Water Resources of the Sycamore Creek Watershed, Maricopa County, Arizona

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1861

Prepared in cooperation with the Arizona State Land Department and the Salt River Valley Water Users' Association

U.S. DEPARTMENT OF THE INTERIOR

WATER RESOURCES OF THE SYCAMORE CREEK WATERSHED, MARICOPA COUNTY ARIZONA

Stream channel emerging from the upper hard-rock area onto the lower alluvial area of the Sycamore Creek watershed.

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By B. W. THOMSEN *and* H. H. SCHUMANN

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By B. W. THOMSEN and H. H. SCHUMANN

ABSTRACT

The Sycamore Creek watershed is representative of many small watersheds in the Southwest where much of the streamflow originates in the mountainous areas and disappears rather quickly into the alluvial deposits adjacent to the mountains. Five years of streamflow records from the Sycamore Creek watershed show that an average annual water yield of 6,110 acre-feet was obtained from the 165 square miles (105,000 acres) of the upper hard-rock mountain area, which receives an average annual precipitation of about 20 inches. Only a small percentage of the annual water yield, however, reaches the Verde River as surface flow over the 9-mile reach of the alluvial channel below the mountain front. Flows must be more than 200 cubic feet per second to reach the river; flows less than this rate disappear into the lower alluvial area and are stored temporarily in the ground-water reservoir; most of this water is released as ground-water discharge to the Verde River at a relatively constant rate of about 4,000 acre-feet per year. Evapotranspiration losses in the lower alluvial area are controlled by the depth of the water table and averaged about 1,500 acre-feet per year.

INTRODUCTION

PURPOSE AND SCOPE

A knowledge of the factors controlling water yield from natural source areas is essential to man's continued existence in arid regions, such as the southwestern United States. The U.S. Geological Survey in cooperation with the Arizona State Land Department and the Salt River Valley Water Users' Association conducted a hydrologic investigation of the Sycamore Creek watershed in the eastern part of Maricopa County, Ariz. (fig. 1). Because Sycamore Creek is representative of many watersheds in Arizona and other southwestern States, the knowledge obtained and the methods developed in this study may be useful in evaluating the water yield of other watersheds in the Southwest.

The purpose of this report is to present findings from the 1961–65 investigation of the Sycamore Creek watershed. The principal objectives of the investigation were (1) to determine the characteristics

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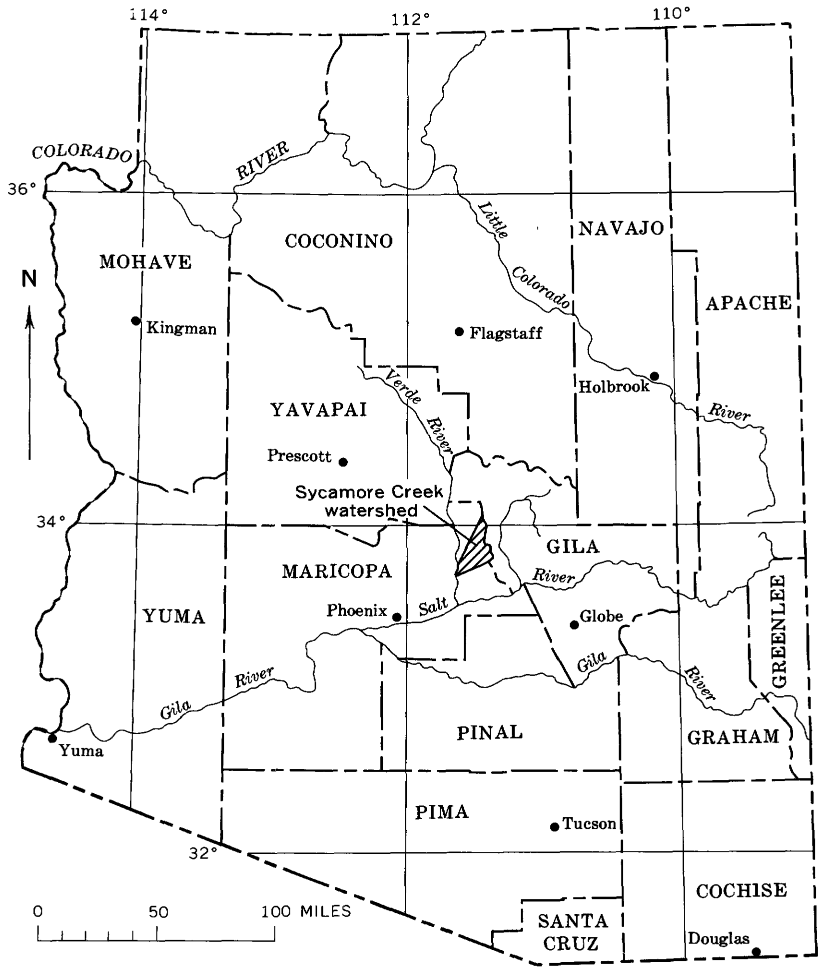

FIGURE 1.—Location of Sycamore Creek watershed.

of the hydrologic system, (2) to determine the potential water yield from the Sycamore Creek watershed, and (3) to determine the amount, location, and nature of water losses from the system.

LOCATION, TOPOGRAPHY, AND DRAINAGE

Sycamore Creek is an intermittent stream that originates in the Mazatzal Mountains in eastern Maricopa County (pl. 1). It flows southwestward to the Verde River, is about 40 miles long, and drains an area of about 195 square miles. Altitudes in the watershed range from about 1,400 feet above sea level near the Verde River to more than 7,100 feet in the Mazatzal Mountains.

For the purpose of this study, the Sycamore Creek watershed has been divided into two parts—an upper hard-rock area and a lower alluvial area (pl. 1). The upper hard-rock area, which includes about 85 percent of the watershed, is rugged mountainous terrain composed chiefly of igneous and volcanic rocks and minor amounts of consolidated alluvial sediments. The lower alluvial area has little relief and gentle slopes and is composed primarily of consolidated alluvium.

In the upper hard-rock area the stream course is cut into bedrock, shallow alluvium overlying bedrock, or well-indurated sediments and has an average gradient of about 120 feet per mile. The stream leaves the upper hard-rock area through a narrow gorge and emerges on a broad channel cut into the alluvial deposits of the lower alluvial area. This part of the channel has an average gradient of about 30 feet per mile in its 9-mile course to the Verde River.

CLIMATE

Data from several climatological stations in and near the Sycamore Creek watershed indicate a wide range in climate because of the large differences in altitude. The lower alluvial area has mild winters, and minimum temperatures of less than 32° F are rare (U.S. Weather Bureau, 1948–65). The summers are hot and dry, and maximum temperatures often are more than 100° F. The higher parts of the upper hard-rock area receive snow in the winter and have freezing temperatures from October to May. January is usually the coldest month, and July the warmest (fig. 2). The average annual temperature at Bartlett Reservoir is about 71° F.

The annual precipitation is about 11.6 inches at Bartlett Reservoir at an altitude of 1,650 feet and 20.0 inches at Sunflower at an altitude of 3,360 feet. The greatest amount of precipitation usually falls in August, and the least in June (figs. 2 and 5).

Evaporation rates are high because of the high temperatures and low relative humidity. The annual pan evaporation at Bartlett Reservoir (fig. 2) ranged from 114.88 inches in 1964 to 126.09 inches in 1961 and averaged 120.33 inches for 1961–65. The 25-year average pan evaporation is 123.33 inches.

ACKNOWLEDGMENTS

The writers gratefully acknowledge the cooperation of the U.S. Forest Service and the Bureau of Indian Affairs for permitting the investigation to be conducted on lands under their administration. The cooperation and assistance of the people who served as rain-gage observers are gratefully acknowledged. The authors also acknowledge the generous assistance of Messrs. J. S. Watkins and G. P. Eaton of

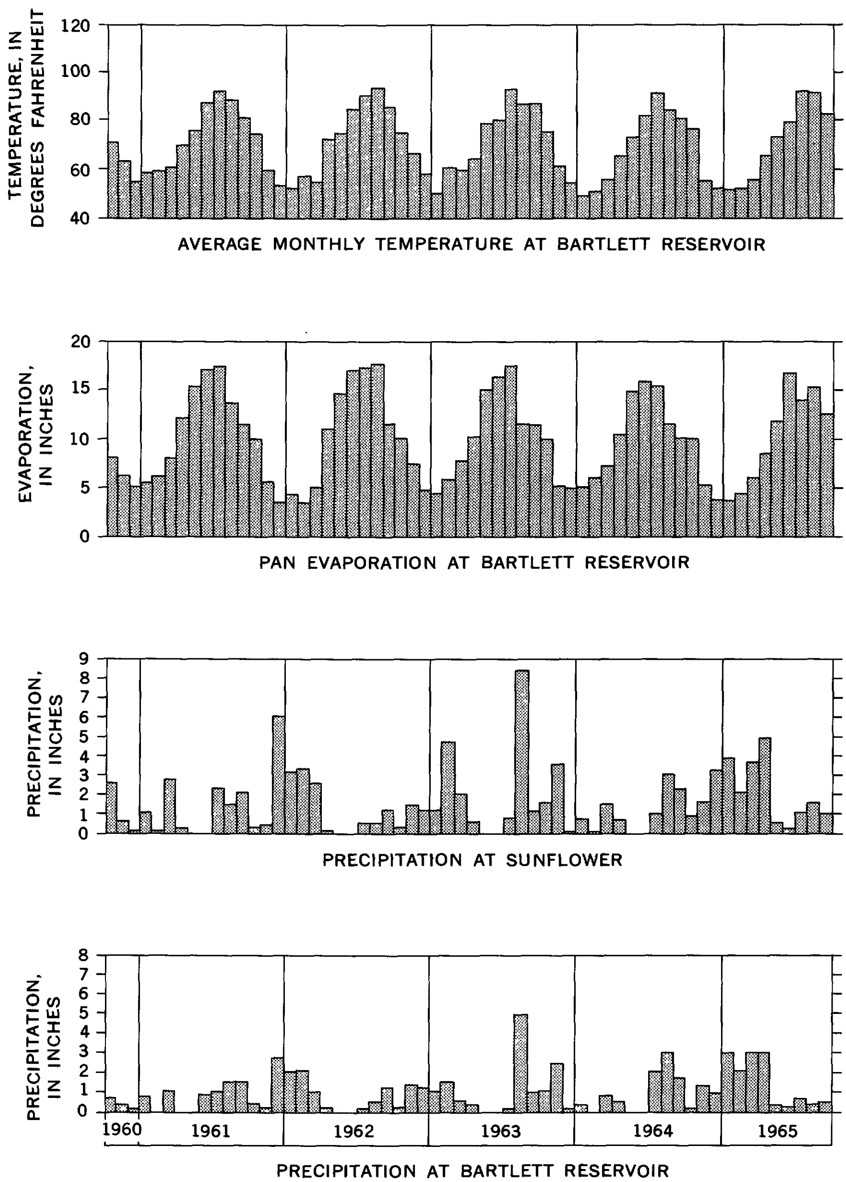

FIGURE.—Monthly temperature, evaporation, and precipitation in and near the Sycamore Creek watershed.

the Geological Survey in running the seismic-refraction profiles in the lower alluvial area. The authors wish to thank the personnel of the Phoenix Research office, U.S. Geological Survey, for furnishing the low-altitude infrared aerial photographs that were used in mapping the geology of the lower alluvial area.

GEOLOGIC SETTING

UPPER HARD-ROCK AREA

The upper hard-rock area is made up of rugged mountainous terrain that has great relief and steep slopes. The average gradient of Sycamore Creek through this area is about 120 feet per mile.

The mountains are composed chiefly of granite and related crystalline and metamorphic rocks of Precambrian age (Wilson, 1939, p. 1113–1164). Consolidated alluvial deposits that are probably of late Tertiary age and terrace deposits of Quaternary age unconformably overlie the crystalline rocks and are exposed in the central part of the upper hard-rock area (pl. 1). These deposits and the crystalline rocks are unconformably overlain by extensive basaltic lava flows of Quaternary or Tertiary age that crop out along the western and central part of the area (pl. 1). Small discontinuous deposits of unconsolidated Quaternary alluvium are found along the channel of Sycamore Creek in this area.

In the upper hard-rock area the crystalline rocks are generally impermeable. The consolidated alluvial deposits have a low permeability, and the precipitation that falls on them collects on the land surface and runs off as overland flow. The metamorphic rocks are highly fractured, faulted, and tilted. These rocks are deeply weathered and have a highly permeable soil cover. The precipitation that falls on areas underlain by metamorphic rocks tends to infiltrate and, therefore, runs off less rapidly than the precipitation that falls on areas underlain by crystalline rocks. The unconsolidated alluvium along the channel of Sycamore Creek is coarse grained and has a moderately high permeability.

LOWER ALLUVIAL AREA

In sharp contrast to the upper hard-rock area, the lower alluvial area has little relief and gentle slopes. The channel of Sycamore Creek has an average gradient of about 30 feet per mile in this area.

The lower alluvial area is underlain chiefly by poorly consolidated alluvial deposits, which consist of sandstone, siltstone, and conglomerate, all of which are probably Tertiary in age. These deposits unconformably overlie granite and related crystalline rocks and are disconformably overlain by basaltic lava flows along the north edge of the lower alluvial area. Thin terrace gravel of Quaternary age unconformably overlies the unconsolidated alluvium along Sycamore Creek.

The broad flat channel and flood plain of Sycamore Creek are underlain by as much as 105 feet of unconsolidated Quaternary alluvium, which consists of sand, gravel, silt, and clay (pl. 1). The unconsolidated alluvium was deposited in channels cut into the consolidated alluvium and the crystalline rocks in the northern part of the lower alluvial area (pl. 1).

The consolidated alluvium contains large amounts of firmly cemented fine-grained material and has a low permeability. The unconsolidated alluvium is composed chiefly of sand- and gravel-size material and is highly permeable. The high permeability and large storage capacity of this unit enable it to receive large volumes of water as seepage from the reach of Sycamore Creek between the Fort McDowell gaging station and the Verde River.

HYDROLOGY

An evaluation of the water resources of an undeveloped area requires a knowledge of the primary factors that affect the hydrologic system—precipitation, streamflow, subsurface flow, and water loss by evaporation and transpiration—and also a knowledge of how these factors interrelate. Precipitation is the initial source of water, but not all the precipitation that reaches the land surface is available for man's use. Water that reaches the land surface as precipitation may proceed along any of three general paths. It may evaporate soon after contact with the land surface, move across the land as surface runoff, or penetrate the earth to become either soil moisture or ground water.

Water that moves over the land surface tends to collect and become streamflow. The amount and duration of streamflow, in general, depend on the amount, intensity, and type of precipitation and on the nature of the material over which the water passes. As streamflow moves along natural channels, some water may evaporate and thus be lost from the system, or a part or all of it may percolate into favorable materials and become either soil moisture or ground water.

Of the water which percolates into the earth from precipitation or streamflow, that which reaches the water table or the zone of saturation is called ground water; that which is retained in the unsaturated zone above the water table is called soil moisture. As water moves through the earth as ground water, it may return to the land surface and become streamflow where the water table intersects the land surface, it may move into the unsaturated zone to become soil moisture, or it may be removed from the system by evapotranspiration. It is clear, therefore, that the factors governing the hydrologic system are highly interrelated (pl. 1). Thus, the initial step in this investigation was the measurement of the component parts of the hydrologic system.

INSTRUMENTATION

Instruments installed during this study included six streamflow gaging stations, four recording precipitation gages, and seven observation-well recorders. In addition, 26 streamflow-measurement sites and 13 observation wells were established. The U.S. Weather Bureau operates nonrecording precipitation gages at Sunflower and Bartlett Reservoir.

PRECIPITATION MEASUREMENTS

To obtain additional information on the rate and amount of precipitation and on the areal and altitudinal distribution of precipitation, four weighing-type recording precipitation gages were installed in the following locations: (1) Near the mouth of Sycamore Creek at Fort McDowell at an altitude of about 1,440 feet, (2) at Sunflower at an altitude of about 3,400 feet, (3) at the Alder Creek gaging station at an altitude of about 4,100 feet, and (4) on top of Mount Ord at an altitude of about 7,120 feet (pl. 1).

STREAMFLOW MEASUREMENTS

Streamflow gaging stations were installed to obtain a measure of the surface runoff and to provide information on runoff characteristics. Records from these gaging stations and periodic streamflow measurements are used to determine water losses and gains in the mountain and alluvial channels.

Six streamflow gaging stations are in operation in the Sycamore Creek watershed—two on the main stem of Sycamore Creek and four on its tributaries (pl. 1). The records from the four tributary stations, Alder Creek, East Fork Sycamore Creek, Camp Creek, and Rock Creek, provide a measure of the tributary inflow to Sycamore Creek. All downvalley flow is brought to the surface by an impermeable rock barrier at the station on the main stem of Sycamore Creek near Sunflower. The other main-stem station, Sycamore Creek near Fort McDowell, is in the granite gorge about 9 miles upstream from the confluence of Sycamore Creek with the Verde River and is equipped with a concrete artificial control that brings the underflow to the surface. The discharge from the upper hard-rock area of the watershed is measured at this station (pl. 1).

Discharge measurements of tributary inflow and of flow in the main channel were made periodically during times of relatively steady flow at 26 measuring sites. Results of these discharge measurements and records of flow at gaging stations provide a measure of tributary inflow and channel losses upstream from the Sycamore Creek near Fort McDowell station and a measure of surface-water losses in the lower alluvial area. During floodflows, when streamflow from Sycamore Creek reached the Verde River, records from the Sycamore Creek near Fort McDowell and the Verde River near Scottsdale gaging stations and discharge measurements at the mouth of Sycamore Creek were used to determine the volume of streamflow entering the Verde from Sycamore Creek.

WATER-LEVEL MEASUREMENTS

A system of 20 observation wells was established to measure water-level fluctuations in the lower alluvial area (pl. 1; fig. 3). Seven of these are 4- to 8-inch diameter wells on which water-level recorders were installed. Five of the recorder wells are about equally spaced in the upstream half of the section, and two are near the confluence of Sycamore Creek with the Verde River. Water levels in the wells not equipped with water-level recorders were measured monthly, or more frequently when there was flow in the lower reach of Sycamore Creek. Three of the observation wells are privately owned. They are equipped with windmills and supply water for livestock.

PRECIPITATION CHARACTERISTICS

Precipitation is the initial source of water in the Sycamore Creek watershed. Based on 18 years of record, the average annual precipitation is about 20 inches at Sunflower (fig. 4), which is near the center of the watershed. About 55 percent of the precipitation falls in the winter, and 45 percent in the summer (fig. 4). During the 5 years of this project, however, the average annual precipitation was 19.11 inches, of which about 60 percent fell in the winter and 40 percent in the summer. Most of the winter precipitation occurred in January, February, and March, and most of the summer precipitation occurred in August (fig. 5). Slow-moving cold fronts produce most of the winter precipitation, which occurs as low-intensity rain or as snow at high altitudes. Most of the summer precipitation occurs as high-intensity short-duration thunderstorms of convective origin.

In this report the word "storm" is defined as any period of precipitation that is separated from another period of precipitation by at least 6 hours. The word "winter" includes the 6-month period from November through April, and "summer" includes the remaining 6 months. The term "water year" is defined as the 12-month period from October 1 through September 30. The water year is designated by the calendar year in which it ends and which includes 9 of the 12 months. Therefore, the year ending September 30, 1961, is called the 1961 water year.

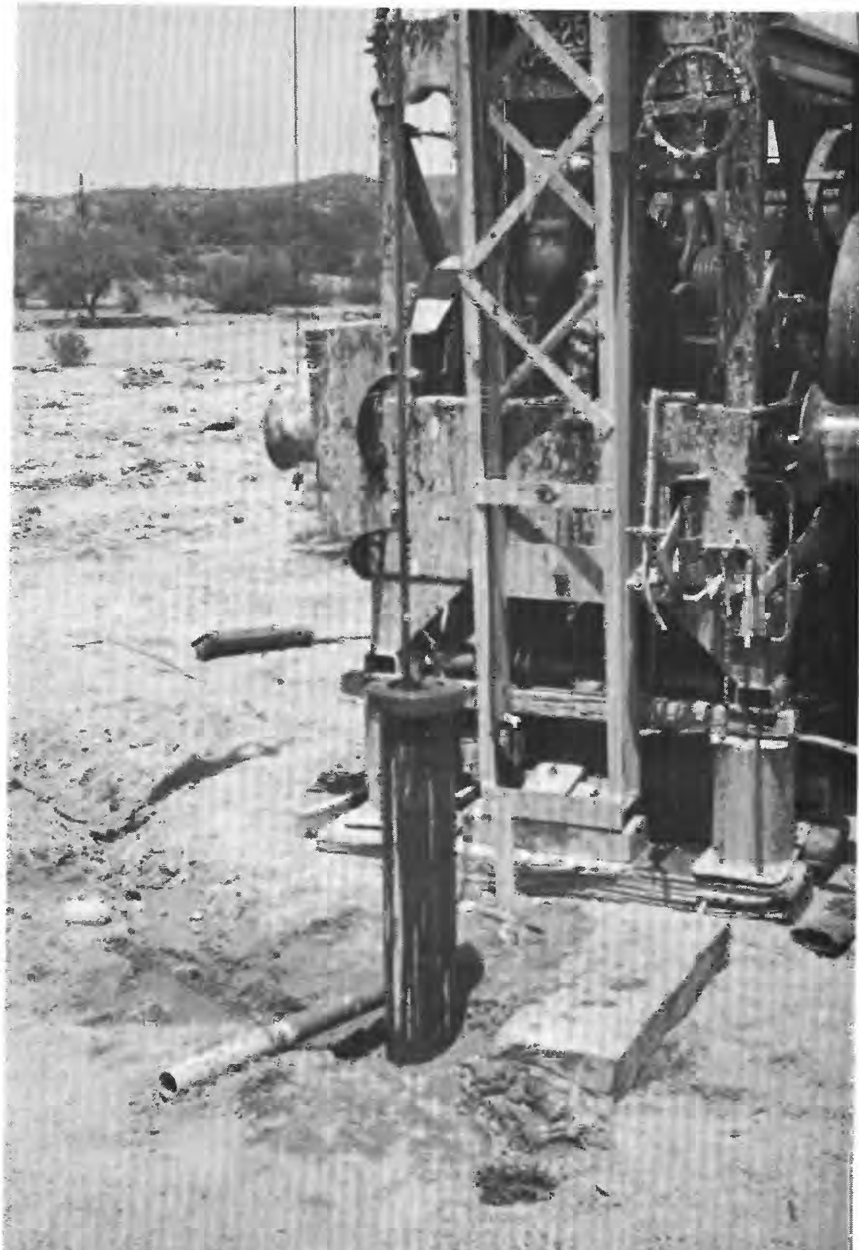

FIGURE 3.—A 6-inch diameter well being drilled in the lower alluvial area.

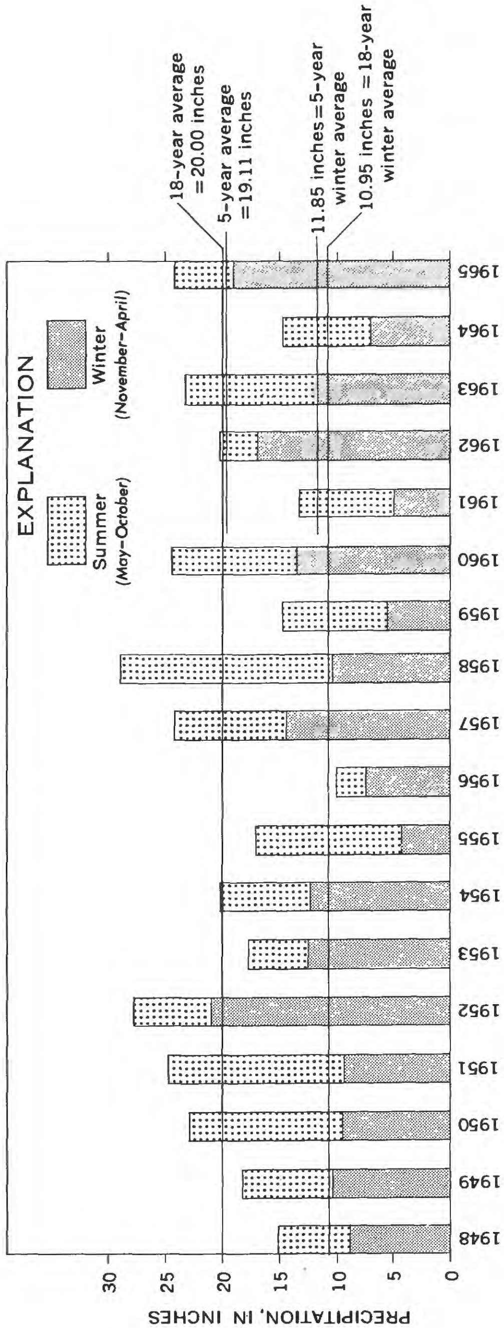

FIGURE 4.—Annual precipitation at Sunflower.

The areal distribution of precipitation on the Sycamore Creek watershed is extremely variable (table 1). Winter storms are widespread and often cover the entire watershed, but summer storms are usually scattered and quite small in areal extent.

On several occasions during the summer, precipitation was recorded at all four gages in the project area within a period of 4 hours or less, and it was impossible to tell whether the source of the precipitation was one large storm that covered the whole area, one or more small storms that moved across the area, or small storm cells that developed separately at about the same time. On many occasions precipitation was recorded at only one of the four recording gages. The maximum precipitation usually occurred at the Alder Creek gage at an altitude of 4,100 feet when precipitation was recorded at all four gages.

In general, the amount of precipitation increases with altitude. For example, in the 1963 water year the measured precipitation at Fort McDowell, altitude 1,440 feet, was 6.91 inches; at Sunflower, altitude 3,400 feet, 20.00 inches; at Alder Creek, altitude 4,100 feet, 23.31 inches; and at Mount Ord, altitude 7,120 feet, 14.36 inches. The amount of precipitation recorded at Mount Ord was much less than normally would be expected; because this gage is near the crest of the mountain peak, where winds moving up the slope tend to impart an upward acceleration to precipitation about to enter the gage, the catch may have been deficient (Linsley and others, 1958, p. 28).

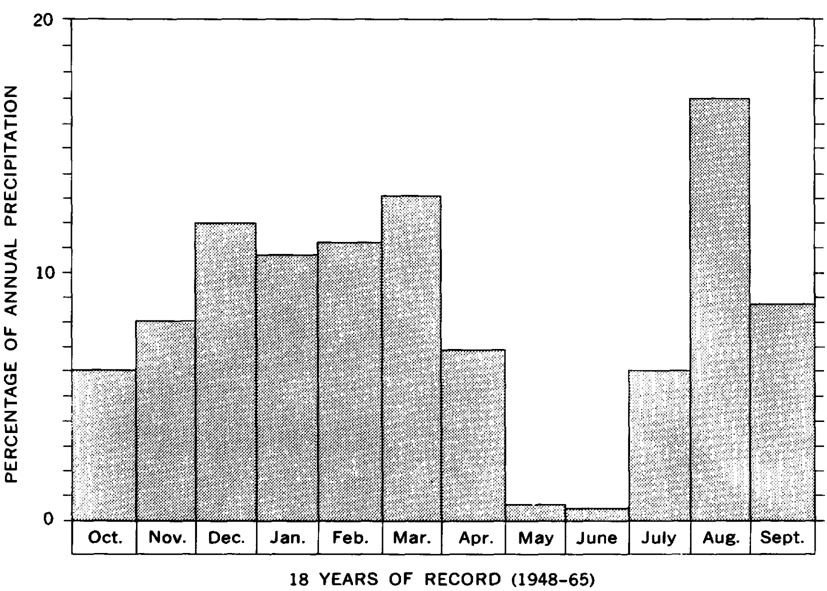

FIGURE 5.—Average monthly distribution of precipitation at Sunflower.

TABLE 1.—*Summary of precipitation, in inches, recorded in the Sycamore Creek area, November 1962 to October 1965*

Date of storm	Gage site			
	McDowell	Sunflower	Alder Creek	Mount Ord
1962				
Nov. 30	0.35	0.40	0.59	0.77
Dec. 1		.05		
17	.06	.09		.07
18	.29	.70	1.16	.94
18	.07			
24	.09	.39	.51	.02
1963				
Jan. 2–3	.78	.82	.80	.30
3	.09			.08
4	[1]	.02		
9	[1]	.02		
10		.29	.73	
11		.03		
Feb. 10–11	1.85	4.62	5.08	1.65
12		.05		
Mar. 17–18	.56	1.99	2.09	.40
19		.02		.10
Apr. 1			.05	
17			.05	
25	.25	.50	.56	.42
26	.06	.12	.39	.10
July 19		.80	.42	.90
27			.08	.25
31				.02
Aug. 1		.11		.29
1	.12	.52	.62	1.30
2		.64		
2		.01		.02
3			.27	.28
4	.55	.09	.86	.15
4	.09	.20	.02	
5				.39
5–6	.85		.46	.03
6	.19	.45		
7		.55	.80	1.25
8		.05		
14	[1]	.15	1.45	
15	[1]		.11	
16–17	[1]	.95	1.05	.37
17	[1]	.62		.05
19	[1]		.10	
22	[1]	1.20	2.22	2.01
22	[1]	.12	.29	
23	[1]		.13	
25–26	.55	1.44	.93	.10
26				.05
28		.10		.25
29				.05
30		1.17	.16	.48
31	.04		.02	
31			.20	
Sept. 1		.18	.92	.50
9	.07	.25	.19	.20
13		.29	[1]	.27
18		[1]	[1]	.30
Oct. 16		.04	[1]	.34
18–19	.52	1.24	[1]	.86

See footnote at end of table.

TABLE 1.—*Summary of precipitation, in inches, recorded in the Sycamore Creek area, November 1962 to October 1965*—Continued

Date of storm	Gage site			
	McDowell	Sunflower	Alder Creek	Mount Ord
1963—Con.				
Nov. 2		0.37	[1]	0.22
7		1.36	[1]	.30
8		.02	[1]	.13
16		.18	[1]	.09
20–21	0.68	1.60	[1]	
21	.02		[1]	
22			[1]	.43
Dec. 9–10		.09		
1964				
Jan. 19	[1]	[1]	.10	[1]
Apr. 28	.10	[1]	[1]	[1]
July 12		.50	[1]	.24
15	.43	.10	[1]	
20		.13	[1]	
23–24	.10	.17	[1]	.25
24			[1]	.02
Aug. 1	.80	1.80	2.68	2.31
2	.10	.50	.87	
9	.03		[1]	[1]
12	.36		[1]	[1]
13	.32		[1]	[1]
26	1.77	[1]	[1]	[1]
30	.06	[1]	[1]	[1]
Sept. 5		[1]		.03
6		[1]	.05	.10
9	.05	[1]	.09	.40
12		[1]	.15	.93
13	.15	[1]	.07	.22
14–15	.08	[1]	.23	.04
15		[1]	.21	.06
19	.05	[1]	.03	.09
19		[1]	.09	
22–23	.04	[1]		
23		[1]		.04
25		[1]	.20	.09
Oct. 16	.12	[1]	.17	.11
16		[1]	.70	.35
17	.06	[1]	.11	.23
Nov. 10	.03	[1]	.02	
11		[1]	.02	
15		[1]	.22	.20
15–16	1.07	[1]	.93	
17		[1]		.13
18	.20	[1]	.07	
Dec. 4	[1]	[1]		.05
9	[1]	[1]		.03
18	.51	[1]		
28	.39	[1]		
31	.30	[1]		
1965				
Jan. 1	.47	1.08	1.06	.12
5–8	1.43	3.01	3.60	1.78
20	.26	.60	1.01	[1]
24		.21	.12	[1]

See footnote at end of table.

TABLE 1.—*Summary of precipitation, in inches, recorded in the Sycamore Creek area, November 1962 to October 1965*—Continued

Date of storm	Gage site			
	McDowell	Sunflower	Alder Creek	Mount Ord
1965—Con.				
Feb. 6–7	1.21	1.84	2.65	[1]
9–10	.15	.28	.46	[1]
Mar. 10–12	1.24	2.61	3.21	1.37
13		.43	.24	.05
15–16	.16	.55	.75	.26
25			.05	
Apr. 1		.23	.29	.06
2		.03		
3–4	1.30	2.75	2.60	.31
5			.05	.16
6		.01		.05
7		.22	.34	.09
8				.03
9	.27	.63	.75	
10	.16	.55	.82	.14
12	.13	.43	.45	.04
May 12	.13	.48	.58	
24			.03	
June 23		.24	.27	.24
July 7			.07	
10–11		.07		.02
15–16		.65	.96	.03
18	.20	.11	.03	
23–24	.04	.13	.43	.07
25		.04		.16
28–29	.50	.06	.04	.10
30			.02	
Aug. 7				.07
8		.05	.08	
10	.10	.02	.09	
12		.05		
15		.18		
16		.07		.67
17	.16	1.22	.46	.33
29		.05	.18	
Sept. 2		.44	2.32	.80
3		.10	.25	
4	.04			
5			.02	
18		.25	.48	.31
19	.20	.32	.50	.28

[1] No record.

A few point measurements do not define accurately the total precipitation on the watershed, because of the great spatial variability of the precipitation. Sunflower, however, is near the center of the watershed and at about the average altitude of the watershed; therefore, the precipitation data collected at Sunflower probably are representative of the average precipitation.

The consistency of the precipitation records for Sunflower was substantiated by using the double-mass curve technique; precipitation data for Sunflower were plotted against precipitation data for four nearby stations. The representativeness of the precipitation date collected during the 5-year study was then tested by statistical methods. At the 5 percent level of significance, statistical tests showed no difference in mean or variance between the 5-year period and the 18-year period of record. This applies to the seasonal data as well as to the yearly data. The yearly and seasonal means and standard deviations for the precipitation data collected at Sunflower are shown as follows:

	Precipitation, in inches 1948–65	*Precipitation, in inches* 1961–65
Yearly (water year)	20.00±5.05	19.11±5.27
Winter (November through April)	10.95±4.67	11.85±6.02
Summer (May through October)	9.05±4.28	7.26±3.16

A comparison of the daily precipitation of different magnitudes is shown in table 2. No unusually large amount of daily precipitation occurred in any 24-hour period during this study.

Precipitation can be defined in terms of two variables—amount and rate. Recording gages were used in this study to provide information on the variables. The precipitation data, which were recorded at Sunflower between September 10, 1961, and September 30, 1965, show that winter storms usually produce more precipitation, last longer, and are less intense than summer storms (table 3). The maximum amount of precipitation recorded at Sunflower for a winter storm was 4.62 inches, whereas the maximum for a summer storm was 1.80 inches (fig. 6). The longest winter storm lasted 64 hours, and the longest summer storm lasted 19.5 hours (fig. 7). The maximum 30-minute intensity recorded for a winter storm was 0.84 inch per hour and for a summer storm was 2.30 inches per hour (fig. 8).

TABLE 2.—*Comparison of storms of different magnitudes at Sunflower*

Period (water year)	Precipitation (inches)	Number of times that precipitation of specified magnitudes, in inches, occurred in a 24-hour period			
		0.5–1	1–2	2–3	>3
1948–60	264.39	80	52	11	6
Average	20.34	6.2	4.0	.8	.5
1961	13.14	6	3	0	0
1962	19.92	5	2	2	0
1963	23.06	10	4	2	0
1964	14.84	3	3	0	0
1965	24.59	9	8	0	0
Average	19.11	6.6	4.0	.8	0

TABLE 3.—*Storm precipitation data for Sunflower, water years 1962–65*

Date of storm		Duration (hours)	Depth (inches)	Maximum increment (inches)		
				30 minutes	60 minutes	24 hours
1961						
Sept.	13	2.5	0.43	0.28	0.32	0.43
	16–17	19.5	.21	.10	.10	.21
	18	.5	.12	.12	--------	.12
Oct.	9	8.5	.12	.07	.08	.12
	30	5.0	.18	.05	.06	.18
Nov.	1	16.0	.08	.03	.05	.08
	21	13.5	.20	.05	.07	.20
	25	4.5	.08	.02	.02	.08
Dec.	3	9.0	.15	.04	.07	.15
	8–9	8.5	.22	.06	.08	.22
	10–11	32.0	2.59	.15	.29	2.42
	14–16	47.5	2.94	.10	.19	2.40
	16	.5	.02	.02	--------	.02
	17	.5	.03	.03	--------	.03
	21	.5	.04	.04	--------	.04
1962						
Jan.	13	4.0	.12	.02	.04	.12
	14	1.0	.23	.12	.23	.23
	21–22	26.0	1.74	.25	.38	1.66
	23	6.0	.04	.02	.02	.04
	24–25	22.0	.99	.10	.15	.99
	26	.5	.02	.02	--------	.02
Feb.	7–8	10.0	.39	.07	.13	.39
	11–12	16.0	.28	.05	.08	.28
	12	1.0	.08	.06	.08	.08
	20	18.0	1.00	.15	.27	1.00
	21	.5	.05	.05	--------	.05
	21	1.5	.13	.07	.11	.13
	22	.5	.03	.03	--------	.03
	25	5.0	.71	.16	.21	.71
	26–27	21.5	.58	.09	.14	.58
	28	.5	.05	.05	--------	.05
Mar.	5	.5	.06	.06	--------	.06
	7	5.0	.03	--------	.01	.03
	8	.5	.02	.02	--------	.02
	10	2.5	.25	.12	.13	.25
	19–20	17.5	1.33	.09	.14	1.33
	21	16.5	.57	.17	.18	.57
	22	.5	.02	.02	--------	.02
	23	10.0	.26	.09	.18	.26
Apr.	26	5.0	.10	.05	.07	.10
July	3	1.0	.03	.02	.03	.03
	4	2.5	.23	.12	.15	.23
	26	1.0	.06	.04	.06	.06
	28	.5	.14	.14	--------	.14
	31	.5	.07	.07	--------	.07
Aug.	13	.5	.05	.05	--------	.05
	18	1.0	.12	.08	.12	.12
	21–22	9.0	.36	.18	.19	.36
Sept.	5	1.0	.06	.06	--------	.06
	6	1.5	.17	.07	.12	.17
	23	13.0	.50	.06	.10	.50
	24	4.0	.02	--------	.01	.02
	25	3.0	.05	.03	.03	.05
	27	7.0	.27	.22	.24	.27
	28	6.0	.12	.09	.10	.12

TABLE 3.—*Storm precipitation data for Sunflower, water years 1962–65*—Continued

Date of storm		Duration (hours)	Depth (inches)	Maximum increment (inches)		
				30 minutes	60 minutes	24 hours
	1962—Con.					
Oct.	18	6. 0	0. 35	0. 24	0. 25	0. 35
Nov.	14	8. 0	. 37	. 09	. 13	. 37
	15	7. 5	. 63	. 42	. 42	. 63
	30	5. 0	. 40	. 04	. 04	. 40
Dec.	1	. 5	. 05	. 05	--------	. 05
	17	4. 0	. 09	. 05	. 05	. 09
	18	16. 0	. 70	. 21	. 30	. 70
	24	10. 5	. 39	. 15	. 23	. 39
	1963					
Jan.	3	16. 5	. 82	. 08	. 11	. 82
	4	2. 0	. 02	--------	. 01	. 02
	9	. 5	. 02	. 02	--------	. 02
	10	10. 5	. 29	. 05	. 07	. 29
	11	. 5	. 03	. 03	--------	. 03
Feb.	10–11	41. 5	4. 62	. 30	. 48	2. 48
	12	. 5	. 05	. 05	--------	. 05
Mar.	17–18	27. 5	1. 99	. 17	. 24	1. 93
	19	. 5	. 02	. 02	--------	. 02
Apr.	25	6. 5	. 50	. 09	. 16	. 50
	26	4. 8	. 12	. 07	. 07	. 12
July	19	3. 0	. 80	. 75	. 78	. 80
Aug.	1	3. 0	. 11	. 07	. 08	. 11
	1	2. 0	. 52	. 50	--------	. 52
	2	. 5	. 64	. 64	--------	. 64
	2	. 5	. 01	. 01	--------	. 01
	4	5. 0	. 09	. 03	. 04	. 09
	4	. 5	. 20	--------	--------	. 20
	6	1. 0	. 45	. 40	. 45	. 45
	7	5. 0	. 55	. 21	. 26	. 55
	8	. 5	. 05	. 05	--------	. 05
	14	2. 5	. 15	. 05	. 10	. 15
	16–17	11. 5	. 95	. 15	. 28	. 95
	17	1. 0	. 62	. 48	. 62	. 62
	22	8. 5	1. 20	. 50	. 55	1. 20
	22	. 5	. 12	. 12	--------	. 12
	25–26	8. 0	1. 44	1. 15	1. 23	1. 44
	28	2. 0	. 10	. 05	. 08	. 10
	30	7. 8	1. 17	. 82	. 84	1. 17
Sept.	1	5. 5	. 18	. 13	. 13	. 18
	9	3. 0	. 25	. 13	. 13	. 25
	13	3. 5	. 29	. 25	. 27	. 29
Oct.	16	2. 0	. 04	. 02	. 02	. 04
	18–19	13. 0	1. 24	. 30	. 40	1. 24
Nov.	2	6. 0	. 37	. 25	. 25	. 37
	7	11. 5	1. 36	. 25	. 45	1. 36
	8	. 5	. 02	. 02	--------	. 02
	16	2. 5	. 18	. 12	. 13	. 18
	21	15. 5	1. 60	. 15	. 24	1. 60
Dec.	9–10	6. 0	. 09	. 02	. 04	. 09
No record Dec. 21, 1963, to June 14, 1964						

TABLE 3.—*Storm precipitation data for Sunflower, water years 1962–65*—Continued

Date of storm		Duration (hours)	Depth (inches)	Maximum increment (inches)		
				30 minutes	60 minutes	24 hours
	1964					
July	12	1.5	0.50	0.45	0.48	0.50
	15	4.5	.10	.05	.05	.10
	20	.5	.13	.13	--------	.13
	23–24	10.0	.17	.03	.06	.17
Aug.	1	9.5	1.80	.75	1.03	1.80
	2	2.5	.50	.30	.37	.50
No record Aug. 15 to Dec. 10, 1964						
Dec.	18	6.0	.47	.12	.20	.47
	18	1.5	.08	.03	.05	.08
	19	.5	.06	.06	--------	.06
No record Dec. 22, 1964, to Feb. 18, 1965						
	1965					
Mar.	10–13	64	3.04	.18	.26	1.85
	15–16	14	.55	.09	.16	.16
Apr.	1	5.0	.23	.10	.15	.23
	2	.5	.03	.03	--------	.03
	3–4	33.0	2.75	.21	.38	2.64
	7	5.0	.22	.12	.13	.22
	9–10	30.0	1.18	.20	.28	1.12
	12	5.0	.43	.13	.20	.43
May	12	7.0	.48	.09	.16	.48
June	23	5.5	.24	.13	.13	.24
July	11	1.0	.07	.05	.07	.07
	16	3.5	.60	.30	.36	.60
	16	1.0	.05	.03	.05	.05
	18	1.0	.11	.07	.11	.11
	24	1.5	.13	.05	.09	.13
	25	1.0	.04	.02	.04	.04
	29	.5	.06	.06	--------	.06
Aug.	8	5.0	.05	.01	.02	.05
	10	.5	.02	.02	--------	.02
	12	1.5	.05	.02	.04	.05
	15	1.5	.18	.10	.12	.18
	16	2.0	.07	.03	.04	.07
	17	3.5	1.22	.92	1.07	1.22
	29	.5	.05	.05	--------	.05
Sept.	2	.5	.44	.44	--------	.44
	3	.5	.10	.10	--------	.10
	18	5.0	.25	.13	.16	.25
	19	2.0	.32	.13	.21	.32

The seasonal patterns of distribution for three storm variables—amount of precipitation, duration, and maximum 30-minute intensity—for 1962–65 are shown by cumulative frequency curves in figures 9, 10, and 11. The ordinates of these curves represent the percent of storms with given variables equal to or greater than the magnitude represented by the abscissa. For example, in figure 9, an inch or more of precipitation was produced by 8 percent of the summer storms and

17 percent of the winter storms; in figure 11, 25 percent of the winter storms had a maximum 30-minute intensity of 0.26 inch per hour or more, and 25 percent of the summer storms had a maximum 30-minute intensity of 0.52 inch per hour or more.

The relation between the maximum amount and frequency of precipitation at Sunflower for 30-minute, 60-minute, and 24-hour intervals is shown in figure 12. The values were computed from partial-duration series data by using the lowest maximum precipitation that occurred in a water year as a base. The 24-hour curve is based on data for the 1948–65 period; the 30- and 60-minute curves are based on data for the 1962–65 period.

STREAMFLOW CHARACTERISTICS

Sycamore Creek is an intermittent stream that is subject to flash floods. Flow is continuous from November through May, at least in the upper reaches of the stream, and most of the runoff from the

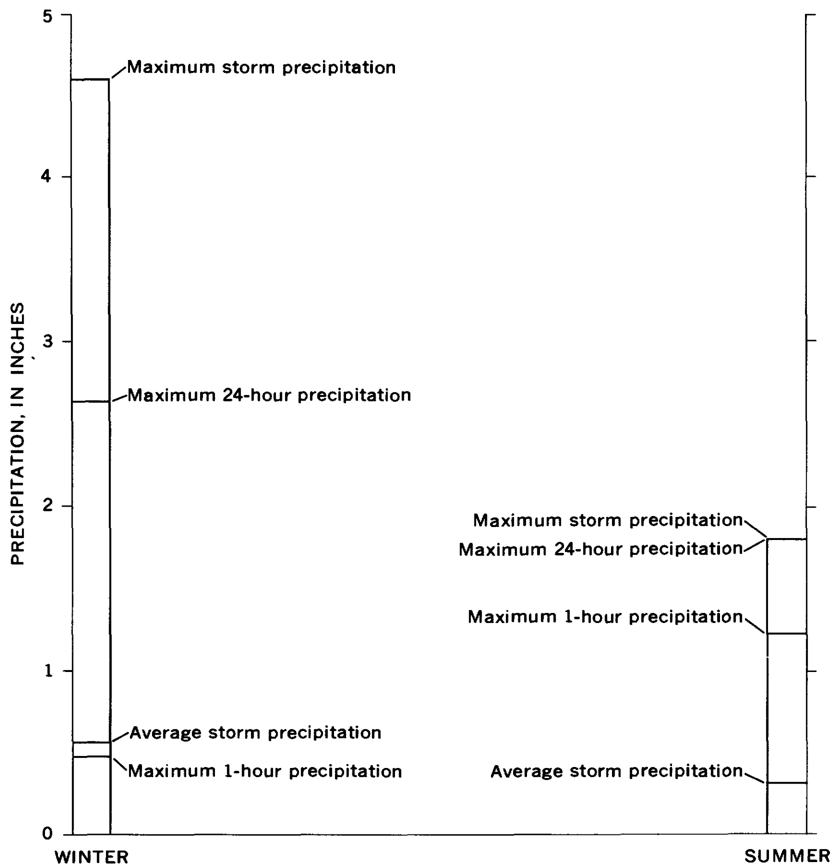

FIGURE 6.—Seasonal precipitation at Sunflower, 1961–65.

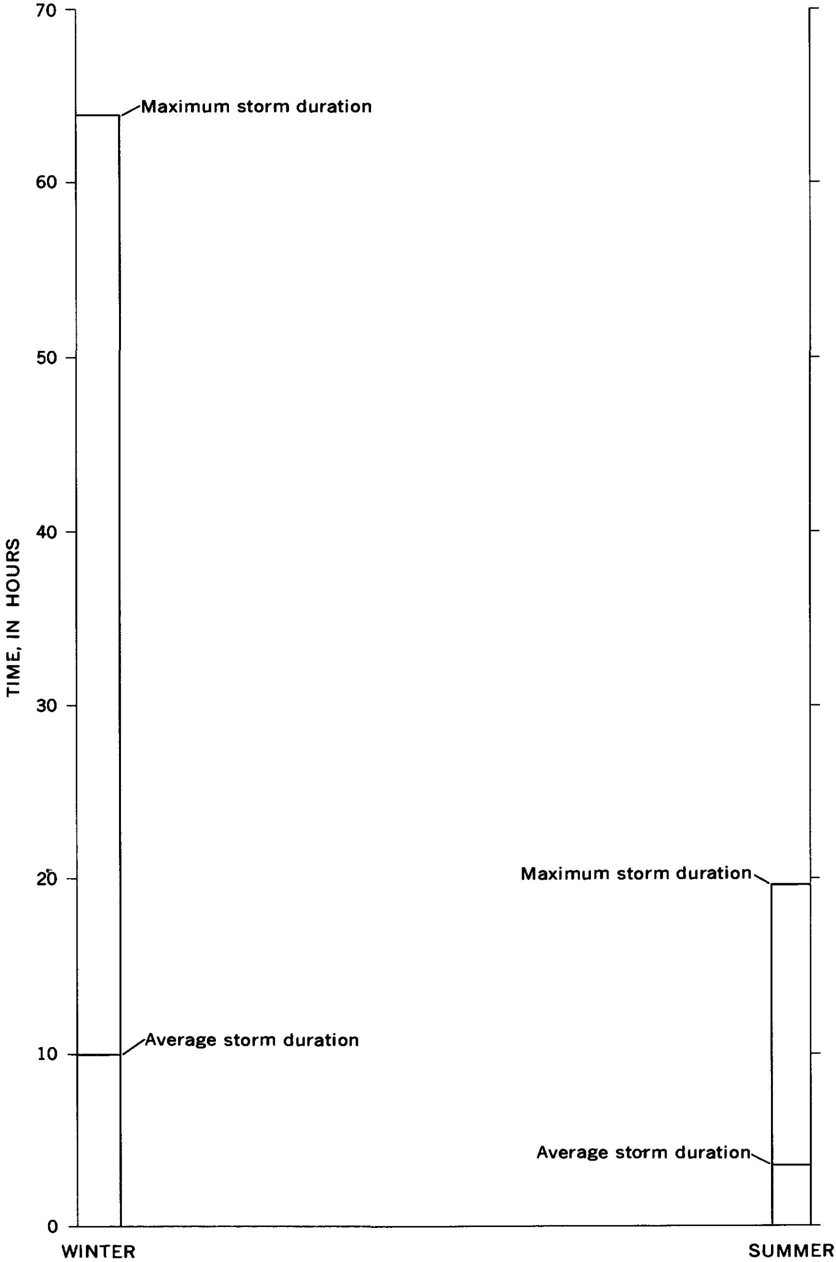

FIGURE 7.—Seasonal storm durations at Sunflower, 1961–65.

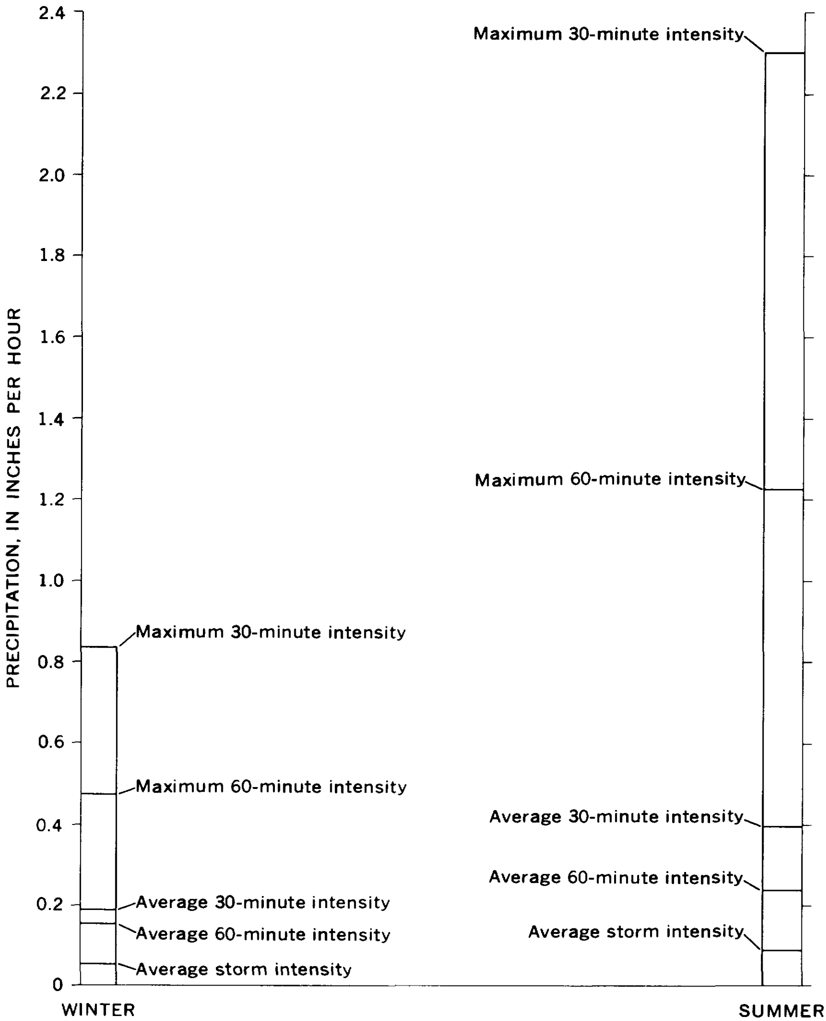

FIGURE 8.—Seasonal precipitation intensities at Sunflower, 1961–65.

watershed occurs during this time (fig. 13). In the summer the flow usually ceases, except for isolated periods of runoff that result from short intense thunderstorms. During periods of low flow, the stream completely disappears in places; it becomes subsurface flow where the underlying alluvial fill will accommodate it and reappears where it is forced to the surface by impermeable barriers. Nearly all the streamflow seeps into the alluvium below the point where the stream leaves the upper hard-rock area (pl. 1), except during large floodflows.

The water yield from the upper hard-rock area differs greatly from year to year. The annual water yield at the Sycamore Creek near Fort McDowell gage for 5 years of record, 1961–65, ranged from 167

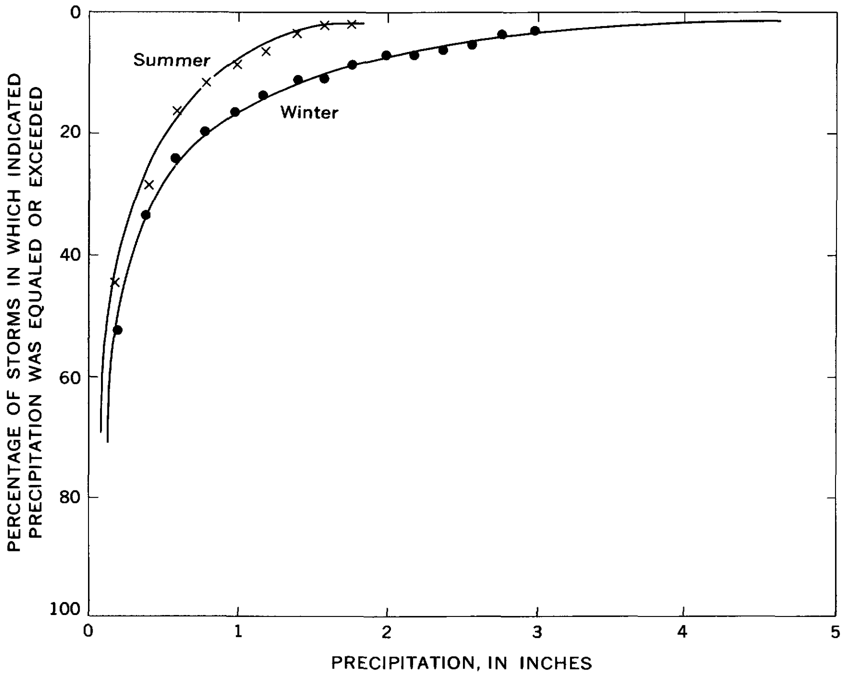

FIGURE 9.—Frequency distribution of seasonal precipitation at Sunflower, 1961–65.

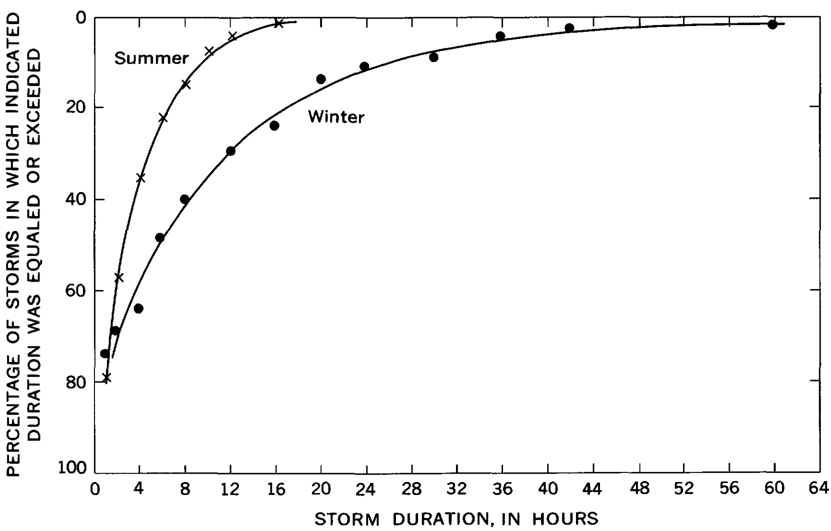

FIGURE 10.—Frequency distribution of seasonal storm durations at Sunflower, 1961–65.

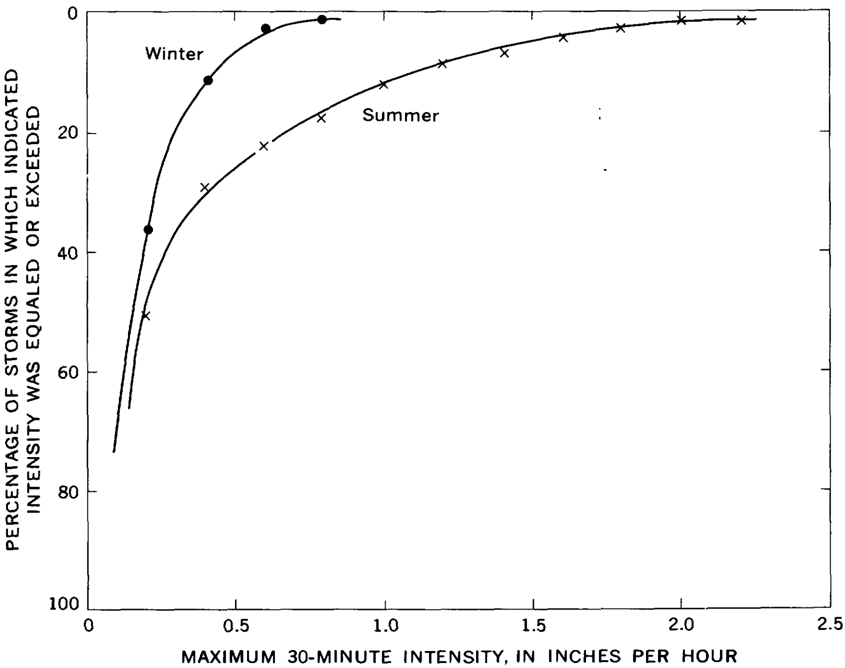

FIGURE 11.—Frequency distribution of seasonal precipitation intensities at Sunflower, 1961–65.

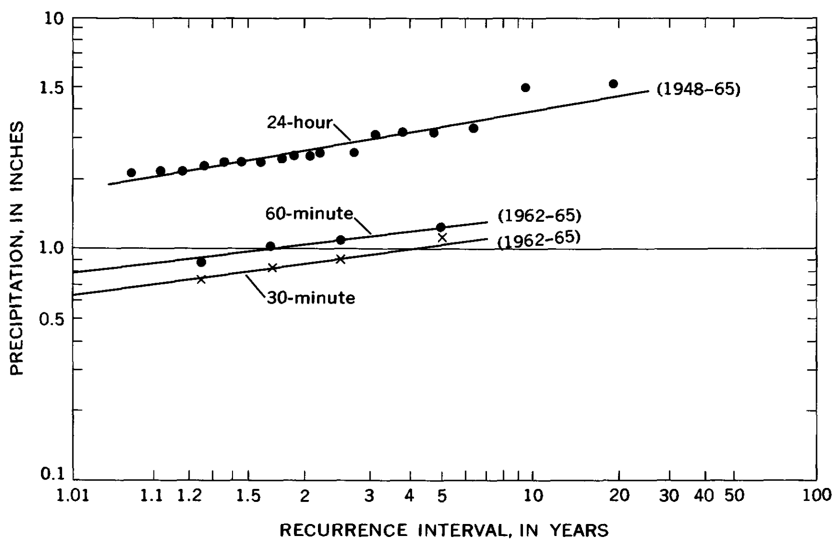

FIGURE 12.—Frequency of yearly maximum 30-minute, 60-minute, and 24-hour precipitation at Sunflower.

acre-feet to 14,320 acre-feet (table 4). The average annual water yield on a water-year basis was 6,110 acre-feet; however, 5 years is a short period on which to base a streamflow analysis.

At the Sycamore Creek near Fort McDowell gage, the stream channel was dry on an average of about 150 days per year. In contrast, at the Sycamore Creek near Sunflower gage 17 miles upstream from the Sycamore Creek near Fort McDowell gage, the stream channel was seldom dry, and "no flow," less than 0.05 cfs (cubic feet per second), was recorded on an average of about 50 days per year. The largest flood peak recorded at the Sycamore Creek near Fort McDowell gage during the period of record was 2,860 cfs on August 16, 1963. Before the recording gage was installed, however, a much larger flood peak passed the gaging site in December 1959; the magnitude of the flood peak was 15,800 cfs, as determined by the slope-area method.

TABLE 4.—*Discharge at streamflow gaging stations, water years 1961–65*

Gaging station	Altitude (ft)	Drainage area (sq mi)	Discharge (acre-ft)				
			1961	1962	1963	1964	1965
East Fork Sycamore Creek near Sunflower	4,100	4.9		341	76	6.4	449
Alder Creek near Sunflower	4,100	9.7		1,390	768	145	1,770
Sycamore Creek near Sunflower	3,360	53.4		5,240	2,070	377	6,790
Camp Creek near Sunflower	2,350	1.8				92	383
Rock Creek near Sunflower	2,200	15.0				397	1,690
Sycamore Creek near Fort McDowell	1,760	165	[1] 167	11,520	3,580	964	14,320

[1] Discharge for Dec. 6, 1960, to Sept. 30, 1961.

A flood-frequency study based on the short-term record of a single station gives extremely variable results (Benson, 1960). Because of the unreliability of such results, the regional flood-frequency method was developed. Patterson and Somers (1966) have developed regional flood-frequency relations for parts of Arizona from available streamflow records. These relations provide a means of estimating the magnitude and frequency of floods for ungaged sites. In their report, Arizona is divided into hydrologic areas, in which the mean annual flood is related to drainage area, and into flood-frequency regions, in which flood-frequency curves for all stations have similar slopes. The Sycamore Creek watershed is in hydrologic area 18, flood-frequency region C.

Figure 14 shows the variation of the mean annual flood with drainage area. The mean annual flood that may be expected from the upper hard-rock area of the Sycamore Creek watershed, which has a drainage area of 165 square miles, is 3,400 cfs (fig. 14). The ratio of the 50-year flood—a flood that will occur on an average of once every 50 years over a longer period of time—to the mean annual flood is 4.45 (fig. 15). Thus, the 50-year flood peak would be about 15,000 cfs.

The water measured at each of the Sycamore Creek gaging stations, near Sunflower and near Fort McDowell, is the total outflow of the

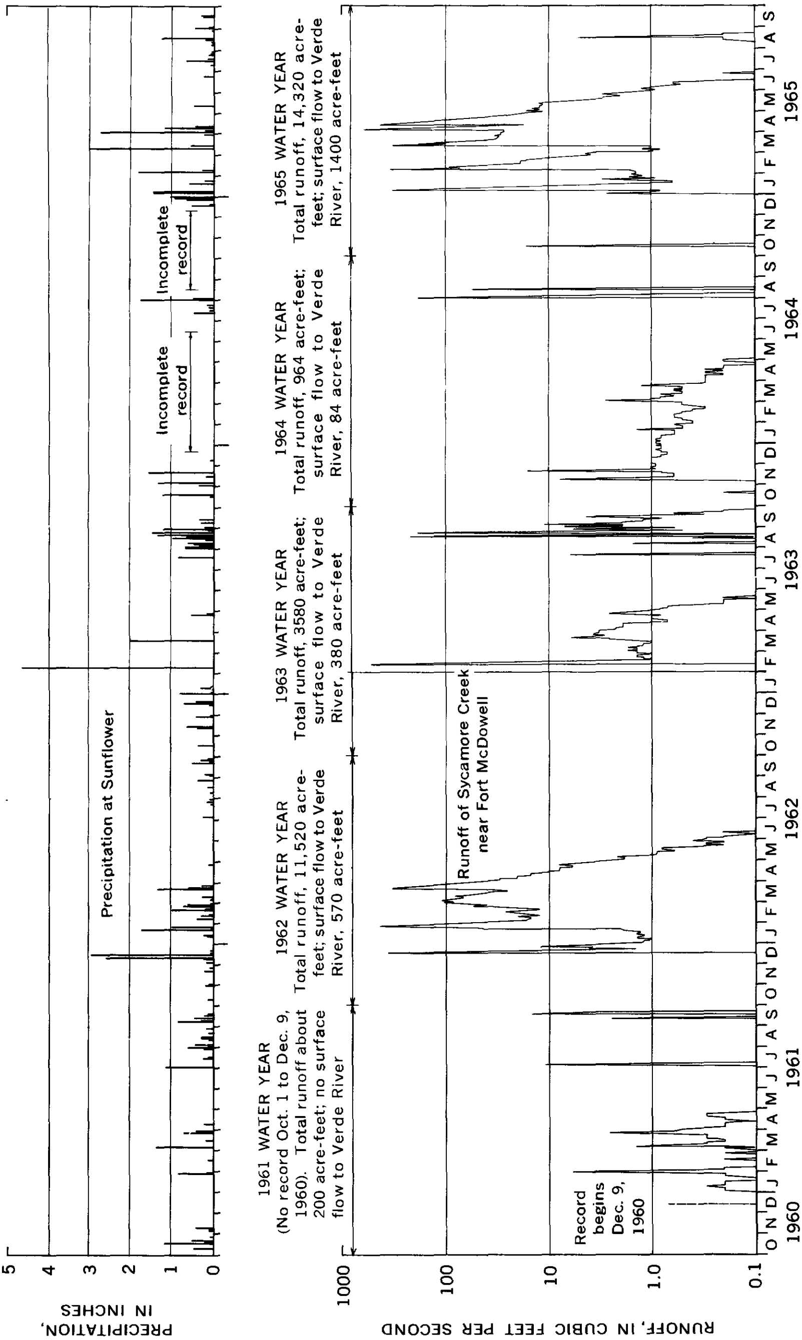

Figure 13.—Runoff of Sycamore Creek near Fort McDowell and precipitation at Sunflower.

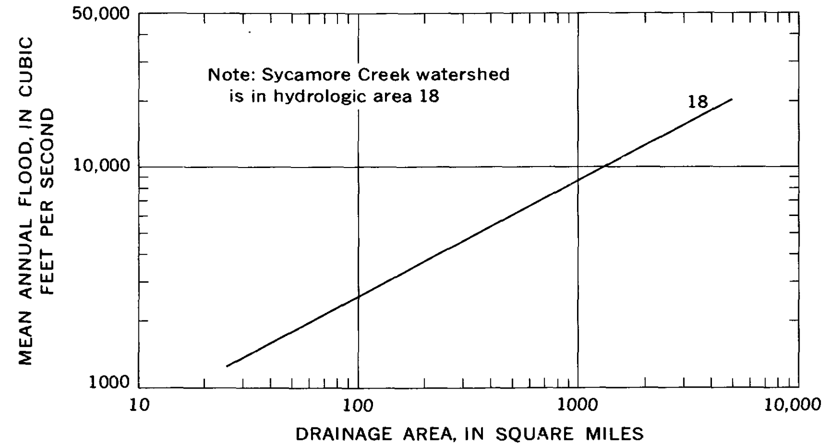

FIGURE 14.—Variation of mean annual flood with drainage area (modified from Patterson and Somers, 1966).

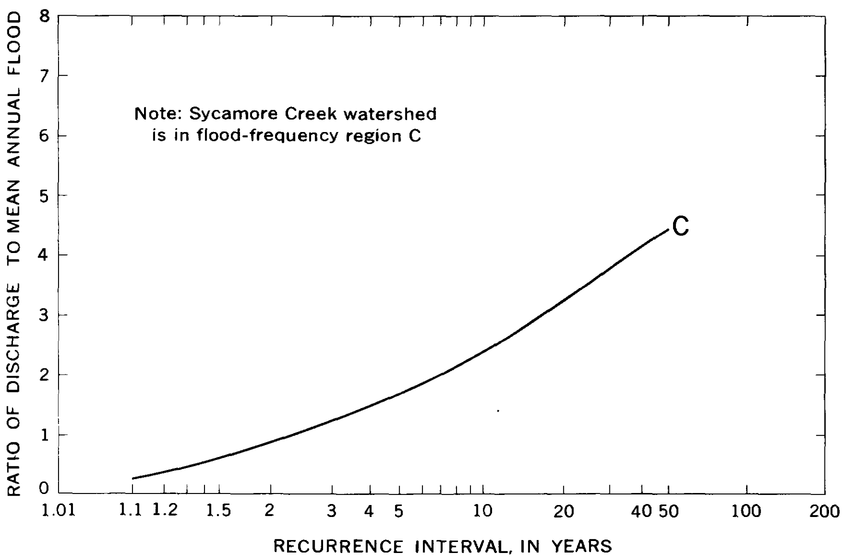

FIGURE 15.—Regional flood-frequency curve (modified from Patterson and Somers, 1966).

watershed above that point. For these two gaging stations, flow-duration curves, adjusted to a long period of record on the basis of flow in nearby Tonto Creek, show the integrated effect of the different factors that influence runoff (fig. 16). The steep slope of the curves denotes a highly variable stream whose flow is mainly from direct runoff (Searcy, 1959, p. 22). The slightly flatter slope at the lower end of the duration curve indicates that only a small amount of the flow is from temporary subsurface storage within the watershed—slightly more

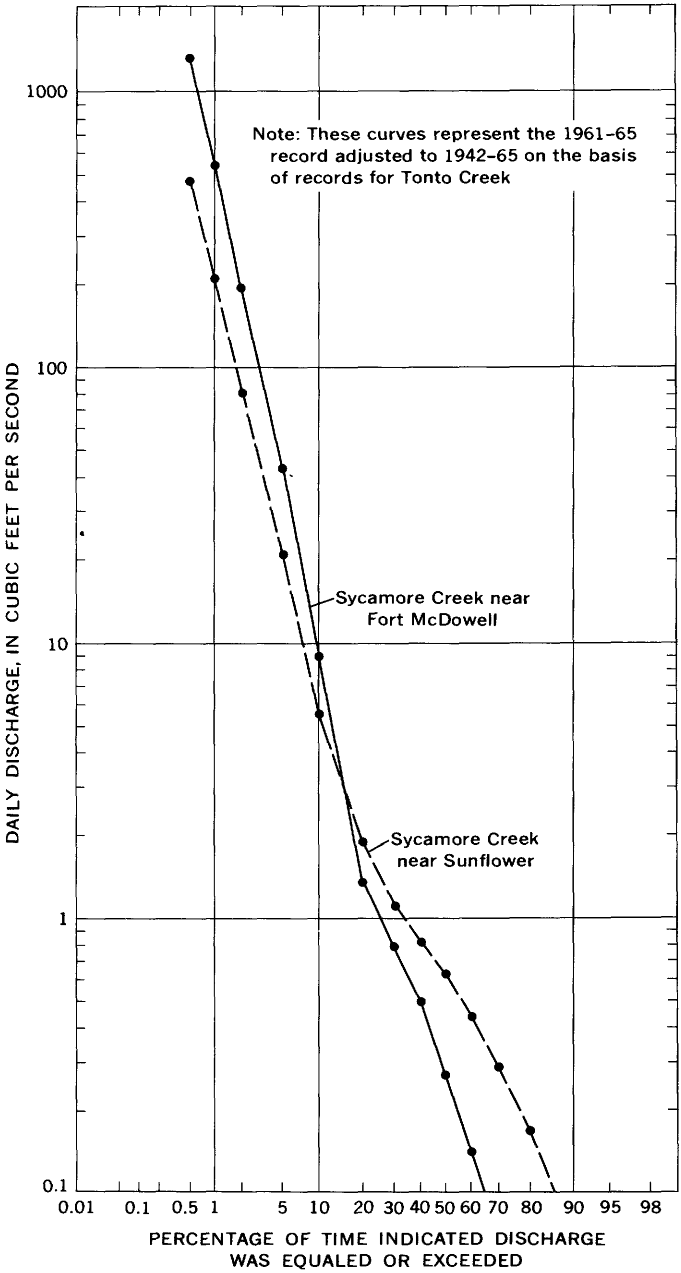

FIGURE 16.—Duration curves of daily mean streamflow.

above the Sunflower gage than above the Fort McDowell gage. This relationship is contrary to what would be expected, for the storage above the Sunflower gage is included in the storage above the Fort McDowell gage; however, much of the meager base flow that passes the Sunflower gage is lost through evapotranspiration before it reaches the Fort McDowell gage.

Most of the tributaries to Sycamore Creek are dry most of the time throughout their channels and flow only for short periods in response to runoff from precipitation. The headwater tributaries at high altitudes, however, contain at least a small amount of water during much of the year, as a result of discharge by springs and seeps, and usually go dry for a month or two near the end of the water year. For example, in the 1964 water year, which was a relatively dry year, Rock Creek, at an altitude of 2,200 feet, had no flow for 360 days; whereas, Alder Creek, at an altitude of 4,100 feet, had no flow for 77 days. In 1965, which was a relatively wet year, Rock Creek had no flow for 250 days, and Adler Creek had no flow for 53 days (U.S. Geological Survey, 1961–65).

During storm runoff and for short periods thereafter, when much of the streamflow is made up of water draining from temporary storage, the flow increases in the downstream direction to the point where the stream course leaves the upper hard-rock area (pl. 1). After the stream leaves the upper hard-rock area, streamflow diminishes in the downstream direction as water infiltrates into the alluvium. Streamflow from Sycamore Creek reaches the Verde River only during floodflows.

Discharge measurements show that streamflow disappears rapidly into the alluvial channel below the hard-rock area. On February 13, 1962, a discharge of 20 cfs at the Fort McDowell gage disappeared in the first 3 miles of channel below the gage; on March 14, 1962, 40 cfs disappeared in 4 miles; on March 23, 1962, 200 cfs disappeared in the 9 miles of channel between the Fort McDowell gage an the Verde River (pl. 1; figs. 17 and 18). A steady flow of 200 cfs disappeared into the channel alluvium on March 23, 1962, although there had been continuous flow past the Fort McDowell gage for 98 days. About 8,000 acre-feet of water passed the gage during this time, and most of the water disappeared into the channel alluvium before it reached the Verde River. Only the peak flows of December 15, January 25, and March 20–21, 1962, contributed surface runoff to the Verde River in the 98-day period (fig. 13). During the 5 years of record (1961–65) at the Fort McDowell gage, streamflow from Sycamore Creek reached the Verde River on 18 occasions, and the average annual surface-water discharge to the Verde was about 500 acre-feet—less than 10 percent of the average runoff from the upper hard-rock area.

FIGURE 17.—Streamflow gaging station on Sycamore Creek near Fort McDowell; discharge is about 170 cfs.

RELATION BETWEEN PRECIPITATION, RUNOFF, AND WATER LOSSES IN THE UPPER HARD-ROCK AREA

Precipitation is the source of all the water in the Sycamore Creek watershed, and the seasonal variations in the amount of precipitation are reflected in the runoff from the watershed. About 60 percent of the precipitation occurs in the winter, and it is responsible for about 90 percent of the runoff from the watershed (fig. 19). Winter precipitation produces more runoff because the evaporation potential is less than it is during the summer (fig. 2). Much of the vegetation is dormant, evapotranspiration is less, and the soil-moisture content is greater; thus, watershed conditions are more conducive to runoff.

All the storms that produced a discernible storm runoff hydrograph at the Fort McDowell gage were used to study the relations between the maximum rate and total volume of runoff at the Fort McDowell gage and the storm precipitation at Sunflower (figs. 20 and 21). These relations show only a general positive trend; both the volume and rate of runoff have a variation of about two orders of magnitude for any given amount of precipitation. The variation between the measured

FIGURE 18.—Downstream view from Sycamore Creek near Fort McDowell gage, showing granite gorge below gage; discharge is about 170 cfs.

storm precipitation and storm runoff is mainly the result of an inadequate measure of the areal variability of storm precipitation on the watershed. When the data are examined on a seasonal basis, however, the relation between precipitation and runoff can be defined more closely (fig. 22). As might be expected, the relation is defined more closely for the winter data than for the summer data.

The 5-year average annual precipitation at Sunflower was 19.11 inches. Assuming that this represents the average precipitation for the entire watershed above the Fort McDowell gage, the 5-year average annual water input was 168,000 acre-feet, of which 0.61 inch, or 6,110 acre-feet, left the watershed as streamflow. Therefore, the average water yield measured at the Fort McDowell gage was 3.6 percent of the precipitation measured at Sunflower.

Water loss may be defined as the difference between the amount of water entering the watershed as precipitation and the amount of water leaving as runoff. On this basis, an average of 162,000 acre-feet of water per year, or 96.4 percent of the precipitation, was returned to the atmosphere by evapotranspiration from the upper hard-rock area. These figures are based on the assumption that the amount of

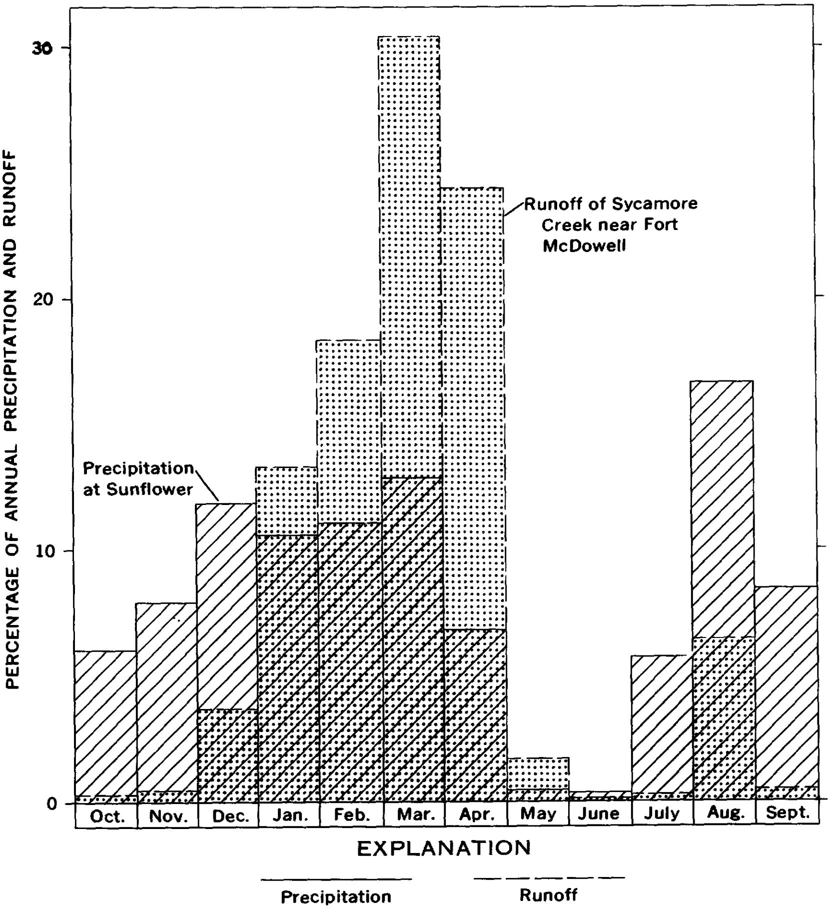

FIGURE 19.—Average monthly distribution of precipitation and runoff, 1961–65.

water in storage in the upper hard-rock area is about the same at the beginning of each water year.

Evapotranspiration losses along the stream channel are reflected by a reduction in streamflow between the Sunflower and Fort McDowell gages and are particularly evident in the spring and fall (fig. 23). In periods of no tributary inflow between the two gages, the reduction in flow is a measurable channel loss that is attributed to evapotranspiration. Evapotranspiration along the stream channel, however, probably is only a small part of the total evapotranspiration from the watershed. During this study, the annual measured water losses between the Sunflower and Fort McDowell gages ranged from 120 acre-feet in 1962 to 320 acre-feet in 1963.

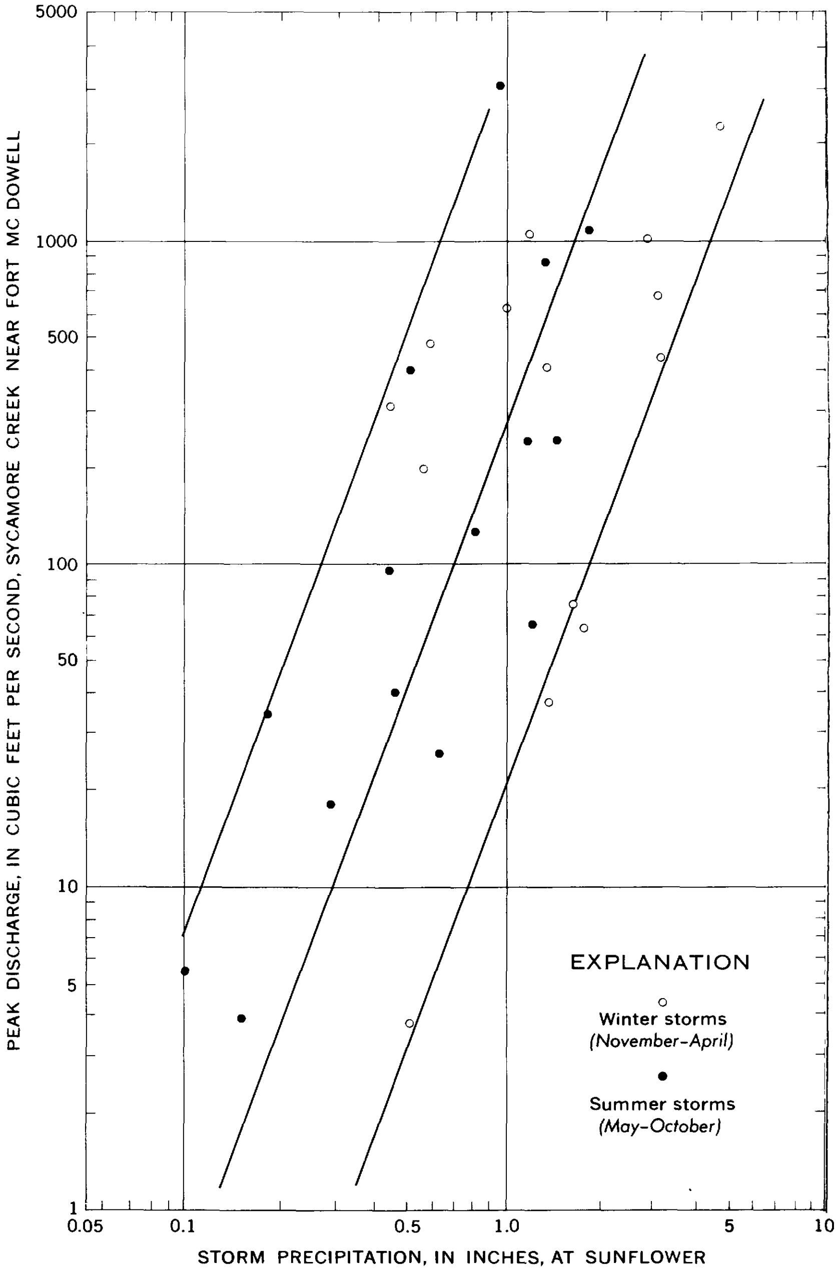

Figure 20.—Precipitation and peak discharge.

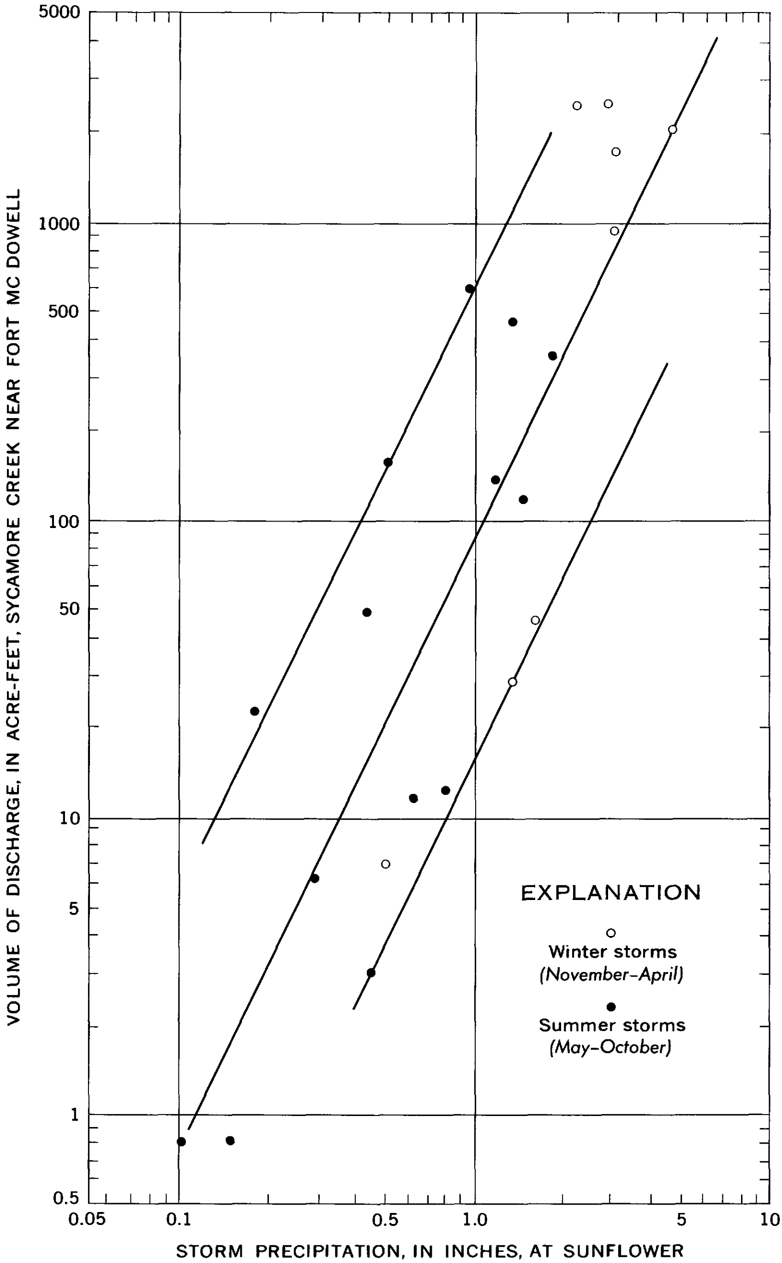

FIGURE 21.—Precipitation and volume of runoff.

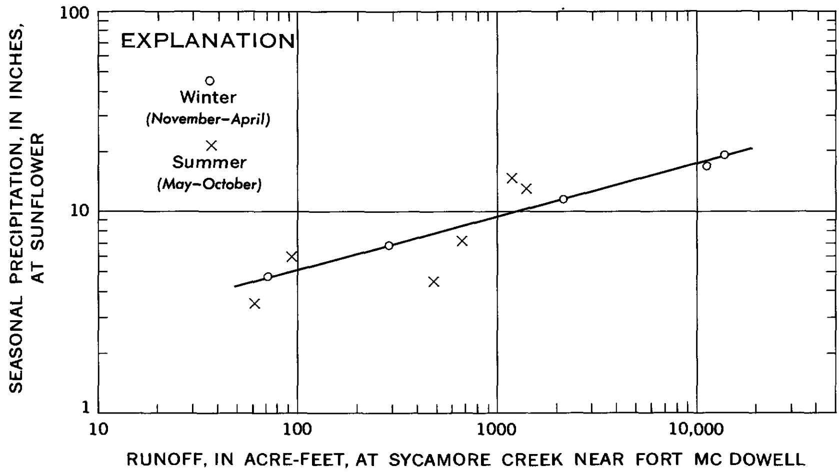

FIGURE 22.—Seasonal precipitation and runoff.

STREAMFLOW IN THE LOWER ALLUVIAL AREA

The major part of the streamflow that enters the lower alluvial area originates in the upper hard-rock area and is measured at the Fort McDowell gaging station. The measured annual streamflow that entered the lower alluvial area ranged from 167 acre-feet in 1961 to more than 14,320 acre-feet in 1965. Based on 5 years of record (1961–65), the average annual streamflow that entered the area was 6,110 acre-feet per water year. This is only a short-term average, and many additional years of record must be obtained before a reliable average can be established. The existing 5 years of record are instructive, however, in terms of the variation that can be expected in streamflow entering the area.

The broad flat channel in the lower alluvial area is underlain by highly permeable sand and gravel (fig. 24), which account for the disappearance of much of the streamflow before it reaches the Verde River (pl. 1). The amount of streamflow that reaches the river depends on the amount and duration of streamflow that issues from the upper hard-rock area and the antecedent moisture conditions in the alluvial channel. Streamflow from Sycamore Creek reaches the Verde River only when the flow that enters the lower alluvial area exceeds the infiltration capacity of the alluvial channel. Records show that a peak flow of about 200 cfs must occur in Sycamore Creek at the Fort McDowell gage before any streamflow from the creek reaches the river. Moreover, figure 25 shows that only 0 to 10 percent of the streamflow that enters the lower alluvial area subsequently is discharged to the Verde River as streamflow.

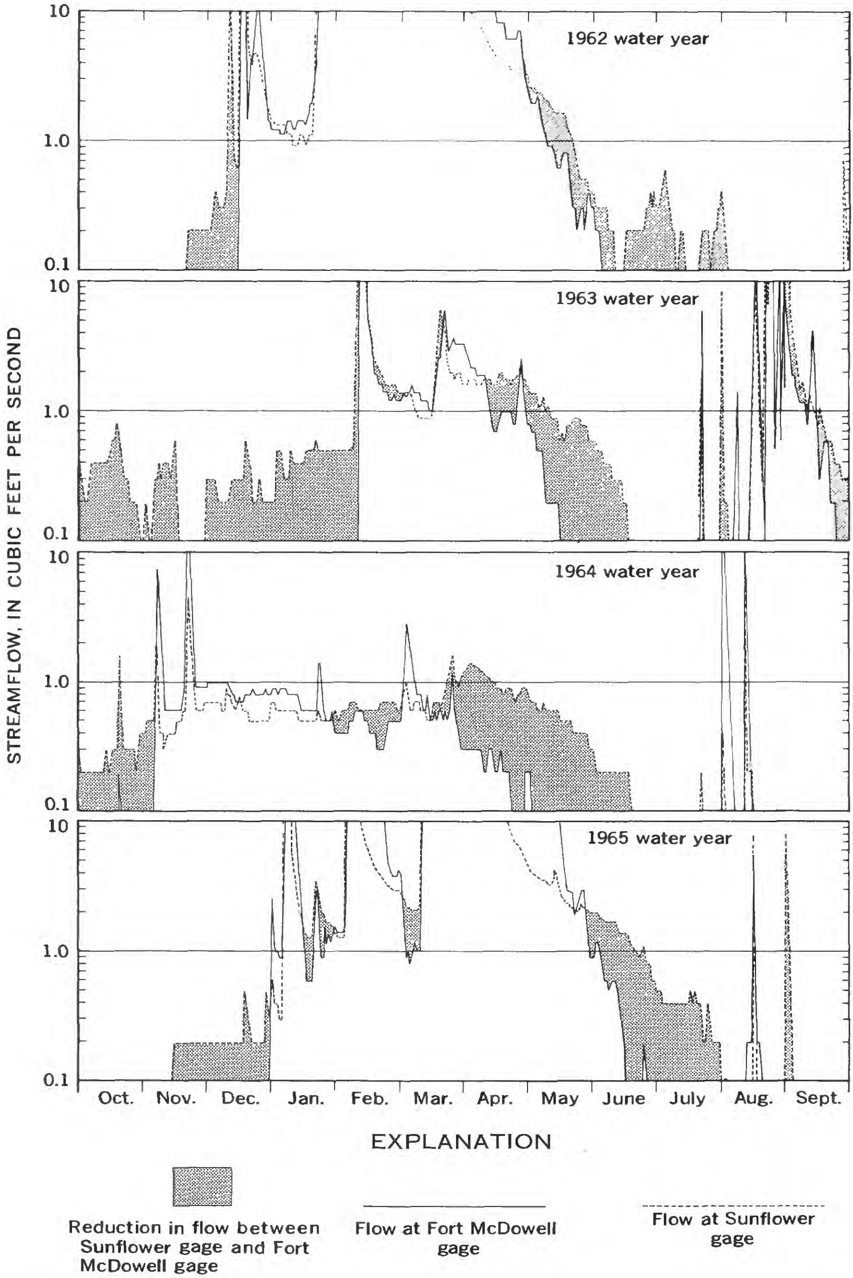

FIGURE 23.—Streamflow in Sycamore Creek near Sunflower and Fort McDowell; reduction in flow shown.

FIGURE 24.—The Sycamore Creek channel in the lower alluvial area.

Streamflow records from the Fort McDowell gaging station indicate relatively short durations for floodflows in excess of the infiltration capacity of the stream channel between the gaging station and the Verde River. Channel storage is not of great importance because of the short duration of the flows, a fact that also precludes any large percentage of the streamflow from being evaporated in the 9-mile reach between the Fort McDowell gaging station and the Verde River.

GROUND WATER IN THE LOWER ALLUVIAL AREA

The broad channel and flood plain of Sycamore Creek are underlain by highly permeable unconsolidated alluvium, which was deposited in channels cut into the consolidated alluvium. The high permeability and large storage capacity of the unconsolidated alluvium enable it to receive large amounts of water from seepage. A detailed examination of the ground-water reservoir in the lower alluvial area is the key to the disposition of a large part of the streamflow that issues from the upper hard-rock area.

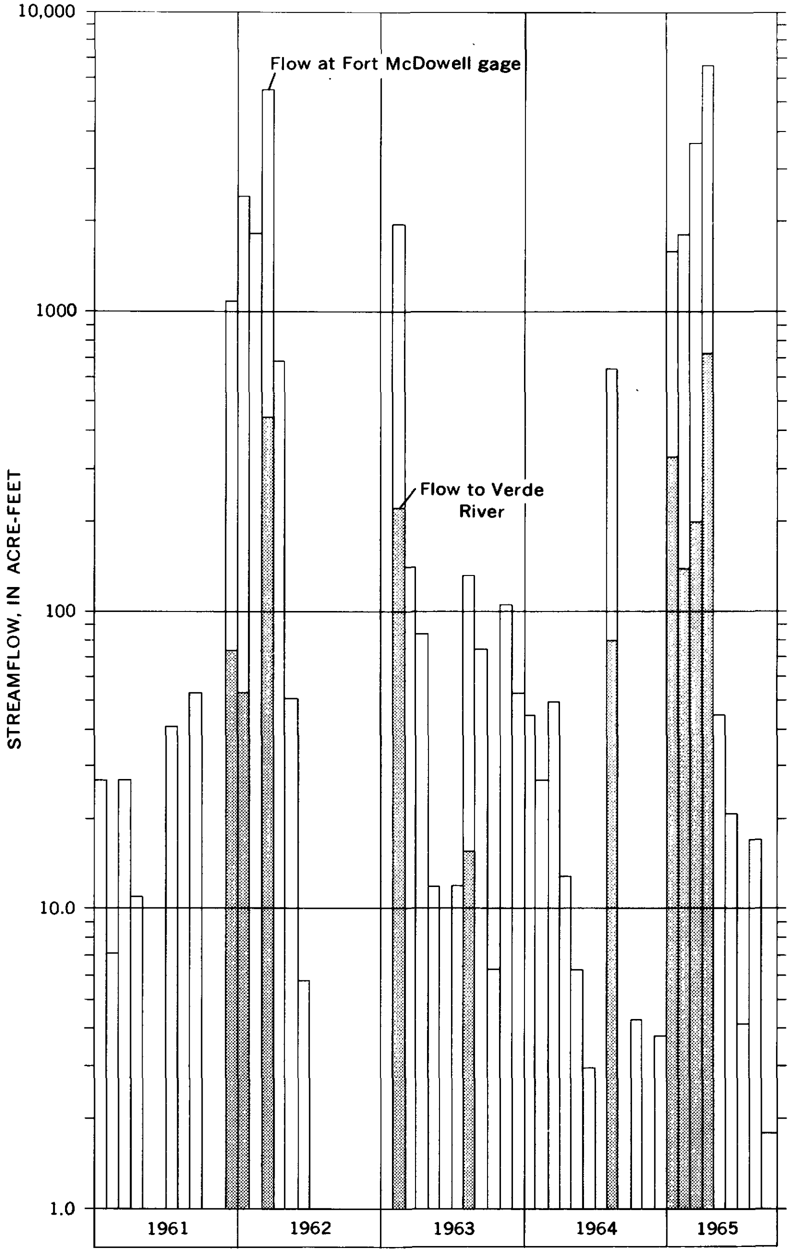

FIGURE 25.—Streamflow entering the lower alluvial area and streamflow discharged to the Verde River from Sycamore Creek.

OCCURRENCE OF GROUND WATER

Test holes drilled along lower Sycamore Creek indicate that ground water occurs under water-table conditions in the unconsolidated and consolidated alluvium. Although the ground water in the consolidated alluvium is hydraulically connected with that in the unconsolidated alluvium, the two aquifers are considered separately because they differ considerably in their ability to transmit water. No deep wells have been drilled in the consolidated alluvium near Sycamore Creek; therefore, little is known about the occurrence of ground water at depth in this unit. Water occurs in the sandstone and conglomerate beds in the consolidated alluvium under artesian (confined) conditions, as indicated by a deep flowing well drilled at Fort McDowell late in the 1800's (McDonald and Padgett, 1945, p. 27).

THE GROUND-WATER RESERVOIR

Ground water in the unconsolidated and consolidated alluvium is associated closely with the flow in Sycamore Creek. The ground-water reservoir system receives water by infiltration from floodflows in the creek; this water moves slowly through the system and is discharged into the Verde River. The unconsolidated alluvium is the main water-bearing unit in the ground-water reservoir. It is highly permeable and receives, transmits, and yields water readily. The relatively impermeable consolidated alluvium does not yield water readily.

The areal extent of the unconsolidated alluvium was determined by surface geologic mapping on infrared aerial photographs (pl. 1). The thickness and geometric configuration of the deposits were determined by a seismic-refraction survey and test drilling. In the lower Sycamore Creek area, 17 test holes were drilled, and three seismic-refraction profiles were run across the flood plain. These data were used to prepare the geologic sections in plate 1.

HYDRAULIC PROPERTIES OF THE GROUND-WATER RESERVOIR

To evaluate the hydraulic properties of the water-bearing materials of the ground-water reservoir, the coefficients of permeability, transmissibility, and storage were determined. These coefficients are quantitative parameters of the ability of the materials to transmit and yield water.

The coefficient of permeability is a measure of the material's capacity to transmit water. The term was defined by Meinzer (Stearns, 1928) as the rate of flow of water in gallons per day through a cross-sectional area of 1 square foot under a hydraulic gradient of 1 foot per foot at a temperature of 60° F.

The coefficient of transmissibility was defined by Theis (1935) as the rate of flow of water, in gallons per day, at the prevailing water temperature, through a vertical strip of the aquifer 1 foot wide and extending the full saturated thickness of the aquifer under a hydraulic gradient of 100 percent. It is equal to the product of the aquifer's permeability and its thickness.

The specific yield is the volume of water that water-bearing material will yield by gravity drainage and is expressed as a percentage of the total volume of the material drained. The coefficient of storage is about equal to the specific yield for aquifers under water-table conditions (Ferris, 1959).

AQUIFER TESTS

The coefficients of transmissibility and permeability of the unconsolidated and the consolidated alluvium were determined (table 5)

TABLE 5.—*Results of aquifer tests*

Well	Aquifer	Saturated thickness penetrated (feet)	Coefficient of transmissibility (gpd per ft)	Coefficient of permeability (gpd per sq ft)	Type of test
18	Unconsolidated alluvium.	51	264, 000	5, 200	Constant discharge.
20	Consolidated alluvium	25	60	2	Slug.
21	do	9	110	12	Slug.
21	do	9	100	11	Bail.

from aquifer tests made at wells 18, 20, and 21 (plate 1). Well 18 penetrated only the unconsolidated alluvium and was pumped at a constant rate; regular measurements of the drawdown caused by the pumping were made. The data from the test were used to compute the coefficients of transmissibility and permeability using the modified nonequilibrium formula described by Cooper and Jacob (1946, p. 526–534).

Aquifer tests were made by bailing and slug methods at wells 20 and 21 to determine the water-bearing characteristics of the unconsolidated and the consolidated alluvium. The coefficients of transmissibility and permeability of the consolidated and unconsolidated alluvium were calculated from the test data by using the methods described by Ferris and Knowles (1963, p. 299–304).

Well 20 was drilled to a depth of 150 feet, and blank casing was driven to 125 feet to shut out water from the unconsolidated alluvium, which is 105 feet thick at this site. A slug test was made leaving the bottom 25 feet of the well open to the consolidated alluvium to determine the coefficient of transmissibility of the 25-foot section. After the consolidated alluvium was tested, the casing was perforated from

30 to 125 feet below the land surface, and a second slug test was made to determine the coefficient of transmissibility of the unconsolidated and consolidated alluvium. The test indicated that the coefficient of transmissibility was more than 50,000 gpd (gallons per day) per foot, which is in excess of the upper limit recommended for use of the slug-test method; therefore, the results of this test did not give a true indication of the transmissibility of the two aquifers.

The consolidated alluvium was tested at well 21 by slug-test and bail-test methods, and the results were in close agreement (table 5). The results of these aquifer tests indicate that the consolidated alluvium is relatively impermeable compared to the highly permeable unconsolidated alluvium (table 5).

GROUND-WATER RECHARGE

INFILTRATION FROM STREAMFLOW

Hydrographs of observation wells along the 9-mile reach of Sycamore Creek between the Fort McDowell gaging station and the Verde River show a general rise in the water table in the spring in response to winter runoff from the hard-rock area and a second rise in response to late summer flows (fig. 26). These water-level rises indicate that a large part of the streamflow that disappears in the lower alluvial area rapidly infiltrates into the unconsolidated alluvium under the stream channel (fig. 18). The greatest water-level fluctuations occur in the upper part of the alluvial area. Only small water-level fluctuations occur in the lower part of the alluvial area (fig. 26). Because streamflow measurements indicate that most of the flow infiltrates into the alluvium before reaching the lower half of the area, the greatest amount of recharge to the ground-water reservoir occurs in the upper half of the area.

Water levels in the consolidated alluvium near Sycamore Creek fluctuate in response to the flow in the creek. Well 13 penetrated only the consolidated alluvium; it is about 300 feet from the channel and reflects recharge from Sycamore Creek.

Streamflow percolates into the unconsolidated alluvium and then moves laterally into the consolidated alluvium. The low permeability of the consolidated alluvium, however, prevents the transfer of large quantities of water into or out of the unit.

INFILTRATION FROM DIRECT PRECIPITATION

Direct precipitation on the lower Sycamore Creek watershed probably is not a significant source of recharge to the ground-water reservoir. The low permeability of the consolidated alluvium precludes penetration of direct precipitation to the water table. Because of the

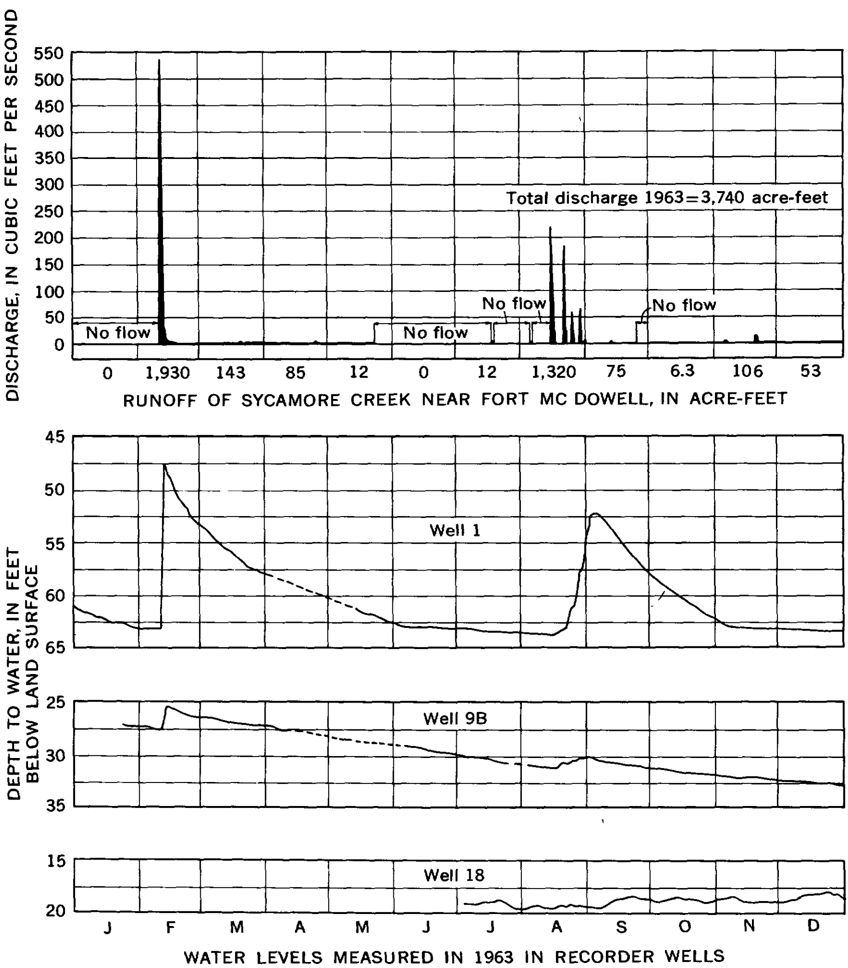

FIGURE. 26.—Streamflow and changes in water levels in wells for 1963.

small amount of rainfall in this area, the unconsolidated alluvium probably does not receive significant recharge from direct precipitation.

MOVEMENT OF GROUND WATER

Ground water moves downslope at right angles to lines of equal potential, or, simply stated, it flows at right angles to lines of equal water-table altitude (water-table contours). Ground water moves downgradient in the unconsolidated alluvium and is discharged into the Verde River at its confluence with Sycamore Creek (pl. 1).

After major floodflows, a rapid buildup of ground water occurs in the upper part of the area. After the rapid buildup, the water levels are lowered as the ground-water mound moves laterally to redistribute itself throughout the rest of the ground-water reservoir.

The rate of ground-water movement through the unconsolidated and consolidated alluvium was computed from the equation

$$V=\frac{PI}{7.48n} \tag{1}$$

where

V=rate of ground-water movement, in feet per day,
P=coefficient of permeability, in gallons per day per square foot,
I=hydraulic gradient, in feet per foot, and
n=porosity expressed as a decimal fraction.

Using a coefficient of permeability for the unconsolidated alluvium of 5,200 gpd per square foot, a hydraulic gradient of 0.008 foot per foot, and an estimated coefficient of porosity of 0.30 (30 percent), the rate of ground-water movement is calculated from equation (1) to be

$$V=\frac{(5{,}200)(0.008)}{(7.48)(0.30)}=18.5 \text{ feet per day,} \tag{2}$$

or about 6,750 feet per year.

Using a coefficient of permeability for the consolidated alluvium of 8.3 gpd per square foot (the average value determined from three aquifer tests), a hydraulic gradient of 0.008 foot per foot, and an estimated coefficient of porosity of 0.20 (20 percent), the rate of ground-water movement is calculated from equation (1) to be

$$V=\frac{(8.3)(0.008)}{(7.48)(0.20)}=0.04 \text{ foot per day,} \tag{3}$$

or about 15 feet per year.

A comparison of the rates of ground-water movement through these units indicates that under the same hydraulic gradient water would move through the unconsolidated alluvium about 450 times faster than through the consolidated alluvium. Because it transmits water rapidly and accepts infiltration from streamflow, the unconsolidated alluvium was the only unit considered in making the analysis of changes in ground-water storage.

GROUND-WATER STORAGE

In the ground-water reservoir, the volume of materials multiplied by their porosity is equal to the storage capacity (Meinzer, 1923, p. 19). The volume of materials extending below the water table multiplied by their porosity is equal to the volume of water stored in the ground-water reservoir. The volume of water than can be drained by gravity from saturated material is less than the total void space or porosity because some water is retained by molecular attraction. The volume of water yielded by gravity drainage from saturated water-bearing material is called the specific yield and is expressed as a percentage of the total volume of the material drained. The volume of water retained by the material against the pull of gravity is called the specific retention and is expressed as a percentage of the total volume of the material. The sum of specific yield and specific retention of a material is equal to its porosity (Ferris, 1959, p. 130).

Specific yield is also an index of the amount of water that can be stored in the material above the water table, provided that the moisture content is at field capacity. If the moisture content has been reduced below field capacity by evaporation or transpiration, the amount of water required to saturate a given volume of material will be greater than that indicated by the specific yield.

The average specific yield of the unconsolidated alluvium, which consists mainly of coarse sand and gravel, ranges from 25 to 30 percent. This estimate is based on laboratory determinations of the specific yield of a similar unconsolidated alluvium made by Cohen (1963, p. 19).

Changes in water levels in the ground-water reservoir can be equated to the net increase or decrease in storage for any given period. In a ground-water reservoir, the water table is not a level surface as it is in an open-surface reservoir. Therefore, changes in water levels in a single well represent only changes in ground-water storage near that well and do not indicate changes in the amount of water in storage in the entire reservoir. Water levels must be measured at frequent intervals in a sufficient number of wells to determine the areal extent in which water-level changes occur in the ground-water reservoir.

The weighted mean water level in the ground-water reservoir was calculated using the Thiessen polygon method (Thiessen, 1911, p. 1082). The water levels in 15 observation wells were multiplied by the areas of the corresponding polygons, and the sum of these products was divided by the total area within the assumed boundaries of the water-level fluctuations (fig. 27). The area of water-level fluctuations was assumed to correspond to the area of outcrop of the unconsolidated alluvium from which the materials underlying the tributary washes above the water table were excluded.

Annual changes in ground-water storage in the reservoir were computed by multiplying the net difference between the weighted mean water levels by the specific yield of the aquifer and by the total area of water-table fluctuations (Weeks, 1964, p. 22).

GROUND-WATER DISCHARGE

Water is discharged from the ground-water reservoir by subsurface discharge to the Verde River and by evapotranspiration. Small amounts of water are discharged from three wells that are equipped with windmills and supply water for livestock; however, the amount of water pumped from these wells does not constitute a significant draft on the ground-water reservoir.

GROUND-WATER DISCHARGE TO THE VERDE RIVER

Water levels in wells 18 and 19, at and near the confluence of Sycamore Creek and the Verde River, respectively, show a definite response to changes in stage of the Verde River. This response indicates a hydraulic interconnection between the ground-water reservoir and the river in this area.

The stage of the Verde River, which was nearly constant on October 6–7, dropped 0.80 foot between October 8 and 12 (fig. 28). On October 8 the water level in well 18 also began dropping at an increased rate

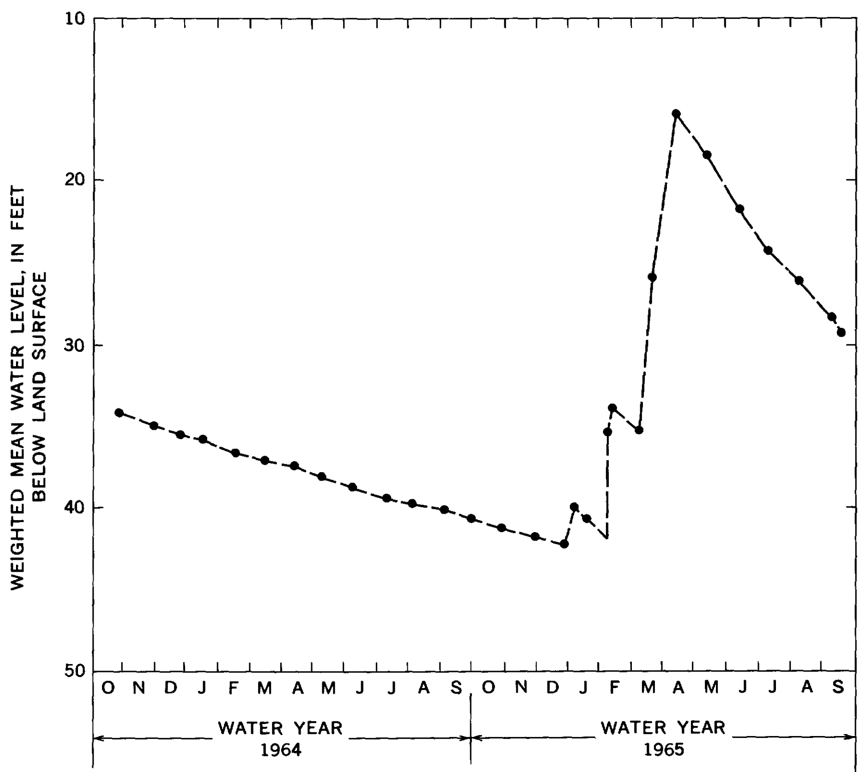

FIGURE 27.—Mean ground-water stage of lower Sycamore Creek for water years 1964–65.

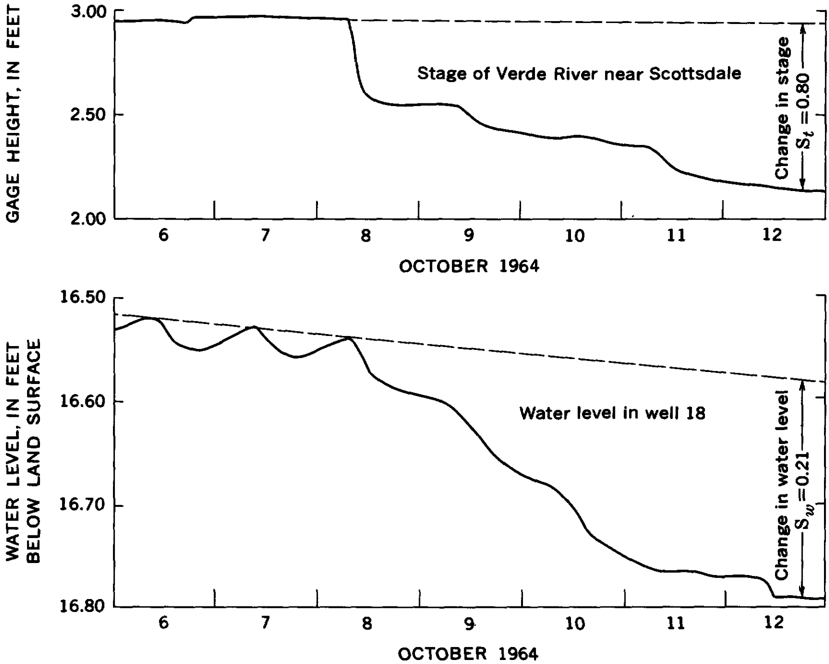

FIGURE 28.—Relation between changes in stage of the Verde River and changes in the water level in well 18.

in response to the drop in stage of the Verde River; it reached 16.79 feet below the land surface on October 12 and then remained constant. The water level in well 18 dropped 0.21 foot between October 8 and 12 in response to the lowering in stage of the Verde River of 0.80 foot in the same period (fig. 28). The water level in well 18 also showed diurnal fluctuations, which were superimposed on the gradual decline of the water table, in response to ground-water withdrawal by evapotranspiration on October 6–7.

Increases in streamflow measured in the Verde River below its confluence with Sycamore Creek indicate that ground water is being discharged to the Verde River in this area. During periods of constant regulated low flow, streamflow measurements were made above and below the confluence of Sycamore Creek and the Verde River. The measurements were made early in the spring, when the riparian vegetation was dormant. The consistent gains measured in this reach probably are indicative of the rate of ground-water discharge to the Verde River. These gains averaged 5.6 cfs or about 4,000 acre-feet per year (table 6).

TABLE 6.—*Measurements of streamflow in the Verde River*

Date	Flow of Verde River (cfs)		Change in flow (cfs)
	Above Sycamore Creek	Below Sycamore Creek	
3-7-63	51. 5	55. 9	+4. 4
3-19-63	46. 4	52. 6	+6. 2
3-9-64	47. 7	54. 9	+7. 2
4-13-64	93. 1	97. 5	+4. 4
Average change in flow			+5. 6

The amount of ground water discharged to the Verde River also was determined by computing the amount of underflow from Sycamore Creek by Darcy's equation

$$Q=TIW \qquad (4)$$

where

Q=discharge, in gallons per day,
T=coefficient of transmissibility, in gallons per day per foot,
I=hydraulic gradient, in feet per foot, and
W=average width of flow channel, in feet.

The coefficient of transmissibility was determined by an aquifer test at well 18, the average width of the flow channel was determined from the geologic map (pl. 1), and the hydraulic gradient was calculated from differences in the altitude of the water levels in wells along Sycamore Creek near its confluence with the Verde River. Using equation (4), the subsurface discharge to the Verde River is

$$Q=(264{,}000)(24.3/3{,}000)(1{,}700)$$
$$=3.64\times10^6 \text{ gpd}$$
$$=5.6 \text{ cfs}^{1} \text{ or about } 4{,}000 \text{ acre-feet per year.}$$

The computed subsurface discharge to the Verde River by this method is the same as the average discharge based on streamflow measurements.

Only small seasonal changes in underflow occur, as shown by the minor water-level fluctuations in wells along lower Sycamore Creek. Therefore, minor variations in the hydraulic gradient and cross-sectional area would not greatly affect the rate of ground-water flow.

GROUND-WATER DISCHARGE BY EVAPOTRANSPIRATION

Most of the ground-water discharge by evapotranspiration occurs in the lower reaches of Sycamore Creek where the water table is near

[1] One cubic foot per second=0.646 million gallons per day.

the land surface. The term "evapotranspiration" is defined as the combined discharge of water to the atmosphere by evaporation and transpiration. Ground water is discharged by transpiration through the riparian vegetation, which grows in moderate to high density along the channel of lower Sycamore Creek and its flood plain (fig. 29). Native vegetation is sparse in the rest of the area, because of the greater depth to water.

The phreatophytes in the area of shallow ground water consist mainly of mesquite and smaller amounts of cottonwood and other trees. "A phreatophyte is a plant that habitually obtains its water supply from the zone of saturation, either directly or through the capillary fringe" (Meinzer, 1923, p. 55). Phreatophytes cover about 1,400 acres along the channel of lower Sycamore Creek and its flood plain and are most dense in the lower half of the area, where the depth to water usually is less than 20 feet below the land surface. In the upper half of the area, above well 9B, vegetation is less dense, and the depth to water usually is more than 20 feet below the land surface; also, the water levels in the upper half of the area are subject to large fluctuations.

FIGURE 29.—Vegetation along the channel of lower Sycamore Creek and its flood plain.

Effect of evapotranspiration on ground-water levels

In Escalante Valley, Utah, White (1932, p. 46) showed that diurnal water-level fluctuations are caused by the discharge of ground water through evapotranspiration. These fluctuations first occur in the spring and disappear in the winter, when the riparian vegetation is relatively dormant. Diurnal water-level fluctuations due to discharge of ground water through evapotranspiration were measured in wells along the lower reaches of Sycamore Creek (fig. 30).

Effect of depth to water on evapotranspiration

Discharge of ground water through evaporation is very small if the water table is more than a few feet below the land surface. Todd (1959, p. 155) summarized the results of measurements made by White (1932) of ground-water evaporation in tanks filled with different soils. The evaporation is expressed as a percentage of pan evaporation (fig. 31). These data and water-level measurements indicate that evaporation from ground water is probably negligible in the lower

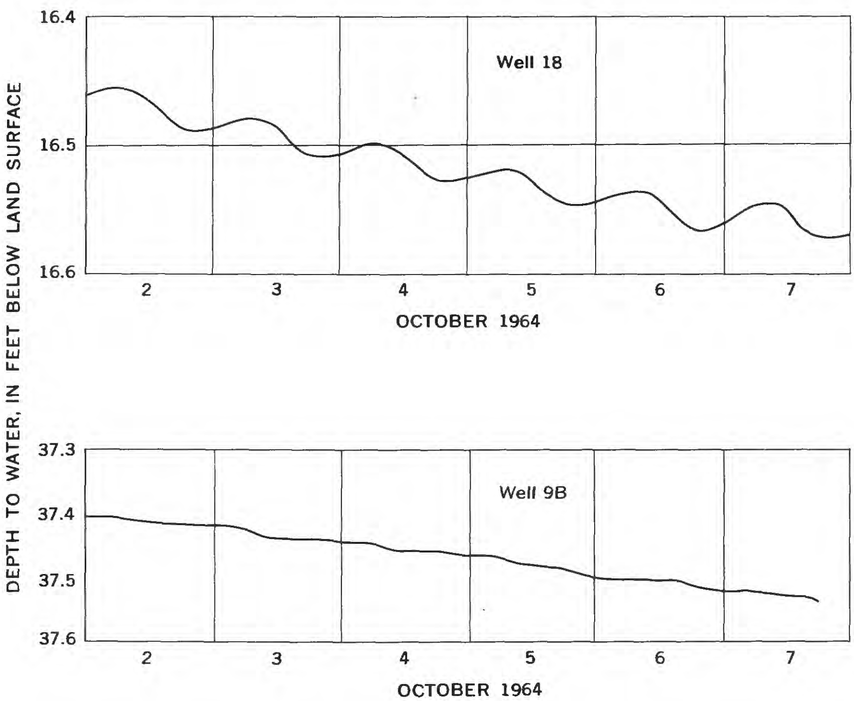

FIGURE 30.—Water-table fluctuations due to ground-water discharge through evapotranspiration.

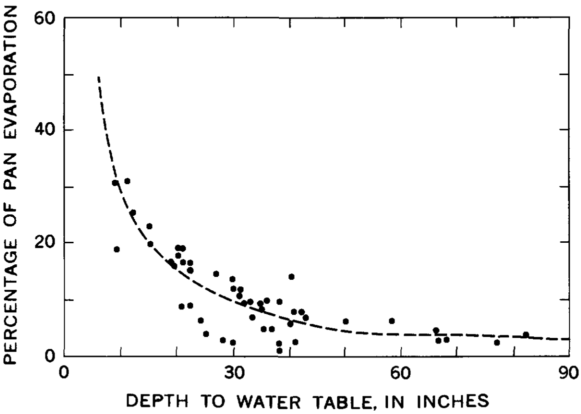

FIGURE 31.—Ground-water evaporation, expressed as a percentage of pan evaporation and determined as a function of the depth to the water table. After Todd (1959, p. 156) and White (1932, p. 80).

Sycamore Creek area when the water levels are more than a few feet below the land surface.

The depth to water is a controlling factor in the occurrence of phreatophytes and their water use. Mesquite has a deep root system and is capable of obtaining water from soil moisture during periods when the water table is at considerable depth. The mesquite in the upper end of lower Sycamore Creek continues to grow during dry periods, when the water table is more than 90 feet below the land surface, and the plants probably exist primarily on soil moisture. When the water table is near the land surface, as in the spring of 1965, these plants probably obtain their water supply directly from ground water.

GROUND-WATER BUDGET FOR LOWER SYCAMORE CREEK

A water-budget analysis of the ground-water reservoir was made to determine the disposition of streamflow entering the area. A ground-water budget is a quantitative statement of the relation between the gains and losses from the ground-water reservoir and is expressed as

$$I = O \pm \Delta S \text{ (general form)} \qquad (5)$$

where

I=inflow,
O=outflow, and
ΔS=change in storage.

Equation (5) can be rewritten as

$$I_{sw} + I_{gw} = O_{sw} + O_{gw} \pm \Delta S_{sm} + \Delta S_{gw} + ET \qquad (6)$$

where

I_{sw}=inflow from streamflow,
I_{gw}=inflow from ground water,
O_{sw}=outflow of streamflow,
O_{gw}=outflow of ground water,
ΔS_{sm}=change in soil moisture,
ΔS_{gw}=change in ground-water storage, and
ET=evapotranspiration.

When equation (6) is rearranged, it becomes

$$ET=I_{sw}+I_{gw}-O_{sw}-O_{gw}\pm\Delta S_{sw}\pm\Delta S_{gw} \quad (7)$$

The quantity of water lost owing to evapotranspiration can be determined by balancing equation (7) for a given period. This method gives only an approximate value for evapotranspiration, as all the errors in the measurement of the different parts of the water budget are included in the value for evapotranspiration.

Because the McDowell gaging station is equipped with a cutoff wall that brings the underflow to the surface, the term I_{gw} can be dropped from the equation. Thus, equation (7) can be written as

$$ET=I_{sw}-O_{sw}-O_{gw}\pm\Delta S_{gw}\pm\Delta S_{sm} \quad (8)$$

The water-budget analysis was first attempted on an annual basis by using the data for water years 1964 and 1965. The analysis, however, yielded divergent estimates of water losses because the periods examined represent extreme conditions and were of short duration. Water year 1964 was a dry period when streamflow into the area was about 16 percent of the 5-year average, and water year 1965 was a wet period when streamflow into the area was about 234 percent of the 5-year average.

The cumulative errors in the estimates of all the components of the water budget are included in the estimate of water losses, which are computed as the residual in the water-budget equation. To minimize these errors, a relatively long period of record is required before accurate estimates of water losses can be made from a water-budget analysis. In an attempt to minimize the measurement errors, the entire 5-year period of record was used in the water-budget analysis to estimate the average annual water loss from the lower Sycamore Creek area (table 7).

The net changes in ground-water storage and soil moisture were assumed to be equal to zero in the analysis. This assumption is valid for a long period, but some error probably is introduced in the analysis when a period as short as 5 years is used.

TABLE 7.—*Average annual water-budget analysis for the lower Sycamore Creek area, water years 1961–65*

	Acre-feet
Inflow from Sycamore Creek near Fort McDowell gaging station	6,110
Outflow:	
Streamflow discharged to Verde River from Sycamore Creek	500
Ground-water outflow	4,100
Net change in storage:	
Ground water	0
Soil moisture	0
Evapotranspiration loss	1,510

SUMMARY AND CONCLUSIONS

The water resources of the Sycamore Creek watershed are controlled by precipitation, streamflow, subsurface flow, and water losses and the interrelation of these factors. Precipitation is the initial source of water; the amount, distribution, and type of precipitation vary considerably in the watershed. The amount increases with altitude, and the upper part of the watershed receives about twice as much as the lower part. Sunflower, near the center of the watershed, receives an average of 20 inches of precipitation a year, an amount which is considered a reasonable index of the average precipitation on the watershed. About 60 percent of the precipitation falls in the winter from large regional storms that are generally of low intensity and moderate duration. About 40 percent of the precipitation falls in the summer from convective storms, that are characterized by high intensity, short duration, and small areal extent.

Streamflow in the upper hard-rock area is characterized by rapid surface runoff and has no significant ground-water component. Discharge measurements indicate that floodflows increase in the downstream direction to the point where the stream leaves the upper hard-rock area and then diminish in the downstream direction as the water seeps rapidly into the alluvium. The amount of streamflow leaving the upper hard-rock area ranged from less than 200 to 14,320 acre-feet per water year, and the 5-year average was 6,110 acre-feet. A comparison of the amount of streamflow that issues from the upper hard-rock area and the amount of water that falls on the area shows that only about 3.6 percent of the precipitation leaves the area as streamflow. The remaining 96.4 percent of the water that falls on the upper hard-rock area is lost to evapotranspiration. During periods of no tributary inflow between the Sunflower and Fort McDowell gages, the reductions in flow are an indication of the channel losses that can be attributed to evapotranspiration; the measured channel losses, which are relatively small, range from 120 to 320 acre-feet of water per year during the 5 years of record.

Streamflow measurements in the lower alluvial area indicate a marked reduction in flow between the Fort McDowell gage and the Verde River. One set of measurements showed that a flow of 200 cfs at the Fort McDowell gage decreased to 0.3 cfs at the Verde River. A comparison of streamflow at the Fort McDowell gage and water-level changes in wells along the channel of Sycamore Creek shows a sharp rise in water levels in response to flow in Sycamore Creek and thus indicates that a large percentage of the streamflow is lost to seepage that rapidly moves down to the water table and recharges the ground-water reservoir.

Aquifer tests conducted to determine the hydraulic parameters of the aquifer provided a basis for the computation of the ground-water discharge from the Sycamore Creek ground-water system to the Verde River. The amount of underflow computed by ground-water flow equations was in close agreement with the measured increases in streamflow in the Verde River—about 4,000 acre-feet per year.

A water-budget analysis for the 5 years of record indicates an average annual water loss from the lower part of Sycamore Creek of about 1,500 acre-feet. Although this figure probably contains some error, as the net change in storage was considered to be zero in the 5-year period, an average annual water loss due to evapotranspiration of about 1.1 acre-feet per acre seems to be a reasonable estimate.

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