ARIZONA WATER COMMISSION

BULLETIN 3

HYDROLOGIC REGIMEN OF LOWER TONTO CREEK BASIN GILA COUNTY, ARIZONA A RECONNAISSANCE STUDY

BY H. H. SCHUMANN
AND B. W. THOMSEN

*Water Rights Adjudication Team
Civil Division
Attorney General's Office:

PREPARED BY THE GEOLOGICAL SURVEY
UNITED STATES DEPARTMENT OF THE INTERIOR

PHOENIX, ARIZONA
NOVEMBER 1972

This report has been designated as an Arizona Water Commission bulletin by permission of Wesley E. Steiner, Executive Director of the Arizona Water Commission. The Water Commission has approved the addition of this report to the bulletin series to promote widespread availability of the data necessary to sound management and optimum utilization of Arizona's water resources. The Commission has not participated in either the collection and compilation of the data or in the preparation and duplicating of the report.

CONTENTS

	Page
Abstract	1
Introduction	2
Purpose of the investigation	2
Methods of the investigation	2
Location, topography, and drainage	5
Climate	5
Rock units and their water-bearing properties	6
Igneous and metamorphic rocks	8
Sedimentary rocks	8
Basin fill	11
Alluvium	12
Hydrology	13
Streamflow	15
Low flows	15
Tributary flows	20
Infiltration of streamflow	20
Flow to Roosevelt Lake	20
Ground water	21
Occurrence and movement	21
Recharge	21
Infiltration of streamflow	23
Infiltration of precipitation and irrigation water	23
Discharge	26
Water losses by evapotranspiration	27
Potential evapotranspiration	28
Evapotranspiration losses	31
Chemical quality of water	32
Summary and conclusions	34
References cited	38

ILLUSTRATIONS

Figure 1.	Map showing area of report and Arizona's water provinces	3
2.	Sketch showing well-numbering system in Arizona	4

CONTENTS

Page

Figure 3. Graph showing average monthly precipitation, pan evaporation, and potential evapotranspiration in and near the lower Tonto Creek basin 7

4. Generalized geologic map of the lower Tonto Creek basin 9

5. Diagrammatic sketch of the hydrologic system in the lower Tonto Creek basin 14

6-9. Graphs showing:

6. Annual flow of Tonto Creek above Gun Creek, near Roosevelt, Ariz., 1942-70 water years 16

7. Average monthly flow of Tonto Creek above Gun Creek, near Roosevelt, Ariz., 1942-70 water years 17

8. Flow-duration curve for Tonto Creek above Gun Creek, near Roosevelt, Ariz., 1942-70 water years 18

9. Low-flow frequency curves for Tonto Creek above Gun Creek, near Roosevelt, Ariz. . . 19

10. Diagrammatic sections showing gaining and losing reaches of lower Tonto Creek 22

11-12. Graphs showing:

11. Relation between changes in stage of Tonto Creek and changes in water levels in wells (A-5-11)8bbc$_1$ and (A-5-11)8bbc$_2$ 24

12. Streamflow and changes in water levels in wells 25

Page

Figures 13-14. Maps showing:

13. Distribution and density of vegetation along the channel and flood plain of lower Tonto Creek 29

14. Location of wells and chemical quality of water along lower Tonto Creek 35

TABLES

Table 1. Chemical analyses of water in the lower Tonto Creek basin 33

HYDROLOGIC REGIMEN OF LOWER TONTO CREEK BASIN, GILA COUNTY, ARIZONA—A RECONNAISSANCE STUDY

By

H. H. Schumann and B. W. Thomsen

ABSTRACT

The 280-square-mile lower Tonto Creek basin is in the Central highlands water province of central Arizona. The basin is drained by Tonto Creek, which flows southward and discharges into Roosevelt Lake. The mountains that border the basin are composed chiefly of igneous and metamorphic rocks, and the basin is underlain by more than 2,000 feet of unconsolidated to semiconsolidated sedimentary deposits. The channel and flood plain of lower Tonto Creek are underlain by as much as 65 feet of alluvium.

In the lower Tonto Creek basin the principal sources of water are the precipitation, which ranges from 17 to more than 20 inches per year, and the streamflow that enters the area from the upper Tonto Creek basin. The precipitation that falls on the lower Tonto Creek basin produces about 20,000 acre-feet per year of streamflow. The streamflow that enters the lower basin from the 675-square-mile upper basin is measured at the northern end of the study area and averages about 80,000 acre-feet per year. An estimated 17,000 to 20,000 acre-feet of streamflow infiltrates annually into the highly permeable alluvium.

The alluvium is the principal aquifer in the lower Tonto Creek basin. Water levels in wells drilled in this aquifer rise quickly in direct response to floodflow in Tonto Creek, which indicates that a large part of the flow loss is recharged to the ground-water reservoir.

In the lower Tonto Creek basin water is discharged to Roosevelt Lake by streamflow and subsurface flow and to the atmosphere by evapotranspiration. The flow from Tonto Creek that enters Roosevelt Lake averages about 80,000 acre-feet per year, the subsurface flow that enters the lake from the alluvium averages about 4,000 acre-feet per year, and the evapotranspiration losses average about 13,000 acre-feet per year.

Flow in Tonto Creek and ground water in the alluvium and the lower part of the basin fill are of excellent chemical quality and are suitable for most uses. The chemical quality of ground water in the alluvium and that of flow in Tonto Creek is similar because the alluvium receives most of its recharge from the creek. Water from a well drilled in the fine - grained facies of the upper part of the basin fill is unsuitable for drinking purposes.

INTRODUCTION

Purpose of the Investigation

The increasing demand for municipal, industrial, and irrigation water in the Salt River Valley in southern Arizona has created a need for an appraisal of the water resources of the watersheds above the storage reservoirs on the Salt River. The U.S. Geological Survey in cooperation with the Salt River Valley Water Users' Association conducted a hydrologic reconnaissance study in the lower Tonto Creek basin in the western part of Gila County, Ariz. (fig. 1), to obtain water-resources information for use in making water-management decisions. The investigation was made under the general supervision of H. M. Babcock, district chief of the U.S. Geological Survey in Arizona.

Methods of the Investigation

All streamflow and precipitation records were analyzed to aid in the appraisal of the water resources of the area. The streamflow that enters the area from the upper basin is measured at the gaging station above Gun Creek, which has been in operation since 1941. A temporary streamflow-gaging station was installed on Tonto Creek above Greenback Creek to obtain a record of the low flows near the downstream end of the basin. In order to determine the amount of water lost to infiltration in lower Tonto Creek, repetitive streamflow measurements were made at selected sites during periods of base flow.

All wells in the area were inventoried, and the well locations were plotted, and the well locations are shown in figure 14 and are described in accordance with the well-numbering system used in Arizona, which is explained and illustrated in figure 2. Three shallow observation wells were dug in the southern part of the basin as a part of this study. Periodic water-level measurements were made in selected wells, and four wells were

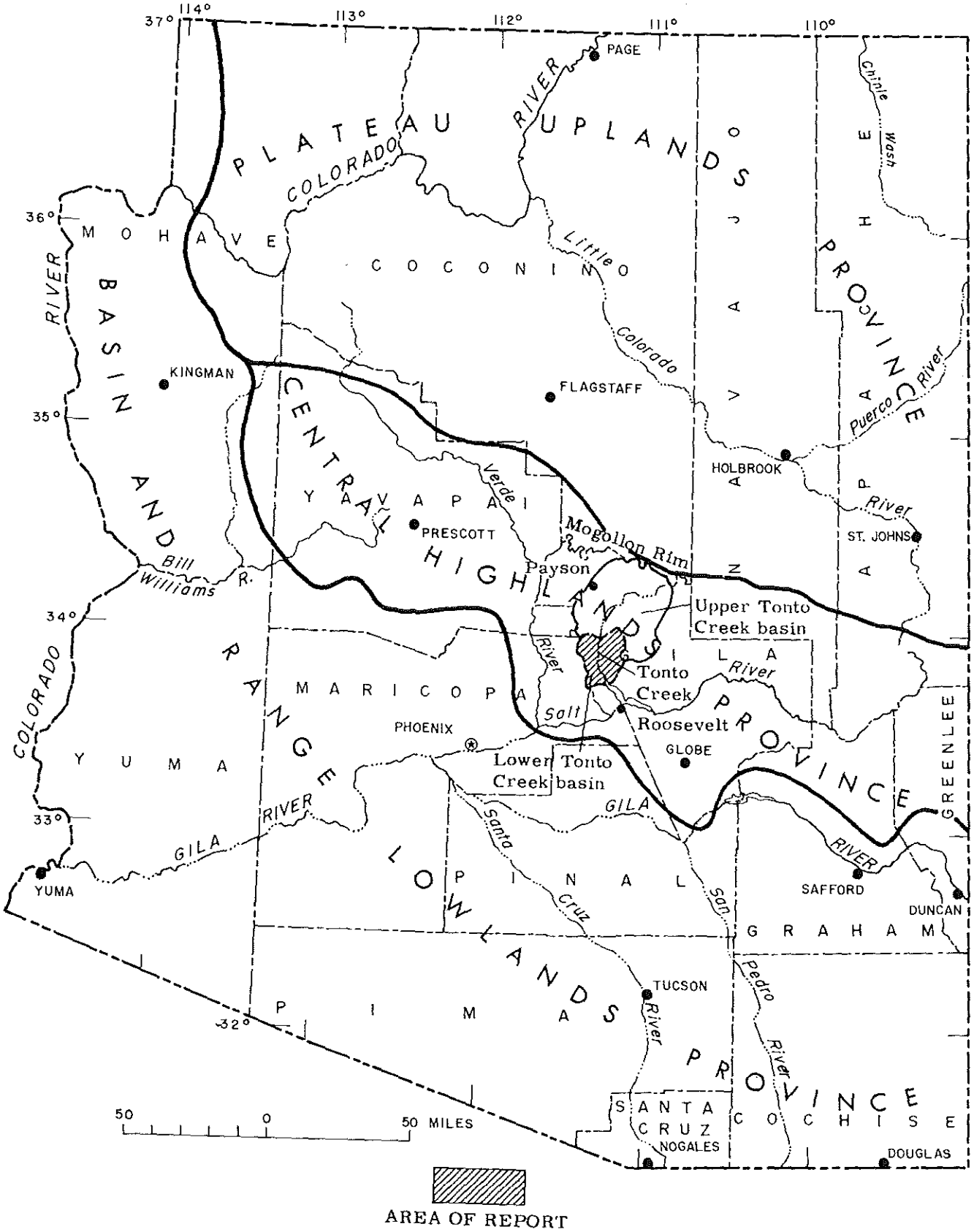
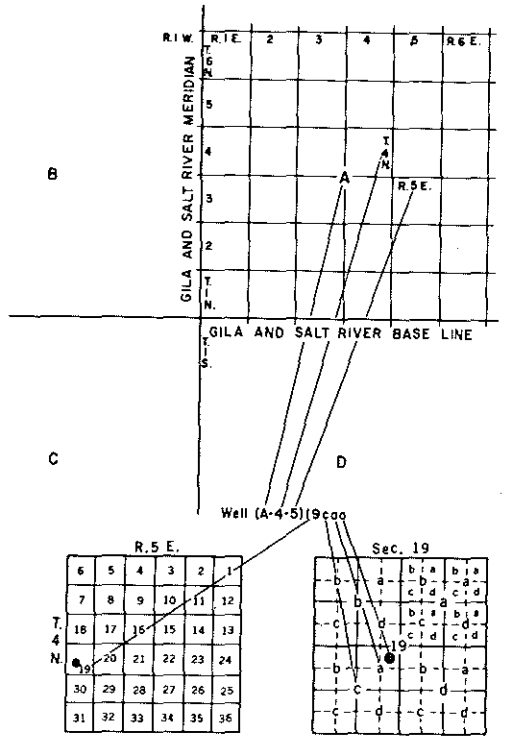


FIGURE 1.--AREA OF REPORT AND ARIZONA'S WATER PROVINCES.



The well numbers used by the Geological Survey in Arizona are in accordance with the Bureau of Land Management's system of land subdivision. The land survey in Arizona is based on the Gila and Salt River meridian and base line, which divide the State into four quadrants. These quadrants are designated counterclockwise by the capital letters A, B, C, and D. All land north and east of the point of origin is in A quadrant, that north and west in B quadrant, that south and west in C quadrant, and that south and east in D quadrant. The first digit of a well number indicates the township, the second the range, and the third the section in which the well is situated. The lowercase letters a, b, c, and d after the section number indicate the well location within the section. The first letter denotes a particular 160-acre tract, the second the 40-acre tract, and the third the 10-acre tract. These letters also are assigned in a counterclockwise direction, beginning in the northeast quarter. If the location is known within the 10-acre tract, three lowercase letters are shown in the well number. In the example shown, well number (A-4-5)19caa designates the well as being in the NE$\frac{1}{4}$NE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 19, T. 4 N., R. 5 E. Where more than one well is within a 10-acre tract, consecutive numbers beginning with 1 are added as suffixes.

FIGURE 2.--WELL-NUMBERING SYSTEM IN ARIZONA.

equipped with continuous water-level recorders to evaluate water-level changes in response to streamflow events in the lower Tonto Creek basin.

Water samples were collected from Tonto Creek and from selected wells for chemical analysis. The analyses were used to interpret the relation between streamflow and ground water. Reconnaissance geologic mapping was done in order to determine the relation of the rock units to the control and availability of water. The density of natural vegetation and the distribution of cultivated acreage along the channel and flood plain of lower Tonto Creek were mapped on low-altitude aerial photographs to estimate evapotranspiration losses from the flood plain.

Location, Topography, and Drainage

The Tonto Creek basin occupies 955 square miles in the Central highlands province and is entirely in western Gila County (fig. 1). The lower Tonto Creek basin is defined as the drainage area from below the streamflow-gaging station, Tonto Creek above Gun Creek, to the high water-line of Roosevelt Lake (fig. 4)—an area of about 280 square miles. The area roughly corresponds to the area described by Feth and Hem (1963, p. 14) as the Tonto basin. The village of Punkin Center is near the center of the study area.

The basin is bounded on the west by the rugged Mazatzal Mountains and on the east by the Sierra Ancha, which rise sharply above the central basin. The south-sloping central basin has moderate relief and is dissected by Tonto Creek and its tributaries. Several levels of stream-cut terraces are present along Tonto Creek in the northern part of the area. Altitudes range from about 2,200 feet above mean sea level near Roosevelt Lake to more than 7,100 feet in the Mazatzal Mountains.

Tonto Creek is an intermittent stream that originates in the Mogollon Rim country northeast of Payson, Ariz., and flows southward into Roosevelt Lake (fig. 4). Lower Tonto Creek is about 17 miles long and has an average gradient of about 23 feet per mile.

Climate

The climate in the lower Tonto Creek basin is semiarid and is characterized by hot dry summers and mild winters. At the Reno Ranger Station near Punkin Center (fig. 4), the monthly mean temperatures range from

44.8°F in January to 86.2°F in July. The highest recorded temperature at this station was 115°F in July 1929, and the lowest recorded temperature was 10°F in January 1962 (Green and Sellers, 1964, p. 343).

The average annual precipitation ranges from about 17 inches in the lowest part of the basin near Roosevelt Lake to more than 20 inches in the mountains (Green and Sellers, 1964, p. 9). The average annual precipitation is 18.73 inches for 35 years of record at the Reno Ranger Station (Green and Sellers, 1964, p. 343). The average annual precipitation at Roosevelt, which is about 10 miles south of the report area, is 13.62 inches for 1949-70 (U.S. Weather Bureau, issued annually).

Most of the precipitation occurs during the summer—July through September—and winter—December through March (fig. 3). The summer precipitation mainly is the result of high-intensity thunderstorms, which are of short duration and small areal extent. During the late summer, however, tropical storms from the Gulf of California or the Pacific Ocean may produce large amounts of precipitation over the basin and may result in large-scale flooding (Green and Sellers, 1964, p. 343). For example, the tropical storm of September 4-6, 1970, dropped more than 11.0 inches of precipitation over the upper Tonto Creek basin, which caused the highest peak flows in the lower basin since possibly the early 1900's (Roeske, 1971, p. 11). The winter precipitation is from frontal storms that move into the basin from the Pacific Ocean; these storms produce rainfall of low to moderate intensities at the lower altitudes and snowfall in the mountainous areas. Although slightly less than half the average annual precipitation occurs during the winter, winter precipitation produces most of the annual streamflow.

The average annual class A pan evaporation at Roosevelt for 1949-70 is 98.27 inches (U.S. Weather Bureau, issued annually). The average annual pan-evaporation rates are more than seven times greater than the average annual precipitation rates at this station (fig. 3).

ROCK UNITS AND THEIR WATER-BEARING PROPERTIES

The lower Tonto Creek basin is bounded on the east and west by rugged mountains that are composed chiefly of igneous and metamorphic rocks of Precambrian age (fig. 4). The south-sloping basin is underlain by more than 2,000 feet of unconsolidated to semiconsolidated sedimentary deposits of Tertiary and Quaternary age.

The basin was formed during Miocene and Pliocene time by large-scale faulting and uplift of the mountains that border the present basin

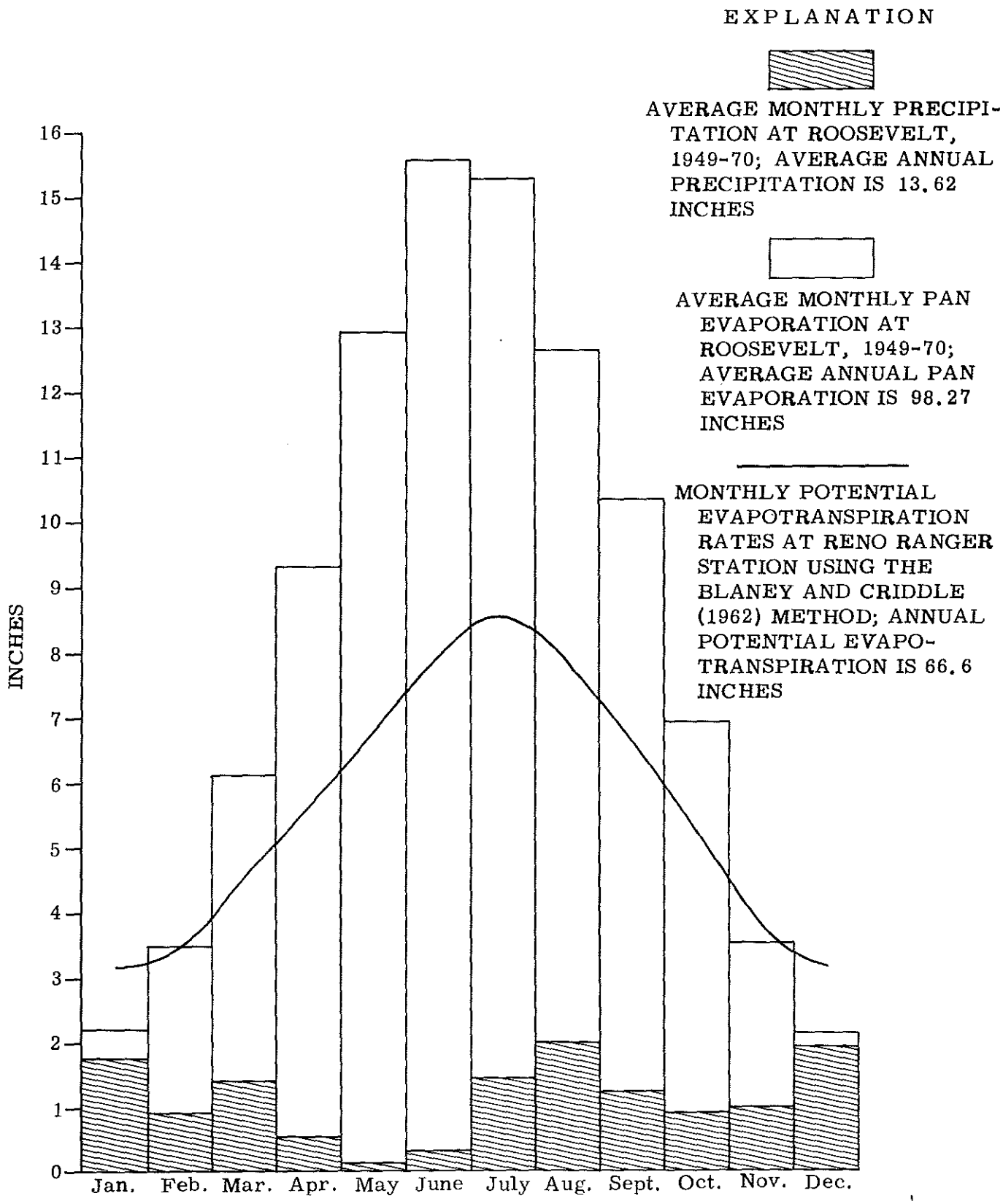


FIGURE 3.--AVERAGE MONTHLY PRECIPITATION, PAN EVAPORATION, AND POTENTIAL EVAPOTRANSPIRATION IN AND NEAR THE LOWER TONTO CREEK BASIN.

(Lance, 1960, p. 157). During and after the period of faulting, large quantities of material were eroded from the mountains and were deposited in the downfaulted central part of the basin.

Igneous and Metamorphic Rocks

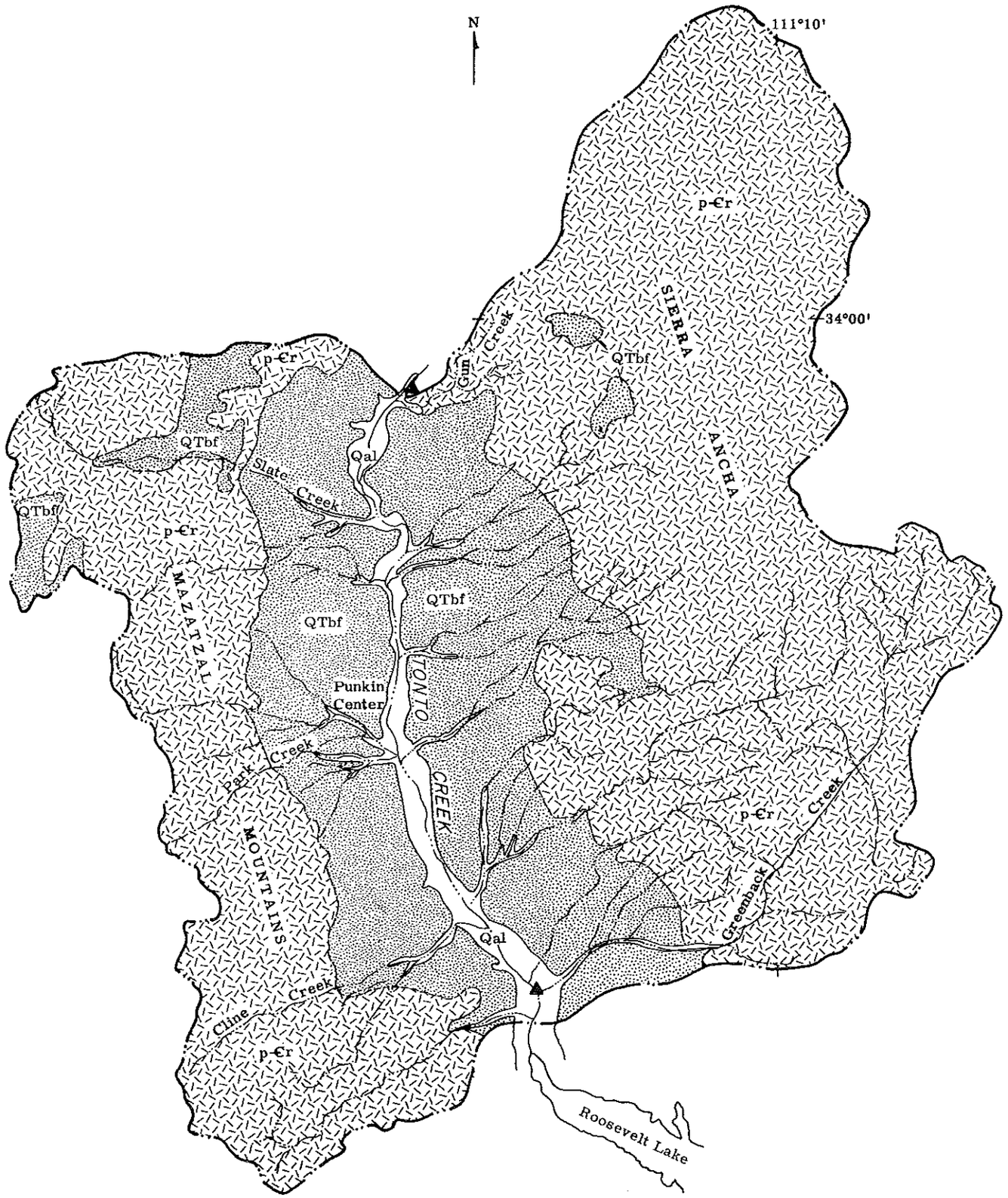
Granite and related intrusive rocks are the main rock types exposed in the Mazatzal Mountains, which border the basin on the west; granite, diabase, and metamorphic rocks are the main rock types exposed in the Sierra Ancha, which border the basin on the east. These rocks are dominantly of Precambrian age. The rocks along the northern part of the basin include schist and rhyolite of Precambrian age and basaltic lava flows of Tertiary age, which crop out in a small area west of the Gun Creek gaging station.

The igneous and metamorphic rocks are relatively impermeable except where fractured or weathered. The fractured rocks and the weathered material, where more than a few feet thick, store a small amount of ground water, which is released slowly through small intermittent springs at the bases of the mountains. Because the igneous and metamorphic rocks are nearly impermeable and crop out in steep slopes, most of the precipitation that falls on the mountains results in overland flow.

Sedimentary Rocks

The basin is filled with more than 2,000 feet of unconsolidated to semiconsolidated sedimentary deposits of Tertiary and Quaternary age, which comprise the undifferentiated upper and lower parts of the basin fill, unmapped piedmont and terrace gravels, and alluvium. The lower part of the basin fill is exposed along Slate and Tonto Creeks in the northwestern part of the area, and the upper part of the basin fill underlies the central part of the area. The basin fill is overlain by thin layers of piedmont gravel of Quaternary age along the slopes of the basin.

The thin discontinuous layers of piedmont gravel extend from the bases of the mountains to the flood plains of Tonto Creek and its major tributaries. The piedmont gravel consists of poorly sorted unconsolidated reddish-brown gravel, sand, silt, and clay. Although the material is moderately permeable, it is cut by several washes and generally occurs above the regional water table; therefore, the piedmont gravel does not store large amounts of water.



EXPLANATION

Qal

ALLUVIUM
UNCONSOLIDATED SAND AND GRAVEL AND SMALL AMOUNTS OF SILT AND CLAY; HIGH PERMEABILITY; YIELDS LARGE AMOUNTS OF WATER TO WELLS

QUATERNARY

QTbf

BASIN FILL, UNDIFFERENTIATED
DIVIDED INTO TWO PARTS. THE UPPER PART CONSISTS OF A COARSE-GRAINED FACIES AND A FINE-GRAINED FACIES; LOW PERMEABILITY. THE LOWER PART CONSISTS OF UNCONSOLIDATED TO SEMICONSOLIDATED INTERBEDDED GRAVEL, SAND, AND SANDSTONE; LOW TO MODERATE PERMEABILITY; YIELDS SMALL AMOUNTS OF WATER TO WELLS

TERTIARY AND QUATERNARY

p€r

IGNEOUS AND METAMORPHIC ROCKS
CONSIST MAINLY OF GRANITE AND RELATED INTRUSIVE ROCKS IN THE MAZATZAL MOUNTAINS; GRANITE, DIABASE, AND METAMORPHIC ROCKS IN THE SIERRA ANCHA; AND SCHIST AND RHYOLITE IN THE NORTHERN PART OF THE BASIN (INCLUDES OUTCROPS OF BASALTIC LAVA FLOWS OF TERTIARY AGE IN A SMALL AREA WEST OF THE GUN CREEK GAGING STATION). GENERALLY VERY LOW PERMEABILITY; LOW TO MODERATE PERMEABILITY WHERE FRACTURED AND IN WEATHERED ZONES

PRECAMBRIAN

CONTACT
DASHED WHERE APPROXIMATE

DRAINAGE DIVIDE

▲ STREAMFLOW-GAGING STATION
(OPERATED BY THE U.S. GEOLOGICAL SURVEY)

BASE FROM U.S. GEOLOGICAL SURVEY,
1:125,000 ROOSEVELT, 1912; 1:62,500
PAYSON, 1936 AND DIAMOND BUTTE, 1937

0 1 2 3 4 5 MILES

GEOLOGY MODIFIED FROM WILSON, MOORE, AND PEIRCE (1959) BY H. H. SCHUMANN (1970)

FIGURE 4.--GENERALIZED GEOLOGIC MAP OF THE LOWER TONTO CREEK BASIN

Thin discontinuous ribbons of terrace gravel of Quaternary age cap the terraces, which crudely parallel the present course of Tonto Creek, and grade into the piedmont gravel. These terraces are well developed north of Punkin Center. The terrace gravel consists of poorly sorted light-brown to gray sand, gravel, silt, and clay and is generally less than 20 feet thick. Although the terrace gravel is highly permeable, it is of limited areal extent and generally occurs above the water table.

Basin Fill

The basin fill is divided informally into two parts—a lower part and an upper part. The boundary between the lower and upper parts of the basin fill is exposed only along streambanks and is not delineated on the map. The reddish-gray coarse-grained lower part of the basin fill overlies the Precambrian schist and is exposed along lower Slate Creek and Tonto Creek above Slate Creek. The lower part of the basin fill consists of unconsolidated to semiconsolidated interbedded gravel, sand, and sandstone. The gravel beds are poorly sorted and contain silt and sand and are weakly cemented with calcium carbonate. The sand and sandstone beds are poorly sorted and commonly contain pebbles.

The lower part of the basin fill unconformably overlies the Precambrian schist and is tilted basinward where it is exposed along lower Slate Creek; there, the lower part of the basin fill contains interbedded basaltic lava flows and is overlain by the upper part and by alluvium along stream channels. Because the overlying upper part of the basin fill contains fossils of Pliocene age, a Pliocene or older age is assigned to the lower part (Lance, Downey, and Alford, 1962).

The cementation and poor sorting of the lower part of the basin fill effectively reduce the size of the pore spaces and the degree of interconnection between them; therefore, the permeability of the lower part is low to moderate. The lower part of the basin fill yields small quantities of water to wells in the northern part of the basin. The lower part of the basin fill is capable of yielding small to moderate quantities of water suitable for stock and domestic supplies if a sufficient saturated thickness of the material is penetrated.

The upper part of the basin fill unconformably overlies the lower part and laps onto the Precambrian rocks of the adjacent mountains (fig. 4). The upper part of the basin fill is overlain by thin layers of piedmont gravel along the bases of the mountains and by thin terrace gravel and alluvium in the channels of Tonto Creek and its major tributaries. The upper part of

the basin fill is exposed along the east and west sides of the basin and consists of a coarse-grained and a fine-grained facies.

The coarse-grained facies crops out in a narrow band along the margins of the basin and consists of light-gray to brown poorly consolidated gravel layers interbedded with silty to gravelly sand. The coarse-grained facies is of limited areal extent and grades into the fine-grained facies toward the center of the basin. The coarse-grained facies overlies the Precambrian schist and the lower part of the basin fill in exposures in the north-central part of the basin. The coarse-grained facies is moderately permeable; however, because the facies is cut by large washes and generally is above the water table, it is not an important aquifer.

The fine-grained facies consists chiefly of red to gray thin- to very thick-bedded poorly consolidated silt and clay and minor amounts of interbedded sand, gypsum, marl, and tuff. Many gypsiferous red beds are exposed in the southern part of the area but thin northward and are not present in the central part of the basin. A thin fossiliferous light-brown silt, clay, tuff, and marl sequence overlies the gypsiferous red beds near Punkin Center. The animal and plant remains in this sequence are of Pliocene age and probably were buried by deposits of a large lake (Lance, Downey, and Alford, 1962).

Most of the upper part of the basin fill is rather impermeable, although thin sand layers intercalated with the silt and clay yield small amounts of water of poor quality to wells near Punkin Center. These beds are a confining layer for underlying water-bearing beds, and also inhibit infiltration of water from the overlying unconsolidated alluvium along Tonto Creek (fig. 4).

Alluvium

Unconsolidated alluvium of Quaternary age is present in a continuous strip along the channel and flood plain of Tonto Creek and along the lower parts of its major tributaries (fig. 4). The alluvium consists of light-brown to gray sand and gravel and small amounts of silt and clay. The alluvium overlies the Precambrian schist at the gaging station on Tonto Creek above Gun Creek; it is as much as 65 feet thick where it overlies and is in hydraulic connection with the lower part of the basin fill between the gaging station and Punkin Center (fig. 4). The alluvium is 30 to 40 feet thick where it overlies the upper part of the basin fill along lower Tonto Creek in the southern part of the area.

The alluvium occupies the lowest topographic position in the basin and receives water from adjacent units and from Tonto Creek; the unit receives water from and discharges it to the creek depending on the stage of the stream. The highly permeable alluvium is the principal aquifer in the basin and yields as much as 2,500 gpm (gallons per minute) of water to large-diameter irrigation wells. Many small-diameter domestic and stock wells obtain their water from this unit.

HYDROLOGY

The Central highlands province, of which the lower Tonto Creek basin is a part, receives the largest amount of precipitation of any of the water provinces in Arizona. The runoff from most of the province is stored in the reservoirs on the Salt River to provide water and hydroelectric power for irrigation, municipal, and industrial uses in the arid Salt River Valley. Tonto Creek drains into Roosevelt Lake, which is the oldest and largest of the reservoirs on the Salt River.

The hydrologic system of the lower Tonto Creek basin is shown diagrammatically in figure 5. Water enters the lower basin chiefly as streamflow from the upper basin and as precipitation. Water that enters the lower basin as precipitation may evaporate soon after contact with the land surface, move across the land surface as runoff, or infiltrate into the earth to become either soil moisture or ground water. Water that moves across the land surface tends to collect and become streamflow. As streamflow moves along natural channels, some water evaporates, and some infiltrates into the streambed and becomes either soil moisture or ground water.

The precipitation or streamflow that infiltrates into the earth and that is retained in the unsaturated zone above the water table is called soil moisture and may be removed by evaporation and by transpiration through plants. Water that reaches the water table becomes ground water and moves through the earth very slowly from areas of greater hydraulic head to areas of lesser hydraulic head. Ground water may return to the land surface and become streamflow where the water table intersects the streambed, it may move upward into the unsaturated zone and become soil moisture, or it may be removed by evaporation and transpiration.

Water leaves the basin as streamflow and ground-water discharge to Roosevelt Lake and by evaporation and transpiration (fig. 5). The combined discharge of water to the atmosphere by evaporation and transpiration is termed "evapotranspiration."

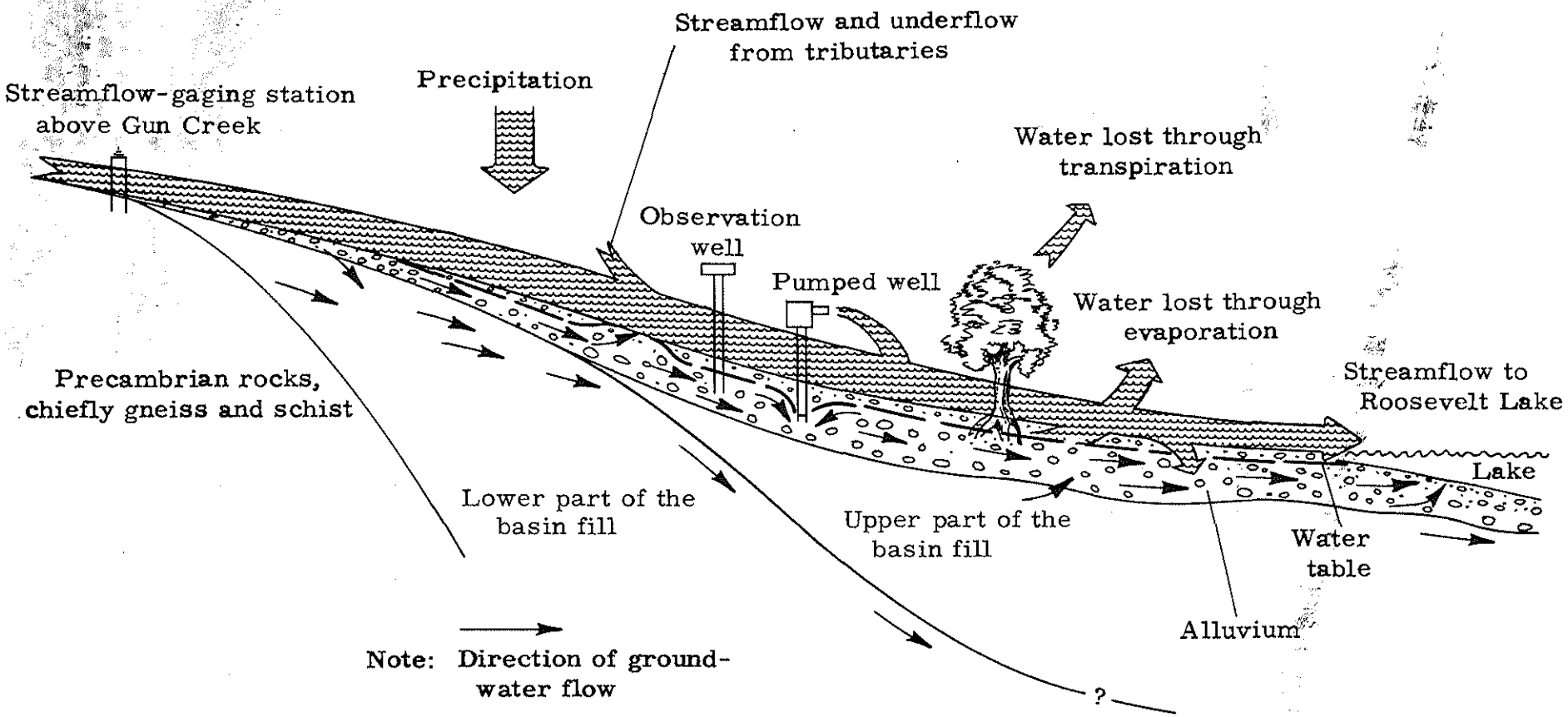


FIGURE 5.--HYDROLOGIC SYSTEM IN THE LOWER TONTO CREEK BASIN.

Streamflow

Most of the streamflow in lower Tonto Creek originates in the upper basin, which has a drainage area of 675 square miles. The flow from the upper basin is measured at the gaging station above Gun Creek and ranged from 17,120 acre-feet in 1956 to 224,500 acre-feet in 1952 (fig. 6). The average annual streamflow for the period 1942-70 was 110 cfs (cubic feet per second) or 79,700 acre-feet per year (U.S. Geological Survey, 1970). Most of the streamflow occurs in the winter and spring—more than 75 percent occurs from December through May—and the lowest flows occur in June (fig. 7). The peak flow was 53,000 cfs on September 5, 1970, and periods of no flow are uncommon.

The time distribution of streamflow may be expressed by a flow-duration curve, which is a cumulative frequency curve that shows the percentage of time that specified discharges are equaled or exceeded in a given period without regard to the sequence of occurrence. For example, the curve in figure 8 does not show whether the lowest flows occurred consecutively in a rare drought year or whether low flows occurred on a few days during each year. Tonto Creek flows on the average of 97.4 percent of the time, and a discharge of 20 cfs is equaled or exceeded 50 percent of the time (fig. 8).

Low Flows

Streamflow from the upper Tonto Creek basin is the only source of sustained flow in the lower basin. In 13 years of the 29 water years of record, 1942-70, short periods of no flow were recorded at the gaging station above Gun Creek. The periods of no flow usually occur in June and July, and the longest period of no flow was 40 days recorded in 1956.

Low-flow frequency curves are based on the lowest mean discharges for intervals of time ranging from 1 to 183 consecutive days for each year of record and give recurrence intervals, magnitudes, and the chronological sequences of the occurrence of the low flows. The low-flow frequency curves in figure 9 show that a 30-day mean flow of 0.1 cfs has an expected recurrence interval of about 6 years at the gaging station above Gun Creek.

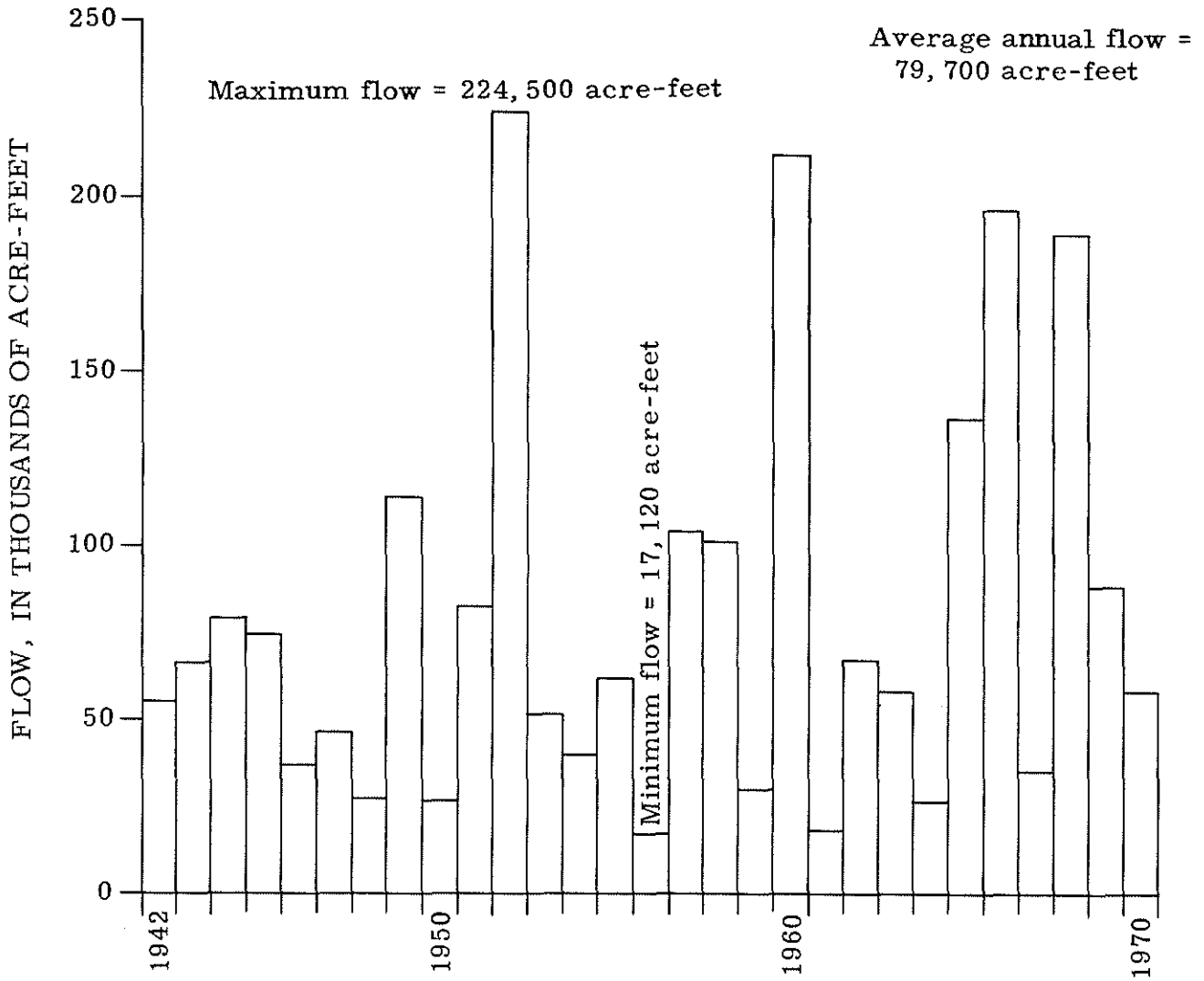


FIGURE 6.--ANNUAL FLOW OF TONTO CREEK ABOVE GUN CREEK, NEAR ROOSEVELT, ARIZ., 1942-70 WATER YEARS.

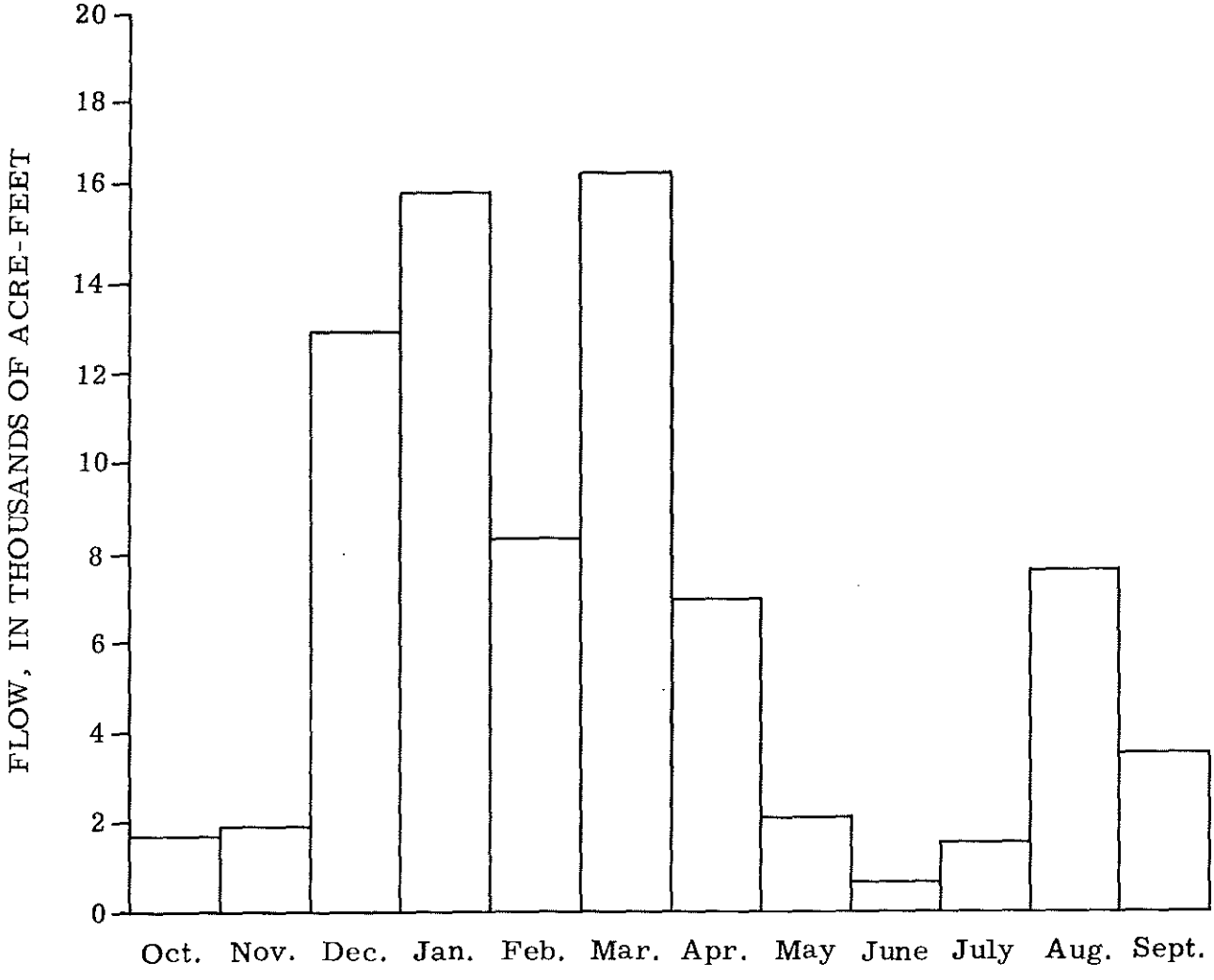


FIGURE 7.--AVERAGE MONTHLY FLOW OF TONTO CREEK ABOVE GUN CREEK, NEAR ROOSEVELT, ARIZ., 1942-70 WATER YEARS.

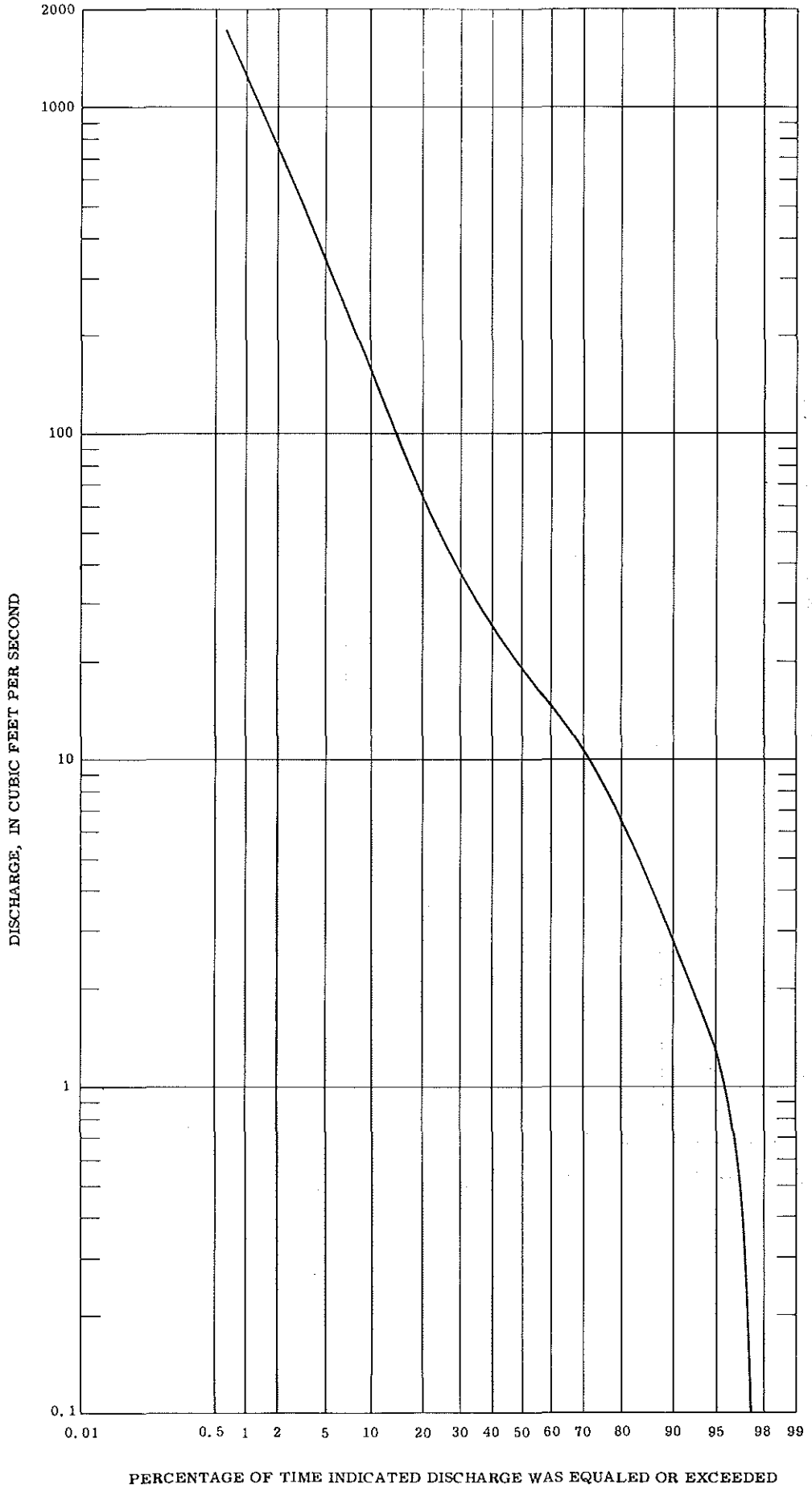


FIGURE 8.--FLOW-DURATION CURVE FOR TONTO CREEK ABOVE GUN CREEK, NEAR ROOSEVELT, ARIZ., 1942-70 WATER YEARS.

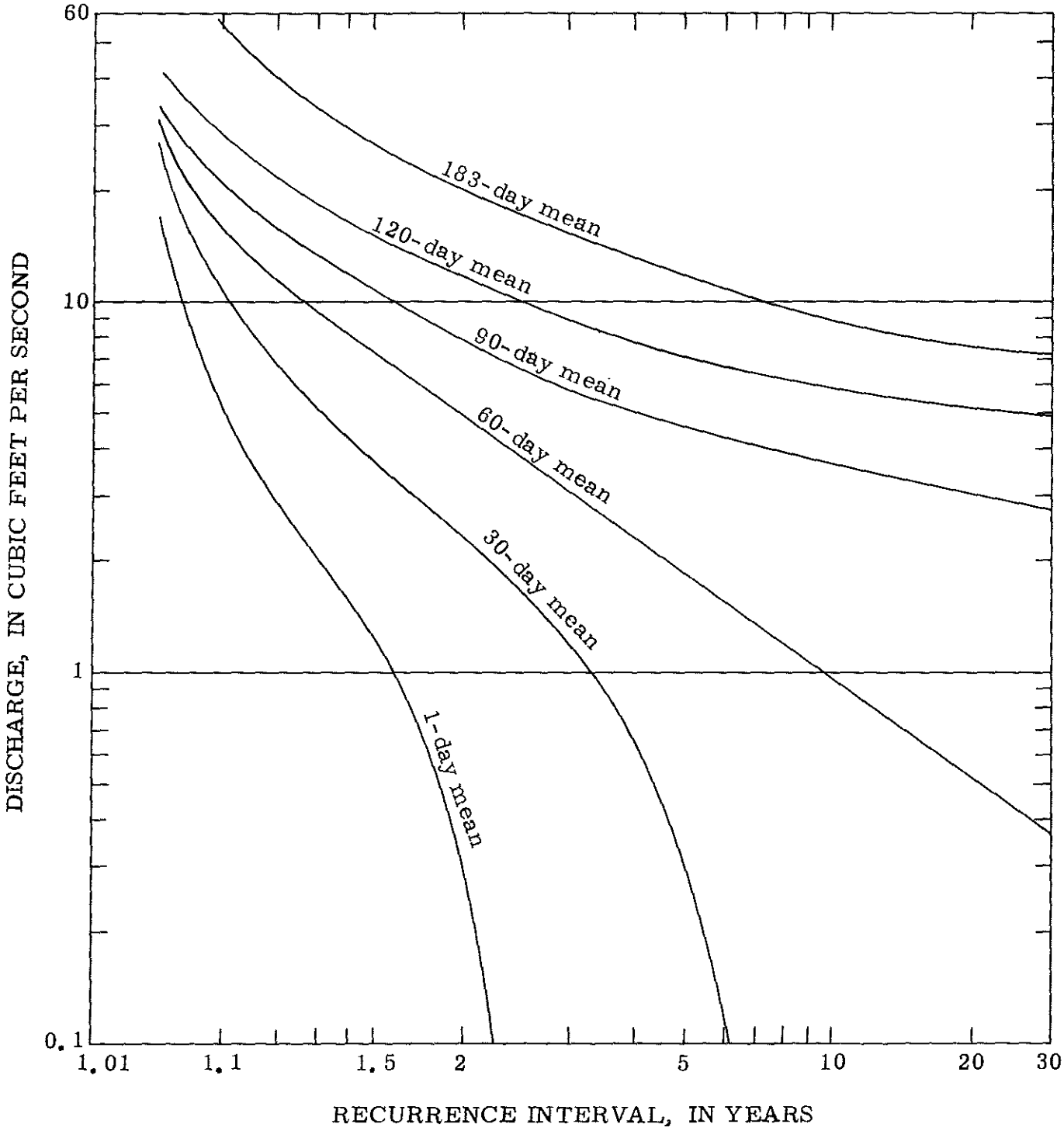


FIGURE 9.--LOW-FLOW FREQUENCY CURVES FOR TONTO CREEK ABOVE GUN CREEK, NEAR ROOSEVELT, ARIZ.

Tributary Flows

The tributaries to Tonto Creek flow only for short periods mainly in response to runoff from precipitation. Although the tributary flows are not measured, it is estimated that about 20,000 acre-feet per year of tributary streamflow reaches Roosevelt Lake. This estimate is based on the average unit discharge from similar nearby watersheds for which long-term runoff records are available.

Infiltration of Streamflow

The channel of lower Tonto Creek is about 500 feet wide and is underlain by the permeable alluvium. The streamflow that passes the gaging station above Gun Creek usually diminishes in the downstream direction as water infiltrates into the alluvium, and the lower reaches are often dry during the summer months. The average annual volume of infiltration for the period 1942-70 was estimated to be about 20,000 acre-feet or about 25 percent of the streamflow that passed the Tonto Creek above Gun Creek gaging station. The estimate is based on the infiltration-duration relation derived from the flow - duration curve for Tonto Creek above Gun Creek and from the average relation between rates of inflow and infiltration (Burkham, 1970). The instantaneous infiltration rates were computed as the difference between instantaneous rates of inflow and outflow measured when the flow in Tonto Creek was fairly constant and when there was no known tributary inflow; the computation was based on the assumption that the aquifer was not completely saturated, which was not true at all times or in all places. Therefore, the actual average annual volume of infiltration probably is less than the estimated annual volume of 20,000 acre-feet. An estimate of 17,000 acre-feet may be closer to the actual average annual volume of infiltration along lower Tonto Creek based on the combined estimated annual volumes of subsurface outflow and evapotranspiration. The amount of tributary flow that infiltrates into the alluvium is unknown.

Flow to Roosevelt Lake

The average annual volume of streamflow that enters Roosevelt Lake from Tonto Creek is estimated to be 80,000 acre-feet per year. This estimate is based on the relation between unit discharge and watershed size for the data-collection sites on Tonto Creek.

Ground Water

Occurrence and Movement

In the lower Tonto Creek basin most of the ground water is stored in the sedimentary rocks that underlie the central part of the basin (fig. 4). Small amounts of ground water are stored in the igneous and metamorphic rocks where they are fractured or weathered; the fractured rocks and the weathered material, where more than a few feet thick, release the water slowly through small intermittent springs at the bases of the mountains.

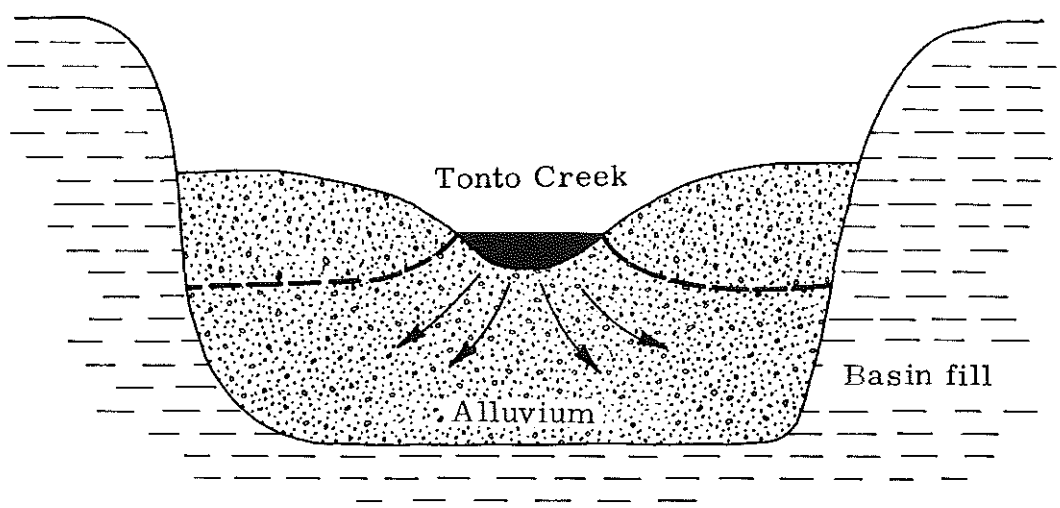
In the north - central part of the basin and elsewhere along Tonto Creek the ground water is under unconfined conditions in the lower part of the basin fill where it is overlain by and hydraulically connected with the alluvium. In the south-central part of the basin ground water is under confined conditions in the lower part of the basin fill where it is overlain by the relatively impermeable fine - grained facies of the upper part of the basin fill. Ground water is under water - table conditions in the alluvium along lower Tonto Creek and its major tributaries; where the piedmont and terrace gravel is saturated, the shallow ground water is under water-table conditions.

Ground water moves from areas of greater hydraulic head to areas of lesser hydraulic head. Water levels in wells drilled in the basin fill indicate that ground water moves from the sides of the basin toward lower Tonto Creek.

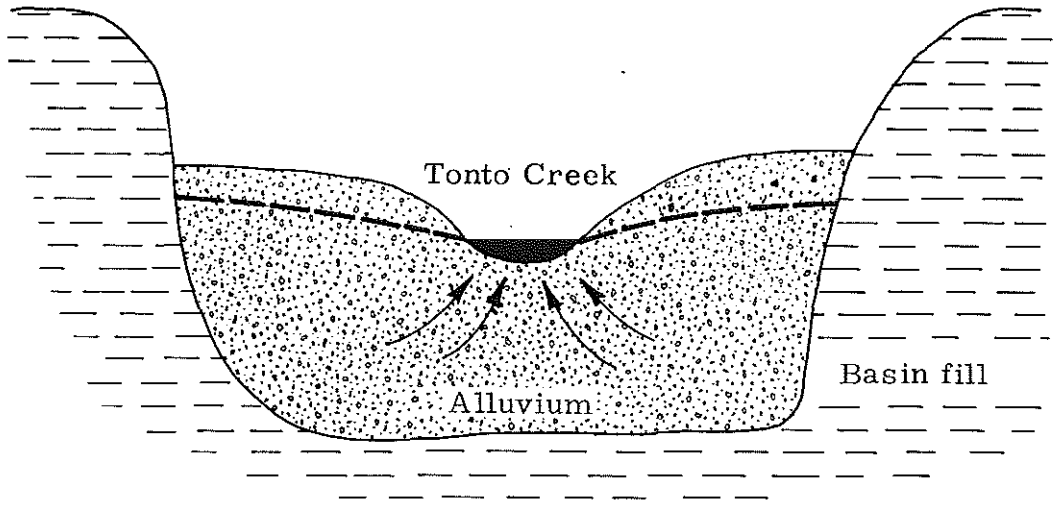
The principal direction of ground-water movement in the alluvium is southward to Roosevelt Lake. Lower Tonto Creek is a losing stream where the altitude of the water table is below the altitude of the streambed, and the ground water moves laterally in the alluvium away from the creek (fig. 10A). Lower Tonto Creek is a gaining stream where the altitude of the water table is above the altitude of the streambed, and ground water moves laterally in the alluvium toward the creek (fig. 10B).

Recharge

The ground - water reservoir in the lower Tonto Creek basin receives recharge from infiltration of streamflow and irrigation water. Most of the recharge to the ground - water reservoir is from the infiltration of streamflow.



A
LOSING REACH



B
GAINING REACH

EXPLANATION

WATER TABLE

DIRECTION OF
GROUND-WATER FLOW

FIGURE 10.--GAINING AND LOSING REACHES OF LOWER TONTO CREEK.

Infiltration of streamflow.--Water-level and chemical data indicate that the ground water in the alluvium is associated closely with the flow in lower Tonto Creek. Water levels in two shallow observation wells drilled in the alluvium near the gaging station Tonto Creek above Greenback Creek fluctuate in response to changes in stage of Tonto Creek (fig. 11), which indicates a hydraulic interconnection between the stream and the ground water in the alluvium.

Hydrographs of water levels in observation wells drilled in the alluvium along Tonto Creek and streamflow at the Tonto Creek above Gun Creek gaging station show general rises in water levels in the early spring in response to winter runoff and declines in the spring and early summer; a second series of rises in water levels occurs during the summer and fall in response to late summer flows (fig. 12). The water-level rises indicate that a large part of the streamflow that disappears from the channel infiltrates into the alluvium and becomes ground water.

In the few wells that penetrate the basin fill east of Tonto Creek water-level measurements indicate that water moves downgradient toward the creek in this unit. Therefore, infiltration of the intermittent streamflow that originates in the adjacent mountains contributes an undetermined amount of recharge to the ground-water reservoir.

Infiltration of precipitation and irrigation water.--Direct precipitation on the lower Tonto Creek basin probably is not a significant source of recharge to the ground-water reservoir. The low permeability of the upper part of the basin fill precludes penetration of precipitation to the water table, and much of the precipitation is lost directly to the atmosphere because of the high evaporation rates. The amount of recharge to the alluvium from direct precipitation probably is small because of interception losses to plant cover, soil-moisture deficiencies during much of the year, and the limited areal extent of this unit.

Some of the irrigation water applied on the flood plain probably returns to the aquifer; however, return of irrigation water pumped from the alluvium is a recycling process and does not constitute recharge of new water to the aquifer. The amount of irrigation water recycled to the aquifer is small because the irrigated area includes only about 350 acres.

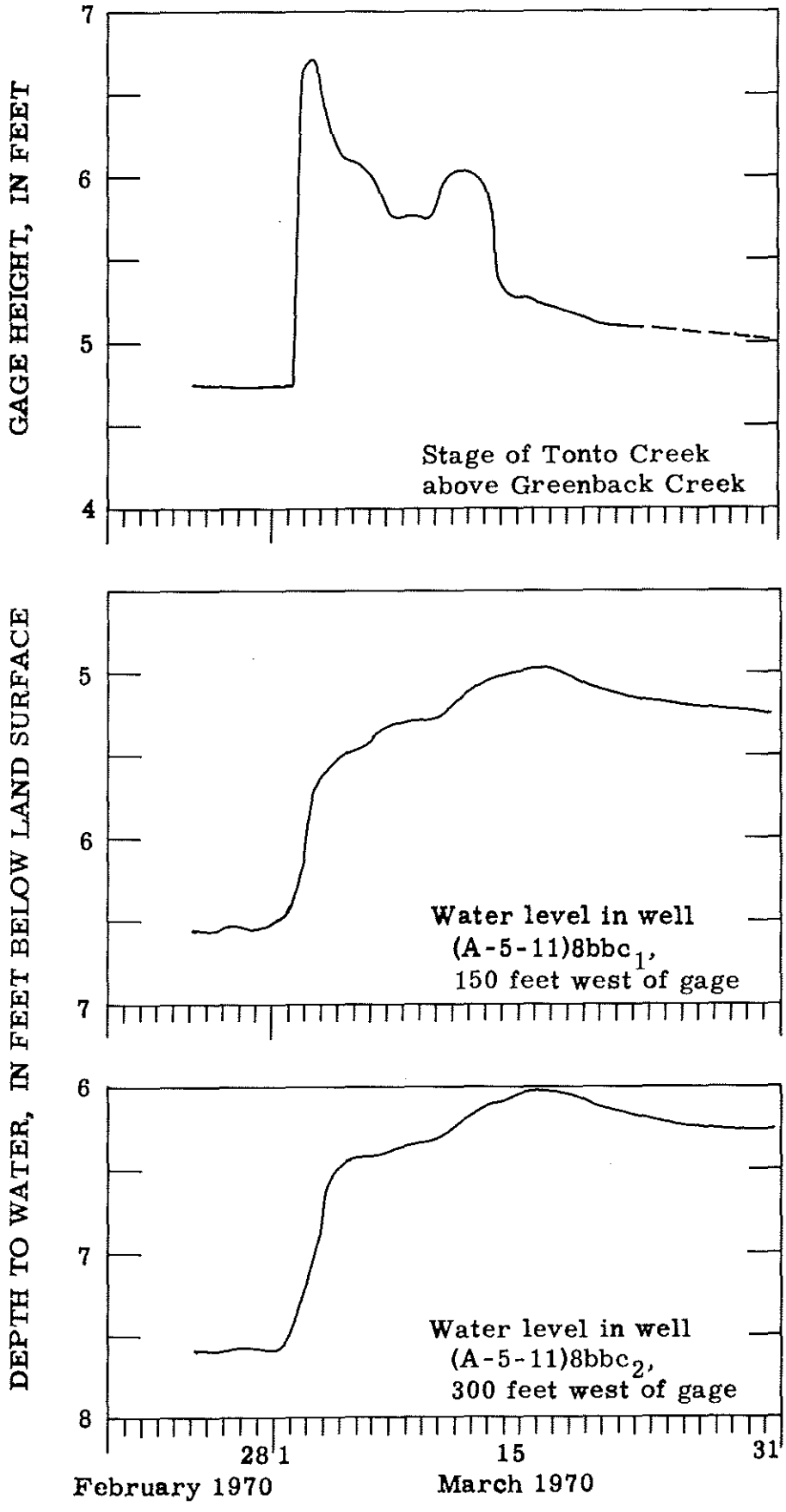


FIGURE 11.--RELATION BETWEEN CHANGES IN STAGE OF TONTO CREEK AND CHANGES IN WATER LEVELS IN WELLS (A-5-11)8bbc$_1$ AND (A-5-11)8bbc$_2$.

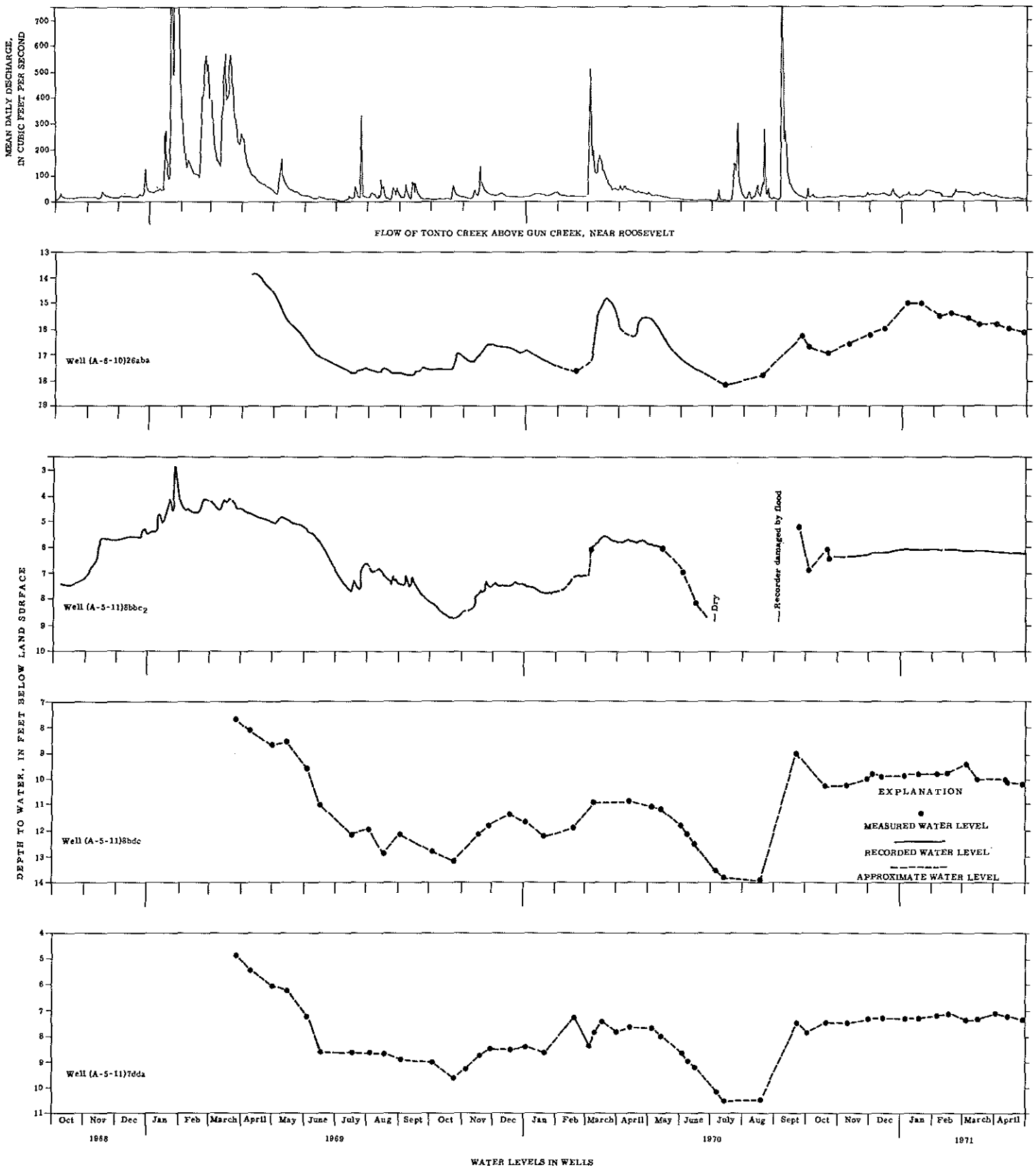


FIGURE 12. --STREAMFLOW AND CHANGES IN WATER LEVELS IN WELLS.

Discharge

About 17,000 acre-feet per year of water is discharged from the ground-water reservoir in the lower Tonto Creek basin—about 4,000 acre-feet by subsurface flow to Roosevelt Lake and about 13,000 acre-feet by evapotranspiration. Ground water also is discharged by subsurface flow to Tonto Creek and by pumping from wells. Small amounts of water are pumped from many small-diameter wells for livestock and domestic uses; a few irrigation wells yield large amounts of water, but the amount of water pumped from these wells does not constitute a large draft on the ground-water reservoir at the present time. Water discharged from the ground-water reservoir by evapotranspiration is discussed separately in the section entitled "Water Losses by Evapotranspiration." The amount of ground water discharged to Tonto Creek is unknown and is dependent on the altitude of the water table in relation to the altitude of the streambed (fig. 10).

The amount of ground water discharged to Roosevelt Lake from the alluvium along lower Tonto Creek can be computed using an equation based on Darcy's law (Wenzel, 1942, p. 3); the terminology and units of measurements have been changed to conform to the current usage of the U.S. Geological Survey (Lohman and others, 1972). The equation is

$$Q = TIW, \tag{1}$$

where

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

The transmissivity of the alluvium can be estimated using the expression

$$T = bK, \tag{2}$$

where

b = saturated thickness, in feet, and
K = average hydraulic conductivity, in feet per day.

The term "hydraulic conductivity" of an aquifer material replaces the term "field coefficient of permeability." Based on field determinations of the coefficient of permeability of a similar aquifer in the adjacent Sycamore Creek watershed (Thomsen and Schumann, 1968, p. 39) and on laboratory studies of unconsolidated sand and gravel (Todd, 1959, p. 53), the hydraulic conductivity of the alluvium is estimated to be 700 feet per day. If the average saturated thickness of the unit is about 40 feet, the transmissivity is estimated to be 28,000 cubic feet per day per foot. The aquifer is about 4,800 feet wide immediately downstream from the confluence of Tonto and Greenback Creeks and the hydraulic gradient is about 18.5 feet per mile. Using equation (1), the subsurface discharge to Roosevelt Lake through the alluvium along lower Tonto Creek is estimated to be

$$Q = (28,000)(18.5/5,280)(4,800) = 4.7 \times 10^5 \text{ cubic feet per day}$$
$$= \text{about } 4,000 \text{ acre-feet per year.}$$

Some water is discharged to Roosevelt Lake from the basin deposits. However, sufficient subsurface geologic data are not available to estimate the amount of discharge from this unit.

Water Losses by Evapotranspiration

Water is discharged to the atmosphere by evaporation of surface water, by evaporation of soil moisture, and by direct evaporation of ground water where the water table is near the land surface. Water also is discharged to the atmosphere by transpiration through plants that use the soil moisture above the water table and through plants that have deep roots that tap the ground-water reservoir. The long-term net change in soil moisture is assumed to be zero in the lower Tonto Creek basin.

A plant that habitually obtains its water supply from ground water is called a phreatophyte (Meinzer, 1923, p. 55). Transpiration by natural and cultivated phreatophytes accounts for most of the water lost by evapotranspiration in the basin. The phreatophytes in the areas of shallow ground water along the channel of lower Tonto Creek and its flood plain consist mainly of mesquite, cottonwood, and saltcedar; the alfalfa that is cultivated on the flood plain also is considered a phreatophyte.

The channel and flood plain of lower Tonto Creek have an area of about 5,080 acres; the distribution and density of vegetation along the channel and flood plain are shown in figure 13. In August 1967 about 350 acres or 7 percent of the area was under cultivation. Dense growths of phreatophytes covered about 865 acres or 17 percent of the area, and growths of phreatophytes of light to medium densities covered 2,700 acres or 53 percent of the area. Relatively clear areas having very little phreatophyte growth covered 1,160 acres or about 23 percent of the area.

Potential Evapotranspiration

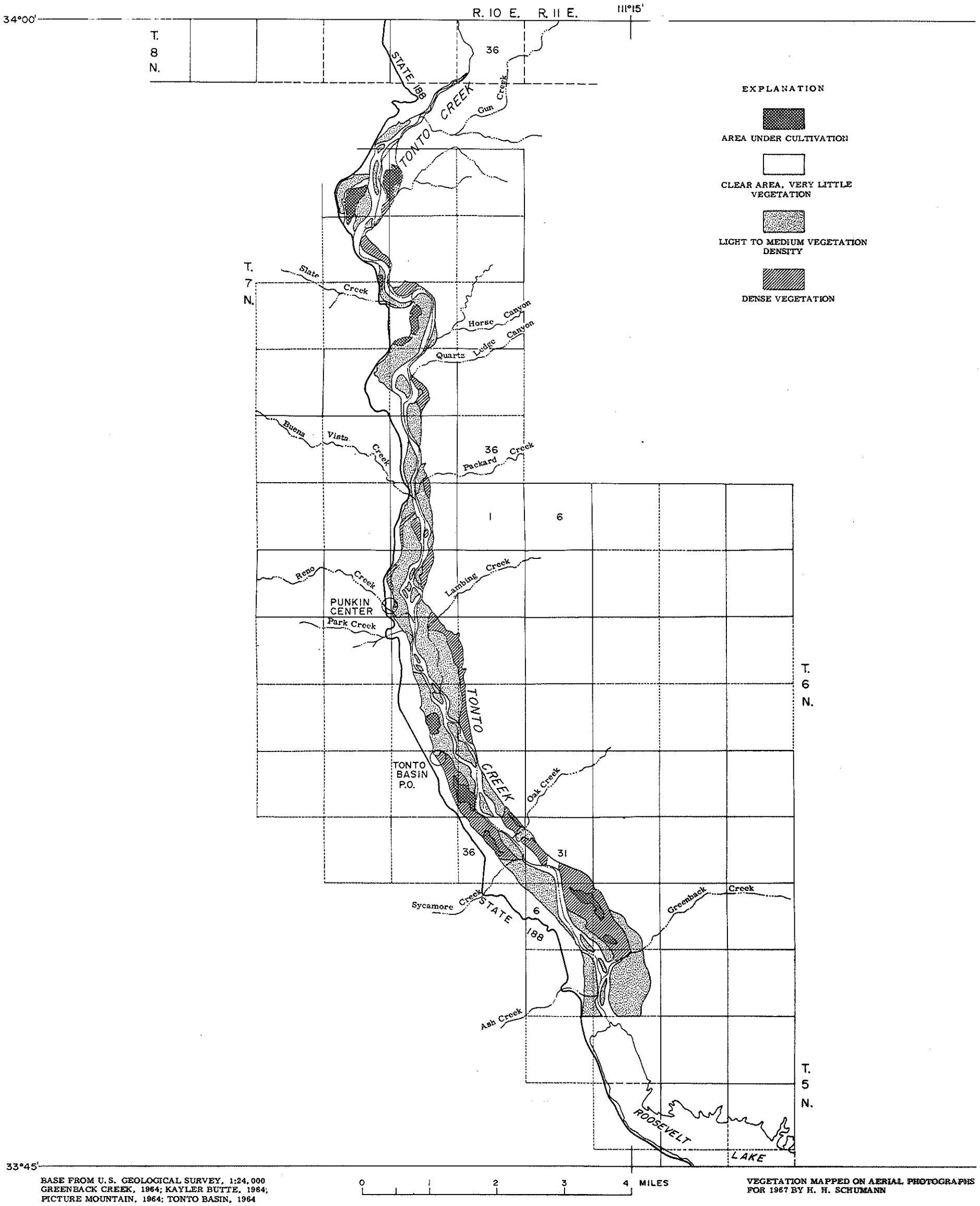
Potential evapotranspiration is defined as the water loss that will occur if at no time there is a deficiency of water in the soil for use by plants (Langbein and Iseri, 1960, p. 15). If it is assumed that potential evapotranspiration is about equal to lake evaporation, the potential evapotranspiration rate can be estimated using the available pan-evaporation data (Cruff and Thompson, 1967, p. 19). Therefore, the average annual potential evapotranspiration rate in the study area is about equal to the average annual class A pan-evaporation rate of 98.27 inches at Roosevelt (U. S. Weather Bureau, issued annually) times 0.7, which is the ratio of lake evaporation to class A pan evaporation, or about 69 inches per year.

The Blaney and Criddle (1962) method of estimating potential evapotranspiration is based on temperature, daytime hours, and available moisture for different crops (Cruff and Thompson, 1967, p. 15). Using these parameters, potential evapotranspiration can be computed by the equation

$$U = K\sum \frac{(T)(p)}{100}, \qquad (3)$$

where

U = consumptive use, in inches, during the growing season,
K = empirical consumptive-use coefficient that is dependent primarily on the type of vegetation,
p = monthly percentage of total daytime hours in the year, and
T = mean monthly temperature, in degrees Fahrenheit.



BASE FROM U.S. GEOLOGICAL SURVEY, 1:24,000
GREENBACK CREEK, 1964; KAYLER BUTTE, 1964;
PICTURE MOUNTAIN, 1964; TONTO BASIN, 1964

VEGETATION MAPPED ON AERIAL PHOTOGRAPHS
FOR 1967 BY H. H. SCHUMANN

FIGURE 13.--DISTRIBUTION AND DENSITY OF VEGETATION ALONG THE CHANNEL AND FLOOD PLAIN OF LOWER TONTO CREEK.

The monthly potential evapotranspiration rates for the lower Tonto Creek basin computed by the Blaney and Criddle method using a value for K of 1.0 are shown in figure 3. The annual potential evapotranspiration rate is 66.6 inches or 5.55 feet, which is within 4 percent of the potential evapotranspiration value computed from pan evaporation.

Evapotranspiration Losses

Evapotranspiration losses can be estimated from potential evapotranspiration rates if the type of vegetation and the depth to water are known. Blaney suggested a value for K of 0.85 for the entire year for estimating evapotranspiration losses from an alfalfa field (Cruff and Thompson, 1967, p. 16). Other investigators have suggested values for K that are dependent not only on the type of phreatophyte but also on the average depth to the water table (Rantz, 1968, p. 11). Using the suggested values of K, estimates of annual evapotranspiration losses were computed by the equation

$$Q = (U)(K)(D)(A), \tag{4}$$

where

Q = evapotranspiration loss, in acre-feet,
U = potential evapotranspiration loss, in feet,
K = empirical consumptive-use coefficient that is dependent mainly on type of vegetation,
D = factor by which to multiply K value for density of growth, and
A = area of phreatophytes by density class, in acres.

Using the equation for cultivated alfalfa and dense phreatophytes,

$$Q = (5.55)(0.85)(1.00)(1,215) = 5,700 \text{ acre-feet.}$$

Using the equation for light to medium phreatophyte density,

$$Q = (5.55)(0.60)(0.75)(2,700) = 6,700 \text{ acre-feet.}$$

Therefore, the water used by phreatophytes is calculated to be about 12,400 acre-feet.

Evaporation losses from the clear areas, which have very little phreatophyte growth and an estimated average depth to water of 5 feet, were computed from pan-evaporation data (Todd, 1959, p. 156). The clear area of 1,160 acres was multiplied by 5 percent of the average annual pan-evaporation rate of 98.27 inches at Roosevelt, which gives an estimated average annual evaporation loss of 500 acre-feet.

The total annual evapotranspiration loss from the lower Tonto Creek basin is estimated to be 13,000 acre-feet. The average annual evapotranspiration loss per acre is estimated to be 2.6 acre-feet.

Chemical Quality of Water

Water samples were collected from lower Tonto Creek and from selected wells for chemical analysis (table 1). The similarity between the chemical composition of the streamflow and that of the ground water in the alluvium indicates that this aquifer receives most of its recharge by infiltration of streamflow from lower Tonto Creek. The chemical composition of water at selected sites along Tonto Creek is shown graphically in figure 14.

The water from Tonto Creek is of excellent chemical quality and is suitable for most uses. The dissolved-solids concentrations in the water sampled on May 25, 1970, ranged from 255 to 274 mg/l (milligrams per liter); hardness, as calcium carbonate, ranged from 157 to 185 mg/l, and the water is classified as hard to very hard. Fluoride concentrations ranged from 0.3 to 0.5 mg/l, and the main constituents were calcium and bicarbonate (fig. 14). The samples were collected during a period of base flow and probably represent the near maximum concentrations of dissolved solids that may be expected in the flow of lower Tonto Creek. The chemical composition of the water samples collected in 1970 is very similar to that of the samples collected in 1952 (table 1).

Water samples from shallow wells drilled in the alluvium along Tonto Creek also were of excellent quality and the chemical composition is very similar to that of the samples collected from the creek. Dissolved-solids concentrations ranged from 235 to 402 mg/l, and hardness, as calcium carbonate, ranged from 211 to 238 mg/l. Fluoride concentrations ranged from 0.3 to 0.5 mg/l, and the main ionic constituents were calcium and bicarbonate (fig. 14).

Water from well (A-7-10)13bba, which is in the northern part of the basin and obtains its water from the lower part of the basin fill, is a

Table 1.--Chemical analyses of water in the lower Tonto Creek basin

[Results in milligrams per liter, except as indicated. Remarks: S, sample obtained from streamflow; W, sample obtained from well]

Location	Date of collection	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Dissolved solids (calculated)	Hardness as $CaCO_3$		Specific conductance (micromhos at 25°C)	pH	Remarks
												Calcium, magnesium	Noncarbonate			
(A-5-11)8bb	5-25-70	18	42	14	30	168	0	40	34	0.5	261	163	26	490	7.7	S.
8bbc$_1$	5-25-70	18	36	33	24	228	0	40	34	.5	298	225	38	530	7.8	W.
8bbc$_2$	5-25-70	18	71	14	8	258	0	30	22	.4	300	236	25	560	7.6	W.
8c	10-23-52	20	64	16	24	208	----	62	30	.4	318	226	----	520	---	S.
(A-6-10)2baa	5-25-70	15	51	14	25	193	0	14	47	.3	261	185	27	475	7.8	S.
10dad$_1$	1-23-70	-------	156	50	1,010	------	----	2,700	24	3.0	3,940	600	----	-----	---	W; arsenic, 0.21.
10dad$_2$	8-27-70	18	71	11	36	254	0	24	32	.4	307	221	----	550	7.9	W.
11cdb	5-25-70	15	50	13	25	193	0	15	42	.3	255	179	21	455	7.9	S.
11cdd	8-27-70	17	47	12	46	170	4	15	54	.4	263	165	----	490	8.3	S.
14aba$_2$	8-27-70	9.1	47	13	38	184	0	11	40	.3	235	169	----	459	7.4	W.
14abd$_1$	8-27-70	11	57	17	26	230	0	11	41	.3	276	212	----	525	7.8	W.
14bbd	8-27-70	30	61	21	51	252	0	79	36	.3	402	238	----	698	8.1	W.
26aba$_2$	5-25-70	17	60	15	26	226	0	34	32	.4	295	211	26	510	8.0	W.
36abc	5-25-70	16	54	12	25	195	0	27	33	.3	263	182	22	450	8.2	S.
(A-7-10)2acc	5-25-70	14	41	13	42	174	0	13	65	.4	274	157	14	500	7.9	S.
10c	10-16-52	16	48	13	27	196	----	13	40	.4	254	174	----	449	---	S.
11bcd	5-25-70	16	65	17	37	276	0	15	48	.3	334	230	4	605	7.7	W.
13bba	5-25-70	29	64	28	34	281	0	16	72	.2	381	274	44	680	7.9	W.
15dda	5-25-70	14	50	14	28	187	0	14	53	.3	265	182	29	490	8.0	S.

calcium magnesium bicarbonate type and is similar in chemical composition to ground water in the alluvium and to water in Tonto Creek (fig. 14); however, the water has a slightly higher dissolved-solids content and hardness. The fluoride content of the water from this well was 0.2 mg/l. The chemical quality of the water from this well probably is indicative of that in the lower part of the basin fill in the northern part of the basin.

Well (A-6-10)10dad$_1$ was drilled to a depth of 207 feet in the fine-grained facies of the upper part of the basin fill near Punkin Center in the central part of the basin. The water sample from this well contained 3,940 mg/l dissolved solids and the hardness was 600 mg/l; the fluoride concentration was 3.0 mg/l. The main ionic constituents were sodium and sulfate, which is in sharp contrast to the calcium bicarbonate water in the alluvium and in Tonto Creek. The water from well (A-6-10)10dad$_1$ is undesirable for most uses owing to the large amount of dissolved solids and the large fluoride content. The arsenic content of 0.21 mg/l is more than four times the mandatory rejection limit of 0.05 mg/l for drinking water (U. S. Public Health Service, 1962). Water of similar chemical composition may be present in the fine-grained facies of the upper part of the basin fill in the central and southern parts of the basin.

The similarity in the chemical composition of streamflow in Tonto Creek and of ground water in the alluvium is indicated by the size and shape of the diagrams in figure 14. On May 25, 1970, the dissolved-solids content of the ground water from the alluvium was slightly higher than that of the water in Tonto Creek (table 1). The difference probably was due to a slight concentration of the dissolved solids in the ground water as a result of evapotranspiration.

SUMMARY AND CONCLUSIONS

Water enters the lower Tonto Creek basin mainly as streamflow from the upper basin and as precipitation. The streamflow that enters the lower basin is measured at the Tonto Creek above Gun Creek gaging station and averages about 80,000 acre-feet per year. The streamflow that originates in the lower basin in response to the annual precipitation of 17 to more than 20 inches contributes about 20,000 acre-feet per year of surface water to Roosevelt Lake. Part of the streamflow infiltrates into the highly permeable alluvium that underlies Tonto Creek and its flood plain. Water levels in wells drilled in the alluvium rise in direct response to floodflow in the creek, which indicates that a large part of the water lost as streamflow infiltrates to recharge the ground-water reservoir.

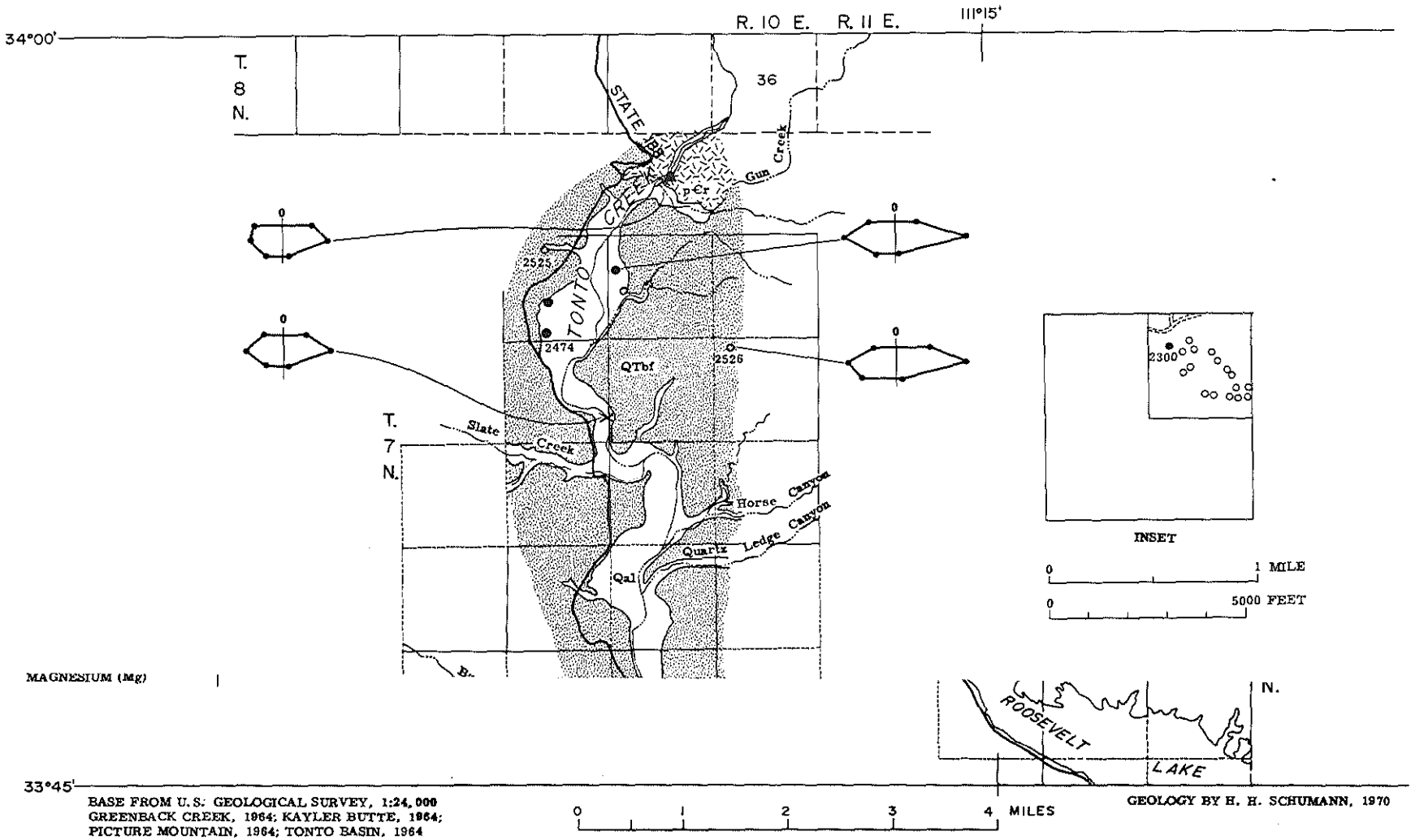


FIGURE 14. --LOCATION OF WELLS AND CHEMICAL QUALITY OF WATER ALONG LOWER TONTO CREEK.

The alluvium is the principal aquifer in the lower Tonto Creek basin and yields large quantities of water to wells. The unit receives recharge from infiltration of flow in Tonto Creek and its tributaries and discharges about 4,000 acre-feet of water annually to Roosevelt Lake. Water lost from the alluvium by evapotranspiration is estimated to be 13,000 acre-feet per year and is estimated to average 2.6 acre-feet per acre per year in the 5,080-acre channel and flood plain of lower Tonto Creek.

Ground-water discharge by subsurface outflow, evapotranspiration, and pumping from wells lowers the water level in the alluvium below the level of the streambed during part of the year, which provides space for streamflow to infiltrate and recharge the ground-water reservoir. Streamflow continues to infiltrate until the aquifer is filled to the level of the streambed. Most of the recharge to the ground-water reservoir occurs from the infiltration of winter runoff.

The estimated annual volume of infiltration of 20,000 acre-feet from Tonto Creek and its tributaries is slightly larger than the combined estimated annual volumes of subsurface outflow and evapotranspiration of 17,000 acre-feet. The estimated infiltration rates were applied to the flow-duration curve for Tonto Creek above Gun Creek and were computed mainly from data collected when the flow in Tonto Creek was fairly constant and when there was no known tributary inflow. Under these conditions, a sufficient volume of unsaturated aquifer material probably is available to accept the infiltration. When the flow in Tonto Creek is large for a prolonged period, however, the volume of unsaturated aquifer material probably decreases to a point where infiltration rates are reduced significantly. Under these conditions, the infiltration rates probably are overestimated, and the amount of surface flow to Roosevelt Lake probably is larger. Therefore, the actual average annual volume of infiltration along lower Tonto Creek probably is about 17,000 acre-feet.

The similarity between the chemical composition of the streamflow in lower Tonto Creek and that of the ground water in the alluvium indicates that this aquifer receives most of its recharge from infiltration of streamflow. The water from Tonto Creek and the ground water in the alluvium are of excellent chemical quality and are suitable for most uses. The lower part of the basin fill yields small quantities of water to wells in the northern part of the area and is potentially a significant aquifer. Water from this unit is of excellent chemical quality and is similar in chemical composition to water in the alluvium. Water from a well drilled in the fine-grained facies of the upper part of the basin fill near Punkin Center contains large concentrations of sodium and sulfate, and the arsenic content of 0.21 mg/l and the fluoride content of 3.0 mg/l exceed the mandatory rejection limits for drinking water.

REFERENCES CITED

Blaney, H. F., and Criddle, W. D., 1962, Determining consumptive use and irrigation water requirements: U.S. Dept. Agriculture Tech. Bull. 1275, 59 p.

Burkham, D. E., 1970, Depletion of streamflow by infiltration in the main channels of the Tucson basin, southeastern Arizona: U.S. Geol. Survey Water-Supply Paper 1939-B, 36 p.

Cruff, R. W., and Thompson, T. H., 1967, A comparison of methods of estimating potential evapotranspiration from climatological data in arid and subhumid environments: U.S. Geol. Survey Water-Supply Paper 1839-M, 28 p.

Feth, J. H., and Hem, J. D., 1963, Reconnaissance of headwater springs in the Gila River drainage basin, Arizona: U.S. Geol. Survey Water-Supply Paper 1619-H, 54 p.

Green, C. R., and Sellers, W. D., eds., 1964, Arizona climate: Tucson, Univ. Arizona Press, 503 p.

Lance, J. F., 1960, Stratigraphic and structural position of Cenozoic fossil localities in Arizona: Arizona Geol. Soc. Digest, v. 3, p. 155-159.

Lance, J. F., Downey, J. S., and Alford, Malcolm, 1962, Cenozoic sedimentary rocks of Tonto basin: New Mexico Geol. Soc. Field Conf., 13th, 1962, Guidebook of the Mogollon Rim region, east-central Arizona, p. 98-99.

Langbein, W. B., and Iseri, K. T., 1960, General introduction and hydrologic definitions: U.S. Geol. Survey Water-Supply Paper 1541-A, 29 p.

Lohman, S. W., and others, 1972, Definitions of selected ground-water terms—Revisions and conceptual refinements: U.S. Geol. Survey Water-Supply Paper 1988, 21 p.

Meinzer, O. E., 1923, Outline of ground-water hydrology with definitions: U.S. Geol. Survey Water-Supply Paper 494, 71 p.

Rantz, S. E., 1968, A suggested method for estimating evapotranspiration by native phreatophytes, in Geological Survey research 1968: U.S. Geol. Survey Prof. Paper 600-D, p. 10-12.

Roeske, R. H., 1971, Floods of September 1970 in Arizona, Utah, and Colorado: Arizona State Land Dept. Water-Resources Rept. 44, 20 p.

Thomsen, B. W., and Schumann, H. H., 1968, Water resources of the Sycamore Creek watershed, Maricopa County, Arizona: U.S. Geol. Survey Water-Supply Paper 1861, 53 p.

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

U.S. Geological Survey, 1970, Surface water records of Arizona: U.S. Geol. Survey open-file report, 246 p.

U.S. Public Health Service, 1962, Drinking water standards: U.S. Public Health Service Pub. 956, 61 p.

U.S. Weather Bureau, issued annually, Climatological data, Arizona: U.S. Dept. Commerce.

Wenzel, L. K., 1942, Methods for determining permeability of water-bearing materials, with special reference to discharging-well methods, with a section on Direct laboratory methods and Bibliography on permeability and laminar flow, by V. C. Fishel: U.S. Geol. Survey Water-Supply Paper 887, 192 p.

Wilson, E. D., Moore, R. T., and Peirce, H. W., 1959, Geologic map of Gila County, Arizona: Arizona Bur. Mines, scale 1:375,000.