WATER RESOURCES OF LOWER SYCAMORE CREEK,
MARICOPA COUNTY, ARIZONA

by

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STATEMENT BY AUTHOR

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TABLE OF CONTENTS

	Page
LIST OF ILLUSTRATIONS	vii
LIST OF TABLES	ix
ABSTRACT	x
INTRODUCTION	1
Purpose and Scope	1
Location, Topography, and Drainage	3
Climate	4
Previous Investigations	6
Methods of Investigation	7
GEOLOGIC SETTING	8
Upper Hard-Rock Area	8
Lower Alluvial Area	10
HYDROLOGY	12
Streamflow in the Lower Alluvial Area	13
Ground Water in the Lower Alluvial Area	17
Occurrence of Ground Water	17
The Ground-Water Reservoir	18
Hydraulic Properties of the Ground-	
Water Reservoir	19
Aquifer Tests	20
Ground-Water Recharge	23
Infiltration from Streamflow	23
Infiltration from Direct Precipitation	24
Movement of Ground Water	24
Ground-Water Storage	26

TABLE OF CONTENTS—Continued

HYDROLOGY—Continued	Page
Ground Water in the Lower Alluvial Area—Continued	
Ground-Water Discharge	30
Ground-Water Discharge to the Verde	
River	30
Ground-Water Discharge by	
Evapotranspiration	35
Ground-Water Budget of Lower Sycamore Creek	40
SUMMARY AND CONCLUSIONS	48
LITERATURE CITED	53

LIST OF ILLUSTRATIONS

Figure	Page
1. Drainage network and instrumentation	In pocket
2. Hydrogeologic map and sections of the lower alluvial area	In pocket
3. Flow diagram of the hydrologic system in the lower Sycamore Creek watershed	In pocket
4. Distribution of streamflow	In pocket
5. Streamflow entering the lower alluvial area and streamflow discharged to the Verde River from Sycamore Creek	In pocket
6. Streamflow and changes in water levels in wells for 1963	In pocket
7. Sycamore Creek watershed	2
8. Precipitation, pan evaporation, and temperature at Stewart Mountain Reservoir	5
9. Stream channel emerging from the upper hard-rock area into the lower alluvial area of the Sycamore Creek watershed	9
10. Sycamore Creek channel in the lower alluvial area	16
11. Mean ground-water stage, lower Sycamore Creek, water years 1964-65	29
12. Relation between changes in stage of the Verde River and changes in the water level in well 18	31

LIST OF ILLUSTRATIONS—Continued

Figure	Page
13. Vegetation along the channel of lower Sycamore Creek and its flood plain	36
14. Water-table fluctuations due to ground-water discharge through evapotranspiration	38
15. Ground-water evaporation, expressed as a percentage of pan evaporation, as a function of the depth to the water table	39

LIST OF TABLES

Table	Page
1. Results of aquifer tests	21
2. Measurements of streamflow in the Verde River . . .	33
3. Water-budget analysis for the lower Sycamore Creek area, water year 1964	43
4. Water-budget analysis for the lower Sycamore Creek area, water year 1965	44
5. Average annual water-budget analysis for the lower Sycamore Creek area, water years 1961-65 . . .	47

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ABSTRACT

Like many small watersheds in the Southwest, streamflow originating in the upper mountainous part of the Sycamore Creek watershed disappears quickly into the alluvial deposits adjacent to the mountains. Streamflow from the upper 165 square miles of the watershed ranged from 167 to 14,320 acre-feet per water year and averaged 6,110 acre-feet per water year for the existing 5 years of record.

Streamflow measurements indicate that most of the water that enters the lower portion of the watershed does not reach the Verde River as surface flow. On an annual basis from 0 to 10 percent of the streamflow entering the area is subsequently discharged to the Verde River as streamflow.

Most of the streamflow that disappears in the lower area rapidly percolates down to the water table and recharges the ground-water reservoir. Most of this water is released as ground-water discharge at a relatively constant rate of about 4,000 acre-feet per year to the Verde River.

Water losses to evapotranspiration by phreatophytic riparian vegetation in the lower Sycamore Creek area are controlled by the depth to the water table. Annual water losses ranged from as little as about 0.1 acre-feet per acre during a very dry year to as much as about 3.1 acre-feet per acre during a very wet year based on a water-budget analysis of these periods. The average annual water loss from the lower area was about 1.1 acre-feet per acre based on a water-budget analysis of the entire 5-year period of record.

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. 7). 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 author was responsible for evaluating the hydrology of the lower part of the watershed, which shall be referred to as the lower alluvial area in this thesis. The principal objectives of the investigation were (1) to define and determine the hydrologic characteristics of the system; (2) to determine the disposition of streamflow discharged from the upper mountainous portion of the watershed;

Figure 7.--Sycamore Creek watershed.

and (3) to determine the amount, location, and extent of water losses from the system in the lower alluvial area.

The findings of this investigation which resulted directly from work done and reported upon by the author shall be presented.

Location, Topography, and Drainage

Sycamore Creek is an intermittent stream that originates in the Mazatzal Mountains in eastern Maricopa County and drains south-westward to the Verde River. It 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 (fig. 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 low relief and gentle slopes and is composed primarily of consolidated alluvium.

In the upper hard-rock area of the watershed the stream course is cut on bedrock, shallow alluvium overlying bedrock, or on

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 in 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

Climatological data from the U. S. Weather Bureau station at Stewart Mountain Reservoir (fig. 1) is the most representative data available for the lower alluvial area. There are generally two main periods of rainfall in the area. One period is during the winter, in December, January, and February, characterized by large regional rains of low to moderate intensity and of several days duration while the other period occurs during the summer and is characterized by high-intensity thunderstorms of relatively short durations (fig. 8).

The area has mild winter temperatures with the minimums, seldom less than 32°F, occurring in the month of January followed by hot and dry summers during which the maximum temperatures often exceed 100°F in the months of June, July, and August (U. S. Weather Bureau, issued annually).

Figure 8.—Precipitation, pan evaporation, and temperature at Stewart Mountain Reservoir.

Closely related to the generally low rainfall and high summer temperatures is the high evaporation rate observed in the area. The pan evaporation, in inches as shown on figure 8, was 117.16 in 1962, 106.55 in 1963, 106.30 in 1964, and 105.48 in 1965.

Previous Investigations

No comprehensive report on the hydrology of the Sycamore Creek watershed has been published to date (1967). The geology of the extreme northern part of the watershed was mapped in detail by Wilson (1939). The geology of the lower part of the watershed was mapped by McDonald and Padgett (1945). The geology of the entire watershed area was mapped subsequently by Wilson, Moore, and Peirce at a scale of 1:375,000 in 1957.

A published report resulting from this investigation by the U.S. Geological Survey presents a discussion of the water-salvage possibilities on Sycamore Creek by Thomsen and Dennis (1963). An unpublished progress report by Thomsen and Schumann (1964) presents the preliminary results of the study and includes a qualitative evaluation of the hydrologic system.

Methods of Investigation

Fieldwork upon which this thesis is based was begun in 1961 and was continued through the fall of 1965. The early work consisted of exploratory test drilling and water-level data collection supervised by Mr. P. Eldon Dennis, then district chief of the Ground Water Branch of the U.S. Geological Survey in Arizona. All streamflow data and subsequent water-level data were collected by personnel of the Phoenix subdistrict office of the Water Resources Division of the U.S. Geological Survey. The author did intensive fieldwork during late 1963 and in 1964.

During the investigation the author supervised additional test drilling, conducted all aquifer testing done during the study, located and participated in the running of seismic-refraction profiles, and supervised and participated in the collection of hydrologic data gathered in the lower part of the area during the latter part of the investigation. The geology of the approximately 30-square-mile lower watershed was mapped by the author upon low-level infrared aerial photographs and then transferred to the base map prepared by the Topographic Branch of the U.S. Geological Survey.

GEOLOGIC SETTING

Sycamore Creek is an intermittent stream that originates in the Mazatzal Mountains and drains southwestward into the Verde River (figs. 1 and 9). On the basis of physiographic, geologic, and hydrologic distinctions, the Sycamore Creek watershed is divided into the upper hard-rock area and the lower alluvial area (fig. 1).

Upper Hard-Rock Area

The upper hard-rock area is made up of rugged mountainous terrain that has high 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, probably of late Tertiary age, are exposed in the central part of the upper hard-rock area. Extensive basaltic lava flows of Quaternary or Tertiary age crop out along the western and central part of the area. Small discontinuous deposits of unconsolidated alluvium are found along the channel of Sycamore Creek in this area.

FIGURE 9

STREAM CHANNEL EMERGING FROM THE
UPPER HARD-ROCK AREA INTO THE LOWER
ALLUVIAL AREA OF THE SYCAMORE CREEK WATERSHED

Lower Alluvial Area

In sharp contrast to the upper hard-rock area, the lower alluvial area has low 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 that consist of sandstone, siltstone, and conglomerate, all of which probably are 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 alluvium of Quaternary age which consists of sand, gravel, silt, and clay (fig. 2). The unconsolidated alluvium was deposited in channels cut into the consolidated alluvium and the crystalline rocks in the north part of the lower alluvial area (fig. 2).

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 from seepage in 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 the interrelation of these factors. 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 be evaporated soon after contact with the land surface, move across the land as surface runoff, or penetrate into 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.

As water 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 (fig. 3). Thus, the initial step in this investigation was the measurement of the component parts of the hydrologic system.

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. This station is located 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 (figs. 1 and 3).

The measured annual streamflow that entered the lower alluvial area ranged from 167 acre-feet in 1961 to 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.

During periods of relatively steady flow, streamflow measurements at selected points along Sycamore Creek indicated that, with the exception of large floodflows, nearly all streamflow disappeared from the land surface before the stream reached the Verde River (fig. 4). It was further determined that the major reduction in streamflow occurred after the stream left the hard-rock portion of the watershed and flowed over alluvial sediments in the lower 9-mile reach between the McDowell gaging station and the Verde River (fig. 4).

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.

The broad flat channel in the lower alluvial area is underlain by highly permeable sand and gravel (fig. 10), which account for the disappearance of much of the streamflow before it reaches the Verde River (fig. 4). The amount of streamflow that reaches the Verde 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 flow of about 200 cfs (cubic feet per second) must occur in Sycamore Creek at the Fort McDowell gage before any streamflow from the creek reaches the river. Figure 5 shows that from 0 to about 10 percent of the streamflow that enters the lower alluvial area subsequently is discharged to the Verde River as streamflow. Thus, most of the streamflow that enters the lower alluvial area does not reach the Verde River as surface flow.

Streamflow records from the Fort McDowell gaging station indicate relatively short durations for floodflows in excess of the

FIGURE 10

SYCAMORE CREEK CHANNEL
IN THE LOWER ALLUVIAL AREA

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, which also precludes any large percentage of the streamflow from being lost to evaporation 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.

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. Because of its high permeability, the unconsolidated alluvium receives, transmits, and yields water readily. The consolidated alluvium, although it contains ground water, does not yield it readily because of its low permeability.

The areal extent of the unconsolidated alluvium was determined by surface geologic mapping on infrared aerial photographs (fig. 2). 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 figure 2.

Hydraulic Properties of the Ground-Water Reservoir

In order 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, at the prevailing water temperature, in gallons per day, 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.

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 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 from aquifer tests made at wells 18, 20, and 21 (fig. 2). 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 non-equilibrium 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 (table 1). The coefficients

TABLE 1
RESULTS OF AQUIFER TESTS

Well number	Aquifer	Saturated thickness penetrated (feet)	Coefficient of transmissibility (gallons per day per foot)	Coefficient of permeability (gallons per day per square foot)	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

of transmissibility and permeability of the consolidated and unconsolidated alluvium were calculated from the test data 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 of the tests were in close agreement (table 1). The results of these aquifer tests indicate that the consolidated alluvium is relatively impermeable compared to the highly permeable unconsolidated alluvium (table 1).

Ground-Water Recharge

Infiltration from Streamflow

Hydrographs of observation wells spaced 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 or series of rises in response to late summer flows (fig. 6). Water levels rise in wells adjacent to the stream channel in response to major flow events, which were measured at the Fort McDowell gaging station (fig. 6). These water-level rises indicate that a large part of the streamflow that disappears in the lower alluvial area rapidly percolates into the unconsolidated alluvium under the stream channel (fig. 2). The greatest water-level fluctuations are in the wells in the upper part of the alluvial area. Relatively small water-level fluctuations occur in wells in the lower part of the alluvial area (fig. 6). Streamflow measurements indicate that most of the flow percolates into the alluvium before reaching the lower half of the area, which indicates that 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 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 (fig. 9).

After major floodflows, a rapid buildup of ground water occurs in the upper part of the area. After the rapid buildup, water levels in the upper part of the area are lowered as the ground-water mound moves laterally and redistributes 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

$$V = \frac{PI}{7.48 n} \quad (1)$$

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

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

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

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

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 percolation 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 that

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 35 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. 11). 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

Figure 11.--Mean ground-water stage, lower Sycamore Creek, water years 1964-65.

mean water levels by the specific yield of the aquifer (estimated to be 0.30) 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 8-12 (fig. 12). The water level in well 18 showed diurnal fluctuations in response to ground-water withdrawal by evapotranspiration on October 6-7,

Figure 12.--Relation between changes in stage of the Verde River and changes in the water level in well 18.

which were superimposed on a gradual decline of the water table. On October 8 the water level in well 18 began dropping at an increased rate in response to a drop in stage of the Verde River, and it reached 16.79 feet below the land surface on October 12, where it remained constant. The water level in well 18 dropped 0.21 foot between October 8-12 in response to a lowering in stage of the Verde River of 0.80 foot in the same period (fig. 12).

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 2).

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

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

TABLE 2
MEASUREMENTS OF STREAMFLOW IN THE VERDE RIVER

Date	FLOW OF VERDE RIVER (cfs)		Change in flow (cfs)
	Above Sycamore Creek	Below Sycamore Creek	
1963			
March 7	51.5	55.9	+4.4
March 19	46.4	52.6	+6.2
1964			
March 9	47.7	54.9	+7.2
April 13	93.1	97.5	+4.4
Average			+5.6

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 (fig. 2), 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

$$\begin{aligned} Q &= (264,000) (24.3/3,000) (1,700) \\ &= 3.64 \times 10^6 \text{ gpd} \\ &= 5.6 \text{ cfs or about 4,000 acre-feet per year.} \end{aligned}$$

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 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 occurs in moderate to high density along the channel of lower Sycamore Creek and its flood plain (fig. 13). 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,

FIGURE 13

VEGETATION ALONG THE CHANNEL OF
LOWER SYCAMORE CREEK AND ITS FLOOD PLAIN

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.

Effect of Evapotranspiration on Ground-Water Levels. White (1932, p. 46)—using wells equipped with automatic water-level recorders in Escalante Valley, Utah—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 evaporation, were measured in wells along the lower reaches of Sycamore Creek (fig. 14).

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. 15). These data and water-level measurements indicate that evaporation from ground water is probably negligible in the lower Sycamore Creek area when the water levels are more than a few feet below the land surface.

Figure 14.—Water—table fluctuations due to ground—water discharge through evapotranspiration.

After Todd (1959, p. 156) and
White (1932, p. 80)

Figure 15.—Ground-water evaporation, expressed as a percentage of pan evaporation, as a function of the depth to the water table.

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 of Lower Sycamore Creek

Streamflow entering the area becomes soil moisture and (or) ground-water recharge, is lost to evapotranspiration, or is discharged to the Verde River as streamflow or underflow. Surface storage of water is very small and discharge from wells for livestock use is not significant in terms of the total quantities of water in the system. Thus, the determination of the disposition of streamflow entering the lower area is directly related to hydrologic budget of the aquifer or ground-water reservoir and can be approached by using the ground-water-budget analysis of this unit. A ground-water

budget is a quantitative statement of the relationship between gains and losses from ground-water reservoir and is expressed as:

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

where

I = inflow;

O = outflow; and

ΔS = change in storage.

Equation (5) can be rewritten as:

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

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 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 quantity of water lost to evapotranspiration can be determined by balancing equation (8) for any given period.

Soil moisture, one of the factors in this equation, was not measured during this study; therefore daily, weekly, and monthly losses to evapotranspiration cannot be determined from the existing information. However, the soil-moisture level is probably about the same at the end of each water year and therefore evapotranspiration can be appraised on an annual basis if the change in soil moisture is considered a part of the evapotranspiration loss.

The water-budget analysis was first attempted using water years 1964 and 1965 (tables 3 and 4). The water year 1964 represents a rather dry period when the net streamflow into the lower area was only 880 acre-feet or about 16 percent of the 5-year

TABLE 3
WATER-BUDGET ANALYSIS FOR THE
LOWER SYCAMORE CREEK AREA,
WATER YEAR 1964

	<u>Acre-feet</u>
INFLOW	
Sycamore Creek near Fort McDowell gaging station	964
OUTFLOW	
Streamflow discharge to Verde River from Sycamore Creek	84
Ground-water outflow	4,030
NET CHANGE IN STORAGE	
Ground water	-3,330
Soil-moisture level	0
WATER LOSS	
Evapotranspiration	180
	(or about 0.13 acre-feet per acre)

TABLE 4
WATER-BUDGET ANALYSIS FOR THE
LOWER SYCAMORE CREEK AREA,
WATER YEAR 1965

	<u>Acre-feet</u>
INFLOW	
Sycamore Creek near Fort McDowell gaging station	14, 320
OUTFLOW	
Streamflow discharge to Verde River from Sycamore Creek	1, 400
Ground-water outflow	4, 030
NET CHANGE IN STORAGE	
Ground water	+4, 540
Soil-moisture level	0
WATER LOSS	
Evapotranspiration	4, 350 (or about 3.1 acre-feet per acre)

average. This was reflected by a net decrease in ground-water storage of some 3,330 acre-feet. The average depth to the water table was initially 34.3 feet below the land surface and increased to 40.5 feet by the end of the period. The relatively great depth to water table over much of the area during this period apparently resulted in only a small measurable loss of ground water by transpiration.

Conditions during the 1965 water year were very different; the net streamflow into the area was 12,920 acre-feet, or 234 percent of the 5-year average, which resulted in a net increase in ground-water storage of some 4,540 acre-feet of water. The average depth to the water table ranged from a maximum depth of 40.5 feet below the land surface at the start of the period to a minimum depth of 15.1 feet in April. The average depth to the water table at the end of the period was 29.3 feet below the land surface. The relatively shallow depth to the water table over a large part of the area during the spring and summer enabled the riparian vegetation to transpire larger amounts of water as is reflected in the water loss from the system.

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. In

order 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 5).

The net changes in ground-water storage and in soil-moisture levels 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 5
AVERAGE ANNUAL WATER-BUDGET ANALYSIS
FOR THE LOWER SYCAMORE CREEK AREA,
WATER YEARS 1961-65

	<u>Acre-feet</u>
INFLOW	
Sycamore Creek near Fort McDowell gaging station	6,110
OUTFLOW	
Streamflow discharged to Verde River from Sycamore Creek	500
Ground-water outflow	4,030
NET CHANGE IN STORAGE	
Ground water	0
Soil-moisture level	0
WATER LOSS	
Evapotranspiration	1,580
	(or about 1.1 acre-feet per acre)

SUMMARY AND CONCLUSIONS

The measured streamflow entering the lower alluvial area ranged from 167 to 14,320 acre-feet per water year. The average annual streamflow entering the area was 6,110 acre-feet per water year based on the existing 5 years of record (1961-65).

Most of the streamflow that enters the lower alluvial area does not reach the Verde River as surface flow. Streamflow measurements made 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 steady flow of about 200 cfs decreased to 0.3 cfs at the Verde River. From 0 to about 10 percent of the streamflow that enters the area is subsequently discharged to the Verde River as streamflow.

A comparison of streamflow at the Fort McDowell gage and water-level changes in wells along the channel of lower Sycamore Creek shows a sharp rise in water levels in response to flow in Sycamore Creek. This indicates that a large percentage of the streamflow is lost to seepage and that this water rapidly percolates down to the water table and recharges the ground-water reservoir.

A comparison of water-level changes in wells at and near the confluence of Sycamore Creek and the Verde River shows a definite response to changes in stage of the Verde River. This relationship indicates a hydraulic interconnection between the ground-water reservoir and the Verde River in this area.

Aquifer tests were conducted to determine the hydraulic properties of materials comprising the ground-water reservoir which had been delineated by surface geologic mapping, test drilling, and seismic-refraction geophysical methods. These tests indicate an average coefficient of permeability of about 5,600 gpd per square foot (U. S. G. S. units) for the unconsolidated alluvium and an average permeability of about 8 gpd per square foot (U. S. G. S. units) for the consolidated alluvium upon which the unconsolidated alluvium is deposited. Thus, the unconsolidated alluvium is highly permeable while the older consolidated alluvium was found to be only slightly permeable.

The large permeability differential can be shown by a comparison of the rate at which ground water would move through these sediments under conditions of equal hydraulic gradients. This comparison indicates that water would move through the unconsolidated alluvium nearly 450 times faster than through the consolidated alluvium.

The hydraulic parameters determined from the aquifer tests 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 the ground-water flow equations was in close agreement with measured increases in stream-flow in the Verde River—about 4,000 acre-feet per year.

Diurnal water-level fluctuations were measured in wells along lower Sycamore Creek which indicate that ground water is discharged in that area by evapotranspiration. The amount of ground water discharged by evapotranspiration is a function of the depth to the water table. This is indicated by a reduction in the amplitude of the diurnal fluctuations in areas of increased depth to water in the upper part of the area where the depth to the water table is usually greatest. The lower density of phreatophytes in the upper part of the area probably is related to the increased depth to water in this area.

A water-budget analysis for the unusually dry period of water year 1964 indicated an annual water loss from lower Sycamore Creek of about 0.13 acre-feet per acre. This low value probably resulted from the great average depth to the water table which was initially about 34.3 feet below the land surface and dropped steadily to about

40.5 feet during this period. The small net streamflow (flow at the Fort McDowell gage minus streamflow discharged to the Verde River) into the area of only 880 acre-feet was not sufficient to sustain the ground-water reservoir which was being depleted by subsurface discharge to the Verde River and by water lost to evapotranspiration. The net streamflow into the area was only about 16 percent of the 5-year average during this time.

Conditions during the wet period of water year 1965 were very different. A water-budget analysis for that year indicated an annual water loss from the area of about 3.1 acre-feet per acre. The average depth to the water table rose from an initial depth of about 40.5 feet below the land surface at start of the period to a minimum depth of about 15.1 feet in April. It then dropped to an average depth of about 29.3 feet below the land surface at the end of the period. The net inflow into the area was 12,920 acre-feet, or about 234 percent of the 5-year average. It is believed that the relatively shallow depth to water over a large part of the area during the spring and summer enabled the phreatophytic riparian vegetation to transpire large amounts of water as is reflected in the water loss from the system.

To minimize measurement errors and to obtain an average annual water-loss figure from the lower Sycamore Creek area, the entire 5-year period of record was used to make a third water-budget analysis. This analysis indicated an average annual water loss from the area of about 1.1 acre-feet per acre. Net changes in ground-water storage were assumed to be equal to zero and the soil-moisture level was assumed to be about the same at the beginning and end of the period. These assumptions are valid if long periods of time are considered, but some error is probably introduced in the analysis when a period as short as 5 years is used.

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Figure 2.--Hydrogeologic map and sections of the lower alluvial area.
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Figure 1.--Drainage network and instrumentation.

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Figure 3.—Flow diagram of the hydrologic system in the lower Sycamore Creek watershed.

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Figure 5.--Streamflow entering the lower alluvial area and streamflow discharged to the Verde River from Sycamore Creek.

5700
1961
200

Figure 6.-- Streamflow and changes in water levels in wells for 1963.

1967
203