Streamflow in the Upper Santa Cruz River Basin, Santa Cruz and Pima Counties, Arizona

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1939-A

Prepared in cooperation with the city of Tucson, the U.S. Bureau of Reclamation, and the University of Arizona

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By ALBERTO CONDES DE LA TORRE

WATER RESOURCES OF THE TUCSON BASIN

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CONTENTS

ILLUSTRATIONS

[Plates 1–6 are in pocket]

TABLES

STREAMFLOW IN THE UPPER SANTA CRUZ RIVER BASIN, SANTA CRUZ AND PIMA COUNTIES, ARIZONA

By Alberto Condes de la Torre

ABSTRACT

Streamflow records obtained in the upper Santa Cruz River basin of southern Arizona, United States, and northern Sonora, Mexico, have been analyzed to aid in the appraisal of the surface-water resources of the area. Records are available for 15 sites, and the length of record ranges from 60 years for the gaging station on the Santa Cruz River at Tucson to 6 years for Pantano Wash near Vail. The analysis provides information on flow duration, low-flow frequency and magnitude, flood-volume frequency and magnitude, and storage requirements to maintain selected draft rates. Flood-peak information collected from the gaging stations has been projected on a regional basis from which estimates of flood magnitude and frequency may be made for any site in the basin.

Most streams in the 3,503-square-mile basin are ephemeral. Ground water sustains low flows only at Santa Cruz River near Nogales, Sonoita Creek near Patagonia, and Pantano Wash near Vail. Elsewhere, flow occurs only in direct response to precipitation. The median number of days per year in which there is no flow ranges from 4 at Sonoita Creek near Patagonia to 335 at Rillito Creek near Tucson. The streamflow is extremely variable from year to year, and annual flows have a coefficient of variation close to or exceeding unity at most stations.

Although the amount of flow in the basin is small most of the time, the area is subject to floods. Most floods result from high-intensity precipitation caused by thunderstorms during the period July to September. Occasionally, when snowfall at the lower altitudes is followed by rain, winter floods produce large volumes of flow.

INTRODUCTION

The growing demand for water in the upper Santa Cruz River basin (fig. 1)—in response to the increase in population, agricultural development, and industry—has created a need for information on the amount of surface water available and the nature of its occurrence. Therefore, streamflow records of sufficient length to define the flow characteristics of the streams are important in long-range planning

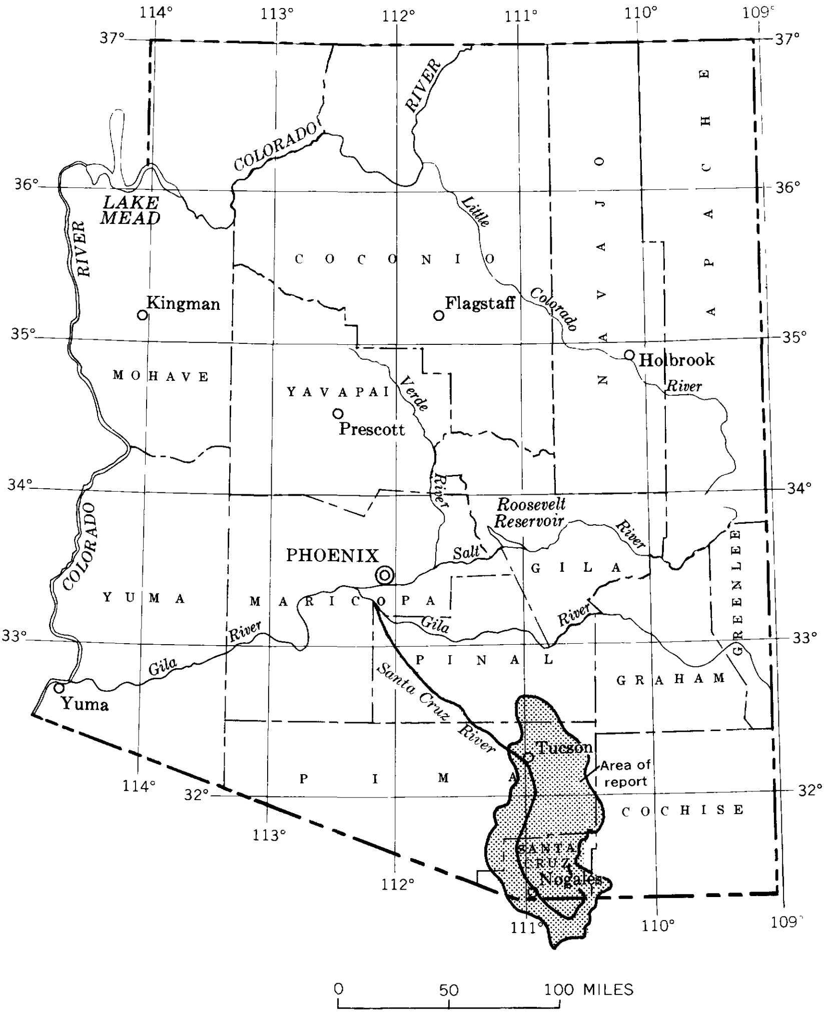


FIGURE 1.—Location of upper Santa Cruz River basin.

and development. The U.S. Geological Survey analyzed the streamflow records for the upper Santa Cruz River basin in conjunction with a cooperative water-resources investigation of the Tucson basin, conducted under the immediate supervision of H. M. Babcock, district chief of the Water Resources Division in Arizona. The cooperating agencies were the city of Tucson, the U.S. Bureau of Reclamation, the University of Arizona, and the Geological Survey.

The purpose of the investigation was to define the magnitude and occurrence of streamflow by summarizing the data available from gaging-station records and to present the information in a usable form. Streamflow records are available from 15 U.S. Geological Survey gaging stations (pl. 1). The length of record at these gaging stations ranges from 60 years (1905–65) for the Santa Cruz River at Tucson to 6 years (1959–65) for Pantano Wash near Vail (table 1).

METHODS OF ANALYSIS USED IN THE INVESTIGATION

The streamflow records were analyzed by statistical and graphical methods for this report. Flow duration, low-flow frequency, flood frequency, flood-volume frequency, daily-flow duration, storage analysis, and the annual occurrence of days having no flow were determined. Daily mean discharge was used in the flow-duration, low-flow, and flood-volume frequency analyses. The analyses were made from data recorded by gaging stations in the upper Santa Cruz River basin through 1963 and later were arranged and sorted by an electronic computer. The period 1936 to 1963, inclusive, was used for the flow-duration curves. The period of record for each gaging station was used for the curves showing low-flow frequency, flood frequency, flood-volume frequency, and days of no flow. Because most streams in the basin are dry for long periods of time, the daily flow-duration graphs are given only for streams having flow adaptable to this type of presentation—Sonoita Creek near Patagonia, Santa Cruz River near Nogales, and Sabino Creek near Tucson. The data for each gaging station in the basin are presented in each type of analysis if the length of record is sufficient for interpretation. The years of record used in this report are water years, unless otherwise specified.

GEOGRAPHY

The upper Santa Cruz River basin, defined as that part of the Santa Cruz River basin above Cortaro, occupies 3,503 square miles in southern Arizona, United States, and northern Sonora, Mexico (pl. 1). The upper basin is bounded on the south by the drainage divide between streams that enter the basin and streams that enter the Rio de Concepcion dainage basin in Mexico; on the east by the Tortolita, Santa Catalina, Tanque Verde, Rincon, Whetstone, and Huachuca Mountains and the Canelo Hills; on the north by the drainage divide between the upper and the lower Santa Cruz and lower San Pedro River basins; and on the west by the Atascosa, Tumacacori, Cerro Colorado, Sierrita, and Tucson Mountains.

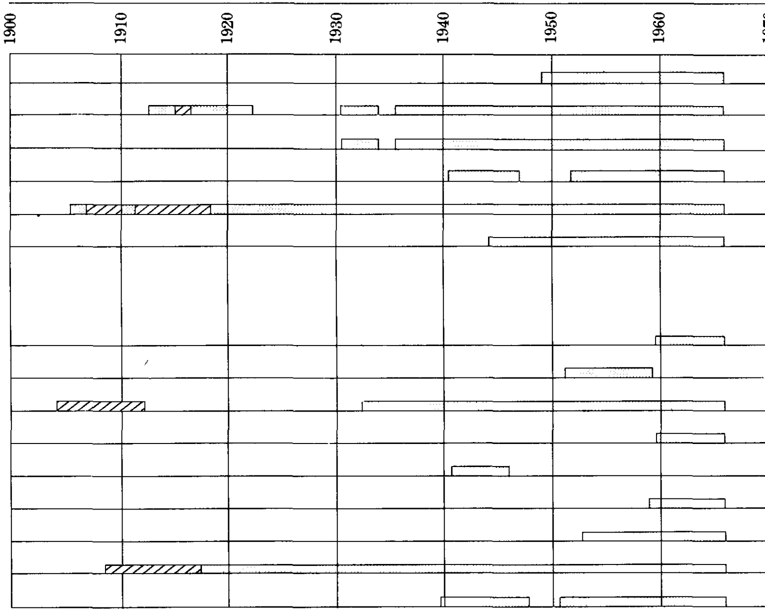
The basin is in the Basin and Range physiographic province (Fenneman, 1931) and is characterized by isolated mountain blocks separated by broad alluvial-filled valleys. The altitude of the valleys ranges from 2,100 to 4,700 feet above mean sea level, and the mountains are as much as 9,400 feet above mean sea level.

The Santa Cruz River drains the west side of the Huachuca Mountains and the east side of the Patagonia Mountains and flows south past Lochiel into Mexico; in Mexico, flow is contributed to the river

TABLE 1.—*Period of record for streamflow-gaging stations*

EXPLANATION: Daily discharge; Monthly discharge (hatched)

Period of record



Gaging station	Altitude above mean sea level (ft)	Drainage area (sq mi)	Station
Santa Cruz River near Lochiel	4,620	82.2	9-4800
Santa Cruz River near Nogales	3,702	533	9-4805
Sonoita Creek near Patagonia	3,818	209	9-4815
Santa Cruz River at Continental	2,836	1,662	9-4820
Santa Cruz River at Tucson	2,317	2,222	9-4825
Tucson Arroyo at Vine Avenue, Tucson	2,412	27.0 (prior to 1945) 8.2 (since 1956)	9-4830
Tanque Verde Creek near Tucson	2,720	43.0	9-4831
Sabino Creek near Mount Lemmon	7,250	3.19	9-4833
Sabino Creek near Tucson	2,720	35.5	9-4840
Bear Creek near Tucson	2,670	16.3	9-4842
Tanque Verde Creek at Tucson	2,460	221	9-4845
Pantano Wash near Vail	3,205	457	9-4846
Rincon Creek near Tucson	3,120	44.8	9-4850
Rillito Creek near Tucson	2,284	918	9-4860
Santa Cruz River at Cortaro	2,137	3,503	9-4865

from a 348-square-mile drainage area. The river then flows north, enters the United States 5½ miles east of Nogales, and continues northwest to Tumacacori. In this reach the Santa Cruz is joined by Sonoita Creek and Josephine Canyon and by tributaries that drain the east slopes of the Pajarito and Atascosa Mountains. The river flows almost due north from Tumacacori to Tucson and receives drainage from the Santa Rita, Tumacacori, and Sierrita Mountains. At Tucson, the river is joined by Rillito Creek, which has a 934-square-mile drainage basin that extends into the Empire and Whetstone Mountains near Benson and the Santa Catalina and Rincon Mountains near Tucson. The river flows northwest from Tucson and leaves the upper basin at Cortaro.

HISTORY

The upper Santa Cruz River basin has had an interesting and colorful history under the flags of Spain, Mexico, and the United States. In 1539 Fray Marcos de Niza is believed to have followed the Santa Cruz River, then unnamed, north from Mexico in his search for civilizations and treasure. The first attempt to settle and Christianize the friendly Indians was undertaken by Father Kino in a 20-year period beginning in 1691. Father Kino referred to the river in his writings as the "Rio de Santa Cruz," which is Spanish for "River of Holy Cross." Father Kino established several missions in the area, and two of the most famous—San Xavier del Bac and Tumacacori—are near the banks of the Santa Cruz River. When Mexico achieved its independence from Spain in 1821, the basin became part of Mexico, and in 1853 it became part of the United States through the Gadsden Purchase.

Many changes have taken place in the basin landscape since the first Europeans explored the upper Santa Cruz River basin. Erosion has lowered the base level of the Santa Cruz River, and the basin is adapting to it. Early settlers found the flow in the river adequate for their needs, and Smith (1910) showed the water table in the Tucson area higher than the streambed in 1908. Davidson (written commun., 1969) showed that the water table ranged from about 20 to 70 feet below the streambed along the Santa Cruz River in 1940–64. The increase in withdrawal of water by pumping accounts for the lowering of the water table, but the exact causes of the erosional activity are not known.

Previous workers agree that the most recent arroyo cutting and lowering of the channel streambeds in the Santa Cruz River basin began about 1890. Leopold (1951) discussed the journals of early explorers and travelers in the Southwest and compared early photographs with more recent ones taken at the same place. He concluded that the vegetation changes in the 50 years between 1895 and 1946 were not significant and that the vegetation changes that most affected the erosional activity possibly occurred before 1895. Hastings and Turner (1965, p. 288) discussed the changes in vegetation and stated:

> To the extent that arroyo cutting accurately reflects changing vegetative conditions it is possible to be more precise. Arroyo cutting began along many of the streams of the desert region in August, 1890. One can infer, then, that by 1890 the vegetation had been altered enough to affect runoff, but it is an uncomfortable inference, resting as it does on the unproven assumption that a change in the vegetal cover inaugurated arroyo cutting.

Hastings (1958–59, p. 35) discussed three theories of what caused the changes in the landscape: (1) the introduction of cattle, which upset the biological balance involving the soil and things that grow on it, (2) a tilting of the land surface that caused the gradient of local streams to increase, and (3) climatic changes—less rain, change in rainfall pattern, and a change in intensity of storms. Hastings and Turner (1965) stated that the event that may have triggered arroyo cutting was an imbalance between infiltration and runoff caused by a combination of climatic variation and cattle grazing.

PRECIPITATION

The normal annual precipitation in the basin ranges from 30 inches in the mountains to about 10 inches on the valley floor near Tucson (University of Arizona, 1965a, b). Precipitation is extremely variable from year to year. The highest average monthly precipitation occurs in the summer, when the average air temperature is the highest and the evaporation potential is the greatest (pl. 2). The average annual precipitation and the peak maximum monthly precipitation increase with altitude (fig. 2). The peak maximum monthly precipitation shown in figure 2 is the highest value shown on the maximum monthly curves (pl. 2).

Precipitation in July, August, and September is of high intensity and of short duration and usually is from thunderstorms that cover a small area. Occasionally, tropical storms move inland—generally in September—and contribute large amounts of precipitation. Winter storms are the result of frontal activity and usually cover most of the basin; winter precipitation is generally less intense, but is of longer duration than summer precipitation (Sellers, 1960; Sellers, oral commun., 1969).

Precipitation either returns directly to the atmosphere by evapotranspiration, infiltrates into the soil, or reaches the stream channel in ratios dependent on the type of storm, temperature, type and density of vegetation, and topography. In the upper Santa Cruz River basin the percentage of rainfall that reaches the stream channels is extremely low. The average ratio of streamflow to rainfall volumes has been computed as follows (Schwalen, 1942, p. 468–469) :

Gaging station	*Average ratio of streamflow to rainfall (percent)*
Sonoita Creek near Patagonia (period of record, 1931–41)	2.5
Santa Cruz River near Nogales (period of record, 1931–41)	3.0
Santa Cruz River at Tucson (period of record, 1923–41)	.6
Rillito Creek near Tucson (period of record, 1923–41)	1.0

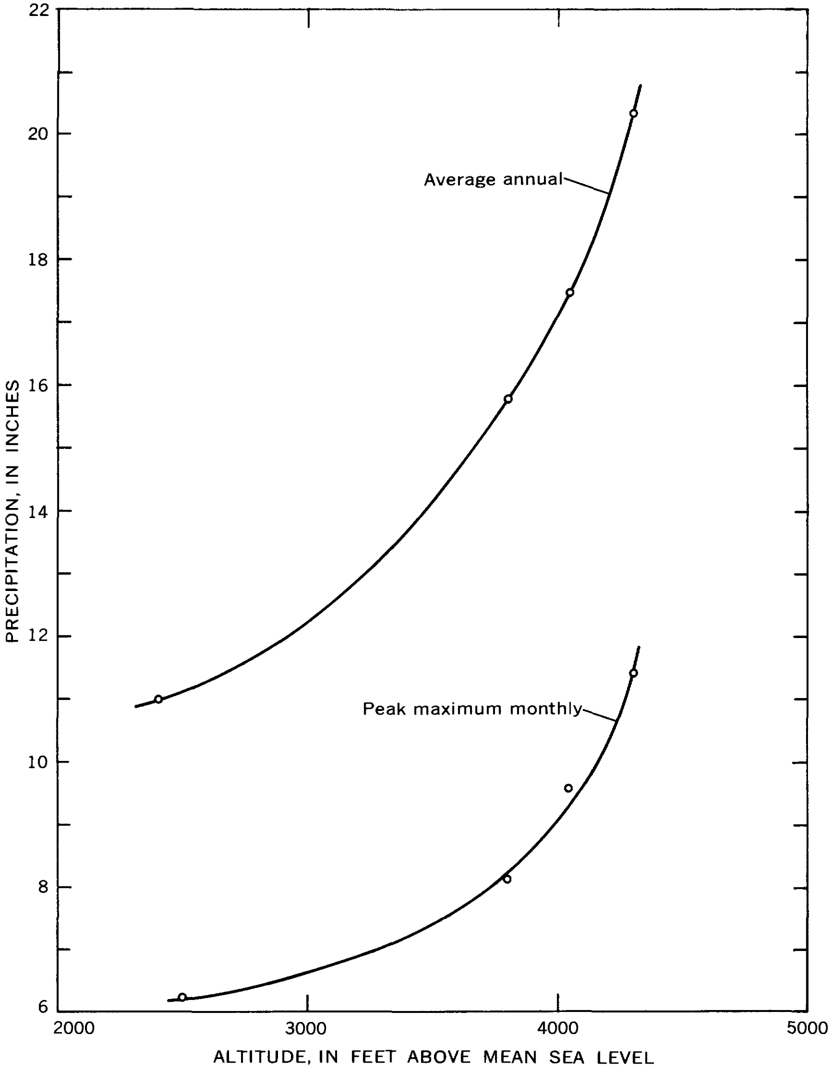


FIGURE 2.—Variation of the average annual and peak maximum monthly precipitation with altitude.

STREAMFLOW

Most streams in the upper Santa Cruz River basin are ephemeral and are dry for long periods of time. Flow in the streams is generally in response to precipitation, except in a few places, such as Santa Cruz River near Nogales, Sonoita Creek near Patagonia, and Pantano Wash near Vail, where ground water is forced to the surface. Streamflow is not used for municipal or irrigation purposes, except for small diversions in Mexico; however, the municipal water supplies for Nogales,

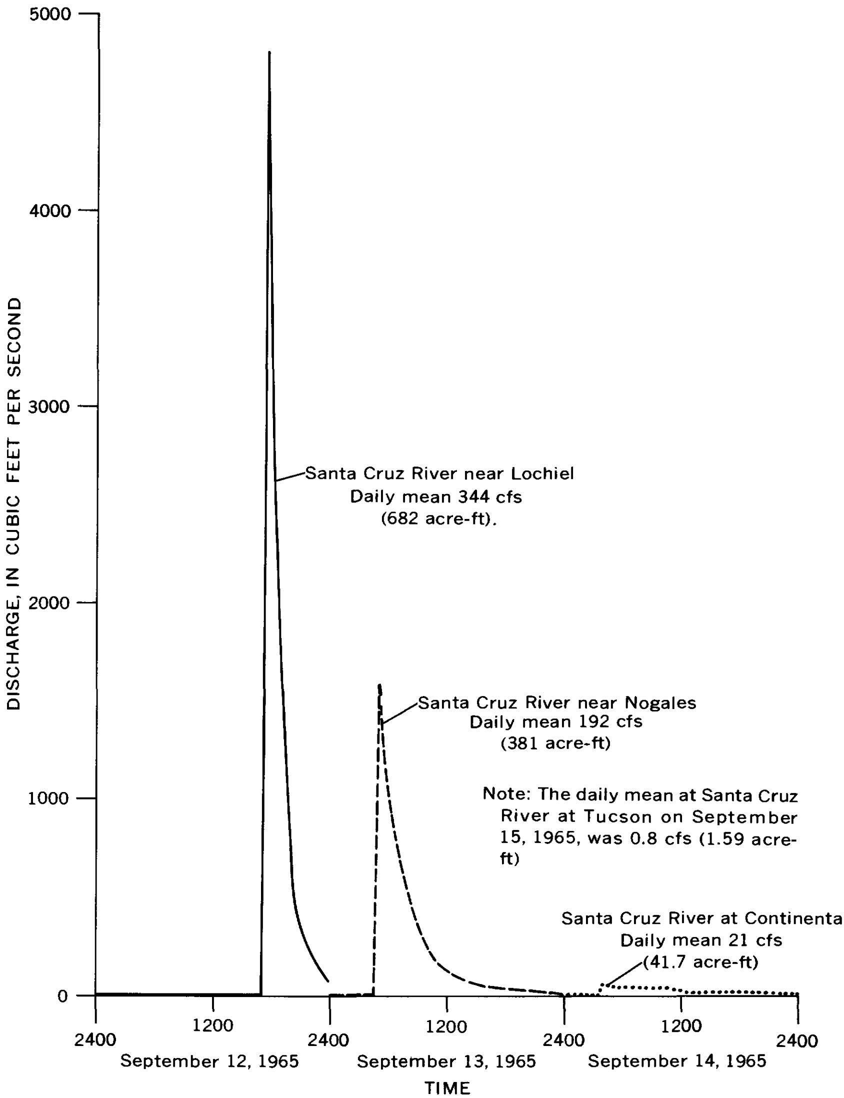


FIGURE 3.—Reduction of the flood peak by channel losses in the Santa Cruz River.

Arizona, and Nogales, Sonora, are from wells drilled in the alluvium near the Santa Cruz River, and, at times, the cone of influence of these wells intercepts and depletes the surface flow in the river.

The streambeds of the Santa Cruz River and its main tributaries are extremely permeable, and water is lost to the subsurface as the flow moves downstream. The flood of September 12–15, 1965 (fig. 3), is an example of the natural channel losses that occur in the main stem of the Santa Cruz River. The flood volume diminished from 682 acre-feet at Lochiel to 1.59 acre-feet at Tucson. The average annual infiltration rate ranges from 320 to 480 acre-feet per mile in the northern part of the main stem of the Santa Cruz River (D. E. Burkham, written commun., 1969). Part of the water lost through infiltration reaches the water table, and water levels in wells near the river fluctuate in response to the streamflow (fig. 4).

Streamflow in the upper Santa Cruz River basin is extremely variable, and the arithmetic average of the annual flow has little meaning with regard to the amount of flow that may be expected each year. The

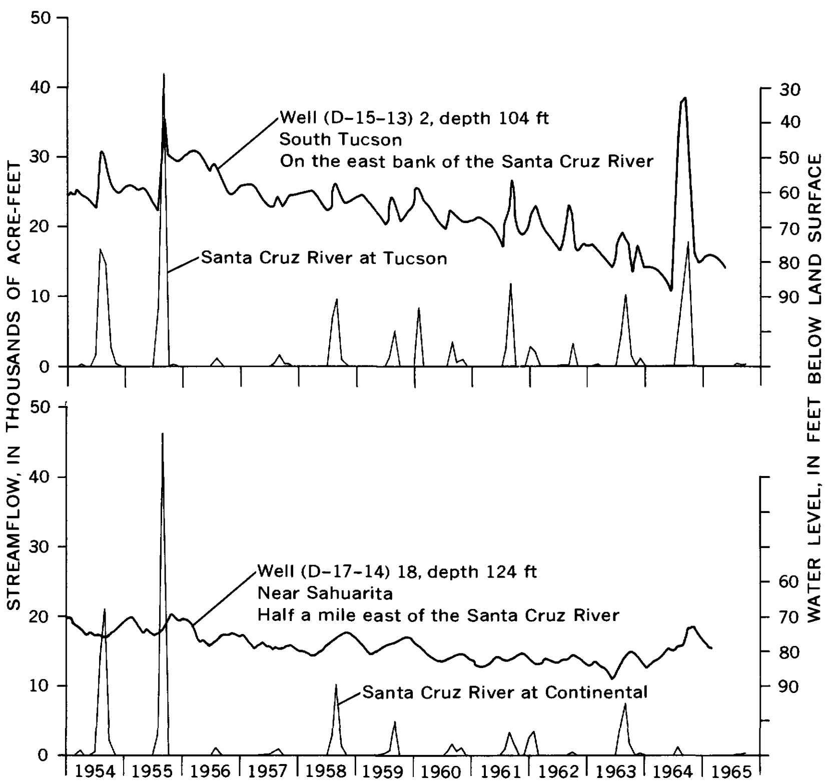


FIGURE 4.—Effects of streamflow on water levels in wells near the Santa Cruz River. See plate 1 for location of wells.

TABLE 2.—*Variation and distribution of annual streamflow*

Station	Drainage area (square miles)	Number of years of record	Annual streamflow: Arithmetic average (acre-feet)	Extremes (acre-feet): High	Extremes (acre-feet): Low	Standard deviation (acre-feet)	Coefficient of variation	Skewness
Santa Cruz River near Lochiel	82. 2	16	2, 540	12, 220	227	3, 020	1. 19	2. 10
Santa Cruz River near Nogales	533	46	15, 530	75, 000	3, 320	13, 490	. 87	2. 51
Sonoita Creek near Patagonia	209	33	5, 230	13, 060	1, 360	2, 520	. 48	1. 30
Santa Cruz River at Continental	1, 662	20	11, 960	49, 220	188	12, 690	1. 06	1. 64
Santa Cruz River at Tucson	2, 222	60	15, 680	80, 920	935	14, 000	. 89	2. 08
Tucson Arroyo at Vine Avenue, Tucson	27. 0–8. 2	21	580	1, 210	84. 4	293	. 51	. 27
Tanque Verde Creek near Tucson	43. 0	6	5, 010	8, 800	1, 910	2, 310	. 46	. 35
Sabino Creek near Mount Lemmon	3. 19	7	1, 180	2, 590	100	757	. 64	. 51
Sabino Creek near Tucson	35. 5	40	8, 190	37, 090	375	7, 240	. 88	1. 81
Bear Creek near Tucson	16. 3	6	3, 080	6, 220	100	1, 980	. 64	. 17
Tanque Verde Creek at Tucson	221	5	12, 500	43, 160	1, 850	15, 640	1. 25	1. 36
Pantano Wash near Vail	457	6	5, 120	9, 340	2, 000	2, 630	. 51	. 36
Rincon Creek near Tucson	44. 8	13	2, 880	5, 680	52	1, 940	. 67	–. 02
Rillito Creek near Tucson	918	57	11, 550	120, 000	315	17, 990	1. 56	4. 18
Santa Cruz River at Cortaro	3, 503	22	19, 890	67, 390	1, 880	15, 320	. 77	1. 65

standard deviation for annual flow at many of the gaging stations in the basin is close to or exceeds the arithmetic average (table 2). The coefficient of variation, a comparative measure of the variability of flow and defined as the ratio of the standard deviation to the mean, for the annual flows at gaging stations in the upper Santa Cruz River basin ranges from 0.46 at Tanque Verde Creek near Tucson to 1.56 at Rillito Creek near Tucson.

FLOW DURATION

The time distribution of streamflow can be expressed by a flow-duration curve, which is a cumulative frequency curve that shows the percentage of time specified discharges are equaled or exceeded in a given period. The flow-duration curves in this report are average curves for the period 1936–63 and do not represent the distribution of the annual flow.

Flow-duration curves for most streams in the upper Santa Cruz River basin have steep slopes, which indicate that the streamflow is in direct response to precipitation and that snowmelt and ground-water discharge do not contribute sufficient amounts of water to sustain flow (pl. 3). The steepness of the flow-duration curves also is indicative of the high variability of streamflow, which is caused by variable precipitation modified by the basin characteristics.

In the upper Santa Cruz River basin the median (50 percent) flow exceeds 1 cfs (cubic feet per second) at only three stations—Sonoita Creek near Patagonia, Santa Cruz River near Nogales, and Pantano Wash near Vail (pl. 3). At these stations, the underlying bedrock forces ground water to the surface. Snowmelt reduces the variability of flow at Sabino Creek near Tucson, Bear Creek near Tucson, and Tanque Verde Creek near Tucson, but the lower end of the curves indicates that there is not sufficient ground-water discharge to sustain perennial flow (pl. 3).

The flow-duration curves can be used to determine the relative suitability of different streams for the development of a water supply. For example, if a water supply of 1 mgd (million gallons per day) is desired without providing storage, comparison shows that Sonoita Creek flows at a rate of 1 mgd (1.55 cfs) for 70 percent of the time and that the Santa Cruz River at Continental flows at 1 mgd for less than 10 percent of the time (pl. 3). If storage is not provided in the basin, streamflow will be available to sustain a 1-cfs draft rate for less than 30 percent of the time at all but four gaging stations, and streamflow will be available to sustain a 10-cfs draft rate for less than 20 percent of the time at all gaging stations (table 3).

TABLE 3.—*Percentage of time in a 28-year period that streamflow would equal or exceed selected discharge rates between 1 and 100 cfs at gaging stations*

Station	Discharge (cfs)				
	1	5	10	50	100
Santa Cruz River near Lochiel	12	5	3	1	0.5
Santa Cruz River near Nogales	67	34	19	6	4
Sonoita Creek near Patagonia	79	20	7	2	1
Santa Cruz River at Continental	9	7	6	4	3
Santa Cruz River at Tucson	11	8	7	4	3
Tucson Arroyo at Vine Avenue, Tucson	5	2	1	.3	.1
Tanque Verde Creek near Tucson	27	16	10	3	1
Sabino Creek near Mount Lemmon	24	5	2	.2	.1
Sabino Creek near Tucson	43	25	17	4	2
Bear Creek near Tucson	21	11	7	1	.5
Tanque Verde Creek at Tucson	19	15	12	5	2
Pantano Wash near Vail	90	7	5	2	1
Rincon Creek near Tucson	17	11	7	2	.5
Rillito Creek near Tucson	8	6	5	3	2
Santa Cruz River at Cortaro	13	11	9	6	4

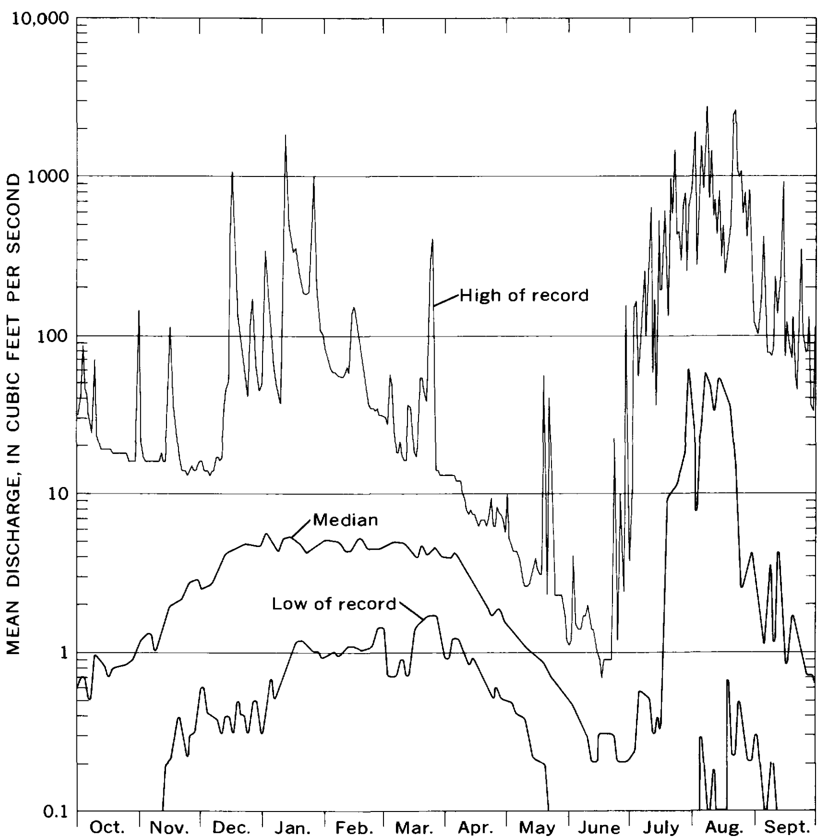


FIGURE 5.—Distribution of the daily high, median, and low flows, 1945–63, for Santa Cruz River near Nogales, Ariz.

Hydrographs of daily flow were prepared to show the seasonal distribution of streamflow at the three stations in the basin where the lowest flow would not be zero on every calendar day (figs. 5, 6, and 7).

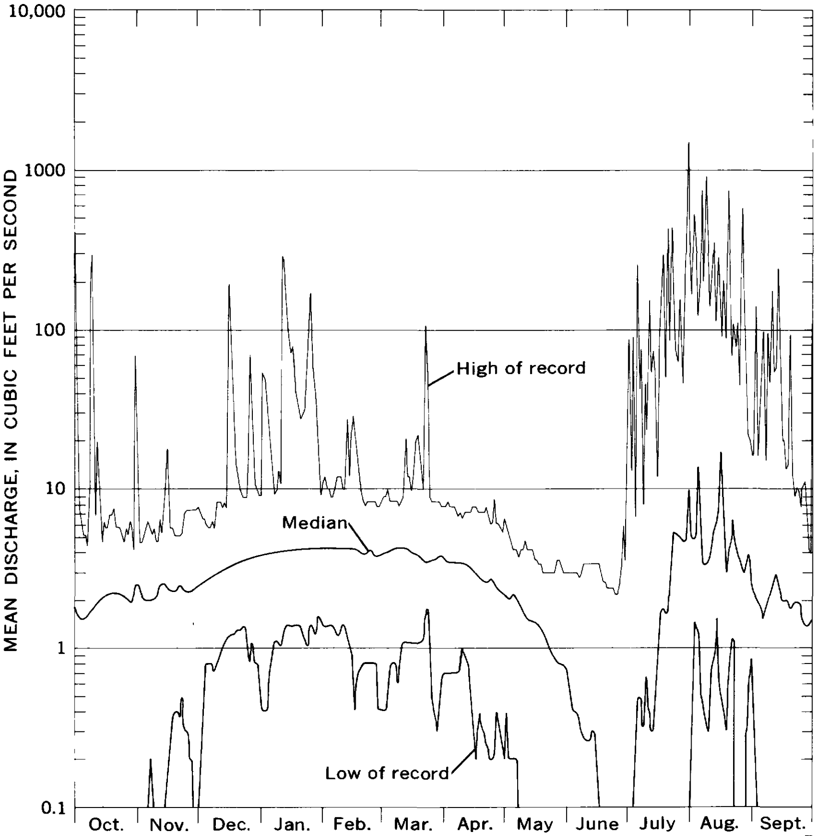


FIGURE 6.—Distribution of the daily high, median, and low flows, 1945–63, for Sonoita Creek near Patagonia, Ariz.

The hydrographs show the highest, the median, and the lowest mean flow for each calendar day. For some days the range in flow is four orders of magnitude. The lowest flows occur in June at all three stations.

ANALYSIS OF LOW FLOWS

An analysis of the low-flow frequency curves indicates a lack of sustained flow in the basin (pl. 4). The flow-duration curves, which were discussed in the preceding section, do not show whether the lowest flows occurred consecutively in a rare drought year or whether there were a few dry days in each year. Low-flow frequency curves, however, are based on the lowest mean discharges for intervals of time ranging from 1 to 274 consecutive days for each year of record and give the recurrence intervals, magnitudes, and the chronological sequences of the occurrence of the low flows.

The sustained flow in the basin was sufficient to define the 1-day and (or) 7-day curves only at Santa Cruz River near Nogales, Sonoita Creek near Patagonia, and Pantano Wash near Vail. The 1- and 7-day means are indicative of the amount of ground-water discharge available to sustain streamflow. At Sabino Creek near Tucson, the 1- and 7-day means were less than 0.01 cfs in each year during the period of record. At the other gaging stations in the basin, the low-flow frequency curves are of little value as a tool for determining the potential of the streams for a water supply or waste disposal, because the streams are dry for long periods during the year; therefore, curves for these stations are not included in the report. A mean flow of 1 cfs or less for a 183-day period will have a recurrence interval of 4 years or less at

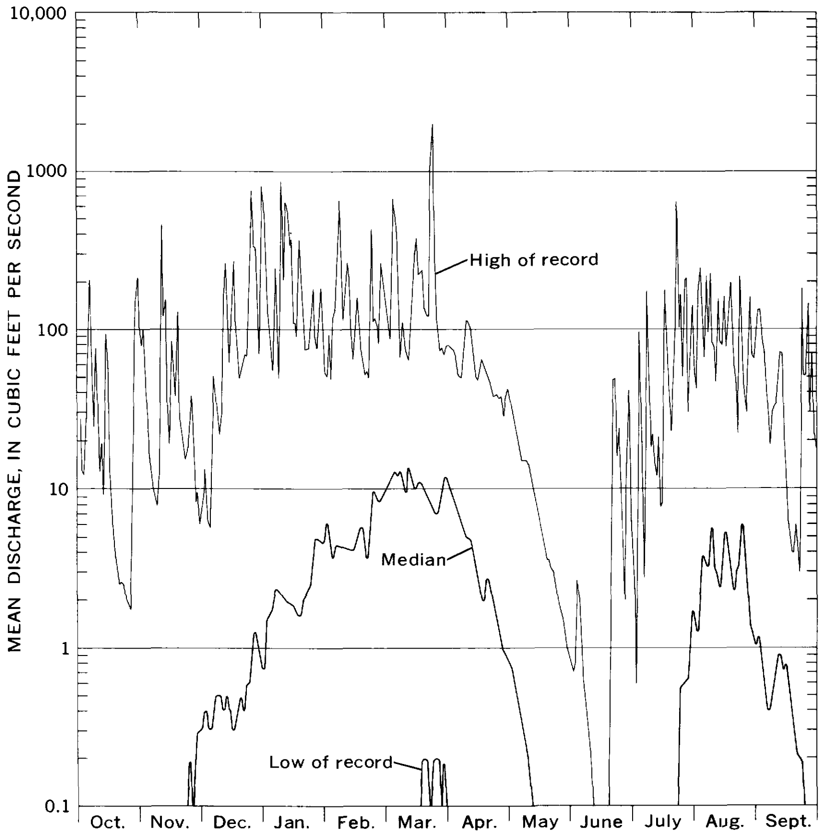


FIGURE 7.—Distribution of the daily high, median, and low flows, 1936–63, for Sabino Creek near Tucson, Ariz.

all gaging stations except Sonoita Creek near Patagonia and Santa Cruz River near Nogales; a 183-day mean of 5 cfs or less can be expected to occur at all gaging stations within a 2-year period (table 4).

TABLE 4.—*Recurrence intervals for 183- and 274-day mean flows of 1 cfs or less and 5 cfs or less at gaging stations*

Station	Recurrence interval, in years			
	Flow of 1 cfs		Flow of 5 cfs	
	183-day mean	274-day mean	183-day mean	274-day mean
Santa Cruz River near Lochiel	<2	2.6	<2	<2
Santa Cruz River near Nogales	14	>50	<2	8
Sonoita Creek near Patagonia	22	>50	<2	2.4
Santa Cruz River at Continental	<2	13	<2	3
Santa Cruz River at Tucson	<2	31	<2	8
Tucson Arroyo at Vine Avenue, Tucson	<2	2	<2	<2
Sabino Creek near Mount Lemmon	<2	<2	<2	<2
Sabino Creek near Tucson	3	6	<2	<2
Rincon Creek near Tucson	<2	2.4	<2	<2
Rillito Creek near Tucson	<2	8	<2	2.2
Santa Cruz River at Cortaro	3.2	>50	<2	10

Most streams in the Santa Cruz River basin are ephemeral and are dry on an average of at least once every 2 years; the number of days of no flow ranges from 4 at Sonoita Creek to 335 at Rillito Creek near Tucson (fig. 8). In any future year there is a 50 percent chance of 4 or more days of no flow at Sonoita Creek near Patagonia and a 5 percent chance of 73 or more days of no flow.

ANALYSIS OF HIGH FLOWS

In the upper Santa Cruz River basin the same streams that are dry for long periods of time carry high flows that have on occasion exceeded the capacity of the channels and overflowed onto the flood plains. Thunderstorms occur in the basin with more regularity and produce more streamflow than do frontal storms. As a result of these high-intensity summer storms, more than 93 percent of the flood peaks above a selected base discharge occur in July, August, and September on the Santa Cruz River (table 5); the base discharge is selected so that an average of three peaks each year is included. The flood peaks are more evenly distributed throughout the year on streams having drainage areas that extend high into the mountains, such as Sabino Creek (table 5). In the Sabino Creek drainage previously precipitated snow commonly is supplemented by rain, and winter floods occur with more regularity than at lower altitudes that have no snow cover. Occasionally, when snowfall at the lower altitudes is followed by rain,

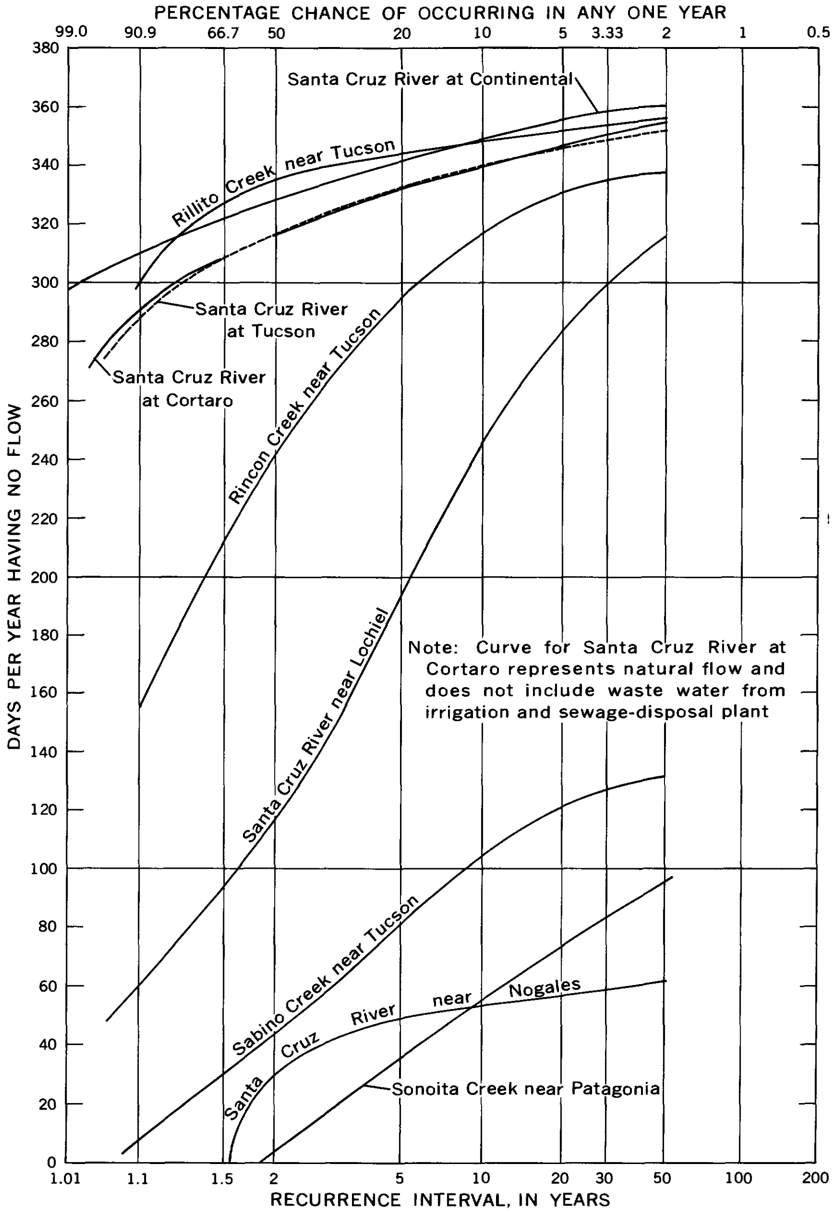


FIGURE 8.—Frequency of days having no flow at selected gaging stations.

the resulting winter flood produces a large volume of flow. Figure 9 compares summer and winter flood volumes on the Santa Cruz River at Tucson.

TABLE 5.—*Monthly distribution of flood peaks above a selected base discharge*

Station	Period of record (water year)	Total number of peaks	Base (cfs)	Percentage of peaks above base												Percentage of peaks in July, August, and September
				Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
Santa Cruz River near Lochiel	1949–1965	39	1,000							43	49	8				100
Santa Cruz River near Nogales	1930–1965	119	2,000	2					2	38	51	6			1	95
Sonoita Creek near Patagonia	1930–1965	111	1,200		2					32	53	12	1			97
Santa Cruz River at Continental	1940–1965	98	2,000	2						29	53	12	4			94
Santa Cruz River at Tucson	1915–1965	169	1,700	2	1				1	30	50	13	1	1	1	93
Tucson Arroyo at Vine Avenue, Tucson	1940–1965	86	150	2	2		1		1	28	37	18	6	1	4	83
Sabino Creek near Mount Lemmon	1951–1959	31	50	10		6				26	42	3	7	3	3	71
Sabino Creek near Tucson	1932–1965	139	150	8	8	6	1		1	17	32	11	6	3	7	60
Rincon Creek near Tucson	1953–1965	59	100	7	1	3				14	61	8	2	2	2	83
Rillito Creek near Tucson	1915–1965	140	1,000	4	5	4			1	26	39	13	2	2	4	78
Santa Cruz River at Cortaro	1940–1965	97	2,700	2		1			1	34	49	10	2		1	93

FLOOD FREQUENCY

Patterson and Somers (1966) made a regionalized flood-frequency analysis for instantaneous peak flows in the upper Santa Cruz River basin. The term "regionalized" refers to the delineation of the boundaries of regions having similar flood characteristics and to the establishment of relations between pertinent characteristics of the flood-frequency curve and basin or climatological parameters within the homogeneous region (Cruff and Rantz, 1965). For the upper Santa Cruz River basin, the mean annual flood was used as the index flood, and the drainage area was used as the basin parameter.

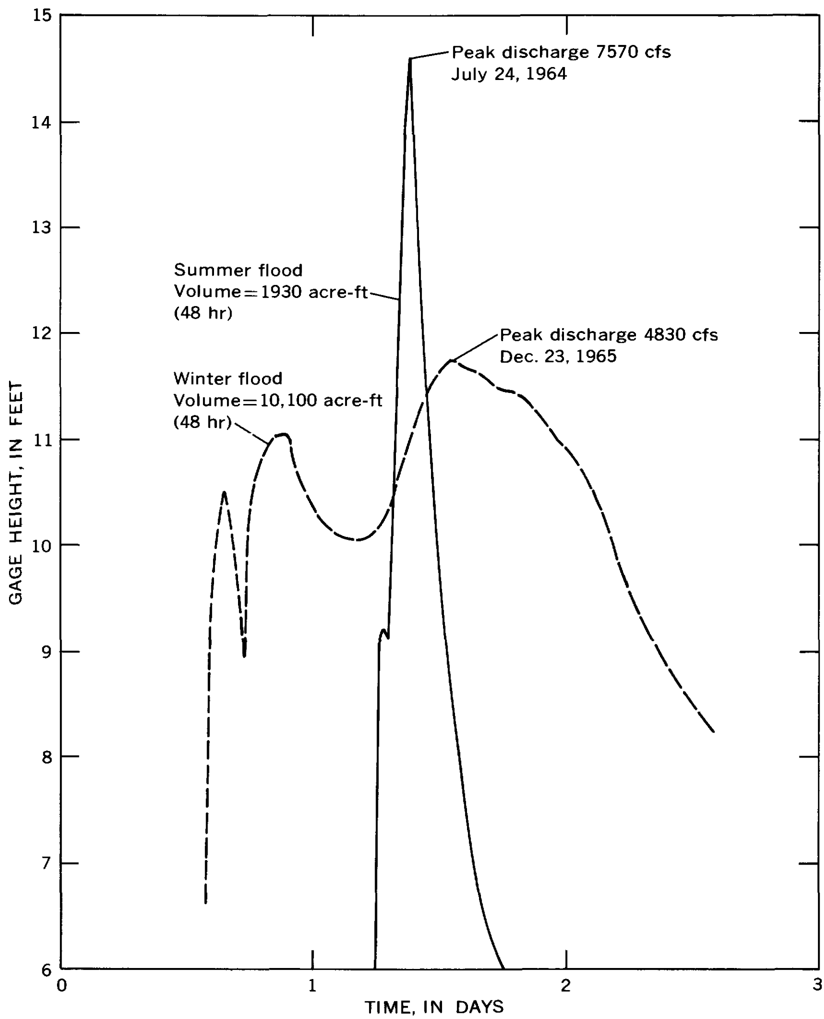


FIGURE 9.—Comparison of a summer flood and a winter flood on the Santa Cruz River at Tucson.

The discharge for a flood of a selected frequency is computed from figures 10 and 11 by the following steps: (1) Determine the discharge of the mean annual flood for the contributing drainage area from figure 10, (2) determine the ratio of the flood of the selected recurrence interval to the mean annual flood from figure 11, and (3) multi-

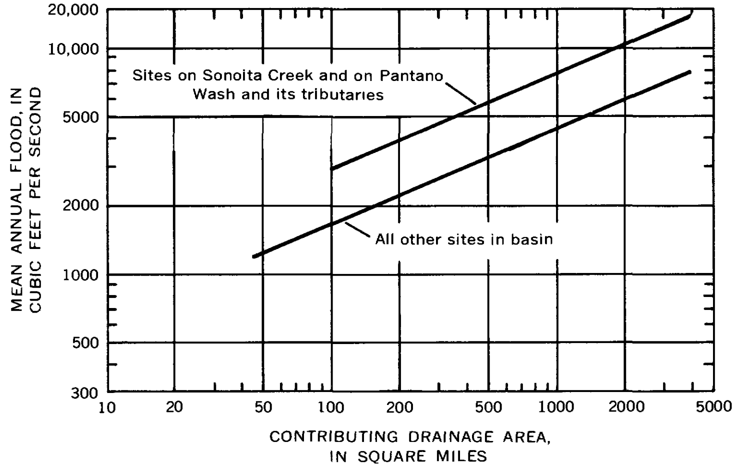


FIGURE 10.—Variation of mean annual flood with drainage area in the upper Santa Cruz River basin. (After Patterson and Somers, 1966.)

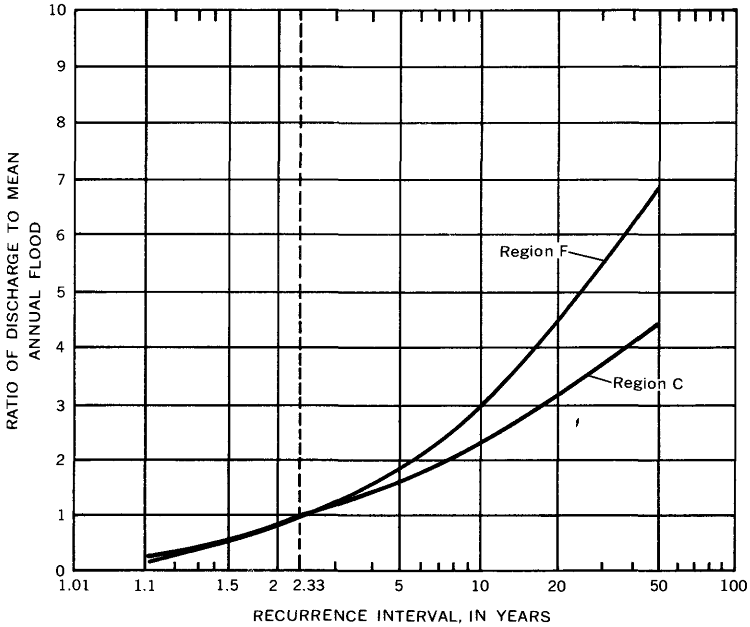


FIGURE 11.—Regional frequency curves for the upper Santa Cruz River basin. (After Patterson and Somers, 1966.)

ply the ratio (step 2) by the mean annual flood to obtain the discharge for a flood of a selected frequency. Additional data collected since Patterson and Somers (1966) made their study indicate that the region F curve (fig. 11) should be used for streams draining directly from the south and west slopes of the Santa Catalina, Tanque Verde, and Rincon Mountains and that the region C curve should be used for the rest of the basin (B. N. Aldridge, written commun., 1968). The magnitudes of floods at gaging stations on the Santa Cruz River for different recurrence intervals follow:

Gaging station	*Mean annual flood (cfs)*	*10-year flood (cfs)*	*20-year flood (cfs)*	*50-year flood (cfs)*
Santa Cruz River near Lochiel	1, 530	3, 550	4, 970	6, 760
Santa Cruz River near Nogales	3, 400	7, 890	11, 000	15, 000
Santa Cruz River at Continental	5, 500	12, 800	17, 900	24, 300
Santa Cruz River at Tucson	6, 250	14, 500	20, 300	27. 600
Santa Cruz River at Cortaro	7, 650	17, 700	24, 900	33, 800

The variability of the annual peak discharge at gaging stations is shown in table 6. The coefficients of variation given in table 6 show that there is less variability in the annual peak flows than in the annual flows relative to their means (table 2). The annual peak discharge usually is the result of a summer storm; summer floods occur more frequently than winter floods (table 5). The less frequent occurrence of a large volume winter flood increases the variability of the annual flow.

FLOOD VOLUMES

Flood-volume frequency curves (pl. 5) were prepared for the 10 gaging stations in the basin having sufficient periods of record. The curves present the floodflow data necessary for studies involving the storage of flood water. The largest volume of flow that can be expected for a selected number of days and a given recurrence interval is determined by multiplying the number of days by the mean discharge for the given recurrence interval. For example, the largest 7-day volume that can be expected to occur once every 20 years on Sonoita Creek near Patagonia is 1,890 cfs-days, or 3,750 acre-feet (pl. 5; table 7).

STORAGE ANALYSIS

Streamflow in the upper Santa Cruz River basin is of small quantity and large variability and causes occasional flooding. The construction of storage reservoirs is a commonly used method of compensating for the variability of streamflow, increasing the usability of available flows, and reducing the magnitude of floods. This section of the report summarizes studies of the magnitude of the storage required to pro-

TABLE 6.—*Variability of annual peak discharge at gaging stations*

Station	Drainage area (square miles)	Period of record	Annual peak discharge: Arithmetic average (cfs)	Extremes (cfs): High	Extremes (cfs): Low	Standard deviation (cfs)	Coefficient of variation	Skewness
Santa Cruz River near Lochiel	82. 2	1949–65	1, 840	4, 810	7. 6	1, 430	0. 78	0. 66
Santa Cruz River near Nogales	533	1930–65	4, 540	12, 000	1, 620	2, 730	. 60	1. 14
Sonoita Creek near Patagonia	209	1930–65	3, 740	14, 000	669	2, 740	. 73	1. 85
Santa Cruz River at Continental	1, 662	1940–65	5, 920	17, 500	370	4, 240	. 72	1. 30
Santa Cruz River at Tucson	2, 222	1915–65	5, 900	16, 600	1, 190	3, 670	. 62	. 95
Tucson Arroyo at Vine Avenue, Tucson	27. 0–8. 2	1940, 1943–65	1, 530	5, 000	149	1, 240	. 81	1. 21
Tanque Verde Creek near Tucson	43. 0	1960–65	1, 330	2, 360	789	638	. 48	1. 21
Sabino Creek near Mount Lemmon	3. 19	1951–58	199	344	68	96	. 48	. 10
Sabino Creek near Tucson	35. 5	1933–65	1, 380	5, 100	55	1, 170	. 85	1. 41
Bear Creek near Tucson	16. 3	1960–65	306	575	53	171	. 56	. 12
Tanque Verde Creek at Tucson	221	1940–45	3, 090	9, 000	573	3, 350	1. 08	. 85
Pantano Wash near Vail	457	1959–65	6, 990	9, 960	1, 500	2, 830	. 40	. 72
Rincon Creek near Tucson	44. 8	1953–65	2, 180	8, 250	150	2, 350	1. 08	1. 30
Rillito Creek near Tucson	918	1915–65	6, 310	24, 000	512	4, 570	. 72	1. 47
Santa Cruz River at Cortaro	3, 503	1940–47, 1950–65	8, 640	17, 000	1, 550	4, 430	. 51	. 47

TABLE 7.—*Flood volumes having 20- and 50-year recurrence intervals for 1-, 3-, and 7-day periods at selected gaging stations*

Station	Flood volume (acre-ft)					
	1-day		3-day		7-day	
	20-year	50-year	20-year	50-year	20-year	50-year
Santa Cruz River near Nogales	4,760	6,250	9,520	14,300	14,600	22,200
Sonoita Creek near Patagonia	2,280	3,670	2,920	3,690	3,750	5,410
Santa Cruz River at Continental	10,300	----------	13,700	----------	23,600	----------
Santa Cruz River at Tucson	11,300	15,500	19,000	29,200	23,600	37,500
Tucson Arroyo at Vine Avenue, Tucson	770	----------	830	----------	930	----------
Sabino Creek near Tucson	2,480	3,770	4,400	6,840	5,830	9,020
Rillito Creek near Tucson	9,120	9,820	17,300	23,800	18,700	30,500
Santa Cruz River at Cortaro	14,700	----------	15,500	----------	23,600	----------

vide a continuous reservoir outflow and the release of floodflows at lower rates. The summary is presented only as an aid in preliminary planning of reservoirs, and analyses of the maximum probable floods, which are used for detailed design of reservoir spillways, were not included in this study.

SUSTAINED FLOW

The volume of storage required to provide a sustained minimum flow may be determined either by the within-year-storage method or by the carryover-storage method. The within-year-storage method is based on the assumption that the volume of flow each year is sufficient to replenish the annual storage required to sustain a selected minimum outflow rate. In contrast, the carryover-storage method is based on the concept of storing water for periods greater than 1 year to sustain a minimum outflow rate. In both methods the amount of evaporation from the reservoir surface is not included, and it is necessary to add the amount of evaporation to the computed storage requirements.

Within-year-storage requirements were analyzed by the annual mass-curve method (H. C. Riggs, written commun., 1964) by a digital

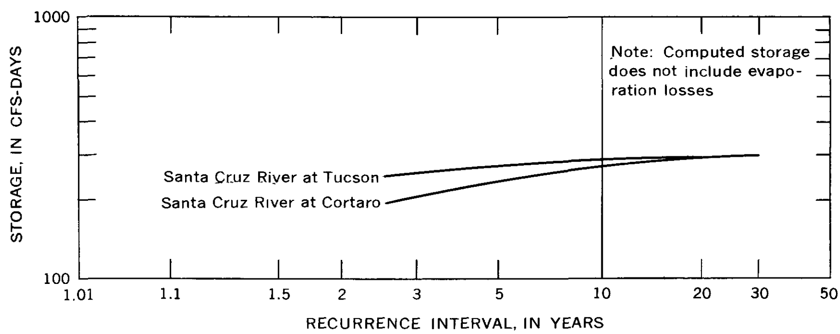


FIGURE 12.—Relation between volume of storage and the average length of time that the indicated storage would be insufficient to sustain a minimum reservior outflow of 1 cfs.

computer. For the period of record, the annual flow was sufficient to replenish the storage required to sustain a flow of 1 cfs at only three of the 15 gaged sites; the annual flow was insufficient to replenish the storage required to sustain a flow of 3 cfs at all the gaged sites (table 8). The length of record at Pantano Wash near Vail is insufficient for reliable analysis; therefore, only the records for Santa Cruz River at Tucson and at Cortaro were used to compute storage requirements by the within-year method (fig. 12).

TABLE 8.—*Percentage of years streamflow would be insufficient to replenish the storage required for selected draft rates*

Station	Number of years analyzed	Percentage of years for draft rate (cfs) indicated					
		1	3	5	7	10	15
Santa Cruz River near Lochiel	14	43	64				
Santa Cruz River near Nogales	31	3	3	10	13	42	58
Sonoita Creek near Patagonia	31	3	10	35			
Santa Cruz River at Continental	17	6	18	18	35	47	
Santa Cruz River at Tucson	49	0	4	12	18	29	51
Tucson Arroyo at Vine Avenue, Tucson	8	62	100				
Tanque Verde Creek near Tucson	4	25	75				
Sabino Creek near Mount Lemmon	6	50	100				
Sabino Creek near Tucson	31	16	42	52	81		
Bear Creek near Tucson	4	50	100				
Tanque Verde Creek at Tucson	4	25	50	75	100		
Pantano Wash near Vail	4	0	25	25			
Rincon Creek near Tucson	11	27	45	55			
Rillito Creek near Tucson	49	6	27	43	57		
Santa Cruz River at Cortaro	19	0	5	5	16	16	26

If streamflow is to be carried over from years when the flow exceeds a desired draft rate and used during years of low flow, then evaporation becomes an even more important factor in the analysis. In the upper Santa Cruz River basin, the average annual lake evaporation is about 5½ feet (Kohler and others, 1959, pl. 2). For example, if a storage reservoir were built on Sonoita Creek to provide a 5-cfs draft rate, a maximum storage of 2,600 cfs-days, or 5,160 acre-feet, would be required. The time that the water must be stored to provide this continuous 5-cfs draft rate is 9 years—from the time the reservoir begins filling in excess of the draft rate to the time when the streamflow deficiency ends (fig. 13). The water level in a reservoir on Sonoita Creek would decline about 50 feet in 9 years as a result of evaporation; therefore, even if storage were available, streamflow would be insufficient to provide a continuous 5-cfs draft rate. At Sabino Creek near Tucson, the maximum storage requirement for a 5-cfs draft rate would be 5,000 acre-feet, and the evaporation loss would be about 38 feet during a 7-year period—for example, if the reservoir had an average depth of 100 feet, the evaporation loss would be 1,900 acre-feet. At Rillito Creek near Tucson the maximum storage requirement for a 5-cfs draft rate would be 8,730 acre-feet, and a storage period

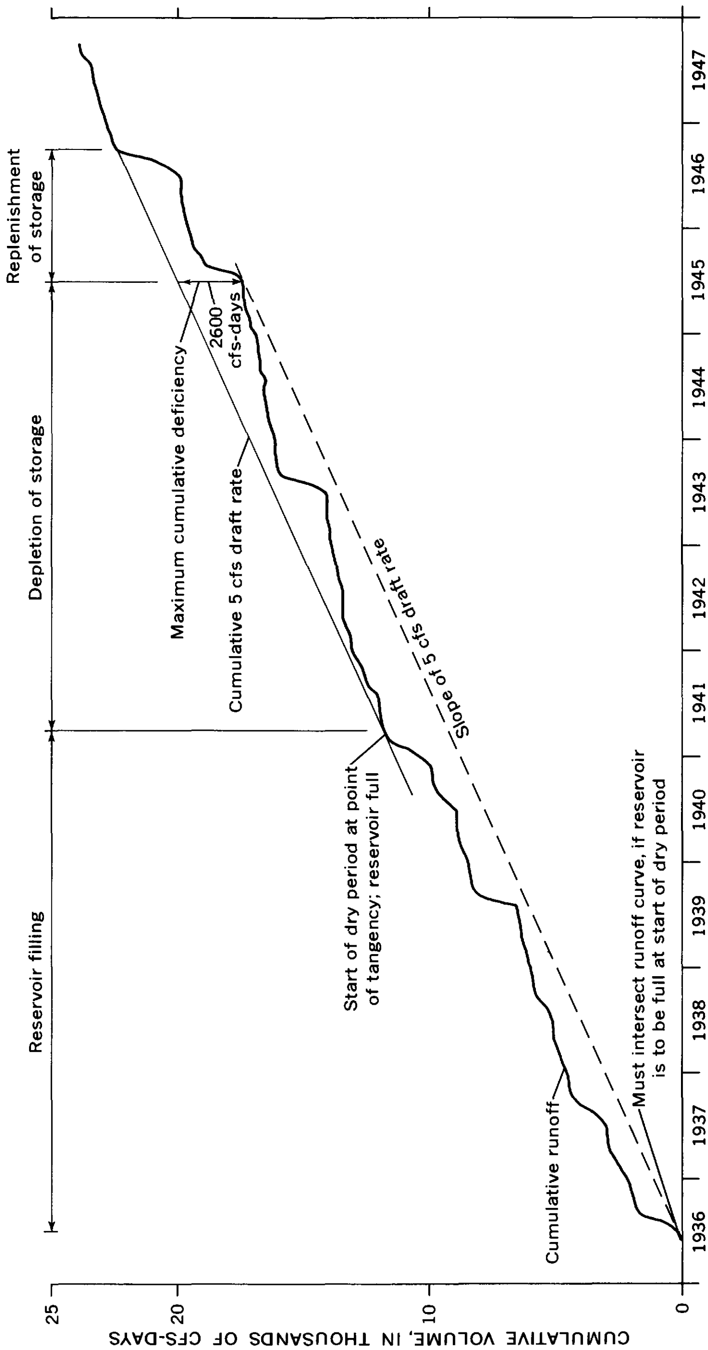


FIGURE 13.—Mass diagram for the determination of storage, Sonoita Creek near Patagonia, Ariz.

of 9 years would be required. At Santa Cruz River at Tucson, the maximum storage requirement for a 15-cfs draft rate would be 24,800 acre-feet, and a storage period of 7 years would be required. The storage requirements for Rillito Creek and the Santa Cruz River would be larger if the losses by evaporation, seepage, and silting were included.

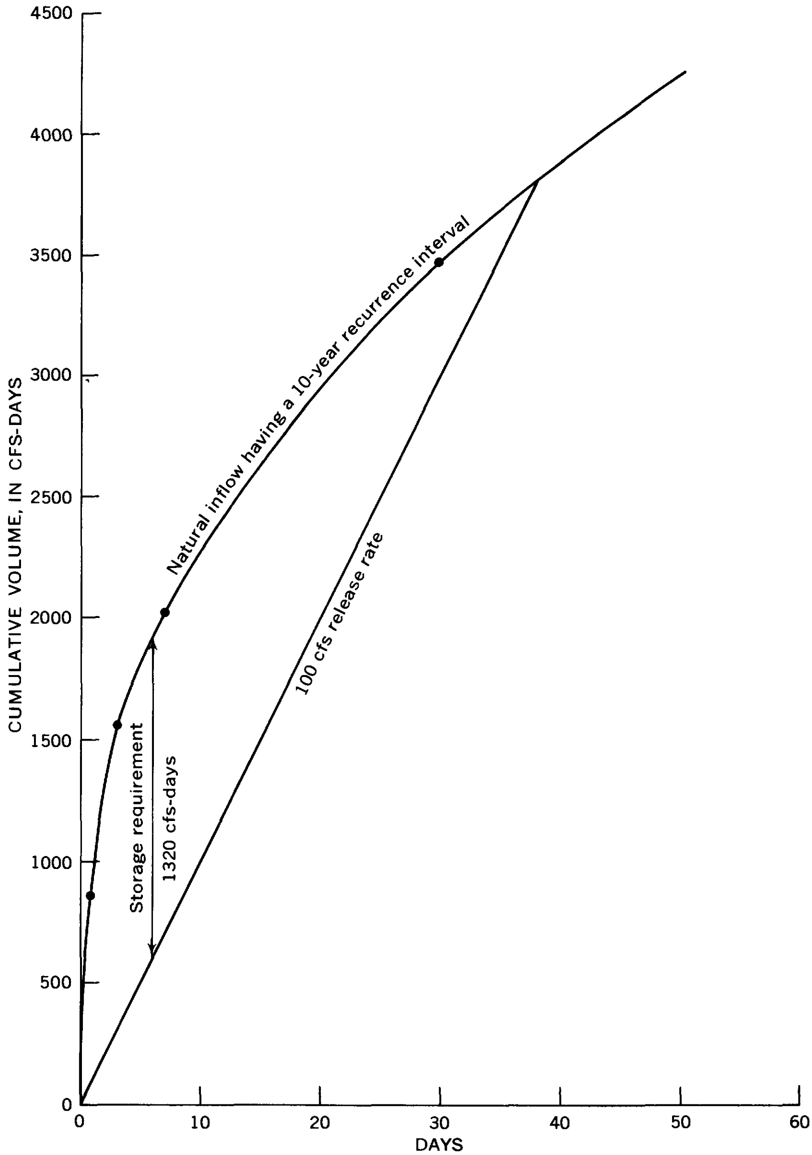


FIGURE 14.—Frequency-mass analysis for Sabino Creek near Tucson.

Because of the high evaporation rates and the extremely low flows in some years, streamflow in the upper Santa Cruz River basin is not a likely source for a continuous water supply of any magnitude. Streamflow, however, could be used in ways other than as a continuous draft. For example, streamflow could be stored and used in a few months to supplement existing ground-water supplies; the short-term storage would reduce the evaporation losses in the reservoirs.

CONTROLLED RELEASE OF FLOODFLOWS

A storage analysis was made to determine the design storage needed to contain floodflows for release at lower sustained rates (pl. 6). The water, when released at lower rates, would increase the amount of ground-water recharge from the floodflows. A frequency-mass curve analysis (fig. 14) of the flood-volume curves (pl. 5) for different release rates was used to develop the storage-release frequency curves.

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