Flow from Small Watersheds Adjacent to the Study Reach of the Gila River Phreatophyte Project, Arizona

GEOLOGICAL SURVEY PROFESSIONAL PAPER 655-I

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GILA RIVER PHREATOPHYTE PROJECT

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CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS

Factors for converting English units to the International System of units (SI) are given below to four significant figures:

English Units	Multiply By	Metric Units
inches (in)	2.540	centimetres (cm)
	25.40	millimetres (mm)
feet (ft)	0.3048	metres (m)
	304.8	millimetres (mm)
miles (mi)	1.609	kilometres (km)
square feet (ft^2)	.0929	square metres (m^2)
acres	4047.	square metres (m^2)
	.4047	hectares (ha)
square miles (mi^2)	2.590	square kilometres (km^2)
feet per year (ft/year)	.3048	metres per year (m/year)
acre-feet (acre-ft)	1233.	cubic metres (m^3)
cubic feet per second (ft^3/s)	.02832	cubic metres per second (m^3/s)
acre-feet per day (acre-ft/day)	.01430	cubic metres per day (m^3/day)

GILA RIVER PHREATOPHYTE PROJECT

FLOW FROM SMALL WATERSHEDS ADJACENT TO THE STUDY REACH OF THE GILA RIVER PHREATOPHYTE PROJECT, ARIZONA

By D. E. Burkham

ABSTRACT

The Gila River in Safford Valley, southeastern Arizona, was the site for a field study of evapotranspiration (Culler and others, 1970). During the period of study, 1963–71, measurements of storm runoff in summer—July through October—from tributaries along a 15-mile (24 km) reach of the Gila River were required for water budget analyses. Most of the outflow from the 43 tributary basins, which range in size from about 0.1 to 20 square miles (0.3 to 50 km^2), resulted from thunderstorms of small areal extent. The mean summer runoff for 1963–71 was about 1,370 acre-ft (1,690,000 m^3), or 9 acre-ft per square mile (6,900 m^3 km^2). The maximum summer runoff was about 3,180 acre-ft (3,920,000 m^3) in 1967 and the minimum was about 130 acre-ft (160,000,000 m^3) in 1970. The largest storm outflow was about 970 acre-ft (1,200,000 m^3). The largest peak discharge occurring in a tributary stream was 8,000 cubic feet per second (230 m^3/s) which came from a 14-mi^2 (36 km^2) watershed. The largest peak discharge per square mile was about 2,300 cubic feet per second (65 m^3/s) which resulted from a storm centering on a 0.79-mi^2 (2.0 km^2) watershed. The streamflow data are of poor quality.

The tributary streamflow to the study reach resulted from an average of nine runoff storms per year. The maximum number of runoff storms in the study reach was 31 in 1967 and the minimum was 12 in 1965. The tributary watersheds contributed to the project area on an average of less than 13 days per year. For a tributary, the average number of days of runoff per year was about 3.

INTRODUCTION

The primary purpose of this report is to present data of storm runoff from tributaries along a 15-mile (24 km) reach of the Gila River in southeastern Arizona for 1963–71 (fig. 1). Secondary objectives are to describe the characteristics of flow in the tributary streams; to describe the procedure used and problems encountered in measuring the flow; and to compare the runoff values obtained for the study tributaries with runoff values for nearby basins.

The storm runoff data were required for the water budget analyses of the Gila River Phreatophyte Project (Culler and others, 1970). In the water budget analyses, the amount of evapotranspiration is estimated as a residual when all other significant quantities of inflow and outflow have been measured. The study area of the Gila River Phreatophyte Project includes three reaches (Culler and others, 1970); however, runoff data were obtained only for watersheds tributary to reaches 1 and 2 (pl. 1). The discussion in the section "Design of Network of Gaging Stations" pertains to tributaries to all the reaches; however, the discussions in the rest of the report pertain only to tributaries to reaches 1 and 2.

This report is one of several chapters of Professional Paper 655, which describes the environmental variables pertinent to the Gila River Phreatophyte Project.

CHARACTERISTICS OF THE STUDY AREA

The study area is near Globe, Arizona, and the tributaries are typical of others in the Basin and Range physiographic province (Fenneman, 1931) which drain mountainous slopes paralleling comparatively flat wide sediment-filled valleys (pl. 1). The composite area of the many small basins contributing flow to reaches 1 and 2 is about 150 mi^2 (390 km^2). The long narrow tributary basins range in size from about 0.1 to 20 mi^2 (0.3 to 50 km^2) and drain the south slopes of the Gila Mountains on the north, and north slopes of Mt. Turnbull on the south. For a watershed of given size, the main stream channel of a tributary basin in the study area is about 60 percent longer than the average main channel in other basins in the southwestern United States (fig. 2). The slopes of the study tributaries range from about 2 percent near the Gila River to more than 40 percent on Mt. Turnbull. Altitudes of the tributary basins range from 2,480 feet (756 m) above sea level at the flood plain of the Gila River to 8,200 feet (2,500 m) on Mt. Turnbull.

Near the Gila River, the ephemeral tributary streams are entrenched in deposits of silt, sand, and gravel, which were divided into basin fill, terrace alluvium, and flood-plain alluvium by Davidson and Weist (in Culler and others, 1970, p. A8). The terrace alluvium, through which the tributary streams flow before reaching the flood plain of the Gila River, ranges from less than half a

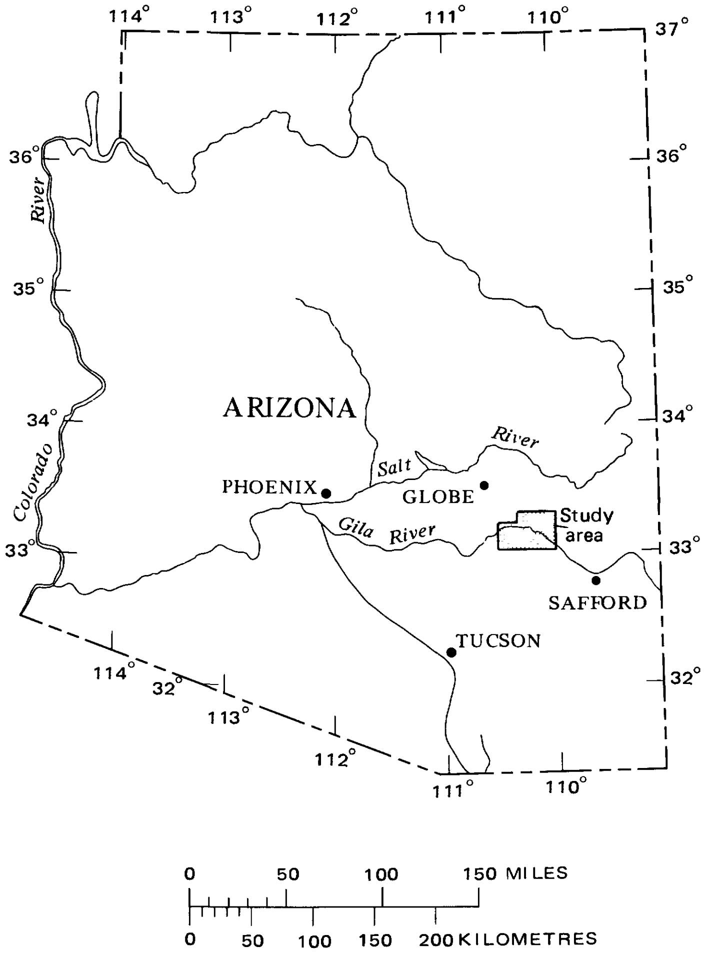


FIGURE 1.—Index map of project area.

mile (about 0.8 km) to more than 2 miles (3.2 km) wide. The flood-plain alluvium along the Gila River is half a mile to 1 mile (0.8 to 1.6 km) wide. The flood-plain alluvium along the study tributaries is of limited extent, ranging from less than 50 to more than 300 feet (15 to 90 m) wide.

Climatically, the study area is in the Sonoran Border Zone (Thomas, 1962, p. 13) and is characterized by a wide range in temperature and average annual precipitation. The temperature extremes recorded at Safford, which is 2,900 feet (880 m) above sea level, are 7° and 114°F (−14° and 46° C) (Sellers, 1960). Safford is about 35 miles (56 km) east of the study area. The long-term average annual precipitation is about 13 inches (330 mm) in the study area. In summer the precipitation is mainly from local convective thunderstorms, which produce rainfall of high intensity and short duration over small areas (Burkham, 1970). The long-term average of summer precipitation is about 7 inches (180 mm) and the temporal variation for summer precipitation is about 40 percent. In winter the precipitation mainly is from convergence, or frontal, storms that distribute moisture over large areas. Because large amounts of precipitation from tropical Pacific storms are infrequent, the temporal variation of winter precipitation is larger than that of summer precipitation (Burkham, 1970). The long-term average of winter precipitation is about 5 inches (130 mm) and the temporal variation of winter precipitation is about 50 percent. In spring the precipitation is generally less than 1 inch (25 mm).

The vegetation in the study area may be grouped according to its location—on the uplands, terraces, or flood plain. The most abundant plants on the uplands are creosotebush (*Larrea tridentata* (Sesse & Mos. ex DC.) Coville), white thorn (*Acacia constricta* Benth.), catclaw (*Acacia greggii* A. Gray), cactus, and mesquite (*Prosopis juliflora* var. *velutine* (Woot.) Sarg.) (Turner, in Culler and others, 1970, p. A19–A20). Scattered clusters of mesquite normally grow along the tributary streams in the uplands. Mesquite communities occupy most of the terrace deposits. Other woody perennials growing on the terraces, according to Turner (in Culler and others, 1970, p. A20), are catclaw, white thorn, gray

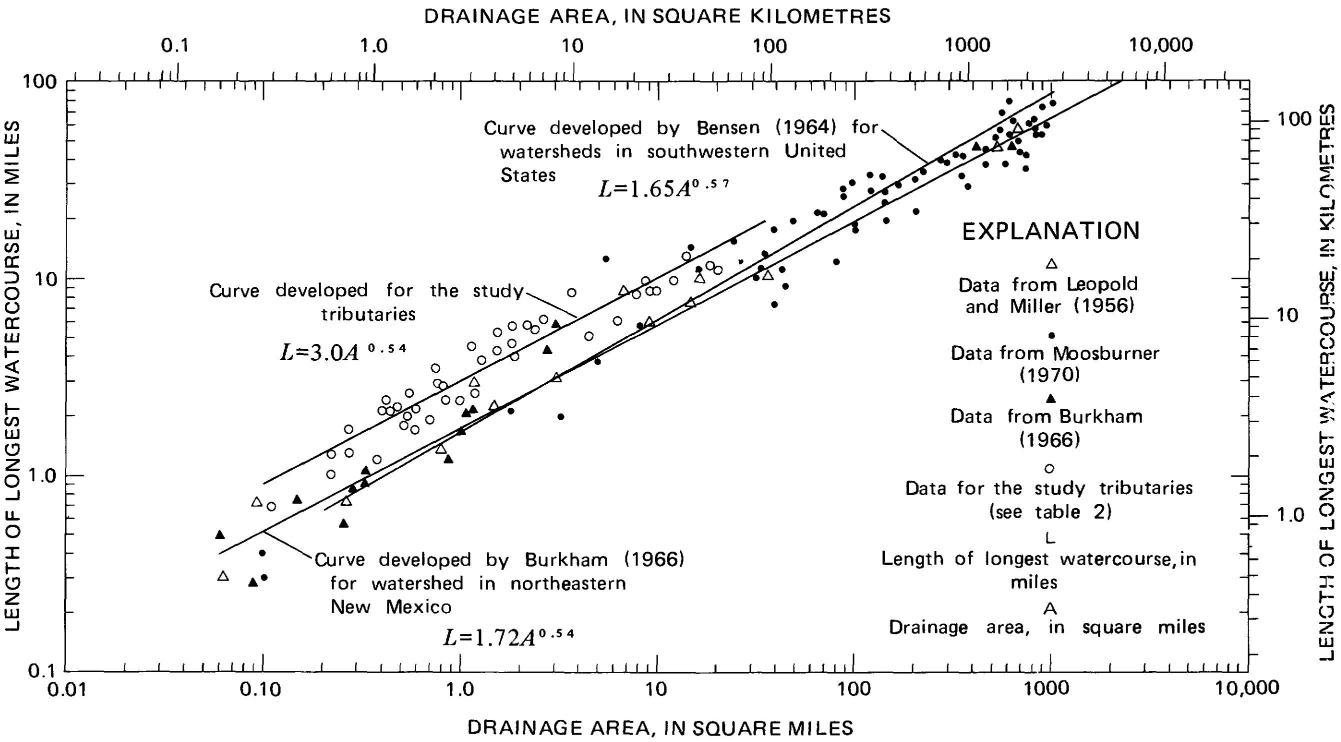


FIGURE 2.—Relation of length of longest watercourse to size of drainage basin.

thorn (*Condaliopsis lycioides* (A. Gray) Suesseng.), and four-wing saltbush (*Atriplex canescens* (Pursh) Nutt.). Saltcedar (*Tamarix chinensis*)[1] is the dominant vegetation on the flood plain of the Gila River. Mesquite and seepweed, however, grow along the outer edges of the flood plain.

Most of the flow in the study tributaries is the result of summer thunderstorms. High unit rates and volumes of flow from the small watersheds characteristically are produced by individual thunderstorms. The crest of a flood from a thunderstorm is typically very sharp when the flood reaches the flood plain of the Gila River. Sometimes, when runoff enters a dry stretch of channel, the flood crest disappears completely because the flow sinks into the alluvium. During late September and October, occasional frontal activity causes precipitation that may produce runoff simultaneously from all the tributary streams. The combined runoff from these general rains and concurrent local thunderstorms often results in relatively large water yields. Infrequently, precipitation during winter may produce small amounts of runoff from some of the tributaries.

Flow in the tributary streams has a high velocity, is almost always in a supercritical state (Chow, 1959, p. 13), carries large sediment loads, and moves large amounts of coarse material along the channel bed. Upon reaching the wide flat flood plain of the Gila River, most of the material is deposited, forming sediment mounds or fans (pl. 2).

DESIGN OF NETWORK OF GAGING STATIONS

The collection of tributary runoff data for three reaches of the Gila River Phreatophyte Project (pl. 1) began in 1962. Plugging of the stream channel of the Gila River with debris from floods in 1962–64 made reach 3 unsuitable for water budget studies (Culler and others, 1970). The design of the procedure to be used to measure flows from tributaries, however, had already been completed before the plugging occurred. The discussions in this section, therefore, are about tributaries to three reaches even though complete sets of data of tributary runoff were obtained only for reaches 1 and 2. The area tributary to the entire study reach of the phreatophyte project is about 260 mi^2 (670 km^2) and the basins range in size from less than 0.1 to 39 mi^2 (0.3 to 100 km^2).

The method of determining flow from tributaries was designed on the following assumptions and criteria:

1. The water budget equation which would be used to evaluate evapotranspiration e as a residual is

$$e = \sum_{j=1}^{8} x_j, \qquad (1)$$

[1]Also referred to as *Tamarix pentandra* and *Tamarix gallica*.

where the components $x_1, \ldots, x_1$ denote (1) surface inflow in the Gila River, (2) surface inflow from tributaries, (3) subsurface inflow in the alluvium of the river and its tributaries, (4) possible artesian inflow from underlying geologic formations, (5) surface outflow in the river, (6) subsurface outflow in the alluvium, (7) precipitation on the flood plain, and (8) change in moisture storage, respectively.

2. The smallest water budget period would be 2 weeks; however, longer water budget periods may be used.
3. Records of tributary flow at or near the flood plain of the Gila River would be needed.
4. Significant amounts of runoff occur only in the summer—July through October.
5. Tributaries contribute surface flow to the study reach for only a small part of the time and this flow is assumed to be a small part of the total water involved in a water budget for most periods.
6. Accurate records of flow for each tributary would not be required.
7. Difficulties in accurately measuring high rates of discharge from tributaries would require that water budgets, which include data for large storms from tributaries, be omitted from study.
8. Periods of no flow in the tributaries would be accurately defined.

Using these assumptions and criteria as guides, a decision was reached that records of tributary flow would be obtained by using gages equipped with continuous-stage recorders in some of the tributary streams and crest-stage gages in most of the remaining tributaries. Runoff records for tributaries having recording gages would be obtained using stage records and stage-discharge relations. Runoff estimates at crest-stage gages would be obtained by use of peak-stage records, stage-discharge relations, and relations between peak discharge and storm volume.

Only 16 continuous-stage recorders were available for the tributary study. The streams in which these recorders were placed were selected on the basis of basin size, physiographic characteristics, and orientation along the study reach of the phreatophyte project. Because runoff increases with the size of the basin, size was given first consideration in selecting streams that would have a continuous-stage recorder. Recording gages were established in the 10 largest basins, which includes about 54 percent of the total tributary area (fig. 3). The remaining six sites were selected on the basis of physiographic characteristics and orientation. About 59 percent of the total tributary area is included in basins where the gages were installed (pl. 1).

Crest-stage gages were installed in 47 tributary streams which drained basins ranging in size from 0.1 to 8 mi^2 (0.3 to 20.7 km^2) (pl. 1). In all, gages were installed in streams draining about 235 mi^2 (610 km^2) or about 90 percent of the composite area of all tributaries along the study reach.

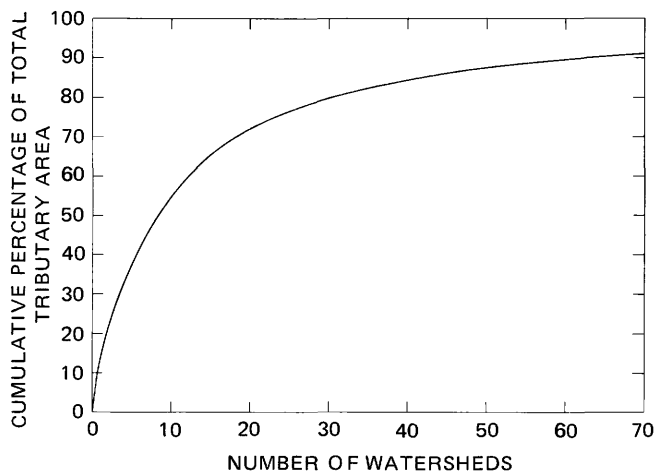


FIGURE 3.—Relation of cumulative percentage of total tributary area to number of watersheds used in computing percentages. Cumulative percentages were derived using the largest watersheds first and continuing with other watersheds arranged in descending order of size.

GAGING STATIONS AND OBSERVATION PROCEDURES

The gaging stations, except for 18 and 26, were established at the downstream ends of highway or railroad structures near the flood plain of the Gila River (pl. 1). The road structures ranged from relatively small box culverts—concrete at highway sites, and wood at railroad sites—to truss bridges spanning more than 300 feet (90 m) of tributary flood plain. Crest-stage gages 18 and 26 were anchored to stream channel banks.

A typical recording gage at a tributary site is equipped with an analog-stage recorder mounted in a metal shelter which is attached to a stilling well. The stilling well is a corrugated metal pipe 12 inches (30 cm) in diameter which is vertically attached to a highway or railroad structure. A staff gage, graduated in feet, tenths of feet, and hundredths of feet, serves as an outside reference gage; the staff gage is attached to the outside of the stilling well. A crest-stage gage mounted near the stilling well serves as a reference gage. The vertical and horizontal scales on the continuous-recorder charts were, respectively, 1 inch equals 1 foot (1 cm equals 0.12 m) and 9.6 inches (24.4 cm) equals 1 day.

The gages were serviced during the summer and current-meter measurements of significant flows were made whenever possible to develop stage-discharge relations; otherwise, only data necessary for indirect measurements were obtained.

STAGE-DISCHARGE RELATIONS

The definition of a stage-discharge relation presented one of the main problems in computing discharge in many of the study tributaries. Control sections were unstable for most streams and current-meter measurements of discharge were difficult or impossible to obtain.

CONTROLS

Alluvial channels with moving boundaries, such as those of the study area, have no naturally occurring permanent control sections. According to Chow (1959, p. 70), the term "control of flow" means*** "the establishment of a definite flow condition in the channel or, more specifically, a definite relationship between the stage and the discharge of the flow. When the control of flow is achieved at a certain section of the channel, this section is a *control section*." Even though there were no permanent controls in the tributary streams, many different time-variant conditions tended to control the flow at the gaging stations. In this report only typical time-variant conditions at gaging stations attached to the downstream ends of box culverts and gaging stations attached to the downstream ends of the bridges are described; these are approximately the extremes of controlling conditions for the sections of streams in the study area. The box culverts in streams draining small basins normally span only a small part of the tributary's flood plain. The bridges on streams draining large basins, however, normally span the total flood plain of the tributary.

Even though the culverts are rigid, control sections at the culverts are not always stable for a full range of flows. A relatively high flow normally goes through a hydraulic jump as it approaches a culvert and dumps most of its load of sand, gravel, and boulders while in the subcritical state. The flow returns to a supercritical state immediately before or after entering the culvert. The flow remains in a supercritical state as it moves through the culvert barrel and downstream. The control section for high flows at a gaging station attached to the downstream end of a culvert, therefore, is the culvert entrance and barrel.

Low flows approaching a culvert may move into the culvert barrel without going through a hydraulic jump. The control section for low flows at a gaging station attached to the downstream end of a culvert, therefore, is the alluvial channel upstream from the culvert entrance and alluvial deposits in the culvert barrel. The alluvial material deposited near the culvert entrance by high flows normally either is removed by maintenance crews or moves slowly through the culvert barrel during low flows; this material may affect the stage-discharge relation of low flow during the time it is in place at the entrance and during the time it is moving through the culvert barrel.

Changes in the channel boundary alter the stage-discharge relation at gages attached to bridges. Changes in the stage-discharge relation normally occur either gradually when low flows are dominant or rapidly when high flows are dominant.

Relatively large adjustments in the channel bed often occur at bridge structures; these adjustments, which affect the stage-discharge relations, are known to result from changes in the alluvial fans at the mouth of tributary streams. The fans form as a result of deposition of sediment carried by the fast-moving tributary flow which is slowed as it reaches the wide, flat flood plain of the Gila River (pls. 1 and 2). Development of the fans causes progressive aggradation in the tributary streams. Short periods of scour, however, occasionally occur at the gage sites of some of the streams as a result of shifts in the location of a tributary stream on its alluvial fan. Channels on a fan are self-formed and, like most others on aggrading alluvial deposits, they have natural levees and are "in grade" with the upstream channel. However, channels on fans aggrade very rapidly, and frequently the beds of the channel become higher than the rest of the surrounding fan. When this occurs, the natural levees fail, usually during high flow, and a new channel forms at a different location and at a lower level on the fan. The lowering of the point of discharge on an alluvial fan causes scouring in the upstream channel. The concurrent scouring in the upstream channel and filling on the fan continues until the bed of the stream is again "in grade." The cyclic scouring occasionally lowers the channel bed at some of the gages by as much as 1 foot (0.3 m).

DISCHARGE MEASUREMENTS

Two methods of measurement were used to determine flow rates in the tributary streams, direct and indirect. Direct methods refer to discharge measurements made using current meters. Indirect methods refer to measurements made using theoretical or empirical equations to determine flow rates after a flow event had occurred.

The indirect methods of determining discharge for a given stage at the gaging stations were based on either the standard-step method of determining surface profiles (Chow, 1959), or the related slope-area method of determining discharge (Dalrymple and Benson, 1967). Both methods are based on a theory of energy balance within a reach and both are designed for uniform flow in which the water surface profile and energy gradient are parallel to the streambed, and the cross-sectional area, hydraulic radius, and depth remain constant through the reach. For lack of a better solution, the methods are assumed to be valid for the flow and channel conditions that prevail in the tributary streams provided that the energy losses are properly considered.

In determining a stage-discharge relation using the standard-step method, the following information was required:

1. An assumed discharge for which the stage at the gaging station was desired.
2. The water-surface altitude at a control section; the control section would be downstream for subcritical flow and upstream for supercritical flow. The starting altitude for the gaging stations at culverts was critical depth for the discharge at the culvert entrance; the starting altitude for the bridge sites was taken to be critical depth at a distance equal to 3 to 5 channel widths upstream.
3. The cross-sectional width, area, and wetted perimeter at various sections along the reach for all depths of flow within the range expected. Reach length between sections also was required.
4. The Manning roughness coefficient n and eddy losses at the various sections. The selection of roughness coefficients was based entirely on the factors that affect the value of roughness for subcritical flow and on the phenomena of supercritical flow. Tables and photographs of typical roughness coefficients for supercritical flow for channels of various types were not available. Boundary changes or channel roughness may cause flow separation or surface disturbances in supercritical flow that are not typical in subcritical flow. The magnitude of the energy losses due to these disturbances of supercritical flow may not be properly covered by the values of n that were selected.

Briefly, the computation steps in using the standard-step method to determine stage for a given discharge are:

1. A water surface altitude is known or assumed at an upstream section for an assumed discharge.
2. A velocity head is computed for the upstream section.
3. A water surface altitude is assumed for the discharge at the next downstream section.
4. Intervening losses due to friction or deceleration are computed through the reach between these two cross sections.
5. The energy balance is tested, and if it does not balance, the assumed altitude at the downstream section (step 3) is revised, and steps 4 and 5 are repeated until a balance can be achieved with an acceptable tolerance.
6. Computations then proceed to the next downstream section and continue through all the subreaches until the section at the gage site is reached.

The altitude for the gage site at which an energy balance is obtained was used, along with the corresponding assumed discharge, as a plotting point in developing a stage-discharge relation for the gaging station. Enough points were obtained using the procedure described above to define a smooth curve.

The slope-area method of determining peak discharges, which makes use of the Manning discharge equation, is described by Dalrymple and Benson (1967). The Manning equation is

$$Q = \frac{1.486}{n} A R^{2/3} S^{1/2}, \tag{2}$$

in which

Q = discharge rate in cubic feet per second;
n = a roughness coefficient;
R = hydraulic radius in feet; equals the cross-sectional area of flow A divided by the cross-sectional wetted perimeter P; and
S = hydraulic gradient in feet per foot.

A stage-discharge relation for each gaging station was computed using the standard-step method. The initial intent was to verify these relations by using current-meter and slope-area measurements of discharge. This plan was later discarded when it became apparent that this refinement of the stage-discharge relation could not be justified because of the limited scope of the tributary study and because of difficulties involved in making the vertification measurements. However, a few current-meter and slope-area measurements of floodflow were made. A discussion of problems encountered in making current meter measurements follows.

Current-meter measurements were extremely difficult to obtain in most of the tributary streams because of the following reasons:

1. Stream gagers could not wade flows deeper than about 1 foot (0.30 m) because of extremely high velocities, rapid erosion of the channel bed around the stream gager's feet, and debris—including trees, boulders, and diamondback rattlesnakes—being washed downstream.
2. Most of the floods came after normal working hours and, during flood, the high rates of flow normally lasted less than 15 minutes. Cableways normally used to measure high flow rates were not con-

structed and equipment usually used to measure floodflows at bridges was not obtained because of prohibitive cost. The equipment probably could not have been used if it had been available because the high flows would have passed before the equipment could have been readied to make a measurement. If the high-flow equipment had been available, the extremely high velocities, shallow depths, and debris would have presented other problems to overcome in order to make a measurement.

3. Flow less than about 1 foot (0.3 m) deep could be waded; however, the flow velocity could not be determined accurately using the pygmy or small Price current meters. The velocity of flow for depths greater than about 0.2–0.3 (0.06–0.09 m) was more than 4 ft/s (0.11 m/s), which is about the maximum velocity that can be measured using a pygmy meter. The small Price current meter was not suited for depths of flow less than about 0.8 foot (0.2 m), because of the shallow depths and because of a separation of the fast-moving flow at the meter when it was set at the proper position in the flow. The separation of flow would result in about half of the cups being completely free of water. The meter undoubtedly was not rated for this type of flow condition.

On two occasions experienced stream gagers attempted to make wading measurements in flows deeper than 1 foot (0.3 m). In both instances, the measurements were not completed because the stream gagers were washed off their feet. A few discharge measurements of flow less than 1 foot deep were made using the small Price current meter; however, the error in the data may be relatively large.

PEAK DISCHARGE–STORM VOLUME RELATIONS

The relation between peak discharge and storm volume for the tributary streams is assumed to be of the form

$$V = m(Q_p)^n, \tag{3}$$

in which

V = volume of runoff, in acre-ft;

Q_p = peak discharge, in cubic feet per second; and

m, n = coefficient and exponent, respectively.

Data of peak discharge and storm volume from watersheds near the study tributaries were used to evaluate m and n in equation (3) (fig. 4). Only data for single-peak storms from watersheds having drainage areas of less than 100 square miles (260 km^2) were used in the analysis. Assumptions were made that most of the flows in the study tributaries and in the different watersheds near the study area resulted from high-intensity rainfall occurring during thunderstorms and that single-peak flood hydrographs have similar shapes. The values of m and n were 0.03 and 1.14 for the data sets used in the analysis giving equation (4):

$$V = 0.03\ (Q_p)^{1.14}. \tag{4}$$

The standard error of estimate for the relation is about 0.3 log unit; this is about 75 percent which is the average of a 100 percent positive error and a 50 percent negative error.

According to equation (4) and the equations developed by Renard and Keppel (1966), Craig (1970), and Aldridge and Condes de la Torre (written commun., 1969), the peak-discharge versus storm-volume relation is approximately linear for the type of storms producing most of the single-peak floods in the region including the study tributaries. By assuming that the relationship in linear and noting that the storm hydrographs have a triangular shape (fig. 5), the following equation is developed:

$$V = 0.041(Q_p)t, \tag{5}$$

in which

t = duration of significant rates of flow for a storm, in hours.

The duration of significant rates of flow for most single-peak floods occurring in the study tributaries is estimated to range from 0.5 to 4 hours. When these t values are inserted in equation (5), the equation reduces to

$$V = 0.02Q_p \tag{6}$$

and

$$V = 0.16Q_p. \tag{7}$$

As shown in figure 4, for t=4 hours most of the plotted points lie between the lines for equations (6) and (7).

RUNOFF

COMPUTATION OF DATA

Runoff from tributaries having recording gages was computed using general methods adopted by the U.S. Geological Survey. These methods are described by Corbett and others (1943) and in standard textbooks on the measurement of streamflow. In general, a mean stage for a period of time is used with a stage-discharge relation. Because the stage changes very rapidly during most floods in the tributary streams, the mean stage and average discharge for short increments of time were

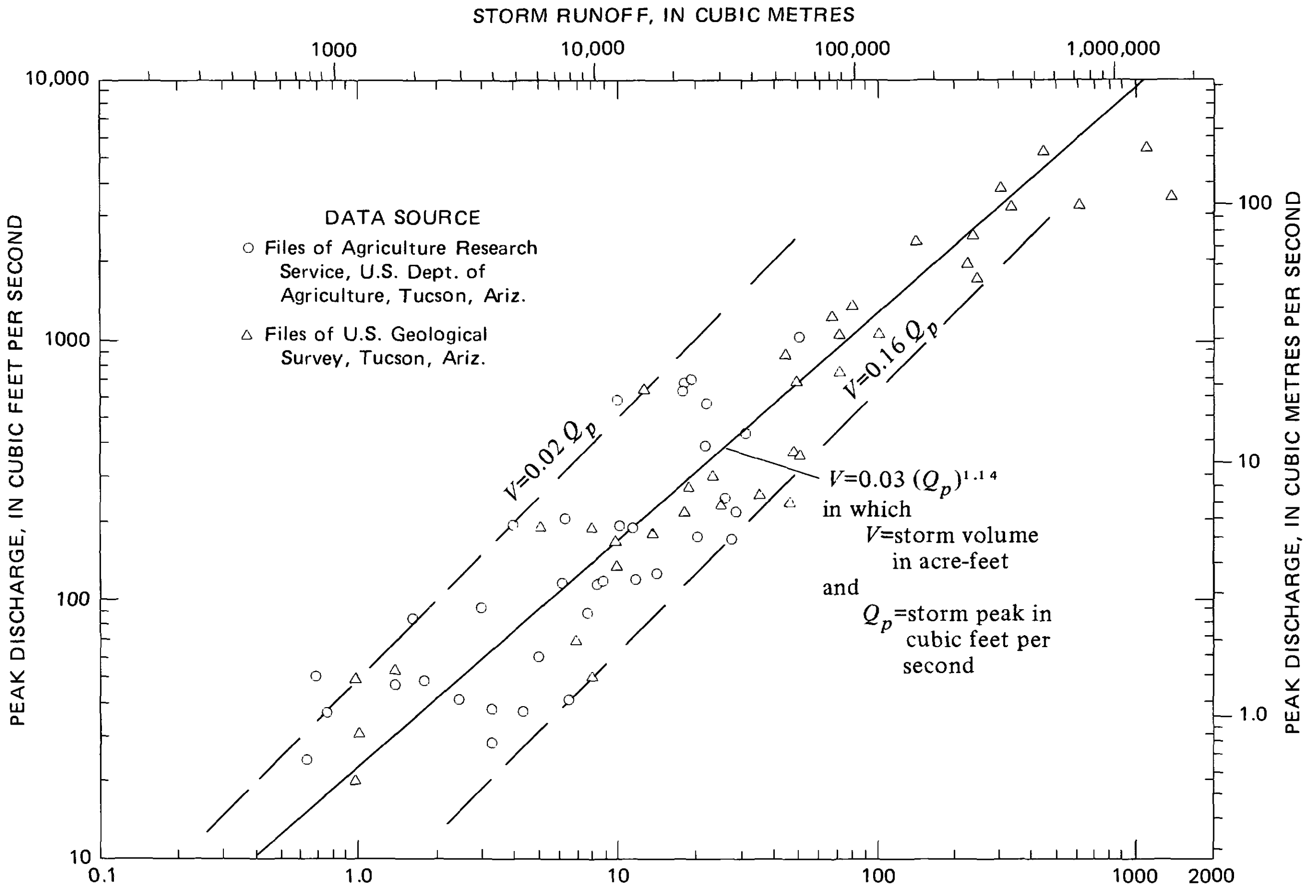


FIGURE 4.—Relation of peak discharge to storm volume for single-peak storms occurring in watershed having area less than 100 mi² (260 km²) in southeastern Arizona.

computed. The stage-discharge relations computed using the standard-step method (see p. I6) were used as basic rating curves. As previously discussed, the stage-discharge relations for the study streams are subject to change because of frequent or continual change in the physical features that control the flow. Because current-meter discharge measurements were not made, shifts in the basic stage-discharge relations were based entirely on notes supplied by the stream gagers describing changes in the channel's properties. Storm and seasonal volumes of runoff were obtained by summing the volumes computed for the incremental time periods.

As discussed in the preceding section, storm runoff from tributaries having crest-stage gages was computed by applying a peak discharge to an average peak-discharge versus storm-volume relation. The method of determining peak discharge from the stage recorded at crest-stage gages is similar to that of determining discharge at the recording gages. The average peak-discharge to storm-volume relation shown in figure 4 was used as the basic discharge-volume curve. This average curve is applicable for single-peak floods produced by typical thunderstorms.

Storms occasionally occur in the study watersheds that produce multipeak floods of relatively long duration. The average peak discharge-volume relation shown in figure 4 was shifted for these multipeak storms in a manner similar to the shifting of a stage-discharge relation for a changing control condition (Corbett and others, 1943, p. 125–130). The amount of shift of the relation for a storm was based on hydrographs of rates of flow from the storm measured in streams having recording gages, and a graph of equation (4) superimposed on a plot of peak discharges and volumes obtained at the recording gages. The adjusted peak discharge-volume relation was used to compute runoff volumes for the given storm in the streams having crest-stage gages.

The stream gagers provided values of the duration of significant rates of flow t for a few storms occurring at crest-stage sites. For these storms, storm runoff values

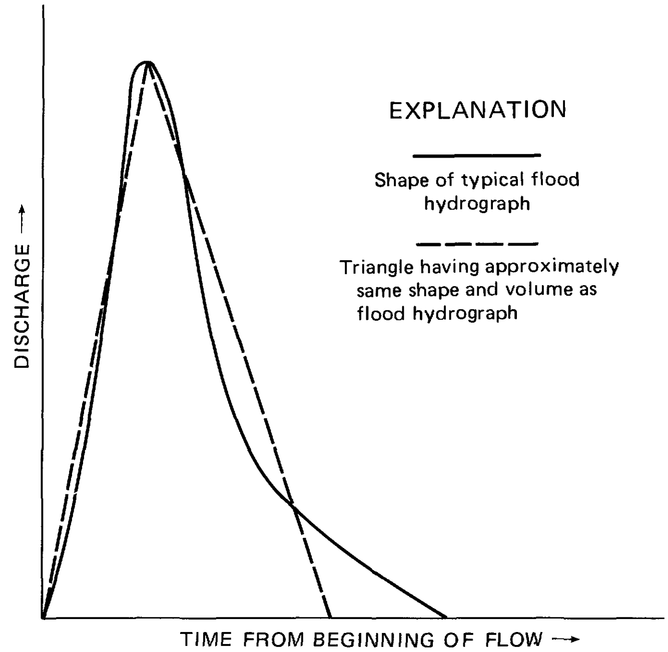


FIGURE 5.—Hypothetical hydrograph for a single-peak flow event in the tributary streams.

were computed using equation (5) as well as equation (4): agreement between the two computed values was fair. The values obtained by using equation (4), however, were used.

STORM AND ANNUAL VOLUMES

The mean summer runoff from all the study watersheds for 1963–71 was about 1,370 acre-ft (1,690,000 m^3) or 9 acre-ft per square mile (6,890 m^3/km^2) per season (tables 1 and 2). The mean summer runoff from watersheds tributary to reach 1 was about 750 acre-ft (925,000 m^3) and from watersheds tributary to reach 2 about 620 acre-ft (2,000,000 m^3) in 1967 and the minimum summer runoff was about 40 acre-ft (49,300 m^3) in 1970. In reach 2, the maximum summer runoff was about 2,220 acre-ft (2,740,000 m^3) in 1971 and the minimum was about 90 acre-ft (111,000 m^3) in 1970. The storm that produced the largest runoff occurred on August 5–6, 1967, when the inflow to reach 1 was about 280 acre-ft (345,000 m^3) and the inflow to reach 2 was about 690 acre-ft (851,000 m^3).

The tributary streamflow into reaches 1 and 2 resulted from an average of nine runoff storms per year (table 1). The maximum number of runoff storms at gaging sites in streams tributary to reach 1 was 15 in 1967, and the minimum number was 6 in 1965 and 1968. In reach 2 the maximum number of storms was 14 in 1967, and the minimum number was 6 in 1965, 1969, and 1970.

The watersheds contributed flow to reaches 1 and 2 on an average of less than 13 days a year. Thus, for 96 percent of the days of a year there was no flow in any of the streams. For the study area, the number of days of runoff per year did not increase greatly with an increase in size of watershed, and, for a given stream in the area, the average number of days of runoff per year was about 3 (fig. 6).

Annual peak discharges for the different streams are given in table 3. An annual flood peak is the highest instantaneous discharge rate occurring during a season. A peak discharge of about 8,000 ft^3/s (226 m^3/s) in tributary 16 on August 5–6, 1967, was the largest peak flow recorded in the tributary streams; a peak discharge of about 7,000 ft^3/s (198 m^3/s) occurred in tributary 17 on the same dates. The largest peak discharge per square mile was about 2,300 ft^3/s (65.1 m^3/s), which resulted from a storm centering on tributary 28 on July 16–17, 1967.

ACCURACY OF DATA

The accuracy of streamflow data for the tributary streams could not be determined directly. The statements that follow, therefore, are of a general nature and are based on the author's experience in determining accuracy of streamflow data for other sites (Burkham and Dawdy, 1970).

The accuracy of discharge data depends primarily on (1) the stability of the stage-discharge relation or, if the control is not stable, the frequency of discharge measurements; and (2) the accuracy of observations of stage, measurements of discharge, and interpretation of data. As previously discussed, the stage-discharge relations for most of the study streams were unstable and, furthermore, discharge measurements could not be made. The streamflow data, therefore, are of poor quality.

In reports of surface-water data published by the Geological Survey there are accuracy statements which say "* * * 'Excellent' means that about 95 percent of the daily discharges are within 5 percent; 'good' within 10 percent; and 'fair' within 15 percent. 'Poor' means that daily discharges have less than 'fair' accuracy." According to these definitions, streamflow data for flashy flows in mobile alluvial channels should never be rated better than fair and rarely should they be rated better than poor. The streamflow data for the study streams are rated poor. The data of peak discharges and storm totals for most of the runoff storms are probably within 100 percent of true values; the data of seasonal runoff probably are within 50 percent of true values.

The data of days of no flow, which were of prime importance to the water-budget analyses, are well documented and are therefore considered excellent. As previously discussed for a given stream, there was no flow 96 percent of the days of a year.

TABLE 1.—*Storm runoff from tributaries, Gila River Phreatophyte Project, 1963–71*

[Runoff, in acre-feet]

A. Reach 1

Date	Tributary No.																				Storm total
	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	38.5	39	40	41	42	
1963																					
Aug. 2–3	2.5	15	----	----	----	----	8	0.4	2	----	----	----	1	----	----	----	1	1	0.4	----	31.3
Aug. 4–5	----	----	----	----	----	----	36	----	----	----	----	----	----	----	----	----	----	----	----	----	36
Aug. 7	----	----	----	----	----	----	----	----	----	----	----	----	----	0.4	8	----	7	----	----	----	15.4
Aug. 13	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	.4	3	3.4
Aug. 22	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	10	----	----	----	10
Aug. 26	----	----	----	----	----	----	----	.4	----	----	----	----	----	----	----	----	----	----	----	----	.4
Oct. 5	----	1	----	----	----	----	----	.4	----	----	----	----	----	----	----	----	----	----	----	----	1.4
Oct. 21	----	----	----	3	----	----	14	----	----	----	4	0.4	----	----	----	----	----	----	.4	----	21 8
Total	2.5	16	----	3	----	----	58	1.2	2	----	4	.4	1	.4	8	----	18	1	1.2	3	119.7
1964																					
July 20	----	----	----	----	----	----	----	4	10	----	----	----	0 4	----	----	----	----	----	----	----	14.4
July 30	----	----	----	----	----	----	----	1	7	----	----	----	----	----	9	----	6	0.5	0.4	----	23.9
Aug. 2	----	----	----	----	----	----	----	----	----	----	----	----	----	1	----	----	----	----	----	----	1
Aug. 4	----	1	1	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	2
Aug. 8–9	----	----	----	----	----	----	----	----	----	----	----	----	----	----	7	----	----	----	----	----	7
Aug. 11	----	----	----	----	----	----	----	----	----	----	----	----	1	----	----	----	----	----	----	----	1
Aug. 13	----	----	----	25	----	----	----	----	4	----	----	----	----	----	----	----	2	1	----	5	37
Aug. 15–17	30	1	40	1	0.4	----	----	1	----	----	----	----	.4	----	9	----	2	2	.4	17	104.2
Aug. 18	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	2	----	----	----	2
Aug. 26	----	----	----	----	.4	----	----	3	5	----	7	14	2	5	50	----	40	2.5	1.4	120	250.3
Sept. 8–9	30	10	40	68	15	----	40	----	35	6	5	----	----	----	----	----	----	----	----	----	249
Sept. 11	30	8	----	20	----	----	----	----	----	----	2	----	----	----	----	----	----	----	----	----	60
Sept. 16	----	1	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	1
Total	90	21	81	114	15.8	----	40	9	61	6	14	14	3.8	6	75	----	52	6.0	2.2	142	752.8
1965																					
July 21	----	----	----	----	0.5	----	----	3	11	----	2	----	----	----	6	----	----	1	----	----	23.5
July 23–24	----	0.5	----	----	10	----	----	----	----	----	----	----	1	8	29	4	----	3	1	36	92.5
July 28	----	----	18	10	----	0.9	1	3	9	----	----	0.4	----	----	40	8	35	12	80	----	217.3
Aug. 14	----	2	51	70	70	27	10	3	7	----	5	8	2	6	50	8	60	4	25	48	456
Sept. 3	----	----	1	----	2	4	1	2	10	----	----	1	1	2	4	----	10	.5	.5	3	42.0
Sept. 14	----	----	----	----	----	----	----	----	----	----	----	----	----	----	8	----	----	.5	.5	----	9
Total	----	2.5	70	80	82.5	31.9	12	11	37	----	7	9.4	4	16	137	20	105	21.0	107.0	87	840.3
1966																					
June 26	----	----	----	----	----	----	----	----	----	----	----	----	0.4	----	----	----	----	----	----	----	0.4
July 10	----	----	----	----	----	----	----	----	----	----	----	----	----	----	7	5	6	2	----	8	28
July 26	----	----	0.4	----	----	0 4	----	7	48	----	7	35	3	----	35	9	24	1	----	20	189.8
July 28	----	----	7	----	----	2	----	5	7	----	7	20	7	----	70	24	31	6	7	----	193
Aug. 6	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	5	----	----	----	----	5
Aug. 18–19	----	----	----	----	----	----	----	----	----	----	----	3	----	----	----	----	40	----	.4	50	93.4
Aug. 20	----	----	----	----	----	----	----	----	----	----	----	----	1	----	94	----	12	----	6	22	135
Sept. 13	----	----	----	----	----	----	----	.6	----	----	3	----	1	----	6	2	2	----	----	28	42.6
Total	----	----	7.4	----	----	2.4	----	12.6	55	----	17	58	12.4	----	212	45	115	9	13.4	128	687.2

1967																					
May 24	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	9	9
July 2	----	----	----	----	----	----	----	----	----	----	----	----	0.3	----	----	----	----	----	----	----	.3
July 9	----	370	2	8	4	4	23	----	----	----	2	0.3	1	----	5	----	----	----	----	----	419.3
July 13	----	10	----	----	----	1	----	----	----	----	----	----	----	----	----	----	----	----	----	----	11
July 16–17	30	1	52	8	60	4	12	----	----	----	----	----	----	2	----	----	6	----	----	12	187
July 21	32	15	12	----	40	7	----	1	20	----	----	----	----	----	----	----	----	----	----	----	127
July 23–25	----	5	----	12	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	17
July 27	2	----	8	18	20	18	----	10	25	----	----	----	----	1	----	----	5	----	----	----	107
July 30	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	38	38
Aug. 2–3	----	----	----	----	----	----	----	----	----	----	----	.3	----	----	----	----	11	----	0.2	56	67.5
Aug. 5–6	50	120	13	90	5	1	----	----	2	----	----	----	----	----	----	----	----	----	----	----	281
Aug. 12	----	----	----	----	----	----	----	----	----	----	5	----	----	1	----	----	----	----	----	----	6
Aug. 17	31	----	----	75	15	15	60	----	5	----	----	----	----	----	----	----	----	----	----	110	311
Aug. 28	----	----	----	----	----	----	----	----	----	----	----	----	----	2	----	----	----	----	----	----	2
Sept 6	----	----	----	----	----	----	6	1	7	----	----	----	----	----	7	----	----	0.5	----	12	33.5
Total	145	521	87	211	144	50	101	12	59	----	7	.6	1.3	6	12	----	22	.5	.2	237	1,616.6
1968																					
July 24	----	1	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	1
July 27	----	----	1	----	3	5	0.4	8	----	----	----	----	----	2	100	----	16	8	50	20	213.4
Aug. 1	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	76	76
Aug. 4–5	----	6	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	6
Aug. 11	----	----	----	----	----	----	----	.4	15	----	----	----	2	2	10	----	5	----	10	26	70.4
Aug. 20	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	2	----	----	----	2
Total	----	7	1	----	3	5	.4	8.4	15	----	----	----	2	4	110	----	23	8	60	122	368.8
1969																					
July 16	----	----	----	----	----	----	----	----	----	----	----	----	1	1	9	3	2	----	----	----	16
July 20	----	1	10	6	20	2	40	4	23	3	----	0.1	.7	2	12	19	6	0.4	----	3	152.2
Aug. 5–6	----	----	----	----	----	----	4	.4	9	2	----	----	----	2	12	4	12	----	----	----	45.4
Aug. 13–15	----	----	----	----	----	----	5	----	----	----	----	.1	.1	3	12	4	8	2	.4	12	46.6
Aug. 26	----	----	----	----	----	----	----	.1	9	----	----	----	----	----	----	----	----	----	----	----	6.1
Sept. 11–15	----	----	----	----	----	----	----	----	.9	----	----	----	----	----	7	----	8	----	.6	30	46.5
Oct. 20–21	----	----	----	----	----	----	----	----	.4	----	----	----	----	----	7	2	4	.1	.4	2	15.9
Total	----	1	10	6	20	2	49	4.5	39.3	5	----	.2	1.8	8	59	32	40	2.5	1.4	47	328.7
1970																					
July 3	----	2	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	2
July 20–21	----	----	----	----	----	----	0.9	0.4	3	----	----	----	----	2	0.4	0.6	----	----	----	1.4	8.7
Aug. 8	----	----	----	----	----	----	----	----	----	----	----	----	----	.4	1.4	.4	0.6	----	----	----	2.8
Aug. 16–17	----	----	----	----	----	----	----	----	----	----	----	----	----	.1	----	----	.6	----	----	----	.7
Sept. 3–6	----	----	----	----	----	----	----	.1	1.5	----	----	----	----	.1	6	----	.1	----	----	----	7.8
Sept. 8–12	----	----	----	----	----	----	----	----	----	----	----	----	----	.1	1.4	----	2.5	0.9	8	3.6	16.5
Oct. 3–4	----	----	----	----	----	----	----	.1	----	----	----	----	----	----	----	----	.1	----	----	----	.2
Total	----	2	----	----	----	----	.9	.6	4.5	----	----	----	----	2.7	9.2	1.0	3.9	.9	8	5.0	38.7
1971																					
uly 16	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	0.1	----	----	----	0.1
July 19	0.1	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	2.4	----	4.2	5	11.7
July 23–24	22	2.4	3.6	----	----	----	----	0.3	0.1	----	----	----	----	----	0.6	0.1	.1	0.1	.6	.4	30.3
July 30	85	1.4	5	0.1	----	2	0.6	1.4	5	----	3	2.4	0.4	0.4	25	2.5	34	4.8	5.4	.1	178.5
Aug. 9–10	.1	----	----	----	----	.8	.8	3.6	5.5	----	.1	.4	.1	.4	.4	----	2.4	----	1.9	4	20.5
Aug. 12	31	27	.4	110	.4	.4	40	5.5	34	----	----	.6	----	.6	6	1.9	----	1.9	6	.4	266.1
Aug. 14	----	21	----	5.5	----	----	.8	----	----	----	----	----	----	----	----	----	----	----	----	----	27.3
Aug. 19	16	4.2	1.9	----	----	----	----	----	----	----	----	----	----	----	----	----	1.4	----	1.4	.4	25.3
Aug. 28	----	----	.1	----	----	.1	----	3.6	7	----	----	----	----	----	----	----	----	----	----	----	10.8
Sept. 1	----	1.9	4.2	4.2	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	10.3
Sept. 30	----	----	----	----	----	----	----	----	----	----	----	.4	.1	----	1.4	.6	----	----	3	----	5.5
Oct. 1	4.2	11	.4	9	5.5	5	90	7	7	----	5	3.6	3.6	2.4	22	9.4	2.4	3	7.5	2.7	200.7
Total	158.4	68.9	15.6	128.8	5.9	8.3	132.2	21.4	58.6	----	8.1	7.4	4.2	3.8	55.4	14.5	42.8	9.8	30.0	13.0	787.1

TABLE 1.—*Storm runoff from tributaries, Gila River Phreatophyte Project, 1963–71*—Continued

B. Reach 2

Date	Tributary No.																							Storm total
	14	15	16	17	18	19	20	21	22	23	43	44	45	46	47	48	49	50	50.5	51	52	53	54	
1964																								
July 20	----	----	----	----	----	----	----	----	----	----	2	1	----	----	----	----	----	----	----	----	----	----	----	3
July 30	----	----	----	----	----	----	----	----	----	----	----	----	----	----	6	1	0.1	----	----	12	----	----	----	19.1
Aug. 8–9	----	----	0.4	----	----	----	----	----	----	----	----	----	----	----	----	.4	.1	2	----	35	----	1	80	118.9
Aug. 13	----	----	44	87	----	----	----	----	----	----	----	1	3	13	16	2	3	----	----	----	----	----	----	169
Aug 15–17	0.4	----	----	----	4	24	----	5	1	----	----	3	----	----	1	.4	1	----	----	2	----	----	----	41.8
Aug. 20	----	----	----	----	----	----	8	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	8
Aug. 26	----	----	----	----	----	----	----	----	----	----	----	4	23	9	20	10	.1	2	----	70	----	----	----	138.1
Sept. 8–9	----	----	24	40	2	----	10	----	----	1	----	----	----	----	----	----	----	----	----	----	----	----	----	77
Sept. 11	----	----	.1	----	----	----	.4	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	.5
Sept. 13	1	----	----	----	----	1	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	2
Sept. 14	1	----	.7	4	2	13	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	20.7
Sept. 15	----	----	18	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	18
Total	2 4	----	87 2	131	8	38	18.4	5	1	1	2	9	26	22	43	13.8	4 3	4	----	119	----	1	80	616.1
1965																								
July 21	----	----	----	----	----	----	----	----	----	9	0.8	0.9	----	----	1	----	----	----	----	----	----	----	----	11.7
July 23–24	----	----	----	24	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	24
July 28	1	3	6	20	40	10	2	9	----	----	17	15	7	14	25	38	4	6	2	----	----	----	----	219
Aug. 14	----	----	9	96	----	7	----	----	----	----	23	17	8	7	12	35	1	----	1	----	----	----	----	216
Sept. 3	----	----	.7	120	6	8	----	----	----	----	----	----	1	3	14	22	1	----	----	1	----	----	12	188.7
Sept. 14	----	----	.8	27	6	9	----	----	----	----	----	.6	----	.8	3	17	1	2	4	----	----	1	----	72.2
Total	1	3	16.5	287	52	34	2	9	----	9	40.8	33.5	16	24.8	55	112	7	8	7	1	----	1	12	731.6
1966																								
June 26	----	----	----	29	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	29
July 10	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	0.8	0.4	----	0.8	----	----	----	----	2.0
July 26	----	----	18	----	----	----	----	----	----	----	2	1	0.2	----	----	----	----	----	----	----	----	----	----	21.2
July 28	----	----	2	----	----	----	----	----	0.2	----	----	.5	----	----	----	----	----	----	----	----	----	----	----	2.7
Aug. 6	----	----	4	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	4
Aug. 10	----	----	.4	----	----	----	0.5	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	.9
Aug. 18–19	----	----	----	----	----	----	----	----	----	----	2	7	6	13	4	37	2	9	3	6	----	----	----	89
Aug. 20	----	----	----	----	7	2	----	----	----	----	1	----	----	2	1	.8	.3	----	----	----	----	----	----	14.1
Aug. 31	----	----	3	----	----	2	----	----	----	----	----	----	----	----	.8	.4	----	----	.6	11	----	----	----	17.8
Sept. 1–10	----	----	.6	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	.6
Sept. 13	----	----	4	----	----	----	.5	----	----	----	1	.7	1	6	2	3	2	----	.9	13	85	0.9	----	120
Total	----	----	32.0	29	7	4	1.0	----	.2	----	6	9.2	7 2	21	7.8	42.0	4.7	9	5.3	30	85	.9	----	301.3
1967																								
May 24	----	----	----	----	----	----	----	----	----	----	0.3	0.7	----	----	----	----	----	----	----	----	----	----	----	1.0
July 9	----	----	1	1	----	----	----	----	.1	----	----	----	----	----	----	----	----	----	----	----	----	----	----	2.1
July 13	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	8	----	----	----	8
July 13–17	0.7	----	10	4	12	4	9	2	----	1	.3	.9	19	13	24	36	2	3	----	25	6	0.6	1	173.5
July 21	----	----	40	28	----	5	18	----	1.2	11	----	----	----	----	----	----	----	----	----	----	----	----	----	103.2
July 23–25	----	----	----	----	----	----	----	2	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	2

July 27	.5	----	28	3	15	6	20	1	----	1	----	----	----	----	8	4	1	----	----	2	----	----	----	89.5
July 30	----	----	1	----	----	1	14	----	----	----	.3	1	1.3	6	7	2	1	----	----	8	----	.6	----	43.2
Aug. 2–3	----	----	----	----	----	----	----	----	----	----	----	----	----	1	----	2	----	----	----	----	----	----	----	3
Aug. 5–6	----	5	300	135	----	32	80	----	----	----	----	.9	.9	1	1	4	1	4	----	60	35	5.6	25	690.4
Aug. 12	----	3	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	3
Aug. 15–17	.9	----	15	1	----	16	5	4	.1	3	2.7	7.5	15	14	58	150	6	18	----	50	8	----	2	376.2
Sept. 6–7	----	----	----	----	----	----	----	----	----	----	.3	.9	2	5	31	8	6	10	----	----	----	----	----	63.2
Sept. 17	----	----	----	----	----	----	----	----	----	----	.7	----	2	2	----	----	----	----	----	----	----	----	----	4.7
Total	2.1	8	395	172	27	64	146	9	1.4	16	4.6	11.9	40.2	42	129	206	17	35	----	153	49	6.8	28	1,563.0
1968																								
July 6	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	4	0.9	----	----	0.6	----	----	----	5.5
July 21	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	.6	----	----	----	.6
July 24	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	.4	----	----	.8	----	----	----	1.2
July 27	----	----	----	0.4	----	----	----	----	----	0.9	2	2	3	4	4	4	1.3	----	----	7	2.5	----	----	31.1
Aug. 1	----	----	----	----	----	----	----	----	----	----	.4	----	6	4	----	----	----	----	----	----	----	----	----	10.4
Aug. 4–5	----	----	----	----	----	----	----	----	----	9	----	----	----	----	----	----	----	----	----	----	----	----	----	.9
Aug. 7	----	----	5	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	5
Aug. 11	----	----	.1	.9	----	3	.9	2	0.4	2	.9	3	5	27	38	75	4	3	----	3	5	----	----	173.2
Total	----	----	5.1	1.3	----	3	.9	2	.4	3.8	3.3	5	14	35	42	83	6.6	3	----	12	7.5	----	----	227.9
1969																								
July 20	----	----	----	6	0.4	3	1	----	----	1	----	----	----	----	2	11	5	14	4	60	1	----	----	108.4
Aug. 5–6	1	----	1	.9	.4	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	3.3
Aug. 13–15	1	----	8	.9	3	.9	1	----	----	.9	0.9	0,7	2	2	3	3	.9	----	----	----	1	----	----	29.2
Sept. 8–9	----	----	.4	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	.4
Sept 11–15	----	----	5	----	----	.7	1	----	----	----	3	3	9	17	3	30	.6	----	----	----	----	----	----	72.3
Oct. 20–21	----	----	.4	.4	2	1	4	----	----	----	1	----	1	4	2	4	.1	----	----	----	----	----	----	19.0
Total	2	----	14.8	8.2	5.8	5.6	7	----	----	1.9	4.9	3.7	11.1	23	10	48	6 6	14	4	60	2	----	----	232.6
1970																								
July 3	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	2.5	----	----	----	----	----	----	----	2.5
July 20–21	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	4.2	0.4	0.9	5.5
Aug. 23–24	0.1	----	0 1	1	30	5	1.4	2	----	----	----	----	----	----	----	2	0.9	----	----	1.4	----	----	----	43.9
Sept. 3–5	----	----	----	----	----	----	----	----	----	----	----	----	----	----	0.1	----	6	12	----	11	4.6	----	----	33.7
Sept. 8–12	.1	----	----	----	----	----	.3	----	----	----	0.1	----	----	----	----	----	----	----	----	----	----	----	----	.5
Oct 3–4	----	----	.1	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	.1
Total	.2	----	.2	1	30	5	1.7	2	----	----	.1	----	----	----	.1	4.5	6.9	12	----	12.4	8.8	.4	.9	86.3
1971																								
July 19	----	----	----	----	----	----	----	----	0.1	0.9	0.1	----	3	3	35	12	6.5	4.6	----	18	0.1	----	----	83.3
July 24	0.1	0.6	7.3	8	23	14	2.4	0.9	2.4	5	.4	0.1	.2	2.5	32	16	8	31	----	22	15	4.2	9	204.1
July 30	.6	2	10	6	14	16	5.5	5	3.6	4	.1	----	----	----	----	----	.4	.9	----	22	7	15	38	150.1
Aug. 9–10	.4	1.4	5	2.4	15	2.4	.4	1.4	.4	.1	.1	----	----	----	.6	2.5	7	10	----	15	5	36	43	148.1
Aug. 12	.1	----	120	21	11	32	270	.4	2	2	.9	.1	----	----	1.4	1.4	.8	3.6	----	9	.4	----	.1	476.2
Aug. 14	----	----	17	120	----	7	160	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	304
Aug. 19	.4	.4	14	20	7	8	33	.4	.4	2	.1	.1	1.4	2.5	.8	.1	3	8	----	----	----	----	----	101.6
Aug. 28	----	----	----	5	----	1.4	110	----	.3	----	----	----	----	----	----	----	----	----	----	----	----	----	----	116.7
Sept. 30	----	----	----	----	----	----	----	----	----	----	1,4	----	----	----	----	----	----	----	----	----	----	----	----	1.4
Oct. 1	.4	3	310	24	7	8	45	3.5	3	3	3	.1	7	2.5	.8	40	9	12	----	84	12	6.8	50	634.1
Total	2.0	7.4	483.3	206.4	77	88.8	626.3	11.6	12.2	17.0	6.1	.4	11.6	10.5	70.6	72.0	34.7	70.1	----	170	39.5	62.0	140.1	2,219.6

TABLE 2.—*Mean June–October runoff for 1963–71, standard deviation of the mean, and sizes of watersheds for tributaries to the study reach of the Gila River Phreatophyte Project*

Tributary	Drainage area (square miles)	Mean June–October flow (acre-ft per season)	Standard deviation of mean (acre-ft)	Tributary	Drainage area (square miles)	Mean June–October flow (acre-ft per season)	Standard deviation of mean (acre-ft)
14	0.38	1.2	1.0	36	0.44	3.4	3.7
15	.27	2.3	3.5	[1]37	1.54	5.2	4.8
[1]16	14.0	129	194	38	6.14	75.2	68.2
[1]17	20.3	104	110	38.5	.22	12.5	16.8
18	.59	25.8	26.9	[1]39	8.83	46.9	38.9
19	2.18	30.3	32.3	40	.59	6.5	6.6
[1]20	7.81	100	218	41	2.62	24.8	36.5
21	.51	4.8	4.5	[1]42	9.77	87.1	78.5
[1]22	.84	1.9	4.0	43	.55	8.5	13.2
23	.73	6.1	7.1	44	.42	9.1	10.7
24	1.14	43.9	67.7	45	.40	15.8	12.3
[1]25	18.7	71.0	170	46	1.52	22.2	13.1
26	4.40	30.2	37.4	47	4.69	44.8	42.2
[1]27	9.22	60.3	77.3	48	1.83	60.0	64.5
28	.79	30.1	50.1	49	.11	11.0	10.4
29	.54	11.1	17.7	50	.48	19.4	22.8
[1]30	1.81	43.7	47.4	50.5	.27	2.0	2.9
31	1.17	9.0	6.4	[1]51	12.1	69.6	68.1
32	.70	36.8	24.0	[1]52	.99	33.9	31.0
33	1.28	1.2	2.4	53	.81	9.0	21.5
34	.22	6.3	6.1	54	2.38	32.6	51.3
35	1.87	10.0	18.7				

[1]Tributary streams having recording gaging stations.

TABLE 3.—*Annual peak discharge for streams tributary to the study reach of the Gila River Phreatophyte Project*

[Discharge, in cubic feet per second]

Tributary	1963	1964	1965	1966	1967	1968	1969	1970	1971
14	----	20	30	0	20	0	30	5	20
15	----	0	60	0	140	0	0	0	60
16	----	850	440	430	8,000	40	100	5	3,500
17	2,000	1,300	500	430	7,000	20	100	20	1,500
18	----	80	850	120	240	0	50	450	350
19	----	360	200	50	460	60	50	100	450
20	----	440	40	10	2,800	20	20	30	3,120
21	----	90	150	0	90	40	0	40	90
22	----	65	0	10	50	10	0	0	70
23	----	20	150	0	180	40	30	0	90
24	50	500	0	0	1,700	0	0	0	1,100
25	200	190	60	0	4,000	100	30	40	400
26	0	540	700	120	720	20	180	0	90
27	60	600	1,600	0	1,800	0	100	0	1,440
28	0	240	1,700	0	1,800	60	300	0	100
29	0	0	640	40	280	100	40	0	40
30	250	460	130	0	800	10	530	20	560
31	10	80	60	150	170	290	80	10	100
32	40	500	450	670	900	360	350	60	500
33	0	120	0	0	0	0	60	0	0
34	80	120	110	130	90	0	0	0	30
35	10	230	140	510	10	0	5	0	70
36	20	40	50	10	20	40	20	0	70
37	0	50	110	0	10	40	60	40	50
38	130	720	1,300	1,200	120	1,900	200	100	360
38.5	----	----	140	370	70	120	300	20	160
39	130	460	820	1,140	180	880	200	50	480
40	20	50	200	120	10	150	50	20	90
41	10	30	3,000	20	10	1,000	20	140	130
42	50	3,000	4,700	850	1,400	1,500	700	70	400
43	----	50	350	40	50	40	60	5	60
44	----	80	260	120	130	60	60	0	5
45	----	350	130	110	300	110	150	0	60
46	----	220	230	210	230	400	280	0	60
47	----	300	590	80	60	40	5	0	500
48	----	160	540	540	2,330	1,000	440	50	510
49	----	60	80	50	50	80	90	110	150
50	----	50	100	150	340	70	230	200	450
50.5	----	----	----	----	----	----	----	----	----
51	----	520	20	210	1,200	120	750	30	330
52	----	0	0	1,100	500	90	0	80	230
53	----	20	20	20	100	0	0	10	480
54	----	1,000	200	0	40	0	0	20	700

[1]A dash indicates that records were not obtained for the indicated period.

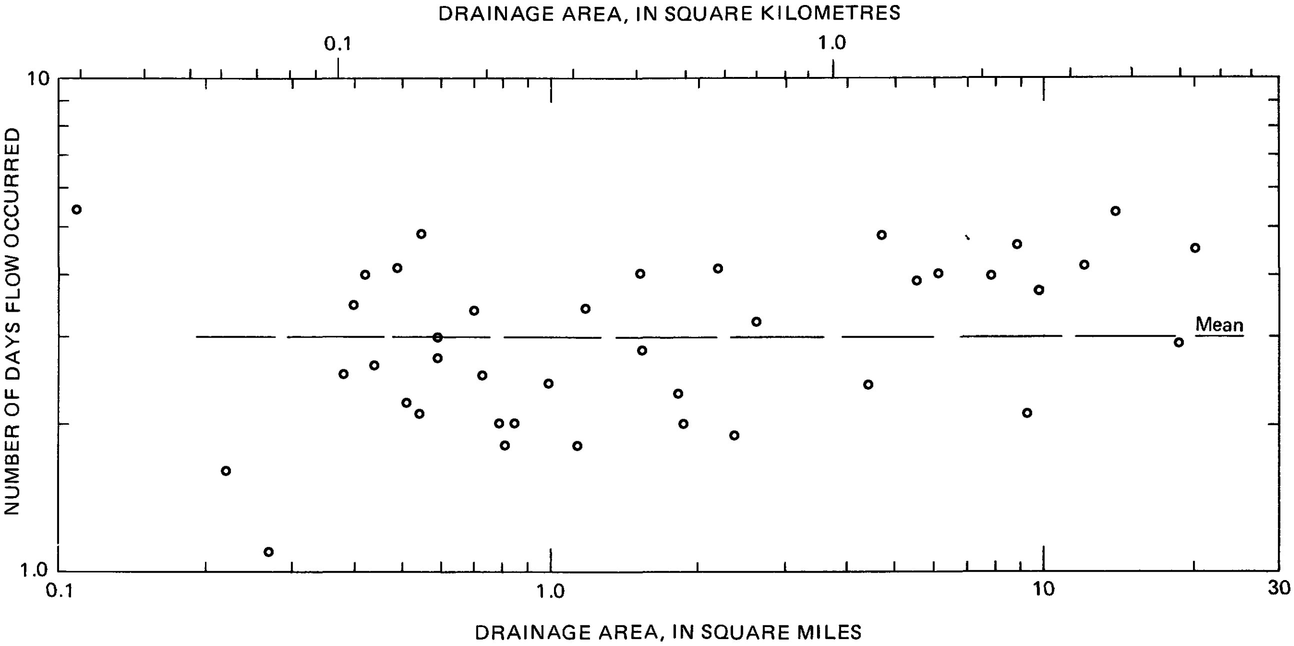


FIGURE 6.—Relation of number of days of flow to size of watershed.

COMPARISONS OF RUNOFF FROM THE STUDY BASINS WITH RUNOFF FROM NEARBY BASINS

An investigation was made to determine whether the runoff-producing characteristics of the study area were representative of other basins in the region by comparing the average annual discharge data for the study watersheds with discharge relations previously developed for other watersheds in the region. The purpose of the comparison was to determine whether the streamflow data for the study tributaries agreed as closely with the relations as did the data used in developing the relations.

A comparison of the study data with runoff relations developed as part of a nationwide evaluation of the streamflow data collection program of the Geological Survey (Moosburner, 1970) was the primary method of analysis used in this investigation. Comparisons of the tributary data in the study area with runoff relations developed for other areas by Burkham (1966, 1970) were of secondary importance. These comparisons offered an excellent opportunity to study prediction errors for the different relations.

The regression equations by Moosburner (1970) were developed using the model

$$y = aA^bB^cC^d, \tag{8}$$

where y is a streamflow characteristic, such as mean annual flow; A, B, and C are physical and climatic basin characteristics, such as drainage area or precipitation; and a, b, c, and d are coefficients or exponents obtained by regression. The following procedure was used in deriving an equation for a region (Moosburner, 1970, p. 20–21):

1. Compute an initial regression equation.
2. Test the coefficients for statistical significance at the 95 percent confidence level.
3. Drop the characteristics that were found to be insignificant.
4. Compute a regression equation using only the significant parameters.
5. Compute a standard error of regression.
6. Determine residuals—the difference between the streamflow characteristics determined by the regression analysis and the streamflow characteristics that are measured.
7. Plot the residuals on a map of Arizona to determine any regional variation.

The procedures used by Burkham (1966, 1970) to develop equations were the same as those of Moosburner except the regional studies described in step 7 were not made.

According to Moosburner (1970, p. 21), two regions in Arizona had enough data so that regression analyses could be made (fig. 7). The equations derived for regions 1 and 2 are (Moosburner, 1970, table 3)

$$Q_s = 1.82 \times 10^{-3}A^{0.71}(PS)^{2.25} \tag{9}$$

and

$$Q_s = 5.89 \times 10^{-3}A^{0.71}(PS)^{2.08}, \tag{10}$$

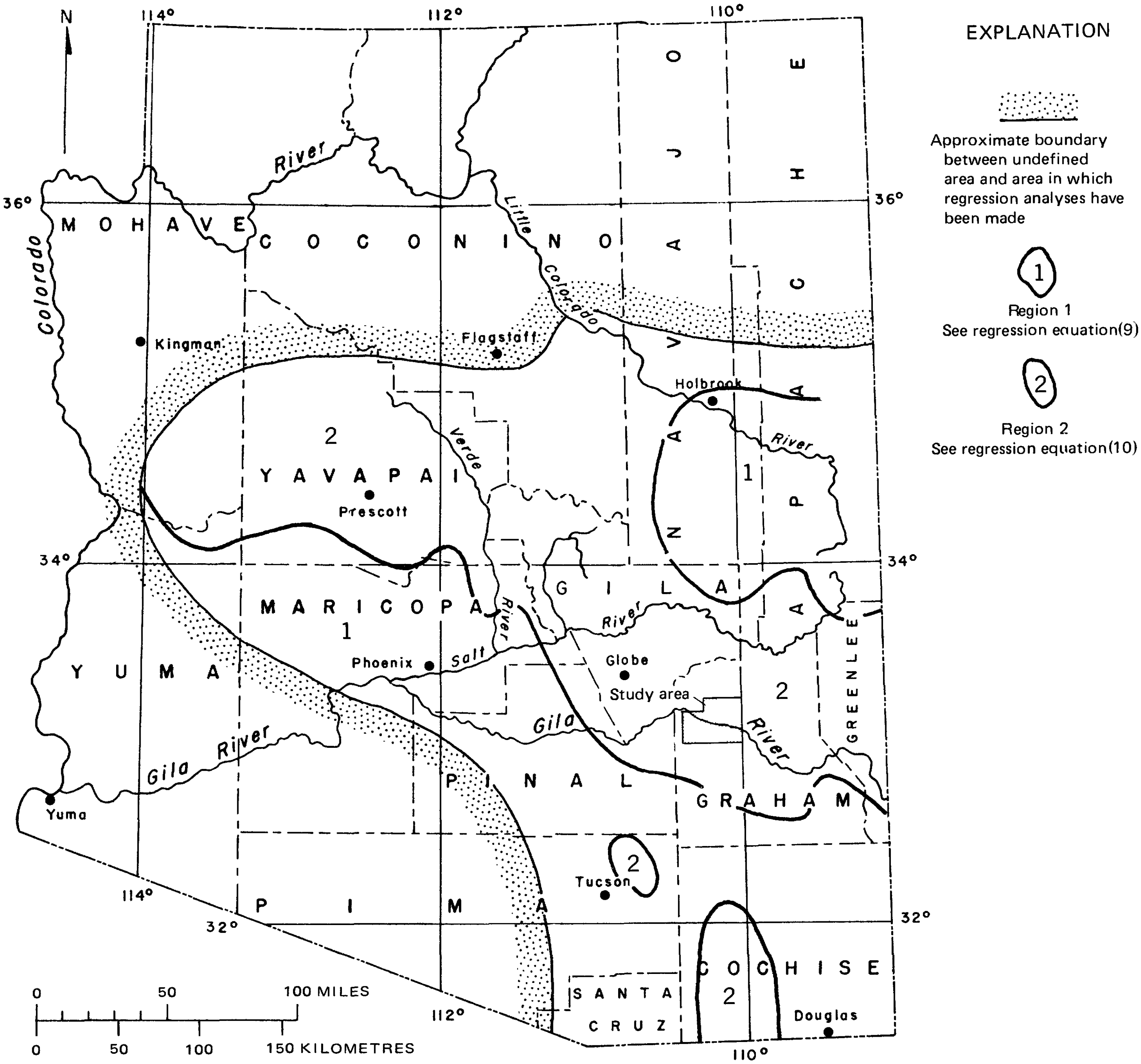


FIGURE 7.—Regions in Arizona where regression analyses have been made. From Moosburner (1970).

in which

Q_s = seasonal mean July–September discharge in cubic feet per second;

A = area of drainage basin in square miles, and

(PS) = seasonal mean May–September precipitation in inches.

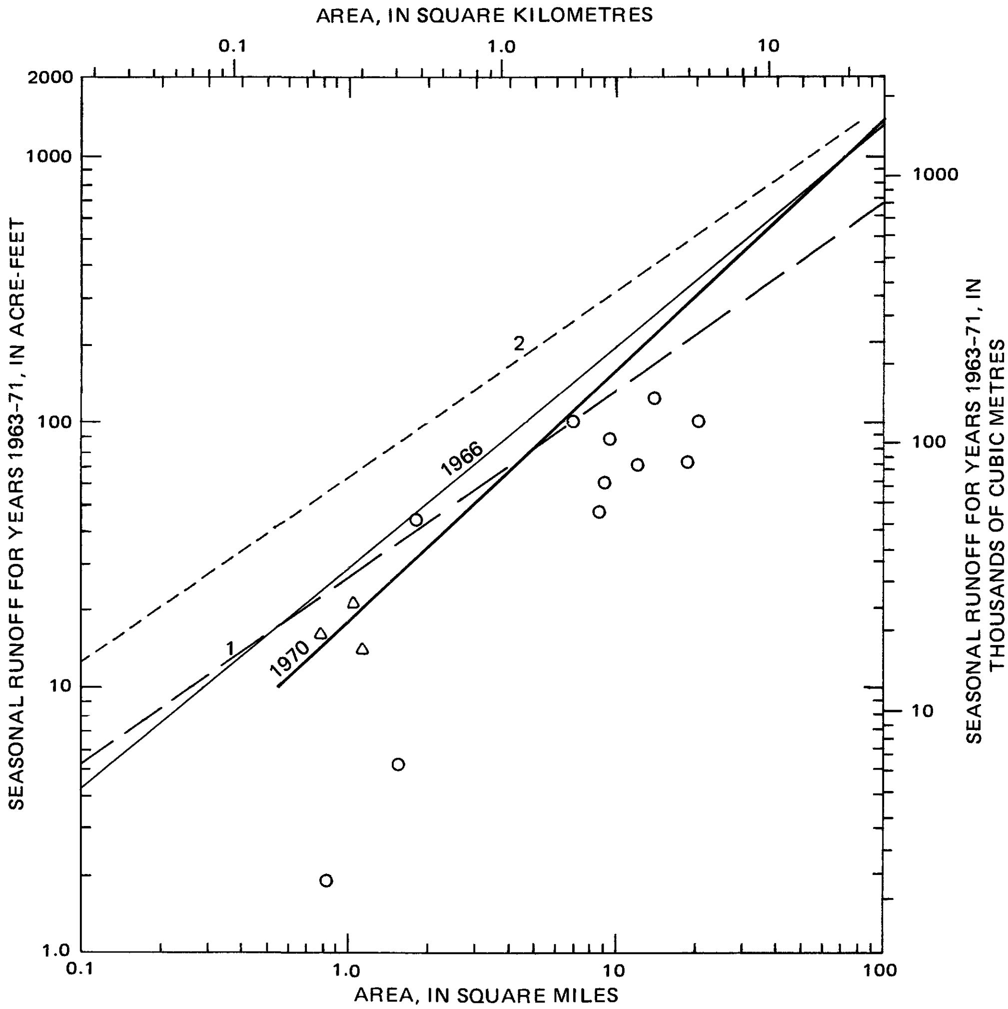
The mean May-to-September precipitation for the study tributaries is about 7.0 inches (180 mm). When the 7.0 is inserted and when changes are made to give results in acre-ft per year, equations (93 and (10) reduce to

$$Q_s=26.6A^{0.71} \tag{11}$$

for region 1 and

$$Q_s=61.5A^{0.71} \tag{12}$$

for region 2. Equations (11) and (12) along with equations developed by Burkham (1966, fig. 21; 1970, fig. 15), and data obtained for the study tributaries are



EXPLANATION

(Data obtained as part of the Gila River Phreatophyte Project)

○
For stream having continuous-stage recorders

△
Data from an Agricultural Research Service project near Safford (Burkham, 1970, table 3)

Curves developed from equations by Moosburner (1970, table 3)

1
Refers to region 1 shown in figure 6

2
Refers to region 2 shown in figure 6

Curve from report by Burkham (1966, fig. 21)

Curve from report by Burkham (1970, fig. 3)

FIGURE 8.—Relation of mean annual runoff to size of basin.

plotted in figure 8. According to Moosburner (1970), the study tributaries lie within region 2 (fig. 7), for which equation (12) is applicable.

The standard error of prediction $(SE)_p$ for equation

(12), when used to estimate mean seasonal discharge for the study tributaries, was determined by comparing the mean annual discharge obtained from equation (12) Q_s, with measured mean annual discharge Q_m, where the standard error of the measured discharge $(SE)_m$ is known. The data of measured mean annual discharge Q_m for the study tributaries were not used in the regression analysis made by Moosburner, therefore, the assumption is made that the errors R_m in the data for the study tributaries, called control data, are independent of the prediction errors R_s. The variance of the difference between computed mean annual discharge and measured mean annual discharge, $(SE)^2{}_{s-m}$, includes the variance of the difference between measured discharge in the control group and the true discharge.

The variance of the difference between computed and measured discharge may be estimated as follows:

$$(SE)^2{}_{s-m} = \frac{\sum_{i=1}^{N} (Q_{s_i} - Q_{m_i})^2}{N} , \tag{13}$$

in which N is the number of sets of discharge data used in the analysis, i denotes individual sets, and the other parameters are as previously defined. The mean annual discharges Q_s and Q_m can be described by the equations

$$Q_s = Q_T \pm R_s \tag{14}$$

and

$$Q_m = Q_T \pm R_m, \tag{15}$$

in which Q_T is true mean annual discharge. Equations (13, (14), and (15) are combined to give

$$(SE)^2{}_{s-m} = \frac{\sum_{i=1}^{N} (\pm R_{s_i} \pm R_{m_i})^2}{N} , \tag{16}$$

or

$$(SE)^2{}_{s-m} = (SE)_s^2 + (SE)_m{}^2 . \tag{17}$$

The expected value of the variance is

$$E\,(SE)^2{}_{s-m} = \sigma_s{}^2 + \sigma_m{}^2 = (\sigma)^2{}_{s-m} , \tag{18}$$

if the measurement errors in the control group are independent of the prediction errors. Therefore, $\sigma_s{}^2 = (\sigma)^2{}_{s-m} - \sigma_m{}^2$ where σ^2 denotes a "true" or population variance as opposed to S^2, which is estimated on the basis of data.

The standard error of the mean for the measured flow $(SE)_m$, in percent, was determined using the equation

$$(SE)_m = \sqrt{\frac{C_v{}^2 + (SE)_c{}^2}{Y}} , \tag{19}$$

in which

C_v = coefficient of variation for the annual discharges in percent; equals the standard deviation of the annual flows (DE), divided by the mean of the annual flows times 100;

Y = the number of years used in determining the mean of the annual discharges—serial correlation between annual discharges is assumed to be insignificant; and

$(SE)_c$ = standard error, in percent, of an annual flow value which is a measurement or computational error.

A value of 100 for C_v was used in equation (19) to compute $(SE)_m$. This value of C_v is large compared to values that have been computed for other watersheds in Arizona (McDonald, 1960, table 1; Burkham, 1970, p. 31–32; Moosburner, written commun., 1971); however, to be on the high side when $(SE)_m$ is determined, the value of 100 is used for this study. The standard error of computation for the control data $(SE)_c$ probably is no larger than 50 percent; however, to be on the high side, a value of 100 percent is used. When values of 100 for C_v, 100 for $(SE)_c$, and 8 years for Y are used in equation (19), a standard error of the mean for the control data of about 50 percent is obtained.

The average coefficient of variation C_v computed for tributaries in which continuous recorders were maintained was 133. This probably is significantly larger than it would have been if the streamflow data did not contain large computational errors. If values of 133 for C_v and 100 for $(SE)_c$ are used in equation (19), a value of 60 for $(SE)_m$ is obtained.

An average value for $(SE)_{s-m}$ of 250 was computed using equation (13) when mean annual discharges obtained from equation (12) are compared with measured mean annual discharges. Only the data for watersheds having recording gages were used in determining $(SE)_{s-m}$; the data include those for 12 watersheds in the study area and 3 watersheds under study by the U.S. Agricultural Research Service (Burkham, 1970, table 3). The standard error of prediction σ_s for equation (12); when estimating discharge from the study tributaries, is about 240 percent, which was determined by using values of 250 percent for σ_{s-m} and 50 percent for σ_m in equation (18).

Many factors may have been involved in causing the standard error of prediction to be large when equation (12) is used to estimate runoff from the study watersheds. The large prediction error, however, probably results mainly from two related reasons:

1. The basin characteristics for the watersheds of this study which affect water yields are significantly different from those for watersheds studied by Moosburner; basin size and shape are known to be significantly different; there may be other differences.
2. The region for which equation (12) is applicable is improperly defined (fig. 7).

Prediction errors of about 100 percent are determined for equation (11) and for the two equations by Burkham (1966, 1970) when they are used to compute average annual discharges for 1963–71 for the study watersheds. The procedure used in determining prediction errors for these equations is the same as that described for equation (12). The runoff data for the three watersheds under study by the U.S. Agricultural Research Service were not used in computing errors for Burkham's 1970 equation because these data were used in developing the equation.

CONCLUSIONS

Conclusions reached as a result of this study are:

1. Feasible methods of accurately measuring flashy streamflow moving in a supercritical state in channels of movable boundaries currently are not available.
2. Data obtained during the study were adequate for the water budget studies of the Gila River Phreatophyte Project but only because there was no flow in any of the streams for more than 96 percent of the days of the year. Periods of no flow are well documented and therefore considered reliable. The data of peak discharges and storm totals for most of the runoff flows probably are within 100 percent of true values; the data of seasonal runoff probably are within 50 percent of true values.
3. Prediction errors for discharge equations developed as part of the nationwide evaluation of the streamflow data collection program of the U.S. Geological Survey (Moosburner, 1970) and for discharge equations developed for other studies (Burkham, 1966, 1970) are 100 to 250 percent when the equations are used to estimate average annual discharge for basins having climatic and basin characteristics similar to those of the study tributaries. The climatic and basin characteristics for the study tributaries are similar to many others in the Basin and Range physiographic province (Fenneman, 1931).

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