Mean Annual Runoff as Related to Channel Geometry of Selected Streams in California

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1999-E

Prepared in cooperation with the California Department of Water Resources

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By E. R. HEDMAN

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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By E. R. Hedman

ABSTRACT

The channel geometry of 48 gaged streams in California where mean annual runoff is known was studied in 1967 and 1968. The analyses show that the mean annual runoff is related to selected dimensions of channel geometry. The width and the average depth of the cross section between bars or berms can be used to estimate annual runoff from ungaged streams. Separate relations are needed for perennial and ephemeral streams. The analyses also showed that it is better to measure several cross sections, compute the discharge for each cross section, and average these discharges to obtain the discharge for the site. A 10-year period, 1958–67, was analyzed to determine if the channel dimensions were affected by recent hydrologic or climatic events. It was determined that the computed runoff represented a long-term mean; that is, the standard error of estimate was less for the regression using the runoff for the period of record rather than for the 10-year period.

INTRODUCTION

The cost and the length of time required to collect data necessary for hydrologic studies of drainage basins in arid and subhumid regions have created the need for other methods for determining runoff. Reconnaissance studies are commonly made to provide preliminary estimates, but most studies are based on sparse and questionable data concerning precipitation and evapotranspiration. On the basis of some exploratory work, W. B. Langbein (written commun., 1966) suggested a method of estimating mean annual runoff based on width and average depth of stream channels at point bars in meandering channels, at island bars in braided channels, or at berms. These bars and berms are described by Leopold and Wolman.[1]

[1] Leopold, L. B., and Wolman, M. G., 1957, River channel patterns: braided, meandering, and straight: U.S. Geol. Survey Prof. Paper 282–B, p. 38–85.

Moore[2] expanded the work of Langbein and developed separate relation curves for ephemeral and perennial streams in Nevada. Streams are commonly classed according to types on the basis of flow. Perennial streams carry flow at all times, except during extreme drought. Intermittent streams carry flow only at certain times during the year when they receive water from springs or from surface sources, such as melting snow or ice in mountainous areas. Ephemeral streams carry flow only after periods of precipitation. Because of the lack of adequate data concerning flow duration, it was not reasonable to classify streams as intermittent; therefore, in this report all streams were classified as perennial if they were flowing and ephemeral if they were dry.

This report was prepared by the U.S. Geological Survey, Water Resources Division, in cooperation with the California Department of Water Resources. The work was done during 1967 and 1968 under the general supervision of R. Stanley Lord, district chief in charge of water-resources investigations in California, and under the immediate supervision of L. C. Dutcher, chief of the Garden Grove subdistrict.

STUDY OF CHANNEL GEOMETRY

On the basis of the results of the earlier studies by Langbein (written commun., 1966) and Moore,[3] the emphasis of this study was placed on developing a relation of the unique dimensions of width and depth of the channels at bars and berms to annual runoff. An alluvial channel adjusts in size to accommodate the discharge it receives. Although the channel geometry is influenced by the slope, channel pattern, sediment loads, cohesiveness of the banks, and vegetation, these studies indicate that the dimensions of the cross sections at the bars and berms are not significantly affected, and that they are related to the annual runoff.

The channel dimensions of 48 gaged streams in the arid and subhumid parts of California were studied in 1967 and 1968. These streams are listed in table 1. Because these dimensions vary greatly in the different cross sections of a stream, as many as five sections were surveyed in a reach of channel about 10 stream widths in length at each site. Each site was chosen near the gaging station, so that the drainage area above the site was

[2] Moore, D. O., 1968, Estimating mean runoff in ungaged semiarid areas: *in* Internat. Assoc. Sci. Hydrology Bull., v. 13, no. 1, p. 29–39.

[3] Moore, D. O., op. cit.

about the same as above the gaging stations, and runoff data would be available. Measurements were made of width and average depth at each cross section.

TABLE 1.—*Computed and observed runoff at 48 gaging stations in California*

[Period of record: e, ephemeral stream; p, perennial stream]

Station No.	Station name	Drainage area (sq mi)	Period of record	Mean annual runoff: Observed: Period of record (acre-ft)	Mean annual runoff: Observed: 10-year period (1958–67) (acre-ft)	Mean annual runoff: Computed (acre-ft)
10–2558.85	San Felipe Creek near Westmoreland.	1,693	1960–67	e3,000	-----	3,660
2560 --	Whitewater River at White Water.	57.4	1948–67	p9,050	10,210	5,800
2580 --	Tahquitz Creek near Palm Springs.	16.8	1947–67	e2,290	2,880	3,760
2585 --	Palm Canyon Creek near Palm Springs.	93.3	{1930–42 1947–67}	e2,720	1,300	2,850
2605 --	Deep Creek near Hesperia.	136	{1904–22 1927–67}	p48,510	36,970	63,300
2610 --	West Fork Mojave River near Hesperia.	74.6	{1904–22 1929–67}	p28,020	17,380	41,400
11–0315 --	Agua Caliente Creek near Warner Springs.	19.0	1961–67	e573	-----	805
0400 --	San Luis Rey River at Monserate Narrows, near Pala.	373	{1935–41 1946–67}	e5.490	1.490	5.400
0410 --	San Luis Rey River near Bonsall.	512	*	e13,680	1,790	9,940
0424 --	Temecula Creek near Aguanga.	131	1957–67	e2,690	2,720	3,050
0465 --	San Juan Creek near San Juan Capistrano.	106	1954–67	p6,660	7,250	17,000
0470 --	Arroyo Trabuco near San Juan Capistrano.	35.7	1930–67	p3,460	3,070	2,290
0570 --	San Timoteo Creek near Redlands.	119	1926–67	e1,010	753	1,350
0585 --	East Twin Creek near Arrowhead Springs.	8.80	1919–67	p3.160	2,390	1,630
0586 --	Waterman Canyon Creek near Arrowhead Springs.	4.65	{1911–14 1919–67}	p1,800	1,240	2,080

* Observed runoff, 13,680, for 1929–67.

TABLE 1.—*Computed and observed runoff at 48 gaging stations in California* —Continued

Station No.	Station name	Drainage area (sq mi)	Period of record	Mean annual runoff		
				Observed		
				Period of record (acre–ft)	10–year period (1958–67) (acre–ft)	Computed (acre–ft)
0670 --	Day Creek near Etiwanda.	4.59	1950–67	p2,610	3,000	2,560
0734.7-	Cucamonga Creek near Upland.	10.1	1927–67	p5,150	4,950	7,000
0780 --	Santa Ana River at Santa Ana.	1,685	1940–67	e10,500	8,270	10,300
0845 --	Fish Creek near Duarte.	6.36	1917–67	p2,870	3,150	4,290
0980 --	Arroyo Seco near Pasadena.	16.0	1910–67	p6,390	5,810	6,430
1105 --	Hopper Creek near Piru.	23.6	1930–67	e3,600	4,130	2,480
1130 --	Sespe Creek near Fillmore.	251	1927–67	p72,400	79,930	47,100
1135 --	Santa Paula Creek near Santa Paula.	40.0	1927–67	p13,680	15,930	13,200
1145 --	Matilija Creek above Reservoir near Matilija Hot Springs.	50.7	1948–67	p15,930	22,150	14,000
1160 --	North Fork Matilija Creek at Matilija Hot Springs.	15.6	{1928–32 1933–67}	p6,530	6,800	7,440
1195 --	Carpinteria Creek near Carpinteria.	13.1	1941–67	e1,400	1,980	2,130
1200 --	Atascadero Creek near Goleta.	18.8	1941–67	e3,260	3,530	2,930
1205 --	San Jose Creek near Goleta.	5.51	1941–67	p1,170	1,760	2,050
1265 --	Santa Agueda Creek near Santa Ynez.	55.8	1940–67	e2,370	3,420	2,840
1284 --	Alisal Creek near Solvang.	12.2	1954–67	e4,200	4,660	2,870
1390 --	La Brea Creek near Sisquoc.	93.8	1943–67	e3,840	5,560	3,190
1395 --	Tepusquet Creek near Sisquoc.	28.6	1943–67	p890	1,160	1,450
1430 --	Big Sur River near Big Sur.	46.5	1950–67	p67,040	64,500	62,100
1435 --	Salinas River near Pozo.	74.1	1942–67	p10,790	12,790	12,800
1470 --	Jack Creek near Templeton.	25.3	1949–67	p9,990	10,810	11,800
1476 --	Huerhuero Creek near Creston.	101	1958–67	e1,150	1,140	762
1478 --	Cholane Creek near Shandon.	227	1958–67	e1,670	1,670	1,440

TABLE 1.—*Computed and observed runoff at 48 gaging stations in California* —Continued

Station No.	Station name	Drainage area (sq mi)	Period of record	Mean annual runoff: Observed: Period of record (acre–ft)	Observed: 10–year period (1958–67) (acre–ft)	Computed (acre–ft)
1600	Soquel Creek at Soquel.	10.2	1951–67	p31,780	29,130	20,700
1615	Branciforte Creek at Santa Cruz.	17.3	1940–43, 1952–67	p14,620	13,090	11,600
1625	Pescadero Creek near Pescadero.	45.9	1951–67	p30,120	27,100	33,500
1695	Saratoga Creek at Saratoga.	9.22	1933–67	p7,010	5,720	4,830
1760	Arroyo Mocho near Livermore.	38.2	1912–30, 1963–67	p2,980	----	3,780
1765	Arroyo Valle near Livermore.	147	1912–30, 1957–67	p22,080	23,220	16,600
1964	Caliente Creek above Tehachapi Creek, near Caliente.	165	1961–67	e1,050	-----	1,220
1972.5	Avenal Creek near Avenal.	57.1	1961–67	e1,250	-----	1,080
2245	Los Gatos Creek above Nunez Canyon near Coalinga.	95.8	1945–67	e2,180	3,380	2,010
3375	Marsh Creek near Byron.	42.6	1953–67	p5,880	6,400	8,740
4560	Napa River near St Helena.	81.4	1929–32, 1939–67	p65,230	67,620	48,500

COLLECTION OF FIELD DATA

The reaches of channel near the gages were reconnoitered to locate cross sections with well-defined and consistent reference levels for obtaining the required channel dimensions. The bars and berms used for the reference level represent the highest streambed forms of which particles are subject to annual sediment movement, and the lowest prominent bed forms. The total reach of channel used for the survey was inspected to be certain that the correct reference levels were chosen. Reference levels should all be about the same elevation above the streambed, and the bars or berms used to determine the reference levels should continue along the reach. Figure 1 shows the point bar along one bank of a perennial stream. The white metallic tape is at the reference level. The bars and berms were usually only 0.2–0.6 foot above the water surface at the low-flow condition in perennial streams and almost level from bank to bank.

Figure 2 shows the reference level defined by bars and berms in a channel of an ephemeral stream. For those streams investigated the bars and berms formed by an ephemeral stream were often more evident than those formed by a perennial stream.

The bed forms that were the basis of the survey were usually related to vegetal zones. Langbein (oral commun., 1967) noted that in midsummer three vegetal zones can be recognized: (1) the in-channel, which is usually free of vegetation; (2) the zone between the level defined by the tops of the point and island bars and the flood plain, which is usually occupied by annuals (forbs and grasses) ; and (3) the true flood plain, which is occupied by shrubs, some species of which may be phreatophytes. The bars that were used as the reference level in this study were always much lower than the flood plain. The crests of the bars along the perennial streams were often covered with vegetation, and, in some place, the crests were held in place by the vegetation.

FIGURE 1.—Point bar along one bank of a perennial stream. White tape is at reference level.

FIGURE 2.—Bars and berms along one bank of an ephemeral stream. White tape is at reference level. Photograph by D. O. Moore.

The reference level was then chosen at the base of the vegetation. Figure 3 shows a vegetation line along the right bank and a bar on the left bank.

Where pools and riffles existed in the channel, it was necessary that cross sections be measured at or near the riffles. The bars or berms that were used to determine the reference levels are not formed along the edges of the pools, and those that are present will probably give erroneous results.

It was often difficult to locate good reference levels on both banks. One bank may be almost vertical. It was also apparent from cross sections with bars on both banks that the elevation was about the same on both banks for straight reaches of channel. Therefore, good results could also be obtained by stretching a level line from a good reference point to the opposite bank.

Manmade structures in the channel, such as bridge piers, gaging-station controls, and lined banks, did not inhibit the formation of the bars or berms, especially if their influence was at elevations higher than the reference level. Point bars and berms with well-defined reference levels were found just downstream from bridges and gaging-station controls. Well-defined point bars were also found just downstream from large boulders in the channels as shown in figure 4—a view of a cross section in Taquitz Creek near Palm Springs. In figure 4 the white tape is at the reference level.

Channel-bed slope and material size appeared to have little effect on width and depth of the cross sections between the bars or berms. The same relation of these channel dimensions to runoff existed for steep reaches of channel in the mountains to the flat slopes of the valley floor. The bed-material size ranged widely even from cross section to cross section within the same reach of channel. Figure 5 shows the material which forms the point bar at section 1 in Arroyo Seco near Pasadena. Figure 6 shows much coarser material on the bar at section 3 about 100 feet downstream from section 1. The relation of channel dimensions to runoff was the same at both sections.

Because the channel dimensions, width and depth, varied greatly along the reaches, several cross sections were taken in each reach. As many as five cross sections were surveyed if it was possible to locate that many independent sections. Sections were located one to two stream widths apart, and the reference level for each cross section was determined from separate bars or berms.

FIGURE 3.—Vegetation line on right bank and bar on left bank. View downstream. White tape is at reference level. Photograph by D. O. Moore.

FIGURE 4.—Well-defined point bar downstream from large boulders in Taquitz Creek near Palm Springs. White tape is at reference level. Photograph by D. O. Moore.

FIGURE 5.—Material forming point bar at section 1 in Arroyo Seco near Pasadena.

A line was stretched tightly across the channel at right angles to the thalweg at each cross section for which reference levels could be determined. Width was measured between the streamward shoulders of the bars or berms at the reference level. The depths were measured from the line to the streambed at about 20 equidistant points, and the mean depth computed. If the channel was so wide that sag in the line was a factor, a level or transit and rod were used. The widths and mean depths at each cross section were recorded for the reach of channel. Photographs were taken at each cross section for review and, at some cross sections, for determination of bed-material size, as shown in figures 5 and 6.

METHOD OF ANALYSIS

Multiple regression was used to obtain the best fit of the variables by an equation of the form:

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3 \qquad (1)$$

where Y is a dependent variable, X_1, X_2, and X_3 are independent variables, a is the regression constant, and b^1, b^2, and b^3 are regression coefficients.

FIGURE 6.—Material forming point bar at section 3 in Arroyo Seco near Pasadena.

The dependent variable, Y, and the independent variable, X, are known data. The regression constant, a, and the regression coefficients, b_1, b_2, and b_3, are constants which are computed with the criterion that the sum of the squares of residuals of the relation be minimized. A logarithmic transformation will linearize the relations of many hydrologic variables. This transformation was done so the resulting equation has the form:

$$\text{Log } Y = \log a + b_1 \log X_1 + b_2 \log X_2 + b_3 \log X_3.$$

By taking antilogs we obtain the equivalent form:

$$Y = aX_1^{b_1} X_2^{b_2} X_3^{b_3} . \qquad (2)$$

The calculations involved in solving for the constants are very extensive, and therefore have been programed on a digital computer.

All streams were classified as perennial or ephemeral, and separate analyses were made for the perennial and ephemeral streams using (1) the mean annual runoff for the period of record at the gaging station and (2) the mean annual runoff for the 10-year period (water years 1958–67, if available) at the gaging station. The 10-year period was analyzed to determine if channel dimensions were affected by recent hydrologic events and to have a common base period. The length of record for the published mean annual runoff ranged from 6 to 58 years.

PERENNIAL STREAMS

Using width and depth for each cross section as independent variables for the 28 perennial streams for the period of record gave the smaller standard error of estimate, about 38 percent, and the equation:

$$Qp = 186\, W^{1.54} D^{0.88} \qquad (3)$$

where Qp is runoff in acre-feet per year for perennial streams, W is width in feet, and D is depth in feet.

Figure 7 shows equation 3 in graphical form. Either equation 3 or the graph can be used for estimating runoff when the width and the depth of the cross sections between bars or berms are known. However, neither the equation nor the graph is reliable beyond the range of the independent variables, that is, width, 6–56 feet, and depth, 0.2–1.3 feet. Table 1 and figure 8 show a comparison of the observed runoff, which is published data for each gaging station, and the computed runoff from equation 3 for the 28 perennial streams. The computed runoff was obtained by computing the runoff at each cross section with equation 3 and

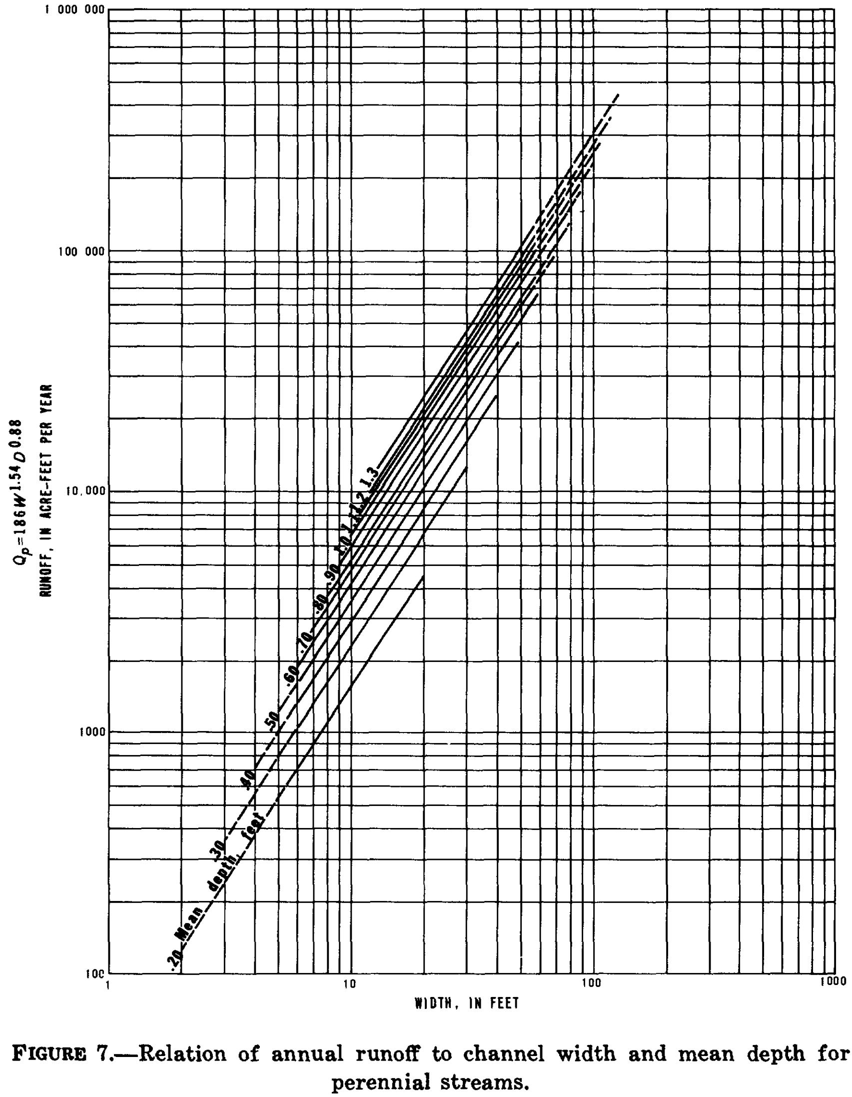

FIGURE 7.—Relation of annual runoff to channel width and mean depth for perennial streams.

taking the average of the cross sections at each gaging site. The gaging station numbers are given in table 1 and figure 8.

The analyses for the perennial streams using runoff for the 10-year period 1958–67 showed that the standard error of estimate of the computed annual runoff was about 43 percent.

EPHEMERAL STREAMS

Using width and depth for each cross section as independent variables for the 20 ephemeral streams for the period of record

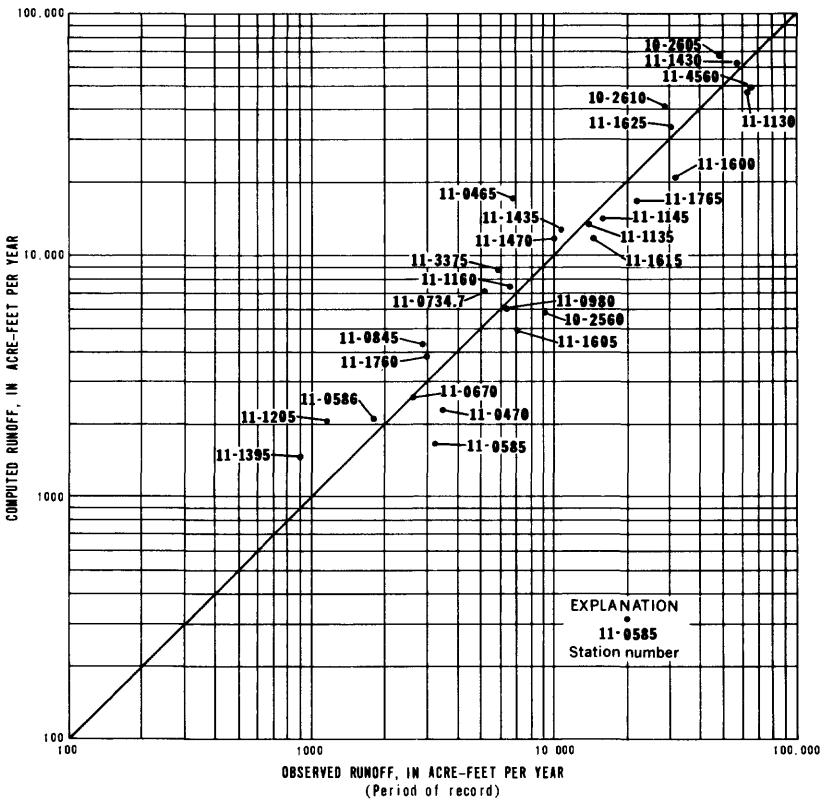

FIGURE 8.—Comparison of observed and computed runoff for perennial streams.

gave a standard error of estimate, about 29 percent and the equation:

$$Q_e = 258\, W^{0.80} D^{0.60} \tag{4}$$

where Q_e is ephemeral runoff in acre-feet per year, W is width in feet, and D is depth in feet.

Figure 9 shows equation 4 in graphical form. The equation or the graph can be used for estimating runoff in ephemeral streams when the width and the depth of the cross sections between bars or berms are known. However, neither equation 4 nor the graph is as reliable beyond the range of the independent variables used in the regression, that is, width 10–135 feet, and depth 0.2–1.1 feet. Figure 10 shows a comparison of the observed runoff, which is published data for each gaging station, and the computed runoff from equation 4 for the ephemeral streams. The computed runoff was obtained for these ephemeral sites by computing the runoff at each cross section with equation 4 and taking the average of all cross sections at each gaging site. The gaging station numbers are given in table 1 and figure 10.

In the anlysis of the shorter period of record (1958–67) for the ephemeral streams, the standard error of estimate of the computed mean runoff was about 48 percent.

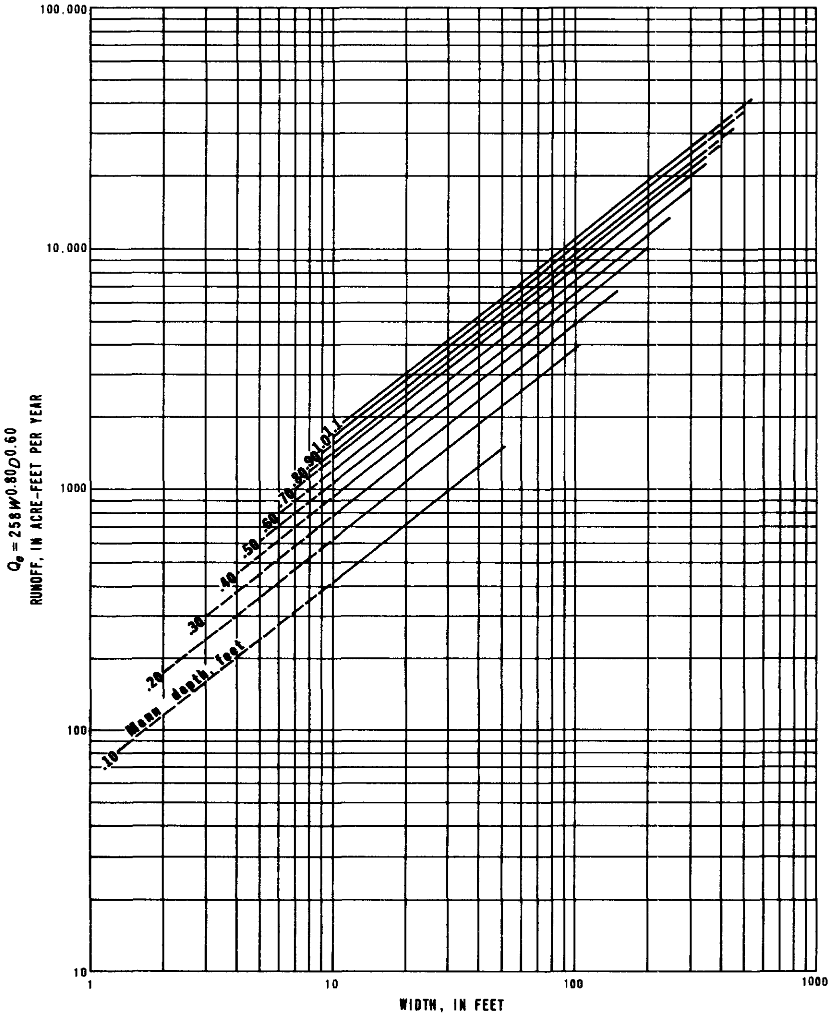

FIGURE 9.—Relation of annual runoff to channel width and mean depth for ephemeral streams.

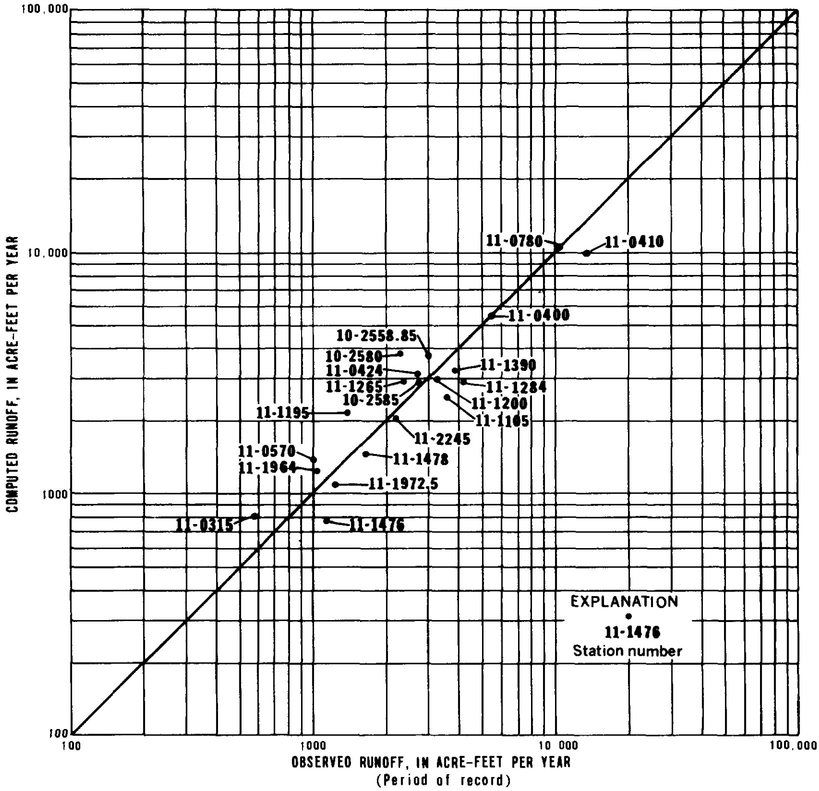

FIGURE 10.—Comparison of observed and computed runoff for ephemeral streams.

REPEATED MEASUREMENTS AT GAGING STATIONS

Two or three visits were made to selected gaging stations following individual storms to see if the results of the measurements could be duplicated and if the channel bars retained their relative position and size following peak flows. Three series of measurements made at Arroyo Seco near Pasadena and two series at Santa Ana River at Santa Ana indicated that measurements could be duplicated and that the bars retain their relative position and size. The results of the computed runoff are given in table 2. The peak discharge that occurred between the series of measurements and the computed average annual runoff are given in cubic feet per second (cfs) to show the relative magnitude of the peak discharge to the average annual runoff.

TABLE 2.—*Results of repeated channel geometry measurements at gaging stations*

Date	Width (feet)	Depth (feet)	Peak discharge (cfs)	Computed average runoff (cfs)	Computed average runoff (acre-feet)
Arroyo Seco near Pasadena (perennial)					
1967					
Nov. 17	18.5	0.36			
Do	19.0	.39		9.0	6,510
Do	13.0	.49			
Nov. 19	---	---	1,720	--	-----
1968					
Jan. 19	15.0	.42			
Do	15.5	.38		8.3	6,040
Do	18.0	.40			
Mar. 8	---	---	192	---	-----
Mar. 21	14.0	.43		9.3	6,730
Do	24.0	.29			
Santa Ana River at Santa Ana (ephemeral)					
1967					
Nov. 18	135	0.72		14.4	10,400
Do	130	.77			
Nov. 21	----	---	1,250	---	----
1968					
Jan. 19	120	.66		12.8	9,300

CONCLUSIONS

These analyses indicate that the best results are obtained by computing the runoff using the width and depth between bars or berms for each cross section and then averaging the runoff for each cross section to determine the runoff for the site. The analyses also indicate that the runoff computed from measurements of the channel dimensions more nearly represents the average annual runoff for longer periods of record. The computed annual runoff for 48 streams studied is given in table 1.

The standard error of estimate for perennial streams (about 38 percent) and for ephemeral streams (about 29 percent) compared favorably with a study of streamflow generalization in the California Central Valley by R. W. Cruff (written commun., 1966). His study showed a standard error of estimate of 33 percent using drainage area, surface storage index, and mean annual precipitation to compute mean annual discharge for perennial and ephemeral streams. Other methods are also available for estimating runoff on ungaged streams using climatologic or topographic factors, but there is a need for a reconnaissance technique based on measurements of the stream itself. Accurate data and good maps are not always available for determining the climatologic and topographic factors, especially in arid and semiarid regions. This method meets the need, and the results obtained were even better for the ephemeral streams that are so common in arid regions than for perennial streams.

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