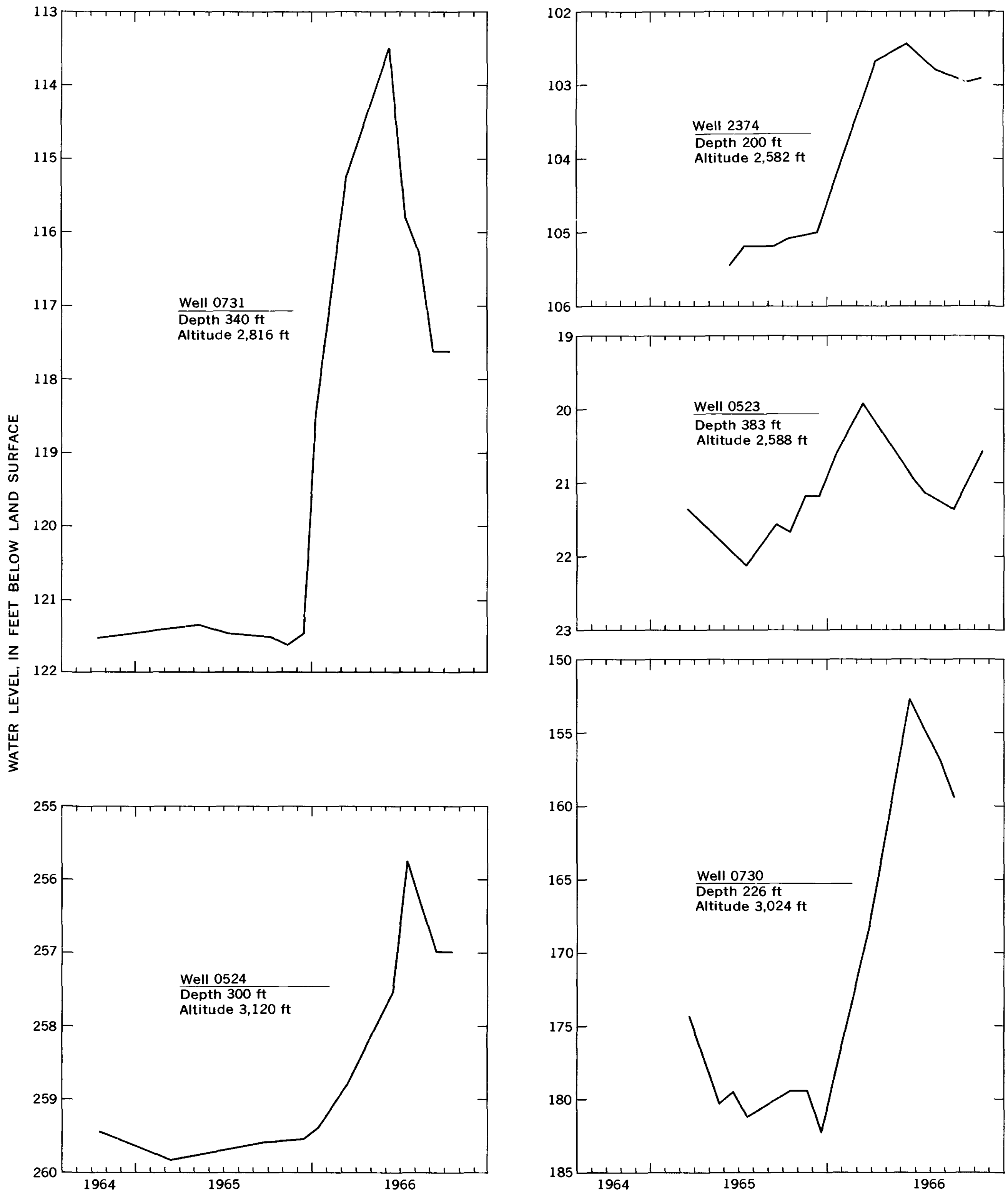

FIGURE 9.—Water levels in five wells tapping the basin-fill deposits.

ever, the amount is small and probably occurs only during wet periods. In April 1966, test holes were drilled along several tributaries, and no water was found in the alluvium.

Recharge to the water table also occurs through percolation of runoff in the Gila River, except during periods of very low flow. The greatest daily recorded loss of streamflow occurred on September 25, 1964, when 1,400 acre-feet of water was lost between cross sections 1 and 9; annual streamflow losses in this reach for water years 1963, 1964, and 1965 were 12,000, 7,300, and 4,100 acre-feet, respectively. In the reach between cross sections 9 and 17, streamflow losses for water years 1964 and 1965 were 2,700 and 6,000 acre-feet, respectively. Streamflow losses fluctuate greatly from day to day in response to fluctuations in streamflow. Much of the streamflow loss is to bank storage, from which most of it is returned to the stream as the flow recedes; however, some of the bank storage percolates to the water table.

Near the Gila River, the water table is close to the land surface, and some ground-water recharge may occur directly from precipitation; away from the river there is an intermediate soil-moisture zone. Measurements with a neutron soil-moisture meter have not shown any downward movement of water in this zone below a depth of about 1 foot in the summer or 4 feet in winter. Most of the precipitation replenishes soil-moisture deficiencies in the root zone or is used almost at once by the plants.

MOVEMENT

Generally, water in the alluvial deposits moves downstream along the Gila River. During periods of high flow in the river there usually is some movement of ground water away from the river as recharge occurs, and during periods of low flow there is some movement toward the river. On December 13, 1966, water from the river was seeping into the alluvial deposits in most of the area, except for a short reach near Calva, where the ground-water flow was toward the river (pl. 3). In the reach upstream from Calva, where the water table was in equilibrium with the river, ground-water movement was parallel to the river. The gradient of the water table decreased from about 9 feet per mile in the upper part of the area to about 2.5 feet per mile in the lower part of the area where backwater from the San Carlos Reservoir affected the water table.

Ground water is discharged from the alluvial deposits chiefly by underflow downstream along the Gila River and by evapotranspiration. In 1964 the underflow past cross section 23 was about 23,000 cubic feet per day, or 200 acre-feet per year. At the present time (December 1966), San Carlos Reservoir extends upstream past cross section 21, and some ground water is discharged into the reservoir; however, the amount is not known.

Large amounts of water are lost through transpiration by the dense growth of phreatophytes—principally saltcedar—along the flood plain of the Gila River. Preliminary studies indicate that the total annual evapotranspiration in the project area is more than 10,000 acre-feet, most of which comes from the ground-water reservoir.

Small amounts of ground water are discharged into the Gila River during periods of low flow. Records from gaging stations at cross sections 1, 9, and 17 indicate that flow in the river may increase a few tens of acre-feet between gages during periods of low flow. Gains in streamflow of more than 200 acre-feet have been recorded; however, the larger gains followed periods of large streamflow losses and probably represent a release of water from bank storage.

WATER-LEVEL FLUCTUATIONS

Water-level fluctuations have been recorded in 72 observation wells since November 1962, and the water levels in most of the wells fluctuate seasonally. The water table is highest between mid-February and the end of April, after the winter rains, and slowly declines to its greatest depth between mid-July and mid-September. Water-level fluctuations in most of the wells range from 1.5 to 2 feet annually; however, ranges from about 1 foot to more than 5 feet have been recorded, depending on the distance of the well from the river and the density of the vegetation. Water levels in many wells exhibit a secondary peak about the first of October.

Many wells in the dense growth of phreatophytes near the river exhibit diurnal fluctuations ranging from a few hundredths to two tenths of a foot, especially during the periods of high evapotranspiration. Most wells near the river respond rapidly to changes in streamflow. Wells 0104, 0105, and 0106 (pl. 1) obtain their water from the flood-plain alluvium; the wells are on the right bank of the river at cross section 1 and are equipped with digital recorders. Well 0104 is 58 feet from the channel, well 0105 is 873 feet from the channel, and well 0106 is 2,000 feet from the channel. Figure 10 illustrates the response of the water levels in the wells to flow in the river.

SUMMARY

The Gila River Phreatophyte Project area is underlain by two water-bearing units—the basin-fill deposits and the alluvial deposits. The basin fill, divided into a silt and sand facies and a limestone facies, consists mainly of very fine sand and silt that is partly ce-

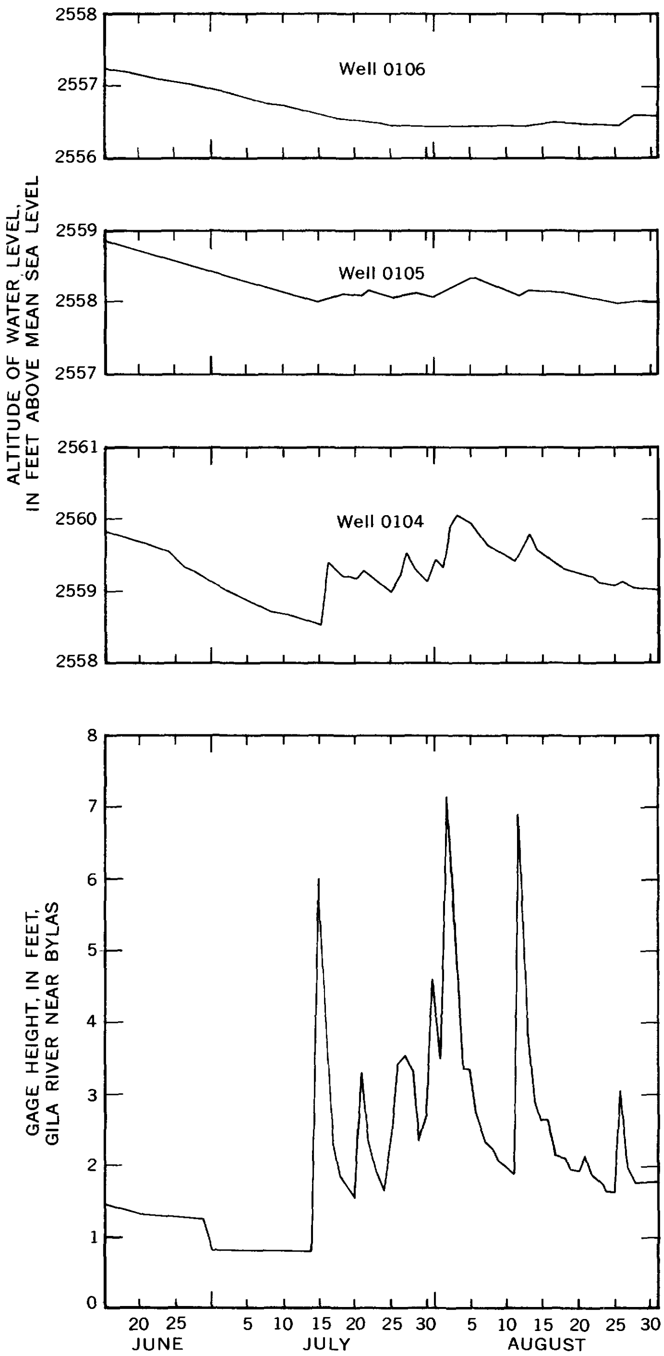

FIGURE 10.—Response of water levels to flow in the Gila River.

mented. At the northwest and west edges of the area, the basin fill consists of limestone, tuff, marl, sand, and silt. The basin fill contains water generally under artesian pressure, but because it is fine grained, it yields only a few gallons per minute of water to wells. An aquifer test in the basin fill indicates a coefficient of transmissivity of 50 sq ft per day and a storage coefficient of 0.00043. Water enters the basin fill along the edge of the area and flows toward the center and downstream. About 5,400 acre-feet of water per year flows from the basin fill into the overlying alluvial deposits.

The alluvial deposits, divided into terrace alluvium, which underlies the entire alluvial trough, and flood-plain alluvium, which underlies the flood plain of the Gila River, consist of poorly sorted lenticular deposits of sand, gravel, and some silt. The flood-plain alluvium is generally coarser grained than the terrace alluvium and may be better sorted. The two units form a single aquifer. Wells in the alluvial deposits yield as much as 600 gpm of water. An aquifer test made near the upstream end of the project area indicates a coefficient of transmissivity of 10,700 sq ft per day and a storage coefficient of 0.12 for the alluvium. The alluvial deposits receive 5,400 acre-feet of water per year from the basin fill and about 610 acre-feet per year of underflow from the alluvium upstream along the Gila River. The alluvial deposits also receive recharge from streamflow in the river and from precipitation.

STRATIGRAPHIC SECTIONS

1.—*Lat 33°13′27″ N.; long 110°24′00″ W.*

[Measured by E. S. Davidson]

	Feet
Quaternary:	
Holocene:	
Soil:	
6. Sand, light-brown, mainly fine; 10–25 percent cobbles as much as 0.4 ft in diameter	0. 9
Total soil	. 9
Pleistocene:	
Terrace gravel:	
5. Gravel, light-brown; similar to underlying unit, but firmly cemented by caliche; nearly continuous ⅛–¼-in. layer of calcium carbonate forms top of unit; ledge former	3. 0
4. Gravel, light-brown, weakly indurated; pebbles, cobbles, and boulders as much as 1 ft in diameter (average size 2 in. in longest dimension), well rounded, flattened, and imbricated (dip to southeast); composed of purple-gray andesite, gray latite or andesitic tuff, grayish-red rhyolite, brown rhyolite, red granite, black basalt, greenish-gray epidotized and chloritized andesite, sparse gray quartzite, white quartzite, and light-brownish-red quartzite; gravel matrix light-brown fine to very coarse arkosic sand	10. 6
Total terrace gravel	13. 6
Unconformity.	
Basin fill:	
Limestone facies:	
3. Limestone, white to light-gray; similar to unit 1; lens of light-brown silt 7.8–7.9 ft above base	11. 2

1.—Lat 33°13′27″ N.; long 110°24′00″ W.—Continued

	Feet
Quaternary—Continued	
Pleistocene—Continued	
Basin fill—Continued	
Limestone facies—Continued	
2. Sandstone, pale-brown; 1/16–1/8-in. laminae form 4-ft-thick beds; composed of fine quartz grains and 20–50 percent fine to medium carbonate grains; carbonate grains are white and protrude on weathered surfaces; unit grades downward into underlying unit, but has sharp contact with overlying unit; forms slope or recess in cliff formed by overlying and underlying units	4.0
1. Limestone, white to light-gray, medium-crystalline; bedded in irregular 1/8–1/4-in. laminae, which are fused into layers 1 in.–5 ft thick (average bed is about 1 ft thick); laminae are crinkly (gently undulatory to ripple laminated); unit contains as much as 10 percent 1/8-in.-thick lenses and laminae of light-brown siltstone to very fine grained sandstone; limestone is moderately indurated, very vuggy, and very porous; cavities are lined with calcite crystals; vugs are 1/4–3/8 in. in average diameter and moderately well connected along bedding planes; local 1/8-in. veins of white calcite cross and parallel bedding planes; local 1–2-in. layers of limestone contain 10–15 percent fine sand	26.3
Total basin fill	41.5
Base of exposure at Gila River.	

2.—Lat 33°13′18″ N.; long 110°19′50″ W.

[Measured by E. S. Davidson]

	Feet
Quaternary:	
Pleistocene:	
Terrace gravel:	
20. Sand, brownish-gray, medium; contains well-rounded pebbles, cobbles, and boulders as much as 1.4 ft in diameter and composed of andesite, rhyolite, altered andesite, gray quartzite, red granite, pink quartzite, and various light-colored welded tuffs	6.0
Total terrace gravel	6.0
Unconformity.	
Basin fill:	
Limestone facies:	
19. Limestone, very light brownish white; 1–2-ft-thick horizontal beds; has a few hard layers and spiny weathered surface; soft; ledgy slope former	23.2
18. Limestone, grayish-white (weathers brownish yellow); dense, hard, thinly laminated; contorted bedding; abundant vugs along bedding planes; very porous, spiny weathered surface; cliff former	5.2

2.—Lat 33°13′18″ N.; long 110°19′50″ W.—Continued

	Feet
Quaternary—Continued	
Pleistocene—Continued	
Basin fill—Continued	
Limestone facies—Continued	
17. Limestone, light-yellowish-white, vuggy and moderately fractured, massive splitting; bedded in poorly defined 1–2-ft layers; contains a few hard limestone nodules and abundant plant casts; may be tuffaceous; permeable; cliff former	5.8
16. Sandstone, light-yellowish-white, arkosic, very calcareous, thin-bedded to laminated, lenticular; cliff former	5.1
15. Silt and sandstone, light-brown very calcareous; sandstone very fine grained; unit is horizontally laminated to lenticularly ripple laminated; numerous lenticular layers of white to yellow soft limestone and nodules of dense limestone; few lenses of fine-grained sandstone near top forms slope	13.1
14. Sandstone, very light brown, arkosic, very fine grained; small-scale crossbeds to ripple laminations; grades into overlying unit; ledge former	1.5
13. Silt to sandstone, light-brown, soft; sandstone very fine grained; unit contains thinly horizontally laminated to laminated lenticular beds; forms smooth slope	10.3
12. Sandstone, light-brown, arkosic, very fine to fine-grained, calcareous; 6-in.–1-ft-thick lenticular beds; ripple laminated; few 1-ft layers of limy silt and 1/2–1-ft layers of light-brown clayey silt; local limestone nodules; grades into overlying unit; ledgy slope former	18.4
11. Silt, very light brown; some limestone nodules in lower 1 ft; few 2–3-ft lenses of fine-grained sandstone in upper 1 ft; soft; slope former	3.6
10. Tuff, white; may be diatomaceous; soft; contains 6–12-in.-diameter irregular-shaped nodules of hard dense grayish-white limestone that contain 1–5 percent 1/8–1/4-in. vugs lined with calcite crystals; unit and overlying unit form ledge in cliff exposure; unit is slope and ledge former	4.0
9. Silt and tuff, light-yellowish-white; unit is soft calcareous silty tuff to tuffaceous silt; few calcareous nodules; thin to very thin lenticular beds; ledge former	3.8
8. Silt and sand, light-brown, calcareous; very fine sand; unit contains few lenticular 6-in. beds of fine- to medium-grained sandstone; contains moderate amounts of limestone and calcareous sandstone nodules in upper 1 ft; grades into overlying unit; slope former	4.6
7. Sand, very light brown, arkosic, fine, horizontally laminated to very thin bedded; few grains as large as very coarse; local 1/2-in. thick calcareous beds containing plant roots and stem casts; soft; slope former	2.0

2.—*Lat 33°13′18″ N.; long 110°19′50″ W.*—Continued

	Feet
Quaternary—Continued	
Pleistocene—Continued	
Basin fill—Continued	
Limestone facies—Continued	
6. Sandstone, very light brown, arkosic; very small scale crossbeds; 1/16-in. laminae 3–4 ft long; ledge former	.3
5. Silt, light-brown, thinly laminated; slope former	1.4
4. Sandstone, very light brown, very fine grained, well-sorted, thinly laminated to ripple-laminated; ledgy slope former	2.1
3. Sandstone, brownish-gray, arkosic, fine-grained to very coarse grained, poorly sorted; grains colored clear, white, black, green, red, and brown; black grains are mica, clear and white grains are quartz, other colors are various rock fragments; ledge former	.5
2. Limestone, light-brownish-yellow, moderately vuggy; trace of mica flakes; soft; ledge former	1.8
1. Silt and siltstone, light-brown; 1/4–1/2-in.-thick beds; ripple-laminated to lenticular horizontal thin beds; poorly exposed; abundant mica; slope formers	2.0
Total basin fill	108.7

3.—*Lat 33°12′24″ N.; long 110°13′24″ W.*

[Measured by E. S. Davidson]

	Feet
Quaternary:	
Pleistocene:	
Terrace gravel:	
11. Gravel, light-brown to very light brown; boulders as much as 2 ft in diameter composed of andesite, welded tuff, and greenish altered andesite; upper 5 ft firmly cemented by caliche and stands in vertical ledge; matrix very poorly sorted mixture of clay, silt, and very fine to very coarse sand	11.6
10. Sand, brown, very fine, ripple-laminated to horizontally laminated; 5–10 percent pebbles and cobbles of andesite, rhyolite, quartzite, and so forth; damp	1.4
Total terrace gravel	13.0
Unconformity.	
Basin fill:	
Silt and sand facies:	
9. Clay, brown, wet, horizontally laminated; some layers contain 10–20 percent silty and very fine sand; green clay 0.2–0.8 ft above base; white salts effloresce on surface of green clay and have gritty texture and no taste	4.6
8. Silt and sand, light-greenish-gray; sand very fine, arkosic; very fine grained sandstone forms resistant ledge 0.5–0.9 ft above base	1.3
7. Claystone, brown; 1–5 percent green spots 1/8-in. in diameter; fractured and damp	.3

3.—*Lat 33°12′24″ N.; long 110°13′24″ W.*—Continued

	Feet
Quaternary—Continued	
Pleistocene—Continued	
Basin fill—Continued	
Silt and sand facies—Continued	
6. Silt and sand, brown- and light-brown-banded; sand very fine, arkosic; wet; layer of siltstone 0.3–0.5 ft below top of unit	.9
5. Clay, brown, horizontally laminated, wet	.4
4. Sand, brownish-gray- and brown-banded, arkosic fine to very fine; light reddish brown on weathered outcrop; ripple laminated to horizontally laminated; similar to unit 2; content of mica and other dark minerals in laminae is cause of banded color; some beds weather to rounded forms; piping commonly developed along vertical fractures; unit contains 10–15 percent discrete lenses of gray to light-brown sandstone 0.1–0.5 ft thick; sandstone is very fine grained and calcareous; unit very porous but not very permeable; forms rounded slope	69.0
3. Sandstone, light-gray, arkosic, calcareous; very fine sand to silt; ripple laminations to very small scale cross laminations (trough type); slaty cleavage; forms resistant ledge	.5
2. Sand, very light brown and brown-banded, arkosic, very fine to fine, well-sorted, subangular, horizontally laminated to ripple-laminated, friable and loosely compacted; forms slope; at 4.1–4.6 ft above base is light-brown arkosic sandstone, very fine grained, well sorted, friable, ripple laminated, ledge forming	9.9
1. Covered interval; float similar to unit 2	4.3
Total basin fill	91.2

4.—*Lat 33°09′20″ N.; long 110°07′46″ W.*

[Measured by E. S. Davidson]

	Feet
Quaternary:	
Pleistocene:	
Terrace gravel:	
9. Gravel, dark-gray; boulders are well rounded, as much as 2 ft in diameter, and composed of andesite, basalt, rhyolite, red granite, and gray quartzite; matrix is medium to coarse sand; upper 10 ft heavily cemented with caliche and stands in vertical cliff (thickness estimated)	25.0
Total estimated terrace gravel	25.0
Unconformity.	
Basin fill:	
Silt and sand facies:	
8. Sand to sandstone, light-brown and dark-brown, very fine grained, interlaminated, cross-laminated; few ledges of very fine grained to fine-grained sandstone; form ledgy slope	27.5

4.—*Lat 33°09'20'' N.; long 110°07'46'' W.*—Continued

	Feet
Quaternary—Continued	
Pleistocene—Continued	
Basin fill—Continued	
Silt and facies—Continued	
7. Clay, brown, and light-brown silt, laminated; few discrete ledge-forming lenses of very fine to fine-grained cross-laminated arkosic sandstone	9. 7
6. Clay, reddish-brown, horizontally laminated; white salts effloresce on exposed surfaces	1. 1
5. Sandstone, light-brown, very fine grained, well-sorted; horizontal laminations to very small scale cross-laminations; ledge of light-brown to brownish-gray sandstone at 5.0–5.3 ft above base that is very fine grained to medium grained (average is fine grained), moderately sorted, and horizontally laminated to ripple laminated	8. 0
4. Clay to silty clay, reddish-brown, cross-laminated; white salts effloresce on fractures and exposed surfaces; few discrete 1–2-in. lenses of gray very fine grained sandstone to siltstone; slope former	3. 2
3. Clay, horizontally and cross laminated; dark-reddish-brown clay and light-brown siltstone	1. 3
2. Clay, dark-reddish-brown, horizontally laminated; few discrete 4-in.-thick lenses of gray to light-brown very fine grained calcareous sandstone	3. 2
1. Silty sand, light-brown, arkosic, very fine, well-sorted, ripple-laminated to cross-laminated, soft; forms layers 2–4 ft thick; at 1–1.2 ft below top are ½–1-in. stringers of brown clay; ½-in. layer of very light brown clay at top of unit; unit weathers to slope	6. 6
Total basin fill	60. 6

5.—*Lat 33°11'29" N.; long 110°16'33" W.*

[Measured by E. S. Davidson]

	Feet
Quaternary:	
Pleistocene:	
Terrace gravel:	
6. Gravel, dark-gray; boulders as large as 2.5 ft in diameter set in very coarse sand matrix; boulders composed of andesite, rhyolite, welded tuff, quartzite, red granite, and basalt are well rounded	10. 0
Total terrace gravel	10. 0
Unconformity.	
Basin fill:	
Silt and sand facies:	
5. Clay, brown, and light-brown silty very fine sand; unit horizontally laminated and separated by 0.1–0.2-foot-thick clay beds into 0.5–0.8-foot-thick units; smooth slope former	7. 4

5.—*Lat 33°11'29" N.; long 110°16'33" W.*—Continued

	Feet
Quaternary—Continued	
Pleistocene—Continued	
Basin fill—Continued	
Silt and sand facies—Continued	
4. Sand, light-brown, arkosic, very fine, cross-laminated; dark minerals show bedding; unit contains a few 4–6-in. layers and lenses of fine-grained calcareous sandstone; ledgy slope former	26. 5
3. Clay, brown, silty and sandy, damp; 5 percent very fine to medium quartz grains; salt crusts on fractures; slope former	1. 4
2. Silt and sand, light-brown, very fine, horizontally laminated to cross-laminated; few 1-in. layers of well-sorted medium sand (very soft "running" sand); slope formers	2. 6
1. Covered unit; not exposed or described	5. 0
Total basin fill	42. 9

DRILL-CORE DESCRIPTIONS

1.—*Lat 33°12'10'' N.; long 110°18'57'' W.*

[By E. S. Davidson]

	Thickness (ft)	Depth (ft)
Quaternary:		
Pleistocene and Holocene:		
Alluvium:		
1. Open hole; no samples	49	49
2. Sand, light-brown, clayey, fine to medium, poorly sorted; maximum grain size very coarse; cored interval 49–54 ft; 5 in. of core	5	54
3. Sandstone, very light brown, arkosic, very fine grained, poorly sorted; grains as large as medium; crossbeds about 10° to core; cored interval 54–59 ft; 2 in. of core	2	56
4. Sandstone, light-grayish-white, arkosic, firmly cemented, coarse-grained; grain size ranges from fine to granule; trace pebbles as large as ½ in.; few stringers of light-brown clay; cored interval 54–59 ft; 8 in. of core	3	59
5. Similar to unit 4; some layers of firmly cemented fine sand; cored interval 59–64 ft; 7½ in. of core	3	62
Total alluvium	62	------
Unconformity.		
Pleistocene:		
Basin fill:		
Silt and sand facies:		
6. Sand, brown, clayey, very fine grained well-sorted; some grains as large as medium; local stringers of light-brown claystone; horizontally laminated, but laminations poorly displayed; cored interval 59–64 ft; 4 in. of core	2	64

1.—Lat 33°12'10" N.; long 110°18'57" W.—Continued

	Thickness (ft)	Depth (ft)
Quaternary—Continued		
Pleistocene and Holocene—Continued		
Basin fill—Continued		
Silt and sand facies—Continued		
7. Sandstone, light-brown, arkosic, very fine grained to silty; some grains as large as fine; 1 percent brown clay streaks ⅛–¼ in. thick; horizontally laminated; cored interval 64–69 ft; 6 in. of core	5	69
8. Sandstone, dark-whitish-gray, arkosic, fine-grained (size ranges from very fine to medium grained), cross-laminated to very thinly crossbedded; dark-mineral concentrations show bedding planes at 5°–10° to core; cored interval 69–74 ft; 3 in. of core	1	70
9. Siltstone, brown; few stringers of very fine grained sandstone; cored interval 69–74 ft; 2 in. of core	4	74
10. Sandstone, light-whitish-brown, arkosic, very fine to fine-grained (size ranges from silt to medium grained), fair-sorted; cross laminated 10°–15° to core; cored interval 74–79 ft; 2 in. of core	5	79
11. Siltstone, brown; some very fine grained sandstone especially in upper 1 ft; cored interval 79–84 ft; 8 in. of core	4	83
12. Sandstone, light-gray, arkosic, very fine to fine-grained, well-sorted, cross-laminated to very thinly cross-laminated; cored interval 79–84 ft; 2½ in. of core	1	84
13. Claystone, brown, silty, moderately indurated; cored interval 84–86 ft; 18 in. of core	2	86
14. Sandstone, light-brownish-white; few light-brown siltstone layers; horizontally laminated to cross laminated; well indurated; cored interval 86–88 ft; 2½ in. of core	2	88
15. Siltstone, light-brown to brown clayey; horizontally laminated 1°–5° to core; cored interval 88–89 ft; 1½ in. of core	1	89
16. Sandstone, brownish-gray, arkosic, very fine to fine-grained, moderately indurated, cross-laminated; cored interval 89–90 ft; 2 in. of core	1	90
17. Siltstone, brown, very clayey, horizontally laminated; cored interval 90–91 ft; 3 in. of core	1	91
18. Sandstone, whitish-gray, arkosic, fine-grained (size ranges from very fine to fine; few medium grains), very thinly crossbedded; cored interval 91–94 ft; 4 in. of core	3	94
19. Sandstone, whitish-gray; similar to unit 18; cored interval 94–96 ft; 1 in. of core	2	96
20. Siltstone, brown, very clayey; cross laminated 10°–15° to core; cored interval 96–99 ft; 1 in. of core	3	99
21. Siltstone and sandstone, interbedded, very fine grained; brown siltstone is clayey and cross laminated 15°–20° to core; whitish-gray sandstone is arkosic, well sorted, horizontally laminated to cross laminated; grain size is very fine to fine; interbeds are 2–4 in. thick; cored interval 99–104 ft; 7 in. of core	5	104
22. Same as unit 16, but siltstone laminae are ⅛–¼ in. thick; cored interval 104–109 ft; 7 in. of core	5	109
23. Siltstone, light-brown, horizontally laminated; cored interval 109–114 ft; 1 in. of core	5	114
24. Clay and sand, brown; clay may be interbedded or mixed in as clay stringers and chips and is 50–75 percent of interval; sand is medium (ranges from very fine to very coarse; trace of ¼-in. pebbles); cored interval 114–119 ft; 14½ in. of core	5	119
25. Clay, dark-reddish-brown, silty; contains few stringers of green clay; cored interval 119–120 ft; 3 in. of core	1	120
26 Sandstone, light-gray, arkosic, very fine grained; few fine grains; cross laminated 1°–5° to core; cored interval 120–121 ft; 3 in. of core	1	121
27. Claystone, dark-greenish-gray, silty, horizontally laminated; cored interval 121–125 feet; 15 in. of core	4	125
Total basin fill	63	
Total depth of hole		125

2.—Lat 33°11'51" N.; long 110°15'13" W.

[By W. G. Weist, Jr.]

	Thickness (ft)	Depth (ft)
Quaternary:		
Pleistocene and Holocene:		
Alluvium:		
No samples	53	53
Total alluvium	53	
Basin fill:		
1. Claystone, tan, silty, moderately indurated; cored interval 53–55 ft; 1 in. of core	0.5	53.5

2.—*Lat 33°11'51" N.; long 110°15'13" W.*—Continued

	Thickness (ft)	Depth (ft)
Quaternary—Continued		
Pleistocene and Holocene—Continued		
Basin fill—Continued		
2. Siltstone, light-tan, clayey, weakly to moderately indurated; cored interval 53–55 ft; 3 in. of core	1	54.5
3. Claystone, tan, moderately indurated; cored interval 53–55 ft; 2 in. of core	.5	55
4. Sandstone, light-brown, very fine grained; cored interval 55–60 ft; 4 in. of core	5	60
5. Siltstone, light-brown, sandy, moderately indurated; cored interval 60–65 ft; 1 in. of core	2	62
6. Sandstone, light-brown, silty, medium-grained to very fine grained, poorly sorted, weakly indurated; cored interval 60–65 ft; ½ in. of core	1	63
7. Siltstone, light-brown, sandy, well indurated; cored interval 60–65 ft; 1 in. of core	2	65
8. Claystone, light-brown, silty; contains thin streaks of reddish clay; horizontally laminated; cored interval 65–70 ft; 1 in. of core	1	66
9. Sandstone, light-brown, arkosic, very fine grained, well-sorted, poorly indurated, very thinly bedded; bedding planes at 5°–10° to core; cored interval 65–70 ft; 1 in. of core	1	67
10. Siltstone, light-brown, slightly sandy, moderately indurated, horizontally laminated; cored interval 65–70 ft; 6 in. of core	3	70
11. Same as unit 10; cored interval 70–75 ft; 2 in. of core	1	71
12. Same as unit 11, but interbedded with very fine grained sandstone and brown clay; cored interval 70–75 ft; 3 in. of core	1	72
13. Sandstone, light-brown, silty, arkosic, very fine grained, horizontally very thinly bedded, moderately indurated; cored interval 70–75 ft; 2½ in. of core	1	73
14. Clay, light-brown; cored interval 70–75 ft; 1 in. of core	.5	73.5
15. Siltstone, light-brown, sandy, clayey, moderately indurated; cored interval 70–75 ft; 4 in. of core	1.5	75
16. Same as unit 12; cored interval 75–80 ft; 4½ in. of core	5	80
17. Siltstone, tan, sandy, weakly indurated; contains some medium grains of sand; cored interval 80–85 ft; 6 in. of core	5	85
18. Siltstone, tan, well-indurated, horizontally very thinly bedded; contains fine grains of sand and chips of clay; cored interval 85–90 ft; 7 in. of core	5	90
19. Siltstone, grayish-brown, slightly sandy, soft; contains fine grains of sand; cored interval 90–95 ft; 7½ in. of core	3	93
20. Siltstone, tan, well-indurated; contains abundant brown clay; conchoidal fractures; cored interval 90–95 ft; 6 in. of core	2	95
21. Same as unit 20, but better indurated; cored interval 95–100 ft; 12 in. of core	5	100
22. Siltstone, tan, slightly sandy, moderately indurated; cored interval 100–105 ft; 19 in. of core	3	103
23. Siltstone, brown, clayey, moderately indurated; cored interval 100–105 ft; 6 in. of core	1	104
24. Sandstone, tan, silty, arkosic, very fine grained; abundant heavy minerals; soft; cored interval 100–105 ft; 5 in. of core	1	105
25. Siltstone, brown, slightly sandy, clayey, weakly indurated; conchoidal fractures; cored interval 105–110 ft; 4½ in. of core	5	110
26. Siltstone, light-brown, clayey, moderately indurated; cored interval 110–115 ft; 3½ in. of core	3	113
27. Siltstone, light-brown, clayey, moderately indurated; contains very fine grained tan sandstone; crossbedding at 3°–5° to core; cored interval 110–115 ft; 3 in. of core	2	115
28. Siltstone, light-brown, very clayey, well-indurated; cored interval 115–120 ft; 2 in. of core	1.5	116.5
29. Sandstone, light-brown, silty, fine-grained, poorly indurated; cored interval 115–120 ft; ¾ in. of core	.5	117
30. Sandstone, gray, medium- to fine-grained, very hard; siliceous cementation; cored interval 115–120 ft; 1¼ in. of core	1	118
31. Siltstone, light-brown, slightly clayey, moderately indurated; cored interval 115–120 ft; 3 in. of core	1.5	119.5
32. Siltstone, light-brown, sandy, weakly indurated; cored interval 115–120 ft; ½ in. of core	.5	120
33. Siltstone, brown, clayey, weakly indurated; cored interval 120–125 ft; 6½ in. of core	5	125
Total basin fill	72	-------
Total depth of hole		125

REFERENCES CITED

Bredehoeft, J. D., and Papadopulos, I. S., 1965, Rates of vertical groundwater movement estimated from the Earth's thermal profile, *in* Water resources research: Am. Geophys. Union, v. 1, no. 2, p. 325–328.

Davidson, E. S., 1960, Geology of the eastern part of the Safford basin, Graham County, Arizona: Arizona Geol. Soc. Digest, v. 3, p. 123–126.

——— 1961, Facies distribution and hydrology of intermontane basin fill, Safford basin, Arizona, *in* Short papers in the geologic and hydrologic sciences: U.S. Geol. Survey Prof. Paper 424–C, p. C151–C153.

Ferris, J. G., 1952, Cyclic fluctuations of water level as a basis for determining aquifer transmissibility: U.S. Geol. Survey open-file report, 17 p.

Ferris, J. G., Knowles, D. B., Brown, R. H., and Stallman, R. W., 1962, Theory of aquifer tests: U.S. Geol. Survey Water-Supply Paper 1536–E, p. 69–174.

Marlowe, J. I., 1961, Late Cenozoic geology of the lower Safford basin on the San Carlos Indian Reservation, Arizona: Unpub. doctoral thesis. Arizona Univ., Tucson, 184 p.

Pierce, J. W., and Good, D. I., 1966, Fortran II program for standard-size analysis of unconsolidated sediments using an IBM 1620 computer: Kansas Geol. Survey, Special Distrib. Pub. 28, 19 p.

Stearns, N. D., 1927, Laboratory tests on physical properties of water-bearing materials: U.S. Geol. Survey Water-Supply Paper 596–F, p. 121–176.

Weist, W. G., Jr., 1965, Geology and occurrence of ground water in Otero County and the southern part of Crowley County, Colorado, *with sections on* Hydrology of the Arkansas River valley in the project area, by W. G. Weist, Jr., and E. D. Jenkins; Hydraulic properties of the water-bearing materials, by E. D. Jenkins; and Quality of the ground water, by C. A. Horr: U.S. Geol. Survey Water-Supply Paper 1799, 90 p.

Wenzel, L. K., 1942, Methods for determining permeability of water-bearing materials, with special reference to discharging-well methods: U.S. Geol. Survey Water-Supply Paper 887, 192 p.