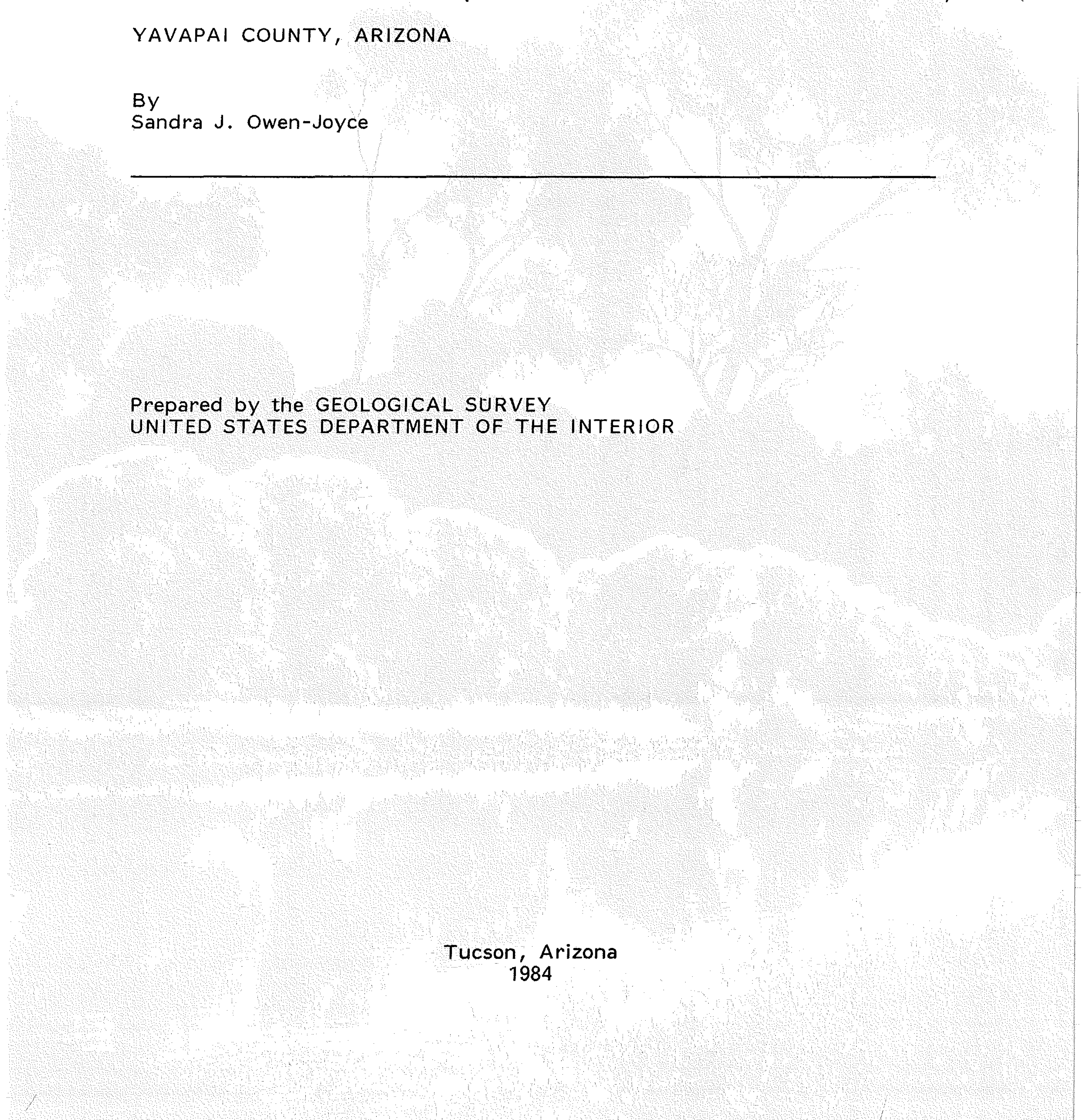
ARIZONA DEPARTMENT OF WATER RESOURCES
BULLETIN 3

HYDROLOGY OF A STREAM-AQUIFER SYSTEM IN THE CAMP VERDE AREA, YAVAPAI COUNTY, ARIZONA

By
Sandra J. Owen-Joyce



Prepared by the GEOLOGICAL SURVEY
UNITED STATES DEPARTMENT OF THE INTERIOR

Tucson, Arizona
1984

CONTENTS

ILLUSTRATIONS

[Plates are in pocket]

TABLES

For readers who prefer to use metric units, the conversion factors for the terms used in this report are listed below:

Multiply	By	To obtain
inch (in.)	25.4	millimeter (mm)
inch per hour (in./hr)	25.4	millimeter per hour (mm/hr)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
acre	4,047	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
acre-foot per acre (acre-ft/acre)	0.3047	cubic meter per square meter (m^3/m^2)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
gallon per day (gal/d)	0.003785	cubic meter per day (m^3/d)
degree Fahrenheit (°F)	(temp °F-32)/1.8	degree Celsius (°C)

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Mean Sea Level."

HYDROLOGY OF A STREAM-AQUIFER SYSTEM IN THE CAMP VERDE AREA, YAVAPAI COUNTY, ARIZONA

By

Sandra J. Owen-Joyce

ABSTRACT

A dynamic interaction between the distribution of 30,000 acre-feet of water diverted from the Verde River to irrigate fields on the alluvium and the inflow of about 1,000 acre-feet of water from the underlying artesian aquifer in the Verde Formation determines the quantity and quality of water in the alluvium south of Camp Verde, Arizona. About 70 percent or 21,800 acre-feet of the diverted irrigation water returns to the Verde River as subsurface flow, which with 14,000 acre-feet of water flowing through the alluvium from West Clear Creek to the Verde River flushes the alluvial aquifer. About 9,300 acre-feet of water is lost to evapotranspiration. Inflow from the Verde Formation locally increases the concentration of dissolved solids, sulfate, chloride, and arsenic in the alluvium. Water quality in the alluvium would deteriorate without the dilution effect caused by the deep percolation of irrigation water applied on the alluvium and ground water in the alluvium along the Verde River is an important source of domestic water.

Ground water in the alluvium is unconfined and hydraulically connected to the Verde River and Verde Formation. Ground-water inflow to the alluvium from the Verde Formation occurs in areas where the hydraulic head in the Verde Formation is higher than the hydraulic head in the alluvium; wells open to both formations are another path of ground-water inflow. Near the southern extent of the alluvium, the hydraulic head in the Verde Formation is lower than the hydraulic head in the alluvium and some water flows from the alluvium into the underlying Verde Formation. In 1981 water levels in wells ranged from about 5 to 50 feet below the land surface and fluctuated as much as 5 feet owing to deep percolation of irrigation water. Saturated thickness in the alluvium ranged from 0 to about 30 feet in February to April 1981; the annual minimum amount of water stored in the alluvium occurs prior to irrigation and was estimated to be 17,500 acre-feet.

Ground water from most of the alluvium contained more than the maximum contaminant level for dissolved solids and in some areas contained more than the maximum contaminant levels for sulfate, chloride, and arsenic in public water supplies proposed by the U.S. Environmental Protection Agency and the State of Arizona. Dissolved-solids concentrations ranged from 251 to 4,400 milligrams per liter; 85 percent of the samples exceeded 500 milligrams per liter. Locally, the presence of

reworked Verde Formation deposited in the alluvium causes large concentrations of dissolved solids and sulfate particularly downslope from the salt mine in sec. 1, T. 13 N., R. 4 E. Ammonia concentrations ranged from 0.01 to 0.25 milligram per liter; more than 0.1 milligram per liter generally indicates organic pollution.

INTRODUCTION

Increases in population and concentration of development along the Verde River flood plain are occurring in the Verde Valley in central Arizona, which is changing the way that land is used along the river. Some areas previously used for agriculture are being subdivided and the amount of ground water used for a domestic and public water supplies is increasing. Some of the residents continue to irrigate with river water. In other areas of the flood plain, land previously covered by natura vegetation has been cultivated.

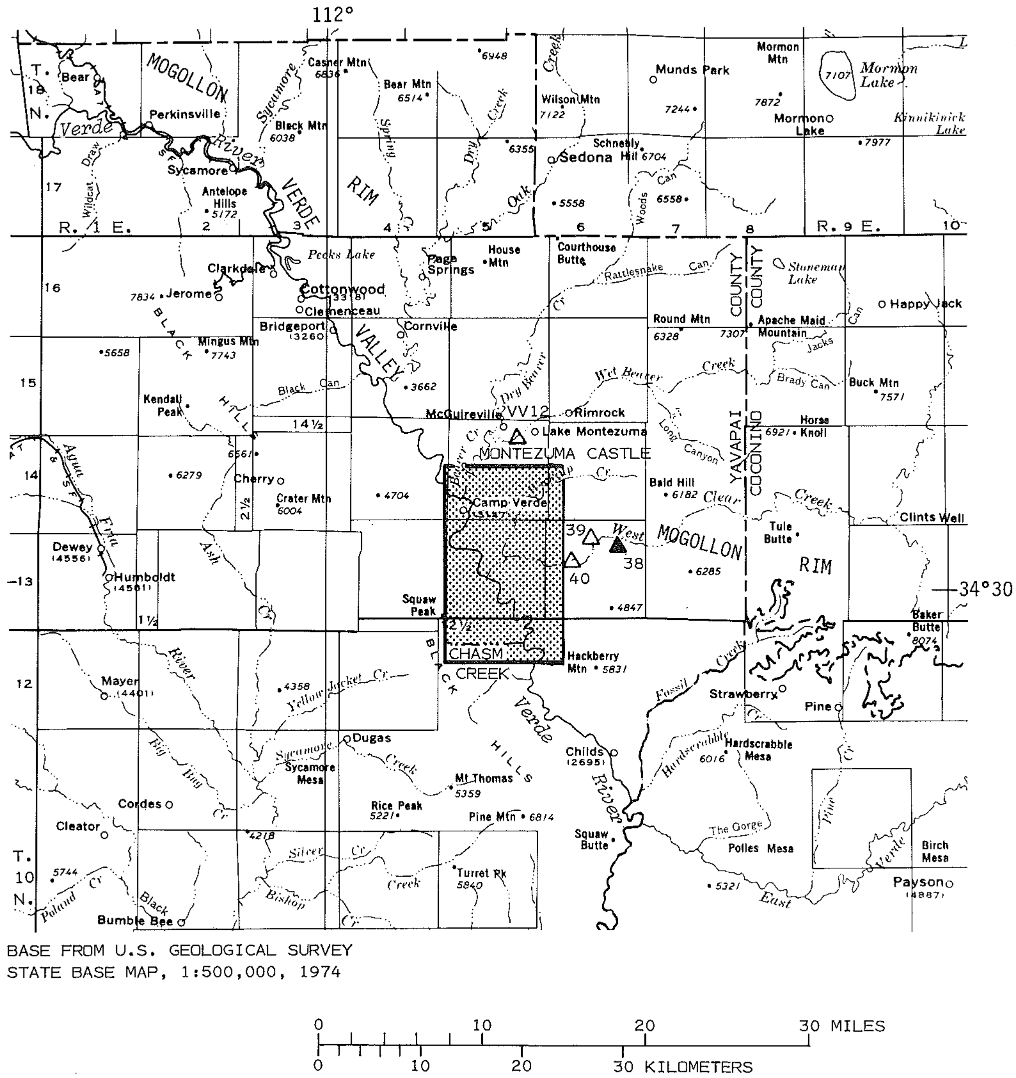
The Verde Valley has been identified as the area with the highest water-quality planning priority in northern Arizona (Northern Arizona Council of Governments, 1979). Residents and managers are interested in identifying and eliminating possible sources of pollution to the waters of the valley. Part of the Verde Valley south of Camp Verde along the flood plain of the Verde River was chosen for intensive study. This area has experienced a population increase in the past 10 years and the population is still growing. This study was made in order to understand the hydrologic system in the alluvium and the role that water quality plays in the system and was made by the U.S. Geological Survey in cooperation with the Arizona Department of Water Resources.

Location of the Area

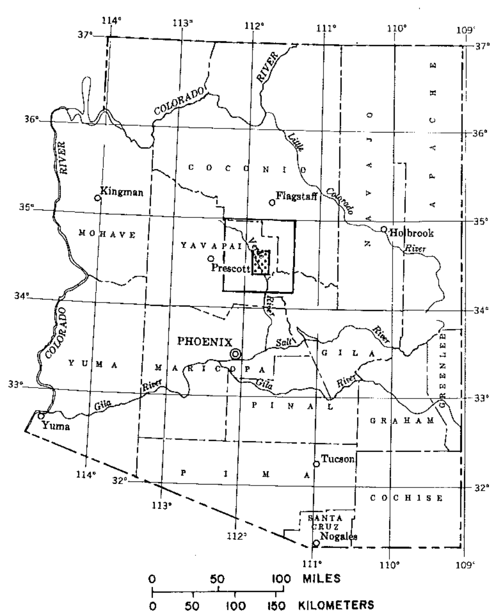
The Camp Verde area is in the southeastern part of the Verde Valley and occupies about 80 mi^2 (fig. 1). The Camp Verde area is bounded by the Black Hills to the southwest; the northeast boundary is near the base of the Mogollon Rim escarpment. Altitudes in the Black Hills range from 4,000 to 6,500 ft above the National Geodetic Vertical Datum of 1929. The base of the Mogollon Rim escarpment lies just outside the area boundary at an altitude of about 4,000 ft. On the upper edge of the Mogollon Rim, altitudes range from 5,500 to 6,000 ft. The Verde River flows southeastward through the area from an altitude of 3,070 ft at Beaver Creek to 2,880 ft at Chasm Creek.

Purpose

Ground water in the alluvium along the Verde River was studied to provide information for planning and managing the use of water



BASE FROM U.S. GEOLOGICAL SURVEY
STATE BASE MAP, 1:500,000, 1974



INDEX MAP SHOWING AREA
OF REPORT (SHADED)

EXPLANATION

▲38 STREAMFLOW-GAGING STATION—Operated by the U.S. Geological Survey. Number, 38, corresponds to that in table 1

△40 MISCELLANEOUS STREAMFLOW-MEASUREMENT SITE—Number, 40, corresponds to that in table 1

Figure 1.--Area of report.

resources in the area. The purpose of the investigation was to describe the hydrologic system in the Camp Verde area and the quantity and chemical quality of the ground water in the alluvium adjacent to a selected reach of the river south of Camp Verde. This report summarizes the results of a 2-year investigation of the primary factors that control the distribution, volume, and quality of water in the alluvium. The findings of the study will aid in planning ground-water development along the Verde River and in monitoring water quality in the alluvium and river.

Scope

This report describes the hydrologic system in the Camp Verde area and emphasizes the interaction of the Verde River, alluvium, and Verde Formation. Base-flow information for the Verde River pertinent to this study is summarized from a detailed study by Owen-Joyce and Bell (1983) and supplemented with additional seepage investigations and low-flow discharge data for the period of this study. The report describes the distribution and lithology of the alluvium and the Verde Formation, ground-water recharge and storage, changes in water levels, and chemical quality of water in the alluvium along the Verde River. Ground water in the Verde Formation is described as it interacts with ground water in the alluvium. The chemical quality of ground water was used as a tool to develop an understanding of how the hydrologic system functions and to evaluate the suitability of the water for domestic use. An annual water budget for the alluvium described in hydrologic-cycle order was prepared to show estimates of the amounts and components of inflow to and outflow from the alluvium. The quality of water and its relation to specific components of the water budget is discussed in the sections dealing with those components. Most of the water-quality sampling was done from February to April to approximate conditions in the alluvium before the start of dilution from irrigation.

Climate

The semiarid climate is a major factor in attracting people to the Verde Valley. Mean daily temperatures at Montezuma Castle National Monument (fig. 1) range from 42° to 80°F; temperature extremes of -1°F and 117°F have been recorded (Sellers and Hill, 1974, p. 332). The daily temperature variation generally exceeds 40°F during the summer. Annual precipitation at Montezuma Castle National Monument ranges from 3.5 to 22 in.; mean annual precipitation is 12 in. South of the valley toward Childs and east to the Mogollon Rim, the mean annual precipitation ranges from 17 to 19 in. Mean annual precipitation at Jerome in the Black Hills is 18 in. Mean annual snowfall at Montezuma Castle is about 3 in., whereas the mean annual snowfall in Jerome is 25 in.

Precipitation in the area is seasonal. At Montezuma Castle National Monument, about 50 percent of the precipitation occurs from

October through April as winter storms spread rainfall of light to moderate intensity across large parts of the southwestern United States. Precipitation often occurs as rain at lower altitudes and as snow at higher altitudes. The driest months are May and June. About 40 percent of the precipitation occurs in July, August, and September when short-duration locally intense thunderstorms are common.

Methods of Investigation

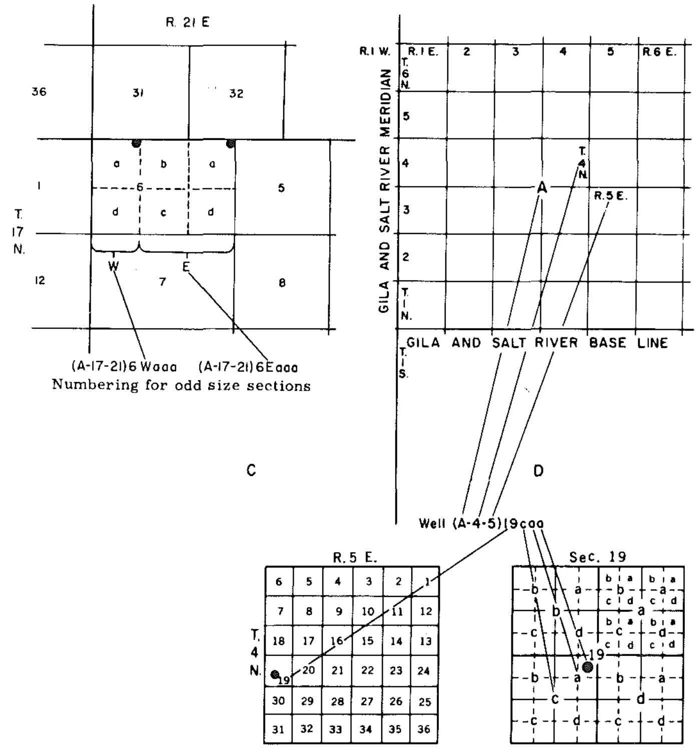
The fieldwork for this report was done from November 1980 to March 1982. An inventory was made of wells and springs; water levels were measured in wells where possible and 17 wells were measured periodically from 1981 to 1982. Well and spring locations are described in accordance with the well-numbering system used in Arizona, which is explained and illustrated in figure 2. The altitudes of wells and springs were obtained from U.S. Geological Survey topographic maps at a scale of 1:24,000 with contour intervals of 20 and 40 ft and topographic maps compiled for the Verde River Flood Study at a scale of 1:2,400 with a contour interval of 5 ft (Henningson, Durham, and Richardson, consulting engineers, Phoenix, written commun., 1982).

Two seepage investigations were made along the Verde River from 0.25 mi upstream from the mouth of Beaver Creek to the Verde River near Camp Verde gaging station. Discharge measurements were made at 18 sites on the Verde River and 40 sites on tributary streams, springs, and irrigation diversions and returns.

Water samples were collected from the Verde River, and selected wells, springs, and tributaries. Water samples from most wells were analyzed for arsenic, nitrate, nitrite, ammonia, and orthophosphate, and some of these water samples were analyzed for common ions and selected trace elements. Water samples from the Verde River, springs, and selected tributaries collected during the seepage investigations were analyzed for common ions, nutrients, and arsenic. Return flows from the irrigation ditches were analyzed for nutrients—nitrate, nitrite, ammonia, and orthophosphate.

The generalized geologic map was compiled from published and unpublished maps, aerial photographs, and fieldmapping. Lithologic and drillers' logs of wells were examined to determine the thickness, physical characteristics, and water-yielding potential of the alluvium.

The hydrologic data collected and used in this report are available, for the most part, in computer-printout form and may be consulted at the Arizona Department of Water Resources, 99 East Virginia, Phoenix, and U.S. Geological Survey offices in: Federal Building, 301 West Congress Street, Tucson, and 2255 North Gemini Drive, Flagstaff.



The well numbers and letters used by the Geological Survey in Arizona 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. 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 is in B quadrant, that south and west in C quadrant, and that south and east in D quadrant. The first digit of a well number indicates the township, the second the range, and the third the section in which the well is situated. The lowercase letters a, b, c, and d after the section number indicate the well location within the section. The first letter denotes a particular 160-acre tract, the second the 40-acre tract, and the third the 10-acre tract. These letters are also assigned in a counterclockwise direction, beginning in the northeast quarter. If the location is known within the 10-acre tract, three lowercase letters are shown in the well number. In the example shown in figure 2, well number (A-4-5)19caa designates the well as being in the NE¼NE¼SW¼ sec. 19, T. 4 N., R. 5 E. Where there is more than one well within a 10-acre tract, consecutive numbers beginning with 1 are added as suffixes.

When a section is more than 1 mile in any dimension, the section number applies as usual. The oversized section is divided so that a full square-mile unit of the section is adjacent to a normal section within the same township; the remainder is considered as a separate unit of land. Appropriate N., S., E., or W. letters are assigned to the units, depending upon where they lie in relation to the full square-mile unit. A well would be designated as shown in figure 2 with the appropriate letter following the section number in which the well is located.

Figure 2.--Well-numbering system in Arizona.

Previous Investigations

Ground-water resources and geology of the Verde Valley were studied by Twenter and Metzger (1963). Ground water, base flow, and water quality were investigated in a water-resources study in the upper Verde River area (Owen-Joyce and Bell, 1983). Basic data have been compiled as maps showing ground-water conditions in the upper Verde River area (Levings and Mann, 1980). The chemical character of ground water was used to indicate potential geothermal resource areas in the Verde Valley (Ross and Farrar, 1980). Evapotranspiration losses were estimated in a study of flood-plain areas in central Arizona (Anderson, 1976).

Water quality is an important issue that was investigated in the Verde Valley (Northern Arizona Council of Governments, 1979; Milne, 1981). These studies resulted in a water-quality management plan for the Verde Valley (Towler, 1982).

Several geologic studies have been made of the Verde Formation. An early study identified the minerals in the deposits of sulphate of soda (Blake, 1890). Studies on the history of the basin and lake deposits followed (Jenkins, 1923; Wadell, 1972; Nations, 1974; Nations and others, 1981). Geologic mapping and mineral-resources studies are in preparation for Arnold Mesa (E. W. Wolfe, U.S. Geological Survey, written commun., 1981) and have been prepared for West Clear Creek (Ulrich and Bielski, 1983).

Acknowledgments

The author gratefully acknowledges the cooperation of the many residents of the area who granted permission to work on their property and supplied information about their wells and the water companies and Arizona Department of Water Resources who furnished information for the study. Special appreciation is extended to the well drillers and residents for invaluable help in supplying historical information and data. Special thanks are due to Mr. E. E. Smith of Henningson, Durham, and Richardson, consulting engineers, for copies of current topographic maps of the area north of West Clear Creek along the Verde River flood plain, and to Mr. J. E. Alam of the U.S. Soil Conservation Service for information on the irrigation system and practices used in the Verde Valley.

HYDROLOGY

The flood plain of the Verde River is underlain by alluvium of Quaternary age that is hydraulically connected to the river. The alluvium is underlain by the Verde Formation of Tertiary age. Ground water in the alluvium and the Verde Formation is used principally for domestic and public water supplies. Water from the alluvium generally is of better quality than water from the Verde Formation; therefore, the alluvium is an important source of domestic drinking water.

Surface water from the Verde River is used for irrigation, livestock watering, and recreation. Water from the Verde River is transferred to the fields in irrigation ditches located on both sides of the river. Direct evidence of springs and measurements of streamflow along the Verde River south of Camp Verde to the Verde River near Camp Verde gaging station indicate that this is a gaining reach of the river. Water-quality problems that involve large concentrations of dissolved solids, sulfate, fluoride, and arsenic have been identified in this area of the Verde Valley (Owen-Joyce and Bell, 1983).

An evaluation of the water resources of the alluvium along the Verde River requires a knowledge of the factors that affect the hydrologic system—precipitation, streamflow, irrigation, subsurface flow, inflow to and outflow from an underlying artesian system, pumpage, and water loss by evaporation and transpiration—and how these factors interrelate. Of these factors, irrigation has the greatest effect on the amount and movement of water in the study area. The primary source of irrigation water is the Verde River; since the late 1800's, water has been diverted and transported in irrigation ditches to fields located on the alluvium (fig. 3). Part of the irrigation water is transpired by crops but most infiltrates to the water table. Some water is transpired by riparian vegetation. Water levels in wells respond almost immediately to irrigation. A mounding of the water table under the fields occurs during the irrigation season steepening the water-table gradient and increasing the flow downgradient (fig. 4) to the Verde River where ground water is discharged (fig. 3). Subsurface flow originating from tributary drainage basins moves through the alluvium to discharge to the river. In several places, ground water flows from the Verde Formation into the alluvium (fig. 4); in another place, ground water flows from the alluvium into the Verde Formation (fig. 5).

About 10 years ago, the farmlands began to be subdivided and pumping of ground water from the alluvium and Verde Formation for domestic use increased as the population increased. As the drilling of wells progressed, it became evident that water obtained from the alluvium was of better quality than water obtained from the Verde Formation. Almost all the water pumped is returned to the alluvium through sewage disposal. Some residences and businesses in Camp Verde are connected to a community septic system; other residences in town and those south of town have septic tanks.

Gravel deposits of Quaternary age are widespread in the study area (pl. 1), unconformably overlie the Verde Formation and volcanic rocks, and are as much as 120 ft thick (Ulrich and Bielski, 1983). Composition is dependent on source area. The gravels are permeable and allow water to infiltrate into underlying units but do not yield water to wells because they lie above the water table.

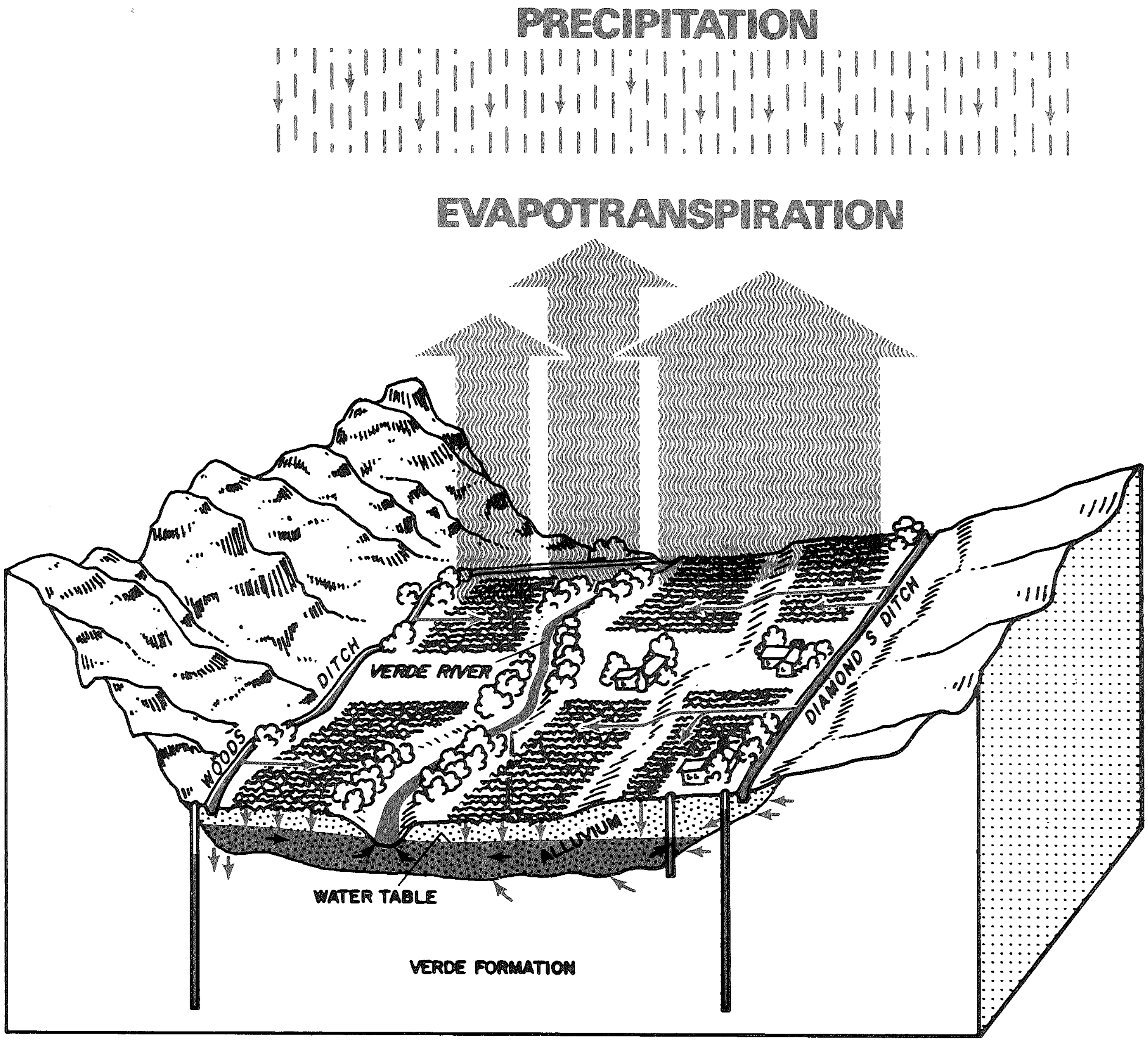


Figure 3.--Generalized block diagram illustrating the hydrologic system.

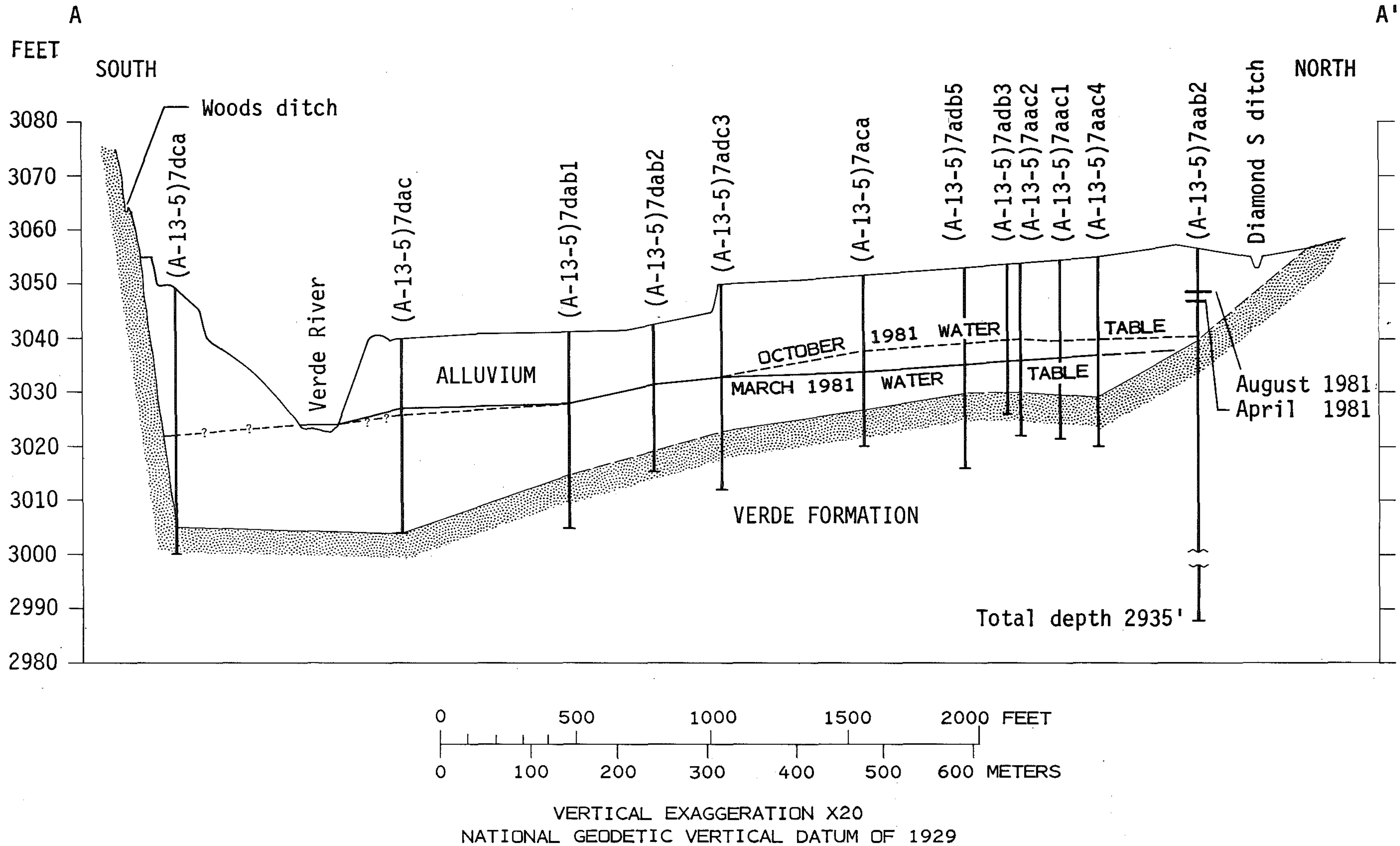


Figure 4.--Geohydrologic section A-A' in secs. 6 and 7, T. 13 N., R. 5 E.
(Location of section A-A' is shown on plate 1.)

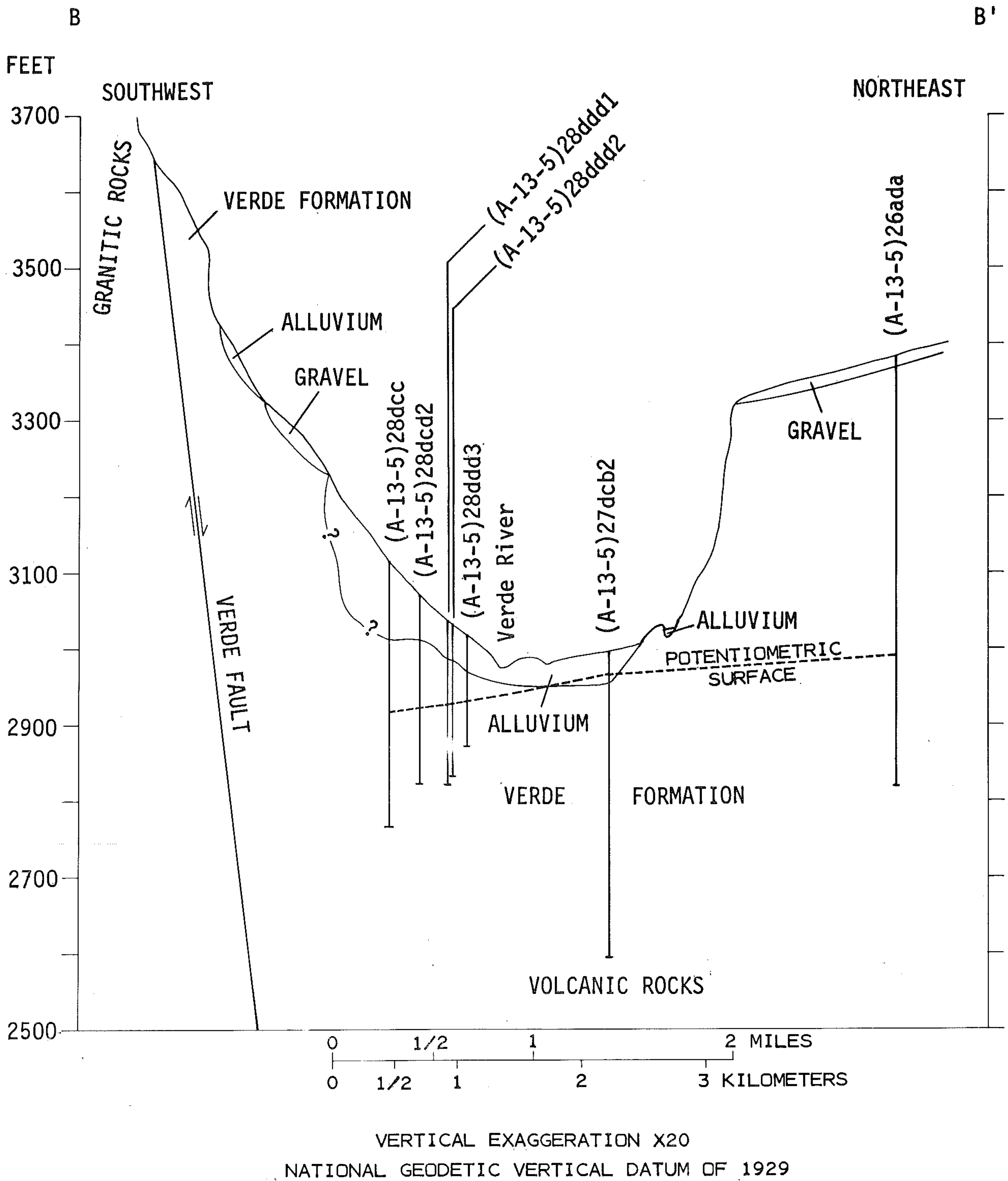


Figure 5.--Geohydrologic section B-B' in secs. 25-28, 32, and 33, T. 13 N., R. 5 E. (Location of section B-B' is shown on plate 1.)

Verde River and Its Tributaries

The Verde River is the main perennial stream that drains the study area. Two interrupted tributaries, Beaver Creek and West Clear Creek, drain a large part of the area east of the Verde River. Water in the streams is diverted and used to irrigate fields. In the summer, irrigation ditches often carry more water than the Verde River, and upstream diversions on the two tributaries leave the creeks dry near the mouths. During the irrigation season, any inflow to the Verde River from the tributary streams occurs as subsurface flow that bypassed the diversion structure. The cross sectional area of the alluvium along the two tributaries determines the amount of subsurface inflow to the Verde River. Tributary streams on the west side of the Verde River flow only in response to rainfall or snowmelt. A detailed discussion of the base flow, availability of streamflow, and water quality for the Verde River, Beaver Creek, and West Clear Creek appears in Owen-Joyce and Bell (1983). The relation between streamflow and the Verde River alluvium is stressed in this report.

Base flow monitored at the Verde River near Camp Verde gage (pl. 2, site 58) from December 1980 to March 1982 is characteristic of average conditions at this site (fig. 6). Base flow at the Verde River near Camp Verde gaging station is ground-water discharge from the area upstream from that site and includes the Camp Verde area. The variation in median base flow for 1935-45 and 1976-79 was from 66 to 200 ft^3/s; base flow ranged from 180 to 240 ft^3/s in January and from 43 to 96 ft^3/s in July (Owen-Joyce and Bell, 1983, p. 34). The large variation is the result of irrigation diversions from streams in the Verde Valley and evapotranspiration along the stream reaches from the headwaters to the gage. Base flow during January in 1981 and 1982 was about 200 ft^3/s. During most of June 1981, the river was at base flow; however, runoff from the thunderstorm season beginning the last week of June kept the river above median base flow for the remainder of the summer.

Irrigation ditches carry water diverted from the Verde River, which is the source of most of the water applied to cropland on the alluvium. Diamond S ditch, on the east side of the river, lies totally within the study area, whereas Woods ditch (Verde Canal) on the west side of the river is only partially within the study area (pl. 2). Water not applied to the fields is returned to the river through gates in the ditches located mostly where the ditches cross tributary channels. Prior to the winter of 1981, water flowed in the ditches all year except during short periods when the ditches were cleaned or high flows washed out the diversion dams. Beginning in late December 1980 through early April 1981, the ditches were dry. It is not known if this is a new operational practice or a one-time occurrence but this condition was considered when data for the 1981 calendar year were analyzed for input into the budget. Another change occurred during June 1981 when Diamond S ditch was out of operation for about 10 days beginning June 5. A conduit was installed under a new bridge to carry the ditch water. This construction effort was underway during the seepage investigation.

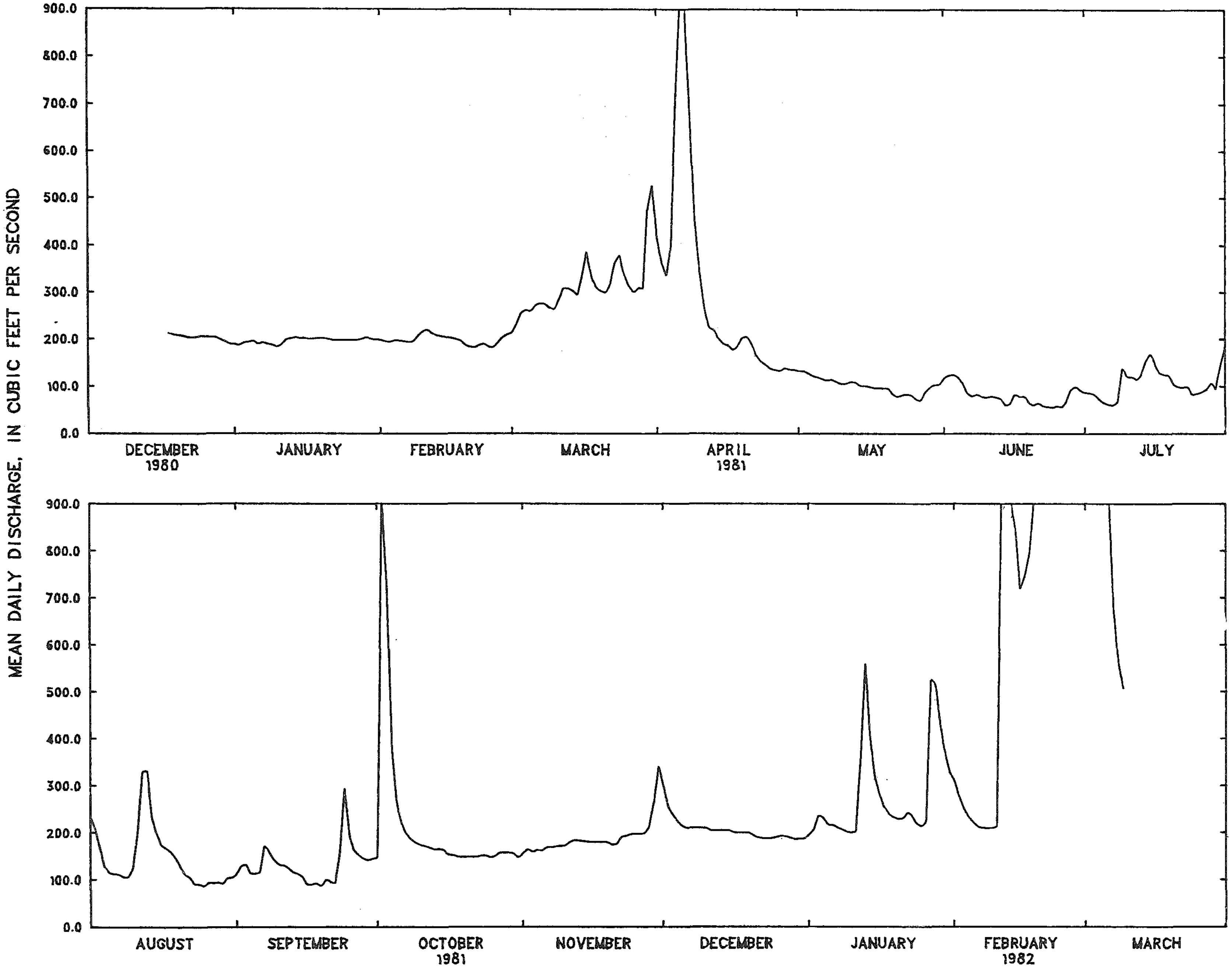


Figure 6.--Flow of the Verde River near Camp Verde from December 1980 to March 1982.

The Verde River and alluvium are hydraulically connected in the study reach. During base-flow conditions, water generally flows from the alluvium into the river. The hydraulic gradient of the ground water in the alluvium next to the Verde River is small (fig. 4); therefore, changes in river stage cause changes in the amount of water in storage in the aquifer. High flows generally result in water-level rises in the alluvium either by infiltration of river water (bank storage) or by a decrease in ground-water outflow from the alluvium (backwater effect). Bank storage is dominant close to the river during a short-term increase in river stage. During runoff events when the stage of the river is high, the hydraulic gradient in the alluvium next to the river is reversed and flow is from the river to the alluvium as shown by water levels in wells near the river. Bank storage quickly drains back to the river once the high flows subside. The backwater effect is dominant throughout the alluvium during long-term increases in river stage, such as sustained high runoff from snowmelt in the spring. Sustained high runoff not only reverses the gradient along the river and increases bank storage but retards the flow of ground water to the river and therefore has an effect on the amount of water that moves through the alluvium. Water levels in wells throughout the alluvium rose in response to the sustained high flows of the winter of 1982. Water stored in the alluvium owing to the backwater effect drains to the river after the high flows subside.

Seepage investigations were limited to periods of base flow as a measure of ground-water discharge during June 1979 (Owen-Joyce and Bell, 1983) and in November 1980 and June 1981 (table 1). A flow event was caused by storm runoff upstream from the study area prior to the June 1981 seepage investigation, but the flow in the river had returned to base-flow conditions from June 8 to 12 (fig. 7).

Base flow is variable because ground-water discharge, evapotranspiration, diversions, and return flows are variable; some of the variations can be quantified or minimized, others cannot. Therefore, streamflow measurements are representative of base flow for the conditions that existed at the time of the measurement. Ground-water discharge may be variable because recharge is variable. Evapotranspiration decreases base flow during the growing season. Evapotranspiration upstream from the gage causes seasonal and daily changes in the amount of base flow in the river. During June, the amount of base flow in the river normally decreases about 1 ft^3/s per day; whereas, in November the amount of base flow normally increases about 0.1 ft^3/s per day as shown by the median base-flow hydrograph (Owen-Joyce and Bell, 1983, fig. 4). Streamflow is variable because of time- and location-dependent changes in the amount of water diverted from and returned to the Verde River. Diversions and water use probably cause the flow in the river to drop below median base flow (fig. 7). During the June 1981 seepage investigation, the river contained an additional 30 ft^3/s more than normal base flow because of the contruction project on Diamond S ditch. Bank storage and runoff into the stream can cause variations in streamflow. Uncertainties inherent in the streamflow measurements are generally less than ±5 percent and need to be considered. During November when the

Table 1.--Discharge data from seepage investigations along the Verde River and West Clear Creek

[E, estimate]

Measurement site[1]	Stream	Date measured	Discharge, in cubic feet per second	Remarks
1	Verde River	Nov. 4, 1980	114	0.25 mi upstream from Beaver Creek.
		Nov. 5, 1980	115	
		Nov. 6, 1980	122	
		Nov. 7, 1980	109	
		June 8, 1981	30.8	
		June 9, 1981	29.2	
		June 11, 1981	25.1	
		June 12, 1981	29.8	
2	Beaver Creek	June 9, 1981	0	Upstream from the confluence with Eureka ditch.
3	Eureka ditch	June 9, 1981	0	Upstream from the confluence with Beaver Creek.
4	Beaver Creek	Nov. 4, 1980	11.4	0.1 mi upstream from mouth.
		June 9, 1981	7.51	
5	Verde River	Nov. 4, 1980	125	0.25 mi downstream from Beaver Creek.
		June 9, 1981	44.2	
6	Woods ditch	June 9, 1981	36.7	Downstream from Montezuma Castle Highway.
7	Verde River	Nov. 5, 1980	E110	0.7 mi upstream from wastewater pond.
		June 9, 1981	47.3	
8	Woods ditch return	Nov. 4, 1980	E2.9	At lower Camp Verde Indian Reservation—did not return to Verde River.
		June 9, 1981	-------	Could not measure—return now in culvert.
9	Woods ditch	June 9, 1981	28.7	Downstream from Main Street.
10	Pump diversion	June 10, 1981	E<1.0	
11	Diamond S ditch	Nov. 4, 1980	33.3	0.4 mi downstream from head.
		June 10, 1981	25.7	
12	Verde River	Nov. 4, 1980	90.4	0.1 mi downstream from wastewater pond.
		June 10, 1981	20.8	
13	Diamond S ditch return	Nov. 4, 1980	4.19	0.4 mi downstream from head.
		June 10, 1981	25.7	
14	Verde River	Nov. 5, 1980	98.9	0.25 mi downstream from bridge and station 09505550.
		June 10, 1981	42.8	
15	Diamond S ditch	Nov. 5, 1980	4.6	0.6 mi downstream from head.
		June 10, 1981	[2]0	
16	Pump diversion	Nov. 5, 1980	2.83	To concrete ditch.
		June 10, 1981	0	
17	Diamond S ditch return	Nov. 5, 1980	5.66	1.2 mi downstream from head.
		June 10, 1981	[2]0	

See footnotes at end of table.

Table 1.--Discharge data from seepage investigations along the Verde River and West Clear Creek--Continued

Measurement site[1]	Stream	Date measured	Discharge, in cubic feet per second	Remarks
18	Verde River	Nov. 5, 1980	105	0.2 mi upstream from Copper Canyon.
		June 10, 1981	44.6	
19	Woods ditch return	Nov. 4, 1980	E0.09	At Copper Canyon.
		June 9, 1981	E0.15	
20	Woods ditch return	Nov. 4, 1980	0	At Double Pipe siphon.
		June 9, 1981	0.87	
21	Woods ditch return	Nov. 4, 1980	10.4	At Ryal Canyon.
		June 9, 1981	E0.03	
22	Verde River	Nov. 4, 1980	122	0.2 mi downstream from Ryal Canyon.
		June 9, 1981	52.7	
23	Verde River	Nov. 5, 1980	125	Upstream from Allen Canyon.
		June 9, 1981	52.8	
24	Woods ditch	June 9, 1981	15.2	Upstream from road to Fort Lincoln.
25	Spring (A-13-5)8dcd	Nov. 5, 1980	0.60	
		June 10, 1981	0.43	
26	Verde River	Nov. 6, 1980	134	At Fort Lincoln.
		June 10, 1981	52.4	
27	Springs	Nov. 6, 1980	E1.0	A number of springs located in the reach upstream from the Verde River measuring site.
28	Verde River	Nov. 6, 1980	157	Just upstream from Diamond S ditch return.
		June 10, 1981	56.3	
29	Springs	Nov. 6, 1980	E4.0	A number of springs downstream from Verde River measuring site and springs that empty into spillway of ditch return.
		June 11, 1981	E0.51	Springs that empty into Diamond S return.
30	Diamond S ditch return	Nov. 6, 1980	14.2	
		June 11, 1981	[2]0	
31	Diamond S ditch return	June 11, 1981	[2]0	
32	Verde River	Nov. 5, 1980	147	0.15 mi upstream from Squaw Peak Canyon.
		June 10, 1981	65.4	
33	Woods ditch return	Nov. 5, 1980	0	At Squaw Peak Canyon.
		June 10, 1981	0	
34	Verde River	Nov. 6, 1980	155	0.4 mi downstream from Squaw Peak Canyon.
		June 10, 1981	57.8	
35	Woods ditch return	Nov. 6, 1980	0	Near Hat Ranch and 0.5 mi downstream from Squaw Peak Canyon.
		June 11, 1981	E0.16	
36	Pump diversion	Nov. 3, 1980	0	Pump removed, 0.5 mi downstream from Squaw Peak Canyon.
		June 10, 1981	0	Pump installed but not operating.

See footnotes at end of table.

Table 1.--Discharge data from seepage investigations along the Verde River and West Clear Creek--Continued

Measurement site[1]	Stream	Date measured	Discharge, in cubic feet per second	Remarks
37	Verde River	Nov. 6, 1980	155	0.1 mi upstream from West Clear Creek.
		Nov. 7, 1980	143	
		June 10, 1981	59.2	
38[3]	West Clear Creek	June 9, 1981	13.8	Near Camp Verde gaging station, 09505800, 11 mi upstream from mouth.
39[3]	West Clear Creek	June 9, 1981	15.0	9.9 mi upstream from mouth.
40[3]	West Clear Creek	June 9, 1981	13.8	6.0 mi upstream from mouth.
41	Ditch diversion	June 9, 1981	5.23	
42	West Clear Creek	June 9, 1981	7.22	4.8 mi upstream from mouth.
43	Ditch return	June 9, 1981	E1.5	Just downstream from measuring site 40.
44	Ditch	June 9, 1981	3.19	
45	West Clear Creek	June 9, 1981	6.57	4.0 mi upstream from mouth.
46	Ditch return	June 10, 1981	E0.3	0.45 mi northeast of measuring site 45.
47	West Clear Creek	June 10, 1981	7.84	3.1 mi upstream from mouth.
48	West Clear Creek	June 10, 1981	5.25	2.3 mi upstream from mouth.
49	West Clear Creek	June 10, 1981	E3.0	1.6 mi upstream from mouth.
50	Ditch	June 10, 1981	E3.0	0.2 mi north of measuring site 47.
51	West Clear Creek	Nov. 6, 1980	E7.0	At the mouth—1.5 ft^3/s measured surface flow and the rest estimated seepage at the Verde River.
		June 11, 1981	0	
52	Verde River	Nov. 7, 1980	160	0.6 mi downstream from West Clear Creek.
		June 11, 1981	79.9	
53	Verde River	Nov. 6, 1980	158	1.6 mi downstream from West Clear Creek.
		June 11, 1981	76.7	
54	Woods ditch	Nov. 6, 1980	0	0.25 mi upstream from end of ditch.
		June 11, 1981	0	Ditch wet with ponded water—no flow.
55	Woods ditch	June 11, 1981	0	Ditch dry and full of weeds.
56	Verde River	Nov. 7, 1980	161	At Beasley Flat.
		June 11, 1981	72.0	
57	Verde River	June 11, 1981	77.4	0.3 mi upstream from The Falls.
58	Verde River	Nov. 7, 1980	163	Near Camp Verde gaging station 09506000.
		June 8, 1981	92.8	
		June 11, 1981	89.4	

[1]Measurement-site numbers correlate to locations plotted on plate 2.
[2]Diamond S ditch was out of operation during the June 1981 seepage investigation.
[3]Measurement-site numbers correlate to locations plotted on figure 1.

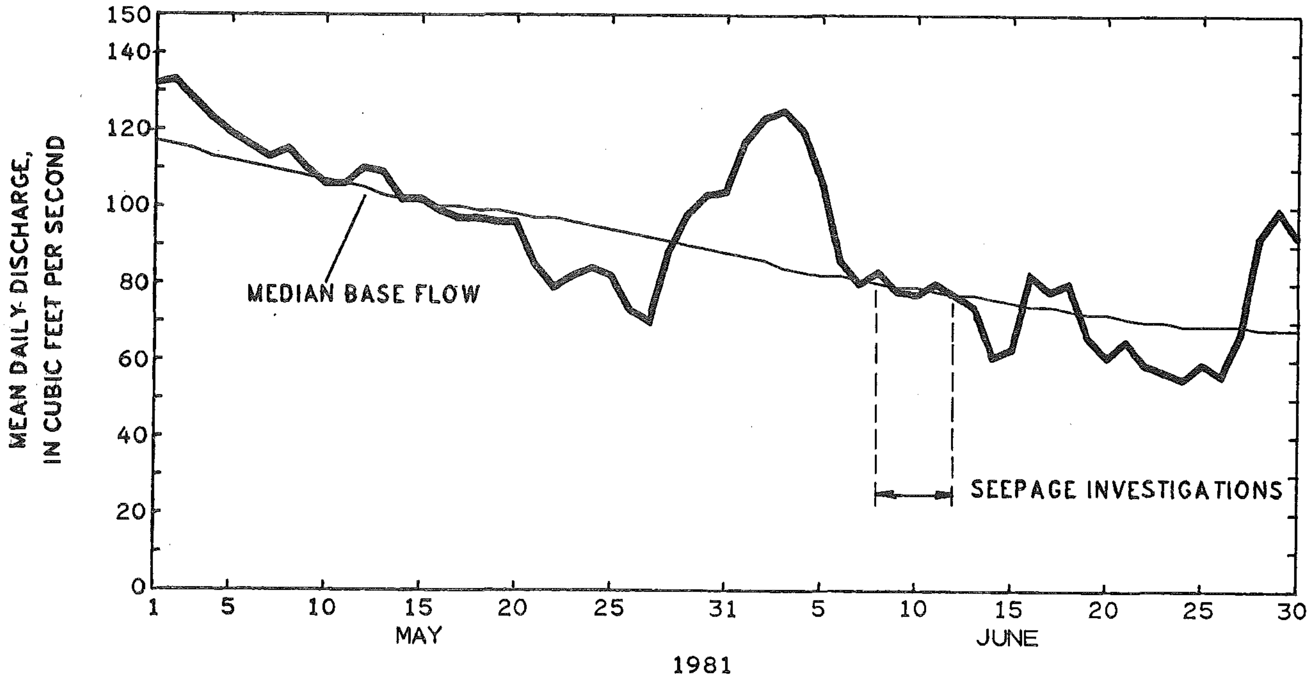


Figure 7.--Flow of the Verde River near Camp Verde during May and June 1981 and median base-flow conditions from 1935-45 water years.

effects of evapotranspiration and irrigation are low, the higher flows in the river can mask a small ground-water inflow component, which makes it difficult to detect or isolate the inflow. During June when smaller flows in the river allow better resolution because the uncertainty is smaller, evapotranspiration and irrigation diversions are largest.

Seasonal variations in the quantity of water that discharges from the alluvium to the river were documented by the seepage investigations. Evapotranspiration is seasonal but is insufficient to account for the variations in the amount of base flow from June to November in the study reach. Application of irrigation water is also seasonal and is sufficient to cause the variation in the amount of base flow. The amount of ground water that discharges to the river is a function of the amount of water applied to the fields. Increasing the hydraulic head under the fields increases the hydraulic gradient and saturated thickness of the alluvium; therefore, larger quantities of ground water move toward and discharge into the river.

Daily and short-term fluctuations in the flow of the Verde River occur in addition to the seasonal variations owing to irrigation and evapotranspiration. The installation of a temporary gaging station on the Verde River upstream from Beaver Creek (pl. 2, site 1) during the June

1981 seepage investigation provided some additional information regarding daily fluctuations in flow that need to be considered in interpreting the relation between consecutive streamflow measurements. The streamflow record at the temporary gage showed the results of evapotranspiration and irrigation diversions and return flows upstream from the study area. Evapotranspiration causes a diurnal fluctuation in flow in the river; however, the magnitude of the fluctuation varies along the river. The average diurnal fluctuation at the temporary gage upstream from Beaver Creek (pl. 2, site 1) was 7 ft^3/s; whereas, at the Verde River near Camp Verde gage (pl. 2, site 58), the average diurnal fluctuation was 14 ft^3/s (fig. 8). In June 1978, the diurnal fluctuation at a discontinued gaging station about halfway between sites 1 and 58 and about 500 ft upstream from measuring site 14 (pl. 2) was less than 2 ft^3/s. Diurnal fluctuations are dampened downstream from diversions because part of the fluctuation is diverted with the water from the river; a greater percentage of the flow in the river is diverted at the peak of the diurnal than at the trough. Variable amounts of flow returning directly from the ditches and as subsurface return flow to the river are superimposed on the diurnal fluctuations.

Three seepage investigations that represent different conditions along the study reach support the theory that irrigation on the alluvium controls the amount of subsurface return flow to the river. A seepage investigation was made in November 1980 at a time when the effects of evapotranspiration and irrigation on flow in the river were small to determine what portion of the gain in river flow was ground-water discharge from the alluvium and Verde Formation. A variation in gains throughout the year was indicated when the gain measured in November 1980 did not agree with the gain measured in the June 1979 seepage investigation. The comparison indicated a smaller gain during November 1980 than during June 1979, which correlates with the lower application rate of irrigation water and indicated that any natural ground-water discharge may be smaller than the detection limits or that all the gains are from irrigation. A subsequent seepage investigation in June 1981 did not duplicate the results of that in June 1979 because of an unusual condition—Diamond S ditch was out of operation during the June 1981 investigation (pl. 2). Using the actual quantities from the streamflow measurements, a comparison between gains in the river and the amount of applied water available for return during the two June seepage investigations showed a difference of 5 percent. Inherent errors owing to the discharge measurements being made on different days over a 5-day period, traveltime of the water through the reach, and diurnal fluctuations in flow make meaningful determination of the relation between consecutive measurements impossible. However, the nature of the difference between the two June seepage investigations strongly supports the significant impact of irrigation on the outflow from the alluvium.

Seasonal changes in streamflow caused by irrigation on the alluvium along the Verde River are shown by the seasonal variations in streamflow gains in the Verde River near the mouth of Beaver Creek (table 1). Beaver Creek meanders through a narrow canyon cut into the Verde Formation; a thin deposit of alluvium lies at the bottom of the

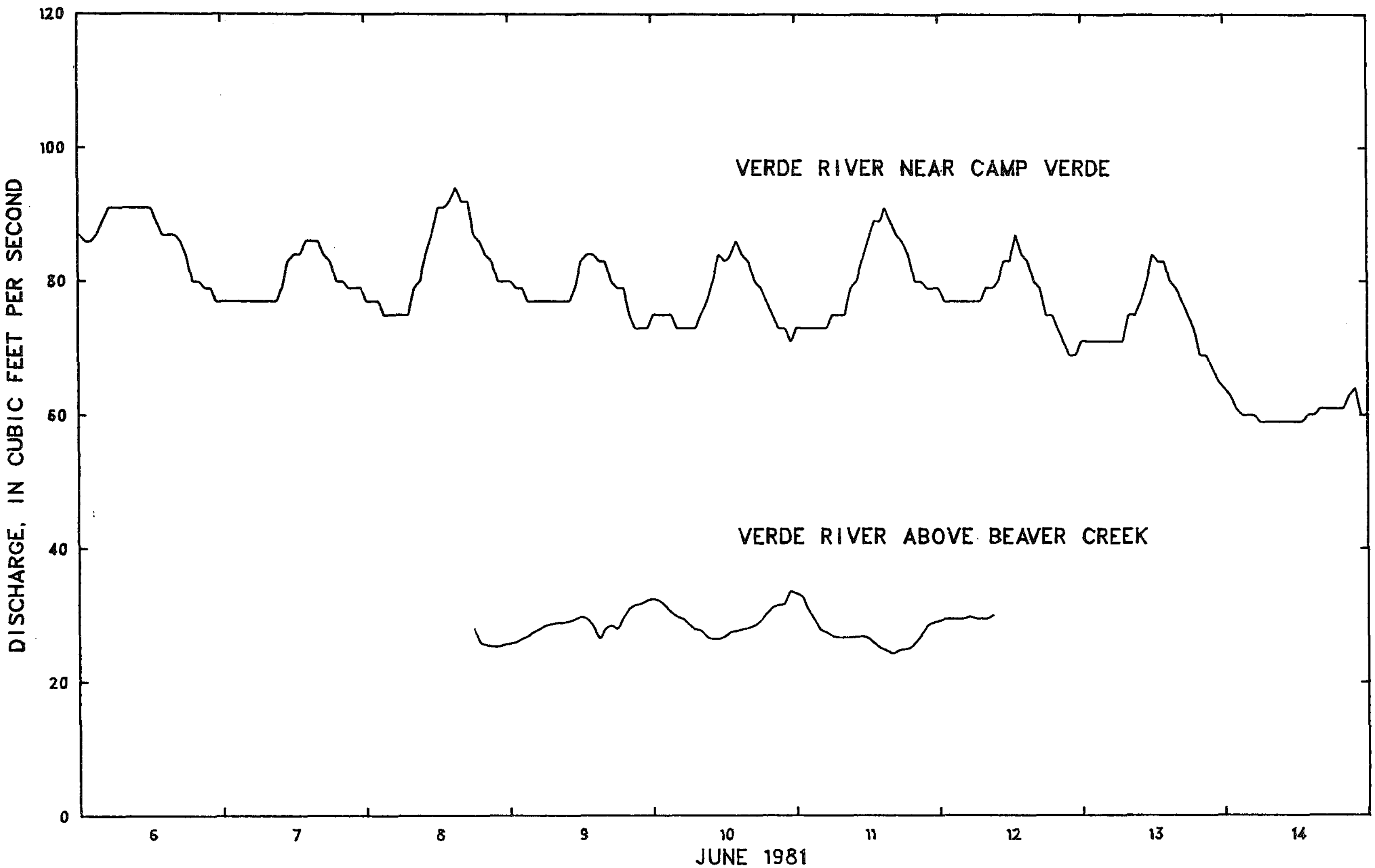


Figure 8.--Flow of the Verde River near Camp Verde, June 6-14, 1981, and Verde River above Beaver Creek, June 8-12, 1981.

canyon upstream from measuring site 2 (pl. 2). The alluvium along Beaver Creek widens downstream from site 2 and interfingers with Verde River alluvium starting about 0.3 mi above the mouth. The thin deposit of alluvium carries little subsurface flow, if any, from Beaver Creek upstream from site 2; therefore, all inflow from the Beaver Creek drainage area to the Verde River would be present at site 2 as surface flow. During the irrigation season, water is diverted upstream from the study area, which leaves the creek dry at site 2. The alluvium deposited by the Verde River near the mouth of Beaver Creek is irrigated using water diverted into Eureka ditch (pl. 2) from the Verde River 0.75 mi south of Oak Creek (fig. 1).

The amount of streamflow at the mouth of Beaver Creek during June 1979 was assumed to be related to irrigation (Owen-Joyce and Bell, 1983); additional data from this study supports this assumption. During the June 1981 seepage investigation, Beaver Creek upstream from the mouth of the Eureka ditch and the ditch were dry (pl. 2, sites 2 and 3; table 1). Flow at the mouth of Beaver Creek accounted for 7.51 ft^3/s of the 15 ft^3/s streamflow gain in the Verde River between measuring sites 1 and 5 (pl. 2). The other half of the gain is attributed to ground-water outflow from the alluvium to the Verde River in this reach. During the November 1980 seepage investigation, no increase in flow between sites 1 and 5 could be attributed to ground-water outflow from the alluvium. The quantity of streamflow gain attributed to ground-water outflow in June is either not present during November when irrigation is minimal or the quantity present in November is much less than in June and is masked by the increase in river discharge. The amount of streamflow in Beaver Creek and the ground-water outflow from the alluvium in June 1981 appear to be from irrigation in the summer and are not present in the winter when all the flow in Beaver Creek originates upstream from the irrigated area near the mouth of the creek.

Water chemistry indicates that the source of water in Beaver Creek at the mouth probably changes during the year. Water chemistry at the mouth of Beaver Creek in June 1981 showed a closer comparison with Verde River water diverted into Eureka ditch than surface water in Beaver Creek upstream from the study area. Data at all three sites were not available for the same year but were available during the month of June for 3 consecutive years for base-flow conditions: 1979, Verde River below the head of Eureka ditch (Owen-Joyce and Bell, 1983); 1980, site VV12 on Beaver Creek below Lake Montezuma (Milne, 1981); and 1981, Beaver Creek upstream from the mouth from the June seepage investigation. Specific-conductance data for November 1980 are available for Beaver Creek at the mouth and below Lake Montezuma; the values equal each other and indicate the source of surface water at the mouth of Beaver Creek in November is not ground-water outflow from the alluvium as it is in June. Water-quality data for Eureka ditch were not available at this time of year.

Inflow from West Clear Creek accounts for the most significant gain in streamflow in the Verde River within the study area. Near the mouth of West Clear Creek, most of the water from this drainage area flows in the alluvium as subsurface flow during periods of base flow. West Clear Creek flows in a canyon upstream from site 45 (pl. 2) where the alluvium is less than 0.2 mi wide and is composed chiefly of volcanic boulders. Downstream from site 45, the alluvium increases to about 1 mi wide near the mouth. The alluvium is composed of volcanic boulders from upstream and reworked Verde Formation washed in from tributary streams to the north. In the West Clear Creek drainage area, the alluvium ranges in thickness from 0 to about 50 ft. Details on the quantity of flow and water quality are discussed under the appropriate water-budget components in this report.

Alluvium

The alluvium in the study area was deposited by the Verde River, West Clear Creek, and Beaver Creek and as the result of slope wash. The alluvium deposited by the Verde River lies within about 0.5 mi of the river. The sand and gravel units are saturated at depth and form a water-table aquifer. Near the river, water levels in wells are influenced by the stage of the river. The alluvium deposited by West Clear Creek interfingers with the Verde River alluvium near the mouth of West Clear Creek. West Clear Creek drains an area of Paleozoic and volcanic rocks (Owen-Joyce and Bell, 1983) and the channel deposits reflect the source area; a fan-shaped deposit of volcanic boulders is deposited at the mouth of the creek. This deposit at the mouth is permeable and is considered part of the alluvium along the Verde River. At the mouth of Beaver Creek, the alluvium deposited by Beaver Creek interfingers with the alluvium deposited by the Verde River. Slope-wash alluvium from the Black Hills, in parts of secs. 28, 29, 32, and 33, T. 13 N., R. 5 E., is composed of granitic material (pl. 1). The slope-wash alluvium is permeable and transmits water downslope, but in most places it lies above the water table and does not provide water to wells.

The water-bearing alluvium includes the channel, flood-plain, and terrace deposits in and near the perennial and intermittent streams (pl. 1). These deposits are unconsolidated and consist of gravel, sand, silt, and clay. The size of the material in the alluvium differs laterally as well as with depth. The terrace and flood-plain deposits usually have fine-grained material at the surface and become coarse grained with depth. In some areas, the terrace deposits contain reworked Verde Formation. The channel deposits are coarse grained, and are generally less than 60 ft thick. Where the slope-wash deposits interfinger with the river deposits, however, the alluvium may be as much as 100 ft thick (pl. 1).

Recharge to the alluvium occurs from infiltration of precipitation, streamflow, irrigation water and septic-tank effluent, and inflow from the Verde Formation where the hydraulic head in the Verde Formation is higher than in the alluvium. Infiltrating water percolates to the water table and then moves downgradient toward the Verde River. The altitude and configuration of the water table is shown on plate 2. The gradient of the water table is toward the river, which indicates a gaining stream. Some ground water is intercepted by wells, some is used by phreatophytes and riparian vegetation, and some infiltrates to the Verde Formation where the hydraulic head in the Verde Formation is lower than in the alluvium; the remainder is discharged to springs and to the Verde River. In the reach near measuring site 23 and between sites 37 and 52, the ground-water gradient is toward the river on the east side and away from the river on the west side, which indicates ground-water flow through the alluvium beneath the river (pl. 2).

In wells where the principal aquifer is the alluvium, water levels range from about 5 to 50 ft below the land surface and fluctuate seasonally. Well depths range from about 12 to 120 ft below the land surface. The deeper wells bottom in the Verde Formation, generally in clay, which provides little water, if any, to the well. Saturated thickness ranges from 0 to about 30 ft (fig. 9). Water levels were measured periodically in 16 wells from February 1981 to March 1982 on both sides of the river and under different land-use conditions to document fluctuations and probable causes of the fluctuations. Water levels measured in 1981 fluctuated as much as 5 ft. The fluctuations in water levels are caused by changes in the stage of the river and by deep percolation of applied irrigation water on fields located on the alluvium.

The influence of river stage on water levels in wells is dependent on the amount of stage increase, distance of the well from the river, water-table gradient, and aquifer characteristics. Water-level fluctuations that result from river-stage fluctuations decrease with increasing distance from the river. Distances to the wells were measured along flow lines and upgradient from the river. December 1980 to March 1981 was mild and dry; the river ran at base flow until snowmelt and rains increased runoff in March (fig. 6). Water levels in wells east of the river in sec. 7, T. 13 N., R. 5 E., responded to the increase in river stage by rising above previous levels. Water-level rises ranged from 1.3 ft in well (A-13-5)7dba1 to 0.4 ft in well (A-13-5)7dba4 (fig. 10). Water levels in wells within 800 ft of the river rose in response to river-stage increases and quickly returned to the levels prior to the stage increase in response to river-stage decreases. Water levels in wells about 1,100 ft from the river rose but did not return to prior levels owing to the start of irrigation. November 1981 to March 1982 was cold and wet; rains and snowmelt increased the runoff in February to a much higher level than the previous year (fig. 6). Water levels in wells as far as 2,500 ft from the river in secs. 6 and 7, T. 13 N., R. 5 E., reacted to the greater increase in river stage. The rise in water levels ranged from 2.0 ft in well (A-13-5)7dba1 to 0.5 ft in well (A-13-5)7abc1. The water level in well (A-13-5)7aac1 did not show a rise above the previous level but the decrease in slope of the hydrograph illustrates a response to the increase in river stage (fig. 10). Water levels in wells on the west side, as far as 800 ft from the river in sec. 6, T. 13 N., R. 5 E., reacted to the increased river stage (fig. 10). The water level in well (A-13-5)6ccc2 rose 1.3 ft above the previous level; the decrease

EXPLANATION

AREAS WHERE THE SATURATED THICKNESS RANGES FROM 20 TO LESS THAN 30 FEET

AREAS WHERE THE SATURATED THICKNESS RANGES FROM 10 TO LESS THAN 20 FEET

AREAS WHERE THE SATURATED THICKNESS IS LESS THAN 10 FEET

AREAS WHERE THE ALLUVIUM IS UNSATURATED

GEOLOGIC CONTACT—Dashed where approximately located. Indicates the outcrop area of the alluvium

BOUNDARY OF ZONED AREAS OF SATURATED THICKNESS IN THE ALLUVIUM—Dashed where approximately located

BOUNDARY OF THE ALLUVIUM FOR CALCULATING STORAGE WHERE THE AQUIFER IS CONTINUOUS

Figure 9

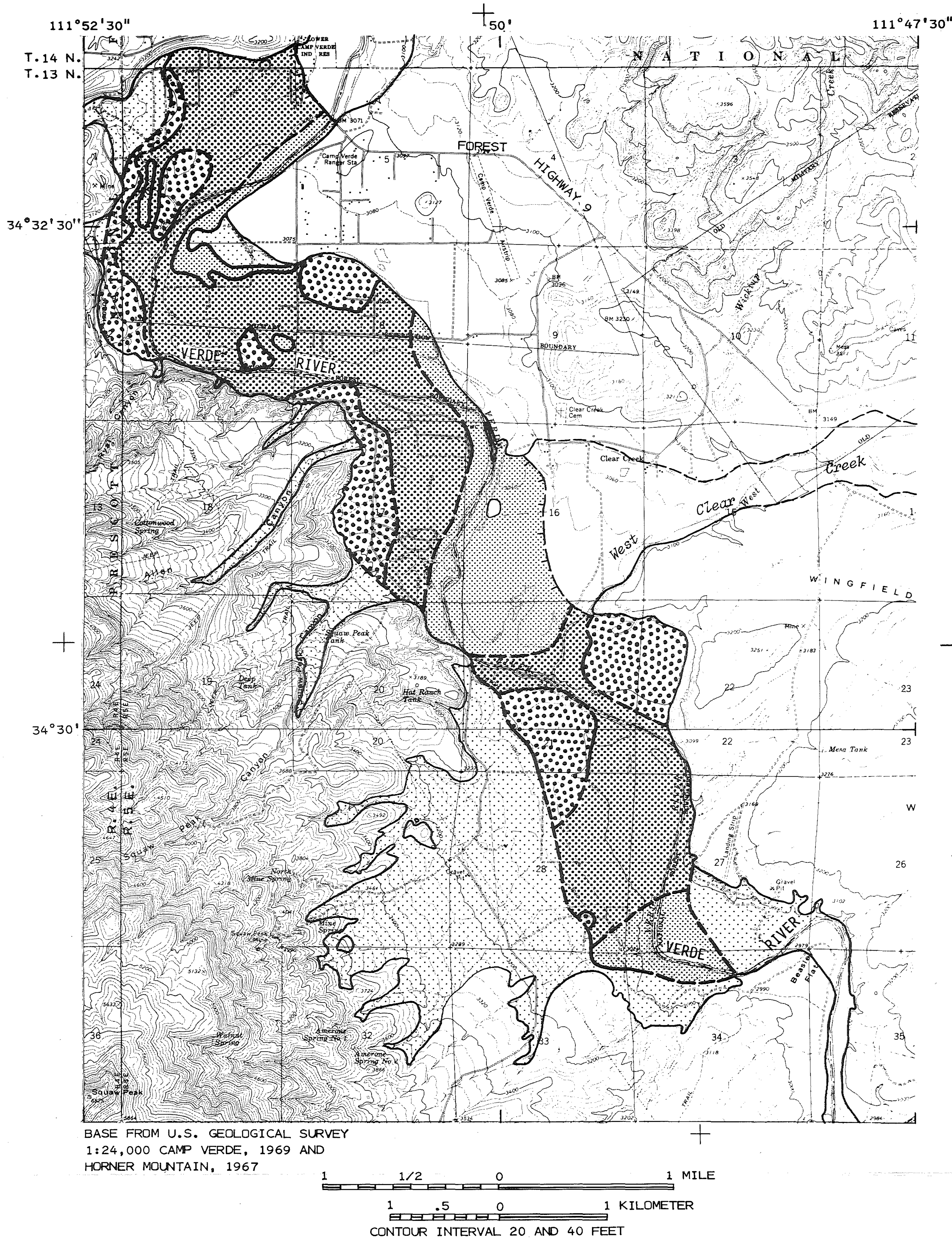


Figure 9.--Saturated thickness of the alluvium along the Verde River, winter 1981.

in the slope of the hydrograph for well (A-13-5)6ccc1 illustrates the response to higher river stage although the water level did not rise above the previous level. Hydrographs for wells 1,000 ft from the river showed little change in slope in response to the increase in river stage. On opposite sides of the river, changes in river stage influence water levels in wells at different distances from the river, which is a function of the difference in ground-water gradients on opposite sides of the river. The ground-water gradient is steeper on the west side of the river in sec. 6 than the ground-water gradient east of the river in secs. 6 and 7 (pl. 2). The steeper the gradient the larger the change in river stage needed to influence water levels in wells farther away from the river.

Water-level fluctuations caused by deep percolation of irrigation water were most noticeable in wells farthest from the river. Wells on both sides of the river showed the same seasonal trend of water-level fluctuation, although the amount of change was different. This difference could be caused by differences in the areal distribution of irrigated areas and the amount of water applied to the fields or the amount reaching the water table, because of differences in crop type, infiltration rates, or both. On the east side of the river where the wells are located in secs. 6 and 7, T. 13 N., R. 5 E., the land is irrigated. In sec. 7, T. 13 N., R. 5 E., the water level in a well within 800 ft of the river rose less than 0.5 ft owing to irrigation (fig. 10). This small water-level rise is due in part to the river being at its lowest stage during the irrigation season because river water is diverted into irrigation ditches and evapotranspiration is at its maximum rate. The water level in a well 550 ft from the river showed a greater response to a flow peak in the river during October than from irrigation (figs. 6 and 10). On the west side of the river in sec. 6, T. 13 N., R. 5 E., the land around the wells is not irrigated but land to the northeast and south is irrigated.

The amount of ground water stored in the alluvium is variable throughout most of the year because the principal component of inflow is deep percolation of irrigation water. If a 1-year period is used, however, net changes in ground-water storage are probably negligible. Base flow in the river, ground-water heads, and irrigation-water deliveries generally follow a 1-year cycle. Water-level fluctuations normally reflect changes in the saturated thickness and in the amount of ground water stored in an aquifer.

The amount of ground water stored in the alluvium can be estimated using saturated thickness and porosity. About 65 percent of the area underlain by alluvium, or 3,400 acres, contains saturated material. The total volume of saturated alluvium—about 50,000 acre-ft—was calculated using values of saturated thickness from water levels measured from February to April 1981 before the start of the irrigation season (fig. 9). The amount of ground water stored in the alluvium is estimated to be 17,500 acre-ft using an assumed porosity of 35 percent (Freeze and Cherry, 1979; Todd, 1959). Saturated thickness and therefore the amount of water in storage increases over about half the area of saturated alluvium during irrigation. After irrigation, water levels in most wells returned to within 0.5 ft of pre-irrigation levels. A

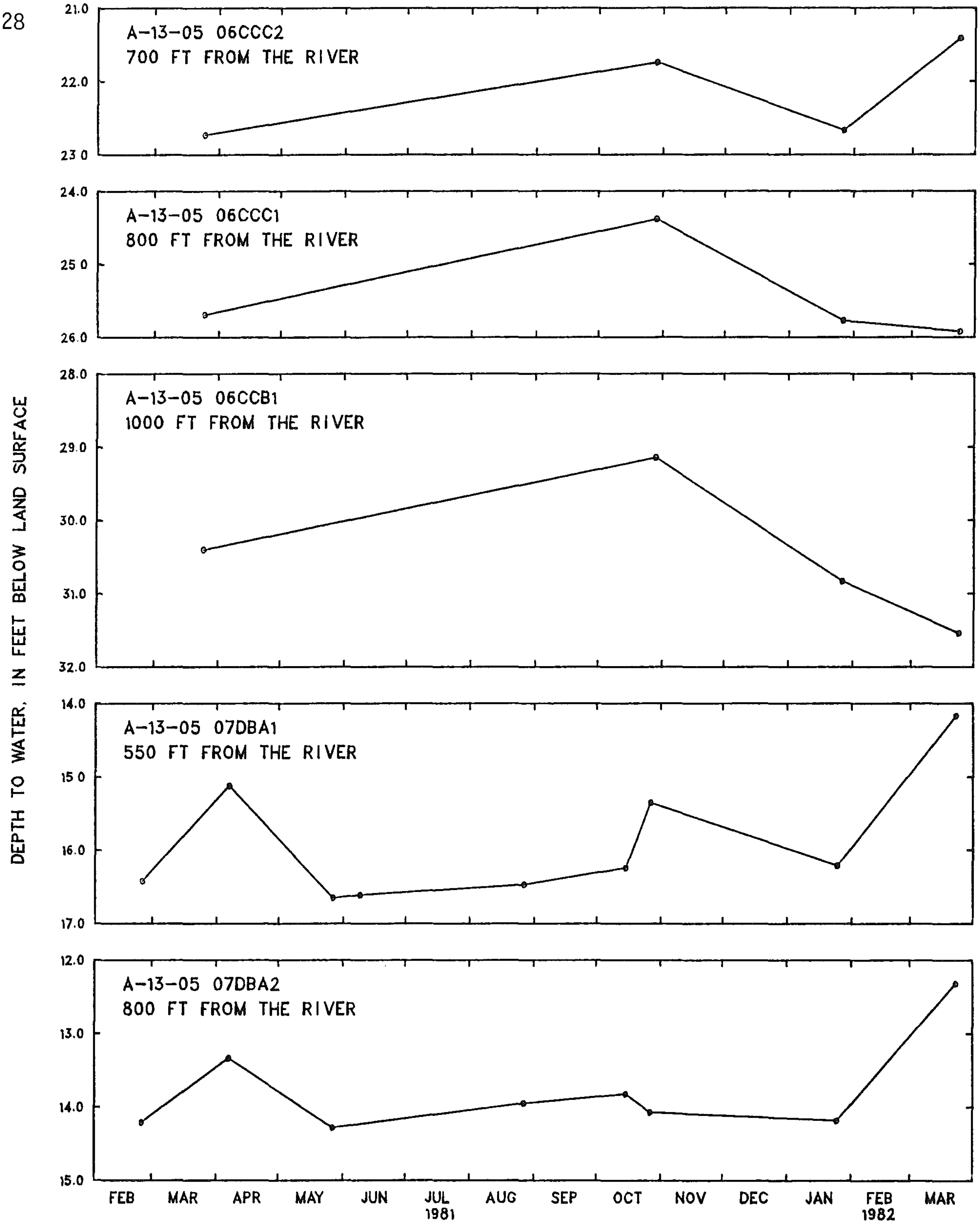


Figure 10.--Water levels in selected wells in the alluvium.

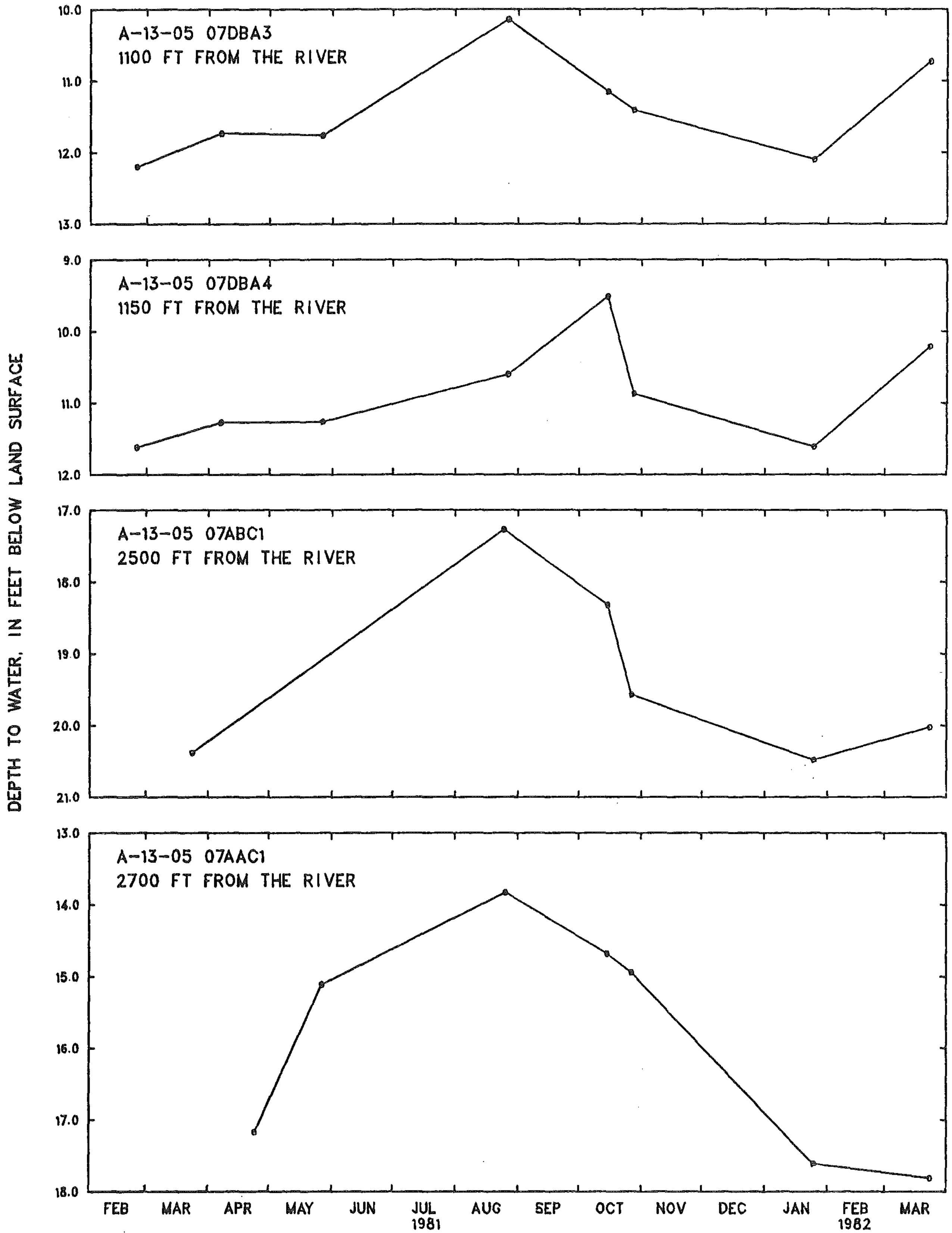


Figure 10.--Continued

change of 0.5 ft in water levels over half the area of saturated alluvium would result in a net change in storage of about 300 acre-ft.

Well yields are a function of the hydraulic conductivity, thickness of the aquifer penetrated, and well construction and development. In short-term tests, wells completed in the alluvium yielded from 3 to 300 gal/min. Hydraulic conductivity is dependent on the lithology and degree of cementation of the rock unit. Wells produce water where they penetrate sand and gravel below the water table in the alluvium. Wells do not yield usable quantities of water when they penetrate only silt and clay in the alluvium. In some places the alluvium is above the water table and is dry (fig. 9). Most wells in the alluvium are fully penetrating and bottom in the top few feet of the Verde Formation, but saturated thickness differs from place to place and varies during the year. Wells have similar construction characteristics and generally are similar in diameter according to their use. Domestic wells are 6 or 8 in. in diameter, and irrigation wells are 10 or 12 in. in diameter. Almost all wells are cased to the top of the Verde, and are perforated in the alluvium. Some wells are drilled deeper into the Verde Formation and are open to both sources of ground water. Water-quality anomalies generally indicate wells that are open to both rock units.

Verde Formation

Ground water in the Verde Formation occurs in the limestone, sandstone, and conglomerate beds and is confined by interbedded mudstone, claystone, and basalt flows. The Verde Formation underlies the alluvium and is composed of sediments deposited in an ancient lake (Twenter and Metzger, 1963). The distribution of the Verde Formation in the Camp Verde area is shown on plate 1. The main rock units in the formation characteristic of most of the area are limestone, mudstone, and claystone. The limestone is found mainly in the northern part of the area. In the southern part of the valley near the southern extent of the Verde Formation, the formation is composed of sandstone, conglomerate, and tuffaceous rocks. Evaporite minerals, mainly sulfate salts, are interbedded with the mudstone and claystone. A blue clay bed is the topmost rock unit of the Verde Formation on the west side of the area south of Camp Verde and underlies most of the alluvium. Volcanic rocks of Tertiary age are interbedded with the lake deposits. Coarse-grained materials were deposited along the margins of the valley, whereas the fine-grained materials were carried farther into the central part of the valley and deposited. The west boundary of the Verde Formation is the Verde Fault where the Verde Formation is in contact with Precambrian and Paleozoic rocks (pl. 1). At the other boundaries, the Verde Formation overlaps Paleozoic rocks or interfingers with volcanic rocks. Descriptions of the individual rock units are given in Twenter and Metzger (1963) and Owen-Joyce and Bell (1983).

The total thickness of the Verde Formation is unknown; however, locally the formation is at least 1,800 ft thick (Twenter and

Metzger, 1963, p. 55). Holes drilled in the Verde Formation range in depth from 24 to 1,625 ft below the land surface. Most water wells are less than 500 ft deep. Oil test holes show the Verde is 1,400 ft thick in sec. 10, T. 13 N., R. 5 E., and 1,225 ft thick in sec. 9, T. 13 N., R. 5 E. In both test holes the Verde Formation is underlain by volcanic rocks. More recent drilling data show that 400 ft of Verde overlies volcanic rocks in sec. 27, T. 13 N., R. 5 E., and 550 ft overlies Paleozoic rocks (Supai Formation) in sec. 26, T. 14 N., R. 5 E.

The Verde Formation provides a water supply where the alluvium is absent or will not produce a sufficient supply. Recharge results from infiltration of precipitation and streamflow and from underflow from the Paleozoic rocks on the east side of the area. Where the Verde Formation overlaps Paleozoic rocks, ground water flows from the Paleozoic rocks into the Verde Formation. This transition is marked by a sharp change in the ground-water gradient (pl. 2). Ground water moves downgradient toward the Verde Fault as shown by the configuration of the potentiometric surface depicted on plate 2. Some ground water is intercepted by wells, some is discharged to springs, some may discharge to the Verde River as seepage where the Verde Formation crops out in the river channel, and some moves into the alluvium where the hydraulic head in the Verde Formation is higher than in the alluvium. Most of the ground water moves downgradient through the Verde Formation southwestward toward the Verde Fault zone (fig. 5) where the water probably flows southeastward along the faults and fractures.

Water levels in wells that tap the Verde Formation range from flowing at the land surface near the river south of Camp Verde to about 390 ft below the land surface on Wingfield Mesa. Water-level measurements were made in well (A-13-5)7aba2 (fig. 11) and the water level fluctuated within about a 1-foot interval between March 1981 and March 1982. The water-level fluctuation follows the same trend as water levels in the alluvium nearby, which indicates the hydraulic connection between the aquifers.

Well yields are dependent on location because of areal and vertical changes in the lithology of the rock units that make up the formation and the lenticular nature of the deposits. Well yields range from 10 to 2,000 gal/min on the basis of data from short-term tests by drillers. High yields occur in the sandstone and conglomerate and where the limestone contains solution channels, fractures, and joints.

QUANTITY AND CHEMICAL QUALITY OF WATER IN THE ALLUVIUM

To aid in understanding the hydrologic system, a water budget for the 1981 calendar year was compiled for that part of the alluvium along the Verde River that extends from the Forest Highway 9 and the bridge over the Verde River in the NW¼ sec. 5, T. 13 N., R. 5 E., to

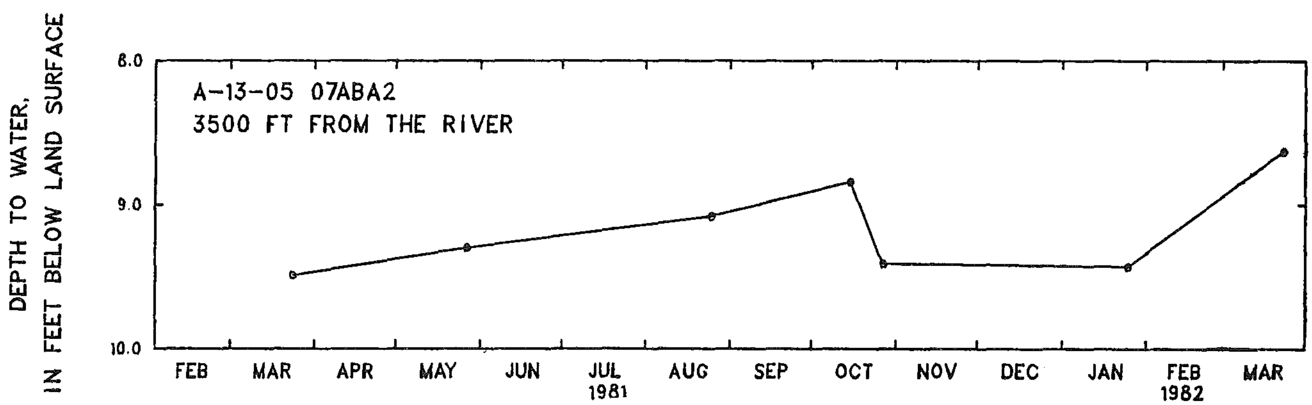


Figure 11.--Water levels in a well in the Verde Formation.

the south boundary of the alluvium (pl. 2). The area of alluvium considered in the budget is 8.2 mi^2. Ground water does not flow across the northeast boundary because the boundary is a flow line and parallels the direction of ground-water movement. The boundary along West Clear Creek approximates the dividing line between the alluvium deposited by the Verde River from that deposited by West Clear Creek. All other boundaries are defined by the outcrop pattern of the alluvium in the area (pl. 2).

The water budget was used to identify the inflow and outflow components and to estimate the relative magnitude of each component. The ground-water system in the alluvium is in dynamic equilibrium, and the annual change in storage is assumed to be zero. Each of the major inflow components provides water of a different quality, which results in differences in water quality in the alluvium. Changes in water quality provided information on how the hydrologic system functions during a year. Deep percolation of irrigation water diverted from the Verde River flushes the alluvium; locally, inflow from the underlying Verde Formation increases the concentrations of some constituents.

Inflow to the Alluvium

Inflow to the alluvium occurs as infiltration of precipitation, subsurface inflow from West Clear Creek, deep percolation of irrigation water, infiltration of septic-tank effluent, and leakage from the Verde Formation. Some inflow occurs from infiltration of precipitation that falls on the alluvium. Subsurface inflow from the alluvium along West Clear Creek is in significant amounts, although the quantity varies during the year mostly owing to variable amounts of diversion for irrigation. The largest component of inflow to the alluvium is from deep percolation of irrigation water applied to cropland adjacent to the Verde River. Most of the water pumped for domestic use infiltrates into the alluvium through septic tanks. Inflow from the underlying Verde Formation provides enough water of a different quality to affect the quality of water in the alluvium in places where the hydraulic head in the Verde Formation is higher than in the alluvium. Each component of inflow and an estimate of the annual amount of each component is discussed in the following sections.

Inflow to the alluvium from the Verde River does not occur during base-flow conditions in the reach between measuring sites 1 and 58 (pl. 2). During the seepage investigations, no losing reaches were identified. During high flows in the river, some water flows into the alluvium as bank storage but drains back to the river after the high flows subside. High flows contain small concentrations of dissolved solids (Owen-Joyce and Bell, 1983) and probably have a dilution effect on the ground water in the alluvium immediately adjacent to the river.

Precipitation

Annual infiltration from precipitation is an estimated 2 percent of the annual precipitation or 100 acre-ft (table 2). The estimated 2 percent is an average of the total infiltration estimates of 1 to 3 percent that were determined for basins in the Southwest Alluvial Basins, Regional Aquifer-System Analysis study (T. W. Anderson, U.S. Geological Survey, Tucson, oral commun., 1982). The value is thought to be transferable to the alluvium in the southern part of the Verde Valley because of the similar climatic conditions, land-surface altitudes, and alluvial material. The combination of distribution of precipitation within a year, air temperatures, potential evaporation, and consumptive use by vegetation results in only a small quantity of water infiltrating to the water table. Almost half the annual precipitation occurs in July, August, and September when the air temperature and potential evaporation are greatest. Potential evaporation is about 70 in./yr as determined by the relation between pan evaporation and altitude developed by Anderson (1976, p. 30) or about five times the average annual precipitation. During the growing season, available precipitation is used by crops and riparian vegetation.

Tributary Inflow from West Clear Creek

West Clear Creek, the major tributary to the Verde River in the Camp Verde area, contributes an average inflow of 19 ft^3/s or 14,000 acre-ft/yr to the alluvium along the Verde River as subsurface flow because irrigation diversions between sites 42 and 51 (pl. 2) often fully deplete the surface flow at the mouth (table 2). Gains in flow in the Verde River at the mouth of West Clear Creek were used to estimate the amount of subsurface inflow to the Verde River alluvium from the West Clear Creek alluvium. A significant gain in flow was measured in the

Table 2.--Estimated average inflow to and outflow from the alluvium located downstream from the bridge south of Camp Verde in 1981

[Values, in acre-feet]

Inflow:		
Infiltration of precipitation		100
Tributary inflow from West Clear Creek		14,000
Irrigation water and septic-tank effluent:		
Irrigation water	30,000	
Septic-tank effluent return flow from alluvial pumpage	27	
Septic-tank effluent inflow from Verde pumpage	13	
Total		30,040
Verde Formation:		
Natural leakage and leakage via wells		1,000
Total inflow (rounded from 45,140)		45,100
Outflow:		
Ground-water pumpage		30
Evapotranspiration:		
Riparian vegetation	4,400	
Consumptive use by crops	4,900	
Total		9,300
Discharge to Verde River		35,800
Discharge to Verde Formation		20
Total outflow (rounded from 45,150)		45,100

Verde River between measuring sites 37 and 52 (pl. 2) during both the November 1980 and June 1981 seepage investigations. During November 1980, the measured gain was about 18 ft^3/s, of which 1.5 ft^3/s was surface flow at the mouth of West Clear Creek. On November 6, 1980, the flow at the gage 11 mi upstream from the mouth of West Clear Creek (fig. 1, site 38) was 18 ft^3/s, which is normal winter base flow. In June 1981 the measured gain was about 21 ft^3/s with no surface flow at the mouth of West Clear Creek. On June 9, 1981, the flow at the gage was 13.8 ft^3/s, which is normal summer base flow. The increase in subsurface flow is from diverted water from the Verde River that was applied to fields near the mouth of West Clear Creek. The amount of applied irrigation water was greater than evapotranspiration losses and a gain in subsurface flow at the mouth of West Clear Creek was recorded rather than a loss. Anderson (1976, p. 77) estimated the evapotranspiration losses in 1975 to be 2,400 acre-ft/yr for the entire length of West Clear Creek. Evapotranspiration is about 1,900 acre-ft/yr for the part of West Clear Creek within the study area. At the time of the summer seepage investigation, about 8 ft^3/s of subsurface irrigation return flow entered the Verde River between sites 37 and 52 (pl. 2), which was attributed mostly to West Clear Creek.

The water in West Clear Creek contains the smallest dissolved-solids concentrations in the area. During the June 1981 seepage investigation, water in the creek was sampled at the gage (fig. 1, site 38) where the dissolved-solids concentration was 198 mg/L. The water quality showed little change except between sites 48 and 49 (pl. 2) where the dissolved-solids concentration increased. At site 49, the dissolved-solids concentration was 242 mg/L, which was caused by an increase in calcium and sulfate between sites 48 and 49 (pl. 2) and correlates with the presence of gypsum (calcium sulfate) in the Verde Formation in this area. Reworked Verde Formation is contained in the alluvium deposited along West Clear Creek from tributary streams on the north side of the creek.

Irrigation Water and Septic-Tank Effluent

The major source of irrigation water for croplands and residential lawns in the study area is the Verde River (fig. 12). About six times the amount of water needed for consumptive use by crops is diverted, and this is the source of the largest component of inflow to the alluvium, although the amount of inflow varies throughout the year and is dependent on the application rate at given time periods. The amount of water diverted in 1981 was estimated to be 30,000 acre-ft (table 2) or 75 percent of the annual diversion because the ditches were not operated during 3 months in winter. The annual diversion of 40,000 acre-ft/yr was calculated by estimating the amount of water available for irrigation in the two main irrigation ditches in the area using the quantity of water diverted during the June 1981 seepage investigation (table 1, sites 9 and 11). The amount of water carried by the ditches varies and depends

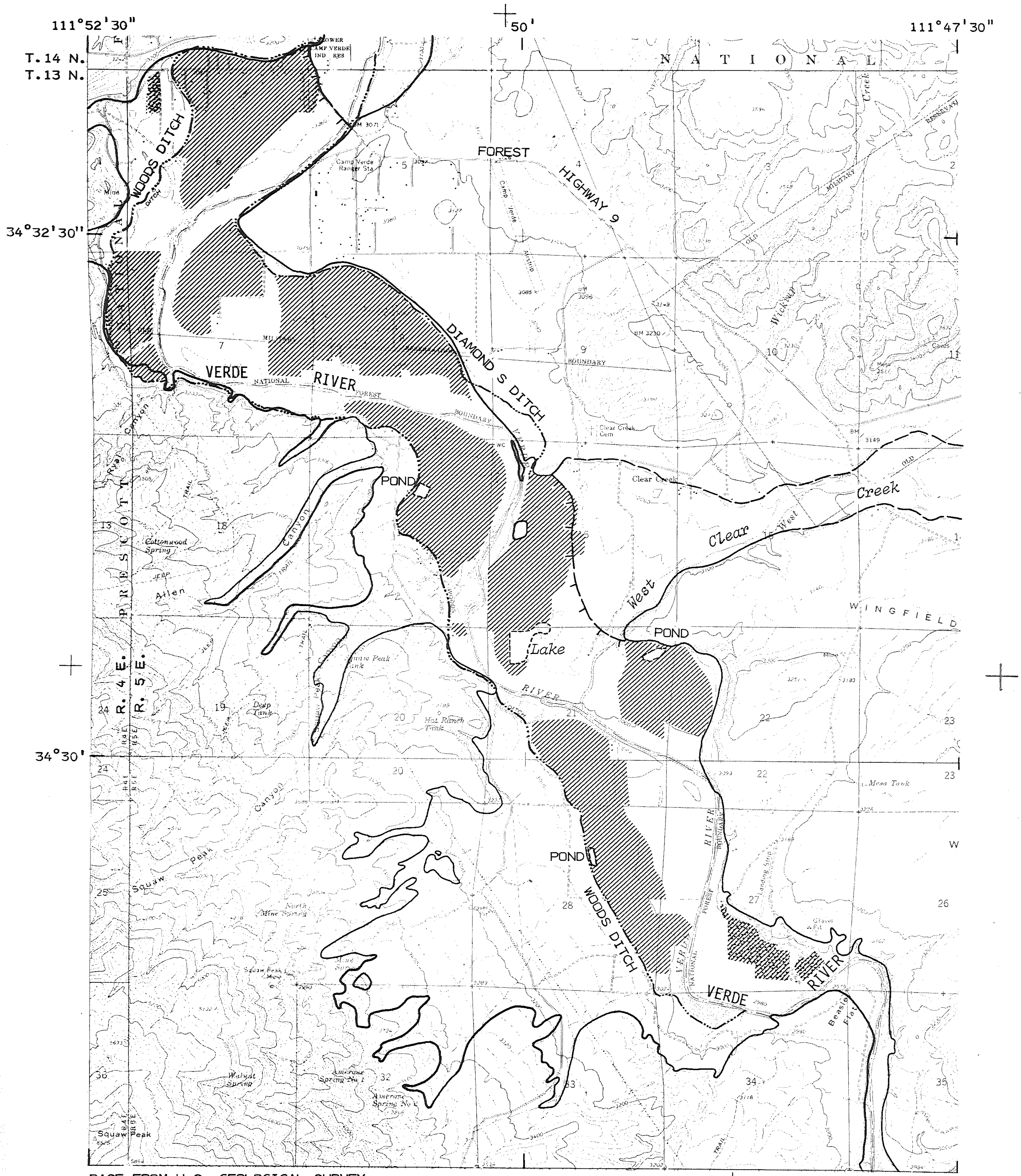
E X P L A N A T I O N

LAND IRRIGATED WITH SURFACE WATER DIVERTED FROM THE VERDE RIVER—Irrigated area from aerial photographs 1977 and 1980 and updated for 1981 from field mapping; areas include crop land and residential areas with lawns

LAND IRRIGATED WITH GROUND WATER PUMPED FROM THE VERDE FORMATION—Irrigated area from aerial photographs 1977 and 1980 and updated for 1981 from field mapping

GEOLOGIC CONTACT—Dashed where approximately located. Indicates the outcrop area of the alluvium

BOUNDARY OF THE ALLUVIUM FOR CALCULATING THE WATER BUDGET WHERE THE AQUIFER IS CONTINUOUS



BASE FROM U.S. GEOLOGICAL SURVEY
1:24,000 CAMP VERDE, 1969 AND
HORNER MOUNTAIN, 1967

1 1/2 0 1 MILE

1 .5 0 1 KILOMETER

CONTOUR INTERVAL 20 AND 40 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

Figure 12.--Location of irrigated land on the alluvium adjacent to the Verde River south of Camp Verde, Arizona, 1981.

in part on the stage of the river at the diversion dam (table 1, sites 7 and 11). Deep percolation of canal-seepage water and irrigation water applied to cropland infiltrates to the water table, flows downgradient, and returns to the river. The large quantity of water that infiltrates to the water table flushes the aquifer and is probably the reason the alluvium is saturated in many places away from the river where the alluvium lies above the altitude of the river. An estimated 90 percent of the annual ground water pumped, 27 acre-ft, is returned to the alluvium through septic tanks (table 2). Irrigation water and septic-tank effluent inflows to the alluvium are discussed together because both can contribute similar chemical constituents to water in the alluvium.

Leakage from the main ditches, unlined lateral ditches, and ponds is considered as part of the deep percolation of water from irrigation. Diversion dams in the Verde River direct water into Woods and Diamond S ditches, and lateral ditches carry the water to the fields. The main ditches are unlined and have been in operation since the 1890's. Investigations of seepage from the ditches made by the U.S. Soil Conservation Service indicate little leakage (J. E. Alam, Flagstaff, oral commun., 1982). Approximately half of the lateral ditches are lined or piped. The lateral ditches are user operated and do not carry water throughout the irrigation season. Leakage from the unlined portions of the ditches occurs at the same time as, and therefore is included as part of, deep percolation in the fields. Leakage from ponds along the main ditches is probably small. Ten small ponds in the study area are filled with water from the main irrigation ditches. Some ponds are used to store water for later use and to maintain a head for water in the lateral ditches, and some are used for livestock watering.

Septic-tank effluent, fertilization of crops and lawns, animal wastes, decomposition of organic material in the soil, and oxidation of atmospheric nitrogen by bacteria can contribute nutrients to the ground water. Water from most wells from which water could be obtained was analyzed for nitrate, nitrite, ammonia, and orthophosphate. Septic-tank effluent also can contribute chloride and increase the dissolved-solids concentration. Deep percolation of large quantities of irrigation water generally decrease the dissolved-solids concentration in the ground water even though these waters can dissolve and carry nutrients from fertilizers and organic material in the soil, which increases the total load in the ground water.

Samples of ground water in the alluvium collected from 12 wells before and after the irrigation season show no overall trend; however, individual trends for each constituent are indicated and are dependent on local irrigation conditions. In and downgradient from areas actively irrigated, water in the alluvium showed irrigation had a dilution effect on arsenic, on ammonia, and on specific conductance, which indicates a decrease in dissolved solids (table 3). Orthophosphate generally increased after irrigation. Nitrate concentrations increased in some locations and decreased in others (table 3), which indicates that local surface conditions differ and that application of fertilizers and the location and amount of organic material decomposing are variable. Nitrate

Table 3.--Seasonal water-quality data from selected wells

[umhos, micromhos per centimeter at 25° Celsius; mg/L, milligrams per liter; ug/L, micrograms per liter; 121VERD, Verde Formation; 111ALVM, alluvium]

LOCAL IDENT-I-FIER	GEO-LOGIC UNIT	DATE OF SAMPLE	SPE-CIFIC CON-DUCT-ANCE (UMHOS)	NITRO-GEN, NO2+NO3 DIS-SOLVED (MG/L AS N)	NITRO-GEN, AMMONIA DIS-SOLVED (MG/L AS N)	PHOS-PHORUS, ORTHO, DIS-SOLVED (MG/L AS P)	ARSENIC TOTAL (UG/L AS AS)
A-13-04 12DAA	121VERD	81-03-24	--	.27	.110	--	36
	121VERD	81-10-30	3650	.13	<.060	.020	110
A-13-05 06CBA	111ALVM	81-03-24	3300	.16	.110	.030	40
	111ALVM	81-10-29	2400	.75	<.060	.080	50
A-13-05 06CCD1	111ALVM	81-03-24	--	.49	.160	.030	40
	111ALVM	81-10-29	2220	.09	<.060	.040	32
A-13-05 06CDD5	121VERD	81-03-26	3150	<.10	.240	.100	66
	121VERD	81-10-27	3150	<.09	.270	.020	57
A-13-05 06DCC1	111ALVM	81-03-24	840	1.8	.140	.030	21
	111ALVM	81-10-28	880	1.6	<.060	.050	21
A-13-05 07AAB2	121VERD	81-04-08	4200	<.10	.290	<.010	44
	121VERD	81-08-26	3850	.08	.340	.040	56
A-13-05 07ADA1	111ALVM	81-04-07	1110	1.2	.190	<.010	42
	111ALVM	81-10-28	1040	1.3	<.060	.030	39
A-13-05 07BDA1	111ALVM	81-03-23	1220	3.9	.100	.050	25
	111ALVM	81-10-28	1280	3.9	.080	.050	29
A-13-05 07DAB1	111ALVM	81-04-07	1100	1.5	.100	<.010	14
	111ALVM	81-10-28	990	.37	.080	<.010	10
A-13-05 07DAC	111ALVM	81-04-07	1130	1.6	.110	.030	20
	111ALVM	81-10-28	965	2.3	<.060	.030	12
A-13-05 07DBD1	111ALVM	81-02-24	1210	4.7	.140	.030	20
	111ALVM	81-10-28	1220	2.8	<.060	.050	23
A-13-05 08BCD1	111ALVM	81-04-08	1340	1.2	.140	<.010	48
	111ALVM	81-10-28	1300	1.1	<.060	.090	52
A-13-05 08BCD2	111ALVM	81-04-08	1430	1.1	.020	<.010	96
	111ALVM	81-10-28	1360	1.2	<.060	.040	92
A-13-05 08DBB1	121VERD	81-02-23	1310	2.0	.120	.040	120
	121VERD	81-10-28	1400	1.7	<.060	.030	110
A-13-05 17ABC2	111ALVM	81-03-25	1500	.62	.140	.040	30
	111ALVM	81-10-29	1320	.83	<.060	.050	28
A-13-05 28AAA	111ALVM	81-04-08	3600	.63	.150	<.010	10
	111ALVM	81-10-29	1280	.43	.100	.030	11

concentrations generally are less than 2.0 mg/L except east of the river in secs. 7 and 8, T. 13 N., R. 5 E., where land use is a combination of subdivided lots and croplands that input septic-tank effluent and fertilizers to the alluvium.

Ammonia is the only nutrient detected in sufficient quantities in ground-water samples to indicate the possiblility of organic pollution. Ammonia concentrations vary seasonally. In 52 percent of the samples collected, ammonia exceeds 0.1 mg/L (table 4), which generally indicates organic pollution (Goerlitz and Brown, 1972, p. 13). Most of the samples that exceeded 0.1 mg/L were collected prior to the irrigation season when septic-tank effluent has a greater effect on ground water in the alluvium. The dilution effect during irrigation drops the ammonia concentrations below the detection limit (0.06 mg/L) of the analysis (table 4). In secs. 6 and 7, T. 13 N., R. 5 E., water from some wells in the Verde Formation that underlies the alluvium contains as much as 0.34 mg/L of ammonia. Large concentrations of ammonia in water from the Verde Formation may be a contributing factor to large concentrations of ammonia in water from the alluvium where the water from the Verde Formation flows into the alluvium.

Verde Formation

The Verde Formation supplies water to the alluvium through vertical leakage and through man's activities in the area. The magnitude of the amount of vertical leakage through the formation and the leakage through wells was estimated to be 1,000 acre-ft/yr (table 2). Vertical leakage can occur where the hydraulic head in the Verde Formation is higher than the hydraulic head in the alluvium. Man's activities and associated impacts include: (1) wells drilled through the alluvium into the Verde Formation that are open to both formations where Verde heads are higher than in the alluvium allow leakage to occur, (2) domestic water pumped from the Verde Formation infiltrates into the alluvium as septic-tank effluent, and (3) irrigation water pumped from the Verde Formation infiltrates into the alluvium.

Most of the vertical leakage through the formation and leakage through wells occurs east of the river in sec. 8, T. 13 N., R. 5 E., and cannot be distinguished from each other. The quantity of inflow can vary with changes in the difference between the hydraulic heads in the alluvium and Verde Formation. Water levels in alluvial wells located in the center of N½ sec. 8, T. 13 N., R. 5 E., are affected by the artesian system because the blue clay is absent and the alluvium is deposited on limestone. In this 80-acre area, water from the Verde Formation flows into the alluvium, which increases the dissolved-solids, sulfate, and arsenic concentrations of the water in the alluvium (pl. 3). Using the range of hydraulic conductivities given in Freeze and Cherry (1979, p. 29) for limestone and dolomite, the amount of vertical leakage ranged from 0 to 1,500 acre-ft/yr.

Table 4.--Summary of nutrient data for water in the alluvium

[Analytical results in milligrams per liter except as indicated]

Constituent	Number of samples	Maximum	Minimum	Median	Contaminant level	Percentage of samples exceeding the contaminant level
Nitrate, dissolved as nitrogen......	67	6.4	0.0	1.1	[1]10.0	0
Nitrite, dissolved as nitrogen......	85	0.03	<0.01	0.01	[2]0.1-2.0	0
Ammonia, dissolved as nitrogen......	82	0.25	0.01	0.11	[3]0.1	52
Orthophosphate, dissolved as phosphorus....	86	0.27	<0.01	0.03	----	--

[1]Maximum contaminant level for public water supplies as set by U.S. Environmental Protection Agency (1977a) and Bureau of Water Quality Control (1978).

[2]Limits differ. The presence of nitrite in water is sometimes an indication of organic pollution (Goerlitz and Brown, 1972, p. 17).

[3]More than 0.1 mg/L usually indicates organic pollution (Goerlitz and Brown, 1972, p. 13).

The amount of vertical leakage from the Verde Formation into the alluvium probably is small over most of the area because the blue clay bed at the top of the Verde Formation, on which most of the alluvium was deposited, acts as a confining bed for water in the Verde Formation. The magnitude of the head differences between the alluvium and Verde Formation is evidence that the blue clay significantly restricts flow from the underlying artesian system to the alluvium. The average amount of vertical leakage is proportional to the average head difference between the alluvium and Verde Formation. During the winter when the head difference between the formations is largest and the dilution effects from irrigation are minimal, no significant change in water quality occurs to indicate the inflow of water from the Verde Formation. If the quantity of flow were significant, inflow to the alluvium should increase with increasing head differences between the alluvium and the Verde Formation. The Verde Formation does not provide significant quantities of water to wells until the rock units underlying the blue clay are penetrated, which results in a water level that is higher than the water level in the overlying alluvium. In most of the alluvium, leakage appears to be associated chiefly with wells open to both formations. Water flows from the Verde Formation to the alluvium as a result of man's development as shown by water-quality anomalies in the alluvium (pl. 3). Verde Formation water can flow into the alluvium where wells are open to both formations and heads in the Verde Formation are higher. The number of wells that are open to both formations is unknown.

Infiltration of septic-tank effluent from residences on the alluvium that obtain their domestic water supply from the Verde Formation contributes an estimated 13 acre-ft/yr of water to the alluvium (table 2). The Verde Formation supplies water to about 240 people; 90 percent of the water flows into the alluvium through septic tanks.

Ground water is used to irrigate 77 acres on the alluvium where fields are upslope from the irrigation ditch or where no irrigation ditch is located. Annual consumptive use was estimated to be 250 acre-ft, and deep percolation of irrigation water is assumed to be negligible. Irrigation water is pumped from the Verde Formation and applied to the fields where the alluvium is dry—NW¼ sec. 6, T. 13 N., R. 5 E.—or where the saturated thickness in the alluvium is small—S½ sec. 27, T. 13 N., R. 5 E (fig. 12). Where the alluvium remains dry, little or no water is infiltrating from irrigation and remaining in the alluvium. Sprinkler-system irrigation rather than flood irrigation is used in sec. 27. During the summer irrigation season, no major gain in flow to the river was detected between measuring sites 53 and 56 (pl. 2).

Ground water from the Verde Formation contains large concentrations of dissolved solids, sulfate, chloride, arsenic, fluoride, boron, and some minor elements; some of these constituents exceed the maximum contaminant levels for public water supplies (table 5). The quality differs throughout the formation owing to the different rock units that were deposited; therefore, the quality of water that flows into the alluvium from the Verde Formation is dependent on location. A limestone bed provides water to well (A-13-5)6aaa in which the major ions are magnesium, calcium, and bicarbonate; the dissolved-solids concentration is 559 mg/L. The sandstone and conglomerate beds in sec. 27, T. 13 N., R. 5 E., produce water with dissolved-solids concentrations that range from 695 to 898 mg/L; the major ions are magnesium, calcium, bicarbonate, and sulfate. Throughout most of the area, mudstone and claystone beds that contain differing amounts of evaporites predominate; in places, beds of gypsum have been encountered. Dissolved-solids concentrations range from 1,020 to 2,590 mg/L, and different combinations of major ions are found. Sodium, sulfate, and chloride are the major ions in water from wells in secs. 6 and 7, T. 13 N., R. 5 E.; calcium and sulfate are the major ions in water from wells in sec. 16, T. 13 N., R. 5 E. Magnesium, sodium, calcium, sulfate, and bicarbonate are the major ions

Table 5.--Summary of quality of water in the Verde Formation near and underlying the alluvium

[Analytical results in milligrams per liter except as indicated]

Constituent	Number of samples	Maximum	Minimum	Median	Contaminant level	Percentage of samples exceeding the contaminant level
Sulfate, dissolved........	32	[1]2,900	78	550	[2]250	84
Chloride, dissolved........	33	[1]3,035	11	60	[2]250	21
Fluoride, dissolved........	25	4.0	0.1	0.7	[3]1.4	40
Sum of constituents, dissolved........	23	2,590	491	1,310	[2]500	96
Nitrate, dissolved as nitrogen......	32	2.0	0	0.13	[3]10	0
Nitrite, dissolved as nitrogen......	42	.03	<.01	.01	[4]0.1-2.0	0
Ammonia, dissolved as nitrogen.....	41	.55	<.06	0.16	[5]0.1	71
Orthophosphate, dissolved as phosphorous...	47	.14	<.01	.02	--------	--
Arsenic, total, in micrograms per liter.....	45	210	2	60	[3]50	58

See footnotes at end of table.

Table 5.--Summary of quality of water in the Verde Formation near and underlying the alluvium--Continued

Constituent	Number of samples	Maximum	Minimum	Median	Contaminant level	Percentage of samples exceeding the contaminant level
Boron, dissolved, in micrograms per liter.....	23	1,700	1	380	[6]750	30
Iron, dissolved, in micrograms per liter.....	24	15,000	<10	36	[2]300	17
Lead, dissolved, in micrograms per liter.....	8	58	1	10.5	[3]50	12
Manganese, dissolved, in micrograms per liter.....	22	360	<1	10	[2]50	4

[1]Analyses for sum of constituents were not obtained for all samples.

[2]Maximum contaminant level for public water supplies as set by U.S. Environmental Protection Agency (1977b).

[3]Maximum contaminant level for public water supplies as set by U.S. Environmental Protection Agency (1977a) and Bureau of Water Quality Control (1978).

[4]Limits differ. The presence of nitrite in water is sometimes an indication of organic pollution (Goerlitz and Brown, 1972, p. 17).

[5]More than 0.1 mg/L usually indicates organic pollution (Goerlitz and Brown, 1972, p. 13).

[6]Maximum contaminant level for boron applicable to water used for long-term irrigation on sensitive crops (U.S. Environmental Protection Agency, 1977c).

in water from wells in secs. 8 and 17, T. 13 N., R. 5 E. Sulfate, chloride, and boron are characteristic of evaporites deposited in closed basins, and fluoride is deposited in evaporite sediments (Rankama and Sahama, 1950). Arsenic is associated with clays in the Verde Formation (Owen-Joyce and Bell, 1983, p. 28). In some water samples from wells in the SE¼ sec. 6 and NE¼ sec. 7, T. 13 N., R. 5 E., the maximum contaminant levels for iron and manganese are exceeded. The large concentrations of iron and manganese probably are caused by a local depositional condition in the Verde Formation.

Outflow from the Alluvium

Outflow from the alluvium occurs as ground-water pumpage, evapotranspiration, discharge to the Verde River, and discharge to the Verde Formation. Pumpage accounts for a small amount of discharge. Water is discharged by direct evaporation and transpiration by riparian vegetation and crops. The largest amount of outflow from the alluvium is discharge to the Verde River and is a seasonal occurrence related to irrigation. Some ground water in the alluvium is discharged to the Verde Formation where the hydraulic head in the Verde Formation is lower than in the alluvium.

Ground-Water Pumpage

The annual ground-water pumpage from the alluvium was estimated to be 30 acre-ft (table 2) and was obtained using a count of housing units, a ratio of residents per housing unit, and water-use figures per person estimated from cities where water use is monitored. The count of housing units was taken from 1980 aerial photographs and 1981 field data. Population and housing figures from the 1980 census provided a ratio of two persons per housing unit for this area of Arizona. The alluvium supplies water to an estimated 420 people. A count of housing units on the alluvium was adjusted because not all the units obtain water from the alluvium. Where the alluvium is dry or does not contain enough saturated thickness to provide a domestic water supply, water is obtained from the underlying Verde Formation. Wells open to both the alluvium and Verde Formation were counted as alluvial wells in order to account for all wells that obtain water from the alluvium. Housing units in areas where the water source is unknown and mapped data and drillers' logs indicate that the alluvium could supply sufficient water were considered supplied by alluvial wells. Per capita water use was estimated to be 100 gal/d or 0.07 acre-ft/yr and allows for the use of surface water for irrigation of lawns and small gardens.

Irrigation wells drilled in the alluvium were not a source of irrigation pumpage during the time of the study. The irrigation wells were drilled to supplement surface water during drier years.

Ground water from most of the alluvium exceeds the maximum contaminant level for dissolved solids in public water supplies and may exceed the maximum contaminant levels for sulfate, chloride, arsenic, and some minor elements. The maximum contaminant level for dissolved solids in public water supplies is 500 mg/L, as proposed in the secondary drinking-water regulations of the U.S. Environmental Protection Agency (1977b, p. 17146). Water that contains a larger dissolved-solids concentration is used when it is the only available water. Dissolved-solids concentrations in water from the alluvium range from 251 to 4,400 mg/L (table 6); most of the water contains between 500 and 1,000 mg/L of dissolved solids (pl. 3).

Three main factors control water quality in the alluvium: (1) the amount and quality of the applied irrigation water, (2) the composition of the materials in the alluvium, and (3) the amount and quality of inflow from the underlying Verde Formation. Differences occur because the factors or combination of factors differ throughout the study area. The major ions in water from the alluvium are magnesium, calcium, sodium, and bicarbonate, which correlates with the major ions in the river water used for irrigation. The dissolved-solids concentration, however, is larger in water from the alluvium than in the river water.

In secs. 6 and 7, T. 13 N., R. 5 E., on the west side of the river, the major ions are sodium, magnesium, and sulfate. The alluvium on the west side of the river contains reworked Verde Formation, and the Verde Formation upslope from secs. 6 and 7 contains sodium sulfate and some sodium chloride salts. Water from the Verde Formation does not flow into the alluvium in this area because the hydraulic head in the Verde Formation is lower than in the alluvium. In sec. 28, T. 13 N., R. 5 E., the alluvium contains silt and clay that are probably reworked Verde Formation.

On the east side of the river in sec. 8, T. 13 N., R 5 E., the major ions are sodium, magnesium, calcium, bicarbonate, and sulfate, which reflect a mixing of the water from the alluvium and the Verde Formation. The largest arsenic concentrations in the alluvium occur in this area, which indicate inflow from the Verde Formation (pl. 3). Downgradient from West Clear Creek in sec. 21, T. 13 N., R. 5 E., water in the alluvium is diluted by water from West Clear Creek, which contains the smallest dissolved-solids concentrations in the study area.

Sulfate and chloride contribute to the large dissolved-solids concentrations. In some wells, sulfate and chloride exceed the maximum contaminant level of 250 mg/L (U.S. Environmental Protection Agency, 1977b, p. 17146). Sulfate concentrations range from 32 to 2,300 mg/L (table 6); in most of the alluvium, the sulfate concentration is less than 250 mg/L (pl. 3). Sulfate exceeds 250 mg/L on the west side of the river in secs. 6 and 7, T. 13 N., R. 5 E., and in individual wells scattered throughout the area where wells are open to the alluvium and Verde Formation or where wells are located downgradient from wells with mixed waters. Chloride concentrations range from 3.9 to 1,500 mg/L

Table 6.--Summary of quality of water in the alluvium

[Analytical results in milligrams per liter except as indicated]

Constituent	Number of samples	Maximum	Minimum	Median	Contaminant level	Percentage of samples exceeding the contaminant level
Sulfate, dissolved........	46	2,300	32	165	[1]250	30
Chloride, dissolved........	47	1,500	3.9	36	[2]250	9
Fluoride, dissolved........	32	1.5	0.1	0.4	[2]1.4	3
Sum of constituents, dissolved........	27	4,400	251	712	[1]500	85
Arsenic, total, in micrograms per liter.....	89	220	3	22	[2]50	18
Boron, dissolved, in micrograms per liter.....	25	1,900	20	310	[3]750	20
Iron, dissolved, in micrograms per liter.....	24	1,100	<10	29.5	[1]300	8
Manganese, dissolved, in micrograms per liter.....	22	70	<1	7.5	[1]50	5
Selenium, dissolved, in micrograms per liter.....	7	16	2	7	[2]10	14

[1]Maximum contaminant level for public water supplies as set by U.S. Environmental Protection Agency (1977b).

[2]Maximum contaminant level for public water supplies as set by U.S. Environmental Protection Agency (1977a) and Bureau of Water Quality Control (1978).

[3]Maximum contaminant level for boron applicable to water used for long-term irrigation on sensitive crops (U.S. Environmental Protection Agency, 1977c).

(table 6). In most of the alluvium, except in secs. 6 and 7, T. 13 N., R. 5 E., on the west side of the river, chloride concentrations are less than 250 mg/L (pl. 3). Well (A-13-5)21dcd2 contains the largest concentration of chloride—1,500 mg/L—and is probably open to both the alluvium and Verde Formation. The bottom of the well is 15 ft below the top of the clay unit in the Verde Formation. The static water level is 2 ft higher than where water was first encountered during drilling, which implies the presence of an underlying artesian system. The major ions in water from this well are sodium and chloride. Sodium chloride salt deposits are localized in the Verde Formation and this well probably taps water from one of these deposits.

Arsenic, fluoride, iron, manganese, and selenium in drinking water and boron in water used for long-term irrigation on sensitive crops (table 6) exceed the maximum contaminant levels set by the U.S. Environmental Protection Agency (1977c) and the State of Arizona (Bureau of Water Quality Control, 1978). Concentrations of these constituents that exceed the maximum contaminant levels, except for arsenic, occur in water from wells scattered throughout the area where wells are open to both the alluvium and Verde Formation or where reworked Verde is contained in the alluvium. Large concentrations of arsenic are found mostly in water from the alluvium east of the river in sec. 8, T. 13 N., R. 5 E.; the source of the arsenic is inflow from the Verde Formation (pl. 3).

Evapotranspiration

The total annual estimated evapotranspiration is 9,300 acre-ft (table 2) and occurs from many sources in the study area. Riparian vegetation and crops transpire water. Water evaporates from open-water surfaces in the river, ditches, laterals, ponds, and bare-soil surfaces near the river where the depth to water is less than 10 ft. Changes in water quality owing to evapotranspiration are masked by the large quantities of irrigation water moving through the alluvium.

Along the Verde River between the bridge near site 14 and site 58 (pl. 2), about 1,100 acres of riparian vegetation—primarily mesquite, cottonwood, and riparian scrub—use an estimated 3,200 acre-ft of water annually; average consumptive use by riparian vegetation therefore is about 3 acre-ft/acre. Phreatophytes along the river, on bottom land along wash channels, and along irrigation ditches obtain water from the alluvium. Transpiration by riparian vegetation was calculated using the unpublished data summarized in a study by Anderson (1976) and was applied to this budget-study area. Acreage, annual water use by the different types of riparian vegetation, and method of calculation were from Anderson (1976). The depth to water was determined during this study. Water evaporating from the surface of 13.9 mi of river, which averages 100 ft wide, is an estimated 1,000 acre-ft/yr; therefore, the total annual evapotranspiration is 4,200 acre-ft for this reach of the Verde River.

An estimated 180 acre-ft/yr was lost to evaporation from the water surface in the main ditches, lateral ditches, and ponds. Diamond S ditch and half the length of Woods ditch lie in the study area and total about 70,000 ft. The main ditches average 8 ft wide and flow about 9 months of the year. The assumption was made that half the lateral ditches off Woods ditch lie in the study area; therefore, about 98,000 ft of laterals branch off from both main ditches. The lateral ditches average about 2 ft wide and probably were used twice a week for 9 months of the year. Evaporation from the main and lateral ditches was estimated to be 60 acre-ft/yr. Evaporation was 120 acre-ft/yr from approximately 20 acres of ponds along the irrigation ditches.

About 1,220 acres of cropland on the alluvium is irrigated by surface water diverted or pumped from the Verde River, and the annual consumptive use is estimated to be 4,900 acre-ft (table 2). Irrigated acreage was determined from aerial photographs taken in 1977 and 1980. The amount of water used per acre depends on soil type, crop type, and methods of irrigation, which are described in the Verde Valley Water Pollution Source Analysis (Northern Arizona Council of Governments, 1979, p. 123-126). Consumptive water use in the Verde Valley was estimated to be 4 acre-ft/acre, and a realistic value for infiltration in the study area is 1 in./hr with little evaporation from the fields (J. E. Alam, U.S. Soil Conservation Service, Flagstaff, oral commun., 1982).

Studies in other areas in Arizona have reported that evapotranspiration is a potential cause of water-quality changes in ground water and surface water. The effects on water quality known to be caused by evapotranspiration in these studies were investigated in the Camp Verde area. The effect that evapotranspiration has on water quality depends on climate, type of vegetation, and amount and type of irrigation methods used in an area. Evapotranspiration as a result of crop and riparian vegetation water use tends to increase the dissolved-solids concentration in an interconnected ground- and surface-water system without increasing total loads of dissolved solids (Gatewood and others, 1950, p. 78-79). Change in ground-water quality owing only to evapotranspiration is indicated by equally increased ionic concentrations in infiltrated water compared to the applied water and is indicated by unchanged or nearly unchanged sodium percentage, which depends on the ratio of sodium concentration to total cation concentration (Olmsted and others, 1973, p. 126).

Evapotranspiration causes little or no detectable change in ground-water quality in the alluvium or surface-water quality in the Verde River. Seasonal sampling of specific conductance in selected wells does not indicate an increase in dissolved solids during the summer when evapotranspiration is greatest. Specific-conductance changes were small, and wells near the river actually showed a decrease in specific conductance during the summer (table 3), which implies dilution rather than concentration of dissolved solids. In comparison to the data from the November seepage investigation, the total loads of dissolved solids and the percentage of sodium in the surface water increased during June; therefore, more than evapotranspiration is causing the increased dissolved-solids concentrations. Water is diverted upstream from where the dissolved-solids concentration increases in the river; therefore, the water applied to the fields generally contains less than 500 mg/L of dissolved solids and the major ions are calcium, magnesium, sodium, and bicarbonate. Water is removed from the area by evapotranspiration and the soluble matter originally in the water is left behind, which can cause an accumulation of salts in the soil at the land surface. The salts are dissolved later by precipitation or irrigation water and transported to the aquifer. Salt accumulation from evapotranspiration does not appear to be a problem in this area during irrigation. Large quantities of diverted river water that are applied to the fields minimize the deposition of salts in the soils and mask any water-quality changes by evapotranspiration to ground water that is in the aquifer or that discharges to the river.

Discharge to the Verde River

Data from seepage investigations limited to periods of base flow were used to define the sources of significant gains to the Verde River: (1) subsurface flow from West Clear Creek and (2) irrigation subsurface return flows. The quantities of discharge to the river are variable and the measurements are representative of base flow and irrigation for the conditions that existed at the time of the individual investigations. Data from a 1979 seepage investigation indicated the study reach exhibited gains in streamflow (Owen-Joyce and Bell, 1983, p. 36). Springs and the shape of the water table, as illustrated by the contour lines in the alluvium (pl. 2), show ground-water movement toward the river. Water-quality changes in the river also indicate ground-water discharge to the river. Subsurface return flows from irrigation dissolve soluble minerals in the alluvium and contribute to water-quality changes in the river.

West Clear Creek supplies the single largest point source of discharge from the alluvium to the Verde River—an estimated 14,000 acre-ft/yr. During June 1981, all the water coming from West Clear Creek that discharged to the Verde River arrived as subsurface flow through the West Clear Creek alluvium deposited at the mouth of the creek. In November 1980, some of the discharge did appear as surface flow at the mouth of the creek. In the lower parts of some of the channels cut in the West Clear Creek alluvium, water flowed for short distances on the alluvium and some ground water seeped to flow as surface water the last 200 ft to the Verde River. The source of most of the gain to the Verde River in November was also subsurface flow, and the surface flow near the mouth of West Clear Creek was probably caused by the higher stage of the Verde River at this time of year. Water-quality changes between sites 37 and 52 (pl. 2) support the concept that subsurface flow in the West Clear Creek alluvium is the source of inflow in this reach. The major ions in water in West Clear Creek are calcium, magnesium, and bicarbonate, and the dissolved-solids concentration was 242 mg/L at site 49 in June of 1981 (pl. 2). During June 1981, a decrease in the dissolved-solids concentration (fig. 13), an increase in the calcium concentration, and a decrease in sodium concentration (fig. 14) were recorded between sites 37 and 52. The concentration of other constituents in the Verde River changed little if at all owing to the inflow.

An estimated 21,800 acre-ft/yr or about 70 percent of the water diverted from the river returns as ground-water discharge from the alluvium. The gains in flow in the river are essentially water from the Verde River rerouted through the irrigation ditches and the alluvium and discharged as ground water from the alluvium farther downstream. The estimate of ground-water discharge was calculated by balancing the water budget. Evaluation of the seepage-investigation data showed the variations in ground-water discharge to the river. Total ground-water discharge was calculated from the difference between flows in the river at measuring sites 14 and 58 in June 1981 (table 1, pl. 2) and accounting for diversions, return flows, and tributaries. The resultant gain in flow was compared to the difference between the amount of water applied to the fields and that consumed by crops. The gain in flow was within 1 ft^3/s of the amount of water not used by crops. The same analysis applied to data from the June 1979 seepage investigation also yielded an agreement in these quantities within 1 ft^3/s.

Water quality in the river is closely associated with the gains in flow that occur in the study reach. The amount of gain and the quality of the water that seeps to the river are reflected in the changes in ionic concentrations in the river. The variations in amounts and locations of irrigation in the area can cause variations in water chemistry at each site; therefore, the water-quality data during the seepage investigations are also indicative of conditions existing at the time. Trends do appear to be consistent between November and June; therefore, quantities probably change but the relation between sites follows a trend throughout the year.

During base-flow conditions, the dissolved-solids concentrations of water in the Verde River vary throughout the year. During November 1980, dissolved-solids concentrations ranged from 357 to 462 mg/L; whereas during June 1981, the concentrations ranged from 460 to 614 mg/L (fig. 13). Dissolved-solids concentrations increased downstream and followed a rather smooth curve during November; a small fluctuation occurred downstream from site 25 (pl. 2) where the springs are located. During June, the dissolved-solids concentrations in the river fluctuate more because of irrigation return flows. Return flows differ in composition and dissolved solids, which depend on where the irrigation water was taken from the river and the composition of the material the water flows

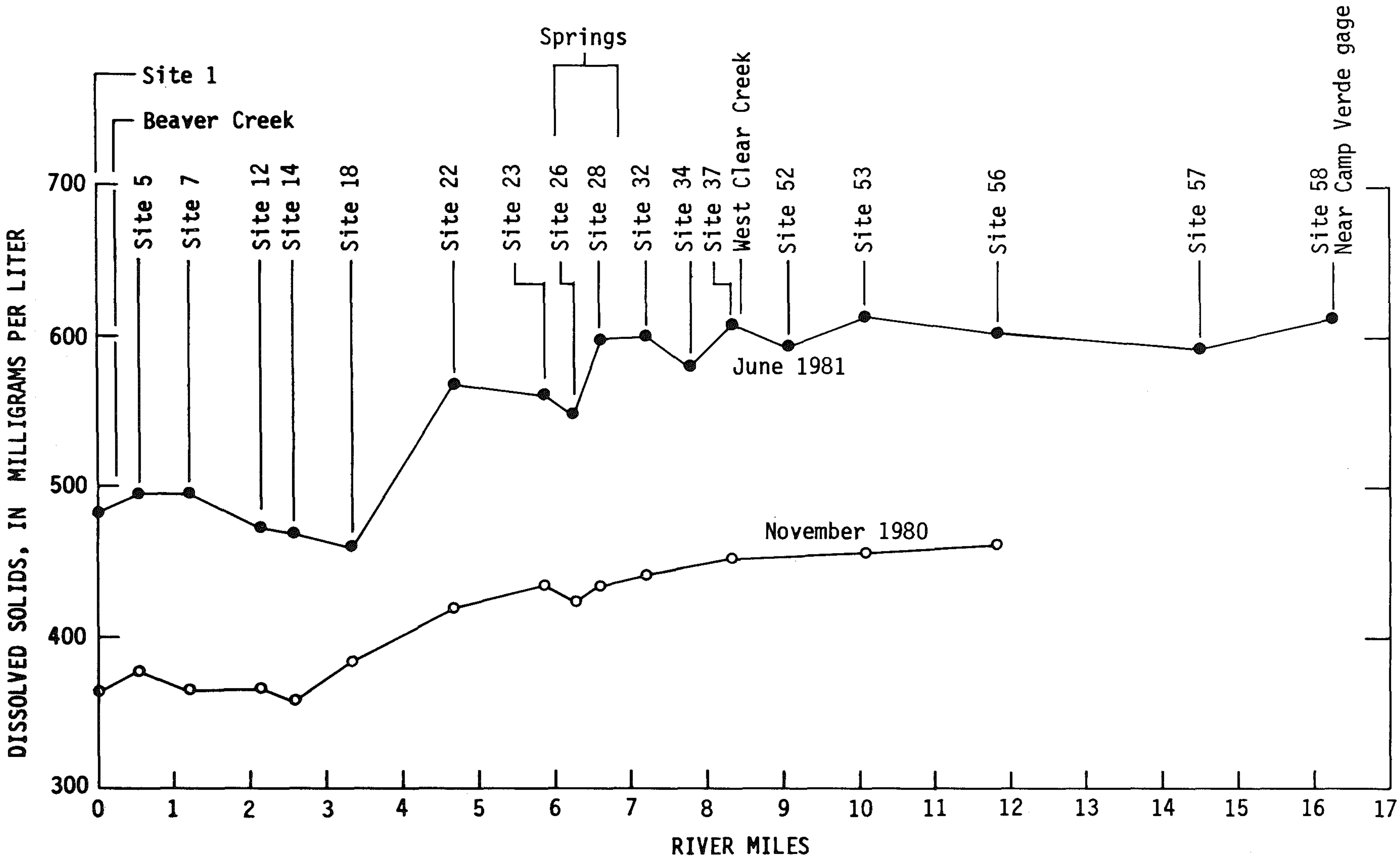


Figure 13.--Dissolved-solids concentrations along the Verde River.

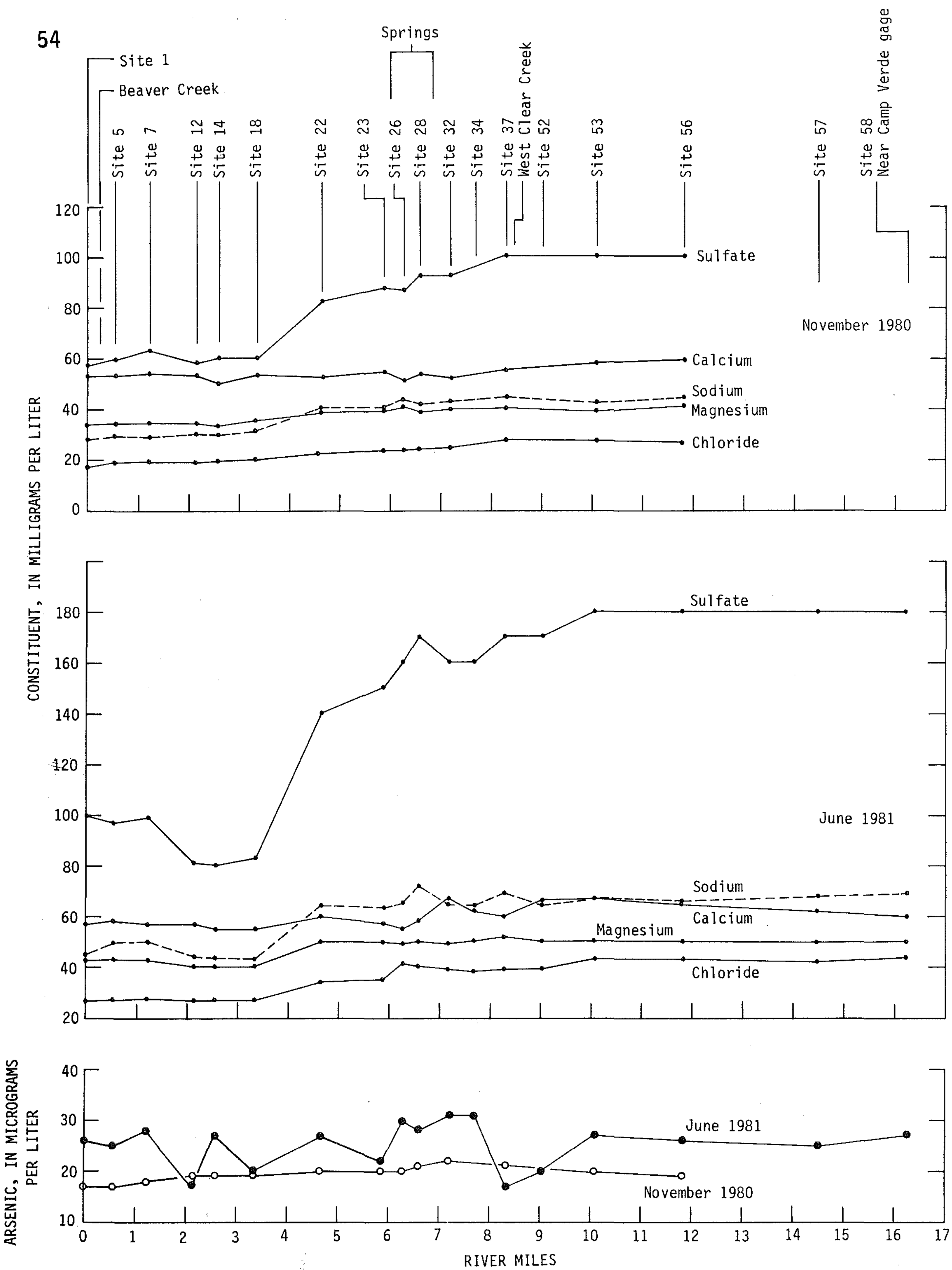


Figure 14.--Calcium, magnesium, sodium, chloride, sulfate, and arsenic concentrations along the Verde River.

through. Water diverted into Woods ditch originates outside the study area in the Verde River upstream from Beaver Creek and in June had a dissolved-solids concentration of 366 mg/L. Diamond S ditch originates upstream from site 14 (pl. 2) and probably would have had a dissolved-solids concentration similar to the river water at site 14, which was 469 mg/L. The alluvium along the west side of the river and away from the river channel contains more reworked Verde Formation than the alluvium on the east side. Subsurface return flows from water used to irrigate lands downslope from the salt mine in secs. 6 and 7, T. 13 N., R. 5 E., and sec. 12, T. 13 N., R. 4 E., contain larger concentrations of sodium and sulfate. These two constituents show a marked increase in the river between sites 18 and 22 (fig. 14), and therefore dissolved-solids concentrations increase (fig. 13). Because the hydraulic head in the Verde Formation is higher than the river level during base flows in this reach and the Verde Formation crops out in the river near site 14, some of the increase in dissolved-solids, sodium, and sulfate concentrations may be the result of inflow from the Verde Formation. During the lower flows in June, arsenic concentrations increase in this reach (fig. 14). Arsenic concentrations in water from wells in the Verde Formation on the east side of the river near site 14 range from 90 to 160 μg/L. The sodium sulfate salts from the salt mine on the west side of the river contain small amounts of arsenic, but if sufficient quantities of clay from the Verde Formation are present in the alluvium, arsenic could be supplied from the clay. Water in the alluvium on the west side of the river does contain larger concentrations of arsenic than that on the east side.

Changes in the dissolved-solids concentrations in the river from one sampling site to another correlate with changes in the sulfate and sodium concentrations. In November 1980, the changes from site to site are not as pronounced because flows in the river are higher and subsurface return flows are lower than in June 1981 (figs. 13 and 14). Irrigation contributes to the water-quality changes in the river by providing the water to dissolve the soluble minerals in the alluvium as the water percolates to the water table and ultimately to the river; therefore, the changes are larger during irrigation. Part of the increase in dissolved solids is contributed by inflow from the Verde Formation to the alluvium, which is diluted by irrigation water and travels to the river through the alluvium. Although irrigation is at a minimum in November, the concentrations of sulfate and sodium still increase at sites in the river. November conditions are a closer indication of the water-quality changes that result from inflow from the Verde Formation.

Natural discharge from the alluvium is probably masked by the irrigation return flows. It is unknown if the springs issuing from the alluvium were present before the installation of the irrigation ditches. In 1981, springs issued from the alluvium in secs. 8 and 16, T. 13 N., R. 5 E. (pl. 2). Most springs seem to be perennial, although some are underwater during high flows in the river. The springs in sec. 8, T. 13 N., R. 5 E., issue from the alluvium along the banks of the river; whereas most springs in sec. 16, T. 13 N., R. 5 E., issue from the alluvium above the alluvium-Verde Formation contact exposed on the east bank of the river. Altitudes of the springs conform to the alluvial water-table contour lines. Water quality of two springs, (A-13-5)8dcd and (A-13-5)16bcd, also indicates that the alluvium is the source of water. The dissolved-solids concentrations range from 461 to 594 mg/L, sulfate concentrations range from 100 to 160 mg/L, and arsenic concentrations range from 18 to 23 μg/L.

Water quality and altitude of three springs—(A-13-5)8dbb, (A-13-5)16baa2, and (A-13-5)16bbd1—indicate the presence of discharge from the Verde Formation, but the total quantity of water discharging is masked by the subsurface irrigation return flows. Changes in the concentrations of cations, anions, dissolved solids, and arsenic in the river near these springs indicate the inflow of some water that contains the larger concentrations of sulfate, sodium, magnesium, dissolved solids, and arsenic (figs. 13 and 14) known to be present in Verde Formation water. Blue Spring, (A-13-5)16bba2, flows an estimated 350 acre-ft/yr. Depending on the location of the sampling site within Blue Spring's pool, the dissolved-solids concentrations range from 491 to 954 mg/L, sulfate concentrations range from 110 to 420 mg/L, and arsenic concentrations range from 34 to 48 μg/L. The large range in values indicates a probable mixing of waters from both the alluvium and Verde Formation that discharge at this site.

Potential Discharge to the Verde Formation

The potential for water to flow from the alluvium into the underlying Verde Formation exists where the hydraulic head in the Verde Formation is lower than the hydraulic head in the alluvium; the estimated outflow is 20 acre-ft/yr (table 2). This head relation occurs along the west side of the alluvium in secs. 6, 7, and 17, T. 13 N., R. 5 E., and in the southern part of the study area in secs. 21, 27, 28, 33, and 34, T. 13 N., R. 5 E. (pl. 2). In secs. 6, 7, 17, 21, and 28, discharge from the alluvium is negligible because in the N½ sec. 6, SW. cor. sec. 21, and W½ sec. 28, most of the alluvium is dry. In secs. 7 and 17, the S½ sec. 6, W¼ sec. 27, and E½ sec. 28, the alluvium is deposited on the blue clay of the Verde Formation, which acts as a perching bed. In sec. 33 and the south-central part of sec. 27, the blue clay no longer underlies the alluvium and the Verde Formation is composed of sandstone and conglomerate, which is coarse-grained material with higher permeabilities. Where water in the alluvium is perched on the blue clay and wells are open to both formations, water cascades from the alluvium to the Verde Formation. In addition to leakage through wells, natural leakage probably occurs in this area but at a slower rate. The saturated thickness of the alluvium in the areas of cascading water is less than 5 ft. Most of the outflow probably occurs as cascading water in five wells, the total outflow was estimated using an assumed flow rate of 2 to 3 gal/min per well.

SUMMARY

To aid in understanding the hydrologic system, part of the Camp Verde area—south of Camp Verde—was selected to study the interconnection of the three water sources and the effects of the interconnection on water in the alluvium. Sources and uses of water in the Camp Verde area are: (1) water diverted from the Verde River and its tributaries is used to irrigate fields on the alluvium, (2) water pumped from the alluvium provides a domestic water supply, and (3) water in the Verde Formation provides domestic and public water supplies where the alluvium is absent or does not provide sufficient quantities of water. Water quality differs depending on the source.

A perennial river and an interrupted tributary, a water-table aquifer in the alluvium along the river, irrigation on the alluvium, and an underlying artesian aquifer in the Verde Formation interact to create a dynamic hydrologic system south of Camp Verde. A water budget was used to estimate the quantities of the inflow and outflow components. Water quality in the alluvium varies because differences exist in the material making up the alluvium and in the main inflow and outflow components functioning in local areas.

The water-bearing alluvium—mainly the channel, flood-plain, and terrace deposits of the Verde River—is hydraulically connected to the river. This unconfined ground-water system is in dynamic equilibrium. The largest component of inflow to the alluvium—an estimated 30,000 acre-ft/yr—is deep percolation of irrigation water. The Verde River functions as a drain. The quantity of water that discharges to the river is proportional to the amount of irrigation water applied at a given time. Generally the alluvium is less than 60 ft thick; as much as 30 ft is saturated. Saturated thickness varies owing to irrigation and mounding of the water table. The amount of water stored in the alluvium is estimated to be 17,500 acre-ft. West Clear Creek contributes 14,000 acre-ft/yr of subsurface flow, which passes through the alluvium to discharge to the river. Inflow from the Verde Formation is 1,000 acre-ft/yr. Outflow is mainly discharge to the Verde River that consists of irrigation return flows and West Clear Creek subsurface flows—estimated to be 35,800 acre-ft/yr—and evapotranspiration by riparian vegetation and crops—estimated to be 9,300 acre-ft/yr. Precipitation, discharge to the Verde Formation, and domestic pumpage, most of which returns through septic tanks, are less than 1 percent of the budget.

The alluvium is hydraulically connected to the underlying Verde Formation and the hydraulic head in the Verde Formation is as much as 10 ft higher than the hydraulic head in the alluvium in some wells. Leakage to the alluvium occurs through the formation and through wells open to both formations mainly in secs. 7 and 8, T. 13 N., R. 5 E. Along the west side of the alluvial outcrop and mainly in parts of secs. 27, 28, and 34, the hydraulic head in the Verde Formation is as much as 50 ft lower than the hydraulic head in the alluvium. Saturated thickness in the alluvium generally is less than 5 ft, and water cascades in some wells that are open to both formations. In places the alluvium is dry. Ground water in the Verde Formation drains to the Verde Fault zone; however, some leakage to the river may occur where the Verde Formation crops out in the river bed and the hydraulic head in the Verde Formation is higher than river level.

Water quality in the alluvium is affected by (1) the quantity and quality of irrigation water, (2) the composition of the materials in the alluvium, (3) inflow from the Verde Formation, (4) inflow from West Clear Creek, and (5) inflow of septic-tank effluent. During the irrigation season, deep percolation of water causes a dilution effect on water in the alluvium. Water moves slowly through the alluvium and dissolves minerals from rocks and soils; the dissolved-solids and sulfate concentrations increase where evaporite minerals from reworked Verde Formation are present. Locally, inflow of water from the Verde Formation increases the dissolved-solids, sulfate, chloride, and arsenic concentrations in the alluvium. Near the mouth of West Clear Creek, inflow from West Clear Creek dilutes ground water in the alluvium. Water-quality changes owing to inflow of septic-tank effluent appear to be seasonal; ammonia concentrations exceed 0.1 mg/L during the winter, which indicates the possibility of organic pollution before dilution by the irrigation water in summer. Evapotranspiration causes little or no detectable change in ground-water or surface-water quality but any changes in water quality may be masked by large quantities of infiltrating irrigation water. Dissolved-solids concentrations in the alluvium range from 251 mg/L near West Clear Creek to 4,400 mg/L where evaporite minerals from the Verde Formation are present in the alluvium. Sulfate, chloride, fluoride, arsenic, boron, iron, manganese, and selenium can exceed the maximum contaminant levels for public water supplies, and large concentrations are associated mostly with material from the Verde Formation in the alluvium or inflow from the Verde Formation.

REFERENCES CITED

Anderson, T. W., 1976, Evapotranspiration losses from flood-plain areas in central Arizona: U.S. Geological Survey Open-File Report 76-864, 91 p.

Blake, W. P., 1890, Thenardite, mirabilite, glauberite, halite, and associates of the Verde Valley, Arizona Territory: American Journal of Science, 3rd ser., v. 39, no. 224, p. 43-45.

Bureau of Water Quality Control, 1978, Drinking water regulations for the State of Arizona: Arizona Department of Health Services duplicated report, 39 p.

Freeze, R. A., and Cherry, J. A., 1979, Groundwater: New Jersey, Prentice-Hall, Inc., 604 p.

Gatewood, J. S., Robinson, T. W., Colby, B. R., Hem, J. D., and Halpenny, L. C., 1950, Use of water by bottom-land vegetation in lower Safford Valley, Arizona: U.S. Geological Survey Water-Supply Paper 1103, 210 p.

Goerlitz, D. F., and Brown, Eugene, 1972, Methods for analysis of organic substances in water: Techniques of Water-Resources Investigations of the U.S. Geological Survey, Book 5, Chapter A3, 40 p.

Jenkins, O. P., 1923, Verde River lake beds near Clarkdale, Arizona: American Journal of Science, 5th ser., v. 5, no. 25, p. 65-81.

Levings, G. W., and Mann, L. J., 1980, Maps showing ground-water conditions in the upper Verde River area, Yavapai and Coconino Counties, Arizona—1978: U.S. Geological Survey Water-Resources Investigations 80-726, maps.

Milne, Michael, 1981, Verde River water quality management study: Report on 1980 water sampling program: Flagstaff, Northern Arizona Council of Governments report, 78 p.

Nations, J. D., 1974, Paleontology, biostratigraphy, and paleoecology of the Verde Formation of late Cenozoic age, north-central Arizona, <u>in</u> Geology of northern Arizona, with notes on archaeology and paleoclimate—Part 2, Area studies and field guide: Geological Society of America, p. 611-629.

Nations, J. D., Hevly, R. H., Blinn, D. W., and Landye, J. J., 1981, Paleontology, paleoecology, and depositional history of the Miocene-Pliocene Verde Formation, Yavapai County, Arizona, <u>in</u> Arizona Geological Society Digest, Volume XIII, 1981, Stone, Claudia, and Jenney, J. P., eds., p. 133-149.

Northern Arizona Council of Governments, 1979, Verde Valley Water Pollution Source Analysis: Flagstaff, Northern Arizona Council of Governments report, 148 p.

Olmsted, F. H., Loeltz, O. J., and Irelan, Burdge, 1973, Geohydrology of the Yuma area, Arizona and California: U.S. Geological Survey Professional Paper 486-H, 227 p.

Owen-Joyce, S. J., and Bell, C. K., 1983, Appraisal of water resources in the upper Verde River area, Yavapai and Coconino Counties, Arizona: Arizona Department of Water Resources Bulletin 2, 219 p.

Rankama, Kalervo, and Sahama, Th. G., 1950, Geochemistry: Illinois, University of Chicago Press, 912 p.

Ross, P. P., and Farrar, C. D., 1980, Map showing potential geothermal-resource areas, as indicated by the chemical character of ground water, in Verde Valley, Yavapai County, Arizona: U.S. Geological Survey Water-Resources Investigations Open-File Report 80-13, map.

Sellers, W. D., and Hill, R. H., eds., 1974, Arizona climate 1931-1972: Tucson, University of Arizona Press, 616 p.

Todd, D. K., 1959, Ground water hydrology: New York, John Wiley and Sons, Inc., 336 p.

Towler, W. L., 1982, Verde Valley Water Quality Management Plan: Flagstaff, Northern Arizona Council of Governments report, 71 p.

Twenter, F. R., and Metzger, D. G., 1963, Geology and ground water in Verde Valley—the Mogollon Rim region, Arizona: U.S. Geological Survey Bulletin 1177, 132 p.

Ulrich, G. E., and Bielski, A. M., 1983, Mineral resource potential map of the West Clear Creek Roadless Area, Yavapai and Coconino Counties, Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF-1555-A, scale 1:24,000.

U.S. Environmental Protection Agency, 1977a, National interim primary drinking water regulations: U.S. Environmental Protection Agency report, EPA-570/9-76-003, 159 p.

__________1977b, National secondary drinking water regulations: Federal Register, v. 42, no. 62, March 31, 1977, p. 17143-17147.

__________1977c, Quality criteria for water: Washington, D.C., U.S. Environmental Protection Agency, 256 p. [Reprinted 1978]

Wadell, J. S., 1972, Sedimentation and stratigraphy of the Verde Formation (Pliocene), Yavapai County, Arizona: Phoenix, Arizona State University, unpublished masters thesis, 110 p.