

Effects of Phreatophyte Removal on Water Quality in the Gila River Phreatophyte Project Area, Graham County, Arizona

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Effects of Phreatophyte Removal on Water Quality in the Gila River Phreatophyte Project Area, Graham County, Arizona

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With a section on STATISTICAL ANALYSIS

By H. W. HJALMARSON

G I L A R I V E R P H R E A T O P H Y T E P R O J E C T

G E O L O G I C A L S U R V E Y P R O F E S S I O N A L P A P E R 6 5 5 - M



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FACTORS FOR CONVERTING ENGLISH UNITS TO INTERNATIONAL SYSTEM UNITS (SI)

The following factors may be used to convert the English units to the International System units (SI). This report contains both the English and SI units equivalents.

<i>Multiply English unit</i>	<i>By</i>	<i>To obtain SI unit</i>
Feet (ft).....	0.3048	Metres (m).
Miles (mi).....	1.609	Kilometres (km).
Acres.....	.4047	Hectares (ha).
Acre-feet (acre-ft).....	.001233	Cubic hectometres (hm ³).
Feet squared per day (ft ² /d).....	.0929	Metres squared per day (m ² /d).
Inches (in.).....	25.4	Millimetres (mm).
Cubic feet per second (ft ³ /s).....	.02832	Cubic metres per second (m ³ /s).

GILA RIVER PHREATOPHYTE PROJECT

EFFECTS OF PHREATOPHYTE REMOVAL ON WATER QUALITY IN THE GILA RIVER PHREATOPHYTE PROJECT AREA, GRAHAM COUNTY, ARIZONA

By R. L. LANEY

ABSTRACT

The Gila River Phreatophyte Project is in southeastern Arizona along a 15-mile (24-kilometre) reach of the Gila River above San Carlos Reservoir on the San Carlos Indian Reservation. Two water-bearing units underlie the area—the basin fill and the alluvial deposits. The basin fill is divided into two facies—a silt and sand facies and a limestone facies—and consists of deposits of clay, silt, sand, tuff, and limestone as much as 1,000 feet (300 metres) thick. The basin fill yields only small quantities of water to wells. The alluvial deposits, which overlie the basin fill along the Gila River and support most of the growth of phreatophytes, consist of as much as 85 feet (26 metres) of silt, sand, and gravel and yield moderate to large quantities of water to wells.

The water quality is considered in terms of four major hydrologic sources: the Gila River, the tributaries to the Gila River, the basin fill, and the alluvial deposits. The dissolved-solids concentrations in the Gila River ranged from about 300 mg/l (milligrams per litre) during high flows to about 4,800 mg/l during low flows. Most of the year sodium and chloride were the principal ions.

Water in tributaries to the Gila River contained less than 300 mg/l of dissolved solids and had a calcium bicarbonate to sodium bicarbonate composition. The amount of water from this source is small and has little effect on the quality of water of the Gila River or the alluvial deposits.

The dissolved-solids concentrations of the basin-fill water ranged from about 200 to 5,000 mg/l; the lowest concentrations were in the silt and sand facies, and the highest concentrations were in the limestone facies. Water containing less than 500 mg/l of dissolved solids had a calcium bicarbonate to sodium bicarbonate composition; water containing more than 500 mg/l of dissolved solids had a sodium chloride composition.

Water from the saturated zone of the alluvial deposits was a sodium chloride type and had dissolved-solids concentrations that generally ranged from about 3,000 to 7,000 mg/l. Lowest concentrations of dissolved solids were in water near the river and concentrations increased with increasing distance from the river.

Dissolved-solids concentrations in water in the saturated zone of the alluvial deposits were monitored for 8 years, during which time the phreatophytes were removed from the area. Evapotranspiration and fluctuations of streamflow in the Gila River caused variations in concentrations of dissolved solids. Concentrations were high during prolonged periods of low streamflow and were low during and following periods of high streamflow. Average dissolved-solids concentrations for the 8-year study period ranged from about 2,600 to 5,800 mg/l. Concentrations of dissolved solids in water from individual wells for the same period varied about 1,000 to 13,000 mg/l. Variations in dissolved-solids concentrations in water in the saturated zone decreased with distance from the river.

Water from the unsaturated zone had dissolved-solids concentrations that ranged from about 600 to 14,000 mg/l. Concentrations were greater in the upper part of the zone than near the water table during periods of low streamflow; chemical composition of the water ranged from a

sodium chloride type near the water table to a calcium chloride type in the upper part of the zone. Following periods of flushing by floodwater, the dissolved-solids concentrations were reduced, and the water had a calcium sodium bicarbonate composition in the upper part of the zone and a sodium-chloride composition near the water table.

Evapotranspiration and the variations of streamflow of the Gila River caused fluctuations in dissolved-solids concentrations in the water in the alluvial deposits and masked the detection of changes in concentrations caused by phreatophyte removal. The infiltration of floodwater from the Gila River removed and diluted the salt buildup in the alluvial deposits and, thus, removed any effects that may have been caused by phreatophyte removal. Statistical analyses of the specific-conductance data indicate that the removal of phreatophytes did not significantly affect the specific conductance of water in the alluvial deposits in the study area.

INTRODUCTION

The Gila River Phreatophyte Project was established to determine the amount of water lost through consumptive use by phreatophytes—mostly saltcedar and mesquite—and the amount of water that might be salvaged by their removal. The objectives of the investigation are to describe the hydrologic and ecologic variables in the project area and to test and develop methods for evaluating these variables in a large area (Culler and others, 1970, p. A2). This report describes the quality of the water in the project area and is one of a series of U.S. Geological Survey Professional Papers issued in connection with the project.

PURPOSE AND SCOPE

The purpose of this study was to determine the chemical quality of water in the project area and to define changes, if any, in water quality caused by phreatophyte removal. Water-quality data were collected during the period June 1964 to June 1972, and more than 200 chemical analyses of water were used to determine the water quality in the alluvial deposits, the basin fill, the Gila River, and the tributaries to the Gila River. Specific conductance was monitored on water from the Gila River for a 3-year period and on water from more than 50 observation wells in the alluvial deposits for the period of the study. Chemical analyses and measurements of specific conductance were made periodically on samples of water from the unsaturated zone of the alluvial deposits at two sites near

the Gila River for part of the period. Statistical methods were used to analyze the effect of the phreatophyte removal on the quality of the water in the alluvial deposits.

LOCATION AND PHYSICAL SETTING OF THE REPORT AREA

The Gila River Phreatophyte Project is in the Basin and Range physiographic province (Fenneman, 1931) in southeastern Arizona and comprises a 15-mile (24-km) reach of the Gila River in the northwestern part of the Safford Valley immediately above San Carlos Reservoir in the San Carlos Indian Reservation (pl. 1). The Gila River in the area occupies a broad terraced valley between two mountain ranges where it has developed a flood plain that ranges from about half a mile to 1 mile (0.8 to 1.6 km) wide. Altitudes range from about 2,500 feet (760 m) above mean sea level along the Gila River to as much as 7,000 feet (2,100 m) above mean sea level in the nearby mountains. At the time the study was begun, the flood plain was covered by a dense growth of saltcedar, which derived water from ground water at shallow depth.

The river and flood plain were divided originally into three contiguous reaches. However, in December 1965, backwater from San Carlos Reservoir inundated reach 3 (the lower reach) and the lower half of reach 2. Consequently, data collection on reach 3 was terminated, and reach 2 was divided into reaches 2a and 2b. Most of reach 1 was cleared of phreatophytes between January and May 1967. Reach 2a was cleared mainly between January and May 1969, and reach 2b was cleared between September 1970 and March 1971. After each reach was cleared, virtually no vegetation remained except for some seasonal grasses and weeds from about March through May of each year.

The climate in the project area is semiarid. The mean annual precipitation at San Carlos Reservoir, at the lower end of the study area, averaged 14 inches (356 mm) per year for the period of record, 1882-1971, but has ranged from 4.0 inches (102 mm) in 1924 to 25.8 inches (655 mm) in 1941 (Hanson, 1972b, p. 5). Most of the precipitation falls in two distinct periods—July to September and December to March. The summer precipitation, which results from convection of warm moist air from the Gulf of Mexico, generally is localized, intense, and of short duration. The winter precipitation, which results from cyclonic storms from the Pacific Ocean, usually is less intense and more widespread than that in summer. Mean monthly temperatures range from about 8°C (Celsius) in January to about 31°C in July (U.S. Weather Bureau, 1964).

WELL-NUMBERING SYSTEM

When the project was begun in 1962, 72 wells were drilled in the alluvial deposits on a series of cross sections at right angles to the Gila River at approximately ¼-mile (2-km) intervals. Three wells were drilled on each side of

the river on each cross section, and the cross sections were identified by numbers 1, 3, 5 . . . 23 (pl. 1). In 1966 five wells were drilled on cross section 12, which was established between cross sections 11 and 13. Also, several additional observation wells were drilled between the cross sections throughout the project area.

Each well is identified by a four-digit number. The first two digits represent the cross section that the well is on or is immediately downstream from; the last two digits represent an arbitrary number unique to the cross-sections. For example, all wells on cross section 9 and between cross sections 9 and 11 have the prefix numbers 09.

GEOLOGY AND GROUND WATER

Two major sedimentary rock units are exposed in the project area—the basin fill and the alluvial deposits (Weist, 1971, p. D3). The basin fill is the most widespread sedimentary unit in the area and is exposed on the steep sides of dissected terraces on the valley slopes. The unit is composed mainly of material ranging from sand to clay and limestone. A silt and sand facies and a limestone facies were mapped in the project area (pl. 1); the silt and sand facies consists of even-bedded well-sorted light-brown to reddish-brown silt and light-brown very fine grained sand. The limestone facies consists of interbedded white limestone, marl, siltstone, fine-grained sandstone, tuff, and local beds of green clay. The limestone facies is exposed only in the northwestern part of the project area. The thickness of the basin fill may be more than 1,000 feet (300 m).

The alluvial deposits overlie the basin fill along the river and were divided into the terrace alluvium and the flood-plain alluvium mainly on the basis of topographic position (Weist, 1971, p. D7). The terrace alluvium has been incised and filled with a channel deposit of flood-plain alluvium (fig. 1). The flood-plain alluvium underlies the present-day flood plain of the Gila River and supports most of the phreatophyte growth along the river. The terrace alluvium consists of poorly sorted cobbles, gravel, sand, and silt and generally is less than 40 feet (12 m) thick where it underlies the flood-plain alluvium. Locally, the unit may be as much as 75 feet (23 m) thick. The flood-plain alluvium consists of lenticular beds of silt, sand, and gravel and ranges in thickness from 0 to 50 feet (0 to 15 m). The combined thickness of the alluvial deposits may be as much as 85 feet (26 m). In most places the flood-plain alluvium and terrace alluvium form a hydraulically continuous aquifer.

Water in the basin fill is under artesian pressure in the project area and moves toward the Gila River and down the valley. Near the river part of the water moves into the alluvial deposits. Water levels in wells that penetrate the basin fill beneath the alluvial deposits generally are nearer the surface than are the water levels in nearby wells that penetrate only the alluvial deposits. Wells tapping the

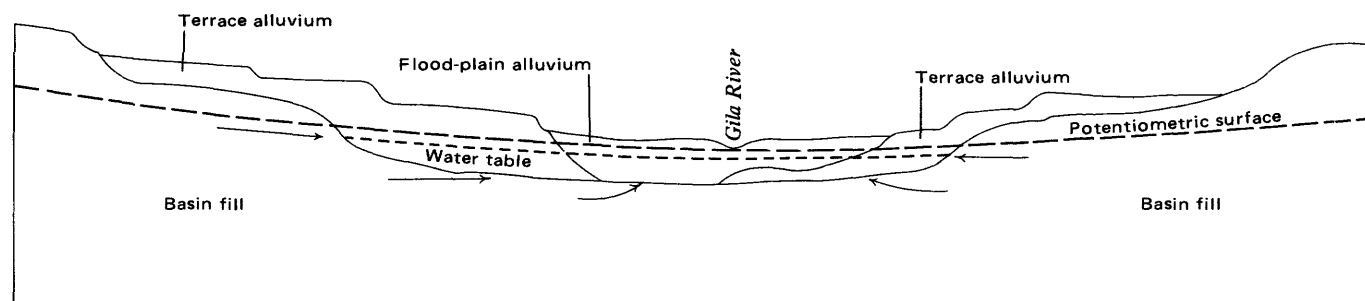


FIGURE 1.—Cross section showing generalized geology of the project area and ground-water movement at right angle to the Gila River. (Geology after E. S. Davidson, written commun., 1964; Weist, 1971.)

basin fill in the project area yield only a few gallons of water per minute, and the average transmissivity is 15 ft²/d (1.4 m²/d; Hanson, 1972a, p. F27).

Water is present in the alluvial deposits under water-table conditions, and movement of the water is down the valley. The alluvial deposits are recharged mainly by large quantities of water from the Gila River during periods of flooding; smaller amounts of water are recharged to the alluvial deposits from tributary underflow and water from the basin fill. The depth to water in the alluvial deposits is about 5 to 40 feet (1.5 to 12 m) below land surface, but during periods of above average streamflow and flooding the water level may be nearly at the ground surface along the river. Wells in the alluvial deposits yield moderate to large quantities of water, and the average transmissivity is 28,000 ft²/d (2,600 m²/d; Hanson, 1972a, p. F27).

WATER QUALITY

For purposes of this report the water quality is considered in terms of four major hydrologic sources—the Gila River, the tributaries to the Gila River, the basin-fill deposits, and the alluvial deposits. Water from each source has identifiable chemical characteristics.

An evaluation of natural variation in water quality is necessary to place in proper perspective any apparent changes in water quality due to removal of vegetation. Variations in water quality in the alluvial deposits were most critically examined because the phreatophytes depend on this water for their supply. The variation of water quality of the Gila River was studied because the river is the principal source of recharge to the alluvial deposits. The quality of the water in the tributaries to the Gila River and in the basin fill is discussed, but the water from these sources has little effect on the quality of the water in the Gila River and the alluvial deposits.

GILA RIVER

The dissolved-solids concentrations of water from the Gila River ranged from about 300 to 4,800 mg/l based on chemical data from more than 50 water samples that were collected at various stages of the river and from individual and continuous specific-conductance measurements that

were made from 1965 to 1968. Specific conductance is a measure of the ability of a substance to conduct an electric current. The presence of charged ionic species in water increases its conductance. Thus, specific conductance increases as dissolved-solids concentrations increase, and specific conductance can be used to determine the approximate dissolved-solids concentrations. The ratio of dissolved solids, in milligrams per litre, to specific conductance, in micromhos, for water from the Gila River is about 0.60 (table 1). The specific-conductance measurements were multiplied by this ratio to obtain an approximate value of dissolved-solids concentrations when only specific-conductance measurements were made and no chemical analyses were available.

Specific conductance of water from the Gila River is large during periods of low flow and is small during periods of high flow (fig. 2). At low flow, a considerable amount of poor quality water is supplied to the river by ground water from the alluvial deposits and from returned irrigation water upstream from the project area. High flow results from snowmelt in winter and spring and localized thunderstorms in summer and is of good chemical quality; however, water during periods of high flow may contain large amounts of suspended sediment.

During most of the year, sodium and chloride are the principal ions in the river water; sulfate and calcium are the next most abundant ions. The approximate range in concentration of the principal constituents in water from the Gila River is shown in the following list:

Constituent	Milligrams per litre
Chloride.....	65 to 2,100
Sodium plus potassium.....	70 to 1,300
Sulfate.....	50 to 800
Calcium.....	50 to 350
Bicarbonate.....	150 to 350
Magnesium.....	10 to 120
Fluoride.....	0.8 to 2.0
Dissolved solids.....	300 to 4,800

The chemical composition of the water from the Gila River is shown in a geochemical graph that was described by Piper (1945; fig. 3, this report). Amounts of the principal cations and anions expressed in percentage of

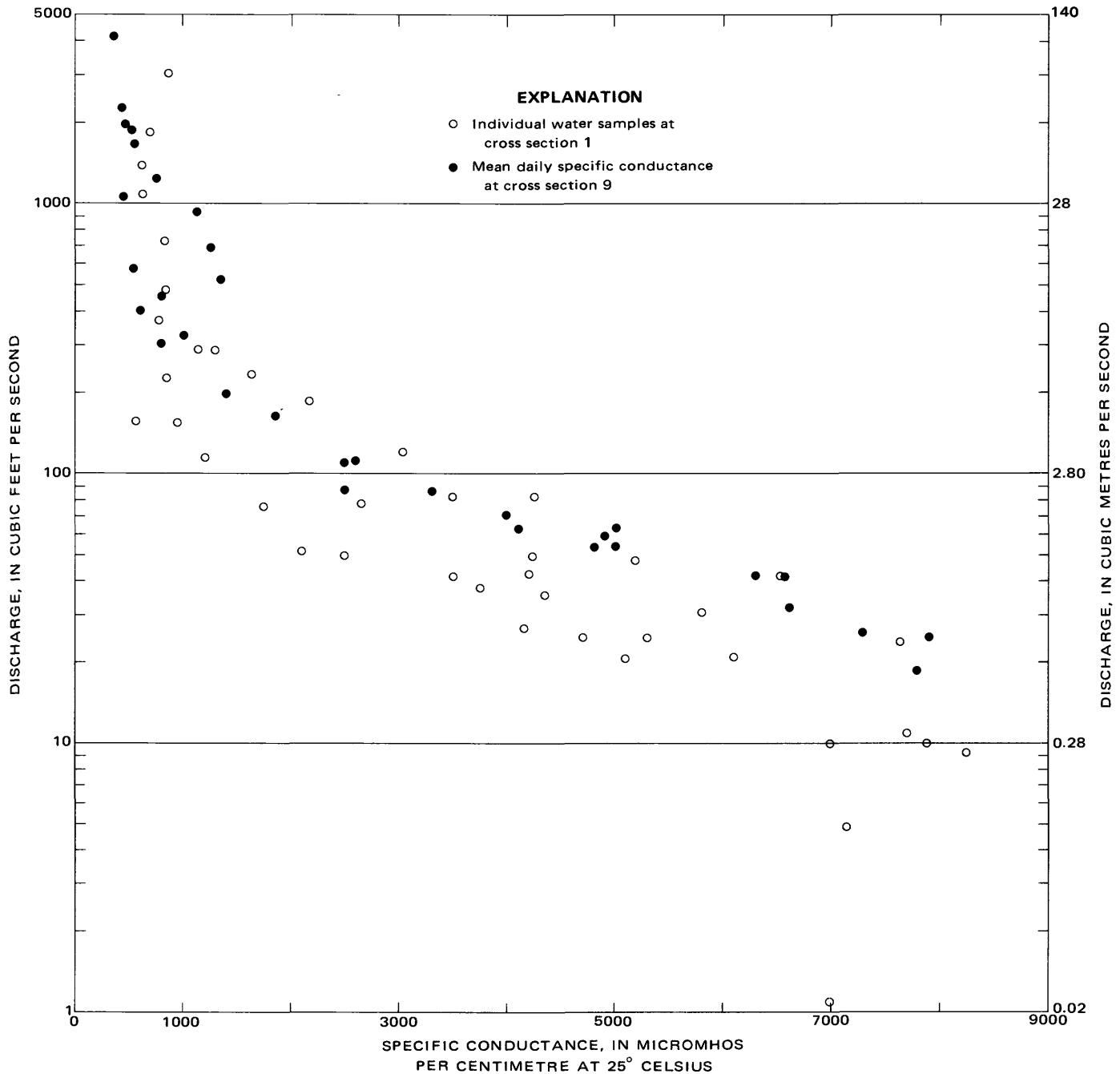


FIGURE 2.—Mean daily discharge of the Gila River at cross sections 1 and 9 versus specific conductance of river water, 1965-68.

milliequivalents per litre are plotted in the lower triangles. The points in the triangles are extended into the diamond field, and the resulting intersection is representative of the composition of the water with respect to both cations and anions.

The composition of the water in the river changes from a sodium chloride type at low flow to a calcium sodium bicarbonate type at high flow (fig. 3; table 1). Sodium and chloride make up as much as 70 percent of the total ions during periods of low flow and less than 40 percent at high

flow. Water in the river at low flow has a similar chemical composition as water in the alluvial deposits.

A continuous record of specific conductance is available at the gaging station on cross section 9 from July 25, 1966, to September 30, 1968 (fig. 4). During the 1968 water year (the period October 1, 1967, through September 30, 1968) the mean discharge of the Gila River was about 300 percent above the mean annual discharge for the period of streamflow record, which was started in 1929. During the 1967 water year (the period October 1, 1966, to September

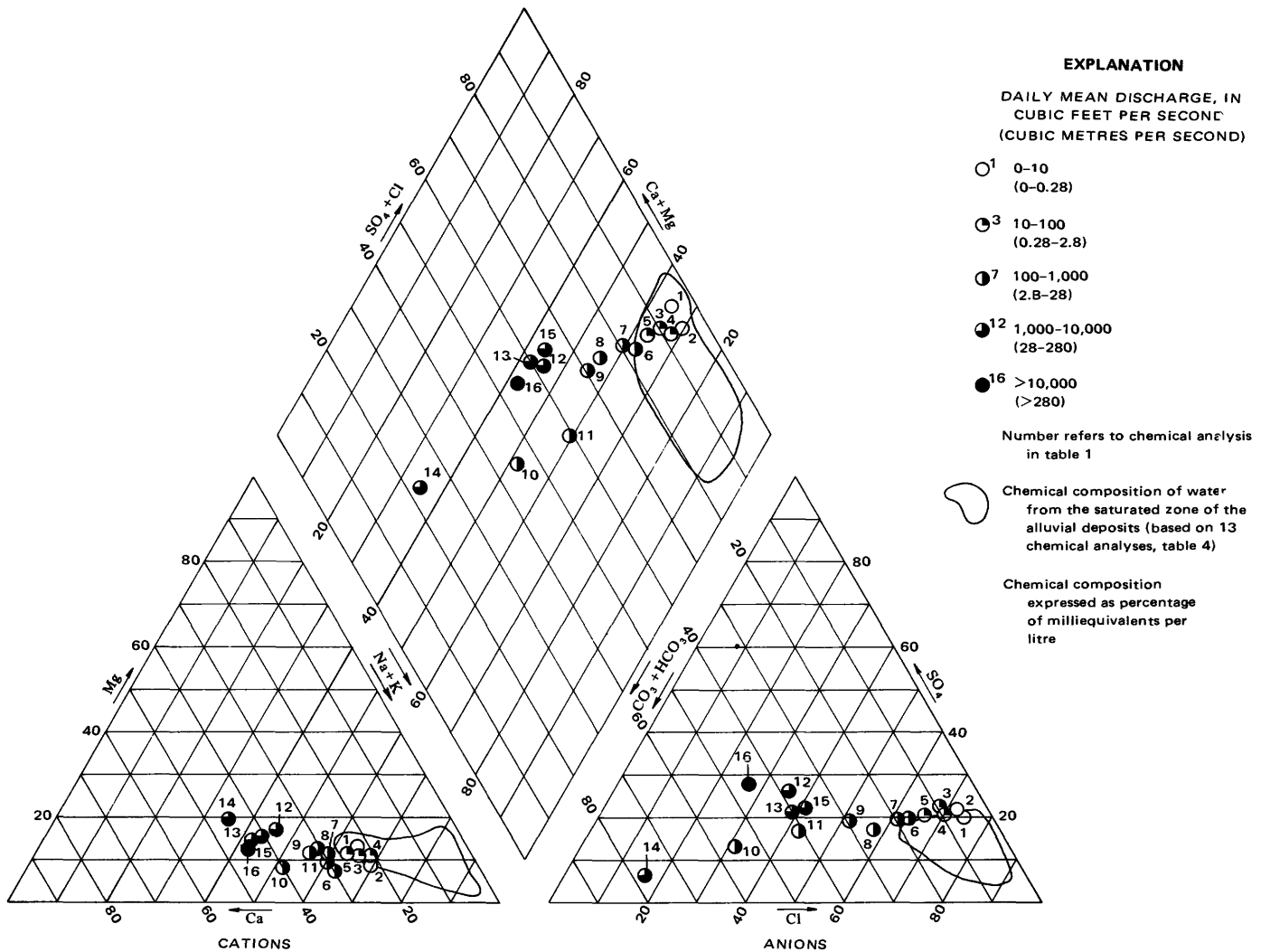


FIGURE 3.—Chemical composition of water versus discharge of the Gila River at cross section 1 and chemical composition of water from the saturated zone of the alluvial deposits.

30, 1967) the mean annual discharge of the river was only 82 percent of the mean for the period of record. The effects of these above and below average discharges are shown markedly in the record of specific conductance (fig. 4). Specific conductance usually is greatest during June and the early part of July, which is the time of lowest flow in the river, and values approach 8,000 micromhos (about 5,000 mg/l of dissolved solids). However, specific conductance was more than 7,000 micromhos for much of the period February through June 1967. Specific conductance generally is lowest from December through March. During this period of the 1968 water year the specific conductance was less than 1,000 micromhos (about 600 mg/l of dissolved solids). The specific conductance varies widely during the period from the middle of July to the middle of September and reflects the rapid fluctuations in river discharge during the summer rainy season.

The large concentrations of dissolved material in the Gila River are derived from the sedimentary deposits that

fill Safford Valley upstream from the project area (Gatewood and others, 1950, p. 76; Hem, 1950, p. 20). Soluble material enters the alluvial deposits and thence to the Gila River by ground-water seepage from the basin fill and older sedimentary rocks; dissolved material is contributed to the Gila River by direct dissolution of surficial deposits by runoff.

TRIBUTARIES TO THE GILA RIVER

Local high-intensity rainfall causes flow in the major tributaries to the Gila River in the project area. This flow may add appreciable amounts of water to the Gila River during wet years and virtually none during dry years (Burkham, 1970, p. B16). The water is of excellent chemical quality; dissolved-solids concentrations of 6 samples of tributary flow ranged from 60 to 282 mg/l, and the water types were mainly calcium bicarbonate, although the water collected from Salt Creek was a sodium chloride type (table 2). Seven additional samples

TABLE 1.—Selected chemical analyses of water from the Gila River at cross-section 1

[Analyses in milligrams per litre and milliequivalents per litre except as indicated; upper figure for all chemical constituents is reported in milligrams per litre; lower figure for ions is reported in milliequivalents per litre; analyses by U.S. Geological Survey except as indicated. Leaders (...) indicate no data available]

Sample No. (fig. 3)	Date of collection (month, day, year)	Daily mean discharge at Catva (ft ³ /s)	Silica (SiO ₂)	Calcium (Ca)	Magnesium (Mg)	Sodium plus potassium (Na + K)	Bicarbonate (HCO ₃)	Carbonate (Co ₃)	Sulfate (SO ₄)	Chloride (Cl)	Fluoride (F)	Nitrate (NO ₃)	Dissolved solids		Hardness as CaCO ₃	Specific conductance (micro-mhos per cm at 25°C)	Ratio of dissolved solids to specific conductance	pH	Remarks
													Sum	Residue at 180°C					
1	6-9-65	10	47	334 16.67	118 9.70	1,139 49.55	261 4.28	0	730 15.20	2,000 56.40	1.4 0.07	1 0.02	4,450	...	1,320	7,000	0.64	7.6	Analysis by Department of Agricultural Chemistry and Soils, University of Arizona. Silica not included in dissolved solids.
2	6-14-65	10	...	344 17.17	107 8.83	1,280 55.77	259 4.25	0	860 17.91	2,110 59.52	1.8 0.09	...	4,830	...	1,300	7,890	.61	7.4	
3	11-14-64	21	42	284 14.71	88 7.23	969 42.14	350 5.74	0	680 14.16	1,540 43.44	1.7 0.09	7.1 0.11	3,780	3,940	1,070	6,100	.61	7.8	
4	10-19-65	25	39	240 11.98	75 6.17	876 38.11	288 4.72	0	580 12.08	1,400 39.49	1.6 0.08	3 0.05	3,360	...	907	5,300	.63	7.7	Analysis by Department of Agricultural Chemistry and Soils, University of Arizona.
5	12-15-64	50	44	211 10.53	59 4.87	632 27.50	328 5.38	0	426 8.87	1,010 28.49	1.7 0.09	4.5 0.07	2,550	2,620	770	4,240	.60	8.2	
6	4-16-65	121	...	179 8.93	26 2.14	432 18.80	302 4.95	0	285 5.93	670 18.90	1.7 0.09	...	1,740	...	556	3,020	.58	7.9	Silica not included in dissolved solids.
7	3-19-65	189	...	122 6.09	30 2.47	283 12.33	249 4.08	0	200 4.16	445 12.55	1.9 0.10	...	1,200	...	424	2,170	.55	7.8	Do.
8	2-18-65	236	...	98 4.89	23 1.89	206 8.97	249 4.08	0	130 2.71	315 8.87	1.8 0.09	...	897	...	336	1,630	.55	7.6	Do.
9	1-25-65	290	47	78 3.89	19 1.55	160 6.96	215 3.52	0	113 2.35	228 6.43	1.3 0.07	2.0 0.03	744	753	272	1,290	.58	7.9	
10	7-29-65	371	25	66 3.29	8 0.66	99 4.30	259 4.24	0	52 1.08	104 2.93	0.8 0.04	1 0.02	484	...	199	780	.62	7.8	Analysis by Department of Agricultural Chemistry and Soils, University of Arizona.
11	7-26-65	735	39	53 2.64	12 0.99	126 5.48	229 3.75	0	76 1.58	134 3.78	0.8 0.04	2 0.03	559	...	185	841	.66	7.4	Do.
12	12-16-65	1,100	.....	52 2.59	14 1.17	73 3.16	159 2.61	0	85 1.77	88 2.48	1.1 0.06	...	391	...	188	638	.61	7.6	Silica not included in dissolved solids.
13	12-14-65	1,400	...	54 2.69	11 0.93	63 2.72	153 2.51	0	65 1.35	86 2.43	0.9 0.05	...	355	...	181	619	.57	7.5	Do.
14	9-4-65	1,850	48	65 3.24	17 1.40	58 2.52	341 5.59	0	24 0.50	40 1.13	1.5 0.08	...	422	...	232	700	.60	7.2	Analysis by Department of Agricultural Chemistry and Soils, University of Arizona.
15	12-28-65	3,070	...	70 3.49	16 1.29	84 3.66	186 3.05	0	94 1.96	120 3.38	1.0 0.05	...	477	...	239	869	.55	7.4	Silica not included in dissolved solids.
16	12-24-65	17,600	...	62 3.09	11 0.93	69 3.02	194 3.18	0	94 1.96	66 1.86	0.8 0.04	...	399	...	201	679	.58	7.4	Do.

pH determined in laboratory.

TABLE 2.—Chemical analyses of water from tributaries to the Gila River within the project area

Location and number (pl. 1)	Date of collection in 1964	Silica (SiO ₂)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO ₃)	Carbonate (CO ₃)	Sulfate (SO ₄)	Chloride (Cl)	Fluoride (F)	Dissolved solids		Hardness as CaCO ₃	Specific conductance (micromhos per cm at 25°C)	pH ²	Remarks
												Sum ¹	Residue at 180°C				
1. At crest-stage gage on the Coolidge Dam Road, 0.3 mile east of well 1337.	Aug. 26.....	35	56 2.09	12 0.99	6 0.26	8 0.20	210 3.44	0	32 0.67	4 0.11	0.7 0.04	258	...	190	400	7.7	Analysis by Department of Agricultural Chemistry and Soils, University of Arizona, Boron 0 mg/l, nitrate 1 mg/l. Pondered tributary runoff; insufficient amount of water for complete analysis; sulfate determined by difference. Insufficient amount of water for complete analysis; sulfate determined by difference; residue at 180°C includes suspended material.
2. Cross-section 1 between wells 0101 and 0102.	...do.....	9.3	13 0.65	1.1 0.09	4.0 0.17	...	40 0.66	0	12 0.24	0.5 0.01	...	60	90	37	101	7.7	
3. Crest stage gage on Coolidge Dam Road, 0.15 mile southeast of well 0101.	Sept. 8.....	11	22 1.10	0 0.00	19 0.83	...	60 0.98	0	24 0.50	16 0.45	...	122	222	55	178	7.9	
4. Salt Creek at U.S. Highway 70, north of map boundary.	Dec. 14.....	...	24 1.20	7.8 0.64	71 3.07	72 1.18	0	46 0.96	98 2.76	<0.2 <0.01	...	282	...	92	527	7.1	
5. At stream crossing on U.S. Highway 70, 1.2 miles northwest of Cottonwood Canyon.	...do.....	...	22 1.10	6.3 0.52	0.9 0.04	45 0.74	0	41 0.85	2.5 0.07	<0.2 <0.01	...	95	...	81	189	7.5	
6. Cottonwood Canyon on U.S. Highway 70.	...do.....	...	39 1.95	8.4 0.69	See remarks...	...	81 1.33	0	56 1.16	4.5 0.13	<0.2 <0.01	148	...	132	287	7.2		Calcium plus magnesium milliequivalents were greater than total anions milliequivalents. Value for sodium plus potassium is probably near zero.

¹Dissolved solids (sum) are computed by adding 0.49 × bicarbonate + other determined constituents.²Determined in laboratory.

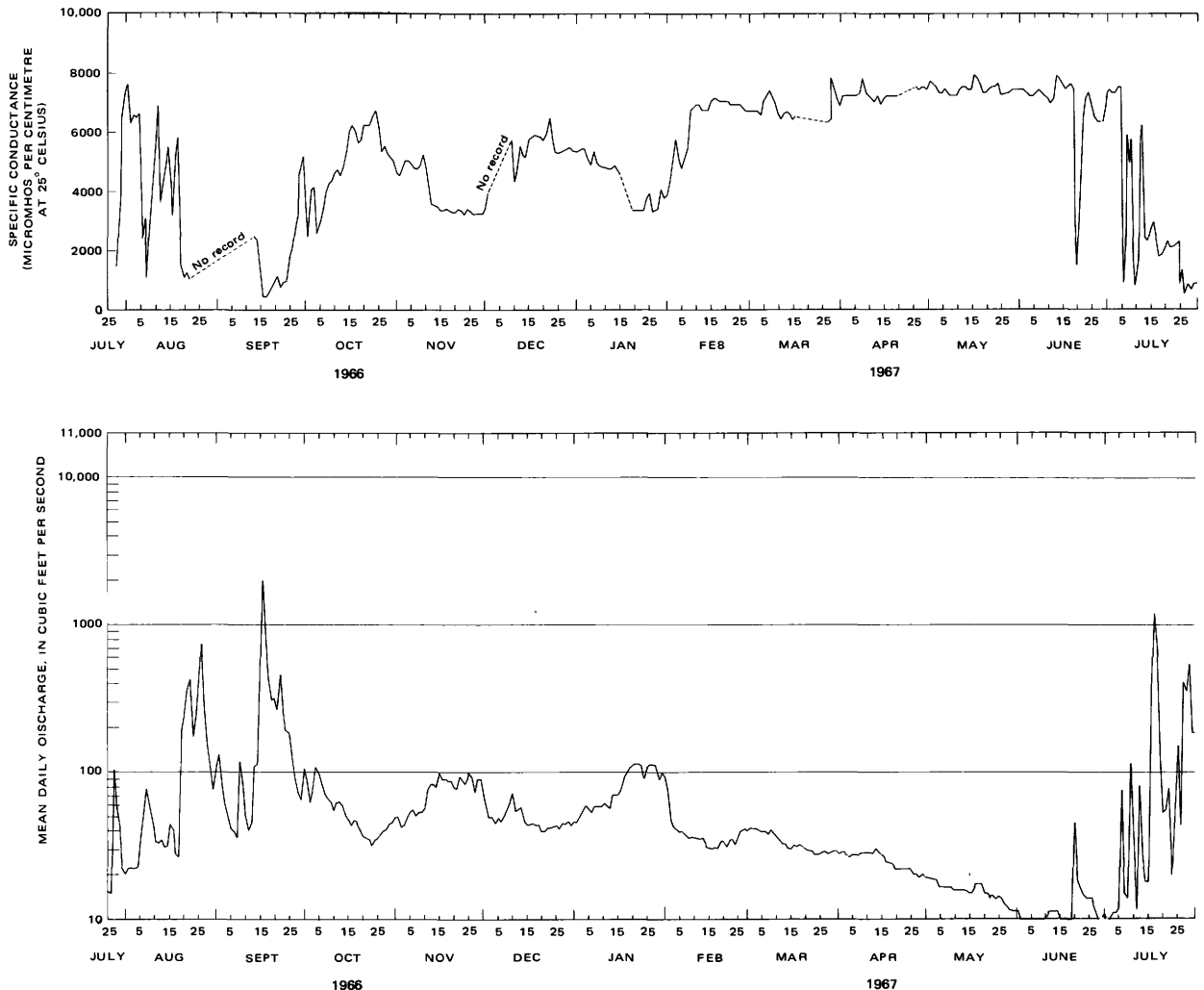


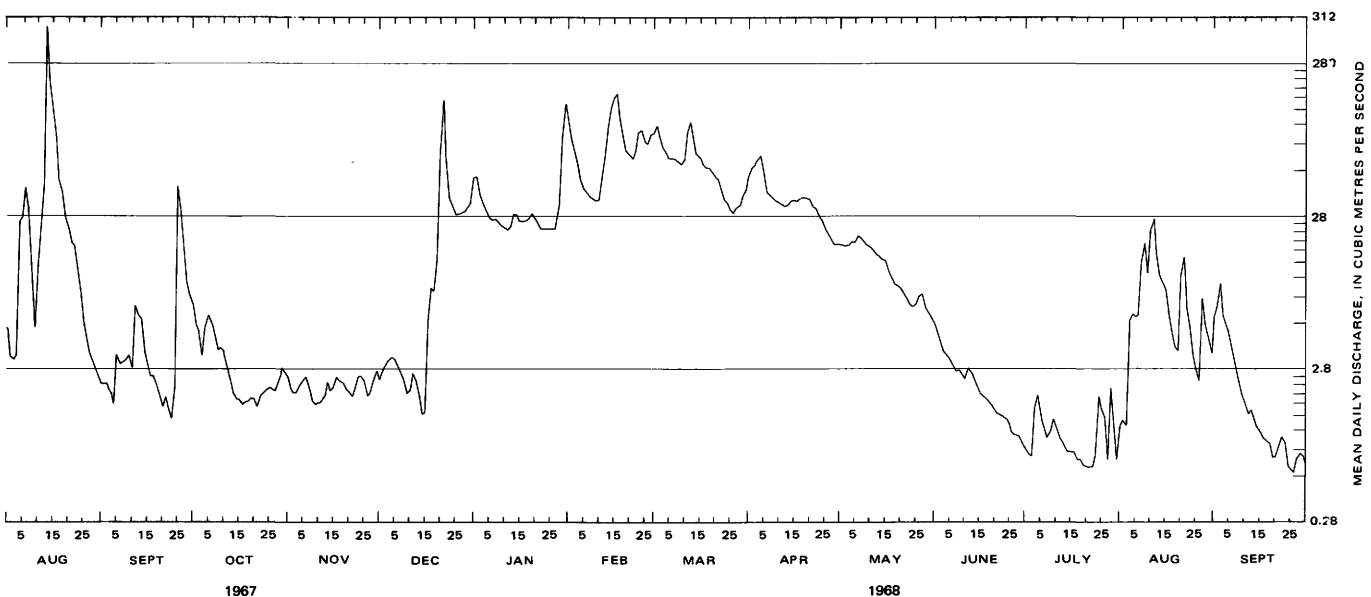
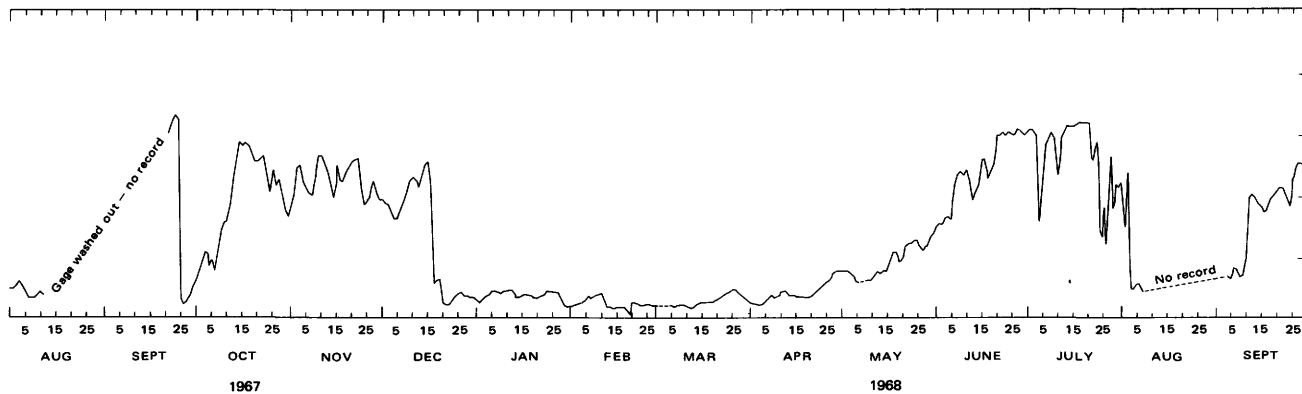
FIGURE 4.—Specific conductance and discharge of the Gila River at

of tributary flow for which only specific conductance was determined had specific-conductance values ranging from 205 to 570 micromhos (about 120 to 340 mg/l of dissolved solids). The total annual tributary flow in the project area is generally less than 10 percent of the flow of the Gila River at Calva (D. E. Burkham, oral commun., 1972). Some ground water may originate by infiltration of tributary flow, but the amount is small and probably occurs only during wet periods (Weist, 1971, p. D13). Therefore, the probable small amount of recharge from tributary flow has an insignificant effect on the water quality of the Gila River or on the ground water in the alluvial deposits.

BASIN-FILL DEPOSITS

The dissolved-solids concentrations in water from 16 wells tapping the basin-fill deposits ranged from about

200 to 5,000 mg/l (table 3; pl. 1). Water from wells that were drilled in or near the limestone facies contained more than 3,000 mg/l of dissolved solids (wells 1962, 1963, and 2374, table 3). These large concentrations resulted from the dissolution of soluble salts that were deposited with the limestone. Water in the silt and sand facies was of better quality and usually contained less than 1,000 mg/l of dissolved solids, except where the percentage of clay was large. For example, the basin-fill deposits penetrated by well 1141 contained about 85 percent silt and clay and 15 percent sand; dissolved-solids concentration of the ground water was 2,570 mg/l. The deposits penetrated by well 1756 contained about 60 percent silt and clay and 40 percent sand; dissolved-solids concentration of the ground water was only 676 mg/l. The clayey parts of the silt and sand facies contained more soluble salts than the coarser grained parts of the facies. The presence of soluble salts



cross section 9, July 25, 1966, to September 30, 1968.

was indicated by the accumulation of salt crusts on many clayey exposures of the basin-fill deposits. Dissolved-solids concentrations generally were greater in the silt and sand facies near the Gila River where the facies was overlain by saturated alluvial deposits (wells 0105, 1140, 1141, and 1756, pl. 1). These higher concentrations may indicate contamination by poorer quality water from the alluvial deposits because nearby wells that did not penetrate the saturated alluvial deposits contained water having noticeably lower dissolved-solids concentrations.

The water in the basin fill in the Safford Valley upstream from the project area generally is highly mineralized because of dissolution of soluble material from lake beds and playa-type deposits (Gatewood and others, 1950, p. 71; Hem, 1950, p. 20). As a result of the artesian conditions and probable faulting in the basin fill in this area, mineralized water moves into alluvial deposits

and is a significant source of poor quality water upstream from and in the project area.

The water in the limestone facies is a sodium chloride type; the water in the silt and sand facies generally is a calcium bicarbonate type near the surrounding mountains (recharge areas) and a sodium bicarbonate to sodium chloride type near the Gila River (pl. 1). The sodium chloride type water was obtained from wells where the facies is overlain by saturated alluvial deposits. Temperatures of water from the basin fill ranged from 18.0° to 26.5°C (table 3).

Water from most of the silt and sand facies would be suitable for domestic and stock use, but water in which sodium is the major cation may not be desirable for irrigation. Water from the limestone facies would not be suitable for domestic and irrigation uses nor desirable for livestock.

ALLUVIAL DEPOSITS

The alluvial deposits consist of flood-plain alluvium and terrace alluvium. In discussions of water quality, no distinction is made between the two units because both are very permeable and form a continuous aquifer. However, the separation of the two units is made because most of the phreatophytes are confined to the flood-plain alluvium.

The ground-water quality in the alluvial deposits is described in terms of the saturated zone and the unsaturated zone. Chemical data on water from the saturated zone were obtained from water from wells that penetrated the water table, and the chemical data on the water from the unsaturated zone were obtained from water that was extracted by soil-water tubes in the alluvial deposits above the water table.

GROUND WATER IN THE SATURATED ZONE

Dissolved-solids concentrations in water from more than 50 shallow observation wells in the alluvial deposits ranged from 395 to 19,200 mg/l, but most of the concentrations ranged between 3,000 and 7,000 mg/l. Dissolved-solids concentrations are lowest in ground water near the Gila River and generally increase with increasing distance from the river. The lower concentrations are caused by infiltrating and flushing of fresh water from the river during periods of high flow.

The water from the alluvial deposits has a sodium chloride composition similar to that of water from the Gila River at low flow, but the amounts of individual constituents in the water from the alluvial deposits are more variable than those in river water at low flow (table 4; fig. 3). However, the average sodium to chloride ratio of the water is slightly less than one and is not significantly different from that of river water.

Most of the water in the alluvial deposits in the project area is not suitable for domestic or public supplies because of the excessive amounts of dissolved solids. In addition, some water contains more fluoride than the recommended maximum concentration of 1.4 mg/l established by the U.S. Public Health Service (1962). Most of the water in the alluvial deposits could be used by livestock because of their higher tolerance to dissolved solids in water. The large concentrations of dissolved solids, the high percentage of sodium, and boron concentrations greater than a few tenths of a milligram per litre make much of the water in the alluvial deposits undesirable for irrigation purposes. The use of water for irrigation in the Safford Valley has been discussed by Hem (1950).

The specific conductance of water from the wells in the alluvial deposits was monitored from June 1964 to June 1972. Measurements were made at approximately 3-month intervals from March 1966 to March 1970 and at 6- to 12-month intervals for the remainder of the period. The sampling procedure consisted of bailing or pumping water from the wells until a constant specific-conductance

value was obtained. Dissolved-solids concentrations, in milligrams per litre, were calculated by multiplying the specific-conductance value by 0.64, which is the average ratio of dissolved solids to specific conductance from more than 50 chemical analyses of water from the alluvial deposits.

The shallow observation wells were drilled only deep enough into the saturated zone to bottom below the maximum water-table decline. Well depths ranged from about 12 feet (4 m) near the river to as much as 35 feet (11 m) near the outer margins of the alluvial deposits. The wells were constructed with blank casing that was open to the alluvial deposits only at the bottom. Along the river where the alluvial deposits are thickest, the wells penetrate only the upper few feet of the saturated deposits, and, because of the manner of well construction, water-quality data from samples taken from the wells should be considered as point sources of data from the very upper part of the saturated zone of the alluvial deposits. The dissolved-solids maps prepared from this data (pl. 2) show the variations of concentrations of dissolved solids primarily in the upper part of the saturated zone of the alluvial deposits and not necessarily average concentrations or changes in concentrations of dissolved solids in the total saturated thickness of the deposits.

Two periods were selected—June 1967 and December 1968—to demonstrate the general distribution of dissolved solids in the upper part of the alluvial deposits and show how differences in the magnitude of discharge in the Gila River can cause large variations in dissolved-solids concentrations in ground water. Phreatophytes had been cleared from reach 1 prior to the collection of the data for the two maps. The effects of phreatophyte removal on dissolved-solids concentrations, if any, would be included in the map for reach 1. Thus, the data on the maps are intended to illustrate only distribution and magnitude of variation of dissolved solids in ground water and do not show changes in dissolved solids caused by clearing. During June 1967 most of the ground water contained 3,000 to 7,000 mg/l of dissolved solids (pl. 2A). Water containing the smallest amounts of dissolved solids generally was in a zone along the central axis of the Gila River flood plain. The streamflow in the Gila River during the year prior to this period was below average. Evapotranspiration and the lack of significant freshening by floodwater caused the dissolved-solids concentration to increase in the alluvial deposits.

In December 1968 most of the ground water in the upper part of the alluvial deposits contained from 1,000 to 5,000 mg/l of dissolved solids, which is considerably lower in concentration than in June 1967 (pl. 2B). However, the relative distribution of dissolved solids is similar; that is, lower concentrations are near the central axis of the flood plain and higher concentrations are along the margins. Streamflow in the Gila River during the year prior to

TABLE 3.—Chemical analyses of water from the saturated zone of the basin fill

[Analyses in milligrams per litre and milliequivalents per litre except as indicated; upper figure for all chemical constituents is reported in milligrams per litre; lower figure for ions is reported in milliequivalents per litre; analyses by Department of Agricultural Chemistry and Soils, University of Arizona, except as indicated. Leaders (...) indicate no data available]

Well No. (pl. 1)	Sedimentary facies	Date of collection (month, day, year)	Temperature (°C)	Silica (SiO ₂)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO ₃)	Carbonate (CO ₃)	Sulfate (SO ₄)	Chloride (Cl)	Fluoride (F)	Nitrate (NO ₃)	Boron (B)	Dissolved solids Sum ¹ at 180°C Residue at 180°C	Hardness as CaCO ₃	Specific conductance (micro mhos per cm at 25°C)	pH ²	Remarks
0105	Silt and sand.	2-18-64	...	...	6 0.30	2 0.16	338 14.70		386 6.33	24 0.80	70 1.46	284 6.60	4.5 0.24	1 0.02	...	870	24	1,640	8.8	Well was drilled through the alluvial deposits into the basin fill for an aquifer test; the well casing was not perforated in the alluvium; water sampled after 2 hours of pumping.
0524	...do.....	7-29-64	...	37	26 1.30	9 0.74	71 3.09	5 0.13	254 4.16	0	17 0.35	24 0.68	0.9 0.05	4 0.06	0	319	101	500	7.7	
0531	...do.....	7-10-64	22.0	21	9 0.45	6 0.49	82 3.57	1 0.03	128 2.10	0.20	53 1.10	40 1.13	0.2 0.01	0	0.02	281	24	470	8.1	
0730	...do.....	6-10-64	22.0	47	36 1.80	11 0.90	10 0.44	1 0.03	151 2.47	0	24 0.50	6 0.17	0.2 0.01	5 0.08	0.03	214	17	350	7.7	
0731	...do.....	6-10-64	26.5	108	47 2.35	69 5.68	664 28.88	12 0.31	347 5.69	0	81 1.69	1,050 29.62	0.8 0.04	1 0.02	0.42	2,200	161	3,200	8.5	
0732	...do.....	6-10-64	21.0	32	28 1.40	17 0.40	28 1.22	1 0.03	176 2.88	5	21 0.44	16 0.6	0.6 0.03	4 0.06	0.08	240	21	400	8.3	
1140	...do.....	7-7-64	23.5	16	17 0.85	5 0.41	298 12.96	1 0.03	146 2.39	6	61 1.27	370 10.44	0.6 0.03	0	0.14	847	75	1,500	8.3	
1140	...do.....	6-17-65	22.0	...	27 1.35	16 1.29	440 19.13		182 2.98	3	110 2.29	580 16.36	0.7 0.04	...	...	1,270	132	2,310	8.4	Analyses by U.S. Geological Survey; silica not included in dissolved solids.
1141	...do.....	11-14-64	19.0	0.8	15 0.75	16 1.29	924 40.19	12 0.31	8 0.13	33 1.10	302 6.29	1,200 35.54	0.5 0.03	0.1 0.00	...	2,570	102	4,580	10.0	Analyses by U.S. Geological Survey; silica not included in dissolved solids.
1282	...do.....	6-16-65	22.0	...	1.6 0.08	1.0 0.08	133 5.80		137 2.25	34 1.10	28 0.58	68 1.92	2.1 0.11	...	...	335	8	640	9.4	Analyses by U.S. Geological Survey; silica not included in dissolved solids.
1283	...do.....	6-10-64	24.5	43	54 2.69	29 2.38	42 1.83	1 0.03	244 4.00	0	101 2.10	28 0.79	0.6 0.03	3 0.05	0.13	422	36	700	8.5	
1343	...do.....	9-3-64	...	14	4.0 0.20	0.7 0.06	63 2.74	...	108 1.77	16	...	...	...	...	...	...	13	346	9.2	Analyses by U.S. Geological Survey.
1347	...do.....	7-28-64	...	41	80 3.99	18 1.48	64 2.78	2 0.05	283 4.64	0	142 2.78	24 0.68	...	...	0	512	277	710	8.1	Do.
1756	...do.....	12-24-64	18.0	3.7	31 1.55	12 0.97	207 9.02		38 0.62	0	63 1.31	340 9.59	0.3 0.02	0.2 0.00	...	676	126	1,310	7.8	
1962	Limestone..	6-11-64	...	110	52 2.59	57 4.69	1,272 55.33	27 0.69	917 15.03	0	385 8.02	1,400 39.49	2.2 0.06	1 0.02	0.89	3,760	366	5,400	8.3	
1963	...do.....	...do...	...	110	56 2.79	61 5.02	1,204 52.33	25 0.64	718 11.77	0	375 7.43	1,440 40.62	2.2 0.06	1 0.02	1.16	3,630	397	5,400	8.5	
2374	Limestone(?)	11-13-65	21.5	68	272 13.57	154 12.63	1,450 63.11		1,300 21.31	0	568 11.83	1,990 56.14	0.5 0.03	0.1 0.00	...	5,140	1,310	8,160	7.6	Do.

¹Dissolved solids (sum) are computed by adding 0.49 bicarbonate + other determined constituents.

²The Department of Agricultural Chemistry and Soils uses a brown cresol green-methylred indicator solution for determining titration end points of bicarbonate and carbonate. These end points do not always correspond exactly to the selected pH end points of 8.3 and 8.3 that are used by the U.S. Geological Survey water-quality laboratories. For example, a sample may have a pH value of slightly more than 8.3, yet the titration with the indicator solution may indicate no carbonate. All pH values determined in laboratory.

TABLE 4.—Chemical analyses of water from the saturated zone of the alluvial deposits

[Analyses in milligrams per litre and milliequivalents per litre except as indicated; upper figure for all chemical constituents is reported in milligrams per litre; lower figure for ions is reported in milliequivalents per litre; analyses by Department of Agricultural Chemistry and Soils, University of Arizona, except as indicated. Leaders (...) indicate no data available]

Well No. (pl. 1)	Date of collection (month, day, year)	Temperature (°C)	Silica (SiO ₂)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO ₃)	Carbonate (CO ₃)	Sulfate (SO ₄)	Chloride (Cl)	Fluoride (F)	Nitrate (NO ₃)	Boron (B)	Dissolved solids (sum) ¹	Hardness as CaCO ₃	Specific conductance (micro-mhos per cm at 25°C)	pH ²	Remarks	
0104	6-24-71	18.0	36	540	180	1,500	23	135	0	1,100	2,900	0.9	0.7	1.1	6,350	2,100	10,100	7.5	Analyses by U.S. Geological Survey. Do. Do.	
0311	6-23-71	18.0	37	26.95	14.81	65.25	0.59	2.21	0	22.90	81.81	0.05	0.01	0.60	3,250	970	5,570	7.8		
0516	6-25-64	20.0	42	12.48	6.99	34.36	0.36	2.26	0	500	1,500	1.2	0.8	0.14	1,840	532	2,950	8.2		
0722	6-24-64	18.0	48	7.14	3.45	20.56	0.23	5.69	0	10.41	42.32	0.06	0.01	0.14	10,300	1,370	17,100	7.5		
0724	6-23-71	23.0	27	10.98	16.37	148.68	0.79	8.00	0	5.10	20.14	0.04	0.03	1.9	1,770	200	3,280	8.2		
1134	6-12-64	...	4	2.05	1.98	26.10	0.14	4.06	0	850	5,340	1.2	0	0.51	3,850	281	5,600	8.1		
1135	6-12-64	17.0	8	297	111	950	20	68	0	2.00	28.98	0.08	0	0.60	1,670	423	2,900	7.9		
1755	7- 8-64	21.0	10	14.82	9.13	41.32	0.51	1.11	0	605	1,850	0.8	0.02	0.24	10,100	3,250	15,500	8.1		
1957	7- 8-64	18.0	4	35.48	28.38	109.90	0.38	7.75	0	3.96	20.31	0.07	0.03	1.08	1,340	401	2,450	8.2		
2161	7- 8-64	21.5	23	1.00	2.96	14.88	0.26	2.72	0	26.02	141.00	0.12	0.03	0.15	1,540	91	2,900	8.2		
2164	6-11-64	16.5	38	1.10	0.66	23.66	0.03	2.64	0	190	670	0.05	0.02	0.10	7,130	3,210	10,200	7.3		
2165	6-11-64	19.5	8	57.09	6.83	57.42	0.44	4.97	0	3.96	18.90	0.03	0.02	0.73	19,200	1,580	31,500	8.4		
2372	6-10-64	...	16	5.59	59.72	269.70	2.25	8.72	0.23	1,025	10,810	0.6	0.03	3.07	7,910	914	12,500	7.7		
				104	158	2,670	39	271	0	21.34	305.00	0.03	0.11	1.38						
				5.19	13.00	116.10	1.00	4.44	0	15.20	114.50	0.07	0							

¹Dissolved solids (sum) are computed by adding 0.49 × bicarbonate + other determined constituents.
²All pH values determined in laboratory.

December 1968 was much above average, particularly during the period December 1967 through April 1968, and flushing by floodwater caused a reduction in the ground-water salinity of the alluvial deposits.

The effects of variations in discharge of the Gila River on specific conductance of ground water in the alluvial deposits are shown in figure 5. Two periods of above average discharge were in early 1966 and early 1968, and one extended period of below average discharge occurred between July 1968 and July 1971. Values of specific conductance generally are lower after periods of above average runoff and higher during periods of below average runoff, although this correlation is not always evident for short periods.

The lowest value of mean specific conductance, 4,270 micromhos, for the period June 1964 to June 1972, was obtained in December 1964 and probably was caused by the large amount of runoff in August and September 1964 (figs. 5A, B). The highest value, 9,200 micromhos, was during June 1967 following a year of below average runoff in the Gila River. In the latter half of 1967 and the first half of 1968, stream discharge was considerably above average, and the mean specific conductance of ground water declined during 1968 and 1969 to a low of 6,480 micromhos in January 1970. Values increased to 7,840 micromhos in June 1971, which was near the end of a prolonged period of below average stream discharge. Details of the specific-conductance variations during the period of above average stream discharge from August 1971 to January 1972 are not defined.

The variations in specific-conductance values of ground water in the alluvial deposits versus stream discharge are even more strikingly shown by a comparison of data from individual wells and stream discharge (figs. 5B, C). About 70 percent of the wells, from which sufficient specific-conductance data were collected, showed an inverse relation between specific conductance and stream discharge. The relation is best illustrated by data from wells nearest the river and least, if at all, from wells farthest from the river. Well 0103 is adjacent to the river and well 0102 is about 0.3 mile (0.5 km) from the river (pl. 1). Specific-conductance data from each well show: A sharp decrease after the above average streamflow in early 1966 and August 1967 to May 1968, and a general increase during most of the prolonged period of below average stream discharge from June 1968 to June 1971. The degree to which specific-conductance changes were detected depended not only on the distance of the well from the river but also on whether the well was inundated by floodwater and how long inundation occurred.

Fluctuations and maximum and minimum of values of specific conductance were greater from 1964 to about 1968, which corresponded to the period of greatest fluctuation of stream discharge for the interval 1964 to 1972 (fig. 5). The magnitude of variation in specific conductance of ground

water from individual wells during the period 1964 to 1972 ranged from about 1,500 to 20,000 micromhos (approximately 1,000 to 13,000 mg/l of dissolved solids); fluctuations of between 5,000 and 10,000 micromhos (approximately 3,200 and 6,400 mg/l of dissolved solids) were the most common, however.

Temperatures of ground water in the saturated zone of the alluvial deposits ranged from about 10° to 22°C. Temperatures generally were lower and fluctuated more in ground water next to the river than those in ground water farthest from the river. Temperatures fluctuated as much as 10°C in ground water from wells next to the river, but fluctuations generally were less than 3°C in water from wells near the outer margins of the flood plain. Lowest and highest annual ground-water temperatures were recorded in March and September, respectively.

GROUND WATER IN THE UNSATURATED ZONE

Ground water from the unsaturated zone was sampled along the Gila River near wells 0103 and 1751 where the depth to water ranged from about 1 to 10 feet (0.3 to 3 m) below land surface during the period of the study. As many as five 2-inch (51-mm) diameter plastic soil-water tubes were inserted into auger holes that ranged in depth from 3 to 7 feet (1 to 2 m) at each location. Each tube had a porous ceramic cup on the lower end and a petcock fitted into a rubber stopper on the upper end. Air was evacuated from the tube, and the petcock was closed to obtain a water sample. The time required for sufficient water to pass through the porous cup ranged from a few hours, if the soil around the porous cup was nearly saturated with water, to several days or weeks, if the soil-moisture content was low. Thus, the date when the sample was removed from the soil-water tube (date of collection) does not represent the actual date when the water entered the tube from the soil; the sample may represent water that entered the tube any time after vacuum was applied on the previous sampling date. Although this method of sampling water was somewhat crude, it has provided some insight into the variations of dissolved-solids concentrations and chemical composition of the water in the unsaturated zone.

The site near well 1751 was established in June 1965. In the spring of 1966 and summer of 1967 the site was inundated by backwater and silt from San Carlos Reservoir. The sampling tubes were uncovered and maintained until February 1968 when the deposition of more than 7 feet (2 m) of silt forced the abandonment of the site. The site at well 0103 was established in March 1965 and was destroyed by floodwater in March 1966. The site was reestablished in March 1967 about 50 feet (15 m) from the original site. The data from the site near well 0103, although not as abundant or as continuous as the data near well 1751, indicate similar trends. Specific-conductance values, which ranged from about 1,000 to

GILA RIVER PHREATOPHYTE PROJECT, ARIZONA

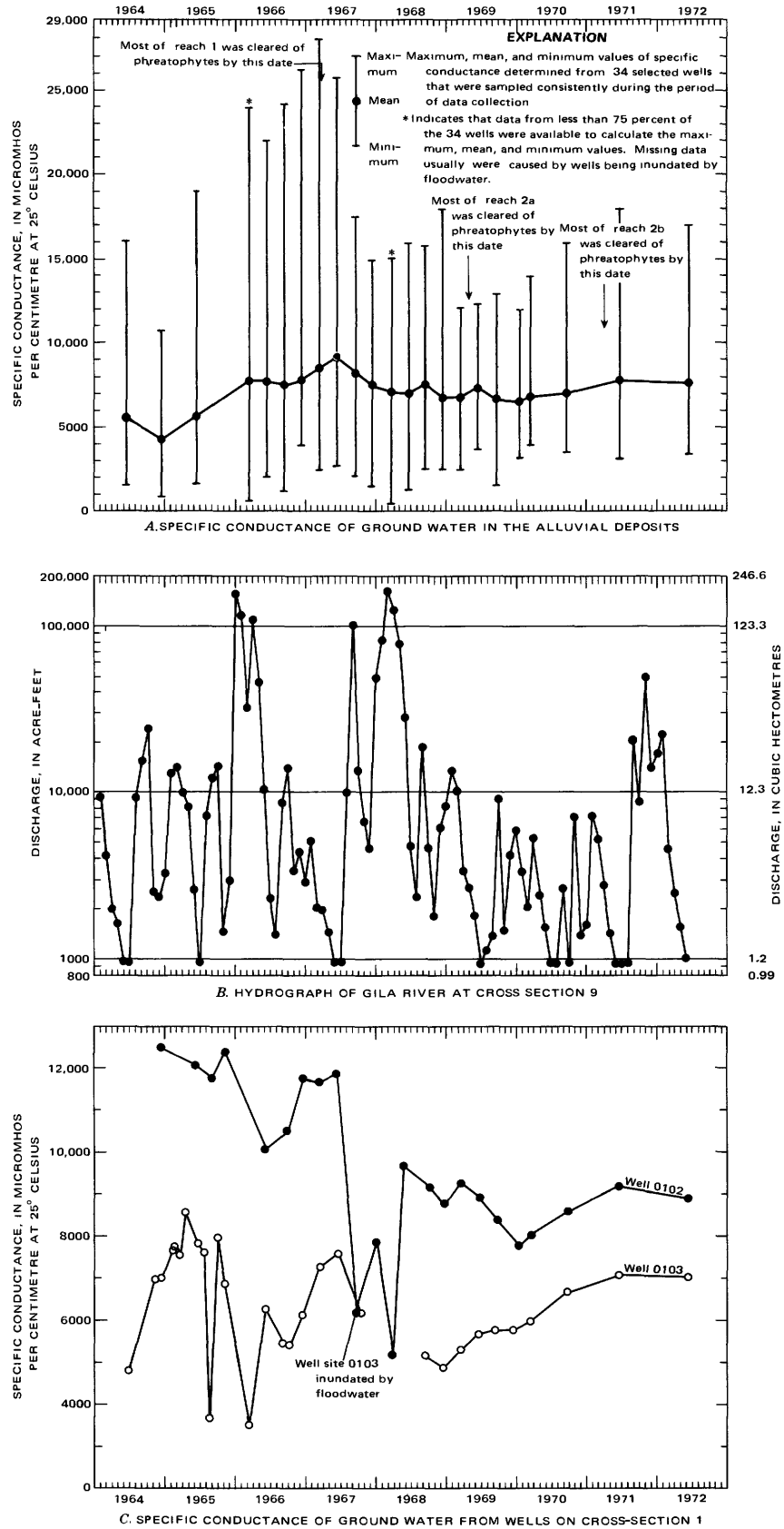


FIGURE 5.—Discharge of the Gila River and specific conductance of ground water from the saturated zone of the alluvial deposits.

22,000 micromhos (about 600 to 14,000 mg/l of dissolved solids), had similar variations as those of ground water in the saturated zone (fig. 6). Values were highest from water in the unsaturated zone following periods of prolonged low flow in the river; concentrations were lowest after major flood events, which flushed the accumulation of salts from the unsaturated zone. During periods of prolonged low flow, not only did the specific conductance of the water in the unsaturated zone increase, but it was higher near the land surface than near the water table (data from well 0103, June 1965, fig. 6B, table 5; well 1751, Aug. 1965, fig. 6C, table 5).

The chemical composition of the water changed from a sodium chloride type near the water table to a calcium chloride type near the land surface (fig. 7). Flushing of salts from the soil by large flood events reduced the specific conductance and changed the water to a sodium chloride type throughout the zone or a sodium chloride type near the water table and a calcium sodium bicarbonate type near the land surface (data from January 1967, figs. 6C, 7, table 5).

Specific conductance of the soil water was as high as 22,000 micromhos (about 14,000 mg/l of dissolved solids) at the site near well 1751 (fig. 6C) and about 15,000 micromhos (about 9,000 mg/l of dissolved solids) at the site near well 0103 in the summer of 1965 (fig. 6B). During the winter of 1965-66 the sites were inundated by floodwater, and specific-conductance values dropped to as low as 5,000 micromhos (about 3,000 mg/l of dissolved solids) at site 0103 in early 1966 and to about 2,000 micromhos (about 1,300 mg/l of dissolved solids) at site 1751 by mid-1966. The specific-conductance values generally increased to as much as 6,000 micromhos during the period mid-1966 to early 1968 corresponding with a period of below average streamflow (figs. 6A, C).

During the period mid-1966 to early 1968, zonation of specific conductance formed in the unsaturated zone, but the reverse of that developed prior to the flood event in the winter of 1965-66—that is, values were higher from water nearest the water table (fig. 6C). Data from samples collected in early 1968, however, indicate that the near-surface buildup of salinity in the unsaturated zone had begun.

The near-surface buildup of dissolved solids in water in the unsaturated zone during prolonged periods of low streamflow at the sites near wells 0103 and 1751 is caused by the upward migration of water from the saturated zone and subsequent concentration by evapotranspiration. The reason for the change from a sodium chloride composition of soil water near the water table to a calcium chloride composition near the ground surface is not so apparent, but it may be caused by ion exchange of sodium from the water for calcium in the sediments as the water moves upward through the unsaturated zone. The calcium-rich water might also be caused by differential rates of upward

migration of sodium and calcium in the unsaturated zone. Sodium may be more concentrated than calcium in the salt crusts that form in places on the surface of the alluvial deposits where the water table is close to the surface.

Most of the calcium chloride water contained large amounts of bicarbonate, and the water may have been saturated with respect to calcite at the indicated pH of the water. For example, a sample collected on September 1, 1965, from 3 feet below land surface at the site near well 1751 contained 13,500 mg/l of dissolved solids of which 2,308 mg/l were calcium and 561 mg/l were bicarbonate (table 5). The laboratory pH of the sample was 7.3, but this value may not be representative because the pH could have changed from the time of collection until the time the laboratory measurement was made. Calcium carbonate precipitated in the sample bottles from some samples of soil water after standing several weeks. The large amounts of calcium and bicarbonate in the water probably are prevented from precipitating in the unsaturated zone by a high partial pressure of carbon dioxide, which may be 10 times that in air (Bear, 1955, p. 205), caused by decay of organic material and root transpiration. In addition, calcite is more soluble as the salinity of water increases.

EFFECT OF PHREATOPHYTE REMOVAL ON WATER QUALITY OF THE ALLUVIAL DEPOSITS

An evaluation of the data presented in the previous sections shows that the fluctuations of dissolved-solids concentrations of water in the alluvial deposits and the Gila River are large. The fluctuations of dissolved-solids concentrations of water in the alluvial deposits are caused by the large fluctuation of streamflow of the Gila River and evapotranspiration. With this large amount of "natural" variation in dissolved-solids concentrations the detection of changes, if any, in water quality due to phreatophyte removal is complex.

The factors that could cause changes in water quality in the alluvial deposits are discussed qualitatively in the first part of this section. Results of a statistical analysis of the effects of phreatophyte removal on the specific conductance of water in the alluvial deposits are presented in the second part of the section.

FACTORS RESPONSIBLE FOR CHANGES IN WATER QUALITY

The Gila River, by flushing away accumulated salts and recharging fresh water, tends to reduce the dissolved-solids concentrations in the alluvial deposits. Conversely, evapotranspiration during periods of prolonged low flow increases the concentration of salts. If other factors were constant, the removal of the phreatophytes from the Gila River flood plain would reduce the amount of evapotranspiration, and a greater amount of water would be

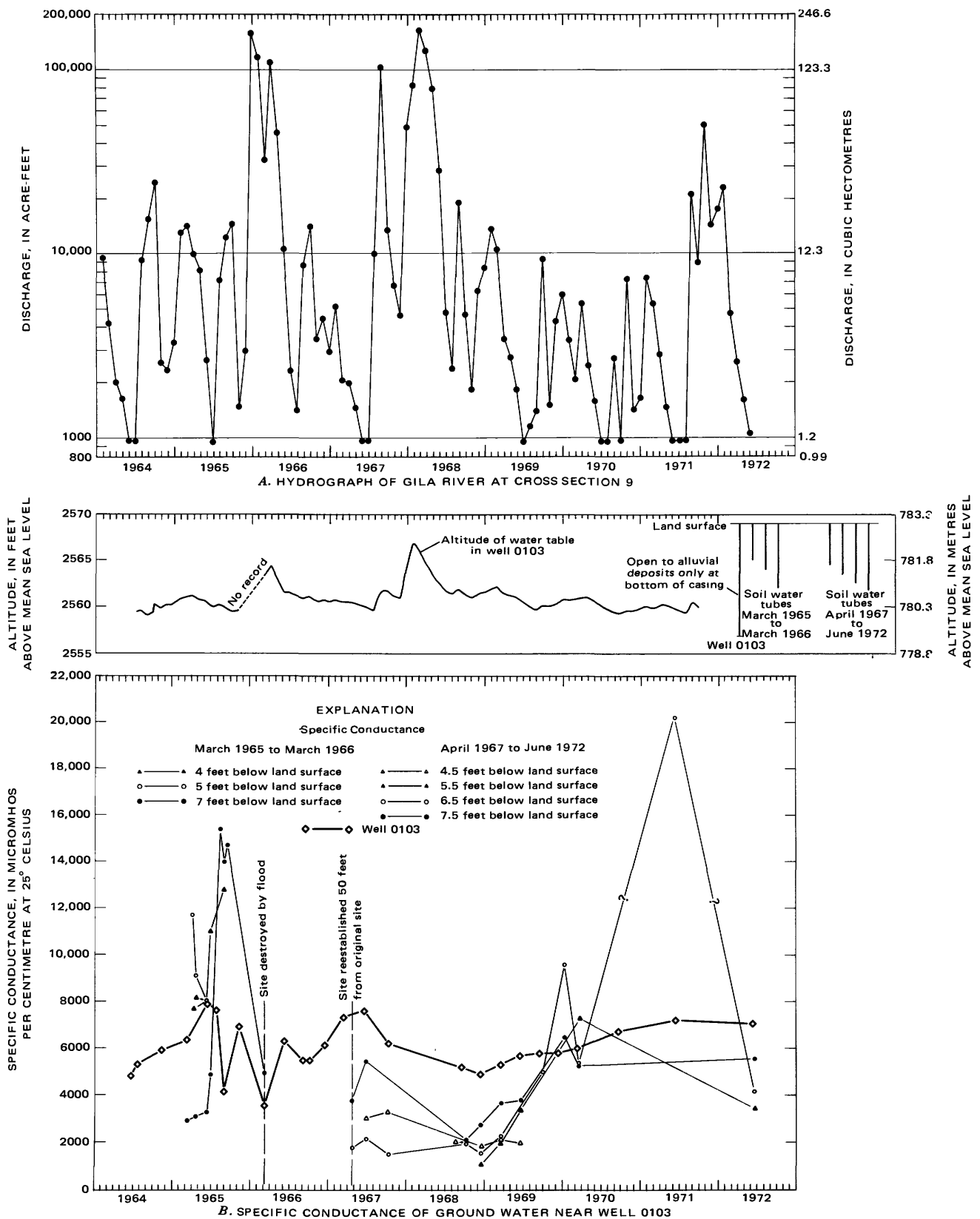


FIGURE 6 (above and facing page). — Discharge of the Gila River, ground-water altitudes, and specific conductance of ground water from the unsaturated zone and saturated zone of the alluvial deposits.

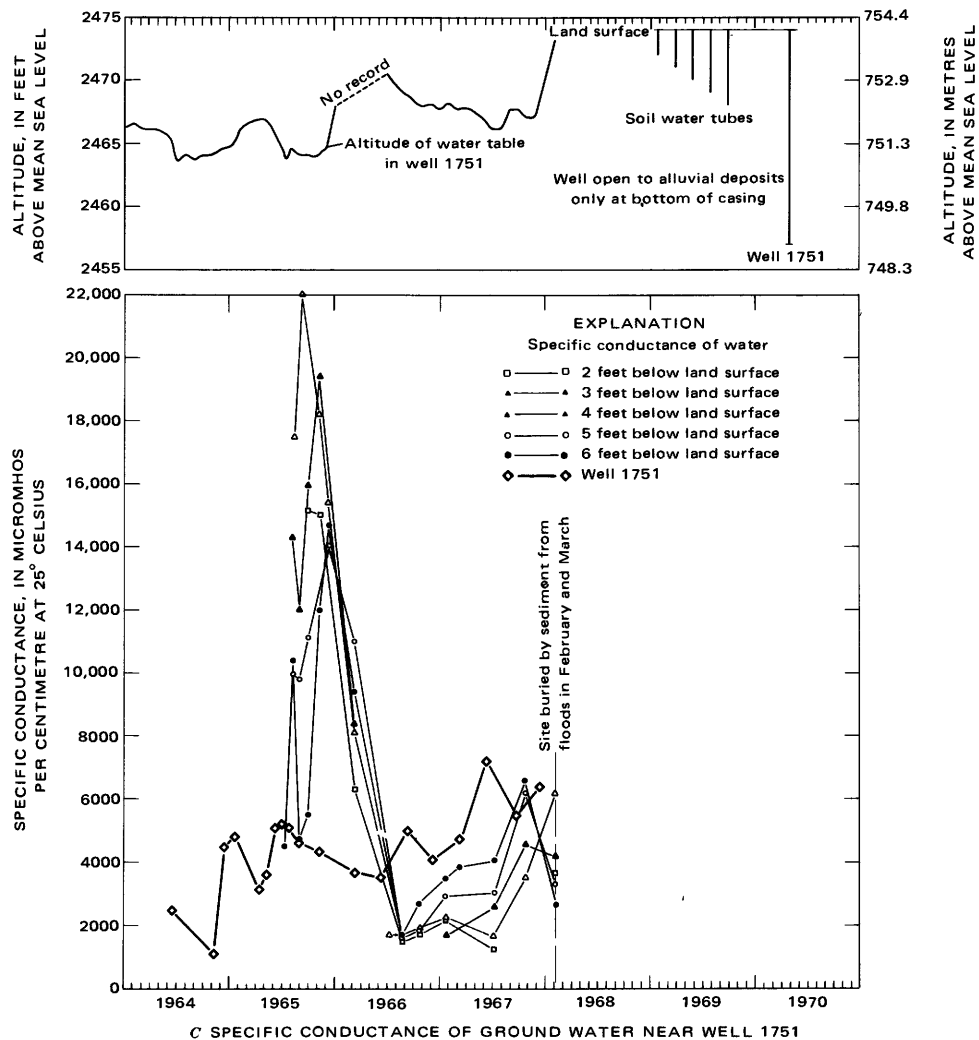


FIGURE 6 — Continued.

present in the ground-water system. The increased amount of ground water may cause the water levels to be higher and (or) the base flow of the Gila River to be greater. After the phreatophytes were removed from reach 1, the evapotranspiration was reduced from 50 inches (1,270 mm) per year to 20 inches (508 mm) per year (Hanson, 1972b), and water levels did not decline as rapidly during the growing season as did water levels before removal of vegetation (F. P. Kipple, oral commun., 1972). Base flow of the Gila River increased after clearing, but antecedent moisture conditions before each reach was cleared made the calculations for the actual amount of increase very complex (R. L. Hanson, oral commun., 1974). Removal of the phreatophytes should likewise cause a less rapid increase in dissolved-solids concentrations of the ground water during the growing season. However, upward movement and subsequent direct evaporation of ground water from the cleared surface occurred even after phreatophytes were removed. Soil-moisture data from the project area indicated that, in terms of the liquid phase, this upward movement of water in the

unsaturated zone probably is not significant where the depth to the water table is more than about 6 feet (2 m) below land surface (F. P. Kipple, oral commun., 1973; McQueen and Miller, 1972, p. E47).

Other factors, such as infiltration of precipitation and accumulation of salts in the soil as a result of water exuded by saltcedar, are of minor importance in affecting water quality. Effects of increased infiltration of rainfall on the cleared surface probably are negligible; even though the phreatophytes no longer are present to intercept the precipitation, the precipitation evaporates readily from the cleared ground surface.

Saltcedar can grow and thrive in areas of salty water by excreting fairly concentrated solutions of salt through the leaf surfaces by a process known as guttation or through "salt glands" (Hem, 1950, p. 80; 1967, p. C2). One sample of this exuded water contained 41,100 ppm (parts per million) of dissolved solids of which 18,200 ppm and 13,800 ppm were chloride and sodium, respectively (Hem, 1950, p. 81). The removal of the exuded water and salt from

TABLE 5.—*Chemical analyses of water from the unsaturated zone of the alluvial deposits*
 [Analyses in milligrams per litre and milliequivalents per litre except as indicated; upper figure for all chemical constituents is reported in milligrams per litre; lower figure for ions is reported in milliequivalents per litre; analyses by Department of Agricultural Chemistry and Soils, University of Arizona]

Date of collection	Depth below land surface (ft. fig. 7)	Silica (SiO ₂)	Calcium (Ca)	Magnesium (Mg)	Sodium plus potassium (Na + K)	Bicarbonate (HCO ₃)	Carbonate (CO ₃)	Sulfate (SO ₄)	Chloride (Cl)	Fluoride (F)	Nitrate (NO ₃)	Dissolved solids (sum) ¹	Hardness as CaCO ₃	Specific conductance (micromhos per cm at 25°C)	pH ²
Site near well 0103															
June 9, 1965	4	90	926	198	669	214	0	640	2,620	1.0	12	5,170	3,100	8,000	7.5
	5	105	46.21	16.28	29.10	3.51	0	13.32	73.88	0.05	0.19	5,030	2,210	8,000	7.2
	7	60	596	174	1,010	460	0	760	2,260	1.4	9	1,990	428	3,220	7.4
			29.74	14.31	43.94	7.54	0	15.82	63.73	0.07	0.15				
			112	35	589	478	0	270	744	2.6	1				
			5.59	2.88	25.62	7.83	0	5.62	20.98	0.14	0.02				
Site near well 1751															
Aug. 6, 1965	3	80	2,280	75	1,840	644	0	1,550	5,560	0.3	14	11,600	8,700	17,000	7.1
	4	76	1,13.77	6.17	80.04	10.55	0	32.27	156.85	0.02	0.23	9,640	5,170	14,300	7.1
	5	66	1,880	109	1,450	688	0	1,150	4,640	0.6	2	6,250	3,280	9,970	6.9
	6	64	93.81	8.96	63.07	11.28	0	23.94	130.89	0.03	0.03	6,830	3,310	10,400	6.9
	3	33	960	212	991	629	0	850	2,860	0.4	2	13,500	11,500	22,000	7.3
	4	38	47.90	17.43	43.11	10.31	0	17.70	80.68	0.02	0.03	8,390	4,370	12,000	7.3
	5	39	964	212	1,200	693	0	1,050	3,000	0.2	2	7,070	3,160	9,800	7.4
	6	39	48.10	17.43	52.20	11.36	0	21.86	84.63	0.01	0.03	3,050	894	4,700	7.4
	2	125	2,308	664	1,590	561	0	1,900	6,720	0.8	2	9,290	8,340	15,100	7.3
	4	45	115.17	54.61	69.17	9.19	0	39.56	189.57	0.04	0.03	11,300	8,350	16,000	7.1
	5	40	1,300	272	1,350	664	0	1,300	3,800	1.0	0	8,110	3,640	11,570	7.1
	6	40	64.67	22.37	58.72	10.88	0	27.07	107.20	0.05	0	3,630	1,150	5,500	7.1
	2	40	944	192	1,350	634	0	1,250	2,980	0.6	2	2,000	744	2,000	7.5
	3	35	47.11	15.79	58.72	10.39	0	26.02	84.07	0.03	0.03	1,410	598	2,080	7.5
	4	34	254	62	800	586	0	490	1,120	0.7	0	1,410	598	2,080	7.5
	5	35	12.67	5.10	34.80	9.60	0	10.20	31.60	0.04	0.0	1,220	342	1,700	7.7
	6	38	2,230	664	59	156	0	935	5,200	0.2	2	1,520	706	2,500	7.8
	2	40	111.28	54.61	25.7	2.56	0	19.47	146.69	0.01	0.03	1,820	824	3,200	7.6
	3	40	2,300	630	829	737	0	1,650	5,540	0.6	2	3,200	1,150	5,500	7.1
	4	40	114.77	51.81	36.06	12.08	0	34.35	156.28	0.03	0.03	2,000	744	2,000	7.5
	5	40	53.89	18.42	65.68	14.47	0	27.06	96.48	0.03	0.02	1,400	598	2,080	7.5
	6	40	340	72	906	834	0	511	1,350	0.5	0	1,400	744	2,000	7.5
	2	40	16.97	5.92	39.41	13.67	0	10.64	38.08	0.03	0	1,400	744	2,000	7.5
	3	35	234	39	266	1,410	0	64	66	0.3	1	1,400	744	2,000	7.5
	4	34	11.68	3.21	11.57	23.11	0	1.33	1.86	0.02	0.02	1,410	598	2,080	7.5
	5	35	182	35	328	1,320	0	72	106	0.8	1	1,410	598	2,080	7.5
	6	38	9.08	2.88	14.27	21.63	0	1.50	2.99	0.04	0.02	1,220	342	1,700	7.7
	2	34	92	48	307	839	0	145	178	0.7	2	1,520	706	2,500	7.8
	3	35	4.59	3.95	13.35	13.75	0	3.02	5.02	0.04	0.03	1,820	824	3,200	7.6
	4	35	202	49	299	654	0	2.71	13.65	0.05	0.03				
	5	38	10.08	4.03	13.00	10.72	0	145	676	0.06	1.2				
	6	38	236	57	363	620	0	3.02	19.07	0.06	0.02				
			11.78	4.69	15.79	10.16	0								

¹Dissolved solids (sum) are computed by adding 0.49 × bicarbonate + other determined constituents.
²All pH values determined in laboratory.

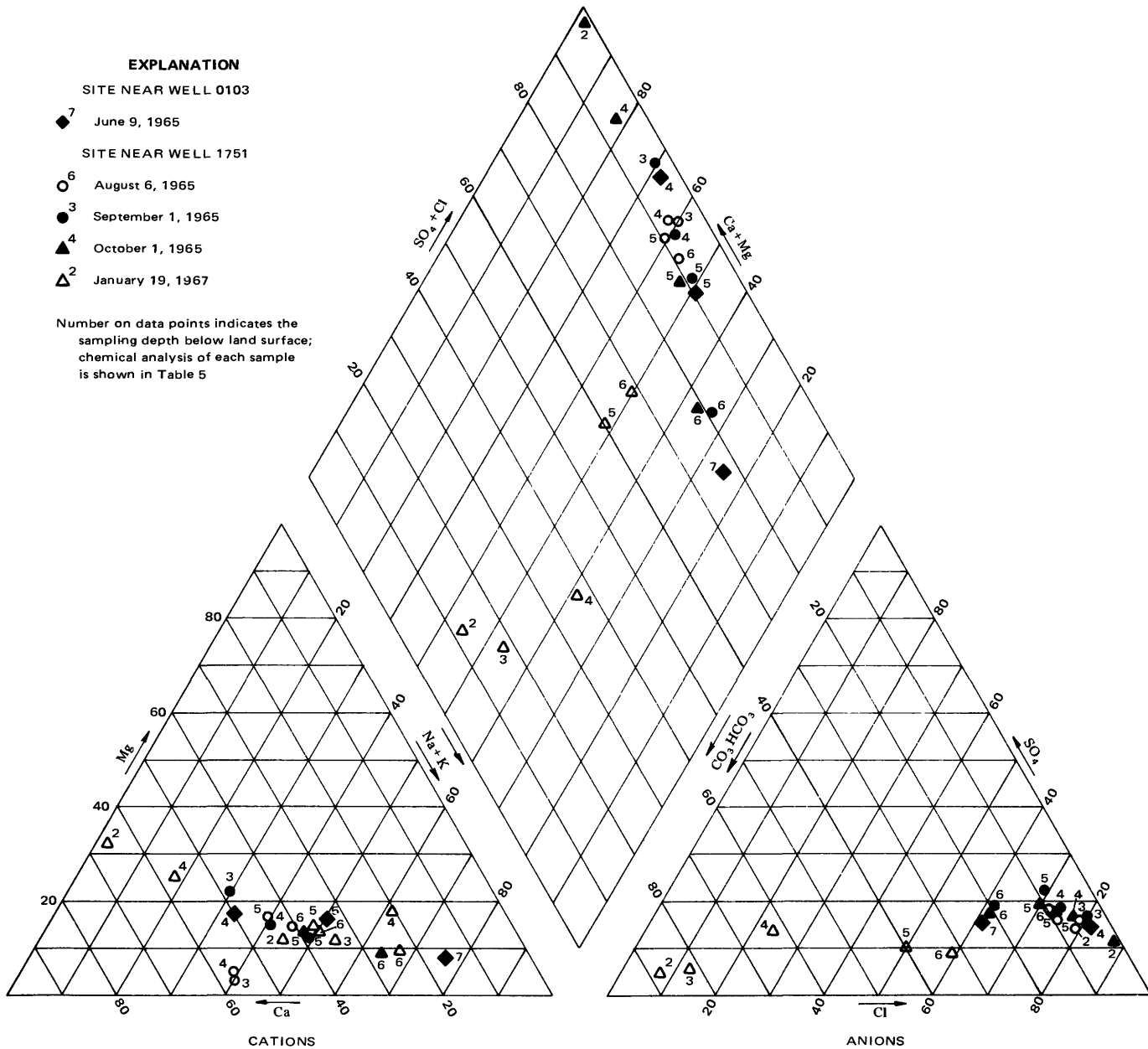


FIGURE 7.—Chemical composition of water from the unsaturated zone of the alluvial deposits.

the leaves and stems by dew, precipitation, and wind temporarily may cause large concentrations of salt to accumulate in the upper part of the soil. The presence of the salt in the soil was indicated by the rapid corrosion of steel well casings and aluminum soil-moisture access pipes at the point where they emerged from the ground. The very rapid decrease in specific conductance of ground water after a major flood event, especially near the river, indicated that salt accumulations in the unsaturated zone resulting either from exuded water or from upward migration and evaporation of water from the water table have no major effect on the salinity of ground water in the saturated zone of the alluvial deposits.

Removal of phreatophytes in the area surrounding the observation wells caused no significant change in the specific conductance of water in the alluvial deposits. The general pattern of graphs of specific conductance versus time for all wells in the alluvial deposits for which sufficient data were available is similar, regardless of the date of phreatophyte removal—that is, large fluctuations occurred prior to 1968 and much smaller fluctuations occurred after 1968. (See section on "Water Quality, Alluvial Deposits.") Wells on the right side of the river on cross sections 1 and 3 were in areas that were cleared of phreatophytes in 1964, yet the specific-conductance plots of the wells in this area show the same general pattern

before and after 1968 as those in areas that were cleared of phreatophytes at a later date. These graphs indicate that any changes in water quality caused by phreatophyte removal are of less magnitude than the normal variations in water quality that are controlled by the effects of streamflow of the Gila River and of evapotranspiration and, therefore, are not detectable.

STATISTICAL ANALYSIS OF EFFECTS OF PHREATOPHYTE REMOVAL ON SPECIFIC CONDUCTANCE OF WATER IN THE ALLUVIAL DEPOSITS

By H. W. HJALMARSON

The objective of this analysis is to determine whether the specific conductance of water in the alluvial deposits changed as a result of the removal of phreatophytes. A simple method of determining whether a change occurred is the comparison of the mean of the preremoval specific-conductance measurements with the mean of the postremoval specific-conductance measurements, using statistical tests. The first statistical test used is the "Student's" t , where the specific-conductance measurements are assumed to be from normally distributed populations. The second is a rank-sum test, where the preremoval and postremoval measurements are assumed to be from continuously distributed populations that differ only in their means. These two tests are advantageous because of their simplicity and because all measurements of specific conductance are used for each test. When using these tests, however, a change in specific conductance of ground water might be caused by flooding of the Gila River or by prolonged periods of evapotranspiration in absence of flooding and not caused by the removal of the phreatophytes. Conversely, a sameness in measured specific conductance of ground water might be the result of offsetting actual conductance changes caused by the phreatophyte removal with a flow change of the Gila River. Thus, a third test known as a factorial experiment is used that considers the effect of a single factor, the phreatophyte removal.

For the first statistical test all measurements of specific conductance can be used to test the hypothesis that the mean of the preremoval conductance is equal to the mean of the postremoval conductance. A two-sided "Student's" t test of the true difference between the means of two normal populations is used. The means of the 342 preremoval and 302 postremoval conductance measurements were 7,410 and 7,130 micromhos, respectively. The hypothesis could not be rejected at a statistical confidence level of 95 percent and, thus, a change of ground-water conductance is unlikely.

The second statistical test used is the rank-sum test of the true difference between means of two continuous probability distributions that might not be normal (Dixon

and Massey, 1957, p. 289). The hypothesis that the means of the two populations are equal is rejected if the test statistic, T' , is significantly large or significantly small where T' is the sum of the ranks of the 302 postremoval conductance measurements. The computed T' value of 96,060 is well within the 5 percent critical limits; therefore, the hypothesis cannot be rejected. The preremoval and postremoval measurements of specific conductance probably are not from different populations.

The equality-of-means hypothesis could not be rejected using either of the tests; therefore, unequal means of the preremoval and postremoval specific-conductance measurements are unlikely. If the factors affecting ground-water specific conductance before the removal of vegetation were the same as those after the removal, it might be concluded that the effect of the vegetation removal on the specific conductance of water in the alluvial deposits was insignificant. A change of ground-water conductance resulting from the vegetation removal may be masked because the factors affecting the amount of ground-water specific conductance, such as the amounts of streamflow in the Gila River (the main factor), were not the same before and after the removal of the phreatophytes. The following test considers the significance of each factor affecting ground-water specific conductance.

In order to isolate the effect of vegetation removal, the third test utilizes a reach of river where the phreatophytes are removed and a reach of river where the vegetation cover is undisturbed. These reaches of river are referred to as the removal and control reaches, respectively. The removal and control reaches are considered as two levels of reach; the periods before and after the removal of the phreatophytes are considered as the two levels of period. Thus, reach and period are the two factors of the experiment, and each factor is at two levels. The combination of the levels of each factor yields four experimental conditions of the factorial experiment for which ground-water specific conductance was measured. The analysis of variance technique for testing of a significant change is used, and the mathematical model for each of the three reaches from which the phreatophytes were removed is

$$X_{ijk} = \mu + R_i + P_j + (RP)_{ij} + \epsilon_{ijk}$$

where

- X_{ijk} = k th measurement of conductance within the i th reach during the j th period,
- μ = true mean effect for whole experiment,
- R_i = effect of i th reach,
- P_j = effect of j th period,
- $(RP)_{ij}$ = effect of reach-period interaction,
- ϵ_{ijk} = random error present in the k th measurement on the i th reach and j th period.

The error term of the model is assumed to be an independently and normally distributed random effect with a mean value of zero and a variance equal at all combinations of reaches and periods. Also, the sum of all

reach, period, and reach-period effects is assumed to equal zero.

If a change in ground-water specific conductance of the removal reach follows the removal of phreatophytes and this change is different than a change in ground-water specific conductance of the control reach, there is an interaction between the periods and reaches. This interaction is a measure of the effect of phreatophyte removal on ground-water specific conductance provided the following conditions are met: (1) Movement of ground water between the removal and control reaches is negligible; (2) both reaches are subject to approximately the same factors affecting ground-water specific conductance; and (3) a change of a factor affecting ground-water specific conductance will result in similar changes of specific conductance in both the removal and control reaches. Effects of the movement of ground water between reaches on specific conductance are considered negligible because the average velocity of the ground water moving between the reaches is less than 400 feet (120 m) per year based on data from Hanson (1972a, p. F4, F25). Hanson (1972b, p. 12) estimated that the total surface and sub-surface flow into reach 1 is about 210,000 acre-feet (259 hm³) per year, of which 95 percent is contributed by the Gila River and only 5 percent by tributary runoff, precipitation, and ground-water inflow. In addition, the amount of variation in specific conductance of water in the Gila River is large, and the river has a very significant flushing effect on the ground water near the river. Because the flow changes of the Gila River are the principal cause of changes in specific conductance of ground water, the specific conductance of ground water for the reaches is affected similarly by a change in the amount of flow of the river. Thus, if the change of ground-water specific conductance of the control reach is significantly different from the change of ground-water specific conductance of the removal reach after the phreatophytes are removed, this difference is due to the removal of phreatophytes (fig. 8).

Reaches 1, 2a, and 2b are analyzed separately in this analysis because the phreatophytes in each reach were removed at different times (table 6). Reach 2a is used as the control for reaches 1 and 2b, and reach 1 is used as the control for reach 2a. Reach 2b is not used as a control reach because a number of observation wells in the reach were inundated by water from San Carlos Reservoir following the high flows during the winter of 1967-68. Four of the wells in the reach were inundated for at least a year. Reach 3 is not used in the analysis because of the limited amount of data. The results of the analysis of variance and tests for significant effects are given in table 7. The hypothesis of interest is that there is no interaction between the reach and period factors. Bias due to missing measurements of specific conductance was removed by treating the data as a case of disproportion subclass numbers (Ostle, 1960, p.

300). For reaches 1, 2a, and 2b, the computed value of F for the reach-period interaction is less than the value of F at the 5-percent level of significance. Therefore, the effect of interactions is not significant for any of the reaches, and a significant change of ground-water specific conductance resulting from the removal of the phreatophytes is unlikely.

Inherent in the analysis is the effect of variable amounts of flow in the Gila River on the measured ground-water specific conductance. The magnitude of the conductance change corresponding to a change of river flow varied from well to well and therefore increased the magnitude of the error (ϵ_{ijk}). This increase of error could be significant because the computed values of F given in table 7 are inversely proportional to the computed amounts of error. Had the flow of the Gila River been less variable, the conclusions reached might have been different; thus, only judicious use of the results should be made.

A significant change of ground-water specific conductance was not detected using the three tests. The conclusions reached are consistent, are based on statistical tests requiring different assumptions, and are based on a large number of specific-conductance measurements. Thus, the removal of the phreatophytes in the study reaches did not result in a specific-conductance change of ground water in the alluvial deposits that could be ascribed solely to removal rather than to changes in river discharge.

SUMMARY

The water quality in the Gila River Phreatophyte Project area is considered in terms of four hydrologic sources: the Gila River, the tributaries to the Gila River, the basin fill, and the alluvial deposits. The dissolved-solids concentrations and chemical composition of the Gila River ranged from about 300 mg/l and a calcium sodium bicarbonate type at high flows to about 4,800 mg/l and a sodium chloride type at low flows. Most of the year sodium and chloride are the principal ions in the river water. The Gila River is the main source of recharge to the alluvial deposits.

Water in tributaries to the Gila River generally contained less than 300 mg/l of dissolved solids and was a calcium bicarbonate type. The total amount of tributary flow was less than 10 percent of the flow of the Gila River, and the tributary flow had little effect on the water quality of the Gila River or on the ground water in the alluvial deposits.

The dissolved-solids concentrations of water from the basin fill ranged from about 200 to 5,000 mg/l. Water from the silt and sand facies contained 1,000 to 3,000 mg/l of dissolved solids in the fine-grained parts of the unit and less than 1,000 mg/l in the coarse-grained parts of the unit. Water from the limestone facies had the poorest quality and contained more than 3,000 mg/l of dissolved solids.

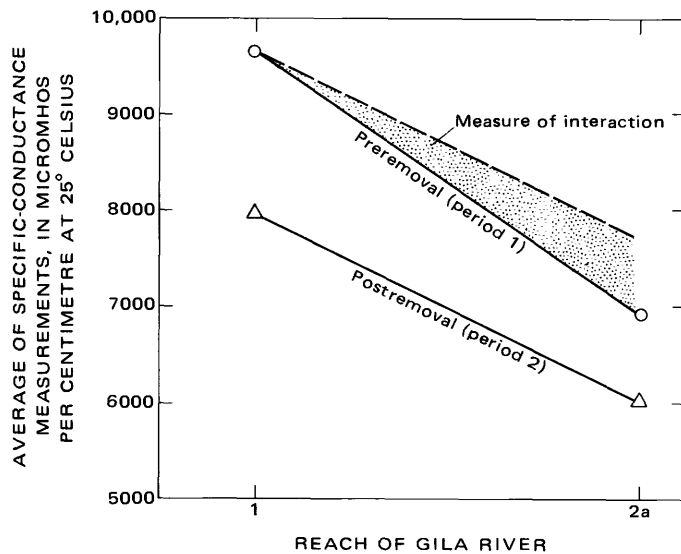


FIGURE 8.—Interaction of specific conductance of ground water between reaches 1 and 2a and periods 1 and 2.

Water that contained less than 500 mg/l of dissolved solids had a calcium bicarbonate to sodium bicarbonate composition, and water that contained more than 500 mg/l of dissolved solids had a sodium chloride composition.

The ground water in the alluvial deposits, which supports the growth of the phreatophytes in the project area, is considered in terms of the saturated zone and the unsaturated zone. Most of the data are from the saturated zone. The dissolved-solids concentrations of water in the saturated zone ranged from about 400 to 19,000 mg/l, but most concentrations ranged from 3,000 to 7,000 mg/l. The water is a sodium chloride type similar to water from the Gila River. The lowest concentrations of dissolved solids are near the Gila River, and concentrations increase with increasing distance from the river.

Water from the unsaturated zone of the alluvial deposits was sampled at two sites in the report area. Dissolved-solids concentrations ranged from about 600 to 14,000 mg/l. Concentrations were greatest in the upper part of the unsaturated zone following prolonged periods of low flow in the river during which time the sites were not inundated by floodwater. Inundation of the sites by floodwater flushed the accumulations of salts from the zone and removed the stratification of dissolved solids. The stratification redeveloped in the zone in absence of major river flooding. During periods when the dissolved-solids stratification was present, the chemical composition of the water ranged from a calcium chloride type in the upper part of the zone to a sodium chloride type near the water table.

Variations in dissolved-solids concentrations in water in the alluvial deposits are related mainly to evapotranspiration and the amount of flow in the Gila River. During periods of above average streamflow, the

TABLE 6.—Summary of data for factorial experiment

Reach	Period ¹	Condition of reach	Number of measurements	Average specific conductance, in micromhos
1	1	Phreatophytes	53	9,690
	2	Cleared	98	7,980
	3	...do.	65	6,870
	4	...do.	25	7,510
2a	1	Phreatophytes	58	6,920
	2	...do.	109	6,020
	3	Cleared	70	6,060
	4	...do.	28	6,520
2b	1	Phreatophytes	41	6,560
	2	...do.	47	8,510
	3	...do.	34	8,620
	4	Cleared	16	8,040
Total and average			644	7,280

¹Period 1, March 1966 to March 1967; period 2, June 1967 to March 1969; period 3, June 1969 to March 1971; period 4, June 1971 to June 1971.

TABLE 7.—Summary of two-way analysis of variance for ground-water specific-conductance measurements

Source of variation	Degrees of freedom	Mean square	Computed F	F _(1-0.05)
Reach 1				
Between reaches 1 and 2a	1	398,650,000	27.3	3.9
Between periods 1 and 2	1	118,670,000	8.1	3.9
Reach-period interaction	1	12,100,000	.8	3.9
Error	314	14,600,000	.....	.....
Reach 2a				
Between reaches 2a and 1	1	192,860,000	20.9	3.9
Between periods 2 and 3	1	20,020,000	2.2	3.9
Reach-period interaction	1	28,230,000	3.1	3.9
Error	338	9,230,000	.....	.....
Reach 2b				
Between reaches 2b and 2a	1	165,890,000	34.4	3.9
Between periods 3 and 4	1	690,000	.1	3.9
Reach-period interaction	1	7,760,000	1.6	3.9
Error	144	4,820,000	.....	.....

dissolved-solids concentrations of the water are low, and subsequent recharge of this water reduces the concentrations in water in the alluvial deposits. The amount of variation is dependent on the frequency, magnitude, and duration of major flood events. The amount of variation in dissolved-solids concentrations in water from individual wells for the period of the investigation (8 years) ranged from about 1,000 to 13,000 mg/l, but varia-

tions of between 3,200 and 6,400 mg/l were most common. Water from wells tapping the alluvial deposits near the river had the greatest variation in dissolved-solids concentrations, and water in wells farthest from the river had the least variation. The amount of these variations may have masked changes, if any, in dissolved-solids concentrations of water caused by phreatophyte removal.

The effects of the phreatophyte removal on the specific conductance of water in the alluvial deposits were analyzed using three statistical tests. The results of the "Student's" *t* test, a rank-sum test, and a factorial experiment indicate that the removal of phreatophytes did not significantly affect the specific conductance of water in the alluvial deposits.

The absence of a significant change of ground-water specific conductance for the area studied does not mean that phreatophyte removal will not result in detectable conductance changes of ground water in other areas. In the reach of river studied in this report, the water in the alluvial deposits was flushed or freshened by floodwater from the Gila River. This flushing may have masked the effects, if any, of the phreatophyte removal on the ground-water specific conductance, and therefore a change in specific conductance was not detected.

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