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GROUND-WATER RESOURCES AND GEOLOGY OF THE GILA BEND AND DENDORA AREAS, MARICOPA COUNTY, ARIZONA

By

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ABSTRACT

The contemplated construction of an earth-fill flood-control dam on the Gila River in the vicinity of Gila Bend, Ariz., required a preliminary evaluation of the effects of such a structure upon the water supply of the area. The proposed dam would temporarily impound the occasional floods that constitute the only surface flow in this reach of the Gila River.

The damsite is in a narrows formed by volcanic rocks of the Gila Bend and Painted Rock Mountains, and these narrows are the only outlet for surface flow or underflow of the Gila River. The Gila Bend area occupies two structural troughs that have been partially filled with alluvium. This alluvial fill is more than 1,000 feet thick in places and constitutes the reservoir in which all ground water in the area is stored. Although the lower part of the fill yields some water to deep wells, most of the irrigation water is pumped from the upper few hundred feet of less consolidated materials.

The principal sources of recharge to the ground-water reservoir in the Gila Bend area are surface flow from occasional floods in the Gila River and seepage of water from canals and irrigated lands. The total estimated recharge in 1953 from canal seepage was 22,500 acre-feet, from seepage of water on irrigated lands, 28,700 acre-feet. Recharge from surface flow in the Gila River is estimated to have averaged between 10,000 and 15,000 acre-feet annually since 1947. Recharge to ground-water storage in the area from all sources in the 7-year period 1947-53 inclusive is estimated to be of the order of magnitude of 58,000 acre-feet annually.

Water is discharged from the Gila Bend area by surface flow, underflow, evapotranspiration, and by pumping from wells. Pumping is the principal means of discharge, and amounted to approximately 144,000 acre-feet in 1953. A study was made of the loss of water by evapotranspiration in the area which, it is estimated, amounted to about 36,000 acre-feet in 1953. Discharge from the area by surface flow occurs only rarely, and the discharge in 1953 was negligible. Underflow leaving the area was estimated, on the basis of partial data, to be less than 10 acre-feet per year. It is estimated that total discharge from all sources in the Gila Bend area amounted to less than 180,000 acre-feet in 1953.

Because of the irregular distribution and relatively small number of wells in the area, little information is available as to the geologic and hydrologic character of the alluvial fill, and no estimate could be made of the amount of water stored in the ground-water reservoir. It is certain, however, that withdrawals of ground water are currently greater than recharge, and that the deficiency is being balanced by drawing upon storage. This condition is reflected by declining water levels in parts of the area.

The water supply of the Gila Bend area is highly mineralized, and only a few of the samples analyzed contained less than 1,000 ppm of dissolved solids. The water is high in sodium and chloride, and most of the samples analyzed contained more than 1.5 ppm of fluoride. Although the quality of the water cannot be considered good, crops are successfully grown in the area.

It is concluded that, if a flood-control dam were constructed, the over-all effects on the downstream water supply would be beneficial because flood waters would be recharged more readily.

INTRODUCTION

Purpose and scope of investigation

At the request of the Corps of Engineers, United States Army, Los Angeles District, the Ground Water Branch of the U. S. Geological Survey in 1953 conducted an investigation of the geology and ground-water resources of the Gila River basin from Gillespie Dam to a point about 10 miles downstream from Painted Rock damsite (fig. 1). This report contains the results of the investigation and brings up to date the data on the water resources of the area (Babcock and Kendall, 1948)1/.

The Flood Control Act of 1950 authorized the construction of an earth-filled dam on the Gila River in the narrows between the Gila Bend and the Painted Rock Mountains. The purpose of this dam would be to provide flood protection for about 360,000 acres along the Gila River as well as lands along the Colorado River between Laguna Dam and the International border and for the Imperial Valley, California. As the construction of this dam would affect certain lands and water rights, it was necessary that adequate and up-to-date information as to quantity, quality, source, and movement of ground water be collected, compiled, and analyzed.

The scope of this investigation included not only the geologic, hydrologic and quality-of-water aspects but also a special study of evapotranspiration by river-bottom vegetation and its effect on the area. The

1/ See references at end of report.

phreatophyte study was financed by a direct grant of Federal funds and is included as part of this report.

Location and extent

The area described in this report is a portion of the Gila River basin between Gillespie Dam in sec. 28, T. 2 S., R. 5 W., and a point about 46 miles downstream in sec. 6, T. 5 S., R. 8 W., Maricopa County, Ariz. (pl. 1). The area is bounded on the north by the Gila Bend Mountains and the Buckeye Hills, on the east by the Maricopa and Sand Tank Mountains, on the south by the Sauceda Mountains and the southern boundary of T. 7 S., and on the west by the western boundary of R. 8 W. The area includes about 1,000 square miles, of which approximately 225 square miles consists of hard rocks and the remaining 775 square miles is underlain by alluvial fill.

Well-numbering system

The numbering system used for well identification embodies an abbreviated description of the well location. The system is based on division of land areas into successively smaller quadrants, and describes the well location to the nearest 10 acres. The land survey of Arizona is based on the Gila and Salt River Base Line and Meridian, which divides the State into four quadrants. These quadrants are assigned the capital letters A, B, C, D, progressing counterclockwise from the northeast quadrant. Thus, all the townships north and east of the base point are in A quadrant; those north and west are in B quadrant, and those south and west or south and east are in C or D quadrants, respectively. The first digit following the quadrant letter signifies the township; the second signifies the range, and the third number, outside the parenthesis, indicates the section within the township. For example, well number (C-5-4)19 designates a well in the southwest quadrant in T. 5 S., R. 4 W., sec. 19. A section is divided into four quadrants of 160 acres each to which lowercased letters a, b, c, and d, are assigned progressing counter-clockwise from the northeast quadrant in the same manner as the capital letters. Further subdivision into 40-acre quadrants and finally into 10-acre quadrants, is designated by two additional lower-case letters. Therefore, the example (C-5-4)19ddd indicates not only the location as given above but also designates location to the nearest 10 acres. This well is in the SE$\frac{1}{4}$, SE$\frac{1}{4}$SE$\frac{1}{4}$, sec. 19. Where there is more than one well in a given 10-acre tract, consecutive numbers beginning with 1 are added as suffixes: (C-5-4)19ddd1 and (C-5-4)19ddd2.

Field work and acknowledgments

Field work was started in the latter part of May 1953 with an inventory of all the wells. During the pumping season, discharge and drawdown measurements were taken and water-level measurements were made on some stock and domestic wells. Samples of water were collected from wells for analysis. Water-level measurements in the cultivated areas were made late in December after the pumping season. Cultivated areas and areal density of phreatophytes were mapped on contact prints of aerial photographs on the basis of ground surveys and aerial check flights. Four "transpiration" wells (observation wells for study of water-level fluctuations due to transpiration) were bored with hand augers and lined with 8-inch galvanized casing. Weekly water-stage recorders were installed on these wells. Records from the wells were used as a basis for computing the amount of water transpired by phreatophytes.

The investigation was under the general supervision of A. N. Sayre, chief, Ground Water Branch, and under the immediate supervision of L. C. Halpenny, district engineer. The phreatophyte studies were made in consultation with T. W. Robinson, staff engineer. Field work was done by P. W. Johnson, geologist, and J. M. Cahill, engineer, assisted by R. H. Garside, J. E. Mernagh, R. S. Stulik, N. P. Whaley, and C. B. Yost, Jr. Mrs. N. D. White and other staff members of the district office aided substantially in the preparation of maps and the compilation of data. The water samples were analyzed by the Quality of Water Branch at Albuquerque, New Mexico, under the direction of J. M. Stow, district chemist. Streamflow data were furnished by J. H. Gardiner, district engineer, Surface Water Branch.

GEOLOGY AND ITS RELATION TO GROUND WATER

Land forms and drainage

Most of the area studied is a broad plain broken only by mountain ranges that rise above the valley floor, typical of the Basin and Range province (Fenneman, 1931). The mountains are roughly parallel and trend northwest except for the Buckeye Hills and parts of the Gila Bend Mountains, which trend northeast.

The basin probably occupies parts of two north-west-trending structural troughs separated by the Gila Bend and Sand Tank Mountains. The eastern trough is rather narrow, and well-developed pediments reduce the width of the ground-water reservoir in the alluvium to as little as 4 miles (pl. 1). In the western trough, pediments are not extensive. All the mountains bordering both troughs are erosional remnants of blocks that have been upfaulted along a northwest alinement. The Gila River channel in this part of the area lies along the northern side, and to the south gentle alluvial slopes extend for 15 miles or more.

The Gila River is the principal stream that traverses the area. In this reach, the river is through flowing only during rare periods of high floods. However, in some places along the river channel the water table is sufficiently near the land surface to form pools of standing water. The many tributary washes which empty into the Gila River in the area are intermittent. Downstream from Gillespie Dam the river channel trends in a south-southeasterly direction, then swings west and northwest in a wide arc around the tip of the Gila Bend Mountains. It continues on in this direction until it reaches the narrows between the Painted Rock and the Gila Bend Mountains. Here it turns sharply to the southwest and continues on in this general direction to its confluence with the Colorado

River. The average gradient of the river is about 5 to 8 feet to the mile (fig. 2), and because of this gentle slope and infrequent flow the stream channel has developed a braided pattern.

Geologic history

Schist and gneiss of probable pre-Cambrian age comprise part of the mountains in this portion of the Gila River basin. Although marine rocks of Paleozoic age have not been observed in outcrops, their former existence is proved by their presence as fragments in fanglomerate in the Sand Tank and Gila Bend Mountains.

Intrusions of igneous rock and widespread earth movements in Mesozoic (Laramide?) time formed parts of the Gila Bend, Sand Tank, and Maricopa Mountains. After the mountain building, and presumably in early Tertiary time, erosion reduced the mountains and contributed rock debris to the basin to form thick sequences of sediments, now consolidated. The erosional cycle was interrupted by volcanic activity and subsequent faulting and uplift which formed fault-block mountains. Although most of the original fault lines have been obscured by erosion, present mountain forms are the result of continuing degradation and faulting.

Deposition of more alluvium occurred later in Tertiary time, continuing into Quaternary time. This material is relatively unconsolidated. Originally the alluvium that was washed from the adjacent mountains was deposited in basins with no outlets. After these closed basins became filled with alluvium the Gila River established its present through-drainage system.

Quaternary volcanic eruptions developed cinder cones and basalt flows that temporarily dammed the Gila River. Evidence of this is seen in the northern part of the Painted Rock Mountains and in the vicinity of Gillespie Dam. As the river breached these obstructions and deepened its channel, three sets of terraces were formed.

After the surface of the lower terrace was formed, the Gila River incised a channel about 80 feet deep and about half a mile wide. The channel was partly refilled with unconsolidated alluvium of Recent age which forms the present inner valley. The braided channels of the Gila River lie in a flood plain, about 5 to 15 feet below the level of the inner valley. The stream is now building up this flood plain with sediments.

Rocks of the area

Crystalline and metamorphic rocks

Crystalline, metamorphic, and volcanic rocks comprise the major mountain areas in this portion of the Gila River basin. The gneiss and schist exposed in the Gila Bend, Sauceda, Sand Tank, and Maricopa Mountains in various amounts are considered to be the oldest rocks in the area and are probably pre-Cambrian. Owing to the deep weathering and highly fractured nature of these rocks, it is conceivable that they might yield a little water to wells for stock or domestic purposes.

Granitic rocks, probably younger than pre-Cambrian, have intruded the gneiss and schist and are exposed in great abundance in most of the mountains in the area. These rocks range from coarse to fine grained, are occasionally porphyritic, and are associated with aplitic and pegmatitic material. The granitic rocks are generally not deeply weathered and are essentially non-water-bearing. As no important supplies of ground water are known to occur in any of the hard rocks in this area, no detailed study of these rocks was made.

Volcanic rocks

Older volcanic rocks, of Tertiary (?) age, occur in parts of the Gila Bend, Sand Tank, Sauceda, and Painted Rocks Mountains, and form hogbacks, mesas, and irregular hills. They also occur interbedded with consolidated sediments in the Sand Tank and Gila Bend Mountains and at a depth of 1,140 feet at Gila Bend (see log of well (C-5-4)31cbd, table 4). These rocks are basaltic flows and tuffs. The tuff is well bedded, grayish pink in color, and has lava fragments as inclusions.

Younger volcanic rocks, of Quaternary age, occur as basaltic lava flows in the Buckeye Hills, the Gila Bend and Painted Rock Mountains, and Oatman Mountain. The Sentinel lava flow, also Quaternary basalt, occupies about 200 square miles south and west of the Gila Bend area. Noneof the volcanic rocks in the area are known to be water bearing.

Consolidated sediments

Consolidated sediments of Tertiary (?) age occur in the Sand Tank and Gila Bend Mountains, and underlie many areas covered by younger volcanic rocks and alluvium. These materials apparently were encountered at depths of over 1,100 feet, as shown by the log of well (C-5-4)31cbd at

Gila Bend (table 4). The sediments consist mostly of cemented alluvial material with fragments of limestone and are interbedded with volcanic rock and sandstone.

Unsorted materials in a conglomeratic facies of these sediments range in size from silt to large boulders. Many of the fragments are granitic but schist and fragments of other metamorphic rocks are present. This indurated unit forms high, rounded hills with steep slopes and cliffs.

The sandstone is well sorted, cross bedded, porous, and arkosic. It is bright red in color and has varying degrees of cementation. Steeply tilted sandstone beds 200 feet thick form a cliff in the southeastern part of the Gila Bend Mountains.

The deep wells at Gila Bend apparently obtain their water from this sandstone. No irrigation wells are known to have been drilled deep enough to encounter these sediments.

Alluvial fill

Alluvial fill of Tertiary and Quaternary age occupies the intermontane troughs of the Gila River basin in this area. This fill has been eroded from the surrounding mountains or brought into the area by the Gila River and its tributary streams. It can best be described by assigning the terms "older fill" and "younger fill." The lower part of the older fill is probably of Tertiary age.

In the western trough of the Gila Bend area the earliest materials were deposited when the basin had only interior drainage, and they consist of about 800 feet of lake-bed clays and some sand. The deposits rest on the consolidated sediments as shown by well logs (table 4). Above the lake beds is about 300 feet of sand and gravel with some clay.

In the trough between the Gila Bend and Maricopa Mountains the older fill consists of more than 1,000 feet of partly consolidated and poorly sorted sand, gravel, and boulders. No lake-bed clays have been encountered in wells drilled in this area. The coarse texture of the alluvium suggests that steep stream gradients were maintained during most of the period of deposition and, possibly, that through drainage existed in this trough in a channel that followed a course much different than at present. Most of the irrigation wells in this part of the Gila Bend area have been drilled in the older fill.

The younger fill was deposited mainly along the course of the Gila River and is considered to be of Recent age. It also extends as a thin mantle over most of the valley floor and underlies the tributary stream channels. The fill beneath the flood plain of the Gila River is about 80 feet thick and consists mostly of unconsolidated coarse sand and gravel. The younger fill is an excellent aquifer and yields large amounts of water to a few irrigation wells northwest of Gila Bend.

GROUND-WATER HYDROLOGY

Source, occurrence, and movement

The primary source of all ground water in the Basin and Range province in Arizona is precipitation that falls on the hard-rock areas and, in the form of runoff, moves toward the axes of the valleys. Infiltration from runoff occurs primarily in the coarse sediments at the mountain fronts.

The yield of wells depends on the water-bearing character of the material in the saturated zone. In the Gila Bend and Dendora areas the best aquifers are in the alluvial fill. Both the older and the younger fill seem for the most part to be interconnected, so that the ground-water reservoir is more or less continuous throughout the basin. All the irrigation wells in the area are in valley fill, and most of them are in the older fill. The deepest known aquifer is in the sandstone beds beneath the lake-bed clays, and the deep wells at Gila Bend are reported to have yielded 150 gallons per minute (gpm) from these beds.

The direction of movement of ground water in the area is shown on the contour map (pl. 2). The movement is down the slope of the water table, from areas of recharge to areas of discharge. The slope of the water table is toward the Gila River and downstream. It approximates the configuration of land surface but the gradient is gentler. Figure 2 is a profile showing the relation of the land surface to the water table along the Gila River from Gillespie Dam to approximately 10 miles west of the Painted Rock narrows.

Recharge

Recharge into the ground-water reservoir in the Gila Bend and Dendora areas occurs from five sources: (1) Surface flow in the Gila River; (2) seepage from canals and infiltration of water applied to irrigated lands; (3) infiltration from runoff at the mountain fronts; (4) direct precipitation; and (5) underflow of the Gila River.

Surface flow in the Gila River

Infiltration from the Gila River is one of the principal sources of recharge to the area. Data collected by the Surface Water Branch of the Geological Survey show that every year some of the water in the river is not diverted but flows into the area at Gillespie Dam, as given in the following tabulation:

Calendar year	Discharge, Gila River below Gillespie Dam (acre-feet)
1946	31,010
1947	9,240
1948	936
1949	11,870
1950	2,810
1951	105,900
1952	2,980
1953	50
Total for 8 years	164,800
Average per year	21,000

Most of the water that passes over the dam percolates downward through the coarse sand and gravel of the river bed and recharges the ground-water reservoir. The effects of the drought conditions which have prevailed in Arizona since 1942 are reflected in the total flow of the Gila River at Gillespie Dam (fig. 6). The amount of flow in the river varies greatly from year to year, as shown in the preceding tabulation, and a quantitative estimate of recharge from this source is difficult to make. The records show that during the years 1946-53 inclusive a total of 164,800 acre-feet of water flowed over the dam. Of this amount, only 6,460 acre-feet passed the gaging station at Dome, approximately 140 miles downstream. It can be assumed that nearly 160,000 acre-feet seeped into the stream bed or was lost by evapotranspiration. It can also be assumed that a large part of these losses occurred in the reach of the river between Gillespie Dam and Painted Rock narrows, because many flood flows are absorbed completely in that reach. Recharge experiments conducted in other areas of Arizona have shown that about 50 percent of the total flood flow of a desert stream is recharged to the ground-water reservoirs, and that a larger percentage of low flows of clear water can be considered recharged (Babcock and Cushing, 1941; Turner and others, 1943). It is assumed, therefore, that a figure of 50 percent of total flow for recharge in the area is conservative. On the basis of these data and assumptions, recharge to the basin in the last 8 years from flow in the Gila River has been at least 80,000 acre-feet, a yearly average of about 10,000 acre-feet.

Seepage from canals and infiltration of water applied to irrigated lands

Another major source of recharge in the area is seepage from canals and infiltration of water applied to lands for irrigation. Water is diverted from the Gila River at Gillespie Dam into the Enterprise and the Gila Bend canals,

Year	ACRE - FEET						
	Total water diverted and pumped into canals	Recharge from this source estimated as 25 percent	Net quantity of canal water available for irrigation	Recharge from this source estimated as 20 percent	Total water pumped directly for irrigation of lands	Recharge from this source estimated as 20 percent	Total estimate of recharge
1947	102,000	25,500	76,500	15,300	8,500	1,700	42,500
1948	90,000	22,500	67,500	13,500	20,000	4,000	40,000
1949	86,500	21,600	64,900	13,000	28,000	5,600	40,200
1950	70,500	17,600	52,900	10,600	25,000	5,000	33,200
1951	84,000	21,000	63,000	12,600	64,000	12,000	45,600
1952	96,500	24,100	72,400	14,500	67,500	13,500	52,100
1953	90,000	22,500	67,500	13,500	76,000	15,200	51,200
Total	619,500	154,800	464,700	93,000	289,000	57,000	304,800

both of which are unlined. The length of the Enterprise canal is about 7 miles and the length of the Gila Bend canal is about 45 miles, a total of about 52 miles. This does not include the many miles of laterals and irrigation ditches which carry the water to the fields. In addition to diversions of surface water, ground water is pumped into the canals from wells along their banks, partly as a supplemental supply and partly to dilute the river water, which except in floods is relatively highly mineralized.

Since 1950 more land has come under cultivation. Additional wells have been drilled to irrigate these new lands and the water is carried only relatively short distances.

Studies by the Geological Survey in Safford Valley (Turner and others, 1941), by the Cortaro Farms (personal communication), and by the University of Arizona (Rhenberg, 1951) show that, where conditions similar to those in the Gila Bend area exist, at least 25 percent of all the water carried in unlined canals and as much as 20 percent of all water applied to lands for irrigation is lost by seepage and infiltration to the ground-water reservoir. Based on these percentages the tabulation on the facing page indicates the possible amount of recharge to the ground-water reservoir from these sources. The estimated total recharge from canals and irrigated fields for the years 1947-53 inclusive is of the magnitude of 300,000 acre-feet, or an average of about 44,000 acre-feet per year.

Infiltration from runoff at the mountain fronts

Recharge from runoff at the mountain fronts is derived from precipitation which falls on the hard-rock areas and, in the form of runoff, finds its way across the coarse alluvial materials at the mountain fronts. It is estimated that, of the amount of rain that falls on a hard-rock area, an average of about 10 percent becomes runoff (Coates and others, 1954). Of this amount, about half can be assumed to recharge the ground-water reservoir. The average annual precipitation in the Gila Bend area is about 6 inches. However, during the years 1946 to 1954 the average has been only about 5 inches. The total hard-rock area within the drainage basin is about 225 square miles. Using an annual precipitation of 5 inches, about 60,000 acre-feet of water fell, of which presumably about 6,000 acre-feet became runoff. Of this amount it is assumed that about 3,000 acre-feet found its way as recharge to the ground-water reservoir, a negligible amount in consideration of the size of the area.

Direct precipitation

Little of the direct precipitation on the valley floor reaches the water table, as studies of soil penetration from rainfall in arid climates and desert conditions indicate that most of this moisture is lost by evaporation or transpiration. The only possibility for recharge from direct precipitation is from rain that falls or enters as runoff into the coarse material in the washes or minor stream channels. Most of the direct precipitation on the bottom lands of the Gila River is considered to be returned to the atmosphere by evapotranspiration, and the net recharge from this source is estimated to be less than 500 acre-feet per year. Quantitative data are not sufficient for the Gila Bend area to estimate the annual amount of recharge from direct precipitation but it is doubtless small in comparison with the other sources.

Underflow

Underflow into the area is a source of gain to the ground-water reservoir. The only possible place where this occurs in the Gila Bend area is at the narrows at Gillespie Dam. Basalt of Quaternary age crops out there on both sides of the river. The dam was constructed across the narrows in 1921 for the diversion of water into the Enterprise and Gila Bend canals. As a result, the underflow entering the area was reduced. The possibility that water is entering the area as underflow in or underneath the basalt has not been proved or disproved conclusively, but it would seem likely that the quantity is small in comparison with the other sources.

Discharge

Discharge from the ground-water reservoir takes place both by natural means and by pumping from wells. Natural discharge is by evaporation, transpiration, or underflow and surface flow leaving the area.

Evaporation

There are no evaporation records available for this area but an annual evaporation loss of 96 inches was assumed, based on records for stations at Yuma and Mesa.

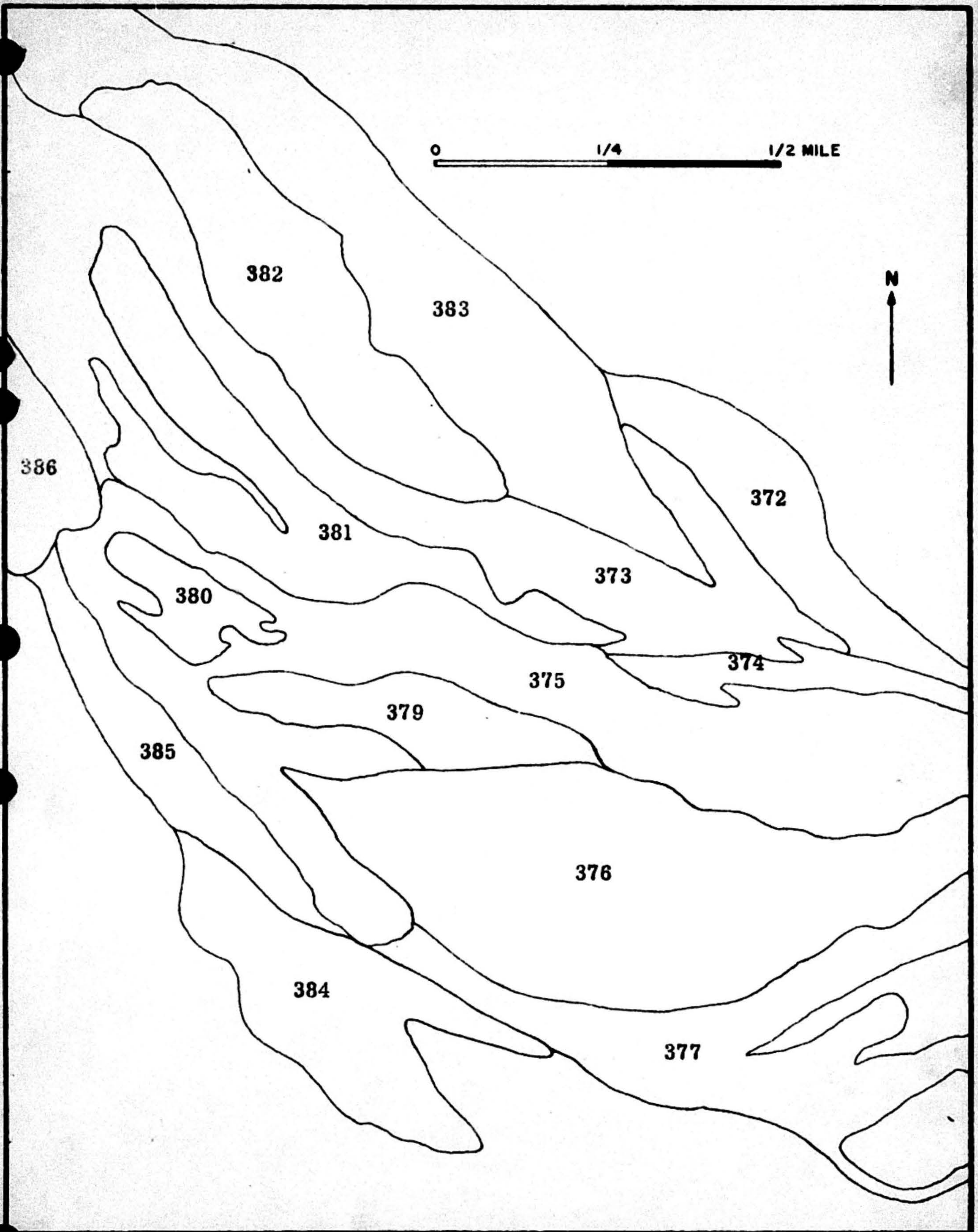

Figure 3. -Portion of Gila River channel showing parcels of approximately uniform density of bottom-land vegetation (See also table 1).

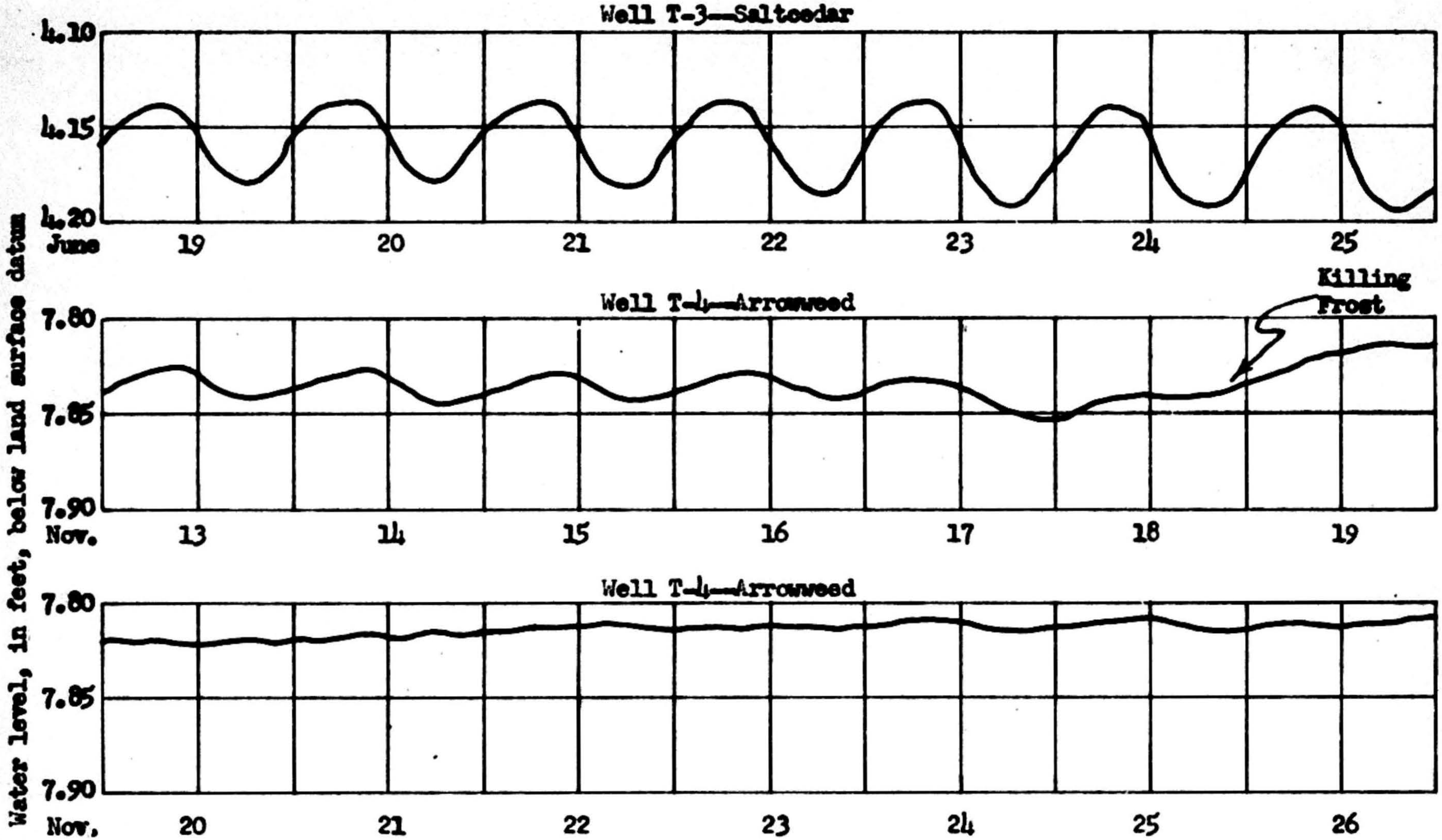

Figure 4.-Typical water-level fluctuations in transpiration wells.

In various places along the river channel, mostly west of Gila Bend, where the water table is slightly higher than parts of the stream bed, open pools of water are formed. Ground water is discharged from these pools by evaporation. In addition, where the capillary fringe reaches the land surface, areas of wetted sand occur and evaporation of ground water results. Evaporation of ground water is considered to occur from an estimated 400 acres of open pools and about 600 acres of wetted sand. Coefficients of 0.86 and 0.7 were applied, respectively, to these classes of areas (Gatewood and others, 1950, 47-49) and an annual evaporation rate of 96 inches was used. On the basis of these figures, a total of about 6,000 acre-feet of ground water is discharged annually by evaporation.

Transpiration

A brief but intensive investigation of water use by river-bottom vegetation along the Gila River channel was made between Gillespie Dam and the Painted Rock narrows. The methods used were developed in Safford Valley, Ariz., and are described by Gatewood and others (1950).

The Corps of Engineers furnished a complete set of aerial photographs on a scale of approximately 5 inches to the mile. The photographs were examined, and the entire bottomland was divided into numbered parcels according to the apparent density of growth in each parcel. The areas of each parcel were then measured by planimeter. Most of the field observations were made from a light plane, flown at an altitude of about

100 feet above the ground. Notes were made as to the types, heights, and densities of the phreatophytes in each numbered parcel (fig. 3, table 1). Checks were made at various sections on the ground to substantiate the aerial observations.

The total river-bottom area occupies approximately 30,000 acres, of which all but about 1,000 acres is covered by phreatophytes. The principal plants are saltcedar (Tamarix gallica), mesquite (Prosopis juliflora), and arrowweed (Pluchea sericea). These plants comprise approximately 95 percent of the vegetation in the river channel. To evaluate the quantity of vegetation it was necessary to determine the volume density, which is the product of areal density and vertical density (Robinson, T. W., in Gatewood and others, 1950, p. 25). Computed in terms of 100-percent volume density, the effective area of evapotranspiration was about 4,600 acres, made up of 2,250 acres of saltcedar, 1,750 acres of mesquite, and 600 acres of arrowweed and miscellaneous brush. The computed total area of 100-percent volume density is only about 18 percent of the gross area. The field work disclosed that a few hundred acres of phreatophytes along the river for about 8 miles downstream from Gillespie Dam have died within the past few years. The cause is not definitely known but is believed to be a decline of the water table. The current depth to water in this reach of the channel is 40 to 75 feet (fig. 2). The cause is not believed to have been changes in quality of the ground water or spraying the plants with chemicals.

To determine the use of ground water by the three principal plant species, "transpiration wells" 8 inches in diameter were augered in areas of dense growth (pl. 1). Soil samples were collected from each well in the zone of saturation to determine the coefficient of drainage (Gatewood and others, p. 82). Water-stage recorders were installed on the wells to measure daily fluctuations caused by plant transpiration. Graphs of typical fluctuations are shown in figure 4. The middle graph shows that a frost reduces transpiration to a negligible amount and effectively ends the growing season. The formula developed by White (1932), $q=y(24r\pm s)$, was used, adjusted for night transpiration (Gatewood and others, 1950, p. 146-150). From the data, the mean monthly use of ground water in the vicinity of each transpiration well was computed for the period of record. Because of the limited time the recorders provided usable records, data for a complete year could not be obtained. Therefore, the more comprehensive Safford data were utilized. Table 2 illustrates the method employed to estimate use of ground water by saltcedar and arrowweed for the full growing season. Owing to similarity in leaves, stalks, and length of growing season, arrowweed was considered comparable to baccharis, for which Safford data were available.

The work described by Gatewood and others (1950) included six methods of determining use of water by phreatophytes, and the final results were a mean of results by all six methods. The transpiration-well method

Table 1.--Method of computing areas of 100-percent volume density for parcels shown in figure 3.

Plot no.	Gross areal density (percent)	Gross area (acres)	Saltcedar			Mesquite			Arrowweed		
			Areal density (percent)	Volume density (percent)	Area of 100-percent volume density (acres)	Areal density (percent)	Volume density (percent)	Area of 100-percent volume density (acres)	Areal density (percent)	Volume density (percent)	Area of 100-percent volume density (acres)
372	80	36.7	0	0	0	60	100	17.6	40	90	10.5
373	50	116.9	0	0	0	0	0	0	100	100	43.8
374	5	12.4	0	0	0	100	100	0.6	0	0	0
375	90	85.7	100	100	77.2	0	0	0	0	0	0
376	5	125.1	100	100	6.3	0	0	0	0	0	0
377	95	71.9	100	100	68.2	0	0	0	0	0	0
379	10	25.2	50	100	1.3	50	100	1.3	0	0	0
380	25	12.9	100	100	3.2	0	0	0	0	0	0
381	8	62.3	30	100	1.5	30	100	1.5	40	100	2.0
382	7	65.8	0	0	0	100	90	4.1	0	0	0
383	80	67.8	0	0	0	30	100	16.3	70	90	34.1
384	60	50.4	0	0	0	40	100	12.1	60	100	18.2
385	35	26.6	100	100	9.3	0	0	0	0	0	0
386	4	45.8	0	0	0	100	100	1.8	0	0	0

Table 2. --Mean monthly use of ground water by bottom-land vegetation of 100-percent volume density in Gila Bend area and Safford Valley, Ariz., on the basis of the transpiration-well method.

Month	Saltcedar				Arrowweed - baccharis			
	Determined mean monthly use, inches		Ratio, use at Safford to use at Gila Bend	Computed mean monthly use, Gila Bend, inches	Determined mean monthly use, inches		Ratio, use at Safford to use at Gila Bend	Computed mean monthly use, Gila Bend (arrowweed) inches
	Safford	Gila Bend			Safford (baccharis)	Gila Bend (arrowweed)		
Jan.	0	-	-	0	0	-	-	0
Feb.	0	-	-	0	0	-	-	0
Mar.	0	-	-	0	.1	-	1.0a/	.1
Apr.	1.2	-	1.1a/	1.1	1.6	-	1.0a/	1.6
May	11.0	-	1.1a/	10.0	7.9	-	1.1a/	7.1
June	17.0	14.1	1.2	14.1	10.8	-	1.2a/	8.6
July	14.8	15.8	.9	15.8	9.7	-	.9a/	10.7
Aug.	13.5	12.6	1.1	12.6	7.0	11.5	.6	11.5
Sept.	11.6	8.8	1.3	8.8	5.5	6.2	.9	6.2
Oct.	3.1	7.7	.4	7.7	1.3	5.5	.2	5.5
Nov.	.2	4.6	.05	4.6	.1	1.8	.1	1.8
Dec.	0	0	-	0	0	.1	-	.1
Total	72.4	-	-	74.7	44.0	-	-	53.2

a/ Estimated on basis of data for subsequent months.

was found to yield results 6.4 percent less than the mean of all six methods. This factor was applied as an adjustment to the figures for the Gila Bend area (table 2).

The figures for mean total use of ground water by the phreatophytes common to the Gila Bend area, computed for a full growing season and for 100-percent volume density, are as follows: Saltcedar, 6.7 feet; mesquite, 2.7 feet; and arrowweed, 4.7 feet. Applying these annual rates, it was computed that the river-bottom vegetation in the Gila Bend area withdraws nearly 23,000 acre-feet of water annually from ground-water storage. In addition, all the precipitation falling on the gross area of phreatophyte-covered lands was considered to be discharged by evapotranspiration. The 40-year annual average precipitation at Gila Bend is 5.9 inches. Mean precipitation during the period 1946-53, inclusive, has been about 5 inches per year. Applying a rate of 5 inches to the 29,000 acres of phreatophyte-covered lands, it is apparent that an average of about 12,000 acre-feet of water from precipitation has been discharged annually since 1946. However, in 1953 precipitation was only about 2.7 inches and only about 6,500 acre-feet of discharge was derived from this source.

The total annual discharge of water from the river-bottom area in 1953 was, therefore, approximately as follows:

Transpiration of ground water		23,000 acre-feet
Evaporation of ground water		6,000
Evapotranspiration of precipitation		6,500
TOTAL	Approximately	36,000 acre-feet

Underflow and surface flow leaving the area

Present studies indicate that there is no underflow leaving the Gila Bend area except at the Painted Rock narrows, where the Gila River passes through the narrow gap between the Painted Rock and Gila Bend mountains (pl. 1). These mountains and a rock outcrop in the bed of the river form a partial barrier that divides the stream into two narrow channels and usually forces ground water to the surface. There is no likelihood of movement of ground water through or underneath the volcanic rocks of the Painted Rock Mountains, on the basis of data from test holes drilled by the Corps of Engineers (B. D. Jorgensen, personal communication, 1954). At times the water table in the narrows declines, reducing the effective area through which underflow moves.

Using a hydraulic gradient of 2 feet per mile, a cross-sectional area of 34,000 square feet, and a permeability of 400 Meinzer units (gallons per day per square foot), it is estimated that the underflow through the narrows is about 5,000 gallons per day (gpd) or about 5½ acre-feet per year. This quantity would probably be increased to about 30,000 gpd during the time seasonal rains fully saturate the sediments in the channel. The factor used for hydraulic gradient was based on the profile (fig. 2), the cross-sectional area on data furnished by the Corps of Engineers, and the permeability on laboratory tests of alluvium from the transpiration wells. Unfortunately the figure used for permeability was based on inadequate data, and a better figure could be obtained if a pumping test were made in the narrows. Current plans of the Corps of Engineers are to conduct such a test in February 1954, too late for inclusion in the present report. Although the estimate of 5,000 gpd is, therefore, provisional and subject to revision, it at least indicates the small magnitude of the underflow leaving the Gila Bend area and entering the Dendora area.

As there is no gaging station on the Gila River at the narrows, the annual quantity of surface water leaving the Gila Bend area is not known. The average quantity of surface flow leaving the area was estimated by Babcock and Kendall (1948) to be less than 4,500 acre-feet per year, and the present investigation did not indicate that their estimate would require substantial revision.

Pumping from wells

Gila Bend area.--Withdrawal of ground water for irrigation currently constitutes the main means of discharge in the area. In 1953 there was about 33,500 acres of cleared or cultivated land in the area (pl. 1), of which about 32,000 acres was irrigated. About 15,000 acres was supplied with water from the Gila Bend and Enterprise canals. In 1953 about three-fourths of the water delivered from the canals was ground water pumped into them within the Gila Bend area. The remaining 17,000 acres was irrigated with water pumped directly from wells. The irrigation wells are, for the most part, in two areas-one along the river channel from Rainbow Valley almost to Gila Bend and the other along the river channel in the western

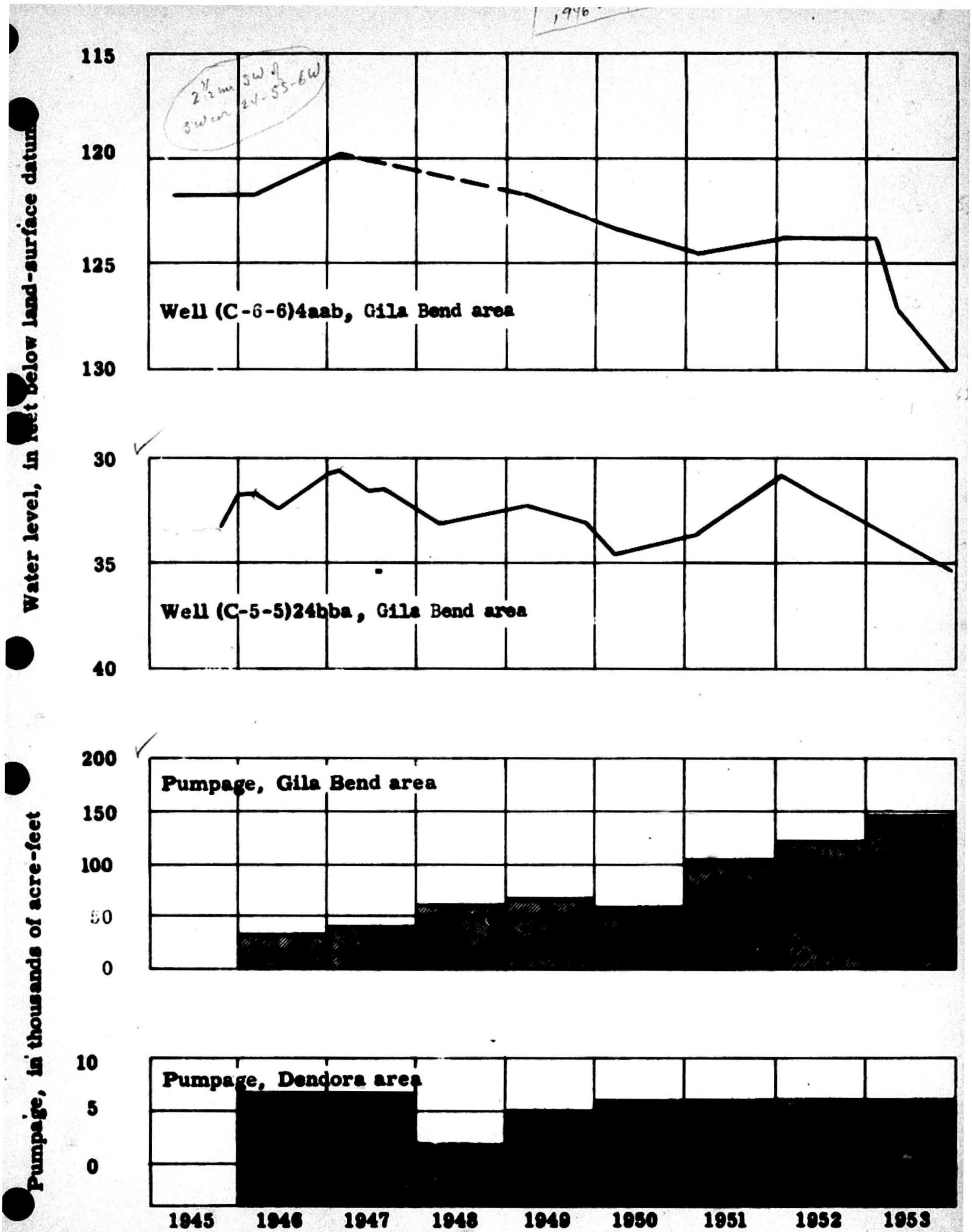

Figure 5. -Water levels in wells and pumpage in the Gila Bend and Dendora areas, Maricopa County, Ariz.

part of the area, mostly in Tps. 6 and 7 W. There are 21 wells along the Gila Bend canal between the Gila Bend and Maricopa Mountains, all of which pump directly into the canal. In 1953 an additional 52 wells were pumped for irrigation. The quantity withdrawn from the ground-water reservoir for irrigation in the Gila Bend area in 1953 was about 144,000 acre-feet.

Pumpage of ground water for uses other than irrigation is estimated to be less than 500 acre-feet per year, including pumpage for municipal, military, industrial, domestic, and livestock use.

The following tabulation shows total water pumped for irrigation in the Gila Bend area in the years 1947 through 1953, the quantities of surface water diverted for irrigation, and ratios among the categories:

	Acre-feet				Ratio, water pumped into canals to total flow in canals (percent)	Ratio, water pumped into canals to total water pumped (percent)	Ratio, water pumped directly for irrigation to total water pumped (percent)
Year	Diverted into canals (rounded)	Pumped into canals	Pumped directly for irrigation	Total pumpage			
1947	69,500	32,000	8,500	40,500	32	79	21
1948	49,000	40,500	20,300	60,800	45	67	33
1949	47,500	39,000	28,000	67,000	45	58	42
1950	36,500	33,500	25,500	59,000	48	57	43
1951	44,000	40,000	64,000	104,000	48	38	62
1952	44,000	52,000	68,000	120,000	54	43	57
1953	22,000	68,000	76,000	144,000	75	47	53

Dendora area.--There is about 1,500 acres of land cleared for farming in the Dendora area (pl. 1), of which 1,400 acres was irrigated in 1953. Ground water, pumped from 10 wells, is the sole source of supply. The quantity pumped during the period 1946-53 inclusive is given in the following table:

Year	1946	1947	1948	1949	1950	1951	1952	1953
Quantity pumped	6,700	6,700	1,900	5,000	6,000	6,000	6,000	6,000

(acre-feet)

Wells.--In the Gila Bend and Dendora areas 83 wells were pumped for irrigation in 1953. Most of the wells are 20 inches in diameter, range in depth from 350 to 900 feet, and yield from 1,300 to 3,000 gpm (table 3). Logs of selected wells are given in table 4. Most of the wells are equipped with electric-powered turbine pumps. Along the Gila Bend canal the average drawdown in 1946 was about 43 feet and the average yield was about 2,400 gpm; by 1953 the average yield had declined to about 2,000 gpm. In the area west of Gila Bend along the river channel the average drawdown in 1953 was about 65 feet and the average yield about 2,500 gpm.

The depth to the water table in the Gila Bend and Dendora areas is shown on plate 3. Ranges in depth to the water table are as follows: Irrigated areas between the Gila Bend and Maricopa Mountains, 60 to 250 feet; in the vicinity of Gila Bend, 15 to 240 feet; irrigated area west of Gila Bend along the river channel, 15 to 60 feet; in vicinity of Theba, 80 to 120 feet; and Dendora area, 20 to 60 feet. The greatest measured depth to water in the area was more than 400 feet in a well near the Sauceda Mountains.

Summary of recharge and discharge to the ground-water reservoir

The following is a summary of the average estimated gains to and losses from the ground-water reservoir in the Gila Bend area for the years 1947-53, inclusive:

Gains	Acre-feet	Losses	Acre-feet
Seepage from flow in Gila River	10,000	Evaporation	6,000
Seepage from canals and irrigated lands	44,000	Transpiration	23,000
Infiltration from runoff at the Mountain fronts	3,000	Underflow out of area	b/
Precipitation on washes and stream beds	500	Pumpage	85,000
Underflow into area	a/		
Rounded totals	58,000		115,000

a/ Amount unknown but probably small.
b/ Negligible.

This summary indicates that withdrawals by discharge from the ground-water reservoir exceed the amount replaced by recharge. The difference is being supplied by the removal of ground water from storage.

Storage

Most of the Gila Bend area is desert land and, until about 4 years ago, the cultivated lands, mostly in the vicinity of Theba, were supplied principally with surface water diverted at Gillespie Dam and ground water pumped into the upstream portion of the canals. Thus, the water was applied to lands many miles distant from the points of withdrawal, and little benefit to the pumped area was derived from seepage recharge. This condition accounts for the ground-water mound in the vicinity of Theba (pl. 2). However, with the expansion of agricultural development and the drilling of new wells northwest of Gila Bend, some of this seepage will be recovered. The scarcity of wells and the consequent lack of information as to the depth, character, and extent of valley fill and as to other pertinent features makes it impossible to calculate the amount of ground water stored in the area.

Fluctuations of the water table

Periodic measurements in a limited number of observation wells confirm other data indicating a general decline throughout the Gila Bend area. The trend is more noticeable in the heavily pumped area along the upstream portion of the Gila Bend canal. From the water-table contour map (pl. 2), it can be seen that continuous pumping has caused a sharp depression there. This area probably is receiving water from storage in Rainbow Valley. Increasing pumping for new development in Rainbow Valley will make less water available to the area along the canal, and an accelerated lowering of the water table may be expected. The following tabulation shows the declines that have occurred during the period 1945-53 inclusive in various parts of the Gila Bend area:

Heavily pumped area between Gila Bend and Maricopa Mountains

Well No.	Water level, in feet below land-surface datum 1945-46	Water level, in feet below land-surface datum 1952-1953	Decline (feet)
(C-2-5)20a	24.06	28.93	4.87
36cbd	54.93	103.87	48.94
(C-3-4)7aab	64.72	100.25	35.53
21bba	68.67	104.80	36.13
Remainder of Gila Bend area			
(C-4-6)29aab	31.50	44.86	13.36
(C-5-4)21bdc	94.06	97.42	3.36
(C-5-6)2dba	19.93	47.89	27.96
(C-6-6)4aab	121.77	126.75	4.98
(C-7-5)6aab	225.25	225.24	0

The hydrograph of well (C-6-6)4aab (fig. 5) shows the spring water-level measurements for the period 1945-53 inclusive. This well is on the eastern edge of the irrigated area near Theba, where recharge has been occurring for about 30 years and there has been no pumping for irrigation. It is considered that, prior to the first measurements in the well in 1945, a near-equilibrium condition may have developed between recharge from irrigation and a compensating increase in natural discharge. Thus, the fact that the water level in the well was not rising rapidly would not mean that substantial recharge was not occurring in the area. The decline since 1947 could be attributed to the drought or to the effects of pumping in the newly developed area to the north, along the river. The sharp decline in the spring of 1953 tends to show that pumping to the north has at least some effect on water levels in the vicinity of this well.

Well (C-5-5)24bba is not far from the river channel, and the water-level fluctuations probably reflect periodic recharge resulting from heavy rains or from floods in the river.

QUALITY OF WATER

Samples of water from 80 wells were collected and analyzed during the investigation. Selected analyses are shown in table 5 and the range in dissolved solids is shown on plate 4. Twenty-five samples collected in 1946 afford a partial basis for evaluating changes in quality of the ground water since that time. Samples of surface water from the Gila River at Gillespie Dam have been collected on a continuing basis since 1934. Figure 6 shows mean dissolved-solids content of the river water for the period 1943-53 inclusive. The samples collected prior to October 1950 were analyzed by the Salt River Valley Water Users' Association and those collected since that date, by the Geological Survey

Ground water

Area between Gila Bend and Maricopa Mountains

Most of the wells in this area obtain water only from the older fill and the dissolved-solids content of the water is generally less than 1,500 parts per million (ppm) as shown in plate 4. According to the standards of the U. S. Department of Agriculture (Wilcox, 1948) these waters may be considered "doubtful to unsuitable" for irrigation use, owing to their high sodium and chloride content. Many of the waters contain more than 1 ppm of boron, a concentration that is undesirable for use in irrigating citrus and some other fruit trees (Wilcox, 1948). Most of the waters in this area are hard, have a noticeable salty taste, and contain more than 1.5 ppm of fluoride. In the northern part of the area, nearest to Gillespie Dam, the dissolved-solids content is, in general, somewhat higher than in wells farther south.

On the basis of comparison of all the 1946 and 1953 analyses of water from wells in the area, little or no change in dissolved-solids content occurred in the interval. If anything, there was a very slight reduction in dissolved solids. Figure 6 indicates a slight trend toward an increase in dissolved solids in river water entering the area, which would be expected to increase the concentration of dissolved material in the ground water. The apparent contradiction is attributed to recharge from flood flows that were fairly low in dissolved solids, particularly in August and September 1951.

Area along Gila River northwest of Gila Bend

Most of the wells in the irrigated area along the Gila River in Rs. 6 and 7 W. obtain water from both the younger and the older fill. The waters are, on the average, more highly mineralized than those farther upstream, a feature common to the valleys along the Gila River (Halpenny and others, 1952, p. 206). Sodium and chloride are the predominant constituents and the waters have a definitely salty taste. According to the standards set forth by Wilcox (1948), waters from this area range from "doubtful" to "unsuitable" for irrigation.

As this area was practically undeveloped in 1946, few samples could be collected for analysis during the previous investigation (Hem, J. D., in

Babcock and Kendall, 1948, pp. 14-17). The meager data available indicate that practically no change in dissolved solids has occurred since 1946.

Although all the fill, in effect, forms one ground-water reservoir in this area, the few data available indicate that water from the younger fill apparently is more highly mineralized than that from the older fill. Table 5 lists three analyses from wells in T. 5 S., R. 6 W. The analyses indicate that the most highly mineralized water was obtained from the shallowest well, the one obtaining the greatest portion of water from younger fill. Collection of additional samples in the future, especially if additional wells are drilled, will indicate the extent of the difference in dissolved-solids content of water in the younger and older fill and may indicate the cause.

Remainder of Gila Bend area

Most of the water samples collected from wells in the older fill in the remainder of the Gila Bend area contained 1,000 to 1,500 ppm. The wells are used primarily for domestic and livestock purposes. The waters generally are hard, have a noticeable taste, and contain more than 1.5 ppm of fluoride. Changes in the quality of these waters from 1946 to 1953 were negligible.

The deep well at Gila Bend taps a sandstone aquifer in consolidated sediments underlying the lake-bed sequence of the older fill. A sample collected from this well in February 1946 contained 1,060 ppm of dissolved solids, including 6.9 ppm of fluoride. Sodium and chloride predominate, and the water is soft in comparison with water from wells supplied from alluvial fill. No significant change in concentration of soluble material has occurred since 1946.

Dendora area

Samples of water from wells in this area were not collected in 1953. Three analyses of samples collected in 1946 indicate that at the time ground water in the Dendora area ranged in dissolved-solids content from 1,420 to 4,010 ppm. All were high in sodium and chloride and lie in the class "unsuitable" for irrigation on the basis of the Department of Agriculture standards (Wilcox, 1948).

Surface water

The Gila River supplies the only surface water for irrigation in the Gila Bend area. Surface waters diverted into the Gila Bend and Enterprise canals at Gillespie Dam are, on the average, considerably more highly mineralized than the ground waters that are pumped into the canals.

The period 1942-53 inclusive has been one of drought in most of the Southwest. Figure 6 shows that, except for the effects of floods of short duration, the flow of the river at Gillespie Dam gradually decreased in the period 1944-53. In 1947 69,500 acre-feet was diverted into the canals; in 1953 the quantity available for diversion was only 22,000 acre-feet. During this same period the waters became more highly mineralized. In the water year 1943-44 the weighted average dissolved-solids content was about 3,800 ppm; in the water year 1952-53, about 5,000 ppm. Except when diluted with flood flows, the surface water diverted into the canals is high in sodium and chloride and is classed as "unsuitable" for irrigation (Wilcox, 1948).

Flood flows in the Gila River contain much less dissolved material than low flows. The water is of excellent quality in comparison with normal river flow, though it is hard. The following tabulation indicates the difference in dissolved-solids content between flows greater than 500 cubic feet per second (cfs) and flows less than 500 cfs.

Date	Flows greater than 500 cfs		Flows less than 500 cfs	
	Mean discharge cfs	Dissolved solids (ppm)	Mean discharge cfs	Dissolved solids (ppm)
1951				
July 11-20			21.8	5,450
July 21-27, Aug. 2			29.9	4,640
July 28-31			457	1,460
Aug. 1, 3			207	1,860
Aug. 4, 5	2,075	487		
Aug. 6-10	734	877		
Aug. 11-15, 18-26			86.7	5,220
Aug. 16, 17			176	2,110
Aug. 27	586	881		
Aug. 28-31	8,500	417		
Sept. 1	4,640	262		
Sept. 2	2,540	543		
Sept. 3, 4	507	2,140		
Sept. 5-10			248	5,660
Sept. 11-20			174	5,790
Sept. 21-30			100	6,000

Ground-water--surface-water interrelationships

The effect of the quality of the surface water in the Gila River upon the quality of the ground-water supply of the Gila Bend area is of great importance. For example, by mixing ground water with the surface water diverted into the canals, the dissolved-solids content can be reduced sufficiently to make the water suitable for irrigation of some crops. Some of this mixture recharges the ground-water reservoir by downward seepage from canals and fields. Some leaching of the alluvial materials is likely to occur as this water moves downward to the water table, and the net effect may be to increase the concentration of dissolved material in the ground water.

An important source of recharge of river water in the Gila Bend area is flood flows. These better-quality waters tend to reduce the concentration of dissolved materials in the ground-water supply.

It is considered likely that a long-term tendency exists for the quality of the water supply in the Gila Bend area to deteriorate, at least in the downstream part. This tendency exists because more dissolved material is being brought into the area than is leaving, as has occurred also in Safford Valley, the Salt River Valley area, and the Wellton-Mohawk area.

Relation of quality of water to use

Irrigation

Although most of the water used for irrigation in the Gila Bend area is classed as "doubtful to unsuitable" for irrigation, crops currently are being raised successfully. Certain features of the situation, not all fully related to the water supply, partially offset the high sodium content of the water and help explain the seeming contradiction.

A good irrigation water must be low in dissolved-solids content and percent sodium. However, it is difficult to classify irrigation water on the basis of dissolved-solids content and percent sodium alone, as the proportions of the various constituents, the character of the soil, and the type of crop to be grown also must be considered (Smith and others, 1949).

The percentage of sodium is greater than that of calcium and magnesium in the majority of irrigation waters in the area. However, the total hardness is high, which partially offsets the high sodium percentage.

Crops grown in the Gila Bend area consist mostly of cotton, alfalfa, barley, and sorghum. These crops are comparatively salt tolerant. However, because of the poor quality of the water, sometimes more than one seeding is required for germination. The soil in the Gila Bend area is sandy rather than clayey. When irrigated, sandy soils drain readily, whereas clay soils tend to accumulate soluble salts.

Domestic use

Practically all the waters sampled in the Gila Bend and Dendora areas exceed the suggested limits for dissolved mineral matter in drinking water, on the basis of U. S. Public Health Service standards (1946). The waters are hard and most of them contain more than 1.5 ppm of fluoride, the lower limit of fluoride concentrations that may cause mottling of the tooth enamel of children.

Exceptions are mainly in waters from wells on the fringes of the Gila Bend area, nearest the mountains. These waters were of the best quality sampled during the present investigation.

COMPARISON OF PRESENT AND PREVIOUS CONDITIONS

The investigation in 1953 afforded an opportunity to compare current ground-water conditions with those prevailing in 1947, when the reconnaissance work by Babcock and Kendall (1948) was done.

Expansion of agriculture since 1947 has been principally in the area along the Gila River northwest of Gila Bend, most of the remainder occurring near the Gila Bend canal in lower Rainbow Valley. The cones of depression in the water table in the vicinity of these areas, caused by pumping for irrigation, are shown by the ground-water contours (pl. 2). The lowering of the water table in the cone of depression along the river south of Gillespie Dam has reduced the loss of ground water by transpiration by native vegetation in that area.

The 1953 estimates for recharge and discharge were averages for a 7-year period, 1947-53 inclusive; the previous estimates were for only the first year of the period. The estimate for recharge in 1947 was 48,000 acre-feet, and for the 7-year period, an annual average of 57,000 acre-feet. The increase is attributed mainly to additional recharge from the flood flows in 1951, a part of it is attributed to the expansion in the irrigated area. The estimate for discharge in 1947 was 88,000 to 138,000 acre-feet, not including underflow at Gillespie Dam; and for the 7-year period, an annual average of 115,000 acre-feet, not including the negligible underflow. The 115,000 acre-foot figure includes an increase in pumpage since 1947 and a downward revision in the estimates of evapotranspiration along the river channel.

CONCLUSIONS

The investigation described in this report provided data that led to the following conclusions:

1. The quantitative estimates indicate that the mean annual discharge of ground water in the Gila Bend area exceeded the mean annual recharge in the 7-year period 1947-53, inclusive. During this period, annual withdrawals of ground water for irrigation increased by more than three times. The difference between recharge and discharge must have been provided from ground-water storage, as is confirmed by the fact that the water table is declining in the heavily pumped areas.

2. On a long-term basis, floods in the Gila River are likely to constitute a major source of the recharge to the area, even though the larger floods are usually several years apart. Recharge from this source occurs where it is most readily usable - in the two major cones of depression. However, the frequency and intensity of floods cannot be precisely predicted, and the probable quantity and frequency of recharge from floods is impossible to estimate.

3. It is believed that a trend exists toward a gradual increase in dissolved mineral matter in at least a part of the ground-water supply,

because more dissolved mineral matter enters the area than leaves. Low-flow waters of the Gila River entering the area at Gillespie Dam in 1953 were more highly mineralized than in 1943. Recirculation of ground-water will tend to increase the concentration of dissolved matter. An offsetting factor is that flood flows in the Gila River are not high in dissolved solids and will provide water of considerably better quality than the average for the area. Although the flood flows have always provided water of relatively low mineralization, their effect is becoming progressively greater because of the increased recharge opportunity provided by the major cones of depression.

4. Underflow out of the Gila Bend area occurs only at the narrows between the Painted Rock and Gila Bend Mountains. On the basis of limited data from the few wells in the vicinity of Theba, it is believed that no ground water leaves the Gila Bend area by moving westward south of the Painted Rock Mountains.

5. Construction of a flood-control dam at the Painted Rock narrows would affect the ground-water supply of the region as follows:

(a) Underflow at the narrows would be reduced or stopped. However, the underflow at the narrows is negligible, and stopping it would have practically no effect on downstream water users.

(b) It is considered likely that the over-all effect of a dam on the ground-water supply of downstream users would be beneficial. The flood waters would be at least partially desilted and would move downstream more slowly than if uncontrolled. Both factors would increase the proportion of flood flows in the river that would be recharged.

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Table 3.--Records of selected wells in Gila Bend and Dendora areas, Arizona.

Well no.	Depth of well (feet)	Water level: Depth below land surface datum (feet) a/	Water level: Date of measurement	Altitude of land surface (feet above MSL)	Type of lift b/	Use of water c/	Discharge: Gallons per minute	Discharge: Date of measurement	Remarks
(C-2-5)									
36cbd	345	103.87	5/6/53	750	T, E	I	1750	9/9/53	See table 4.
(C-3-4)									
4baa	250	159.68	2/13/51	815	T, E	I	1750	5/6/53	See table 5.
4cba	240	171.70	5/6/53	800	None	N	-	-	See table 4.
8bab	406	105.10	4/1/52	765	T, E	I	1300	5/8/53	See tables 4 and 5.
16daa	-	159.30	4/1/52	806	T, E	I	2650	5/5/53	
22ddd	465	248.33	5/6/53	854	T, E	I	2600	9/9/53	See tables 4 and 5.
27baa	-	203.53	5/6/53	815	T, E	I	2500	9/9/53	
33aba	800	78.35	12/18/45	745	T, E	I	3000	4/24/53	See tables 4 and 5.
33dab	-	133.60	4/24/53	730	T, E	D, I	-	-	
(C-3-5)									
2bcc	-	60.04	12/30/53	737	T, E	I	-	-	
(C-4-4)									
3bcc	543	121.44	5/8/53	745	T, E	I	1700	9/9/53	
4bdd	316	84.06	12/30/53	710	T, E	I	2400	4/24/53	See tables 4 and 5.
9baa	300	70.90	4/24/53	705	T, E	I	-	-	
15bbb	385	77.36	4/23/53	715	C, E	D	-	-	See table 5.
18aab	378	37.26	4/23/53	690	T, Bu	I	-	-	See table 4.
32bbb	-	-	-	683	T, E	I	2450	9/4/53	
(C-4-6)									
27bdb	-	47.95	4/16/53	595	T, E	I	2200	7/24/53	See table 5.
31cdd	600	23.04	12/30/53	572	T, E	I	2550	4/15/53	See table 5.
36adc	960	33.03	12/30/53	615	T, E	I	2550	4/16/53	See table 5.

a/ Depth was adjusted to land-surface datum from measuring point.
b/ T, turbine; Cf, centrifugal; C, cylinder; J, jack; Bu, butane; G, gasoline; D, diesel; E, electric; W, windmill.
c/ I, irrigation; P, public supply; D, domestic; S, stock; RR, railroad; N, not used.

Table 3.--Records of selected wells in Gila Bend and Dendora areas--continued.

Well no.	Depth of well (feet)	Water level		Altitude of land surface (feet above MSL)	Type of lift b/	Use of water c/	Discharge		Remarks
		Depth below land surface datum (feet) a/	Date of measurement				Gallons per minute	Date of measurement	
(C-4-7)									
25ada	16	14.10	4/16/53	570	C, W	N	-	-	
34ccd	830	37.23	4/15/53	580	T, E	I	-	-	
34ddc	1000	29.90	12/30/53	575	T, E	I	2400	4/15/53	See table 5.
36daa	600	30.78	4/15/53	569	None	N	-	-	
(C-4-8)									
15bad	40	-	-	540	Cf, G	I	-	-	Dug well.
23ddd	180	70.84	12/17/53	535	T, D	I	-	-	
26ddd	152	50.57	12/17/53	560	T, E	I	-	-	See tables 4 and 5.
34ddd	100	37.89	12/17/53	535	T, E	I	-	-	See table 5.
(C-5-3)									
8bbc	-	297.0	4/23/53	950	C, W	S	-	-	See table 5.
(C-5-4)									
8dbd	135	33.88	12/29/53	670	T, Bu	I	1050	4/23/53	See table 5.
18add	501	26.44	4/22/53	655	T, E	-	1300	7/3/53	See tables 4 and 5.
19ddd	926	77.35	12/18/53	705	T, E	I	1950	4/23/53	See tables 4 and 5.
31cbd1	1752	129.10	12/30/53	735	T, E	P	-	-	See tables 4 and 5.
(C-5-5)									
18dcb	945	-	-	635	T, E	I	470	4/16/53	See table 5.
24bba	650	35.18	12/18/53	650	C, W	D	-	-	See table 5; fig. 5.
(C-5-6)									
2dba	418	47.89	4/16/53	600	T, E	I	1600	7/20/53	See table 5.
4ddd	650	16.70	4/16/53	602	None	N	-	-	
6ada	956	25.83	12/18/53	585	T, E	I	2200	4/15/53	
11dcb	440	57.22	4/16/53	617	T, E	I	2900	7/24/53	See table 5.
13add	280	62.55	4/10/53	622	T, E	I	1600	9/4/53	See table 5.
(C-5-7)									
1aaa	700	21.42	4/15/53	570	T, E	I	2050	4/16/53	See table 5.
1abb	700	-	-	575	T, E	I	2000	4/15/53	

Table 3.--Records of selected wells in Gila Bend and Dendora areas--continued.

Well no.	Depth of well (feet)	Water level		Altitude of land surface (feet above MSL)	Type of lift b/	Use of water c/	Discharge		Remarks
		Depth below land surface datum (feet) a/	Date of measurement				Gallons per minute	Date of measurement	
(C-6-4)									
5aba	229	-	-	775	T, E	D	-	-	See table 5.
7bcb	160	159.78	4/17/53	780	None	N	-	-	
29caa	302	-	-	890	C, W	S	-	-	See table 5.
(C-6-5)									
6dad	-	80.26	4/17/53	730	C, G	D, RR	-	-	See table 5.
20aaa	381	242.65	12/17/53	855	T, E	D	-	-	
(C-6-6)									
4aab	161	126.75	5/8/53	730	None	N	-	-	See fig. 5.
8dcd	325	119.26	4/17/53	730	T, E	D	-	-	See table 5.
18dcc	300	88.25	4/17/53	730	T, E	D, S	-	-	See table 5.
(C-7-4)									
3aba	-	275.7	4/17/53	980	J, G	S	-	-	See table 5.
(C-7-5)									
6aab	290	255.14	4/22/53	860	J, G	S	-	-	See table 5.
(C-8-5)									
2bdd	495	407.9	4/22/53	1120	J, G	S	-	-	See table 5.

Table 4.--Logs of selected wells in Gila Bend and Dendora areas, Arizona.

	Thickness (feet)	Depth (feet)
(C-2-5)36cbd		
Silt	30	30
Gravel to 10 inches	32	62
Coarse sand	8	70
Clay and gravel	24	94
Caliche	8	102
Clay and gravel	64	166
Hard clay and gravel	8	174
Loose gravel to 4 inches	10	184
Clay and gravel cemented	2	186
Clay and gravel	22	208
Loose gravel to 3 inches	32	240
Clay and gravel	66	306
Loose gravel	6	312
Clay and gravel	12	324
Granite	21	345
TOTAL DEPTH		345
(C-3-4)4cba		
Top formation	8	8
Clay	32	40
Caliche and gravel	10	50
Clay and gravel	23	73
Gravel and clay	17	90
Gravel	30	120
Gravel	24	144
Clay	4	148
Gravel and hard streaks of sand	26	174
Gravel and small boulders	34	208
Gravel	29	237
Rock (large boulders)	3	240
TOTAL DEPTH		240
(C-3-4)8bab		
Soil	15	15
Gravel, streaks of sandstone	105	120
Water gravel	280	400
Cemented gravel	6	406
TOTAL DEPTH		406
(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 clay	105	275
Sand, clay	55	330
Sand, gravel	13	343
Grey sand	107	450
Hard granite formation	15	465
TOTAL DEPTH		465
(C-3-4)33aba		
Sandy gravel	8	8
Sandy clay	19	27
Gravel	34	61
Gravel #2	59	120
Clay	14	134
Decomposed granite, not loose	466	600
Decomposed granite, [illegible] with loose streaks	200	800
TOTAL DEPTH		800
(C-4-4)4bdd		
Silt soil	3	3
Gravel (dry)	7	10
Clay	2	12
Gravel (dry)	6	18
Clay	2	20
Gravel in clay	8	28
Clay	10	38

Table 4. --Logs of selected wells in Gila Bend and Dendora areas. --continued.

	Thickness (feet)	Depth (feet)
(C-4-4)4bdd (Con.)		
Gravel (first water).....	8	46
Sand	11	57
Gravel Gila (coarse)....	11	68
Gravel granite	16	84
Clay	2	86
Gravel in clay	2	88
Gravel	4	92
Clay	4	96
Gravel	12	108
Clay	8	116
Gravel	12	128
Clay and sand	30	158
Clay	4	162
Sandy clay	11	173
Shell	2	175
Clay and sand mucky ...	15	190
Clay	26	216
[illegible]w of gravel	30	246
Clay	3	249
Gravel in clay..........	17	266
Strata of clay and gravel	18	284
Clay	4	288
Gravel and clay stratas .	15	303
Clay	3	306
Mucky sand............	10	316
TOTAL DEPTH		316
(C-4-4)18aab		
Surface soil............	18	18
Sand and gravel (water) .	20	38
Tight sandy clay	56	94
Tight sand and gravel...	80	174
Gravel and streaks of boulders	76	250
Cemented gravel	10	260
Gravel and boulders	118	378
TOTAL DEPTH		378

	Thickness (feet)	Depth (feet)
(C-4-8)26ddd		
Top soil	3	3
Caliche	3	6
Dry mountain wash	18	24
Clay and caliche mixed with mountain wash.........	12	36
Sand, gravel, and boulders, water at 46 feet	18	54
Cemented sand and gravel	5	59
Dry mountain wash mixed with clay and strata of cemented mountain wash, water bearing	51	110
Mountain wash and loose mountain rock, water bearing...............	34	144
Mountain wash and mountain rock, dry.........	8	152
TOTAL DEPTH		152
(C-5-4)18add		
Sandy silt..............	18	18
Sand	6	24
Sand and gravel with a little clay	6	30
Sand gravel and boulders	24	54
Stratas of clay and sand (from 24-100, water bearing)	46	100
Dry clay................	22	122
Clay and stratas of sand (water)	82	204
Dry clay	6	210
Sandy clay with small gravel (water)	40	250
Dry clay................	10	260
Stratas of clay, pack sand and sand............	20	280

Table 4. --Logs of selected wells in Gila Bend and Dendora areas. --continued.

	Thickness (feet)	Depth (feet)
(C-5-4)18add (Con.)		
Stratas of cemented sand and sand	20	300
Sandy clay	20	320
Stratas of cemented sand, sand and small gravel.	10	330
Stratas of clay and sand	14	344
Sandy clay	66	410
Stratas of dry clay and sandy clay (280-422) same water)	12	422
Stratas of sandy clay and sandstone	18	440
Dry clay	12	452
Sandy clay (water?)	18	470
Clay with small gravel (dry)	31	501
TOTAL DEPTH		501
(C-5-4)19ddd		
Soil	3	3
Silt, gravel, clay	15	18
Sand, small gravel	16	34
Sand, gravel, boulders	6	40
Sand, sandstone, clay	50	90
Strata of sand, clay	74	164
Sand, small gravel with strata of cemented sand	21	185
Strata of sand, gravel, clay, cemented sand	51	236
Dry clay	19	255
Sandy clay with strata of sand rock	71	326
Dry clay	14	340
Strata of clay, sand, cemented sand (water).	42	382
Dry clay	9	391
Strata of clay, sand, sandstone (water)	49	440
Dry clay	11	451
Sand clay with strata of dry clay, some water in sandy clay	49	500
Dry clay with small gravel	20	520
Dry clay	58	578
Strata of sand clay and cemented sand, some water	6	584
Dry clay	46	630
Silty clay, a little water	20	650
Dry clay	6	656
Strata of clay, pack sand, and small gravel, water	34	690
Dry clay	10	700
Strata of sand, gravel, cemented sand gravel	38	738
Strata of clay, sand, gravel, cemented sand, gravel.	20	758
Strata sand gravel, clay with mountain rock	43	801
Mountain wash sand and mountain rock	125	926
TOTAL DEPTH		926
(C-5-4)31cbd1		
Dry gravel	30	30
Clay	20	50
Sand	20	70
Dry gravel	4	74
Cemented gravel	16	90
Sandy clay	150	240
Clay	860	1,100
Shells and mud	25	1,125
Clay and Malapai	15	1,140
Rock	36	1,176
Fine sand	2	1,178
Rock	81	1,259
Clay with gravel	12	1,271
Rock	13	1,284

Table 4. --Logs of selected wells in Gila Bend and Dendora areas. --continued.

	Thickness (feet)	Depth (feet)
(C-5-4)31cbd1 (Con.)		
Clay and gravel	23	1,307
Rock	5	1,312
Clay and gravel	10	1,322
Red rock	9	1,331
Clay and gravel	24	1,355
Light rock	6	1,361
Clay and gravel	32	1,393
Quartz rock	5	1,398
Cemented gravel	18	1,416
Clay	11	1,427
Cemented gravel	18	1,445
Clay	20	1,465
Boulders in clay	9	1,474
Clay and gravel	21	1,495
Boulders and clay	15	1,510
Clay and gravel	20	1,530
Rock	25	1,555
Clay	13	1,568
Hard rock	33	1,601
Clay	11	1,612
Rock	9	1,621
Clay	19	1,640
Rock	7	1,647
Clay	17	1,664
Rock	9	1,673
Clay	8	1,681
Rock	13	1,694
Clay	14	1,708
Rock	6	1,714
Sand carrying water	18	1,732
Clay	8	1,740
Rock	12	1,752
TOTAL DEPTH		1,752

Table 5.--Analyses of water from selected wells in Gila Bend and Dendora areas, Arizona.
(Parts per million except specific conductance and percent sodium.)

Well no.	Date of collection	Depth of well (feet)	Temperature (°F.)	Specific conductance (micromhos at 25° C.)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids	Total hardness as $CaCO_3$	Percent sodium
(C-3-4)																	
4baa	5/6/53	250	89	2950	29	92	7.4	524	134	180	770	4.0	5.8	1.2	1,680	260	81
8bab	5/8/53	406	78	2140	30	105	38	293	200	124	515	.8	2.7	.28	1,230	418	60
22ddd	4/1/52	465	83	2500	25	76	6.3	444	128	179	615	4.4	14	-	1,430	216	82
33aba	5/27/46	800	78	2200	-	92	21	346	240	157	495	2.0	4.9	-	1,240	316	70
(C-4-4)																	
4bdd	4/24/53	316	75	6200	29	351	112	865	273	553	1,700	.7	23	2.2	3,770	1,340	58
15bbb	4/23/53	385	-	2160	23	112	27	298	202	116	530	.6	4.6	-	1,210	390	62
(C-4-6)																	
27bdb	7/24/53	-	83	2210	34	139	16	289	143	150	535	3.2	6.7	-	1,240	413	60
31cdd	4/15/53	600	76	3350	37	52	21	643	152	305	822	3.0	5.9	2.3	1,960	216	87
36adc	4/16/53	960	83	2440	29	116	22	358	150	142	618	3.2	8.8	-	1,370	380	67
(C-4-7)																	
34ddc	4/15/53	1000	84	1880	-	-	-	-	75	-	470	-	-	-	-	-	-
(C-4-8)																	
26ddd	4/11/46	152	95	2530	-	74	12	442	94	225	615	5.1	4.1	1.4	1,420	234	-
34ddd	4/11/46	100	79	5020	-	159	23	936	177	601	1,220	6.8	21	-	3,050	401	-
(C-5-3)																	
8bbc	4/23/53	297	89	2360	21	67	6.1	418	90	165	595	5.0	4.5	-	1,330	192	83

Table 5. --Analyses of water from selected wells in Gila Bend and Dendora areas--continued.

Well no.	Date of collection	Depth of well (feet)	Temperature (°F.)	Specific conductance (micromhos at 29° C.)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids	Total hardness as $CaCO_3$	Percent sodium
(C-5-4)																	
8dbd	4/23/53	135	78	6860	37	307	82	1,110	327	575	1,820	2.5	82	3.2	4,180	1,100	69
18add	7/3/53	501	79	1690	24	30	3.5	316	132	100	392	4.0	2.2	-	937	90	88
19ddd	4/23/53	926	82	2390	28	65	6.3	423	106	155	600	4.0	1.7	1.2	1,310	188	83
31cbd1	4/17/53	1752	119	1910	-	-	-	-	42	-	475	-	-	-	-	-	-
(C-5-5)																	
18dcb	4/16/53	945	80	4830	35	192	63	767	172	356	1,320	3.1	30	2.0	2,850	738	69
24bba	4/17/53	650	-	2130	26	114	40	268	238	136	484	.6	14	-	1,200	449	56
(C-5-6)																	
2dba	4/10/46	418	76	1680	-	50	9.4	293	191	92	382	2.6	2.9	-	926	164	80
11dcb	7/24/53	440	80	1820	36	42	5.7	327	162	98	422	3.0	2.8	-	1,020	128	85
13add	9/11/52	280	76	5680	37	296	90	811	257	399	1,580	1.9	16	-	3,360	1,110	61
(C-5-7)																	
1aaa	4/16/53	700	88	2290	36	38	13	427	124	142	580	3.2	1.5	.75	1,300	148	86
(C-6-4)																	
5aba	4/14/53	229	82	2380	-	-	-	-	82	-	620	-	-	-	-	-	-
29caa	4/17/53	302	87	2110	34	62	14	364	126	164	500	4.0	18	1.0	1,220	212	79
(C-6-5)																	
6dad	4/17/53	-	-	1170	35	25	4.8	211	79	153	208	7.0	5.2	1.8	688	82	85

Table 5.--Analyses of water from selected wells in Gila Bend and Dendora areas--continued.

Well no.	Date of collection	Depth of well (feet)	Temperature (°F.)	Specific conductance (micromhos at 25° C.)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids	Total hardness as $CaCO_3$	Percent sodium
(C-6-6)																	
8dcd	4/17/53	325	78	2400	-	-	-	-	60	-	558	-	-	-	-	-	-
18dcc	4/17/53	300	77	2090	-	-	-	-	85	-	492	-	-	-	-	-	-
(C-7-4)																	
3aba	4/17/53	-	88	2230	35	63	7.0	392	62	225	520	5.0	8.2	-	1,290	186	82
(C-7-5)																	
6aab	1/31/46	290	80	1200	-	23	4.4	227	107	124	236	6.9	2.0	1.84	676	76	-
(C-8-5)																	
2bdd	4/22/53	495	80	880	40	48	24	108	260	105	72	.6	35	-	561	218	52

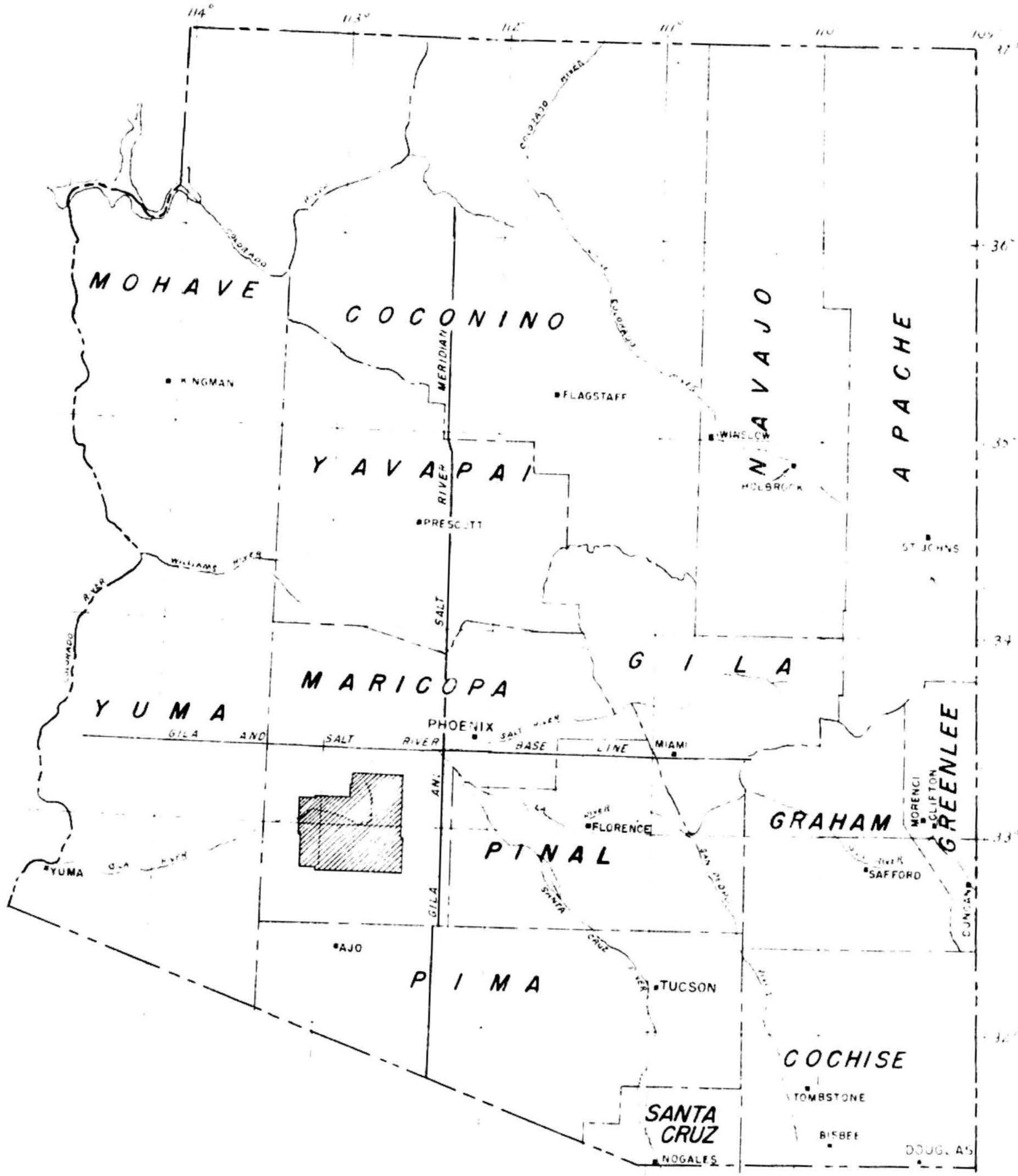

Figure 1. - Map of Arizona showing location of area investigated.

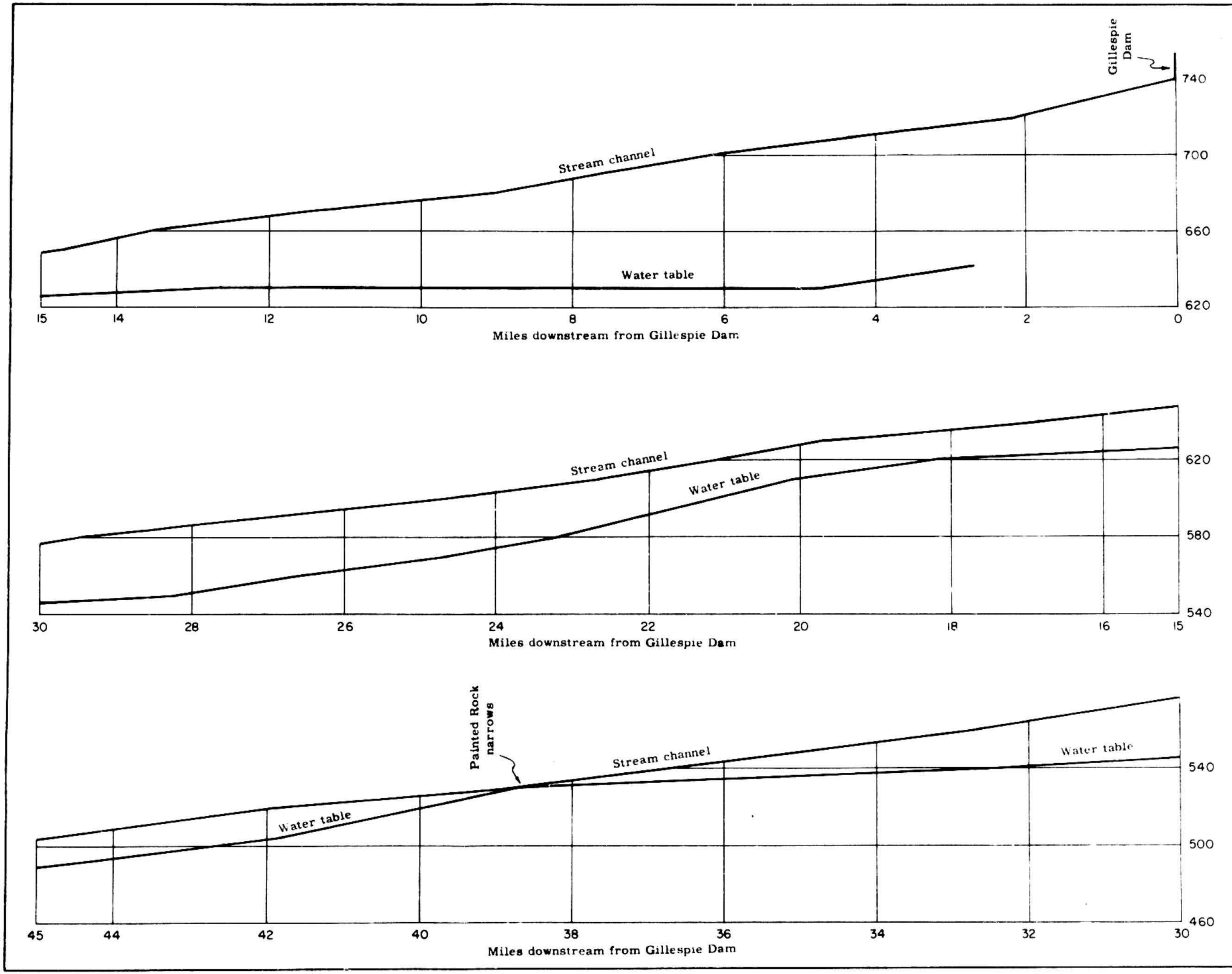

Figure 2. -Profile of Gila River channel and of mean position of water table beneath river-bottom lands, from Gillespie Dam to 6 miles downstream from Painted Rock narrows.

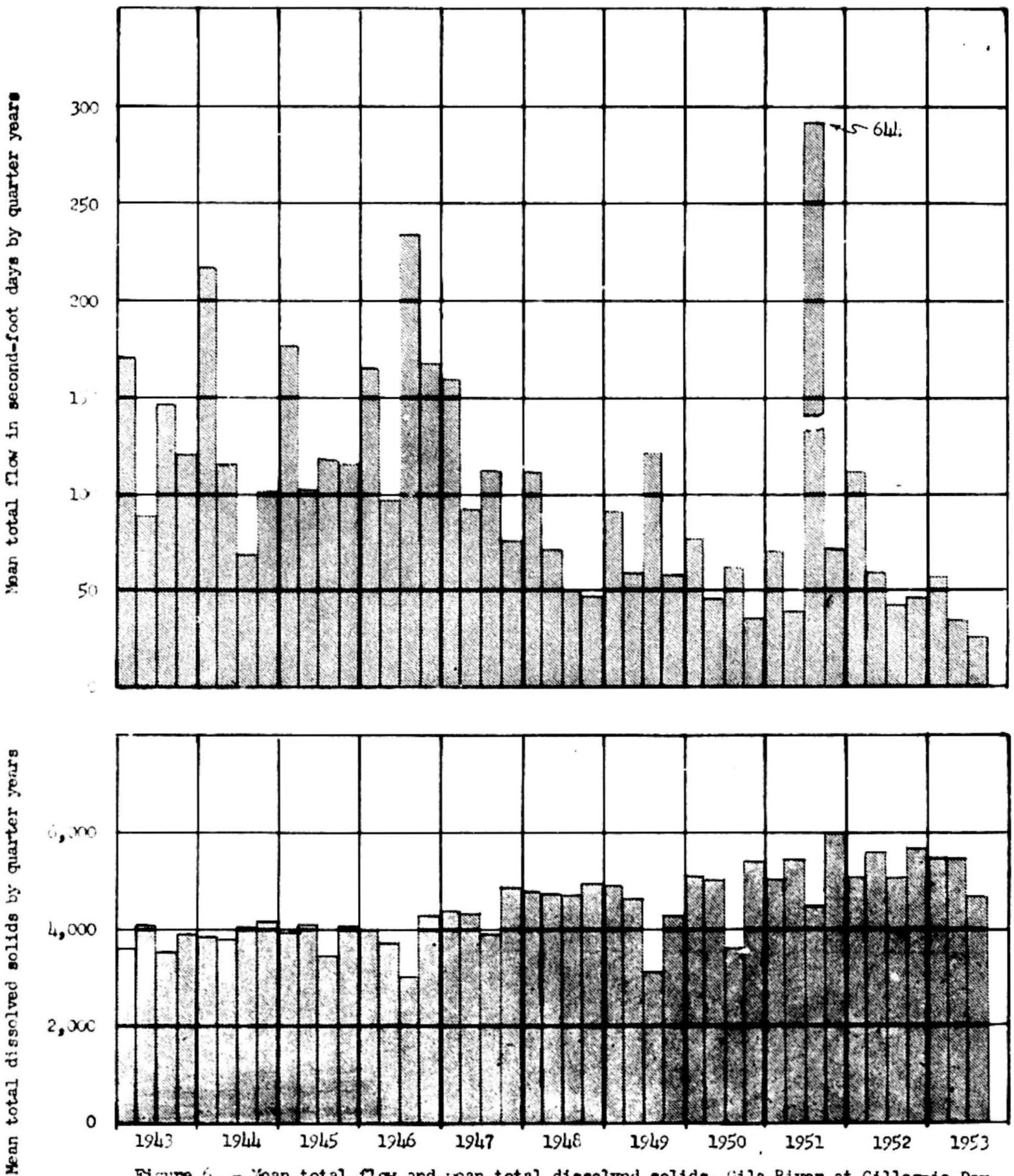

Figure 6. - Mean total flow and mean total dissolved solids, Gila River at Gillespie Dam.