Water Regimen of the Inner Valley of the San Pedro River Near Mammoth, Arizona (A Pilot Study)

By HARRY G. PAGE

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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By Harry G. Page

ABSTRACT

A small area along the San Pedro River near Mammoth, Pinal County, Ariz., was selected as the site of a preliminary investigation of the water regimen of the inner valley of an intermittent stream in a semiarid basin. Three principal alluvial units are exposed, and the study evaluates the feasibility of determining quantitatively their interrelations with respect to ground-water recharge and discharge and their combined relation to streamflow. Qualitatively, the regimen in the reach studied involves loss in streamflow, changes in ground-water storage, discharge by pumping and evapotranspiration, and movement of ground water between the alluvial units. The annual cycle of events is generally reflected in water-table fluctuations and is controlled largely by the seasonal streamflow, precipitation, irrigation, and evapotranspiration. Long-term records of water-table fluctuations indicate very little decline of the water table in the area near the river. Quantitative evaluation of the regimen will involve measurement of the hydrologic factors to an accuracy within the magnitude of the amount of annual recharge. The hydrologic factors to be measured include those mentioned above and, in addition, recharge from irrigation and precipitation.

INTRODUCTION

On behalf of the Bureau of Indian Affairs, San Carlos Irrigation Project, an investigation was made of a small area along the San Pedro River near Mammoth, Pinal County, Ariz., primarily to determine whether transpiration by vegetation and pumping from wells near the San Pedro River affected the volume of surface flow in the river and whether further study could prove quantitatively what these effects might be. To satisfy these purposes, the study attempted to determine the influence of various geohydrologic factors on ground-water recharge and discharge, stream discharge, and the nature of water movement between different alluvial units.

The area discussed in this report was selected for investigation because it is typcial of many southern Arizona valleys containing superposed alluvial units of different water-bearing characteristics and wells tapping aquifers to supply water for irrigation, stock, domestic, and industrial uses along the San Pedro River. One factor of special interest in the description of the water regimen is whether the flow of water between the aquifers is free or restricted. If the flow is free, the ground-water reservoir supplying pumping wells would be relatively large; whereas, if the flow is restricted, the size of the reservoir would be much smaller, and the demand upon streamflow to replenish the adjoining reservoirs being pumped would be greater. The intermittent northward flow of the river contributes to irrigation downstream.

The investigation was started in the spring of 1958 and was continued until the spring of 1959; it was under the immediate supervision of J. W. Harshbarger, L. A. Heindl, and P. E. Dennis.

The investigation was not intended to be an exhaustive study of the water of the area. Many of the computations are made necessarily on conjecture and are pending collection of corroborative data beyond the scope of the present work. Also, much work involving the tests and data collection that would be required to fulfill quantitative aspects of the problem was omitted from the study.

GEOGRAPHY

The area studied—referred to in this report as the Mammoth area—is about 40 miles north-northeast of Tucson by State Highways 789 and 77. It is about 2 miles wide by 15 miles long and includes the San Pedro River from about 5 miles north to about 10 miles south of Mammoth, Ariz. (fig. 1). Much of the area is river bottom land. The meandering river channel averages about 800 feet in width, and the flood plain extends about half a mile on either side of the river channel. The channel banks range in height from 2 to 75 feet and are cut in various units of Pleistocene and Recent alluvial deposits.

The climate is semiarid; most of the annual precipitation of about 14 inches occurs in February and August largely as heavy rainfall. The average monthly temperature ranges from about 46°F in December and January to about 86°F in July and August; the daily temperature is seldom much below freezing in winter and is frequently as high as 105°F in summer. The evaporation rate is high, ranging from about 14 inches per month in summer to 4 inches per month in winter, as measured in a U.S. Weather Bureau class A land pan.

Native vegetation consists primarily of heavy growths of mesquite on the flood plain and scattered creosote bush on the adjacent terraces.

Other native plants include tamarisk (saltcedar), baccharis, cottonwood, and several types of cactuses.

The town of Mammoth was settled in 1881 as a copper-mining camp, and a post office was established in 1895 (Barnes, 1935, p. 262). The early settlers were mostly miners, farmers, and ranchers; the present residents, numbering about 2,000, still follow these occupations.

The San Manuel copper mine, about 3 miles southwest of Mammoth, is the nearest large mine; small manganese and gypsum mines operate a few miles to the north, and one diatomite plant is currently in operation in the southern part of the area.

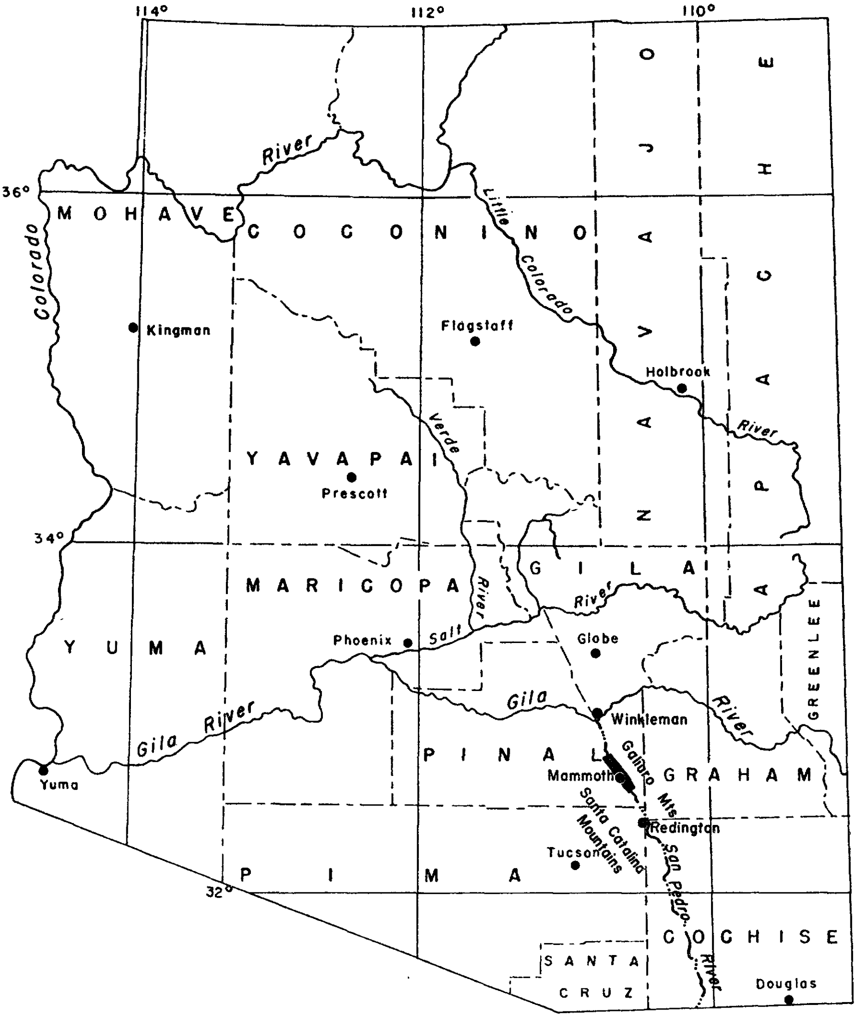

FIGURE 1.—Map of Arizona showing Mammoth area.

About 2,500 acres of the river flood plain is under cultivation. Cotton and alfalfa are the main crops, but small acreages of barley constitute a secondary crop. Currently, as many as 1,500 head of cattle may graze in the area.

ACKNOWLEDGMENTS

The writer is indebted to Mr. Marvin Young and other personnel of the Bureau of Indian Affairs, San Carlos Irrigation Project, for their assistance in nearly all phases of the study and to the farmers, ranchers, and townspeople of the Mammoth area who gave their kind permission to gather well data on their properties. Appreciation is especially extended to Mr. F. E. Mauldin and to the San Manuel Copper Corp. and its personnel for permission to drill and maintain observation wells on their properties.

PREVIOUS STUDIES

The most extensive investigations previously made in the immediate area of this study are those dealing with the Cenozoic geology in the vicinity of Mammoth (Heindl, 1963) and with the ground water in the lower San Pedro River basin (Heindl, 1952). Other investigations bearing on this study include work dealing with the geographic cycles of the San Pedro Valley (Bryan, 1926), a study of fossils of the San Pedro Valley (Gidley, 1922), and geologic mapping near Mammoth (Peterson, 1938) and of the San Pedro and Aravaipa Valleys by Creasey and others (1961).

Hydrologic investigations by several authors were helpful in evaluating water conditions in the Mammoth area. These included Rosenshein (1959), Robinson (1958), Gatewood and others (1950), and Theis (1941).

METHODS OF STUDY

The geologic map of the area (pl. 1) was compiled primarily from the work of L. A. Heindl with minor revisions by the writer. Topographic maps on the scale of 1:24,000 and Soil Conservation Service aerial photographs taken in 1935 also were used. Drillers' logs, well cuttings, and outcrop samples were studied for geologic correlation and for estimating hydrologic properties.

The study was begun with a reconnaissance of the area, a complete well inventory, and the selection of 30 wells for monthly water-level observations. Altitudes at nearly all wells were surveyed by San Carlos Irrigation Project personnel. Fluctuations of the water table were determined by study of water-level records of previous years and by periodic measurement of water levels during this investigation. Most of the water levels were measured with a steel tape; however, three of the observation wells were equipped with recording gages.

Six test wells were constructed for this study by San Carlos Irrigation Project personnel. Cuttings from these wells were examined for lithologic and hydrologic information, and water levels in the wells were observed throughout the study. Depths of the wells ranged from about 30 to 100 feet, and each well penetrated at least 20 feet of the water-bearing zone.

WELL-NUMBERING SYSTEM

The well numbers used in this report follow the system used by the U.S. Geological Survey in Arizona and are in accordance with the Bureau of Land Management's System of land subdivision. The land survey in Arizona is based on the Gila and Salt River meridian and base line, which divide the State into four quadrants (fig. 2). These quadrants are designated counterclockwise by the capital letters A, B, C, and D. All land north and east of the point of origin is in A quadrant, that north and west in B quadrant, that south and west in C quadrant, and that south and east in D quadrant; the D quadrant encompasses all the Mammoth area. The first digit of a well number indicates the township, the second the range, and the third the section in which the well is situated. The lowercase letters a, b, c, and d after the section number indicate the well location within the section. The first letter denotes a particular 160-acre tract (fig. 2), the second the 40-acre tract, and the third the 10-acre tract. These letters also are assigned in a counterclockwise direction, beginning in the northeast quarter. If the location is known within a 10-acre tract, three lowercase letters are shown in the well number. In the example shown, well No. (D–4–5)19caa designates the well as being in the NE¼NE¼ SW¼ sec. 19, T. 4 S., R. 5 E. Where more than one well is within a 10-acre tract, consecutive numbers beginning with 1 are added as suffixes.

GEOLOGY

The San Pedro River Valley in the area of this report is a northwest-trending structural depression lying between the Galiuro Mountains on the east and the Santa Catalina Mountains on the west. It forms a small part of the Basin and Range physiographic province. Only late Tertiary to Recent sedimentary rocks crop out in the area mapped (pl. 1), although several other units are recognized within a few miles of the area under study. A brief description of the rock units of the area follows; for a more detailed discussion of the geology see Heindl (1952, 1963). The following descriptions are adapted from Heindl (1963).

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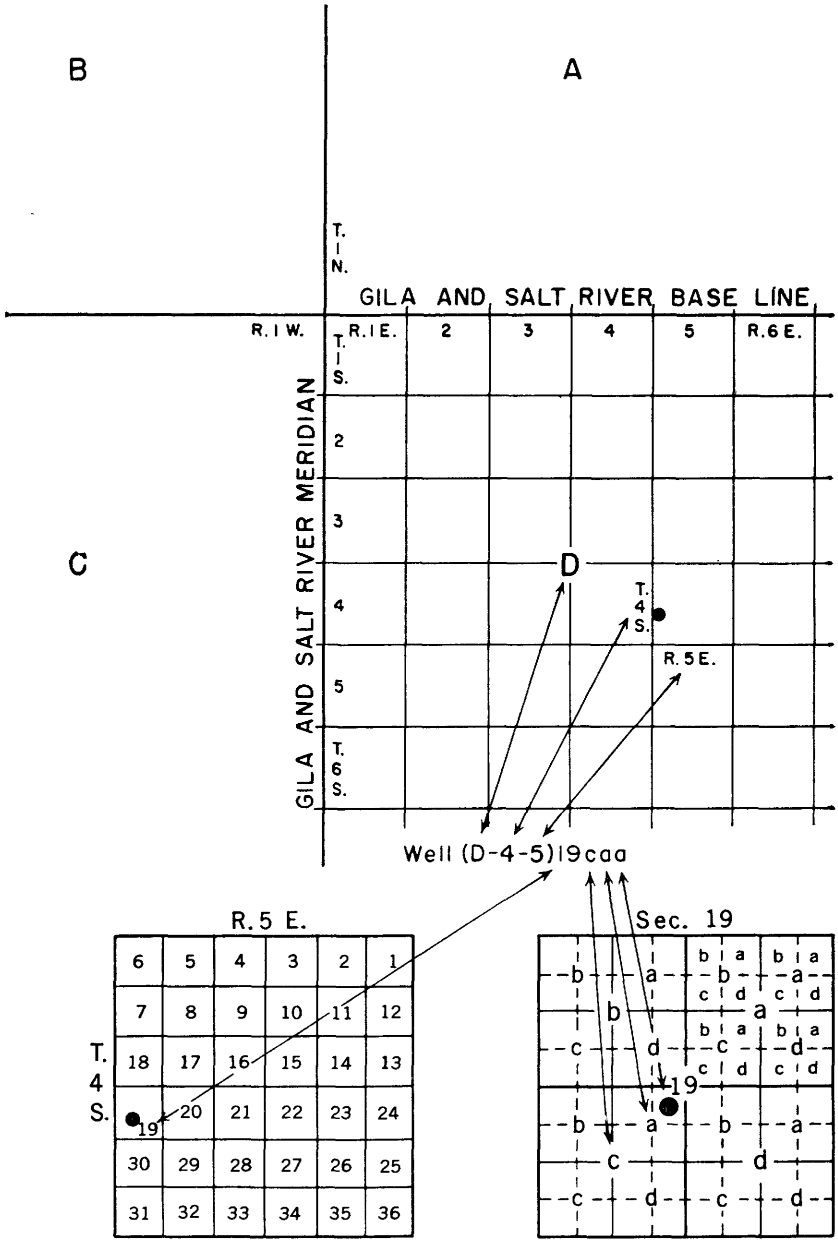

FIGURE 2.—Sketch showing well-numbering system in Arizona.

The mountain blocks and the crystalline basement are composed largely of quartz monzonite, commonly called the Oracle Granite (Peterson, 1938, p. 8). The rocks overlying the granite have been divided by Heindl (1963) into two volcanic and seven sedimentary units, ranging in age from Late Cretaceous(?) to Recent, as shown in the following tabulation:

- Pleistocene and Recent alluvial deposits (Quaternary)
- Gila Group (Tertiary and Quaternary)
  - Sacaton Formation (Pleistocene)
  - Quiburis Formation (Pliocene and Pleistocene)
  - San Manuel Formation (middle? Tertiary)
    - Tucson Wash Member
    - Kannally Member
    - Local conglomerate member
- Volcanic rocks (middle? Tertiary)
- Cloudburst Formation (Late Cretaceous(?) and Tertiary)
  - Fanglomerate unit
  - Volcanic unit
- Quartz monzonite (Precambrian)

All units except the volcanic unit of the Cloudburst Formation and the Pleistocene and Recent alluvial deposits have been included in the Gila Conglomerate at one time or another by several authors.

The Quiburis Formation of the Gila Group is the oldest formation exposed in the area of the present study (pl. 1). It consists of fine-grained lake and playa deposits that grade laterally into and are overlain by conglomerate. The lower beds, interpreted as lake and playa deposits, consist of laminated pinkish-light-tan mudstone, sandy mudstone containing small pebbles, and interbedded gypsiferous, tuffaceous, pumiceous, and diatomaceous beds. These fine-grained deposits abruptly grade outward to the east and west into pebbly sandstone and sandy conglomerate. The lower lake beds are overlain by pebble and boulder conglomerate containing channel-type cross-bedding. The fragments in the Quiburis Formation include basic and acidic flow rocks, tuff, intrusive rocks, and epidotized volcanic conglomerate and schist. The beds of the Quiburis Formation form a shallow syncline whose axis lies parallel to and about 2 miles east of the present river channel. The beds rarely have dips in excess of 5°. Drillers' logs indicate that this unit is at least 1,100 feet thick in the center of the valley underlying the flood-plain deposits. The age of the Quiburis is considered to be Pliocene and Pleistocene. This unit serves as an important artesian aquifer in the Mammoth area. Flowing wells tapping Quiburis deposits at depths greater than 500 feet indicate a very effective confining bed at that horizon; however, passageways afforded by unsealed wells and probably by fractures allow some interflow of water between artesian and water-table aquifers.

The rocks overlying the Quiburis Formation are referred to as the Sacaton Formation of the Gila Group. The deposits consist predominantly of poorly consolidated sand and gravel and a basal conglomerate, as much as 20 feet thick, which is discontinuous between channel fillings. The mineral and rock-fragment composition reflect the rock composition of the flanking mountains. The Sacaton Formation is considered to be a distinct unit, because it was deposited only in the central part of the valley on a channeled surface of the Quiburis Formation from 30 to 50 feet above the present San Pedro flood plain; in turn, it was dissected by erosion before deposition of the Pleistocene and Recent alluvial deposits. The unit is as much as 250 feet thick near the center of the valley. Its age is considered tentatively as Pleistocene. The unit is not known to yield water to wells in the Mammoth area.

The Pleistocene and Recent alluvial deposits along the inner valley of the San Pedro River and its tributaries consist of flood-plain, channel-fill, and terrace deposits. Terrace deposits, ranging from silty sandstone to silty boulder conglomerate, are composed of a wide variety of materials and stand 10 to 30 feet above the surface of the present riverbed. The flood plain, standing 2 to 10 feet above the riverbed, is underlain by a few feet of sandy silt and mudstone that overlie sand and gravel deposits, which extend to depths of 80 feet. Below the flood-plain deposits are gypsiferous beds of the Quiburis Formation. The riverbed is floored with unconsolidated sand and gravel and locally with small areas of mudstone. These Pleistocene and Recent alluvial deposits serve as the water-table reservoir in the Mammoth area.

The structure of the area is characterized by a northwest-trending system of faults that have offset all except the Pleistocene and Recent alluvial deposits and the Sacaton Formation in the valley. The most prominent ones are the San Manuel, Cholla, and Copper Creek faults. All these major faults are outside the area discussed in this report. The San Manuel fault (Steele and Rubly, 1947), a thrust fault which has offset rocks as young as the San Manuel Formation, strikes generally northwestward through the San Manuel mine area on the west side of the valley and dips 20° to 30° SW. The Cholla fault (Schwartz, 1953), a normal fault roughly parallel to and a short distance east of the San Manuel fault in most of that area, dips steeply to the northeast and offsets rocks as young as the Quiburis Formation. The Copper Creek fault (Davis and Brooks, 1930), also a normal fault, dips steeply to the west and trends roughly north-northwestward several miles east of the river channel. By comparison of drillers' logs (table 1), at least two other major faults in the system are indicated within a mile west and 4 miles east of the river channel; the faults dropped the central part of the valley at least several hundred feet. Other, less well-defined fault zones are poorly exposed, and these appear to fit into the system mentioned previously.

Table 1.—*Drillers' logs of selected wells in the Mammoth area, Pinal County, Ariz.*

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
(D-8-17)29dda [Surface elevation: 2,382 ft]					
Sand and clay	22	22	Boulders, water	10	80
Water sand	48	70	Reddish clay	20	100
(D-8-17)32daa [Surface elevation: approximately 2,385 ft]					
Sand and gravel	80	80	Sticky brown shale (show oil)	5	1,040
Sand	5	85	Red clay and gravel	65	1,105
Sand and boulders	55	140	Gypsum	5	1,110
Sand	20	160	Red clay and gravel	25	1,135
Gravel	45	205	Brown lime	9	1,144
Hard sand	15	220	Red clay and gravel	16	1,160
Gravel	65	285	Hard sand (small amount water)	35	1,195
Sand	30	315	Red clay	2	1,197
Sand and boulders	136	451	Hard brown sand	8	1,205
Sand	144	595	Hard gray lime	15	1,220
Sand and gravel	10	605	Conglomerate with lime	37	1,257
Gravel	20	625	Red clay	8	1,265
Sand and gravel	35	660	Hard conglomerate	2	1,267
Running gravel	5	665	Red clay	8	1,275
Sand	80	745	Sandstone (artesian water—20 gpm)	95	1,370
Clay and gravel	10	755	Hard sandstone	70	1,440
Sand and clay	10	765	Red beds	45	1,485
Red clay and gravel	240	1005			
Brown shale with sand	10	1015			
Red clay and gravel	15	1030			
Sticky black clay (show oil)	5	1035			
(D-9-17)25aab [Surface elevation: 2,553 ft]					
River gravel	45	45	Sandy clay	60	540
River sand	26	71	Clay	20	560
Sandy gypsum	33	104	Sandy clay	60	620
Solid gypsum beds	56	160	Sand with clay nodules	40	660
Clay seams and gypsum beds	160	320	Sand and gravel	20	680
Sandy gypsum; water at 325 ft, not artesian	40	360	Artesian water-bearing sand and fine gravel	120	800
Gypsum beds and clay seams	120	480	Heavy clay, boulders; hole stopped at 870 ft	70	870

TABLE 1.—*Drillers' logs of selected wells in the Mammoth area, Pinal County, Ariz.*—Continued

(D-9-17)25bdd

[Surface elevation: 2,539 ft]

	Thickness (feet)	Depth (feet)
River sand and silt	20	20
River gravel	60	80
Heavy clay and a little gravel	240	320
Sandy clay	140	460
Sandy gypsum	20	480
Gypsum sand; water at 487 ft, not artesian	120	600
Clay and sand	28	628
Artesian water-bearing coarse sand	12	640
Fine sand	60	700
Coarse sand, few clay seams	120	820
Sand and gravel	40	860
Sand and clay seams. Flow of water increased steadily from 628 to 864 ft. No increase below 864 ft	95	955
Hard clay	10	965
Running sand but no increase in water flow. Hole stopped at 967 ft	2	967

HYDROLOGY

SURFACE WATER

During 1958, streamflow at Mammoth was highest in February, March, and June through September. The maximum observed flow occurred about September 12, and moderately high flows were noted in March and August. The nearest stream-gaging station on the San Pedro River is at Redington, 25 miles upstream from Mammoth. However, because of considerable evaporation and seepage losses and the many tributary washes between Redington and Mammoth, the Redington flow records are a poor indication, at best, of the flow in the area under study. For example, the highest flows at the Redington gage occurred on August 6 and 17 but were not observed at Mammoth; and the highest flow observed at Mammoth, September 12, could be related only vaguely to a moderate flow indicated at Redington on September 2. The high flows at Mammoth appear more closely related to local precipitation than to river discharge measured 25 miles upstream. Two stream-gaging stations on the Gila River—one near Winkleman, 2 miles upstream, and the other 17 miles downstream from the mouth of the San Pedro River, 13 miles north of the Mammoth area—give some indication of the outflow of the San Pedro River. Again, however, too many factors affect the flow between the Mammoth area and the mouth of the river to use that outflow figure for the area under study.

From 1931 to 1941, a period during which a stream-gaging station was operated at Mammoth, the highest riverflows consistently occurred during July and August. Moderate flows occurred during the winter in 2 of the 10 years of record—1932 and 1941—according to the U.S. Geological Survey (1954, p. 644). During the period 1943 to 1958, the Redington gage recorded highest flows during July and August, but it recorded only very low flows during the winter (table 2). In 1958, the year of this study, the whole San Pedro River basin had the third greatest streamflow since 1926; almost 83,000 acre-feet passed the Redington gage, and about 60,000 acre-feet entered the Gila River from the San Pedro River. Greater flows were recorded only in 1954 and 1955, when about 93,000 and 120,000 acre-feet, respectively, entered the Gila River from the San Pedro River.

TABLE 2.—*Flow, in thousands of acre-feet, of San Pedro River near Mammoth and at Redington, Ariz.*

[Compiled from U.S. Geol. Survey Water-Supply Papers 1213, 1243, 1283, 1313, 1343, 1393, and 1443 and from open-file records]

Water year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Total
Charleston [1]													
1926	0.6	1.3	1.0	1.2	0.9	1.0	0.9	0.4	0.1	1.6	1.6	112.3	122.8
Mammoth													
1931	------	------	------	------	------	------	------	------	0.7	2.3	57.3	18.2	------
1932	12.2	4.2	6.6	7.2	8.8	3.3	0.5	------	------	11.9	11.2	Tr.	65.9
1933	------	------	.4	1.0	.8	1.1	------	------	------	6.1	2.1	4.6	15.0
1934	2.6	.1	.2	.1	Tr.	Tr.	------	------	------	2.9	18.0	.9	24.9
1935	------	Tr.	.3	1.7	1.9	1.2	------	------	------	.1	29.2	10.6	45.0
1936	.2	1.8	3.2	.9	2.9	.1	------	------	.3	4.1	14.9	9.7	38.0
1937	Tr.	.2	.5	1.0	4.5	.1	------	------	Tr.	1.2	42.3	13.2	63.0
1938	.5	------	.3	Tr.	Tr.	1.2	------	------	.4	7.0	14.5	7.1	31.1
1939	------	------	.6	Tr.	.1	------	1.0	------	------	7.5	39.0	7.4	55.5
1940	1.6	Tr.	.1	Tr.	.7	------	------	------	.6	6.1	51.9	2.5	63.5
1941	.4	.3	11.4	8.5	6.9	6.9	.9	0.2	------	------	------	------	------
Redington													
1943	------	------	------	------	------	------	------	------	6.0	5.7	29.3	0.8	------
1944	0.1	0.1	0.1	0.1	Tr.	0.1	0.1	Tr.	------	3.7	12.6	6.4	23.2
1945	.5	.2	.4	.4	0.2	.1	.1	Tr.	Tr.	4.6	35.1	.1	41.7
1946	.7	Tr.	Tr.	.1	Tr.	Tr.	Tr.	------	------	5.6	18.3	1.8	26.8
1947	.2	.1	.1	.1	.1	.1	.1	Tr.	------	------	(?)	------	------
1948	------	------	------	------	------	------	------	------	------	------	(?)	------	------
1949	------	------	------	------	------	------	------	------	------	------	(?)	------	------
1950	------	------	------	------	------	------	------	------	------	32.7	2.9	Tr.	------
1951	------	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	------	1.8	12.5	.1	14.5
1952	.2	.1	.3	.3	Tr.	1.2	.1	Tr.	.7	4.3	12.9	.5	20.7
1953	.1	.1	.1	.1	.1	.1	.1	Tr.	Tr.	16.8	.8	Tr.	18.4
1954	------	Tr.	Tr.	Tr.	Tr.	.8	Tr.	------	Tr.	12.2	53.0	1.6	67.6
1955	.4	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	------	------	38.2	90.9	.3	129.9
1956	1.3	Tr.	Tr.	.1	Tr.	Tr.	Tr.	Tr.	------	7.9	1.4	Tr.	10.9
1957	Tr.	Tr.	Tr.	1.2	------	------	------	------	------	3.8	10.5	1.3	16.9
1958	.2	Tr.	Tr.	Tr.	Tr.	.8	.1	Tr.	Tr.	11.6	48.2	21.8	82.8

[1] No records available for 1926 for Mammoth or Redington station. Charleston is located 60 miles upstream from Redington.

Major losses from streamflow occur in the Mammoth area by evaporation from the river surface and by seepage into the alluvial fill of the valley. For the period of this study, evaporation was greatest during June—a total of 15.66 inches in 1958 and 15.74 inches in 1959. This was total evaporation measured from a U.S. Weather Bureau class A land pan at the P Z Ranch weather station, about 4 miles north of the Mammoth area (table 3). The least monthly evaporation measured during this study was 3.70 inches for January 1958. Seepage losses (ground-water recharge) and pumping from wells, which affects streamflow, as described by Theis (1941), account for additional major losses of streamflow. According to Gatewood and others (1950, p. 57) about 30 percent of the streamflow may infiltrate to the water table through channel seepage, and from the method of Theis (1941) it seems safe to estimate that about half the water pumped from most wells in the Mammoth area is probably contributed directly by the stream while it is flowing.

TABLE 3.—*Precipitation, evaporation, and average temperature at P Z Ranch, 4 miles north of the Mammoth area*

[U.S. Weather Bureau, 1958, 1959]

Year and month	Precipitation (inches)	Evaporation (inches)	Average temperature (°F)
1958			
Jan	0	3. 70	46. 0
Feb	2. 04	[1] 4. 0	52. 8
Mar	2. 69	4. 45	52. 0
Apr	. 93	9. 10	61. 2
May	Tr.	14. 90	75. 9
June	. 57	15. 66	83. 8
July	2. 68	14. 87	86. 0
Aug	. 53	12. 50	85. 8
Sept	2. 42	8. 78	79. 2
Oct	1. 50	6. 96	68. 8
Nov	1. 20	4. 83	55. 0
Dec	0	4. 02	50. 4
Total	14. 56	103. 77	
1959			
Jan	0. 12	4. 28	49. 8
Feb	1. 14	4. 16	49. 8
Mar	0	9. 15	57. 1
Apr	. 42	11. 44	68. 2
May	0	15. 47	71. 6
June	. 03	15. 74	85. 5

[1] Estimated.

GROUND WATER

WELL INVENTORY AND RECORDS

In the report area, 108 wells were inventoried of which 30 were used for regular water-level observations during the period of study. Included in these 108 wells are 14 irrigation, 38 domestic and stock, 9 public-supply, 6 industrial, 33 unused, and 8 flowing wells (table 4). Records of some value are available for 12 additional wells which have been destroyed and for 2 springs which flowed as recently as 1951 but which were dry during the present study. The wells are rather uniformly scattered along the riverbanks over the 15-mile stretch of the area, except for heavier concentrations in the vicinity of Mammoth and at the south end of the area in the artesian well field (pl. 1).

Water-level records for most of the wells in the area include no more than 5 years preceding this study, but several measurements are on record from 1948 and a few from 1921. All these were occasional measurements and reported water levels that were not observed regularly enough to be very useful in this study.

Drillers' logs for 28 wells in the area are available. Four of these wells are more than 1,000 feet deep, 16 between 100 and 1,000 feet, and 8 less than 100 feet. Representative logs are included in table 1 of this report.

TABLE 4.—*Use of wells in and near the Mammoth area, Pinal County, Ariz.*

Use	Observation	Other	Total
Irrigation	5	9	14
Domestic and stock	6	32	38
Public supply	2	7	9
Industrial	1	5	6
Unused	12	21	33
Flowing (industrial, irrigation, and unused)	[1] 4	4	8
Total	30	78	108
Destroyed			12
Springs (dry)			2

[1] Two intermittent.

GROUND-WATER OCCURRENCE AND FLUCTUATIONS

Ground water is obtained from the Quiburis Formation and the Pleistocene and Recent alluvial deposits in quantities and of quality sufficient to satisfy present domestic and irrigation demands in the central part of the valley. Wells penetrating the Quiburis Formation at depths of 500 feet and more in most of the area adjoining the river channel flow at the surface. Drillers' logs of wells and the temperatures and chemical quality of the artesian water indicate that the major artesian aquifers are sand and gravel lenses in the Quiburis Formation that lie at depths of about 600 to 800 feet and 1,200 to 1,300 feet (Heindl, 1952, p. 89). No wells have been drilled to 500 feet in the northern two-thirds of the area. Uncontrolled artesian flow from wells was observed to range from an intermittent trickle from well (D–9–17)23dbc to a constant flow estimated to be about 350 gpm (gallons per minute) from well (D–9–17)24ddc.

The Pleistocene and Recent alluvial deposits locally contribute seepage to the river channel in the greater part of some years. Few wells near the river have water levels more than 50 feet below the land surface. Most domestic and stock wells draw their water from the Pleistocene and Recent alluvial deposits, whereas many of the irrigation and most of the public-supply and industrial wells tap the artesian water of the Quiburis Formation.

During this study, water levels in most of the observation wells rose from 0.2 to more than 7 feet (average rise about 1 foot) during the 5 months immediately after the summer period of streamflow (pl. 2). This period of rise in water level also coincided roughly with a lower evaporation rate and a lower average air temperature and followed the period of heaviest precipitation in the area. A slow rise in the water level in most wells was noted during the period of irrigation—April through July—regardless of the heavy pumping. This rise in water level may be explained by several factors that seem to have influenced ground-water conditions during this study. The unusually heavy precipitation and streamflow apparently caused sufficient recharge to the ground-water reservoir to outweigh the effects of irrigation pumping, which would be lighter during a wetter growing season than during a drier one. Evapotranspiration demands on ground water also would be less during the more humid weather. The water level in several of the wells was higher than it was in 1948. Representative water-level fluctuations are shown in hydrographs of three wells—(D–7–16)35acb, (D–9–17)10dcb, and (D–9–17)23dbc—in plate 2.

GROUND-WATER DISCHARGE

Ground water is discharged from the area by evapotranspiration, underflow, water-table seepage to streamflow, and pumping and artesian flow of wells. Most of the wells in the area pump water for domestic and stock use (table 4); however, the discharge from these wells is probably only a small percentage of that from the irrigation wells.

Transpiration of ground water in the area probably is appreciable because of the heavy growth of plants on the flood plain. Nonbeneficial phreatophytes cover almost all the flood plain except where it is cleared for cultivation. The plants consist primarily of mesquite and smaller amounts of tamarisk, baccharis, and cottonwood. The creosote bush also is prevalent but is not considered to be a phreatophyte. These plants not only use an appreciable amount of water from ground-water storage but also intercept part of the rainfall which otherwise would be available for runoff and ground-water recharge. In addition to plant transpiration, a relatively large amount of water probably is evaporated from the wet stream channel (Gatewood and others, 1950, p. 47). A small amount of ground water is discharged into the stream by effluent streambed seepage after periods of riverflow.

GROUND-WATER RECHARGE

The water table is recharged by direct percolation of precipitation, percolation from riverflow, underflow, and seepage from irrigation water. Surface water infiltrates readily to the subsurface through most of the riverbed and through some of the flood-plain deposits and the Sacaton and Quiburis Formations. Study of a few samples selected at random from the outcrops of these units showed averages of only 15 percent total silt and clay in the Recent channel deposits, 70 percent in the flood-plain deposits, 40 percent in the Sacaton Formation, and 10 percent in the Quiburis Formation. These are by no means representative of the units as a whole but provide some indication of local permeabilities because high silt and clay content restrict movement of ground water. The riverbed through this area has a rather steep gradient, averaging 21.5 feet per mile; the velocity of streamflow, therefore, is sufficient to keep the channel floor relatively free of silt and clay, leaving coarse, permeable deposits to transmit recharge.

Total precipitation in the area was about 14 inches during 1958 (U.S. Weather Bureau). Although much precipitation is lost in the form of evapotranspiration and runoff, an appreciable amount finds its way to the shallow water table. When rainfall is adequate to cause prolonged streamflow, ground-water recharge is sufficient to raise the water table until it contacts the bottom of the river.

GROUND-WATER MOVEMENT

After water infiltrates from the land surface to the zone of saturation, it moves laterally from points of higher head toward points of lower head. The rate of movement is controlled by the permeability of the material through which the water flows and the gradient of the water table. Lateral movement continues until points of artificial (wells) or natural (seeps, springs) discharge are reached.

The configuration of the water table in the Mammoth area is shown in plate 1. Contour lines connect points of equal water-table altitude based on water levels measured in wells penetrating the Pleistocene and Recent alluvial deposits and the Sacaton Formation. Contour lines were not drawn on the piezometric surface of the artesian aquifer because too few points on that surface were available. As shown in plate 1, the water-table gradient approximately reflects, with subdued relief, the land-surface gradient.

The water-table gradient steepens in two places near Mammoth—one at the southeast end of the area and the second near Mammoth. Steepened water-table gradients, indicated by closely spaced contours, may be explained by changes in permeability, changes in thickness of saturated sediments, and recharge. Both of the areas are near major washes, which may contribute ground-water recharge from underflow in the channel deposits; however, no comparable steepening is evident near other large washes, such as Cronley and Zapata. Available data are insufficient to determine whether the saturated sediments changed significantly in thickness in these reaches of the San Pedro River.

The steepened water-table gradient near the southeast end of the area may be caused by leakage of artesian water into the water-table reservoir, as is indicated by anomalous temperature measurements and chemical-quality analyses of water from water-table wells near deep artesian wells (Heindl, 1952, p. 89).

In the area near Mammoth, the steepened gradient reflects the difference in permeability of the Sacaton Formation and the Pleistocene and Recent alluvial deposits.

Local differences in water levels in the area discussed in this report also may reflect significant differences in the amount of water pumped. Particularly in the Mammoth area, the wells are predominantly domestic, and the volume of water pumped is small compared to the pumpage for irrigation in areas immediately upstream and downstream.

The apparent curving of the contour lines upstream on the east side of the river and downstream on the west side indicates that ground water flows into the stream area from the west and away from the stream area toward the east. Additional water-level observations on either side of the river would be necessary to delineate accurately the shape of these contours in areas away from the river. Two possible explanations of ground-water influence from the west and effluence toward the east are as follows: (1) The axis of the ground-water reservoir of the water-table aquifier may lie east of the present river channel, and (2) the water-table aquifer may be recharging an artesian aquifer that is stratigraphically higher than those being tapped in the Mammoth area and that dips eastward away from the area. Evidence supporting the view that the axis of the ground-water reservoir of the water-table aquifer lies east of the present river channel is the fact that the Quiburis Formation forms a broad syncline whose axis is 1 to 3 miles east of the channel (Heindl, 1952, fig. 10a; oral communication, 1959). The concept of stratigraphically higher artesian aquifers is entirely hypothetical.

Although the amount of artesian head fluctuates periodically, appreciable pressure is maintained, as indicated by the flowing wells. As long as this head prevails, water from the water-table aquifer or from streamflow in this area could not recharge the deep artesian aquifers. However, should continued discharge of the deep artesian water reduce the head below the water-table altitudes, the gradients would be reversed and water from the water-table reservoir would move into the artesian aquifer.

RELATIONSHIPS BETWEEN GROUND WATER AND SURFACE WATER

The time relations between water-level fluctuations, streamflow, precipitation, and irrigation are shown in plate 2. The hydrographs reproduced here were selected as representative of 30 hydrographs. Three of the illustrated hydrographs were drawn from data obtained from recording gages. For this report, the vertical scales of the different graphs are varied to emphasize times and directions of fluctuations rather than amounts. The streamflow fluctuations were determined by observations of the writer rather than by gaging. Precipitation data were interpolated from U.S. Weather Bureau records for San Manuel, 3 miles southwest of the Mammoth area, and for P Z Ranch ("Winkleman 9 S" in "Climatological Data" of the U.S. Weather Bureau), 4 miles north of the limits of the area under discussion.

The streamflow in 1958 was highest from the middle of June to the middle of October (pl. 2); during this time the flow was constant and appreciable. Precipitation was heaviest in the area in February through April and in July through November.

Ground-water pumping was heaviest during the months of irrigation—April through July (San Carlos Irrigation Project personnel, oral communication, 1959). Discharge by evapotranspiration is greatest from June through September, when temperatures and evaporation rates are highest, and least from November through March, when temperatures and evaporation rates are lowest (table 3; Gatewood and others, 1950, p. 115–117). Evapotranspiration is also less during periods of high humidity and precipitation. Ground-water discharge by pumping of domestic, stock, and industrial wells is relatively constant throughout the year; however, the amount of this discharge probably is less than that from other wells.

Five of the eight hydrographs in plate 2 show rising water levels during the irrigation season of 1958, as is true in approximately this same proportion among the wells of the whole area. Apparently the unusually high streamflow and heavy precipitation of that year outweighed the effects of ground-water discharge. During this period of heavy precipitation, evapotranspiration should have also been less because of lower temperatures, higher humidity, and availability of precipitation to meet plant requirements. Early in the 1959 irrigation season, when precipitation and streamflow were negligible and evaporation rates and temperatures were increasing, the water levels of nearly all wells of the area were declining. This study does not include a discussion of the continuing effects of this irrigation season; however, water-level records obtained immediately after the 1959 irrigation season, during a period of heavy precipitation and high streamflow, show the anticipated rise in ground-water levels.

Flowing wells tapping the deep artesian aquifer appeared to have a relatively constant discharge throughout the period of study. Variations in flow were evident in only two wells of small, intermittent flow (½ to 5 gpm). These two wells were observed to flow only in December, January, and April, indicating that flows from other wells probably were highest during these months also.

As water-table well (D–8–17)32dac is about a mile from the nearest irrigation well, the fluctuations of the water level in this well (pl. 2), beginning in July about a month after streamflow increased, seem best explained as reflections of minor changes in rate of flow of the San Pedro River, a few hundred feet east of the well. These minor streamflow fluctuations could be verified only with accurate local-streamflow data, which were not available during this study. Fluctuations similar in character but subdued in magnitude are shown in the hydrograph of water-table well (D–8–16)1cbb, which is about 1,500 feet from the river channel, about five times the distance of well (D–8–17)32dac. These fluctuations took about five times as long to appear in the farther well as they did to appear in the closer well. The curves of the water levels of these two wells also smoothed out about 1 month and 5 months, respectively, after decrease in streamflow. If the suggestion that streamflow effected these ground-water fluctuations is correct, it would mean that the effect of recharge water moved westward in the flood-plain and channel deposits at the rate of about 300 feet per month under the ground-water gradient and river-stage conditions then prevailing.

HYPOTHETICAL WATER BUDGET

To determine the quantitative effects of transpiration and the pumping of wells upon the flow of the San Pedro River, it would be necessary to determine a water budget for the area. Accurate measurement of the several factors involved in such a budget was not within the scope of the investigation. Nevertheless, the following hypothetical water budget, based on estimates made in this area and other similar areas for the year of study, is presented to outline a method of analysis and to indicate the factors that would require measurement for an actual budget.

Hypothetical recharge	*Acre-feet*
1. On the basis of 1959 flows elsewhere, 60,000 acre-feet of streamflow entered the area and about one-third of this amount infiltrated to the water table (Gatewood and others, 1950, p. 57); ground-water recharge from this source would then be about	20,000
2. Precipitation was equal to about 5,000 acre-feet over the irrigated field and stream channel during periods of no flow. The sediments are very porous and the water table was shallow. Therefore, at least 20 percent of the precipitation might have penetrated to the water table, amounting to	1,000
3. Irrigation pumpage averaged 3 acre-feet per acre (Heindl, 1952, p. 93) over 2,500 acres under cultivation, or 7,500 acre-feet; if 15 percent of this water returned by seepage to the water table (Heindl, 1952, p. 92), then recharge would be about	1,000
4. Ground-water underflow entering the basin from the south was approximately equal to underflow leaving the basin to the north; net recharge, then, would be about	0
5. Recharge from other sources, including underflow from the east and west and leakage from artesian aquifers	5,000
The total hypothetical recharge would be about	27,000

Hypothetical discharge	
6. Plants required 3 acre-feet of ground water per acre (Heindl, 1952, p. 93; Gatewood and others, 1950, p. 195) over 5,500 acres of flood plain covered with phreatophytes and cultivated crops; phreatophyte transpiration plus irrigation pumpage would then be about	16,500
7. Domestic, stock, and industrial pumpage was about	500
8. The stream channel through the area includes 2,500 acres; if it was wet one-third of the year, after periods of flow, during which time pan evaporation was about 3 feet, and if evaporation from the channel surface was 0.7 of pan evaporation (Gatewood and others, 1950, p. 47), then evaporation from the channel would be about 2 acre-feet per acre, or about	5,000
9. The average specific yield of the water-table aquifer in the area of 2 by 15 miles was about 25 percent and the average rise in the water table was 1 foot; the water required for this rise would then be about	5,000
The total recharge required to supply the hypothetical discharge plus the amount required to raise the water table the observed average of 1 foot would be about	27,000

If the foregoing hypothetical recharge and discharge figures are substantially correct, it is shown that, during this particular year, transpiration of ground water through phreatophytes was about half the recharge from streamflow and that the net loss of ground water by irrigation pumping, subtracting the part assumed returned as recharge, was about 30 percent of the recharge from streamflow. As much as 20 percent of the water pumped onto irrigated fields was possibly contributed to streamflow as runoff. The total irrigation pumpage would have been transpired if the cultivated areas on the flood plain were covered with phreatophytes.

CONCLUSIONS

The following conclusions are made:

1. Ground water appears to move between different alluvial units; however, the freedom of movement and degree of change in the water-table gradient at the interfaces can be determined only by further study. Artesian ground water moves to the water table through leaking wells and possibly through subsurface fractures in confining beds.
2. Anamalous water-table gradients occur in the area. These may be caused by (1) variation of ground-water movement between geologic units, (2) local variation in amount of recharge, (3) local variations in amount of ground-water discharge, or (4) a combination of these factors.
3. Streamflow is the source of most ground-water recharge, as is indicated by rising water levels after periods of high streamflow.
4. Ground water is probably discharged mainly by evapotranspiration and probably to a much smaller extent by irrigation pumping.
5. The geologic and topographic trough in which the Mammoth area lies directs surface and subsurface flow into the area from the south, east, and west. Locally, ground-water contours indicate movement eastward from the river. The porous texture of most of the surface formations, especially the channel sediments, insures rapid ground-water recharge from runoff entering the area. The Quiburis deposits yield moderate quantities of artesian water to wells in the area.
6. Any discharge of ground water from the water-table aquifer will reduce the volume of streamflow. Lowering of the water table, especially near the flowing stream, induces infiltration from the stream to the water table. If there is no streamflow at the time of the ground-water discharge, the depleted part of the reservoir will be recharged from subsequent runoff; as long as the water

table is below the level of the stream surface, there is a potential loss from streamflow. (See Rosenshein, 1959, p. 509–510). As described on page 19, evapotranspiration and irrigation pumping account for most of the ground-water discharge. Without irrigation pumping the crop areas would probably revert to phreatophytes, and the total amount of ground-water discharge would remain virtually the same.

7. To obtain the quantitative data needed to define the water regimen in the area, several geohydrologic factors require further study. Pumping tests with wells penetrating the different alluvial units to various depths could reveal the nature of ground-water movement within and between the units. Measurements could determine more accurately the amount of precipitation, streamflow, and pumping in the area. Given a longer period of comparison of the relation between water use and water availability, a relatively accurate relationship between surface water and ground water could be defined.
8. The amount of water moving through any given section of the valley can be computed if the cross-sectional area, the hydraulic gradient, and the permeability of materials are known. The water-table map indicates the hydraulic gradient. The cross-sectional area can be determined by a line of test holes across the valley at selected locations, and the permeability can be determined by making pumping tests.

RECOMMENDATIONS FOR FURTHER STUDY

This study has shown that transpiration and pumping from wells near the San Pedro River affect the volume of streamflow. Fair estimates of the quantitative effects of these factors might be made from additional hydrologic data collected for years of average rainfall, streamflow, and pumping and from more detailed geologic and hydrologic studies in sections of the river valley where the interrelations herein outlined are capable of analysis.

The studies would require stream-gaging stations, additional water-level measurements, evapotranspiration studies, collection of meteorological data, irrigation-pumpage inventories, water-sample collection and analysis, and drilling of test wells to determine cross-sectional areas of aquifers and to permit making pumping tests, studying well cuttings, and observing water-level fluctuations.

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