MAP OF MEAN ANNUAL RUNOFF FOR THE NORTHEASTERN, SOUTHEASTERN, AND MID-ATLANTIC UNITED STATES, WATER YEARS 1951–80

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CONVERSION TABLE

For readers who prefer metric (International Systems) units, inch-pound units in this report may be converted by the following facors.

Multiply inch-pound unit	*By*	*To obtain metric unit*
inch (in.)	25.4	millimeter (mm)
square mile (mi^2)	2.590	square kilometer (km^2)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
inch per year (in/yr)	25.4	millimeter per year (mm/yr)

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By
William R. Krug[1], Warren A. Gebert[1], David J. Graczyk[1], Donald L. Stevens[2], Barry P. Rochelle[3], and M. Robbins Church[4]

ABSTRACT

A map of mean annual runoff for States within the Northeastern, Southeastern, and Mid-Atlantic United States was prepared by the U.S. Geological Survey for the Direct/Delayed Response Project being conducted by the U.S. Environmental Protection Agency. This map shows mean annual runoff during water years 1951–80.

Mean annual runoff from the Northeastern Region during water years 1951-80 ranged from less than 12 to greater than 40 inches. Runoff from the Southeastern Region ranged from less than 12 to greater than 55 inches. In the Mid-Atlantic Region runoff ranged from less than 10 to greater than 40 inches.

Error analysis, based on data from 93 gaging stations not used to prepare the runoff map, indicated that the runoff map could be used to predict mean annual runoff having an average error of less than 10 percent if runoff was estimated at the centroid of the drainage basin or if a weighted average over the basin were used. Errors in runoff estimation averaged about 12 percent if runoff was estimated at the gaging station site. If the location of the gaging station were used to estimate runoff, there also was a significant negative bias of the errors that did not occur if the centroid or a weighted-average runoff of the drainage basin were used.

The runoff map is expected to be more accurate in areas that have a relatively high concentration of gaging stations and little topographic variability, such as parts of the Northeast. On the basis of these criteria, the least reliably mapped areas would be in the Smoky Mountains along the North Carolina–Tennessee border

INTRODUCTION

This report presents maps that show runoff prepared by the U.S. Geological Survey, in cooperation with the U.S. Environmental Protection Agency (EPA), for the Direct/Delayed Response Project (DDRP) being conducted by the EPA. The EPA project personnel are studying the effects of acidic deposition on watersheds and surface-water chemistry. A goal of the project is to predict the long-term effects of acidic deposition on surface-water chemistry in small (less than 12-mi^2 [square miles]) watersheds in three regions—the Northeastern, Southeastern, and Mid-Atlantic United States (Lee and others, U.S. Environmental Protection Agency, written commun., 1988). Runoff estimates will be used in a variety of analyses in the DDRP, ranging from computation of input-output budgets for ions of interest to the use of complex simulation models for predicting watershed response.

The States in the EPA study include all of Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, New York, Pennsylvania, New Jersey, (the Northeastern Region); all of West Virginia, Virginia, Maryland, and Delaware, and parts of Kentucky (Mid-Atlantic Region); and parts of North Carolina, Tennessee, South Carolina, Georgia, Alabama, and Mississippi (the Southeastern Region). The study areas are shown in figure 1. The runoff map was prepared for water years 1951–80 (October 1, 1950, to September 30, 1980) for the entire study area.

Runoff is the water in a river or stream that is derived from precipitation. It includes contributions from both

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surface-water and ground-water sources. Runoff generally is expressed in units of volume or in units of depth over the entire drainage basin. Mean annual runoff is expressed as a depth on a runoff map and needs to be converted to a volume by multiplying by the drainage area and dividing by a conversion factor, to be used, for example, to compute ion outputs.

MAP PREPARATION

Information Sources

The primary sources of data used to compute runoff are streamflow records from U.S. Geological Survey streamflow-gaging stations. Secondary sources are a previous runoff map (Gebert and others, 1986) and various U.S. Geological Survey topographic maps.

The preferred sources of information for computing mean annual runoff and preparing the runoff map were records from gaging stations operated during water years 1951–80 in small- to medium-sized (up to about 1,000 mi²) drainage basins with little or no diversion or regulation. Few gaging stations with drainage areas greater than 1,000 mi² were used for preparing the runoff map. Runoff values from such stations are composites of runoff over a large area and may not adequately illustrate the variability within the area.

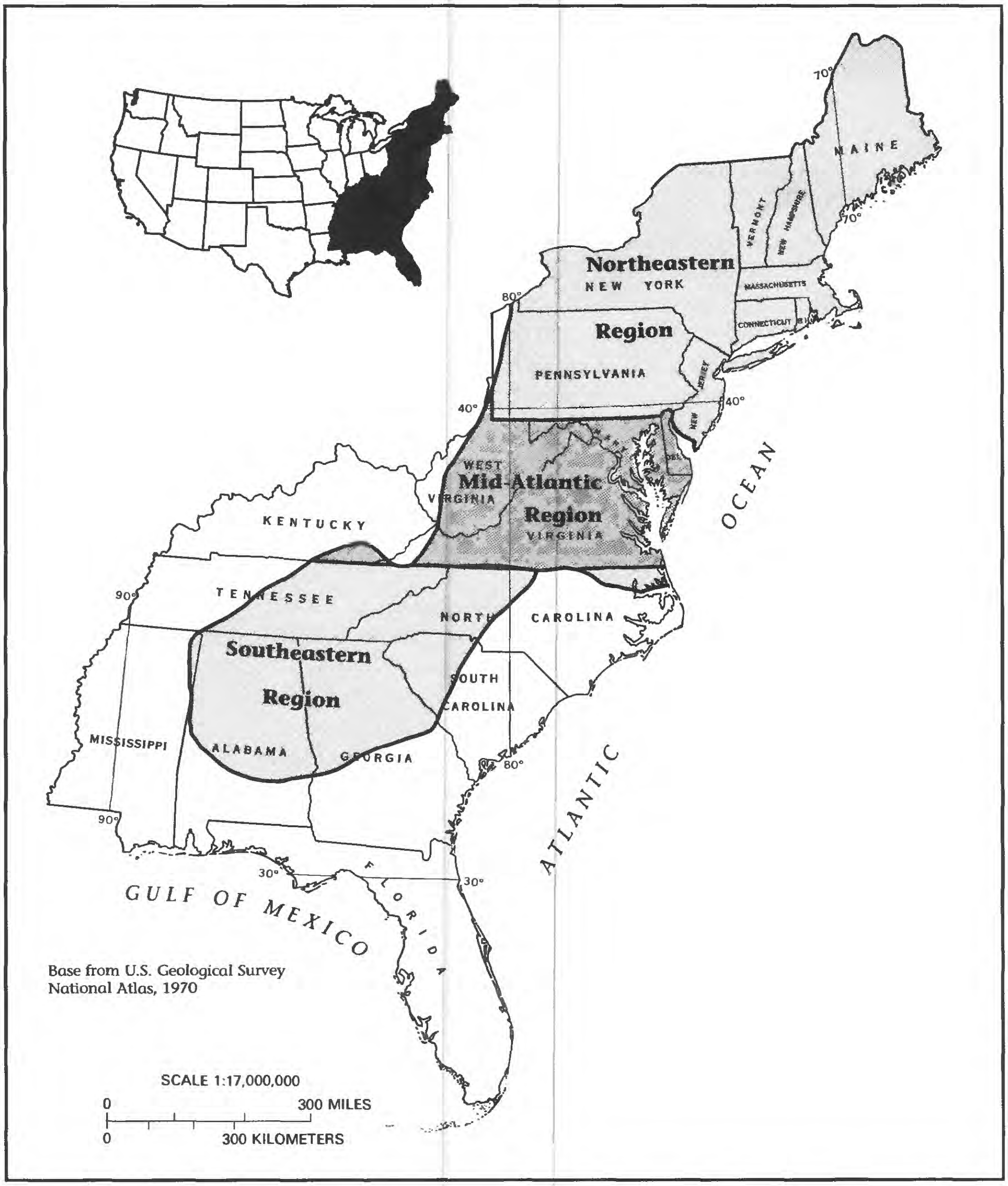

Figure 1. Location of the study area.

Stations with records influenced by diversions were used only if the average amounts of the diversions for water years 1951–80 were known or if the amounts of the diversions were known to be insignificant. The mean annual discharges were adjusted for known diversions. Stations with large amounts of diversion, usually on streams or rivers that large cities in the Northeast use for municipal and industrial water supplies, were not used.

Records for regulated streams were used where information on annual change in storage permitted adjustment for the change. No adjustment was made if a reservoir was small and the change in storage did not affect annual mean discharge.

The difference in mean annual discharge at two stations on a large river was used to estimate the runoff for some intervening areas. This method was used with caution because small errors in the measurement of discharge at the two stations could cause large errors in the difference. This method was applied only when the percentage increase in drainage area between the stations was large and data for the intervening area were not available. Runoff was computed as the difference in average discharge divided by the difference in drainage area and multiplied by a conversion factor to convert to inches of runoff.

Streamflow records for all or part of water years 1951–80 were available for 2,802 U.S. Geological Survey gaging stations in the study area. This study used records from 1,232 of the stations to prepare the runoff maps. The size of drainage areas for the gaging stations used ranges from 0.08 to 1,590 mi^2; stations with drainage areas up to 5,100 mi^2 were used to compute differences between two stations on the same stream. The intervening areas used range from 175 to 2,685 mi^2, with a median of 554 mi^2. These areas are from 11 to 82 percent of the larger drainage area, with a median of 50 percent.

Table 1 lists the State, area of the study, total number of gages available, number of gages used in the study area, and square miles per gage used.

Data Processing

Data were retrieved from the National Water Data Storage (WATSTORE) (Hutchison, 1975) on a State-by-State basis for all stations that had any recorded streamflow data for water years 1951–80. An additional retrieval was made to obtain the name, latitude, longitude, drainage area, and hydrologic code for each of the stations.

The first step in data processing was to combine the data retrieved into a single file. This involved computing the average runoff and sorting the station by hydrologic cataloging units. The file was sorted by cataloging unit and printed to be used as a worksheet.

If records for the 30-year period 1951–80 were incomplete for a station, the records were extended by regression with a nearby station having complete records for that period. The method used was explained by Matalas and Jacobs (1964) and used in the preparation of a national runoff map (Krug and others, 1987).

The long-term mean at the short-term station computed by using the regression equation is a better estimate of the true long-term mean than is the unadjusted short-term mean, if the following condition is met (Matalas and Jacobs, 1964, p. E4, equation 38):

$$r^2 > \frac{1}{(N-2)}$$

where

r is the correlation coefficient between concurrent 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 2. Negative correlation coefficients indicated an inverse relation. Such correlations were rare in this study and were not used to adjust mean annual runoff.

Initially, 2,802 gaging stations were available for analysis. Some stations were eliminated from consideration because they had insufficient record or because they represented drainage basins that were too large. Of the remaining 1,895 gaging stations, 100 were randomly selected to be used to test the accuracy of the runoff map, and others were found to be unsuitable because of diversions or because no satisfactory correlation could be found to extend the record to water years 1951–80. The runoff maps were prepared with data from the remaining 1,232 stations.

Preliminary Determination of Runoff Contours

Preparation of the runoff maps started with plotting water years 1951–80 mean annual runoff for each selected station on the map of each State (U.S. Geological Survey State base maps, scale 1:500,000). The runoff values were plotted by visual interpretation at the approximate centroid of the drainage areas. Runoff values for the intervening area between two gaging stations were plotted at the centroid of the intervening area. These values were used in conjunction with topographic maps to draw the contour lines. Runoff values were plotted at the centroid because that was more representative of the whole basin than the gage location.

The runoff maps have a 2-in. (inch) contour interval where runoff is less than 30 in., and a 5-in. contour

Table 1.—Number of gaging stations available and used, by State
[mi² = square miles]

State	Study area (mi²)	Totalnumber of gages available	Number of gages used in study	Square miles per gage used
Alabama	32,960	196	71	463
Connecticut	4,870	104	26	187
Delaware	2,050	18	14	146
Georgia	30,500	167	81	376
Kentucky	29,800	189	62	481
Maine	31,000	61	42	738
Maryland	10,600	116	60	176
Massachusetts	7,830	98	31	252
Mississippi	4,850	131	17	285
New Hampshire	8,990	62	43	209
New Jersey	7,470	115	51	146
New York	49,600	301	143	346
North Carolina	18,100	226	94	192
Pennsylvania	45,300	313	153	296
Rhode Island	1,050	24	10	105
South Carolina	19,300	50	43	450
Tennessee	18,820	198	59	318
Vermont	9,270	49	42	220
Virginia	40,800	236	121	337
West Virginia	24,200	148	69	350
TOTALS	397,000	2,802	1,232	[1]322

[1] Square miles per gage used in entire study area.

Table 2.—Minimum acceptable correlation coefficient for extending the record mean at a station with a short period 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

interval where the runoff is greater than 30 in. The relief of an area and the general distribution of rainfall and topographic affects were considered and used to guide the shape of the contour lines where streamflow information was sparse. The contour lines were matched and adjusted at the boundaries of adjoining States.

Contours were not drawn in some coastal areas where data were sparse or contradictory; these areas included Cape Cod in Massachusetts and Long Island in New York.

Digitization of Runoff Contours

Contours were digitized by using a geographic information system (GIS); an edit plot was then created. The edit plot was overlain on the original map to verify the accuracy of the digitized data. Any discrepancies were adjusted so that all plotted lines were within the original manuscript lines. The GIS was used to combine the State maps into a map for the study area. Contour lines were verified at the State boundaries for consistency and smoothed where necessary.

Review of Runoff Contours

Contours of mean annual runoff were independently reviewed by hydrologists in the Wisconsin District office of the U.S. Geological Survey. The runoff map and the data used to construct the map also were submitted to the respective U.S. Geological Survey State offices for their reviews. The comments from the State offices were examined for conformance to the purpose and goals of the project and were used to revise the State maps where necessary. The local knowledge of the hydrology of the separate States was valuable for refining the final map.

All of the State maps were again edge-matched with adjoining maps. The contours on the maps were digitized again if there were any changes and the digital data were used to prepare the final maps.

MEAN ANNUAL RUNOFF DURING WATER YEARS 1951–80

The map showing mean annual runoff for the Northeastern, Southeastern, and Mid-Atlantic Regions is shown on plate 1. Mean annual runoff ranged from less than 12 in. in western New York to greater than 40 in. in the White Mountains in New Hampshire in the northeastern region, from less than 12 in. in southern Alabama to greater than 55 in. in the Smoky Mountains of North Carolina in the southeastern region, and from less than 10 in. in northeastern West Virginia to greater than 40 in. in southeastern West Virginia in the Mid-Atlantic Region.

The runoff map is probably more reliable in areas that have a higher concentration of gaging stations and little topographic variability, such as central Maryland and central Massachusetts. On the basis of these criteria, the least reliable area is in the Smoky Mountains along the North Carolina–Tennessee State line.

QUALITY CONTROL AND ASSURANCE

The accuracy of the runoff map depends on several factors; such as the accuracy of the streamflow records, how closely the runoff values at the gaging stations represent the variation of runoff within the monitored watershed, the number of gaging stations in an area, the accuracy of the placement of the contours that represent runoff, and the error associated with digitizing the maps. Quality-control and quality-assurance procedures for runoff mapping were explained in an earlier report (Graczyk and others, 1987, p. 4).

ERROR ANALYSIS

A test procedure was used to determine the accuracy of using the runoff maps to estimate runoff for specific watersheds. The location of each of the gaging stations available for map development and each of the 125 EPA surface water-chemistry study sites was plotted on a map, and 9 areas were delineated based on gaging-station density, chemistry-site density, and physiographic landform (fig. 2). The GIS was used to determine the exact number of gaging stations and chemistry sites within each area (table 3). Of the 1,895 gaging stations available for the analysis after preliminary screening, 100 were selected to be used to test the accuracy of the runoff map and were not used to develop the map. The 100 stations represent about 5 percent of the total stations available for map development; therefore, about 5 percent of the stations in each area were selected. The stations were selected on the basis of spatial density of gaging-station sites and EPA water-chemistry study sites. Table 3 indicates the number of stations selected for each region.

A map indicating the site location of each gaging station within each area was developed. A randomized procedure, based on the ratio of stations to be selected to the total number of stations within an area, was then used to select the specific sites. This procedure insured that the sites would be chosen randomly but still have reasonable spatial coverage within each area. Some of the 100 stations had less than 30 years of record. The mean annual runoff for 57 of these sites was estimated by the same correlation process described earlier. The

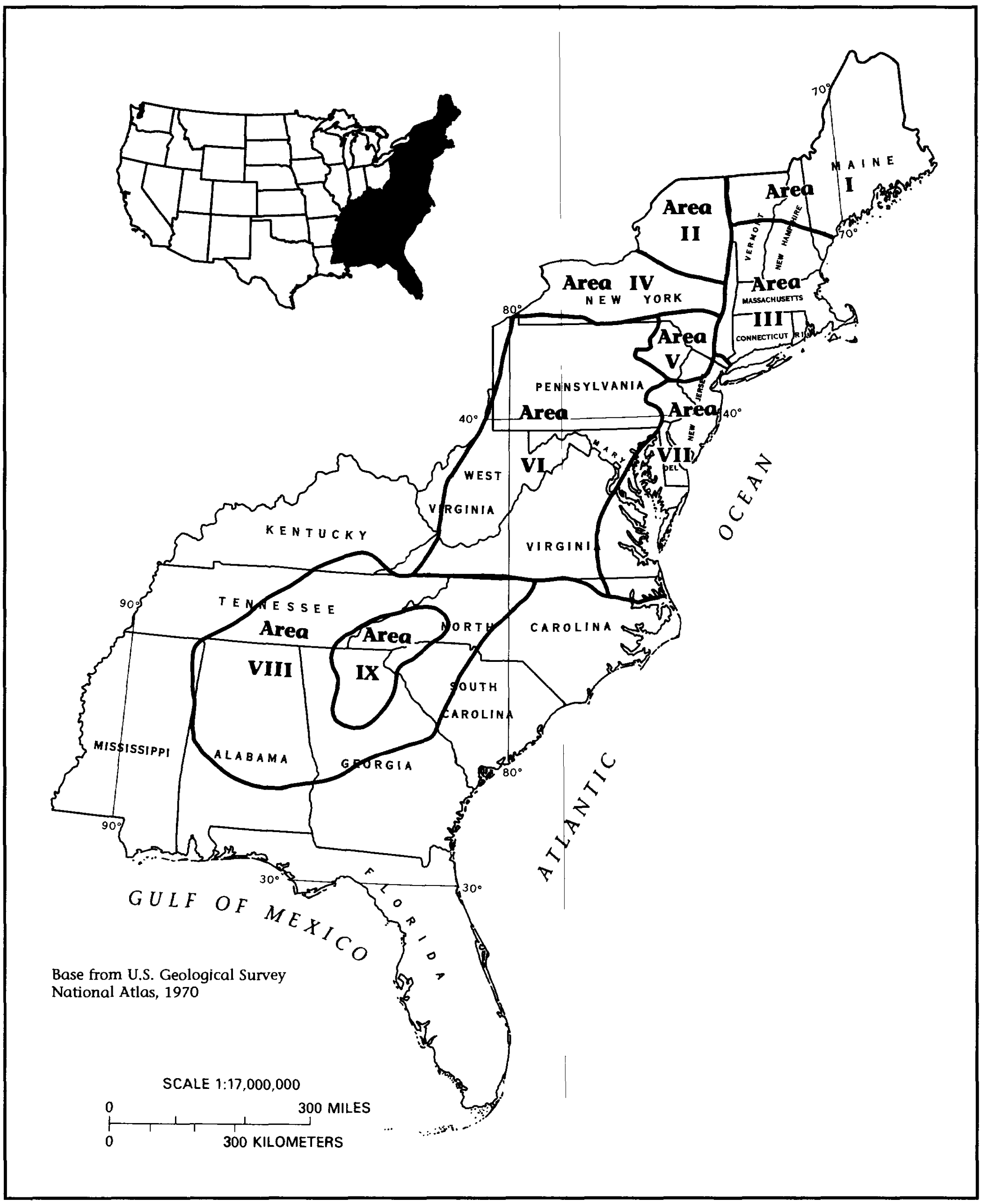

Figure 2. Location of areas used for selecting test stations.

Table 3.—Summary of U.S. Geological Survey stations and U.S. Environmetal Protection Agency water-chemistry sites, by area

Area	Number of U.S. Environmental Protection Agency water-chemistry sites	Number of U.S. Geological Survey gaging stations	Number of gaging stations selected to test runoff map
I	257	98	5
II	173	59	3
III	208	298	16
IV	6	103	5
V	166	109	6
VI	164	566	30
VII	39	200	11
VIII	93	328	17
IX	151	134	7
TOTAL	1,257	1,895	100

correlation of annual mean runoff was inadequate at six sites and the record could not be extended and, therefore, they were deleted from the test. Pertinent data could not be obtained for one additional site, and it too was deleted from the test. The remaining 93 stations used are shown in table 4.

The 93 stations were used to test the accuracy of the mean annual runoff map. Five different methods were used to estimate the runoff for each station from the runoff map. These five estimates of runoff for each station were used to determine the accuracy that could be attained for different levels of effort. The methods are called weighted average, centroid, GIS, nearest inch, and nearest contour.

The weighted-average method consists of combining a map of the drainage basin of a gaging station with the runoff map. The area within the drainage basin between each pair of contour lines is determined by using a planimeter. The weighted-average mean annual runoff is determined from the area between each pair of contour lines and the average runoff represented by the contours. This method involves the most effort, but gives the most accurate results.

The centroid method consists of estimating the centroid of the drainage basin by visual inspection of a map of the basin. The runoff at the centroid of the basin is interpolated from the contour map. This involves less effort than the preceding method, but provides less accurate results because it considers runoff at only one point rather than throughout the whole basin.

The GIS method consists of using the programs available in the geographic information system used to prepare the runoff maps to interpolate the runoff for the location of the gaging station. The latitude and longitude of the gaging stations are readily available, making this method easier than the preceding two. However, this method is less accurate, because the site used, the gaging station, is located at the downstream edge of the drainage basin.

The nearest-inch method consists of plotting the locations of the gaging stations on the mean annual runoff map and manually interpolating to the nearest inch at that point. This method requires about the same effort as the GIS method, but is slightly less accurate.

The nearest-contour method is similar to the nearest-inch method, except that the mean annual runoff of the nearest contour to the station site is used as the runoff for the station. This means that runoff is estimated to the nearest 2 in. if it is less than 30 in., and to the nearest 5 in. if it is greater than 30 in. This is the easiest method, but is also the least accurate.

The weighted-average method and the centroid method are the most accurate because they estimated the runoff for the entire basin, or for the middle of the basin. The GIS method, the nearest-inch method, and the nearest-contour method are less accurate because they estimated the runoff at a point that was not at the middle of the basin. In addition, these last three methods are biased because the gaging station is always at the lowest elevation in the drainage basin, and runoff normally is lower at lower elevations, because precipitation is normally lower.

A summary of the estimates by the weighted average and nearest inch methods is included in table 4.

The stations used for verification were selected by area in proportion to the number of stations available in each area. As a result, the distribution of these stations was not uniform throughout the study area. The error for each of the stations was weighted by a factor to account for the differences in density of stations among the areas. For example, Area I covers 61,780 mi^2, and has 5 stations used in this analysis. The weighting factor for stations in Area I is 61,780/5 or 12,360. Use of these weighting facors avoids biasing the results of the error analysis. The area-weighted statistics of the errors (estimated mean annual runoff minus observed mean annual runoff), expressed both as inches and as percent, are summarized in table 5.

The three methods using interpolation with respect to the gaging-station location (GIS, nearest-inch, and nearest-contour) had similar errors. All of them showed a highly significant negative bias (that is, estimated runoff averaged less than actual runoff). The probable cause of this bias is the tendency for rainfall and runoff to increase with elevation in mountainous areas. The gaging stations are at the lowest point in the drainage area and, thus, are normally at locations of lower runoff than the drainage basin as a whole.

The percent errors in runoff values estimated by the GIS were slightly higher than the percent errors in either of the manual interpolation estimates. Apparently, the surface-fitting routines were not able to fit the sudden changes in the rate of change of runoff in some areas. The estimated runoff for a few stations that were close to a runoff contour were several contour intervals different from the runoff at the nearest contour.

Runoff errors from the centroid of the basin and the area-weighted average methods were smaller than runoff errors from the other three methods. There was no statistically significant bias in these estimates.

The errors in estimated mean annual runoff at the 93 stations were further analyzed by examining the regression of actual runoff on estimated runoff, treating the estimated runoff as a predictor of actual runoff. The results are summarized in table 6.

Table 6 shows little difference among the methods that estimated runoff at the gaging-station locations. The regression analyses confirm the previous conclu-

Table 4.—Comparison of actual mean annual runoff for water years 1951–80 for 93 gaging stations with mean annual runoff estimated from runoff maps by two methods

Station	Station name	Drainage area (square mile)	Years of record during 1951-80	Mean annual runoff (in inches): Observed	Adjusted to 1951-80	Estimated by nearest inch method	Difference: inches	Difference: percent	Estimated by weighted-average method	Difference: inches	Difference: percent
1125500	Quinebaug River at Putnam, Conn.	328.00	19	23.1	25.3	27	1.7	6.8	25.4	0.1	0.5
1187680	Cherry Brook near Canton Center, Conn.	8.23	5	26.1	28.8	28	- .8	-2.6	29.0	.2	.8
1189995	Farmington River at Tariffville, Conn.	577.00	9	32.0	25.2	26	.8	3.3	28.0	2.8	11.2
2190000	North Fork Broad River near Lavonia, Ga.	42.00	15	22.1	22.4	22	-.4	-1.9	22.3	-.1	-.5
2192000	Broad River near Bell, Ga.	1,430.00	30	17.5	17.5	16	-1.5	-8.6	17.1	-.4	-2.3
2388000	West Armuchee Creek near Subligna, Ga.	36.40	20	25.6	24.4	27	2.6	10.8	25.8	1.4	5.9
1488500	Marshyhope Creek near Adamsville, Del.	43.90	27	17.5	17.3	16	-1.3	-7.6	17.0	-.3	-1.8
1490500	Culbreth Marsh near Chapeltown, Del.	11.60	5	17.4	19.5	16	-3.5	-17.9	15.9	-3.6	-18.5
1590700	North Fork Muddy Creek at South River, Md.	.88	4	17.0	11.0	16	5.0	45.5	17.0	6.0	54.5
1595500	North Branch Potomac River at Kitzmiller, Md.	225.00	30	27.2	27.2	19	-8.2	-30.2	27.5	.3	1.0
1645200	Watts Branch at Rockville, Md.	3.70	23	15.6	15.2	16	.8	5.3	15.0	-.2	-1.3
1016500	Machias River near Ashland, Maine	329.00	29	23.5	23.7	23	-.7	-3.0	23.0	-.7	-3.0
1022500	Narraguagus River at Cherryfield, Maine	227.00	30	30.4	30.4	30	-.4	-1.3	31.2	.8	2.6
1045000	Dead River at the Forks, Maine	872.00	29	24.5	24.1	24	-.1	-.4	26.4	2.3	9.6
1076000	Baker River near Rumney, N.H.	143.00	27	24.5	24.4	22	-2.4	-10.0	25.2	.8	3.1
1082000	Contoocook River at Peterborough, N.H.	68.10	27	23.7	24.1	24	-.1	-.5	24.6	.5	2.0
1085000	Contoocook River near Henniker, N.H.	368.00	27	24.3	24.7	23	-1.7	-6.7	24.5	-.2	-.6
1089000	Soucook River near Concord, N.H.	76.80	29	19.5	19.6	22	2.4	12.5	21.0	1.4	7.4
1101300	Maple Meadow Brook at Wilmington, Mass.	3.99	11	19.5	22.0	24	2.0	9.0	23.0	1.0	4.5
1134800	Kirhy Brook at Concord, Vt.	8.05	11	20.3	20.1	20	-.1	-.4	20.6	.5	2.5
1150500	Mascoma River at Mascoma, N.H.	153.00	30	19.4	19.4	20	.6	3.4	20.4	1.0	5.4
1157000	Ashuelot River near Gilsum, N.H.	71.10	30	24.8	24.8	23	-1.8	-7.4	23.7	-1.1	-4.5
1165300	Lake Rohunta Outlet near Athol, Mass.	20.30	15	24.2	23.2	22	-1.2	-5.3	23.0	-.2	-.9
1171500	Mill River at Northampton, Mass.	54.00	30	25.2	25.2	24	-1.2	-4.6	26.4	1.2	5.0
1176000	Quaboag River at West Brimfield, Mass.	151.00	30	22.8	22.8	24	1.2	5.0	24.3	1.5	6.3
1197300	Marsh Brook at Lenox, Mass.	2.19	11	30.0	31.7	24	-7.7	-24.4	23.4	-8.3	-26.3
1332000	North Branch Hoosic River at North Adams, Mass.	39.00	30	33.8	33.8	32	-1.8	-5.3	35.5	1.7	5.1
1153000	Black River at North Springfield, Vt.	158.00	30	26.0	26.0	22	-4.0	-15.3	25.3	-.7	-2.5
4284000	Jail Branch at East Barre, Vt.	38.90	30	18.5	18.5	20	1.5	8.3	19.1	.6	3.4
1397000	South Branch Raritan River at Stanton, N.J.	147.00	30	22.8	22.8	21	-1.8	-8.0	23.2	.4	1.7
1410810	Fourmile Branch at New Brooklyn, N.J.	7.74	7	23.5	20.9	24	3.1	14.7	23.8	2.9	13.8
1412000	Menantico Creek near Millville, N.J.	23.20	10	22.5	22.4	18	-4.4	-19.6	19.0	-3.4	-15.2
1464500	Crosswicks Creek at Extonville, N.J.	81.50	29	23.3	23.6	20	-3.6	-15.4	19.0	-4.6	-19.6
1348000	East Canada Creek at East Creek, N.Y.	291.00	30	31.3	31.3	20	-11.3	-36.1	25.6	-5.7	-18.3
1361500	Catskill Creek at Oak Hill, N.Y.	98.00	27	17.7	17.8	21	3.2	17.9	19.6	1.8	10.1
1362198	Esopus Creek at Shandaken,, N.Y.	59.70	17	32.5	33.8	30	-3.8	-11.1	32.0	-1.8	-5.2
1369000	Pochuck Creek near Pine Island, N.Y.	98.00	27	23.4	23.7	20	-3.7	-15.6	19.0	-4.7	-19.8
1371500	Wallkill River at Gardiner, N.Y.	711.00	30	20.8	20.8	18	-2.8	-13.3	19.9	-.9	-4.2
1414000	Platte Kill at Dunraven, N.Y.	35.00	12	25.2	25.4	26	.6	2.3	27.0	1.6	6.2
1502500	Unadilla River at Rockdale, N.Y.	520.00	30	22.3	22.3	22	-.3	-1.4	22.1	-.2	-.9
1527000	Cohocton River at Cohocton, N.Y.	52.20	30	14.8	14.8	13	-1.8	-12.2	13.0	-1.8	-12.2
3013000	Conewango Creek at Waterboro, N.Y.	290.00	30	25.0	25.0	25	.0	.1	24.3	-.7	-2.7
4234018	Salmon Creek at Ludlowville, N.Y.	81.70	4	12.7	24.7	16	-8.7	-35.2	18.5	-6.2	-25.1
4244000	Chittenango Creek near Chittenango, N.Y.	66.30	18	21.7	25.1	20	-5.1	-20.3	22.0	-3.1	-12.3
4278300	Northwest Bay Brook near Bolton Landing, N.Y.	23.40	12	21.8	19.3	18	-1.3	-6.8	17.9	-1.4	-7.3
2071000	Dan River near Wentworth, N.C.	1,053.00	30	15.9	15.9	13	-2.9	-18.3	15.8	-.1	-.7
2112360	Mitchell River near State Road, N.C.	78.80	16	22.9	21.8	18	-3.8	-17.4	19.1	-2.7	-12.4
2117030	Humpy Creek near Fork, N.C.	1.05	12	14.6	12.9	15	2.1	16.4	13.0	.1	.9
2143000	Henry Fork near Henry River, N.C.	83.20	30	22.4	22.4	17	-5.4	-24.0	18.4	-4.0	-17.7
3446500	Clear Creek near Hendersonville, N.C.	42.20	5	17.6	22.9	24	1.1	4.8	24.6	1.7	7.4
3453500	French Broad River at Marshall, N.C.	1,332.00	30	25.7	25.7	12	-13.7	-53.3	26.4	.7	2.8
3456000	West Fork Pigeon River below Lake Logan near Waynesville N.C.	55.30	26	41.0	39.8	36	-3.8	-9.7	47.5	7.7	19.2
3505500	Nantahala River at Nantahala, N.C.	144.00	30	47.2	47.2	35	-12.2	-25.8	41.4	-5.8	-12.2
1427650	North Branch Calkins Creek near Damascus, Pa.	7.02	9	25.4	26.8	24	-2.8	-10.5	25.0	-1.8	-6.8
1439500	Bush Kill at Shoemakers, Pa.	117.00	30	28.0	28.0	21	-7.0	-24.9	25.1	-2.9	-10.3
1470720	Maiden Creek tributary at Lenhartsville, Pa.	7.46	15	22.9	21.6	21	-.6	-2.7	21.0	-.6	-2.7
1472157	French Creek near Phoenixville, Pa.	59.10	12	22.2	18.4	20	1.6	8.8	19.6	1.2	6.6
1481000	Brandywine Creek at Chadds Ford, Pa.	287.00	21	21.1	20.0	20	.0	.0	19.1	-.9	-4.5
1518500	Crooked Creek at Tioga, Pa.	122.00	21	12.5	13.6	14	.4	2.6	16.0	2.4	17.2

Table 4.—Comparison of actual mean annual runoff for water years 1951–80 for 93 gaging stations with mean annual runoff estimated from runoff maps by two methods—Continued

Station	Station name	Drainage area (square mile)	Years of record during 1951-80	Mean annual runoff (in inches) Observed	Adjusted to 1951-80	Estimated by nearest inch method	Difference inches	Difference percent	Estimated by weighted-average method	Difference inches	Difference percent
1539500	Little Fishing Creek at Eyers Grove, Pa.	56.50	8	20.8	20.8	17	-3.8	-18.2	20.0	-.8	-3.8
1541500	Clearfield Creek at Dimeling, Pa.	371.00	30	22.0	22.0	20	-2.0	-9.0	21.8	-.2	-.8
1555000	Penns Creek at Penns Creek, Pa.	301.00	30	20.7	20.7	19	-1.7	-8.3	19.7	-1.0	-4.9
1573160	Quittapahilla Creek near Bellegrove, Pa.	74.20	4	23.4	18.3	19	.7	3.7	17.1	-1.2	-6.7
1576500	Conestoga River at Lancaster, Pa.	324.00	30	17.2	17.2	16	-1.2	-7.1	16.1	-1.1	-6.6
3020500	Oil Creek at Rouseville, Pa.	300.00	30	25.0	25.0	21	-4.0	-16.0	24.9	-.1	-.4
3027500	East Branch Clarion River at East Branch Clarion River Dam, Pa.	73.20	30	25.0	25.0	24	-1.0	-4.2	24.3	-.7	-3.0
3032500	Redbank Creek at St. Charles, Pa.	528.00	30	23.0	23.0	20	-3.0	-13.0	19.6	-3.4	-14.8
3039200	Clear Run near Buckstown, Pa.	3.68	14	23.1	22.0	22	.0	.0	22.2	.2	1.0
3042200	Little Yellow Creek near Strongstown, Pa.	7.36	18	25.1	24.8	24	-.8	-3.4	23.1	-1.7	-7.0
3074300	Lick Run at Hopwood, Pa.	3.80	12	25.4	26.4	18	-8.4	-31.9	20.2	-6.2	-23.6
2159800	Fairforest Creek at Spartanburg, S.C.	17.00	4	23.9	25.2	20	-5.2	-20.8	19.4	-5.8	-23.2
2167000	Saluda River at Chappells, S.C.	1,360.00	30	19.8	19.8	13	-6.8	-34.4	21.3	1.5	7.5
2186000	Twelvemile Creek near Liberty, S.C.	106.00	10	25.2	27.0	29	2.0	7.5	32.8	5.8	21.6
3421000	Collins River near McMinnville, Tenn.	640.00	30	26.1	26.1	27	.9	3.4	26.9	.8	3.0
3461500	Pigeon River at Newport, Tenn.	666.00	30	25.8	25.8	16	-9.8	-38.1	25.4	-.4	-1.7
3538275	Bear Creek near Oak Ridge, Tenn.	7.15	4	23.4	23.5	22	-1.5	-6.4	22.0	-1.5	-6.4
3539500	Daddys Creek near Crab Orchard, Tenn.	93.50	8	27.3	28.0	28	.0	.1	28.6	.6	2.2
3556500	Hiwassee River near McFarland, Tenn.	1,136.00	30	29.2	29.2	26	-3.2	-11.0	34.8	5.6	19.2
3566000	Hiwassee River at Charleston, Tenn.	2,298.00	14	29.1	27.5	22	-5.5	-20.0	30.2	2.7	9.9
1626000	South River near Waynesboro, Va.	127.00	28	15.0	15.2	17	1.8	12.0	17.3	2.1	14.0
1633000	North Fork Shenandoah River at Mt. Jackson, Va.	506.00	30	10.5	10.5	10	-.5	-4.5	13.2	2.7	26.1
1656500	Broad Run at Buckland, Va.	50.50	29	14.0	14.2	14	-.2	-1.3	15.0	.8	5.8
1662800	Battle Run near Laurel Mills, Va.	27.60	22	13.4	13.0	16	3.0	22.6	15.3	2.3	17.2
1669000	Piscataway Creek near Tappahannock, Va.	28.00	29	16.2	16.0	14	-2.0	-12.2	13.0	-3.0	-18.5
2039500	Appomattox River at Farmville, Va.	303.00	30	12.4	12.4	13	.6	5.1	13.1	.7	5.9
2055100	Tinker Creek near Daleville, Va.	11.70	24	13.8	13.4	14	.6	4.7	14.1	.7	5.5
2073000	Smith River at Martinsville, Va.	380.00	30	16.1	16.1	15	-1.1	-6.8	16.6	.5	3.2
3173000	Walker Creek at Bane, Va.	305.00	30	15.0	15.0	15	-.0	-.3	15.9	.9	5.6
1611500	Cacapon River near Great Cacapon, W. Va.	677.00	30	12.5	12.5	12	-.5	-3.8	11.9	-.6	-4.6
3068000	Shavers Fork at Bemis, W. Va.	115.00	6	43.1	42.1	35	-7.1	-16.8	29.4	-12.7	-30.1
3114650	Buffalo Run near Little, W. Va.	4.21	8	18.9	16.5	24	7.5	45.6	24.6	8.1	49.3
3182500	Greenbrier River at Buckeye, W. Va.	540.00	30	22.5	22.5	23	.5	2.4	21.9	-.6	-2.5
3196800	Elk River at Clay, W. Va.	992.00	20	26.4	26.8	19	-7.8	-29.1	24.3	-2.5	-9.4
3199400	Little Coal River at Julian, W. Va.	318.00	6	23.5	20.7	17	-3.7	-17.9	18.0	-2.7	-13.0
Maximum							7.5	45.6		8.1	54.5
Minimum							-13.7	-53.3		-12.7	-30.1
Mean							-1.83	-6.23		-.37	-.43
Standard deviation							3.66	15.55		3.07	13.37
Root mean square							4.08	16.68		3.07	13.31
Absolute mean							2.86	12.28		2.09	9.22
Standard error of mean							.378	1.60		.316	1.38

sions that the methods that used the area-weighted average of the drainage area or the centroid of the drainage area produced somewhat better correlations—that is, the interecept was closer to zero, the standard errors were small, and the correlation coefficients were larger. These methods have slightly greater power to predict actual runoff
Additional statistical investigation found no significant differences in reliability of the runoff estimates among the areas. No significant differences existed in the errors for stations with drainage areas of differing size.

USE OF MEAN ANNUAL RUNOFF MAP

Mean annual runoff for a site can be estimated from the runoff map by several methods. The simplest method of estimating the runoff is to locate the site on the runoff map and to identify the runoff contour nearest the site. This method, however, is less accurate than other methods. The most accurate method is to draw the drainage basin on the runoff map, and use the runoff contours to divide the basin into bands of differing runoff. The area of each of the bands within the drainage basin is then determined. The areas of the separate bands are then used to compute a weighted average runoff for the basin. For example, if 50 percent of the basin is in an area of 18 in/yr (inches per year) of runoff, 30 percent in an area of 20 in/yr of runoff and 20 percent in an area of 22 in/yr of runoff the mean annual runoff would be calculated as follows:

$$0.5 \times 18 + 0.3 \times 20 + 0.2 \times 22 = 19.4$$

Runoff estimated from the map is in inches per year, averaged over the entire drainage basin. Multiply this value by the drainage area, in square miles, and divide by 13.58 to convert to mean annual discharge, in cubic feet per second. In the above example, assume the drainage area of the site is 100 mi^2. The mean annual discharge, in cubic feet per second, would be:

$$19.4 \times 100/13.58 = 143$$

The runoff map was prepared to allow estimation of mean annual runoff at sites where no streamflow data are available. The map represents mean annual runoff for areas with natural land cover. Caution should be used in applying the map to estimate runoff for areas that are not natural land areas. The runoff map should not be used for areas, such as large urban areas, where the land cover has been altered in ways that would change the amount of runoff. The runoff map is not applicable for lakes or bays, for coastal wetlands affected by tides, for streams controlled by reservoirs large enough to influence the total annual streamflow, or for streams with substantial diversions.

Local features could cause the runoff at a particular site to differ substantially from the runoff indicated by the runoff map. The geology of the drainage basin might cause substantial amounts of water to enter or leave the basin as ground water. This could substantially increase or decrease the runoff. For example, a stream with a small drainage area that includes a large spring probably would have higher average streamflow than indicated by the runoff map.

Table 5.—Descriptive statistics of errors in estimated runoff at 93 test stations

Method	Mean absolute value	Mean	Standard error of mean	Standard deviation
		Error, in inches		
Area-weighted	2.0	-0.35	0.30	2.9
Centroid	2.2	-.71	.33	3.1
GIS	2.7	-1.74	.37	3.6
Nearest-inch	2.8	-1.77	.38	3.7
Nearest contour	2.8	-1.79	.39	3.8
		Percent error		
Area-weighted	9.0	-0.54	1.3	12.9
Centroid	9.8	-.71	1.4	13.5
GIS	12.0	-6.42	1.6	15.9
Nearest-inch	12.1	-6.20	1.6	15.6
Nearest-contour	12.2	-6.26	1.6	15.8

Research by Rochelle and others (1988) found no correlation between runoff in inches per year and drainage area for 5 data sets with from 60 to 531 gaging stations or experimental watersheds in each set. Drainage areas ranged from 0.2 mi^2 to more than 6,000 mi^2. The errors between estimated and measured runoff at 93 test stations used in this study appeared to be more variable for small drainage areas than for large drainage areas, but the differences in errors were not statistically significant. Local variations in topography and geology, however, might have a greater effect on runoff from small drainage basins than large drainage basins.

SUMMARY

A mean annual runoff map for water years 1951-80 was prepared for the Northeastern, Southeastern, and Mid-Atlantic United States. All or part of the following States were included: Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, New York, Pennsylvania, New Jersey, West Virginia, Virginia, Maryland, Delaware, Kentucky, North Carolina, Tennessee, South Carolina, Georgia, Alabama, and Mississippi.

The map was prepared from streamflow-gaging-station records. A total of 1,232 stations were used to construct the maps. The mean annual runoff for the 30-year period for stations that had less than 30 years of record was determined by correlation analysis with a nearby gaging station that had records for the full 30 years. The maps were compiled at a scale of 1:500,000.

Mean annual runoff in the Northeastern Region ranged from less than 12 to greater than 40 in.; in the Southeastern Region, runoff ranged from less than 12 to greater than 55 in.; and in the Mid-Atlantic Region, runoff ranged from less than 10 to greater than 40 in.

The mean annual runoff map probably is more accurate in areas that have a relatively high concentration of gaging stations and little topographic variability, such as parts of the Northeast. On the basis of these criteria, the least accurately mapped areas would be in the Smoky Mountains along the North Carolina-Tennessee border.

The general accuracy of the runoff-mapping procedures was assessed by use of 93 stations that were not used to construct contours on the map. After the mean annual runoff map was prepared the runoff values for. these stations were estimated from the map and compared to the actual runoff. This comparison indicated that the runoff map provided estimates of runoff with an average absolute error of 9.0 to 12.2 percent, depending on the method used. Methods that used the centroid of the drainage basin or an area-weighted average for the drainage basin produced lower errors than methods that estimated runoff at the outlet of the basin.

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Table 6.—Summary of regression analyses of estimated runoff

Method	Slope (inch per inch)	Intercept (inch)	Residual root mean square (inch)	R^2 (in percent)
Area-weighted	0.89	2.8	2.9	75.9
Centroid	.90	2.8	3.1	71.5
GIS	.89	4.1	3.5	64.2
Nearest-inch	.90	3.9	3.6	61.0
Nearest-contour	.89	4.1	3.7	59.8

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