ARIZONA DEPARTMENT OF WATER RESOURCES
BULLETIN 4

WATER RESOURCES OF SOUTHERN COCONINO COUNTY, ARIZONA

By
E. H. McGavock, T. W. Anderson, Otto Moosburner, and Larry J. Mann

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Prepared by the GEOLOGICAL SURVEY
UNITED STATES DEPARTMENT OF THE INTERIOR

Tucson, Arizona
1986

CONTENTS

ILLUSTRATIONS

[Plates are in pocket]

TABLES

CONVERSION FACTORS

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

Multiply	By	To obtain
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
acre	0.4047	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
ton (short)	0.0972	tonne (t)
degree Fahrenheit (°F)	°C = 5/9 (°F-32)	degree Celsius (°C)

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ABSTRACT

Southern Coconino County includes about 10,600 square miles in north-central Arizona. Water-resources development has been slight, and less than 8,000 acre-feet of ground water and surface water was used in 1975. The amount of ground water in storage is estimated to be between 100 and 200 million acre-feet. The main sources of ground water are the Coconino and limestone aquifers.

The Coconino aquifer includes three principal formations, which in ascending order are the Supai Formation, Coconino Sandstone, and Kaibab Limestone of Pennsylvanian and Permian age. In the southeastern part of the area, the Naco Formation of Pennsylvanian age underlies and intertongues with the lower member of the Supai Formation. The Coconino aquifer furnishes about 75 percent of the ground water used in southern Coconino County, although the aquifer does not underlie the entire area. Depth to water ranges from about 75 feet below land surface near Winslow to about 2,500 feet below land surface north of Flagstaff, and well yields range from about 1 to 1,000 gallons per minute. The chemical quality of the water generally is acceptable for most uses, and dissolved-solids concentrations generally are less than 500 milligrams per liter.

The limestone aquifer consists of a sequence of limestone, dolomite, sandstone, and shale units, which are hydraulically connected. The units, in ascending order, include the Tapeats Sandstone, Bright Angel Shale, and Muav Limestone of Cambrian age; the Temple Butte Limestone, an unnamed limestone unit, and the Martin Formation of Devonian age; the Redwall Limestone of Mississippian age; and an unnamed limestone unit of Pennsylvanian age. The limestone aquifer underlies the entire area and has the greatest water-yielding potential. Because the depth to water is more than 2,500 feet in most places, however, the limestone aquifer generally is not tapped by wells.

In places the Moenkopi and Chinle Formations of Triassic age, volcanic rocks, and sedimentary deposits will yield sufficient water of suitable chemical quality for livestock and domestic uses. Water occurs at depths of less than 300 feet below the land surface, and well yields of 10 to 50 gallons per minute are common.

Streamflow is extremely variable, and most streams are intermittent. Chemical quality of flow in intermittent and perennial streams during medium to high flows generally is acceptable for most uses; dissolved-solids concentrations generally are less than 200 milligrams per liter. Dissolved-solids concentrations in low flows in the perennial streams range from 200 to 2,000 milligrams per liter.

In southern Coconino County about 2,600 acre-feet of ground water and 4,200 acre-feet of surface water was used for public supply and irrigation in 1970. In 1975 about 5,200 acre-feet of ground water was withdrawn and about 2,500 acre-feet of surface water was used. The amount of surface water used annually is dependent on the amount of precipitation and is extremely variable. Ground-water withdrawals have not exceeded the rate of recharge, and water levels have been nearly constant.

INTRODUCTION

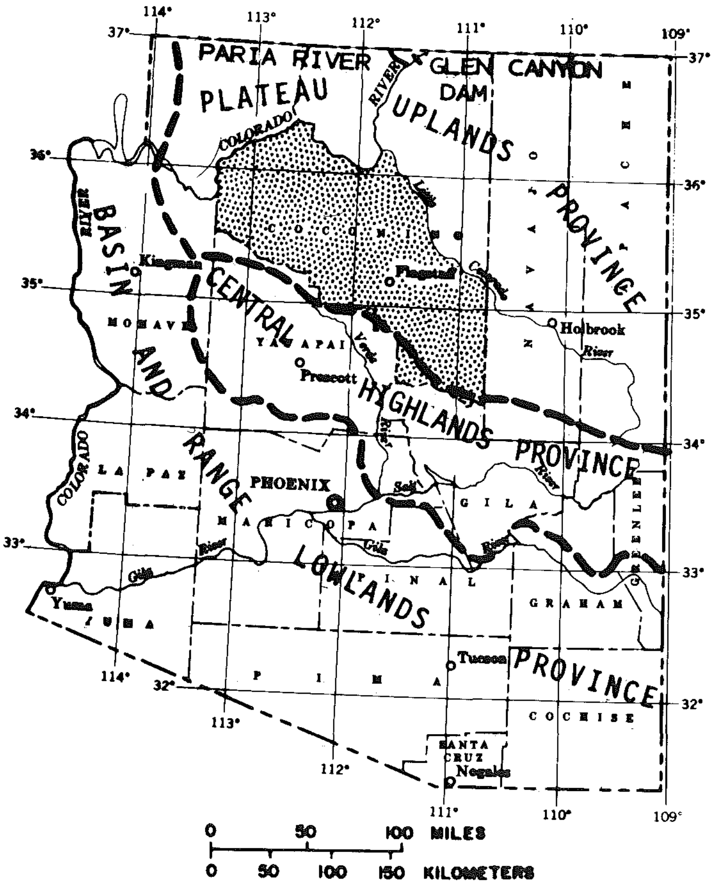
Southern Coconino County includes about 10,600 mi^2 in north-central Arizona and is the part of the county south of the Colorado and Little Colorado Rivers (fig. 1). The area includes the Coconino, Kaibab, and Sitgreaves National Forests and part of the Grand Canyon National Park. The steady increase in population, especially near Flagstaff, and the large seasonal influx of people to the recreational areas have caused an increasing demand for water supplies of sufficient quantity and suitable chemical quality. The study was made by the U.S. Geological Survey in cooperation with the Arizona State Land Department and the Arizona Department of Water Resources.

Purpose and Scope

The purpose of the study was to determine the availability, chemical quality, and use of water in southern Coconino County. The report describes the (1) surface-water characteristics, (2) distribution and general water-yielding characteristics of the aquifers, (3) chemical quality of the water, and (4) amount and effects of water-resources development in 1975. Data for contiguous parts of Yavapai, Navajo, and Gila Counties that relate directly to the hydrology of southern Coconino County are included in the report.

Methods of Investigation

An inventory was made of most wells and springs in the area (McGavock, 1968), and water samples were collected from selected wells, springs, and streams for chemical analysis. Chemical-analysis data are given in tables 4, 5, and 6 at the end of the report. Well and spring

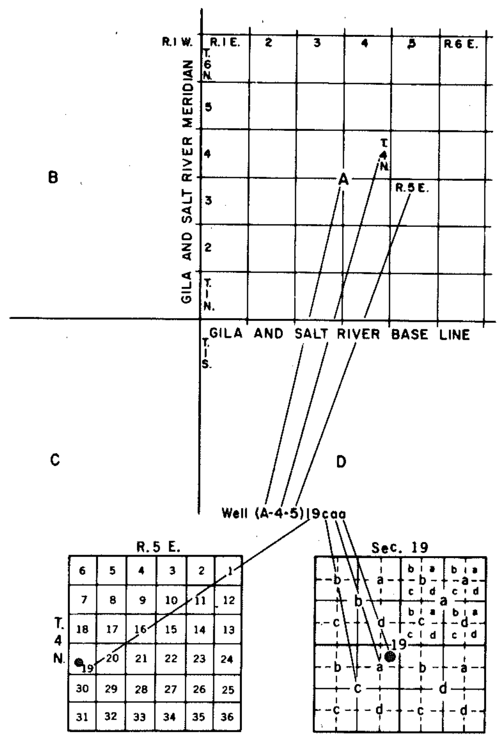


INDEX MAP SHOWING AREA OF REPORT (SHADED)

Figure 1.--Area of report and Arizona's water provinces.

locations are described in accordance with the well-numbering system used in Arizona, which is explained and illustrated in figure 2. Lithologic and drillers' logs of wells and drill cuttings were examined to determine the water-yielding potential of the aquifers. A reconnaissance geologic map was compiled from previously published maps to emphasize the aquifers as delineated and discussed in this report.

Records for 39 continuous-record gaging stations and 12 partial-record stations were used to evaluate the surface-water resources of the area. Gaging stations on streams are the most common tool for measuring streamflow; however, gaging every stream is impractical. Certain streamflow characteristics at ungaged sites were estimated by indirect techniques using data transferred from gaged sites. Continuous-record gaging stations provided data for the determination of mean annual flow, flood magnitude and frequency, and low-flow characteristics. Data obtained at crest-stage partial-record gaging stations were used to determine flood magnitude and frequency.



The well numbers 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 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 also are 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, well number (A-4-5)19caa designates the well as being in the NE¼NE¼SW¼ sec. 19, T. 4 N., R. 5 E. Where more than one well is within a 10-acre tract, consecutive numbers beginning with 1 are added as suffixes.

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

Regionalization of streamflow data provides an estimate of mean annual flow at any site on any stream in most of southern Coconino County (see section entitled "Mean annual flow"). In addition, the probability of a flood of any magnitude from a given drainage-basin size can be estimated. For most of the area, equations have been developed by which the 1-, 3-, and 7-day mean flow volume for a flood having a 50-year recurrence interval may be estimated.

Previous Investigations

The first detailed geologic study in Coconino County was made in the San Francisco Peaks volcanic field by Robinson (1913). Moore and others (1960) prepared a geologic map of Coconino County, and Cooley (1960) described the geology of the San Francisco Plateau. Geology and water resources of the Navajo Indian Reservation are described in reports by Davis and others (1963), Kister and Hatchett (1963), McGavock and others (1966), and Cooley and others (1964; 1966; 1969). The water resources of other parts of southern Coconino County are discussed by Metzger (1961), Cosner (1962), Twenter (1962), Twenter and Metzger (1963), Levings and Mann (1980), and Levings (1980). Data for many springs in the area are shown in Feth and Hem (1963) and Johnson and Sanderson (1968). Rush (1965) and Beus and others (1966) discussed the relation of geology and surface-water runoff in the Beaver Creek watershed, which is about 30 mi south of Flagstaff. Studies concerning the municipal water supplies for Flagstaff and Williams were made by Akers (1962), Akers and others (1964), and Thomsen (1969). Most of the hydrologic data collected during this investigation were presented by McGavock (1968); selected data collected from 1968 to 1975 are included in this report.

Acknowledgments

The authors gratefully acknowledge the assistance and cooperation of the well owners and drillers in the area. Valuable information concerning municipal water supplies was provided by H. F. Dunham and J. L. Rawlinson, Water and Sewer Department, city of Flagstaff; R. B. Stinson, city of Winslow; and M. B. McCutchan, Arizona Water Company. W. J. Breed, Museum of Northern Arizona; J. R. Scurlock, State of Arizona Oil and Gas Conservation Commission; and H. E. Brown, U.S. Forest Service, permitted access to their records. K. M. Reim, Chief Mining Engineer for Kern County Land Company, provided well records and geologic maps of the company's holdings in southern Coconino County.

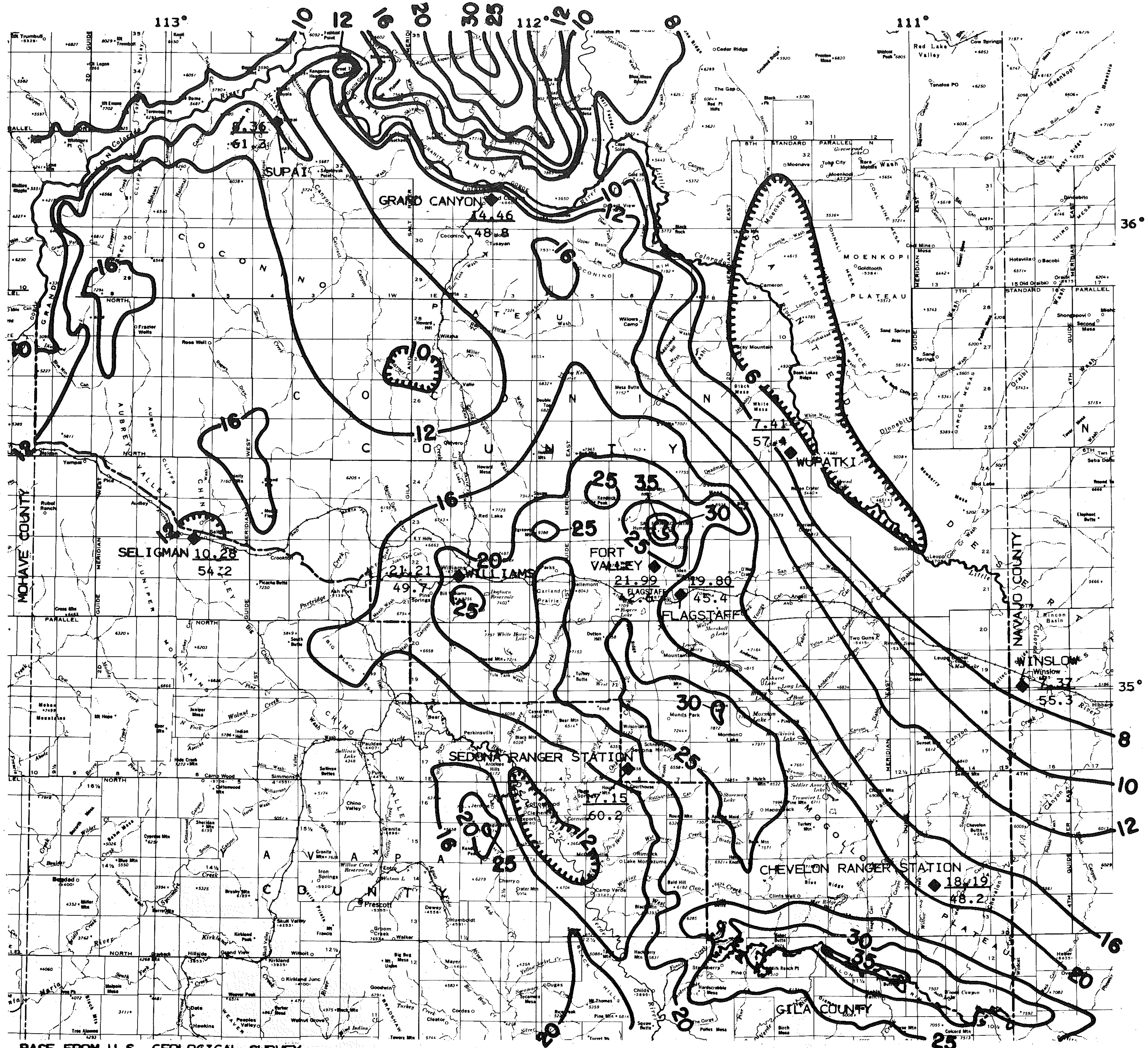
GEOGRAPHIC SETTING

Nearly all of southern Coconino County is in the Plateau uplands water province of Arizona (fig. 1). The dominant topography is the north- and northeast-sloping plateau, which is cut by steep-walled canyons. Rolling hills, peaks, and cones of volcanic rocks are superimposed on the plateau, where altitudes generally are from 5,000 to 7,000 ft above sea level. A 250-mi^2 area near Flagstaff is underlain by volcanic rocks and is at an altitude of 7,000 to more than 12,500 ft, which is as much as 6,500 ft above the altitude of the surrounding plateau. The Mogollon Rim escarpment has a relief of 2,000 to 3,000 ft and terminates the plateau along its south edge. The steep south-facing slopes of the rim form the demarcation line between the Plateau uplands and Central highlands water provinces of Arizona. Several deeply incised streams breach the Mogollon Rim and drain southward and westward from the plateau. The rim, which is the boundary between Coconino and Gila Counties, is the south boundary of the study area. The study area is further bounded on the south and southwest by Yavapai County and on the west by Mohave County. The Colorado and Little Colorado Rivers form the north and northeast boundaries, respectively, and Navajo County forms the east boundary.

Most streams that drain the area are tributary to the Colorado and Verde Rivers (fig. 1), although a few small areas have interior drainage. The eastern and northeastern parts of the area are drained by the Little Colorado River and its tributaries; the Little Colorado River joins the Colorado River in the Grand Canyon. Havasu and Cataract Creeks drain most of the northwestern part of the area; Havasu Creek is the lower reach of Cataract Creek and joins the Colorado River near the west boundary of Grand Canyon National Park. Between the Little Colorado River and the Coconino-Mohave County line, several small tributaries drain directly to the Colorado River. Tributaries of the south-flowing Verde River drain the southwestern part of the area.

The climate is characterized by extreme temporal and spatial variations in precipitation and temperature. Storms generally move into the area from the south and southwest. In general, the amount of winter precipitation is about equal to the amount of summer precipitation (University of Arizona, 1965a, b). Winter storms commonly distribute low-intensity precipitation over a large area and may last for several days. Major floods occur when rain falls on snow or when rainfall is abnormally intense. During July, August, and September, convectional storms of high intensity but small areal extent and short duration are common. Less frequently, in late summer, large moist airmasses originate off the coast of Mexico and deposit heavy rains that last from 1 day to several days; these infrequent and intense storms cause major floods.

The mean annual precipitation ranges from less than 6 in. along the Little Colorado River to more than 35 in. along the Mogollon Rim and on the San Francisco Peaks (fig. 3). The distribution of the precipitation is influenced by the orographic effect of the Mogollon Rim. At the Sedona Ranger Station at the base of the Mogollon Rim, the mean annual precipitation is 17.15 in. (Sellers and Hill, 1974, p. 460). About 50 mi north of the rim at Winslow, which is at about the same altitude as the Sedona station, the mean annual precipitation is 7.37 in. (Sellers and Hill, 1974, p. 570) The local orographic effects of the San Francisco



EXPLANATION

12 — LINE OF EQUAL MEAN ANNUAL PRECIPITATION—Interval 2, 4, and 5 inches. Hachured to indicate closed areas of lower precipitation. Data from University of Arizona (1965a, b)

◆ 21.21 / 49.7 — WEATHER STATION—Upper number, 21.21, is mean annual precipitation in inches; lower number, 49.7, is mean annual temperature in degrees Fahrenheit. Data from Sellers and Hill (1974)

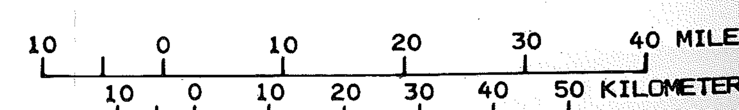


Figure 3.--Mean annual precipitation, 1931-60, and mean annual temperature, 1941-70.

Peaks and Bill Williams Mountain cause greater precipitation at Flagstaff, Fort Valley, and Williams than at about the same altitude at the Grand Canyon (fig. 3). Mean annual snowfall ranges from less than 10 in. along the Colorado and Little Colorado Rivers to more than 80 in. in the areas of highest altitude along the Mogollon Rim and the San Francisco Peaks. The mean annual temperature ranges from about 40°F at altitudes above 8,000 ft to about 60°F along the Colorado and Little Colorado Rivers. Mean annual temperatures at selected weather stations in or adjacent to the study area also are shown in figure 3.

SURFACE WATER

Most of the precipitation in the area evaporates, is transpired by plants, flows to the Colorado and Verde Rivers, or infiltrates to the underlying ground-water reservoirs. A small part of the precipitation is stored in natural or manmade impoundments for municipal, livestock, or recreational use. Nearly all streams in the study area are intermittent and flow only in response to rainfall or snowmelt; a few streams contain perennial flow that is maintained by ground-water discharge. A significant but unknown amount of streamflow percolates through the streambeds and recharges ground-water reservoirs.

Mean Annual Flow

Data from 39 continuous-record gaging stations having 5 years or more of record show the large variation in flow in the area and the variation in flow at a station with time (table 1). The coefficient of variation (table 1) is a measure of annual flow variability—the larger the value, the larger the variability. A zero value would indicate constant flow. Data collected at crest-stage gaging stations further indicate the variability of flow and the small amount of runoff. Results indicate that zero flow occurred in about 50 percent of the years at these sites. The infrequent flow events typically are less than a few hours in duration. Additional and more detailed daily streamflow data including monthly and annual flow totals and low- and peak-flow data are published annually (U.S. Geological Survey, 1919-60; 1961-75).

A multiple-regression technique was used to regionalize mean annual flow. Measurements of basin and climatic characteristics, such as drainage area, slope of the stream, mean annual precipitation, and snowfall in gaged basins, are treated as independent variables and are related to various dependent streamflow characteristics, such as mean annual flow. A study by Moosburner (1970) using data collected at 104 streamflow sites throughout Arizona provided a method for estimating mean annual flow in part of southern Coconino County on the basis of regionalization of the data. The data for all streamflow-gaging stations (fig. 4) in southern Coconino County and adjacent areas were handled in a similar manner to provide a method for estimating the mean annual flow in most

Table 1.--Mean flow characteristics at continuous-record gaging stations

Station number	Station name	Period of record	Drainage area, in square miles	Mean flow: Cubic feet per second	Mean flow: Acre-feet per year[1]	Mean flow: Inches per year	Mean flow: Standard error, in percent	Maximum yearly flow, in acre-feet[1]	Minimum yearly flow, in acre-feet[1]	Coefficient of variation
09397500	Chevelon Creek below Wildcat Canyon, near Winslow.......	1947-70	275	49.5	35,860	2.44	14	95,490	9,610	0.66
09398000	Chevelon Creek near Winslow....................	1917-19, 1930-33, 1936-72	794	50.3	36,440	.86	9	105,300	5,560	.63
09398500	Clear Creek below Willow Creek, near Winslow........	1947-74[2]	321	78.7	57,020	3.33	16	201,800	7,620	.82
09399000	Clear Creek near Winslow.....	1930-33, 1936-74[2]	607	77.7	56,290	1.74	13	196,500	5,050	.83
09400600	Rio de Flag at Flagstaff.....	1956-60	50.4	.15	109	.04	102	531	0	2.28
09400850	Upper Lake Mary near Flagstaff.................	1949-70	53.5	9.21	6,670	2.34	19	17,500	0	0.82
09401000	Little Colorado River at Grand Falls...............	1925-51, 1953-59	21,200	253	183,200	.16	12	586,800	18,670	.72
09402000	Little Colorado River near Cameron..............	1948-74[2]	26,500	228	165,200	.12	18	815,900	19,340	.93
09404040	Cataract Creek near Williams..................	1966-72	46.4	3.10	2,250	.91	43	7,750	344	1.14
09503700	Verde River near Paulden.....	1964-74[2]	2,530	33.7	24,420	.18	14	55,340	17,330	.47
09503720	Hell Canyon near Williams....	1966-72	14.9	3.31	2,400	3.02	29	5,090	216	.78
09503800	Volunteer Wash near Bellemont.................	1966-72	131	3.82	2,770	.40	33	6,040	0	.89
09504000	Verde River near Clarkdale.................	1915-16, 1917-20 1965-74[2]	3,520	193	139,800	.74	17	306,300	60,960	.58
00504500	Oak Creek near Cornville.....	1941-45 1949-74[2]	357	83.4	60,420	3.17	11	173,600	21,440	.60
09505200	Wet Beaver Creek near Rimrock...................	1962-74[2]	111	32.6	23,620	3.99	22	74,500	6,400	.81
09505250	Red Tank Draw near Rimrock...................	1958-74[2]	49.4	7.18	5,200	1.97	31	26,740	32	1.29
09505300	Rattlesnake Canyon near Rimrock...................	1958-74[2]	24.6	7.29	5,280	4.02	27	21,720	100	1.11
09505350	Dry Beaver Creek near Rimrock...................	1961-74[2]	142	37.4	27,100	3.58	27	97,940	990	1.01
09505800	West Clear Creek near Camp Verde................	1966-74[2]	241	59.8	43,300	3.37	32	143,800	13,330	.97
	<u>U.S. Forest Service gaging stations</u>									
	Beaver Creek Watershed 1....	1958-73	0.52	0.04	30.5	1.10	35	140	0	1.38
	Beaver Creek Watershed 2....	1958-74[2]	.20	.01	10.4	1.00	36	53	0	1.49
	Beaver Creek Watershed 3....	1958-74[2]	.57	.04	32.2	1.07	36	177	0	1.49
	Beaver Creek Watershed 4....	1958-73	.54	.21	152	5.29	26	608	5.4	1.02
	Beaver Creek Watershed 5....	1958-73	.10	.04	29.0	5.28	28	128	.8	1.14
	Beaver Creek Watershed 6....	1959-73	0.16	.04	31.5	3.64	31	144	.5	1.21
	Beaver Creek Watershed 7....	1958-73	3.18	.71	515	3.03	27	2,099	.6	1.08
	Beaver Creek Watershed 8....	1958-74[2]	2.82	1.41	1,024	6.82	22	3,465	78	.89
	Beaver Creek Watershed 9....	1958-74[2]	1.75	.90	649	6.95	23	2,384	26	.96
	Beaver Creek Watershed 10....	1958-74[2]	.89	.28	205	4.31	28	872	3.7	1.16
	Beaver Creek Watershed 11....	1959-74[2]	.29	.07	49.2	3.14	30	227	.2	1.22
	Beaver Creek Watershed 12....	1959-74[2]	.71	.36	258	6.81	25	1,046	7.3	1.00
	Beaver Creek Watershed 13....	1959-74[2]	1.42	.38	274	3.61	25	1,072	28	1.00
	Beaver Creek Watershed 14....	1959-74[2]	2.11	.72	519	4.61	28	2,295	10	1.11
	Beaver Creek Watershed 15....	1963-74[2]	.25	.08	54.5	4.01	29	155	.1	1.00
	Beaver Creek Watershed 16....	1963-74[2]	.39	.17	126	6.00	27	426	7.3	.95
	Beaver Creek Watershed 17....	1963-74[2]	.47	.28	205	8.24	25	631	20	.82
	Beaver Creek Watershed 18....	1963-74[2]	.38	.18	132	6.56	25	389	6.0	.87
	Beaver Creek Watershed 19....	1962-74[2]	16.71	7.58	5,490	6.16	27	19,440	167	. 97
	Beaver Creek Watershed 20....	1962-74[2]	25.75	11.3	8,160	5.94	26	28,810	244	.94

[1]Based on water year, October 1 through September 30.
[2]Active gaging station.

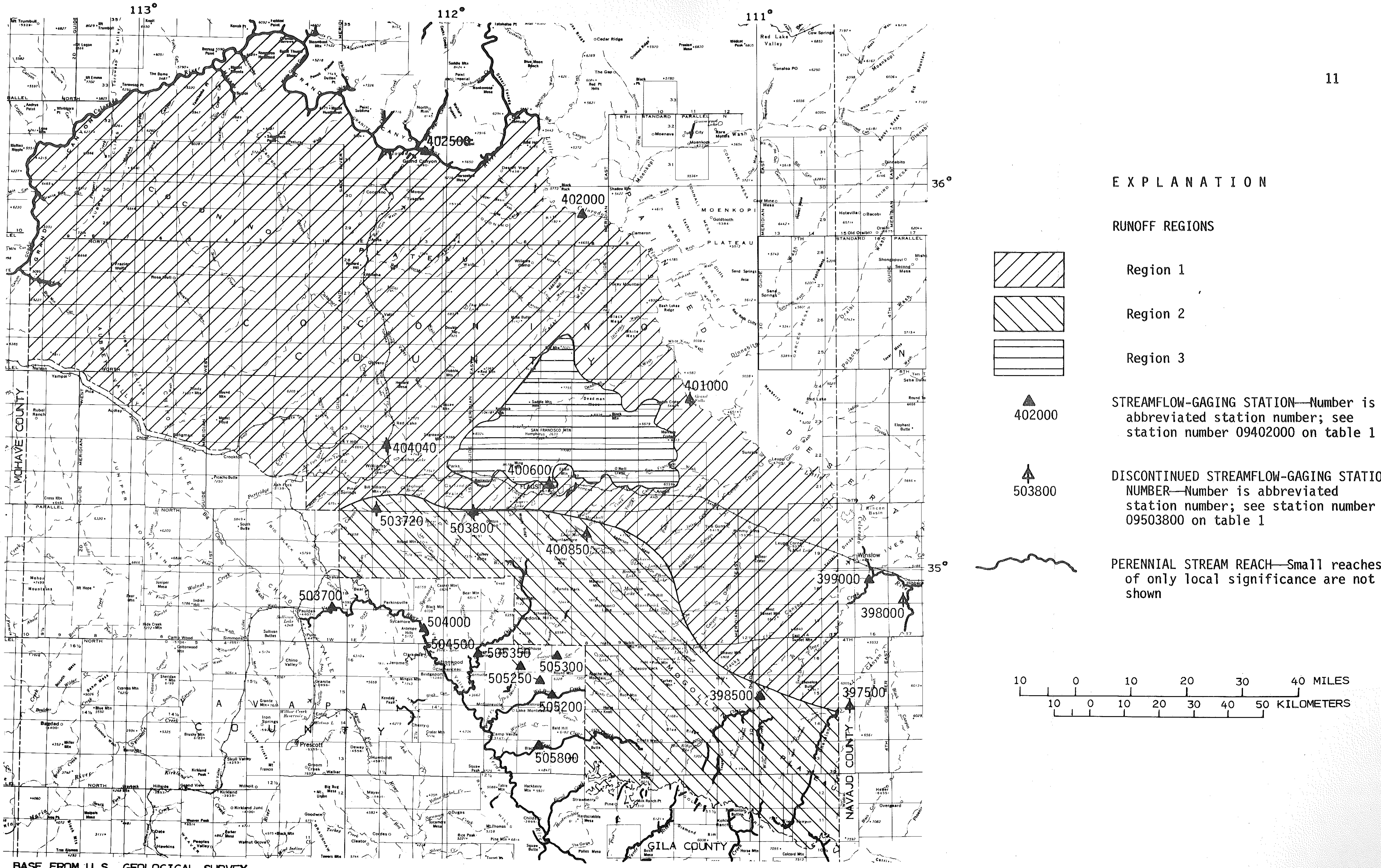


Figure 4.--Perennial stream reaches, location of streamflow-gaging stations, and runoff regions in southern Coconino County.

of the study area. As a result of the data analysis, southern Coconino County was divided into three runoff regions (fig. 4). The applicable equations for regions 1 and 2 are:

$$\text{Region 1:} \quad Q = 1.30 \times 10^{-6} A^{0.77} P^{3.94}$$

and

$$\text{Region 2:} \quad Q = 5.09 \times 10^{-5} A^{0.82} P^{2.76} S^{0.41},$$

where

Q = mean annual flow, in cubic feet per second;
A = drainage area, in square miles;
P = normal annual precipitation on the drainage area, in inches; and
S = shape factor, defined as the square of the length of main channel from site to divide, in miles, divided by the drainage area, in square miles.

The third region is an area largely underlain with volcanic cinders north of Flagstaff where surface-water runoff may be negligible. A regression equation could not be defined for this region because data are insufficient. The regression equations should be used with judgment and in conjunction with other procedures, such as those recommended by Moore (1968), and with correlation methods whenever possible.

The Colorado River is almost completely regulated by releases from Glen Canyon Dam near the Arizona-Utah State line (fig. 1). Tributary inflow from the Paria and Little Colorado Rivers and some smaller streams represent the only uncontrolled flow. Before 1963 when regulation by Glen Canyon Dam began, the mean annual flow of the Colorado River near Grand Canyon for 1922-62 was 16,930 ft^3/s and ranged from a high of 26,840 ft^3/s in 1929 to a low of 6,431 ft^3/s in 1934. Most of the flow occurred from April to July from snowmelt in the upper Colorado River basin. For 1964-74, which included the period when Lake Powell was filling, the flow averaged 12,840 ft^3/s.

The greatest surface-water unit runoff in the study area is from the Mogollon Rim area where the normal annual precipitation is greater than 20 in. (fig. 3). Mean annual runoff of as much as 8.24 in. has been measured from small high-altitude drainages in the Mogollon Rim area by the U.S. Forest Service (table 1). Mean annual runoff from larger watersheds—greater than 10 mi^2—tributary to the Verde River and the upper reaches of Clear and Chevelon Creeks ranges from 1.97 to 6.16 in. (table 1). Runoff is least in the area of the volcanic cinders north of Flagstaff, in some of the low-altitude and comparatively flat parts of the Havasu drainage, and along the Little Colorado River. The mean annual surface-water runoff in these areas probably is much less than 0.5 in. and may be near zero. The lowest surface-water runoff measured at a gaging station in the study area—0.04 in./yr—was for Rio de Flag at Flagstaff (table 1).

Flood Peaks

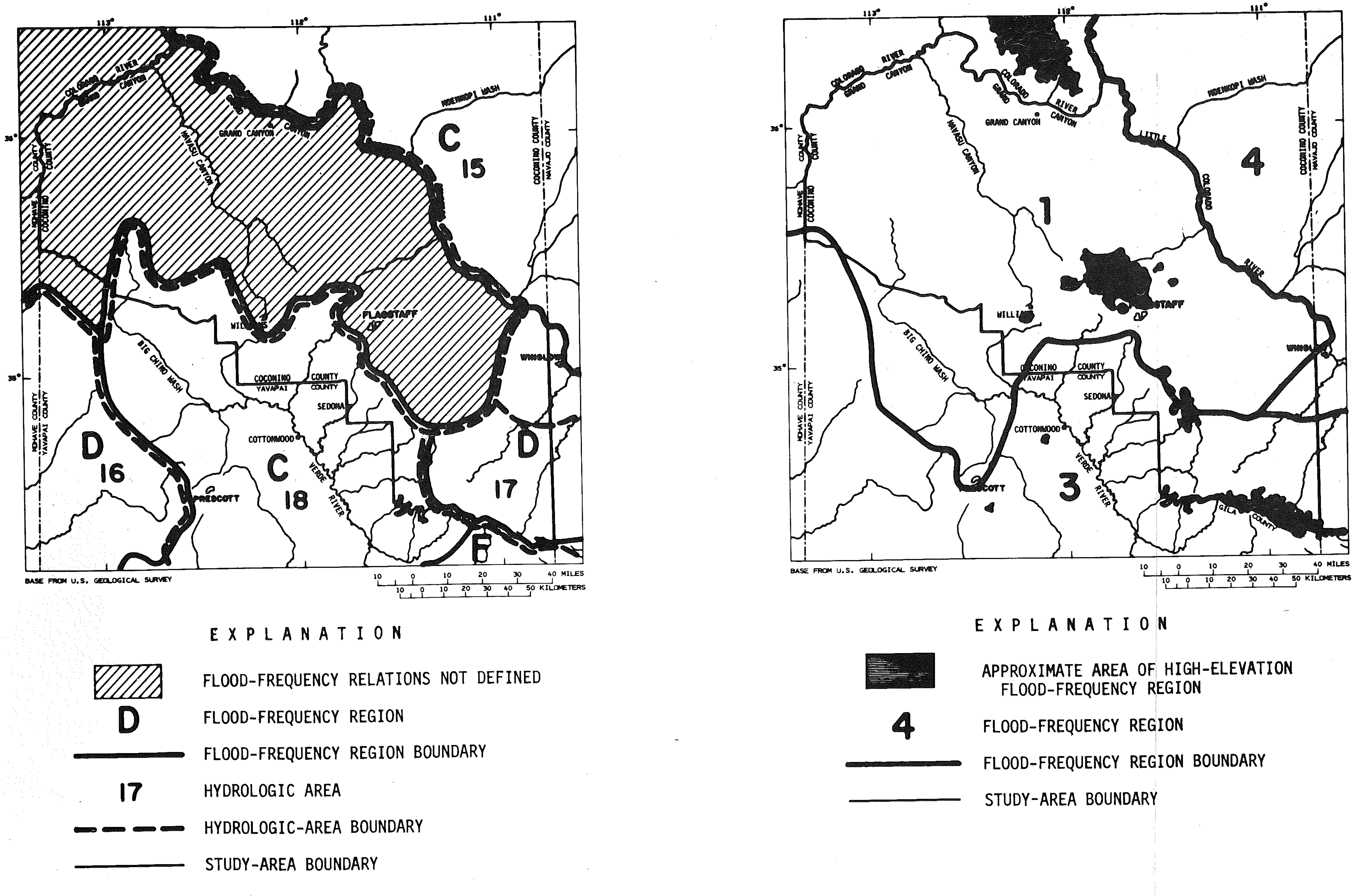
Flood discharges and frequency of occurrence in the area are reported as peak instantaneous discharges, flood volume for a specified period of time, and flow duration. These data must be known for proper design of hydraulic structures, highways, and storage projects; floodway zoning; and other purposes where consideration of water supply or flood hazard is a factor.

Flood-peak frequency data for a site commonly are plotted as peak discharge versus recurrence interval. Recurrence interval is defined as the average interval of time within which a peak flow of a given magnitude will be equaled or exceeded once. The probability of a flood of a given magnitude occurring in any one year may be estimated from a given recurrence interval. For example, if the recurrence interval of a flood of a given magnitude is 25 years, the probability of it occurring in any one year is 4 percent. Although the average frequency of a flood of a given magnitude can be estimated, the time of its next occurrence cannot be predicted.

Flood-peak frequencies can be determined directly from flow records for a specific site where streamflow is gaged. Regionalization of the data involves combining the frequency curves developed for individual gaging stations in a region into one frequency curve that would be applicable to any stream in a region at either a gaged or ungaged site. By assuming that the data can be regionalized, an inherent assumption of homogeneity is made with respect to flood-producing characteristics within the region.

The three hydrologic areas and two flood-frequency regions defined by Patterson and Somers (1966) that are included in southern Coconino County are shown in figure 5A. The index method is one method of regionalizing the flood-peak frequency curve. Peak discharges that have a recurrence interval of 2.33 years ($Q_{2.33}$), which is defined as the mean annual flood, are utilized in developing two relations. One is the relation of the mean annual flood to the size of the drainage area from which the floods originate. The relations for each of the hydrologic areas are shown in figure 6. The second relation uses the dimensionless ratio of any discharge to the mean annual flood to relate to recurrence interval. The relations for the two flood-frequency regions are shown in figure 7. The combined use of these two relations allows the estimation of the peak discharge of a flood of any recurrence interval at any stream site in the region where the flood-frequency relations are defined.

Roeske (1978) used multiple-regression techniques to develop regional flood-frequency relations based on gaging-station data collected throughout Arizona. Equations were presented for estimating peak-flow magnitudes for recurrence intervals of 2, 5, 10, 25, 50, 100, and 500 years (Roeske, 1978, p. 5-7). The study area includes parts of



A. Flood-frequency regions and hydrologic areas of Patterson and Somers (1966, pl. 1).

B. Flood-frequency regions of Roeske (1978).

Figure 5.--Hydrologic areas and flood-frequency regions in southern Coconino County.

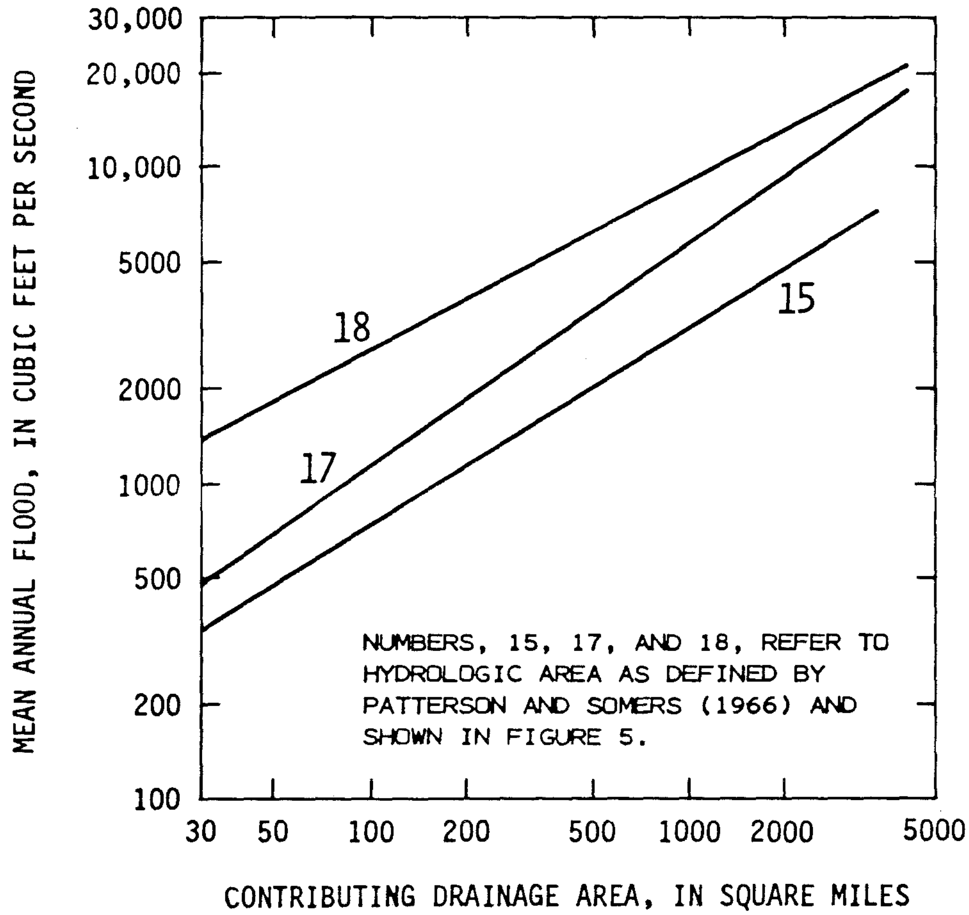


Figure 6.--Drainage area versus mean annual flood (Patterson and Somers, 1966, p. 12).

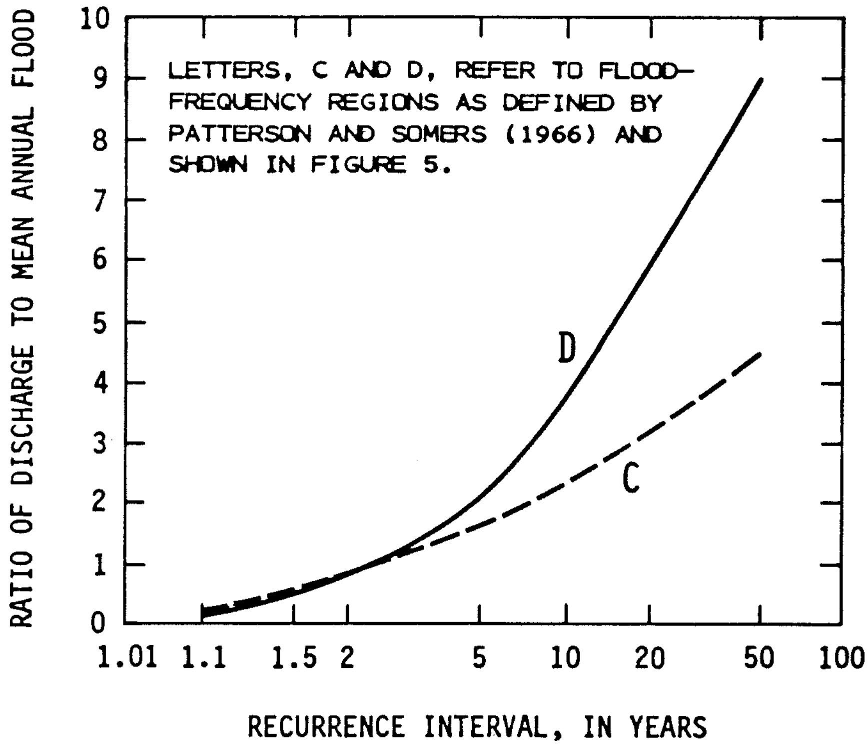


Figure 7.--Ratio of T-year flood to mean annual flood ($Q_{2.33}$) (Patterson and Somers, 1966, p. 4).

Roeske's Region 1—Northwest plateau area, Region 3—Central mountain area, Region 4—Northeast plateau area, and the high-elevation region (fig. 5B).

Flood Volumes

The relation of flood volumes for various flow durations and recurrence intervals was determined from a regression analysis of the data from gaged streams in the study area. The equations that resulted from the analyses are given in table 2. The equations are applicable to runoff regions 1 and 2 (fig. 4); no equation was determined for region 3. The 1-, 3-, and 7-day mean flow volumes for a 50-year recurrence interval can be estimated for ungaged stream sites in most of the area by use of the equations in table 2.

Flow-Duration Curves

A flow-duration curve for a stream site is a cumulative frequency curve that shows the percentage of time that specified discharges are equaled or exceeded (Searcy, 1959, p. 1). The curve combines the flow characteristics of a stream site throughout the range of discharge without regard to the sequence of occurrence and provides a convenient means for comparing streams. The slope of the flow-duration curve is indicative of the hydrologic and geologic characteristics of a drainage area.

Representative flow-duration curves for selected perennial and intermittent streams in the study area are shown in figure 8. Chevelon Creek near Winslow and Oak Creek near Cornville are perennial at the gage sites; this is indicated by the flat-slope part of the curve to the right (fig. 8). The intermittent streams are illustrated by the steep slope of the curve and the lack of a flat-slope part. Although duration curves are not available for small intermittent streams typical of the northwestern part of the study area, crest-stage gaging-station data indicate that flow occurs only about 1 percent of the time when a time unit of a day is used. The percentage of time in most places probably is less than 1 percent because each flow event encompasses only a few hours rather than a full day.

Perennial Streams and Low Flows

Only a few streams in or near the study area are perennial. The known perennial reaches are shown in figure 4, exclusive of the small perennial spring-fed streams tributary to the Colorado River in the Grand Canyon and a few reaches of minor streams of only local significance. Ground-water discharge is the source of water in the perennial streams.

Table 2.--Regression equations used to estimate 1-, 3-, and 7-day mean flow volumes on ungaged streams in runoff regions 1 and 2 for a 50-year recurrence interval

[Runoff region is shown in figure 4. $V_{1,50}$, $V_{3,50}$, and $V_{7,50}$ are the highest 1-, 3-, and 7-day mean flow volumes that occur on the average of once every 50 years; A is drainage area, in square miles. P is mean annual precipitation in drainage area, in inches. I is maximum 24-hour point rainfall, in inches, having a recurrence interval of 10 years (U.S. Weather Bureau, 1967). SO is the soil index, which is dimensionless; the soil index is an index to the capacity of the soil to accept infiltration and is based on soil type, soil cover, and agriculture practices. An index of 3 generally should be used in southern Coconino County except in the Grand Canyon area, where 4 should be used and in some parts of the Flagstaff area where the index is 2]

Region 1		Region 2	
Mean flow, in cubic feet per second	Standard error, in percent	Mean flow, in cubic feet per second	Standard error, in percent
$V_{1,50} = 0.582A^{0.65}I^{4.34}$	104	$V_{1,50} = 1.76\ A^{0.80}I^{-.78}(SO)^{3.68}$	67
$V_{3,50} = 0.331A^{0.67}I^{4.21}$	86	$V_{3,50} = 1.01\ A^{0.82}I^{-.73}(SO)^{3.56}$	55
$V_{7,50} = 0.254A^{0.65}I^{4.09}$	74	$V_{7,50} = 9.34 \times 10^{-2}A^{0.83}P^{0.97}(SO)^{-0.80}I^{2.62}$	47

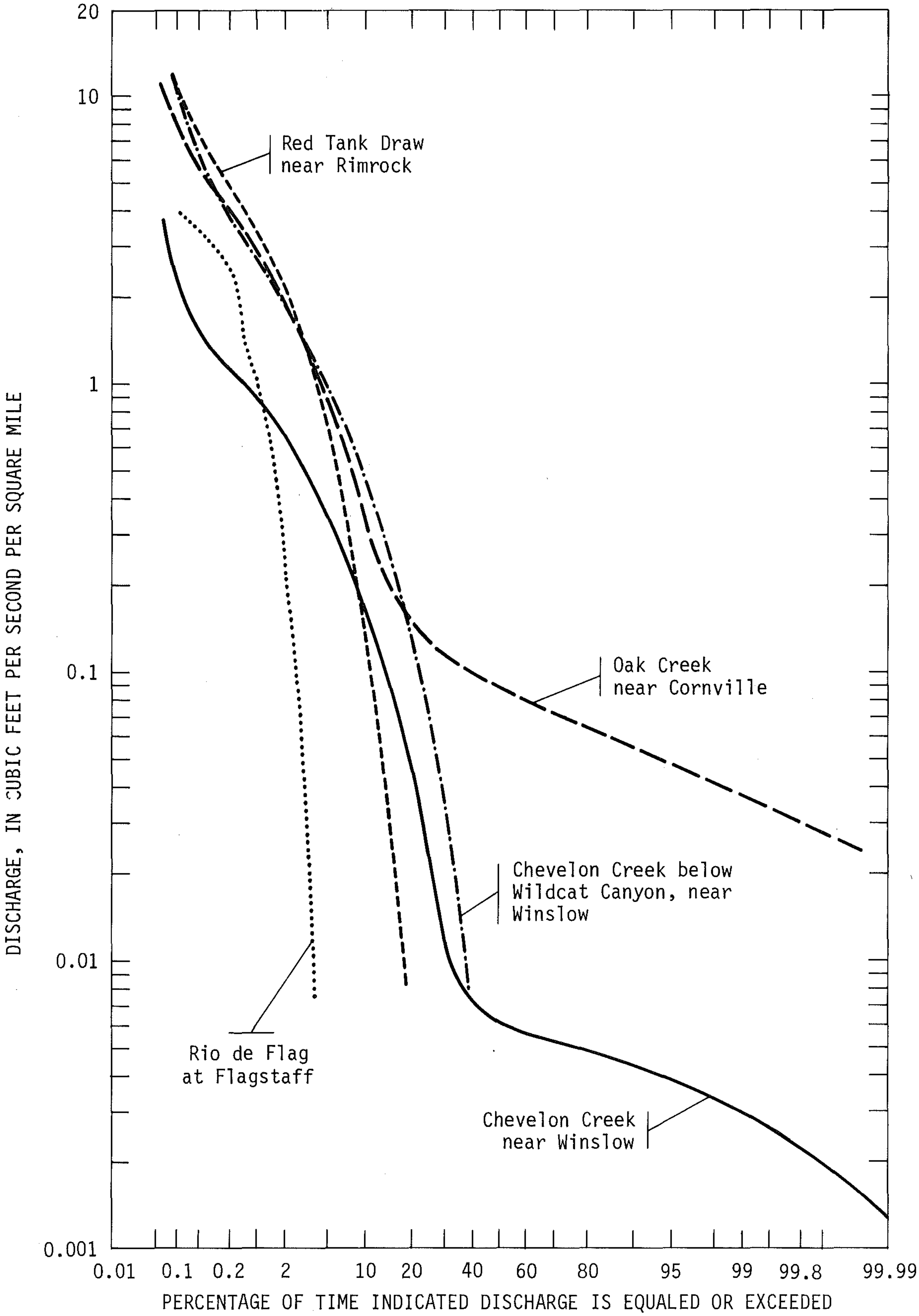


Figure 8.--Flow-duration curves for selected streamflow-gaging sites.

The perennial streams in the Little Colorado River drainage in or near the study area include (1) parts of Chevelon Creek, which has a low-flow rate of 3,260 acre-ft/yr at the gaging station Chevelon Creek near Winslow; (2) parts of Clear Creek, which has a low-flow rate of 3,100 acre-ft/yr downstream from the gaging station Clear Creek near Winslow (Mann, 1976); and (3) the Little Colorado River from Blue Spring to its mouth, which has a low-flow rate of 161,000 acre-ft/yr. Blue Spring is the largest of several springs that issue into the Little Colorado River from about 3 to 13 mi above its mouth. This is the only reach of the Little Colorado River in the study area that is perennial. Thirteen discharge measurements made from 1952 to 1967 indicate that little variation occurs in the total spring flow (Johnson and Sanderson, 1968).

Havasu Spring is the source of perennial flow in Havasu Creek. The spring is a series of seeps that emerge from the bottom of Havasu Canyon along several branches of Havasu Creek. The seeps occur in a quarter-mile reach about 10 mi upstream from the mouth of Havasu Creek. Discharge measurements made downstream from Havasu Spring since 1950 indicate a nearly constant base flow of about 46,000 acre-ft/yr.

Several spring-fed tributaries to the Verde River, which include Oak Creek, Wet Beaver Creek, and West Clear Creek, head and are perennial in a part of the study area. Additional information on springs in or near the study area is presented by Feth and Hem (1963) and Johnson and Sanderson (1968).

Quality of Surface Water

Most of the dissolved constituents in streamflow are derived from reactions of rainfall or snowmelt with minerals on the surface of the ground or in the ground. A smaller component is contained in the rain and snow prior to its contact with the ground surface. At the same sampling site in a stream, concentrations of dissolved solids will be greater in the base flow than in the floodflow. Owing to the longer ground-contact time, base-flow water dissolves more minerals than does floodflow water.

Dissolved-solids concentrations in streamflow during periods of storm or snowmelt runoff are extremely low in most streams that drain the area. The concentrations range from 34 to 916 mg/L (milligrams per liter) and generally are less than 100 mg/L (table 4). The main dissolved-solids constituents during the high-runoff periods are silica, calcium, and bicarbonate.

The base flow of the Little Colorado River below Blue Spring and in the lower reaches of Chevelon Creek contains from 1,870 to 2,600 mg/L or more of dissolved solids (table 4); the main constituents are sodium and chloride. Flow of Havasu Creek below the springs generally has a dissolved-solids concentration that ranges from 380 to 485 mg/L (table 4); the main constituents are calcium and bicarbonate. The chemical quality of the base flow of the Verde River tributaries is markedly better than that of the Colorado River and its tributaries. The dissolved-solids concentrations range from 153 mg/L in Wet Beaver Creek to 220 mg/L in Oak Creek; the main constituents are calcium and bicarbonate (table 4).

Stream temperatures (table 4) are dependent mainly on air temperature, size of the stream, and proximity of the measuring site to the streamflow source. Storm and snowmelt runoff temperatures probably are closely related to local air temperatures, whereas streamflow temperatures immediately downstream from perennial springs are nearly constant, especially below springs that are the outflow from large ground-water reservoirs.

Streamflow transports disintegrated rock material either in suspension or as bedload. The sediment load of any stream depends on the characteristics of the drainage basin, such as lithology, vegetal cover, mean annual precipitation, storm intensity, topography, and type and degree of development. The sediment yield, which is the volume of sediment load per unit area, varies widely in the study area and generally is lowest in the highest altitudes (W. F. Mildner, Soil Conservation Service, written commun., 1971). Quantitative data are sparse for most streams, but floodflow in the Little Colorado River at Cameron transported a total of 2,580,000 tons of suspended sediment on September 21, 1952 (Love, 1961, p. 155).

GROUND WATER

Ground water occurs in nearly all the geologic formations that underlie southern Coconino County and is the major source of reliable water supplies. Many of the geologic formations are hydraulically connected and combine to form aquifers. An aquifer is a formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs (Lohman and others, 1972, p. 2).

On the basis of subsurface geologic data from wells and test holes, two major aquifers are delineated in southern Coconino County. The Coconino aquifer is the uppermost and main source of ground water in the eastern part of the area. In the central and western parts of the area, the Coconino aquifer generally does not contain water. Water occurs mainly in a sequence of hydraulically connected limestone, dolomite, and sandstone units that are found at considerable depth below the units that make up the Coconino aquifer. Because the rocks that form the deeper aquifer are mainly limestone, the aquifer is informally referred to as the "limestone aquifer."

In addition to the widespread occurrence of water in the Coconino and limestone aquifers, ground water also occurs in the Moenkopi and Chinle Formations, volcanic rocks, and sedimentary deposits. Although these units do not contain wate[illegible]rge areas, they do provide locally important sources of water main[illegible]mestic and livestock use.

Coconino Aquifer

The Coconino aquifer is the main source of ground water in the eastern part of the study area. West of Flagstaff, the units that make up the aquifer generally are drained of water. The aquifer consists of three principal formations, which, in ascending order, are the Supai Formation of Permian and Pennsylvanian age and the Coconino Sandstone—the main water-bearing unit in the aquifer—and the Kaibab Limestone of Permian age (pl. 1). In the southeastern part near Fossil Creek, the Naco Formation of Pennsylvanian age underlies and intertongues with the lower member of the Supai Formation. No wells are known to tap the Naco, but the Naco is the source of Fossil Springs, which discharge about 18,000 gal/min of water. In the central part of the area the Toroweap Formation of Permian age separates the Coconino Sandstone from the Kaibab Limestone. In the northwestern part the Hermit Shale of Permian age lies between the Supai Formation and the Coconino Sandstone. Where the Toroweap and Hermit are present, they generally are above the water table.

The Supai Formation is the thickest and most lithologically variable formation in southern Coconino County. The formation is about 800 ft thick at the west end of the Grand Canyon, 1,750 ft thick along the Mogollon Rim in Fossil Creek Canyon (Huddle and Dobrovolny, 1945), and 2,200 ft thick near Winslow. In the northwestern part the Supai is overlain by the Hermit Shale and consists of alternating beds of silty sandstone and siltstone.

In the central and southeastern parts of the area, three distinct members of the Supai have been recognized. The upper member of the Supai is composed of moderately silty sandstone that in places intertongues with the overlying Coconino Sandstone. The middle member is composed of alternating beds of siltstone and mudstone with some sandstone, conglomerate, and limestone. The lower member of the Supai is mainly sandstone, siltstone, and limestone. Part of the lower member is lithologically similar to and may be the lateral equivalent of the Naco Formation that underlies the Supai east of Verde Valley (Twenter and Metzger, 1963, p. 30).

In the extreme northeastern part of the area, the upper member of the Supai is mainly a very fine grained sandstone and silty sandstone that grades downward into mainly siltstone. The siltstone impedes the downward movement of water into the underlying limestone aquifer. As the Supai is traced east and south, however, the siltstone beds grade laterally into very fine grained sandstone and silty sandstone. The siltstone beds are fractured along major faults and folds, such as the Oak Creek and Anderson Mesa faults, the Tolchaco anticline, and the East

Kaibab monocline. The fractures provide a direct hydraulic connection between the Coconino aquifer and the deeper limestone aquifer, and water in the Coconino aquifer moves downward into the limestone aquifer. In places, such as near Sedona, the Coconino and limestone aquifers probably function as a single hydraulic unit (Levings, 1980).

In the northwestern part of the area, no wells produce water from the Supai Formation. The sandstone in the upper 500 ft of the unit however is an important source of water in the rest of the area, especially near Flagstaff. The alternating beds of sandstone, limestone, siltstone, and mudstone in the middle and lower members presently are the chief source of ground water in the Sedona area.

The Hermit Shale is about 930 ft thick near the Grand Canyon, thins rapidly to the south and east, and is not recognizable near the towns of Williams or Cameron. The Hermit is composed of very fine grained sandstone, silty sandstone, and limestone and does not yield water to wells in the area. The Hermit may perch water in the overlying Coconino Sandstone in places where the sandstone is commonly drained of water.

The Coconino Sandstone is the most productive and wide-spread unit of the Coconino aquifer in southern Coconino County. The Coconino is a very fine to medium-grained, cross-bedded sandstone that is moderately to well cemented. The Coconino is about 900 ft thick along the Mogollon Rim near Pine and near Wupatki National Monument and thins to about 100 ft thick at the west end of Grand Canyon National Park. The Coconino Sandstone is only moderately to poorly permeable in the study area except where it is well jointed or faulted.

The Toroweap Formation in the Grand Canyon area is composed of about 375 ft of limestone, siltstone, sandstone, and some gypsum beds. Southeastward, toward Flagstaff, the Toroweap thins and becomes principally a sandstone; the formation is not recognizable east of the Flagstaff area. The Toroweap is rarely water bearing in the study area except near Grand Canyon Village where the siltstone beds perch water in overlying sandstone beds.

The Kaibab Limestone is composed of sandy limestone and dolomite and is uniform in lithology throughout most of the area. The thickness of the Kaibab generally increases in a northwesterly direction from about 50 ft near Winslow to 380 ft near the Grand Canyon. In places, especially in canyon areas, the Kaibab has been completely removed by erosion. The Kaibab Limestone generally is highly fractured; thus, it readily accepts recharge from precipitation and allows downward percolation of water into underlying formations. The Kaibab generally is above the water table except for small areas near the Little Colorado River where it is hydraulically connected with the underlying Coconino Sandstone. Near Flagstaff, chert beds and dense limestone beds locally perch water in overlying beds of jointed limestone.

Occurrence and Movement of Water

The occurrence and movement of water in the Coconino aquifer are controlled to a large extent by the lithology, or composition, of the rock units that make up the aquifer. The occurrence and movement of ground water in the northwestern and southeastern parts of the study area are discussed separately because of the difference in lithology and because the two areas are hydrologically distinct with respect to ground-water characteristics.

Mogollon Rim-Flagstaff area.--The Mogollon Rim-Flagstaff area includes the eastern and southern parts of southern Coconino County and corresponds with the western limit of the Coconino aquifer (pl. 2). The Coconino aquifer in this area includes the Kaibab Limestone, the Coconino Sandstone, the Supai Formation, and, in a small area near the Mogollon Rim, the Naco Formation.

Recharge to the aquifer occurs primarily in the areas of high precipitation, which generally are at altitudes above 7,000 ft along the Mogollon Rim. Precipitation in these areas readily infiltrates in outcrop areas of fractured limestone, sandstone, and volcanic rocks and percolates downward into the Coconino aquifer.

Ground-water movement in the Mogollon Rim-Flagstaff area is to the northeast or to the southwest. A ground-water divide, which approximately coincides with the principal recharge area, occurs near the Mogollon Rim (pl. 1). Much of the ground water moving southward and westward from the divide is discharged as springs and seeps along the Mogollon Rim and provides the source of base flow in the tributaries to the Verde River. The largest single discharge point, Fossil Springs, discharges about 18,000 gal/min from the Naco Formation at the base of the aquifer. Some water in the Coconino aquifer percolates downward along fracture zones into the underlying limestone aquifer and eventually discharges to the Verde River.

In most of the Mogollon Rim-Flagstaff area, water in the Coconino aquifer moves northeastward away from the ground-water divide near the Mogollon Rim and generally flows toward the Little Colorado River (pl. 1). Near the river, however, the direction of movement changes abruptly to the northwest. This change in direction of movement is influenced by at least three factors: (1) recharge to the aquifer occurs along the channel of the Little Colorado River and causes a local mound that underlies the river; (2) ground water moves into the study area from Navajo County (Mann, 1976) and then moves northwestward along the Little Colorado River; and (3) a major discharge area for the Coconino aquifer is along the faulted East Kaibab monocline and the Mesa Butte fault system (pl. 1). Ground water percolates downward along this fault and fracture zone into the underlying limestone aquifer. The ultimate area of discharge for this water is the group of springs in a

10-mile reach in the canyon of the Little Colorado River beginning at Blue Spring about 13 mi upstream from the mouth.

Ground water in the Coconino aquifer is unconfined in nearly all the Mogollon Rim-Flagstaff area. In a small area between Winslow and Leupp, ground water occurs under artesian conditions because the aquifer is fully saturated and is confined by the overlying Moenkopi Formation.

Grand Canyon-Williams area.--The Grand Canyon-Williams area comprises about 6,000 mi^2 in the northwestern part of the study area. In this area the Coconino aquifer includes two formations—the Toroweap Formation and Hermit Shale—not recognized in the Mogollon Rim-Flagstaff area and does not include the Naco Formation. The Coconino aquifer is dry throughout most of the Grand Canyon-Williams area; only three wells completely penetrate the Coconino aquifer. The area of highest precipitation, and presumably the greatest recharge potential, is near Williams. However, two deep holes that completely penetrated the Coconino aquifer—one near Ash Fork and one about 20 mi north of Williams—were dry during drilling until the Redwall Limestone was penetrated. Records for an oil test in sec. 35, T. 28 N., R. 1 W., indicate that the aquifer was penetrated fully, but hydrologic data are not available. The siltstone beds of the Toroweap Formation and the Hermit Shale are not present in the area near Williams, and the rest of the Coconino aquifer apparently is sufficiently permeable to allow downward percolation of ground water into the underlying limestone aquifer.

Some water is present in the Coconino aquifer in the northern part of the area near the Grand Canyon owing to the presence of fine-grained perching beds. Water is perched in the Coconino Sandstone by the underlying Hermit Shale. The reported saturated thickness of the Coconino Sandstone in wells drilled into this perched water zone ranges from about 10 to 120 ft. Most wells however penetrated 50 to 60 ft of water-bearing sandstone above the Hermit Shale. Near Tusayan, 6 mi south of Grand Canyon Village, several wells reportedly yield from 0.5 to 4.5 gal/min from fractured limestone interbedded with siltstone in the Toroweap Formation.

Availability of Water

The depth to water in the Coconino aquifer in the Mogollon Rim-Flagstaff area ranges from about 75 ft near Winslow to about 2,500 ft below the land surface north of Flagstaff. The formations that compose the Coconino aquifer are dry in most of the Grand Canyon-Williams area; deep wells tap the limestone aquifer in which the depth to water is believed to be at least 3,000 ft below the land surface. Near Cataract Creek and Tusayan where the Coconino aquifer contains perched water, the depth to water is about 950 ft and 550 ft below the land surface, respectively.

Well yields from the Coconino aquifer range from about 1 gal/min where the sandstone has a high degree of cementation and the saturated thickness is a few tens of feet to about 1,000 gal/min where the aquifer is extensively fractured and has a saturated thickness of more than 250 ft. The yield of a properly constructed well depends on the saturated thickness and the hydraulic conductivity of the aquifer near the well site. The hydraulic conductivity is a function of the degree of interconnection of open space in the aquifer material. Some of the open space is between grains in sandstone aquifers, but cracks and fissures created by faulting and jointing increases the hydraulic conductivity in the Coconino aquifer.

The city of Flagstaff well fields at Woody Mountain and at Lake Mary are in or near fault zones; these wells yield from 200 to 1,000 gal/min and are some of the most productive wells in southern Coconino County. The fault zones also may provide a highly permeable drain for ground water. Sterling Spring at the head of Oak Creek Canyon is on the Oak Creek fault and its flow is maintained by ground-water discharge from the Coconino aquifer.

Chemical Quality of Water

In most of the study area, water in the Coconino aquifer contains less than 500 mg/L of dissolved solids and is suitable for most uses. In the southern and central parts of the Mogollon Rim-Flagstaff area, the dissolved-solids concentrations in the water range from about 100 to 500 mg/L (pl. 2), and the principal constituents are calcium and bicarbonate. In the northern part of the Mogollon Rim-Flagstaff area, near the Little Colorado River, the water contains from 500 to as much as 7,640 mg/L dissolved solids; the principal constituents are sodium and chloride. Chemical analyses of the water from many of the wells in the area were published by McGavock (1968). The ranges and median values of the major dissolved constituents are shown in table 3; analyses of the water from selected springs and wells also are included in tables 5 and 6.

Table 3.--Range and median value of dissolved constituents in water from selected aquifers

[Analytical results in milligrams per liter except as indicated]

Aquifer	Silica (SiO_2)	Iron (Fe) in solution at time of analysis	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Dissolved solids	Hardness as $CaCO_3$	Specific conductance (micromhos at 25°C)	pH
Volcanic rocks														
Range	20-67	0.0-0.14	12-82	6.8-24	2.8-17		84-262	3-34	2-44	0.0-0.4	124-324	70-282	174-623	6.8-8.1
Median value	37	0.00	2.25	11	8.6		124	10	8	0.2	160	100	242	7.2
Number of analyses	14	11	16	16	16		16	16	16	16	14	16	16	14
Coconino aquifer														
Range	5.2-56	0.00-0.18	14-229	4.1-96	0.7-2,600		66-890	0.0-667	1-4,200	0.0-1.0	66-7,640	52-834	107-12,900	6.8-8.2
Median value	13	0.01	76	40	29		240	134	51	0.2	551	353	846	7.5
Number of analyses	97	62	130	129	123		119	120	123	127	112	122	115	95

The general distribution of total dissolved solids in ground water in the Coconino aquifer is shown on plate 2. In some areas, specific-conductance values were used to estimate dissolved-solids concentrations.

Specific conductance is a measure of the ability of ions to conduct an electrical current and is a general indication of the amount of dissolved material in the water. An estimate of the dissolved solids can be made by multiplying the specific conductance by a factor that generally ranges from 0.55 to 0.75. On the basis of 108 measurements of both parameters in the study area, the ratio of dissolved solids to specific conductance in water from the Coconino aquifer is 0.60.

In the Mogollon Rim-Flagstaff area, ground water is mostly of the calcium magnesium bicarbonate type and generally contains less than 500 mg/L dissolved solids (pl. 2). The calcium, magnesium, and bicarbonate are derived from recharge areas near Flagstaff and along the Mogollon Rim where the water percolates downward through the Kaibab Limestone and then moves northeastward or southwestward through sandstone that contains little soluble material. The chemical quality of the water is fairly uniform except for that in an area that extends about 5 to 20 mi southwestward from the Little Colorado River where a sodium chloride type water dominates (pl. 2). The source of the sodium and chloride is halite deposits in the Supai Formation 10 to 80 mi east of the study area (Akers, 1964, p. 80; Mann, 1976, p. 17).

The chemical quality of water does not change significantly with depth of penetration into the Coconino aquifer in the southwestern three-quarters of the Mogollon Rim-Flagstaff area. In Navajo County east of the study area, the chemical quality of water generally deteriorates with depth in areas where the aquifer contains water of a sodium chloride type (Mann, 1976). Along the Little Colorado River where sodium chloride water is present, a similar deterioration with depth probably occurs (pl. 2).

During this study, samples of water from the Coconino aquifer were collected at 14 wells that had been sampled 10 to 33 years previously. No significant change in chemical quality with time was found except in four of the wells in the Winslow municipal well field (table 6). The principal change in the quality of the water from these wells was an increase in the sodium and chloride concentrations. Analyses of water from city of Winslow well No. 1 collected in 1953 and again in 1966 indicate an increase in dissolved solids from 531 to 1,040 mg/L; the sodium concentration increased from 79 to 249 mg/L, and the chloride concentration increased from 92 to 410 mg/L. Similar changes in water quality occurred in three other wells. In the fifth well no change in quality was noted. The reason for the changes in water quality is not known. It is postulated, however, that the relatively heavy pumping is causing saline water to move into the well field, either vertically from greater depths in the aquifer or from the east and northeast as a result of local alteration of the regional hydraulic gradient. The chemical quality of water in this area may continue to deteriorate as a result of the influence of this local cone of depression.

Limestone Aquifer

The limestone aquifer consists of several hydraulically connected limestone, dolomite, sandstone, and shale units. The units, in ascending order, include the Tapeats Sandstone, Bright Angel Shale, and Muav Limestone of Cambrian age; the Temple Butte Limestone, an unnamed limestone unit, and the Martin Formation of Devonian age; the Redwall Limestone of Mississippian age; and an unnamed limestone unit of Pennsylvanian age (pl. 1). In most of the area, the Redwall Limestone is the uppermost unit of the aquifer and is about 2,500 ft below the land surface. The unit is exposed in the Grand Canyon, along the Mogollon Rim, and in a small area west of Aubrey Valley. The combined thickness of the units that make up the aquifer generally increases from southeast to northwest. Three of the units included in the aquifer are present only in parts of the area. The unnamed limestone units of Devonian and Pennsylvanian age are present in and near the Hualapai Indian Reservation, and the Temple Butte Limestone is present in the eastern part of the Grand Canyon.

Occurrence and Movement of Water

The limestone aquifer underlies all of southern Coconino County but crops out only in the extreme northern and western parts of the area. Thus, most of the water in the aquifer is derived from the downward movement of water from the overlying Coconino aquifer. In the eastern part of the area, a thick sequence of siltstone in the overlying Supai Formation impedes the downward movement of water from the Coconino aquifer. In the central part of the area, however, the Supai is largely a very fine grained sandstone interbedded with siltstone. The sandstone, particularly where fractured, is more permeable than the siltstone and allows the water to move downward. Much of the water probably moves downward into the limestone aquifer along major fracture zones, such as the Oak Creek fault and East Kaibab monocline, and possibly along the Mesa Butte fault system (pl. 1).

Storage and movement of water is primarily in fractures and solution channels in the carbonate rocks—mainly limestone and dolomite. Water is also stored in fractures and intergranular pore spaces in the Tapeats Sandstone and in sandstone beds in the other units. In the northern part of the study area, the Bright Angel Shale at the base of the carbonate rocks in the aquifer and above the Tapeats Sandstone impedes the downward movement of water. In the Grand Canyon many springs issue from solution cavities in limestone and dolomite that overlie the Bright Angel Shale.

The limestone aquifer may be nearly or completely saturated in most of the area east of Flagstaff where the lower part of the overlying Coconino aquifer is saturated. Water in the limestone aquifer may be confined in places by siltstone in the overlying Supai and Naco Formations but probably is unconfined in most or all the area between Williams and the Grand Canyon. In the Sedona area, the Coconino and limestone aquifers are hydraulically connected in highly fractured areas such as the Oak Creek fault zone and combine to form a regional aquifer (Levings, 1980).

The direction of ground-water movement in the limestone aquifer can be only inferred from points of spring discharge and from wells south of the study area. A large part of the ground water probably moves northward toward springs along the Little Colorado and Colorado Rivers and Havasu Creek. South of Williams, ground water probably moves southward toward discharge areas along the Verde River. The location of the ground-water divide in the western part of the area is unknown owing to the extreme paucity of data; however, the continuance of the limestone aquifer is assumed. The principal discharge points of the limestone aquifer are Havasu Spring along Havasu Creek and springs in a 10-mile reach in the canyon of the Little Colorado River beginning at Blue Spring about 13 mi upstream from the mouth. Blue Spring and the other springs along the Little Colorado River have a combined flow of about 220 ft^3/s or about 100,000 gal/min. A large part of this flow however represents ground water from the Coconino aquifer, which moves downward into the limestone aquifer through the sandstone and fractured siltstone of the Supai Formation.

Havasu Spring is about 10 mi above the mouth of Havasu Creek (pl. 2) and discharges about 64 ft^3/s or about 29,000 gal/min (Johnson and Sanderson, 1968, p. 17) from the unnamed limestone unit of Pennsylvanian age at the top of the limestone aquifer. The altitude of the springs is about 3,250 ft, which is nearly 1,000 ft below the bottom of any water well in the northern part of the area. A significant amount of ground water also may move out of the area to the south. The base flow in the Verde River increases by about 50 ft^3/s in a 25-mile reach south of Williams. A large but unknown part of this water may be discharging from the area north of the river.

Blue Spring may be associated with small faults below the foot of the East Kaibab monocline. Cooley (1976, p. 9) concluded that ground-water movement occurs through the highly fractured zone along and near the East Kaibab monocline. Other faults in the study area, especially the Aubrey, Toroweap, and Hurricane faults, may exert a similar influence on local ground-water conditions.

Availability of Water

In most of southern Coconino County, ground water in the limestone aquifer is beyond an economical well depth for most purposes. The Redwall Limestone is 2,500 to 3,000 ft below the land surface in most of the area east of Flagstaff. Because water generally is available in overlying shallower units, few wells penetrate the limestone aquifer. In most of the western part, the top of the Redwall Limestone is about 2,200 to

2,500 ft below the land surface. The Redwall and some of the other carbonate units that overlie the Bright Angel Shale may be dry in much of the area. Depth to water in the limestone aquifer therefore is expected to be about 3,000 ft below the land surface throughout most of this part of the study area. Between Chino Point and the Mohave County line where the units that form the aquifer crop out, depth to water ranges from 625 ft below the land surface near Chino Point to about 800 ft at Pica, which is south of the study area in Aubrey Valley.

The yields of wells that penetrate the limestone aquifer are expected to be highly variable and unpredictable from place to place. Where the limestone and dolomite of the aquifer are relatively unfractured, the hydraulic conductivity is low and well yields may be 25 gal/min or less. Where the limestone and dolomite are fractured, especially if the fractures are enlarged by solution, the hydraulic conductivity is high and well yields of 1,000 gal/min or more are possible.

In 1976, only one well in southern Coconino County was withdrawing water from the limestone aquifer. This well, about 20 mi north of Williams, produced about 5 gal/min of water from the Redwall Limestone at a depth of 2,800 ft. After the well was deepened to the Tapeats Sandstone, about 20 gal/min of water was produced from a pumping level of about 3,000 ft below the land surface. At Pica, several wells reportedly yield 50 to 145 gal/min of water from the limestone aquifer. Southwest of Sedona, some wells penetrate the Redwall Limestone at a depth of about 1,000 ft. Water levels in these wells range from 600 to 800 ft below the land surface; well yields are reported to range from 20 to 1,000 gal/min.

Chemical Quality of Water

The water from springs that discharge from the limestone aquifer along Havasu Creek, the Colorado River, and tributaries of the Verde River generally is of acceptable chemical quality for most uses. The dissolved-solids concentrations range from 282 to 623 mg/L, and the principal constituents are calcium, magnesium, and bicarbonate (table 5). The dissolved-solids concentrations in the water from two wells that penetrate the aquifer west of Sedona were 355 and 451 mg/L (McGavock, 1968, p. 44). The water from other wells that penetrate the limestone aquifer southwest of Sedona and south of Aubrey Valley is acceptable for public, domestic, and stock use. Levings (1980) showed that the dissolved-solids concentrations of water from wells that tap the Redwall Limestone generally are less than 500 mg/L; analyses are not available for wells south of Aubrey Valley. The water from the well about 20 mi north of Williams that taps the limestone aquifer is unfit for most uses. Specific conductance of the water is 20,200 micromhos, and the dissolved-solids concentration is 12,400 mg/L; sodium and chloride are the major constituents (table 6). Most of the water is produced from the upper part of the Tapeats Sandstone.

Springs that discharge from the limestone aquifer in the lower reaches of the Little Colorado River yield water in which the dissolved-solids concentrations range from 2,320 to about 24,380 mg/L (table 5). The principal constituents of the water from Blue Spring are sodium, calcium, bicarbonate, and chloride. The ratio of sodium chloride to calcium bicarbonate in the water downstream from Blue Spring increases until, at a point 3.1 mi above the mouth of the Little Colorado River, the water is predominantly of the sodium chloride type. Si-Pa-Po Spring (pl. 1) discharges water that contains 24,380 mg/L dissolved solids, principally sodium and chloride. Several small "salt springs" issue from the Tapeats between Blue Spring and mile point 3.1. The source of the sodium chloride probably is the halite deposits in the Supai Formation, which are 10 to 80 mi east of the southern Coconino County area.

Other Aquifers

In places, ground water can be obtained from units that overlie the Coconino aquifer. The Moenkopi and Chinle Formations, volcanic rocks, and sedimentary deposits locally will yield quantities of water adequate for domestic and livestock use. The occurrence and quantity of water that can be developed cannot be ascertained on the basis of areal distribution of the units nor on existing data but are dependent on the lithology of the unit, the presence of fractures, and the lithology of the underlying formations. If the underlying formations are permeable sandstone or fractured limestone, the water generally moves downward into the Coconino or limestone aquifers. If the units are underlain by siltstone, which is relatively impermeable and impedes the downward movement of water, the units may contain perched ground water.

Moenkopi and Chinle Formations

The Moenkopi Formation includes an interbedded sequence of siltstone, mudstone, silty sandstone, and gypsum. The Moenkopi is overlain by the Chinle Formation, which is mainly siltstone and mudstone with sandstone and conglomerate near the base (pl. 1). The combined thickness of the Moenkopi and Chinle Formations of Triassic age is about 800 ft.

The Moenkopi and Chinle Formations generally are not water bearing but yield some water to wells in three small areas. Three wells in the Slate Mountain-Cedar Ranch area extend through volcanic rocks into sandstone that may be part of the Chinle Formation. No change in water level was reported after drilling through the volcanic rocks, therefore the sandstone probably is water bearing and is hydraulically connected to the overlying volcanic rocks. Several wells near Fort Valley are reported to yield 5 to 15 gal/min from fractured silty sandstone in the Moenkopi Formation. Northwest of Winslow, several wells yield water from the Moenkopi; reported yields range from 1 to 20 gal/min. The Moenkopi and Chinle may yield water in other places, but subsurface data are inadequate to assess this possibility.

One chemical analysis of water from the Chinle Formation was available and none for water from the Moenkopi Formation. The water sample from the Chinle is from a dug well in the extreme northeastern part of the study area—well (A-27-10)6abc. The dissolved-solids concentration in the water is 766 mg/L, and the major constituents are sodium, bicarbonate, and sulfate (McGavock, 1968, table 4). Water from wells thought to penetrate the Chinle and Moenkopi Formations in the Fort Valley and the Slate Mountain-Cedar Ranch areas is reportedly of acceptable chemical quality for domestic use. Water from the Moenkopi Formation near Winslow, where the Moenkopi contains gypsum beds, is reported to be of unacceptable chemical quality and normally is cased out of wells.

Volcanic Rocks

The volcanic rocks consist of basalt flows, cinder cones and beds, and tuff beds. These rocks are as much as 1,000 ft thick, excluding the volcanic mountains such as San Francisco Peaks and Bill Williams Mountain. The occurrence and availability of water in the volcanic rocks are extremely variable and unpredictable. Some of the variation may be due to seasonal recharge, differences in well-drilling and construction methods, and to a limited extent, the techniques used to estimate the well yields. Much of the variability however is due to the extent of local fracturing in the rocks and to the openness of the fractures.

About 50 wells have been drilled into volcanic rocks in the Fort Valley area near Flagstaff. Well yields range from 0.5 to about 15 gal/min during sustained pumping. Well depths generally are from 100 to 200 ft, and water levels are from 20 to 170 ft below the land surface. Six producing wells have been drilled into volcanic rocks in the Slate Mountain-Cedar Ranch area. Water levels in these wells are from 85 to 375 ft below the land surface, and well depths are from 112 to 450 ft; well yields reportedly range from about 10 to 100 gal/min. Water supplies have also been developed from volcanic rocks near Mormon Lake, in Spring Valley, and at the Navajo Army Depot at Bellemont. Generally, the wells are less than 250 ft deep and produce 1 to 20 gal/min of water.

Water samples from 14 wells that tap only the volcanic rocks contain from 124 to 324 mg/L of dissolved solids. Calcium and bicarbonate are the dominant ions (table 5).

Sedimentary Deposits

The sedimentary deposits include alluvial deposits and glacial moraine and outwash. They are composed of silt, clay, sand, and gravel and boulders of Quaternary and Tertiary age. The greatest known thickness of the deposits is in Aubrey Valley where an oil-test hole penetrated 420 ft of sand, gravel, and clay. In most places, however, the deposits are from 50 to 100 ft thick.

The sedimentary deposits are an important source of ground water in three places—the Inner Basin on the northeastern side of the San Francisco Peaks, Munds Park about 20 mi south of Flagstaff, and the northern part of Aubrey Valley. Minor amounts of ground water are withdrawn at scattered places for livestock and domestic use. Because the water is derived totally from local precipitation or runoff that infiltrates downward into the thin narrow alluvial deposits along major stream channels, these supplies generally are not reliable for sustained use, especially during prolonged dry periods.

The Inner Basin of San Francisco Peaks is a glacially carved valley that is partly filled by glaciofluvial deposits of sand, clay, and boulders. Water from springs and wells in the Inner Basin is used by the city of Flagstaff as a part of the municipal supply. The depth to water in the Inner Basin is from zero to about 200 ft below the land surface and is subject to large seasonal fluctuations. The more permeable deposits yield as much as 500 gal/min to wells from depths of 300 to 500 ft.

At Munds Park, clay, sand, and gravel have filled a valley incised in the volcanic rocks. Several wells that penetrate mainly sand and gravel have produced 100 to 400 gal/min for several days or weeks. Most of the wells however yield about 50 gal/min and some holes that penetrate mainly clay yield little or no water. Water levels in Munds Park are from about 80 ft to as much as 150 ft below the land surface depending on location, time of year, and precipitation conditions. Large fluctuations in water levels can be expected owing to the seasonal demands and the seasonal recharge conditions. The hydrograph of the water level in well (A-18-7)15ccb1 in this area is included in figure 9.

Aubrey Valley contains the largest volume of sedimentary deposits in the study area. Only deposits in the north end of the valley are known to be water bearing. Five wells in that area yield usable quantities of water; the largest reported yield was 30 gal/min near Frazier Wells. Water levels in the five wells ranged from 47 to 422 ft below the land surface. An oil-test hole—(B-25-8)34aa—penetrated 420 ft of clay, sand, and gravel in southern Aubrey Valley but no water was reported at that depth. The sedimentary deposits may be dry in much of the central and southern parts of Aubrey Valley.

Water samples were collected from the five wells that yield water only from sedimentary deposits. The dissolved-solids concentrations in water from four of the wells range from 202 to 388 mg/L and average 298 mg/L (McGavock, 1968, table 4). The principal constituents in the water are calcium and bicarbonate. The water from well (B-27-6)1adc contains 2,220 mg/L dissolved solids, of which about 1,970 mg/L are calcium and sulfate. The alluvial deposits at this site contain some thin

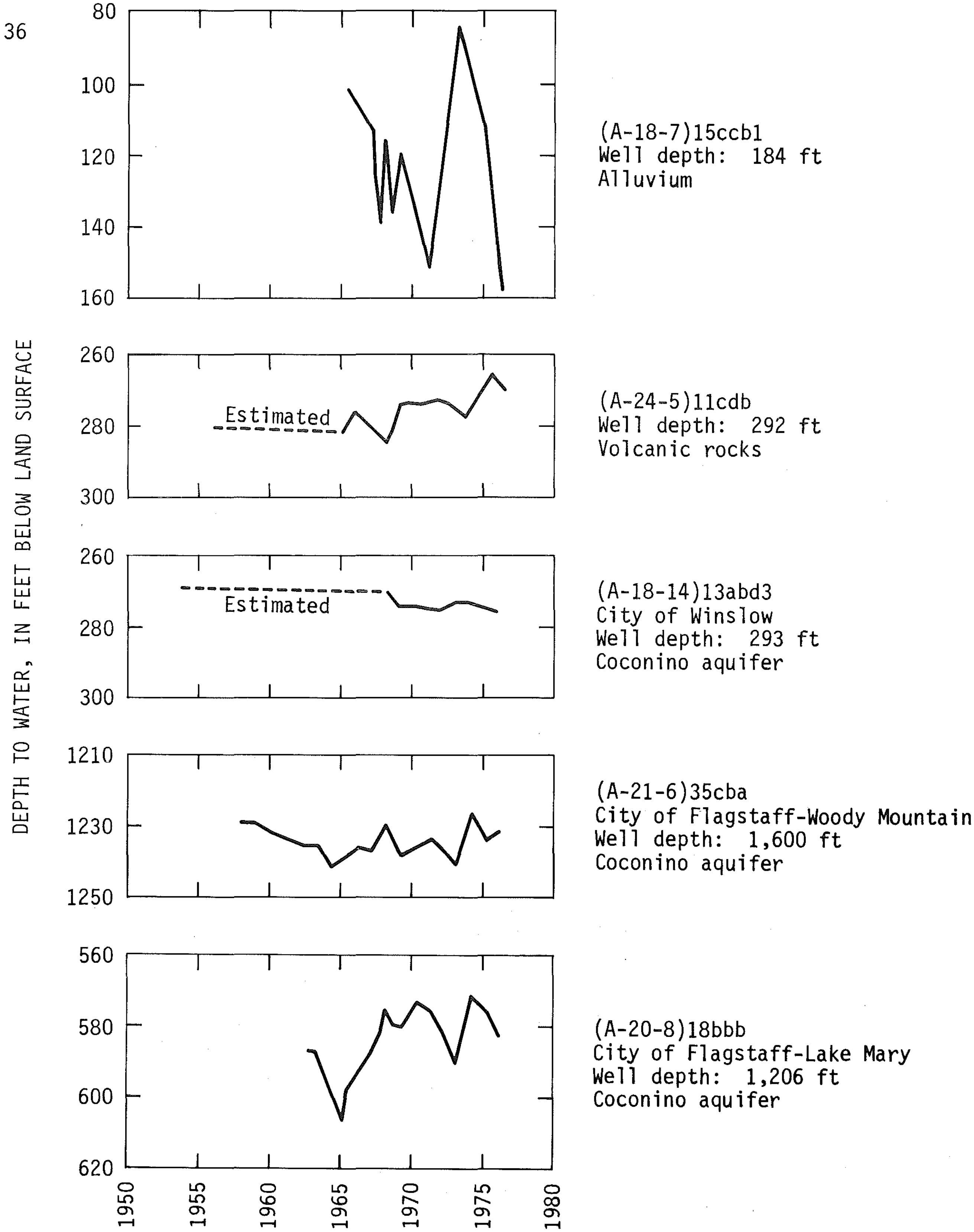


Figure 9.--Water levels in selected wells.

beds of gypsum that are the source of the large concentrations of dissolved solids in the water.

DEVELOPMENT OF WATER RESOURCES

Water-resources development in southern Coconino County has been slight. The principal use of water in the area is for municipal supplies for Flagstaff and Winslow. Most of the major industries in the area are served by city water systems, and their consumption is included in the estimate of municipal use. Domestic and livestock wells account for a small part of the total use. Agricultural use is minimal; the only cropland and pasture in the study area are a few miles northeast of Flagstaff. Total water use in southern Coconino County from surface-water and ground-water sources is estimated to have been slightly less than 8,000 acre-ft in 1975.

Ground-water development generally is limited by the great depth to water and by the low yields of wells. In some areas, the chemical quality of the water may restrict development for certain uses. The total ground-water production from all aquifers in 1970 was estimated to be 2,600 acre-ft. Estimated ground-water withdrawal in 1975 was 5,200 acre-ft. Most of the ground water withdrawn in southern Coconino County is from the municipal well fields near Flagstaff and Winslow. Water levels in the Winslow well field and Flagstaff well fields near Woody Mountain and Lake Mary have remained relatively stable. Large water-level fluctuations occurred in the nonpumping wells (fig. 9), but this probably is due to the effect of nearby or recent pumping.

Water levels in the aquifers in southern Coconino County have not been seriously affected by historic ground-water withdrawals. The volume of ground water in storage in the study area probably is between 100 and 200 million acre-ft; thus, withdrawal at the estimated 1975 rate should not result in long-term depletion of the system except possibly on a local basis such as in the municipal well fields.

The development of surface-water resources is hindered by the economic considerations of transporting water over long distances and by prior appropriation of water by downstream users. In southern Coconino County more than 4,200 acre-ft of surface water was used for nonrecreational purposes in 1970. The estimated total surface-water use in 1975 was 2,500 acre-ft; the city of Flagstaff used about 2,200 acre-ft, and the city of Williams used less than 300 acre-ft. Annual use of surface-water resources can be extremely variable. Most impoundment structures are constructed on ephemeral streams that flow only in response to rainfall and snowmelt; the available supply is dependent entirely on precipitation.

Leakage from surface-water reservoirs is a major problem in the study area; the land surface commonly is underlain by permeable volcanic rocks or limestone, and many drainages follow zones of broken permeable rocks. Leakage occurs from Kaibab Lake and Dogtown Reservoir—the major reservoirs for the city of Williams water supply (Thomsen, 1969). Dogtown Reservoir was lined with plastic in 1971 in an attempt to decrease leakage. Data collected by the Geological Survey subsequent to the lining of the reservoir indicates that the lining has been effective. Efforts were underway in 1976 to seal Kaibab Lake. Seepage from Upper Lake Mary, which is the principal source of municipal water for the city of Flagstaff, was 42 percent, or about 3,200 acre-ft/yr, of the total reservoir inflow during 1950-71 (J. W. H. Blee, U.S. Geological Survey, written commun., 1973).

The impounding of surface water for recreational purposes has increased rapidly since 1963. Six reservoirs constructed since 1963 in the headwaters of Clear and Chevelon Creeks have a total controlled storage capacity of more than 27,000 acre-ft. Blue Ridge Reservoir, which is the largest of the six reservoirs, has a usable storage capacity of 15,000 acre-ft. This reservoir is used partly as a holding basin for diversion of water south to the East Verde River. During 1966-73, these diversions averaged 11,400 acre-ft/yr (U.S. Geological Survey, 1961-75).

The water supply for the city of Flagstaff is obtained primarily from surface-water storage in Upper Lake Mary, but a significant part of the supply is obtained from other sources. Springs and infiltration galleries in the Inner Basin of the San Francisco Peaks have been used by the city since 1900, and shallow wells in the Inner Basin have been used since 1968. Deep wells that tap the Coconino aquifer have been used since 1956 to supplement the city's water supply. During 1956-70, the city obtained about 65 percent of its water supply from Upper Lake Mary, about 20 percent from springs in the Inner Basin, and about 15 percent from the Woody Mountain well field. The amount of water obtained from each source has varied greatly from year to year. Since 1970, a well field at Lower Lake Mary has been an added source of water for municipal supply. Total municipal water use by the city of Flagstaff in 1975 was about 5,500 acre-ft.

The city of Winslow is in Navajo County but obtains its entire water supply from five wells in Coconino County about 8 mi southwest of the city. Municipal water consumption in Winslow increased from about 1,270 acre-ft in 1956 to about 1,500 acre-ft in 1975. Ground water in storage in the Coconino aquifer in and near the Winslow well field is sufficient to supply many times the current demand. The chemical quality of the water from four of the municipal wells however has deteriorated gradually, and the city may need to seek other sources of water in the future.

The water supply for the city of Williams is obtained from six reservoirs, which have a total controlled storage capacity of about 2,800 acre-ft. Three reservoirs—Dogtown, Kaibab, and Cataract—contain 85 percent of the storage capacity. The use of water by the city is estimated to be less than 300 acre-ft/yr for 1963-75. Despite this relatively low consumption, the reservoir storage is often insufficient to meet the demand because of high seepage losses in the reservoirs (Thomsen, 1969).

The water supply in the Sedona area is primarily from wells owned by private water companies or individuals. Most of the wells are west of the study area in Yavapai County. An estimated 1,300 acre-ft of water was pumped from the wells in the Sedona area in 1975; no depletion of the ground-water system was occurring.

SUMMARY

Southern Coconino County includes about 10,600 mi^2 in the Colorado River basin in north-central Arizona. The topography includes rolling high plateaus, deeply incised canyons, and rugged mountains. The areal distribution of precipitation is dependent on altitude and orographic effects; mean annual precipitation in the study area ranges from about 6 to 35 in.

Mean annual surface-water runoff is a small percentage of mean annual precipitation; most precipitation is lost to evapotranspiration or infiltration. Nearly all the streams in the study area are intermittent. Streamflow generally is of acceptable chemical quality for most uses in intermittent and perennial streams during periods of storm and snowmelt runoff; dissolved-solids concentrations commonly are less than 200 mg/L. Dissolved solids in low or base flows in the perennial streams that drain the area range from 200 to 2,600 mg/L.

Ground water occurs chiefly in two aquifers—the Coconino aquifer and a limestone aquifer. The Coconino aquifer is the most highly developed aquifer but does not underlie the entire study area; about 75 percent of the ground water pumped in southern Coconino County comes from this aquifer. Well yields range from about 1 to 1,000 gal/min. Depth to water ranges from about 75 ft near Winslow to about 2,500 ft north of Flagstaff. The chemical quality of the water generally is good; dissolved-solids concentrations commonly are less than 500 mg/L. The limestone aquifer contains water throughout the study area and has the greatest potential well yields but generally is not tapped because the required well depth exceeds 2,500 ft in most places.

In places, ground water also is obtained from the Moenkopi and Chinle Formations, volcanic rocks, and sedimentary deposits. These units yield water of suitable chemical quality for livestock and domestic use in the central part of the area, mainly near Flagstaff, Fort Valley, the Inner Basin of the San Francisco Peaks, and Munds Park. Although the units do not contain water in large areas, they typically contain water at depths of less than 300 ft, and well yields of 10 to 50 gal/min are not uncommon.

The development of ground-water or surface-water resources in southern Coconino County has not been extensive. Ground-water

development generally is hindered by the great depth to water and by the relatively low yields of existing wells. The development of surface-water resources has been hindered by the economic considerations of transporting water over long distances and by prior appropriation of water by downstream users. In 1970 total ground-water production from all sources was about 2,600 acre-ft, and about 4,200 acre-ft of surface water was used for nonrecreational purposes. In 1975 ground-water production was about 5,200 acre-ft, and about 2,500 acre-ft of surface water was used for nonrecreational purposes. Between 100 and 200 million acre-ft of ground water is estimated to be in storage in the study area. Ground-water withdrawals are not resulting in depletion of water in the system or large declines in water levels.

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HYDROLOGIC DATA

Table 4.--Chemical analyses of water from selected streamflow sites

[Analyses in milligrams per liter, except as indicated. T, trace. Dissolved solids: Sum of determined constituents]

Location	Sampling site	Date of collection	Discharge (cubic feet per second)	Temperature (°C)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO^3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Dissolved solids	Hardness as $CaCO_3$		Specific conductance (micromhos at 25°C)	Ph
																Calcium, magnesium	Noncarbonate		
LITTLE COLORADO RIVER DRAINAGE BASIN																			
	Chevelon Creek																		
T. 18 N., R. 17 E., SE¼SW¼ sec. 27	Near gaging station 09398000; base flow	5-25-54	4.0	21	9.6	69	39	591		228	0	139	910	0.4	1,870	332	146	3,440	---
		7-12-55	3.4	24	9.4	70	43	587		249	0	139	905	.3	1,880	352	148	3,380	7.2
		5-12-71	4.2	17	6.8	68	45	640	5.9	263	0	170	960	.2	2,030	350	140	3,590	7.6
Do.	Near gaging station 09398000; storm runoff	10- 4-71	123	13	3.7	18	5.2	15	1.1	75	0	12	22	.1	114	66	5	207	7.2
	Clear Creek																		
T. 15 N., R. 13 E., SW¼SE¼ sec. 19	Near gaging station 09398500; snowmelt runoff	3-11-66	500	2	----	7.2	3.9	2.1		34	0	8.0	1.0	.1	39	34	6	68	7.1
Do.	Near gaging station 09398500; storm runoff	10-13-71	0.38	14	3.7	25	12	1.6	.5	128	0	6.5	1.7	.0	114	110	7	201	8.1
		10-17-72	4.9	16.5	4.6	20	9.8	2.8	1.0	102	0	7.0	4.1	.1	100	90	7	180	7.5
Do.	Near gaging station 09398500; snowmelt runoff	3-20-73	258	----	4.0	9.0	4.2	1.0	0.5	45	0	6.7	1.5	.1	49	40	3	84	7.7
		4-25-73	1,910	----	4.7	9.2	4.1	1.0	0.6	45	0	5.4	1.6	.0	49	40	3	85	7.6
	Jacks Canyon																		
T. 18 N., R. 15 E., NW¼NW¼ sec. 31	Near gaging station 09399400; storm runoff	8-21-71	4.0	23	9.1	25	2.2	2.2	4.7	97	0	3.3	1.4	.4	98	71	0	157	7.4
		12-28-71	127	3.5	14	13	2.5	2.6	2.4	46	0	5.8	3.7	.2	67	43	5	85	6.8
		12-30-71	23	2.0	14	11	2.6	1.0	2.7	46	0	5.5	2.8	.2	63	38	0	86	6.9
		12-31-71	10	.5	15	13	3.0	2.0	2.7	47	0	5.9	1.9	.1	68	45	6	89	7.0
	Schultz Canyon																		
T. 21 N., R. 7 E., SE¼SW¼ sec. 4	At partial-record station 09400595; storm runoff	3-13-73	15	7.0	26	11	4.2	4.3	2.7	52	0	8.2	1.6	.2	107	45	2	109	7.2
	Rio de Flag																		
T. 21 N., R. 7 E., NW¼NE¼ sec. 9	At partial-record station 09400600; storm runoff	3-13-73	94	6.5	23	10	4.3	3.8	2.6	53	0	6.1	2.0	.2	104	43	0	108	7.2

Table 4.--Chemical analyses of water from selected streamflow sites—Continued

Location	Sampling site	Date of collection	Discharge (cubic feet per second)	Temperature (°C)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO^3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Dissolved solids	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	Ph
								LITTLE COLORADO RIVER DRAINAGE BASIN—CONTINUED											
	Switzer Canyon																		
T. 21 N., R. 7 E., SW¼SE¼ sec. 10	At partial-record station 09400680; storm runoff	3-13-73	75	4.5	11	4.9	1.9	1.6	1.4	29	0	2.3	0.5	0.1	51	20	0	50	7.0
	Little Colorado River																		
T. 29 N., R. 8 E., NW¼ sec. 5	At gaging station 09402000; storm runoff	10-28-69	75	11.0	----	34	4.6	170	4.3	232	0	202	72	---	628	104	0	990	7.8
		3-26-70	56	4.5	----	17	2.8	96	2.6	155	0	37	78	---	355	54	0	570	8.2
		1-27-71	0.60	0.5	8.0	91	24	160	5.2	205	0	420	38	0.6	916	330	162	1,270	8.0
		10-28-71	2,300	9.0	7.7	11	2.4	89	1.9	118	0	63	65	0.5	326	37	0	497	7.8
		1-27-72	31	1.0	9.8	76	18	200	3.9	209	0	180	250	0.4	868	260	92	1,500	---
T. 33 N., R. 6 E., NW¼SW¼ sec. 33	3.1 miles above mouth of river; base flow	5-17-66	-----	22	17	112	77	761		464	0	170	1,200	0.2	2,560	595	215	4,540	7.3
		7-12-66	230	24	15	120	79	765		494	0	170	1,210	0.2	2,600	625	220	4,580	7.8
		11- 2-66	217	--	18	96	76	795		476	0	175	1,210	0.3	2,600	550	160	4,580	7.7
		3-15-67	-----	18	18	120	69	777		488	0	175	1,200	0.3	2,600	585	185	4,610	7.4
								HAVASU CREEK DRAINAGE BASIN											
	West Cataract Creek																		
T. 22 N., R. 2 E., NW¼ sec. 31	At partial-record station 09403930; storm runoff	3-26-73	3.3	0.5	19	11	4.0	2.9	2.2	56	0	5.4	2.2	0.1	106	44	0	103	7.3
	Cataract Creek																		
T. 27 N., R. 2 W., NE¼SE¼ sec. 13	At partial-record station 09404100; storm runoff	4- 6-73	17	13.0	15	16	3.3	3.6	2.5	75	0	4.6	1.7	0.0	109	54	0	109	7.3
	Havasu Creek																		
T. 33 N., R. 4 W., sec. 10	2 miles below Supai Village; base flow	8-23-68	53.7	----	23	78	44	41		436	0	36	48	0.3	485	374	16	836	7.8
T. 34 N., R. 4 W., sec. 32	4 miles below Supai Village; base flow	6-16-51	-----	21	---	52	47	28		338	trace	38	48	0	380	323	46	704	---
T. 34 N., R. 4 W., sec. 31	500 feet above mouth; base flow	6-16-51	63.3	21	---	--	---	---		304	trace	----	48	---	-----	---	---	661	---

Table 4.--Chemical analyses of water from selected streamflow sites—Continued

Location	Sampling site	Date of collection	Discharge (cubic feet per second)	Temperature (°C)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Dissolved solids	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	Ph
VERDE RIVER DRAINAGE BASIN																			
	Oak Creek																		
T. 16 N., R. 4 E., NE¼NW¼SE¼ sec. 23	At gaging station 09504500; base flow	9-14-67	24.7	22	18	47	20	1.6		224	0	4.0	10	0	211	198	64	396	7.5
Do.	At gaging station 09504500; snowmelt runoff	4-15-68	63	16	15	24	11	4.1		126	0	5.0	3.5	0.1	125	104	1	210	7.1
Do.	At gaging station 09504500; base runoff	10-12-71	25	22	15	42	20	8.6	1.0	242	0	4.8	8.9	0	220	190	0	380	8.1
Do.	At gaging station 09504500; snowmelt runoff	4-10-73	764	10	12	14	5.2	2.2	0.8	64	0	3.6	1.3	0.1	71	56	4	112	7.5
	Wet Beaver Creek																		
T. 15 N., R. 6 E., NW¼SW¼ sec. 24	At gaging station 09505200; base runoff	9-15-67	6.2	22	21	29	14	5.0		164	0	2.0	4.5	0	156	132	0	267	7.3
T. 15 N., R. 6 E., NW¼SW¼ sec. 24	Near gaging station 09505200; base runoff	10-14-71	6.9	17.5	20	24	14	6.3	1.1	164	0	3.8	2.8	0.1	153	120	0	249	8.1
Do.	Near gage, snowmelt runoff	4- 3-73	110	6	14	11	4.7	2.2	1.3	56	0	7.8	2.1	0.0	71	47	1	99	7.7
T. 15 N., R. 6 E., NE¼NE¼ sec. 28	2.5 miles below gaging station 09505200; snowmelt runoff	4-15-68	32	14	17	11	6.4	3.2		68	0	4.0	1.5	0.1	76	54	0	118	6.7
	Red Tank Draw																		
T. 15 N., R. 6 E., SE¼NE¼ sec. 16	At gaging station 09505250; snowmelt runoff	4-15-68	0.3	17	25	38	17	6.9		200	0	5.0	7.0	0.1	197	164	0	330	7.4
		4- 3-73	52	8	14	12	4.4	2.2	1.5	57	0	7.0	2.4	0.0	72	48	1	105	7.8

Table 4.--Chemical analyses of water from selected streamflow sites—Continued

Location	Sampling site	Date of collection	Discharge (cubic feet per second)	Temperature (°C)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Dissolved solids	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	Ph
VERDE RIVER DRAINAGE BASIN—CONTINUED																			
	Rattlesnake Canyon																		
T. 16 N., R. 7 E., SE¼SE¼ sec. 18	2 miles above gaging station 09505300; snowmelt runoff	4-15-68	6.9	14	17	6.0	3.6	4.4		30	0	11	2.5	0.1	60	30	6	79	6.4
T. 16 N., R. 6 E., NW¼SW¼ sec. 24	Near gage 09505300; snowmelt runoff	4-16-73	78	6	13	5.8	2.8	1.8	0.5	29	0	3.6	0.1	0.0	43	26	2	58	7.6
	Dry Beaver Creek																		
T. 15 N., R. 5 E., NE¼NW¼ sec. 1	At gaging station 09505350; snowmelt runoff	4-15-68	58	15	16	7.6	3.6	2.1		40	0	4.0	1.0	0.1	54	34	1	77	7.0
		3- 2-73	139	7.5	13	7.1	3.1	1.9	0.7	39	0	6.1	1.8	0.1	53	31	0	71	7.8
		4-26-73	548	----	11	4.8	2.2	1.3	0.5	26	0	3.7	1.5	0.0	38	21	0	50	7.7
	West Clear Creek																		
T. 13 N., R. 6 E., NW¼NW¼NW¼ sec. 11	At gaging station 09505800; base flow	9-15-67	14.3	22	18	42	20	8.7		236	0	5.0	4.5	0	214	186	0	366	7.5
		10-12-71	15	----	17	39	23	5.7	1.1	251	0	1.5	3.3	0.1	214	190	0	370	---
Do.	At gaging station 09505800; storm runoff	10-7-72	1,040	17	14	14	5.6	1.5	1.9	63	0	9.3	1.9	0.1	80	58	6	127	6.8
Do.	At gaging station 09505800; snowmelt runoff	4-11-73	1,300	5.5	10	9.3	3.8	1.5	0.8	45	0	4.0	0.9	0.1	53	39	2	81	7.3
T. 13 N., R. 5 E., SW¼NE¼ sec. 13	5 miles below gaging station 09505800; snowmelt runoff	4-15-68	135	15	18	17	8.1	3.4		96	0	3.0	1.5	0.1	98	76	0	161	7.0

Table 5.--Chemical analyses of water from selected springs

[Analyses in milligrams per liter, except as indicated. Discharge: R, reported; E, estimated. Dissolved solids: Sum of determined constituents. Remarks: Stratigraphic names indicate water-bearing unit]

Location	Date of collection	Discharge (gallons per minute)	Temperature (°C)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Dissolved solids	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	Ph	Remarks
LITTLE COLORADO RIVER DRAINAGE BASIN																			
(A-17-17)22ccc	7- 8-66	-------	19	14	114	38	152		166	0	300	230	0.1	930	442	306	1,530	7.4	Seep zone in Chevelon Creek; Coconino Sandstone
(A-18-16)30dd	7- 7-66	-------	17	13	50	24	178		222	0	32	280	.1	686	224	42	1,280	7.7	Seep zone in Clear Creek; Coconino Sandstone.
(A-18-16)31bbb	7- 7-66	-------	20	14	46	27	576		160	0	50	920	.2	1,710	228	97	3,200	7.8	Do.
(A-32-6)3bd(a)	1-29-66	-------	23	----	646	291	8,184		2,470	0	2,950	11,000	1.5	24,380	2,810	787	33,800	6.5	Si-Pa-Po Spring; Little Colorado River mile 4.5; Tapeats Sandstone.
(A-32-6)36ada	7-12-66	15,750	----	17	214	73	623		936	0	135	910	0	2,430	835	68	4,170	7.0	First spring below Blue Spring; Little Colorado River mile 12.9; Muav Limestone.
(A-32-6)36add	6-14-50	42,750	----	19	264	79	513	23	964	0	147	815	.2	2,340	984	194	3,940	6.5	Blue Spring; Little Colorado River mile 13.1; Muav Limestone.
	5-17-66	42,250	21	17	252	76	535		951	0	140	835	.3	2,320	940	161	3,960	6.8	Do.
(A-32-7)31bbc	7-12-66	11,250	----	16	238	67	785		840	0	175	1,210	.2	2,900	870	182	5,000	6.9	Second spring below Blue Spring; Little Colorado River mile 12.8; Muav Limestone.
(A-33-6)33b	5-17-66	-------	22	17	112	77	761		464	0	170	1,200	.2	2,560	595	215	4,540	7.3	Composite of all spring flow from Blue Spring to Little Colorado River mile 3.1; Muav Limestone and Tapeats(?) Sandstone.
	7-12-66	-------	24	15	120	79	765		494	0	170	1,210	.2	2,600	625	---	4,580	7.8	Do.
COLORADO RIVER DRAINAGE BASIN																			
(A-31-2)7	10-16-57	210	----	9.2	52	31	27		267	0	33	44	.2	328	257	38	584	---	Hermit Springs; Muav Limestone.
(A-31-2)13abb	4-9-58	300R	12	12	54	35	11		308	0	28	14	.2	305	278	26	543	---	Indian Gardens Spring; Muav Limestone.
(B-27-9)20acb	5-15-58	>300	22	26	50	21	18		228	0	15	24	.5	282	212	---	460	---	Diamond Spring; Muav Limestone.
(B-33-8)36d	6-20-60	2,700E	26	----	54	80	58		532	0	38	80	---	572	462	26	1,100	---	Warm Spring; Muav Limestone.

Table 5.--Chemical analyses of water from selected springs—Continued

Location	Date of collection	Discharge (gallons per minute)	Temperature (°C)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Dissolved solids	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	Ph	Remarks
HAVASU CREEK DRAINAGE BASIN																			
(B-33-4)26b	10-20-50	27,900	21	---	133	48	27		588	0	36	48	0.2	584	530	48	1,030	---	Havasu Springs; Pennsylvanian Limestone.
	8- 7-65	26,700	----	---	74	45	36		416	0	36	48	.2	------	368	27	820	7.7	Do.
	12-28-66	29,900	21	18	118	45	33		542	0	38	46	.3	565	478	34	973	7.7	Do.
	11-12-67	27,700	21	18	125	32	40		523	0	40	45	.2	558	446	18	961	7.4	Do.
	6-29-68	-------	20	20	134	43	42		602	0	38	50	.3	623	512	18	1,050	7.2	Do.
VERDE RIVER DRAINAGE BASIN																			
(A-12-7)14da	2-16-52	18,600	21	14	104	40	6.9		485	---	27	9	.1	440	424	---	753	---	Fossil Springs; Naco Formation.
(A-14-8)32aa	5-28-59	1,000E	16	20	51	22	5.5		268	---	1.6	6.0	0	239	218	---	401	8.0	Buckhorn Spring; Coconino Sandstone.
(A-14-9)31dd	5-27-59	100E	11	21	55	22	5.1		284	---	.6	4.0	.1	248	228	---	418	7.8	Bear Spring; Coconino Sandstone.
(A-15-7)14acc	10-19-59	1,350E	16	23	29	10	4.8		147	---	.2	2.5	.2	143	115	---	236	7.4	Wet Beaver Creek Springs; Coconino Sandstone.
(A-16-4)23bbd	7-14-59	-------	20	20	56	22	13		270	---	4.7	20	.2	270	228	---	463	7.6	Bubbling Pond; Supai(?) Formation.
	5-20-68	3,900	19.5	21	54	25	16	1.0	279	0	5.0	22	.2	281	238	10	498	7.3	Do.
(A-16-4)23dda	8- 4-49	-------	20	18	42	19	8.7		227	---	3.7	8.0	0	212	183	---	364	---	Page Springs; Supai(?) Formation.
	5-20-68	2,075	20	19	42	18	10		229	0	3.0	8.5	.2	214	180	0	374	7.1	Do.
(A-17-3)5db	10-10-51	2,700	19	15	72	27	5.8		341	---	7.6	10	.2	307	290	---	543	---	Summers Spring; Redwall Limestone.
(A-19-6)15ddd	8-10-46	290	11	---	32	13	9.2		163	6.9	2.9	3.0	.4	135	134	---	270	---	Sterling Spring; Coconino Sandstone.

Table 6.--Chemical analyses of water from selected wells

[Analyses by U.S. Geological Survey, except as indicated. Analyses in milligrams per liter, except as indicated. Dissolved solids: Sum of determined constituents. Remarks: CT, sample obtained from closed storage tank at well; ATL, analysis by Arizona Testing Laboratories; stratigraphic names indicate water-bearing unit]

Well location	Date of collection	Temperature (°C)	Silica (SiO_2)	Iron (Fe) in solution at time of analysis	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	pH	Remarks
(A-18-14)13abd2	8-25-53	--	19	----	60	34	79		264	0	110	92	0	---	531	289	---	------	7.5	Winslow 1; ATL; Coconino Sandstone.
	11-17-59	--	11	----	90	39	254		256	0	110	432	0.4	---	1,060	386	---	------	7.2	Do.
	10-25-65	--	7	----	98	--	389		251	0	325	390	.4	---	1,340	360	---	------	7.5	Do.
	3- 3-66	--	----	----	82	44	249		258	0	130	410	.2	---	1,040	384	---	1,850	7.5	Coconino Sandstone.
13baa	1- 8-55	--	6.8	----	70	37	93		276	0	100	246	0	---	692	326	---	------	7.7	Winslow 2; ATL; Coconino Sandstone.
	11-17-59	--	10	----	70	43	133		276	0	90	226	.5	---	710	354	---	------	7.3	Do.
	11-17-64	17	12	----	38	44	178		150	8	123	280	.2	---	758	274	138	1,370	8.6	Coconino Sandstone.
	10-25-65	--	8	----	92	10	294		288	0	230	308	.3	---	1,090	370	---	------	7.5	ATL; Coconino Sandstone.
13bad	1-10-63	--	10	----	113	12	64		249	0	111	106	.4	---	541	330	---	------	7.6	Winslow 5; ATL; Coconino Sandstone and Supai Formation.
	10-16-64	--	10	----	116	8	152		300	0	100	214	.3	---	750	322	---	------	7.6	Do.
	10-26-65	--	----	----	76	12	288		300	0	250	254	.2	---	1,040	340	---	------	7.6	Do.
13cab	1-8-55	--	8.2	----	64	32	14		251	0	90	16	1.2	---	351	290	---	------	7.9	Winslow 3; ATL; Coconino Sandstone.
	3-3-66	--	----	----	66	36	7.1		257	0	99	11	.2	---	348	314	---	587	7.6	Coconino Sandstone.
13dbb	4-27-55	--	5.2	----	65	35	13		246	0	110	12	0	---	366	306	---	------	7.8	Winslow 4; ATL; Coconino Sandstone and Supai Formation.
	10-25-65	--	----	----	74	9	133		288	0	215	36	.2	---	620	320	---	------	7.6	Do.
36daa	8- 2-50	--	----	----	--	--	-----		259	0	---	90	---	---	---	308	---	887	---	Coconino Sandstone.
	5- 3-66	17	----	----	72	37	55		255	0	122	82	.1	---	494	332	123	844	7.7	Do.
(A-19-13)7bbb	11-20-33	--	----	----	94	44	16		224	0	226	21	0	1.0	512	415	---	------	---	Do.
	6- -66	--	14	0.01	91	40	18		230	0	205	21	.2	---	502	392	204	778	7.5	Do.
(A-19-14)21a	11-11-33	--	----	----	79	47	239		264	0	135	392	0	.4	1,020	390	---	------	---	Do.
	5-11-66	16	15	0	73	47	260		265	0	135	413	.1	---	1,070	374	157	1,890	7.3	Do.
(A-20-6)2bca	3-29-68	23	22	0.07	21	11	7.4		132	0	2.0	3.0	.1	---	132	98	0	220	7.1	City of Flagstaff, Woody Mountain 6; Coconino Sandstone and Supai Formation.
(A-20-12½)14dda	11-20-33	--	----	----	108	50	25		226	0	295	26	0	1.2	616	475	---	------	---	Coconino Sandstone
	3-12-53	--	7.6	----	98	47	20		207	0	269	22	.3	.2	566	438	268	859	---	Do.
24cbb	7- 8-46	--	----	----	105	45	31		225	0	280	26	0	1.7	600	447	262	891	---	CT; Coconino Sandstone.
	5- -66	--	13	0.01	106	44	30		224	0	281	24	.2	---	608	446	263	890	7.5	Do.
(A-20-13)35da	11-20-33	--	----	----	78	43	33		232	0	157	63	0	.2	488	371	---	-----	---	Coconino Sandstone.
	3-12-53	--	12	----	78	40	33		233	0	143	64	.2	.4	486	359	168	808	---	Do.
	5-12-66	--	13	.07	76	40	36		236	0	147	62	.1	---	490	356	163	799	7.6	Do.
(A-23-10)1bb	10-19-54	--	8.5	----	57	47	159		205	0	213	205	.8	.3	792	336	168	1,330	---	Coconino(?) Sandstone.
	7-19-65	--	----	----	73	57	147		200	0	230	236	.5	---	-----	416	252	1,440	8.0	Do.
13dc	10-19-54	--	12	----	93	59	370		172	0	270	605	.6	3.2	1,500	474	334	2,590	---	Do.
	7-18-65	--	----	----	89	65	359		---	0	255	615	.6	---	-----	490	353	2,610	7.6	Do.
(A-25-2)27aba	1-10-70	--	9.4	0	9.6	351	4,330		1,110	132	270	6,720	.5	---	12,400	1,470	339	20,200	8.4	Tapeats Sandstone.
(A-27-9)6dcl	5-15-56	17	11	----	101	58	27		536	0	32	53	.4	.6	547	490	51	980	7.5	CT; Supai Formation.
	5-12-66	--	----	0	95	62	39		527	0	43	70	.4	---	-----	492	60	1,000	7.6	Supai Formation.