PREPARATION OF AVERAGE ANNUAL RUNOFF MAP OF THE UNITED STATES, 1951–80

By
William R. Krug, Warren A. Gebert, *and* David J. Graczyk

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CONVERSION FACTORS

For the use of readers who prefer metric (International system) units, conversion factors for the inch-pound terms used in this report are listed below.

Multiply	*By*	*To obtain*
inch (in.)	25.4	millimeter (mm)
square mile (mi^2)	2.590	square kilometer (km^2)

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ABSTRACT

Average annual runoff was computed or estimated for each of the 2,148 hydrologic cataloging units in the United States and Puerto Rico, for the period 1951–80. Runoff was computed from the recorded streamflow at 5,951 U.S. Geological Survey gaging stations. For the more than 3,000 of these stations that have incomplete discharge records for 1951–80, the mean runoff was estimated by correlation with nearby stations having complete records. Runoff from gaged areas was used to compute the runoff from the hydrologic cataloging units.

These runoff data were used to draw a map depicting the amount and variation of runoff throughout the United States and Puerto Rico. Average annual runoff varied from less than 0.01 inch in parts of the Great Basin (Utah, parts of Nevada, Oregon, and California) to more than 240 inches in southeastern Alaska.

INTRODUCTION

Background

Runoff is that part of the precipitation that appears in surface streams. Average annual runoff is a volume expressed in this study as the average depth in inches over the drainage area.

Maps of the average annual runoff in the United States have been prepared for the periods 1921–45 (Langbein, 1949), 1931–60 (Busby, 1966), and 1951–80 (Gebert and others, 1986). The data base for making these maps has expanded and the data-processing methods have been improved. The period of the most recent 1951–80 map by Gebert and others (1986) was selected to coincide with the base period used by the National Weather Service for computing mean meteorologic data. Individual State runoff maps were prepared for the U.S. Geological Survey's 1985 National Water Summary (U.S. Geological Survey, 1986). These State runoff maps were compiled into a national runoff map (Gebert and others, 1986).

The surface-water systems of the United States have been divided into successively smaller hydrologic units called regions, subregions, accounting units, and cataloging units. (Seaber and others, 1984). A cataloging unit is a geographic area representing part or all of a surface-drainage basin, a combination of drainage basins, or a distinct hydrologic feature. Almost all cataloging units are larger than 700 mi^2

Purpose and Scope

The purpose of this report is to (1) document the methods used to compile and process the runoff data and to prepare the 1951–80 map of Gebert and others (1986), and (2) present the runoff from each gaging station used and from each of the 2,148 hydrologic cataloging units in the country.

One objective of this analysis was to determine the average runoff near its source, rather than the cumulative runoff after several sources have contributed runoff to large rivers. This is most important in arid areas, where significant quantities of water evaporate after it is first measured as runoff. Also, some hydrologic cataloging units comprise a closed basin that has no net runoff when considered as a whole; but parts of a closed basin may have runoff, making the average runoff slightly greater than zero, even if no runoff leaves the unit.

Acknowledgments

This study was greatly aided by the following U.S. Geological Survey personnel: Walter A. Lear, who prepared the runoff map for Texas; Iwao Matsuoka, who prepared the map for California; and Roger P. Rumenik, who prepared the map for Florida.

DATA COMPILATION AND PROCESSING

Information Sources

The primary source of data used to compute runoff was the streamflow records from U.S. Geological Survey streamflow-gaging stations. Secondary sources included previous runoff maps, precipitation-distribution maps, and topographic maps.

The preferred source of information for computing average runoff and for preparing the runoff map was stations with complete records for the period 1951–80, with no diversions, and with drainage areas no larger than a single hydrologic cataloging unit. In some areas of the country, primarily in the eastern States, enough stations were found that meet these criteria so that no additional information was needed.

If additional information was needed to define the areal variation of runoff, stations with no diversions and shorter periods of record were used. A correlation procedure (Matalas and Jacobs, 1964) was used to estimate the average runoff for these stations for the full period 1951–80.

Where very little information was available from stations with no diversions, stations with diversions were used if an estimate could be made of the amount of the diversion. The observed average discharge was corrected for the diversion, and the correlation procedure was used, if necessary, to adjust the mean discharge to the 1951–80 period.

The difference in average discharge at two stations on a large river was sometimes used to estimate the runoff for the area contributing runoff to the reach between the gages. This method was used carefully, because small errors in the measurement of discharge at the two stations could cause large errors in the difference. This method was used only if the percentage increase in drainage area between the stations was large.

Where no satisfactory correlation could be found to adjust the mean discharge of stations to the full 1951–80 period, the mean discharges for stations with records less than the full period were used without adjustment to estimate the runoff.

Finally, no information was available to compute runoff for some areas. Estimates for such areas were based on runoff in adjacent areas and on known variations in precipitation and elevation.

The number of stations used to determine the runoff varied throughout the country. In some areas of the East and Midwest, where there was little areal variability in runoff, only a few of the best stations were needed to estimate the runoff. For example, in Wisconsin, where the average annual runoff ranges from 10 to 15 in., 89 stations were used. But in mountainous areas of the West, almost every possible station was needed to define the areal variation. For example, in Washington, where the average annual runoff ranges from 0.1 to more than 160 in., 300 stations were used.

Data Retrieval

Data were retrieved from the National Water *Data Storage and Retrieval System* (WATSTORE) (Hutchison, 1975) for each State for all stations that had any recorded streamflow data for the period 1951–80. The data were retrieved in two parts: one contained the average discharge for each station for the period 1951–80; the other contained the individual annual mean discharges for each station. An additional retrieval was made from the header file to obtain the name, latitude, longitude, drainage area, and hydrologic unit code for each of the stations. These three parts were stored in separate files for each State.

Data Consolidation

The first step in data processing was to combine the data retrieved into a single file. This involved counting the number of years of record for each station, computing the average runoff, and sorting the stations by hydrologic cataloging units. Most of the computations were performed using the P-STAT[1] statistical package (Buhler and others, 1983). The P-STAT program listing used to perform these computations are in Appendix A (at back of report).

Several files, grouped by hydrologic cataloging unit, were produced during data processing:

(1) A file of all of the pertinent data for each station (including hydrologic unit code, station number, station name, latitude, longitude, State code, drainage area, earliest year of record, latest year of record, number of years of complete record, mean discharge, and runoff).

(2) A file of all stations retrieved (including the same data as the preceding file, except for the years of the earliest and latest record).

(3) A file of only those stations for which mean runoff could be computed (including the same data as the preceding file).

(4) A file of only those stations from the preceding file that had a complete record for the period 1951–80 (including the same data as the preceding file).

(5) A file of all stations with computed runoff for the period, (including only the station name and number, drainage areas, number of years of record and the average runoff, in inches).

The last four files contained titles and column headings for easier reference. The final file was printed as a worksheet for computing average runoff by cataloging units. The worksheet contained blank columns for adjusted runoff, correlation coefficient, and comments.

Record Extension

If records for the 30-year period 1951–80 were incomplete for a needed station, the records were extended by correlation with a nearby station having complete records for that period. The method used was explained by Matalas and Jacobs (1964); equation (34) (p. E4) of that report can be rewritten as:

$$y_l = y_s + b(x_l - x_s), \qquad (1)$$

where:

- y_l is the estimated 30-year mean discharge for the short-term station,
- y_s is the mean discharge for the short-term station for its period of record,
- b is the slope of the regression line between concurrent annual mean discharges at the short-term and long-term station,
- x_l is the 30-year mean discharge for the long-term station which is equal to

$$x_l = \frac{n_1 x_1 + n_2 x_2}{n_1 + n_2}$$

in Matalas and Jacobs (1964), equation 34, and

- x_s is the mean discharge for the long-term station for the concurrent period with the short-term station.

This estimate of the long-term mean at the short-term station will be better, on the average, than the observed mean for the short period of record if the following condition is met (Matalas and Jacobs, 1964, p. E4, equation 38):

$$Abs(r) > 1/(N-2)^{0.5},$$

where:

- $Abs(r)$ is the absolute value of the correlation coefficient between annual mean discharges at the short-term and long-term stations, and
- N is the number of years of record at the short-term station.

The minimum acceptable correlation coefficient needed for various years of record as computed by this equation is shown in table 1.

Table 1.—*Minimum acceptable correlation coefficient for extending the record mean at a station with less than 30 years of record*

Number of years of record	Minimum acceptable correlation coefficient
6	0.50
7	.45
8	.41
9	.38
10	.35
11	.33
12	.32
13	.30
14	.29
15	.28
16	.27
17	.26
18	.25
19	.24
20	.24
21	.23
22	.22
23	.22
24	.21
25	.21
26	.20
27	.20
28	.20
29	.19

Two stations were selected to illustrate the effects of this correlation procedure. These stations both have complete records for the period 1951–80. They are located near each other and their annual runoffs are highly correlated as shown in column 2 of table 2. Similkameen River near Nighthawk, Wash., was selected as a "short-term station". Each series of 5 consecutive years at this station was taken separately and correlated with the annual means at Wenatchee River at Peshastin, Wash., to produce 26 separate (but not independent) estimates of the long-term mean at

Table 2.—*Summary of the results of correlating 5-year periods of record from the Similkameen River near Nighthawk, Wash. (12442500) with the Wenatchee River at Peshastin, Wash. (12459000)*

[in/yr, inches per year]

Years	Correlation coefficient	Runoff (in/yr) based on For 5 years	Runoff (in/yr) based on By correlation	Improvement by correlation Yes	Improvement by correlation No
1951–55	0.99	10.33	9.88	x	
1952–56	.95	10.35	9.73	x	
1953–57	.92	10.84	10.00	x	
1954–58	.90	10.37	9.44	x	
1955–59	.91	10.43	9.37	x	
1956–60	.94	10.21	8.93	x	
1957–61	.95	9.46	8.90		x
1958–62	.98	8.93	8.78		x
1959–63	.94	9.29	9.20		x
1960–64	.57	9.18	9.55	x	
1961–65	.61	9.01	9.81	x	
1962–66	.84	8.48	10.70		x
1963–67	.85	9.06	10.75		x
1964–68	.71	9.41	9.79		x
1965–69	.68	8.51	8.70	x	
1966–70	.81	7.84	8.55	x	
1967–71	.83	8.83	8.72		x
1968–72	.96	10.49	8.46	x	
1969–73	.95	9.47	9.38		x
1970–74	.97	10.55	9.65	x	
1971–75	.96	11.15	9.59	x	
1972–76	.95	11.34	9.46	x	
1973–77	1.00	8.54	9.13	x	
1974–78	.99	9.36	9.01		x
1975–79	.99	8.00	8.93	x	
1976–80	.97	8.09	9.28	x	
Mean		9.52	9.37		
Standard deviation		1.00	.58		
Minimum		7.84	8.46		
Maximum		11.34	10.75		
Values computed using complete 30-year record, Similkameen River					
1951–80	.91	9.44	9.44		

Similkameen River. The results are summarized in table 2. In 17 of 26 trials the estimates of 1951–80 mean by correlation are better than the means based on 5 years of record. The standard deviation of the 26 correlation estimates is smaller than the standard deviation of the corresponding short-term means. This further indicates the suitability of the correlation procedure.

Where no long-term stations acceptably correlated with the short-term station available, the mean runoff based on the short-term record was used as the long-term estimate.

Adjustment for Diversion

Diversions presented a variety of problems in computing average runoff. If the gaging station records indicated an amount for the diversions, it was used to adjust the streamflow. Data on major transbasin diversions furnished by Harold E. Petsch (U.S. Geological Survey, written commun., 1984) were used to adjust certain gaging station records. Irrigation diversions are more commonly described only by the approximate number of acres irrigated. The amount of such a diversion was estimated by multiplying the area irrigated by the amount of water typically used for irrigation in that area (minus an allowance for return flows). This estimate was used to adjust the measured streamflow in order to compute runoff.

Computation of Average Runoff

Several methods of determining the average runoff for a cataloging unit were used. The first method used only a single station at or near the outlet of the unit. In this case the hydrologic cataloging unit was nearly coincident with the drainage basin of a gaging station. This gaging station measured the average runoff for the unit. This situation is the best measure of average runoff from a unit.

The second method used a number of stations on tributary streams each draining a separate part of the unit. Stations on tributary streams were selected to represent the average runoff from the unit. Stations that were tributary to other stations in the unit were not used because runoff at a tributary gaging station is included in the runoff of the downstream gaging stations. The average runoff for the unit was computed as the average of the individual stations, weighted by their drainage areas.

The third method used two stations on a main stream that flowed through the unit. In cases where a large river flowed through a hydrologic cataloging unit, and there were not enough stations on tributary streams to determine the runoff, the increase in the average flow of the mainstem as it flowed through the unit was used to compute the runoff from the unit. The runoff computed in this way was checked against other streams in the area before it was used, because large errors can be introduced by taking the difference between streamflows at two stations on the same river. In some arid regions, flow on the mainstem could actually decrease through a unit, making it impossible to use this method.

If data were insufficient to compute average runoff by these methods, runoff was estimated from whatever data was available, including runoff from adjacent units, 1- or 2-year records in the unit (compared with other nearby stations), and precipitation maps.

Runoff from Hydrologic Cataloging Units

The average annual runoff for each of the hydrologic cataloging units is summarized in Appendix B.

MAP PREPARATION

Preparation of the runoff map started with plotting representative runoff runoff amounts on a map of each State. Contour lines were then drawn and checked.

The mean runoff for each hydrologic cataloging unit was plotted on a State map at a scale of 1:2,000,000; then the runoff at all the stations in the unit was inspected for variability. If there was significant variability in runoff within the unit, representative stations were selected and their runoff values were plotted on the map at the approximate centroids of their respective drainage basins. The approximate centroid was usually estimated by visual inspection of the drainage network on the map. All of the stations used to compute mean runoff or to define areal variability of runoff are listed in Appendix C (at back of report).

Preliminary contour lines were drawn to delineate areas of equal runoff after representative runoff amounts for all hydrologic cataloging units in a State were plotted. Irregular contour intervals provided adequate resolution in areas of low runoff and eased crowding of lines in areas of high runoff. The contour lines chosen for the national map were 0.1, 0.2, 0.5, 1, 2, 5, 10, 15, 20, 25, 30, 40, 60, 80, 100, 120, 160, 200, and 240 in. Supplemental contours were added to the State maps as needed to represent the area variability of runoff adequately. The relief of the area and the general distribution of rainfall were kept in mind and used to guide the position of the lines in areas where there was little streamflow information. If maps for the adjoining States had been completed previously, the lines were matched and adjusted at the boundaries.

At this point, the State map and the data used to prepare it were sent to the U.S. Geological Survey District offices for their reviews and suggestions. The comments from the various Districts were checked for conformance with the purpose and goals of the project and used to revise the maps where necessary. The local knowledge of the hydrology of the separate States was valuable for refining and improving the final map.

After comments from all the Districts were received and used to revise the State maps, all of the maps were again edge-matched with adjoining maps. The individual State maps were combined into 17 regional maps. The contours on these maps were digitized and the digital data were used to prepare the final maps for the United States and Puerto Rico.

SUMMARY

Average annual runoff was computed for each hydrologic cataloging unit in the United States. Average annual runoff ranged from less that 0.01 in. in parts of the Great Basin to 240 in. in southeastern Alaska. These averages were computed or estimated for the period 1951–80.

The average runoff for hydrologic cataloging units and the runoff for selected gaging stations were used to prepare a national runoff map for the period 1951–80 (Gebert and others, 1986).

[1]Use of the program in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

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APPENDIX A

Listing of P-STAT Program

The following is a P-STAT program for correlating short-term stations with long-term stations. In this program "#SHORT#" is replaced by the 8-digit station number of the short-term station, and "#LONG#" is replaced by the 8-digit station number of the long-term station. The files "ANNQ. #SHORT#" and "ANNQ. #LONG#" are files containing the annual mean discharges of the two stations. Each line in the files contains the water year followed by the mean discharge for that year. Incomplete data are represented by a "*".

```
    SCREEN 0$
    OUTPUT.WIDTH 132$
    COMMAND.WIDTH 132$
    VBAR (:)$
    MAKE S.#SHORT#,
       NAMES YEAR Q.#SHORT#,
       MISSING '*',
       FILE ANNQ.#SHORT#$
    MAKE S.#LONG#,
       NAMES YEAR Q.#LONG#,
       MISSING '*',
       FILE ANNQ.#LONG#$
    COLLATE S.#LONG# S.#SHORT#,
       FILL,
       OUT BOTH$
    CORRELATE BOTH (KEEP Q.#LONG# Q.#SHORT#),
       COMPLETE,
       OUT COR,
       DES DES$
    REG BOTH, OUT BOTH2,
       P ADJQ.#SHORT#,
       COEF COEF;
       DEPENDENT Q.#SHORT#,
       COMPLETE,
       NOSTEP,
       IND Q.#LONG# $
MOD BOTH2 (IF Q.#SHORT# ^= .M1. , GENERATE S.#LONG# = Q.#LONG#),
    OUT BOTH2.REPLACE$
P ADJQ.#SHORT#$
PLOT BOTH2;
PLOT Q.#SHORT# BY Q.#LONG#. OVERLAY PRE.Q.#SHORT# BY Q.#LONG#$
LIST BOTH2$
P$

MOD BOTH2 (KEEP Q.#SHORT#,Q.#LONG#,S.#LONG#),DES DES2$
JOIN DES2 COEF , FILL,NO CHECK,OUT DES.COEF$
MOD COR (IF .N. = 1, SET P(5) = Q.#SHORT#) $
MOD DES.COEF (IF .N. = 1, SET P(1) = Q.#SHORT#)
               (IF .N. = 2, SET P(2) = MEAN)
               (IF .N. = 3, SET P(3) = MEAN)$
MOD DES.COEF (GENERATE LONG.MEAN = MEAN + P(1) * (P(2) - P(3)))
               (IF .N. = 1, GENERATE R = P(5))
               (IF .N. =3, SET LONG.MEAN = .M1.)
               (IF .N. =2, SET LONG.MEAN = .M1.),
               OUT DES.COEF,REPLACE$
LIST DES.COEF(KEEP NAME,R,GOOD,MEAN,LONG.MEAN,Q.#SHORT#),P ADJQ.#SHORT#$
LIST DES.COEF(KEEP NAME,R,GOOD,MEAN,LONG.MEAN,Q.#SHORT#),P$
END$
```

APPENDIX B

Runoff from Hydrologic Cataloging Units

Hydrologic unit code	Runoff (in/yr)	Remarks code[1]
02020007	21.7	A
02030103	28.4	A
02030104	23.6	A
02030105	21.3	A
02040104	28.2	A, B
02040105	21.7	A, B
02040201	20.8	A, B
02040202	21.5	A, B
02040206	19.9	A
02040301	21.7	A
02040302	21.4	A

[1]*CODE* indicates the primary method or methods used to compute the average runoff for the hydrologic cataloging unit. Codes of more than one letter indicate a combination of methods.

A = Complete 30 year record(s) within the unit.
B = Less than 30 year record(s), extended by correlation.
C = Less than 30 year record(s), without extension.
D = Difference between two stations on a main stream.
E = Estimated from runoff in adjacent units.
F = Other estimation methods.

APPENDIX C

List of Stations and Hydrologic Cataloging Units

List of the stations used in computing average annual runoff by hydrologic cataloging unit, or to define runoff variability for the national runoff map, together with their drainage areas, periods of record, mean discharge, and runoff.

ERRATA

The following remarks codes for the unit averages indicate the primary methods used to compute the average runoff for the hydrologic cataloging units listed in Appendix C. Codes of more than one letter indicate a combination of methods.

A=Complete 30 year record(s) within the unit.
B=Less than 30 year record(s), extended by correlation.
C=Less that 30 year record(s), without extension.
D=Difference between two stations on a main stream.
E=Estimated from runoff in adjacent units.
F=Other estimation methods.

A code for a single station indicates the type or types of adjustment made to the runoff, and whether the station was used to determine the average runoff for the cataloging unit or was used to define variability of runoff within the unit or both.

I=Adjusted for diversions.
S=Short record adjusted to 1951–80 period.
M=Station used to determine average runoff for a cataloging unit.
V=Station used to determine variability of runoff within the unit.

Appendix C.--List of the stations used in computing average annual runoff by hydrologic cataloging unit, or to define runoff variability for the national runoff map, together with their drainage areas, periods of record, mean discharge, and runoff--Continued

[mi^2, square miles; ft^3/s, cubic feet per second; in., inches]

Station number	Station name	Drainage area (mi^2)	Years of record	Mean discharge (ft^3/s)	Runoff (in.)	Adjusted runoff (in.)	Remarks code
	Hydrologic cataloging unit: 15050100						
09478500	Queen Creek at Whitlow Damsite near Superior, Ariz.	144	8	4.74	0.45	0.42	S,M
09479200	Queen Creek tributary at Apache Junction, Ariz.	0.51	7	0.01	0.27	0.49	S,V
	Average for Unit				0.42		B
	Hydrologic cataloging unit: 15050201						
	Average for Unit				0.30		E
	Hydrologic cataloging unit: 15050202						
09470500	San Pedro River at Palominas, Ariz.	741	30	31.6	0.58		V
09471000	San Pedro River at Charleston, Ariz.	1,219	30	50.1	0.56		V
09471550	San Pedro River near Tombstone, Ariz.	1,740	13	49.2	0.38	0.51	I,M
	Average for Unit				0.51		B
	Hydrologic cataloging unit: 15050203						
09471800	San Pedro River near Benson, Ariz.	2,500	10	31.9	0.17	0.26	S,V,M
09472000	San Pedro River near Redington, Ariz.	2,939	30	46.5	0.21	0.43	I,S,V
09473000	Aravaipa Creek near Mammoth, Ariz.	541	14	29.5	0.74	0.27	S,V
09473500	San Pedro River at Winkelman, Ariz.	4,471	12	49.1	0.15	0.19	I,S,V,M
	Average for Unit				0.18		D
	Hydrologic cataloging unit: 15050301						
09480000	Santa Cruz River near Lochiel, Ariz.	82.2	30	3.13	0.52	0.66	I,V
09480500	Santa Cruz River near Nogales, Ariz.	533	30	30.6	0.78	1.0	I,V
09481500	Sonoita Creek near Patagonia, Ariz.	209	22	8.89	0.58	0.65	S,V
09482000	Santa Cruz River at Continental, Ariz.	1,662	29	24.4	0.20	0.64	I,S,V
09482500	Santa Cruz River at Tucson, Ariz.	2,222	30	24.6	0.15	0.85	I,M
09482400	Airport Wash at Tucson, Ariz.	23.0	15	0.42	0.25	0.26	S,V
09482950	Railroad Wash at Tucson, Ariz.	2.30	5	0.21	1.24	1.1	S,V
09486300	Canada Del Oro near Tucson, Ariz.	250	13	1.56	0.08	0.08	S,V
	Average for Unit				0.85		A