RUNOFF FOR SELECTED SITES IN SHENANDOAH NATIONAL PARK, VIRGINIA, JULY 18, 1981, THROUGH JULY 17, 1982

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

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CONVERSION FACTORS

For the use of readers who prefer metric (International System) units, rather than the inch-pound terms used in this report, the following conversion factors may be used

Multiply	*By*	*To obtain*
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)

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ABSTRACT

Estimates of runoff for 56 sites within the Shenandoah National Park were made by the U.S. Geological Survey for the Direct/Delayed Response Project that is being conducted by the U.S. Environmental Protection Agency. The purpose of that project is to determine the long-term effects of acidic deposition on surface-water chemistry. Runoff was estimated for the period July 18, 1981, through July 17, 1982—during which periodic water-quality samples were collected for a study by the U.S. Geological Survey to determine the sensitivity of the area to the current input of acid deposition. The runoff values and water-quality samples will be used by the U.S. Environmental Protection Agency (EPA) to determine chemical budgets for 56 watersheds in the Park.

The runoff estimates were determined by a graphical-correlation procedure. Six discharge measurements at each site were made when water-quality samples were collected; these were then correlated with the concurrent recorded discharges at one of 13 nearby streamflow-gaging stations. The mean discharge at the gaging station for the subject period was transferred through the relation line to estimate the mean discharge and runoff at the water-quality sampling site. The runoff estimates during the study period ranged from 10.9 to 38.7 inches.

The accuracy of the method was evaluated by treating 13 nearby gaging stations as if they were water-quality sampling sites. A comparison of estimated and recorded runoff for the same period showed differences ranging from −28.2 to 49.5 percent, with an absolute average of 14.7 percent.

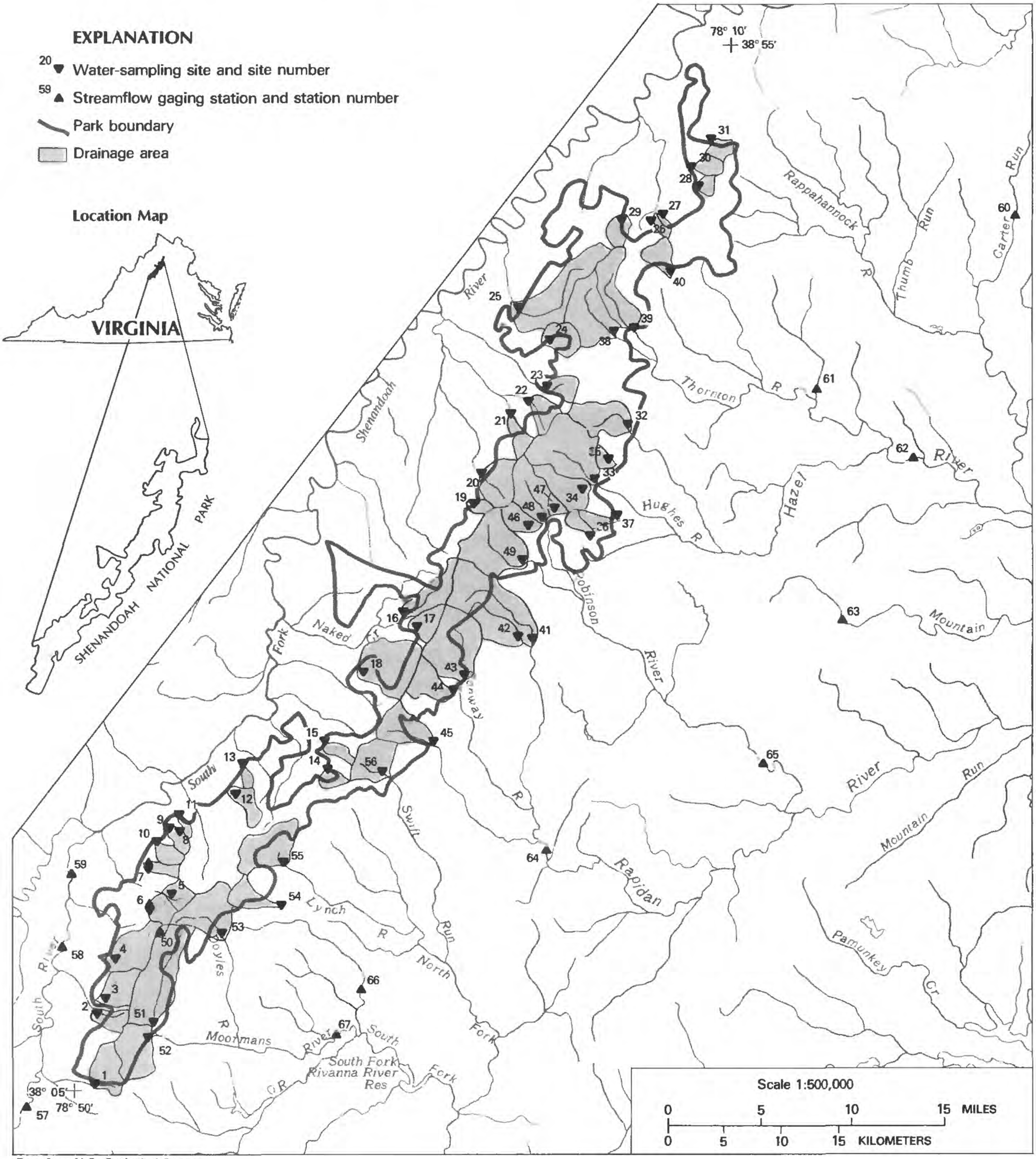
INTRODUCTION

This report presents estimates of runoff at 56 sites within the Shenandoah National Park (fig. 1) for the Direct/Delayed Response Project that is being conducted by the EPA. The purpose of the Direct/Delayed Response Project is to predict the long-term response of surface water to acidic deposition. Determination of sulfur-retention patterns in the Eastern United States is a goal of the project. Sulfur budgets for 56 watersheds in the Shenandoah National Park will be computed by the EPA to estimate sulfur retention. The purpose of this report is to provide an estimate of runoff during the water-quality sampling period that is required to calculate these budgets. The study was conducted in cooperation with the EPA Environmental Research Laboratory, Corvallis, Oregon.

Runoff is the water in a river or stream that is derived from precipitation. It includes contributions from surface-water and ground-water sources. Runoff is commonly reported as a mean discharge rate or the average volume discharged per year, expressed as equivalent depth on the drainage area. Discharge data in this report are expressed in cubic feet per second, and the estimated runoff is expressed in inches in depth over the drainage basin.

DATA BASE

The data used to compute runoff in Shenandoah National Park for the study period were obtained from two sources. Streamflow measurements were made and water-quality samples collected at the 56 sites (fig. 1) during 6 synoptic surveys by Lynch and Dise (1985). The purpose of that study was to evaluate the sensitivity of dilute headwater streams to acid deposition and to determine the degree of acidifica-



Base from U.S. Geological Survey Virginia state base map, 1973, 1:500,000

Figure 1. Locations of 56 water-sampling sites and 13 streamflow-gaging stations.

tion of drainage basins. Water samples were collected during that study from August 1981 through June 1982.

Miscellaneous discharge measurements collected by Lynch and Dise (1985) and the recorded streamflow at 13 nearby streamflow-gaging stations were used in this study. Table 1 lists the 13 stations, their respective drainage areas, and the runoff for the study period. The gaging-station locations are shown in figure 1. Two of these gaging stations—White Oak Run near Grottoes (# 6) and Deep Run near Grottoes (# 7)—were included in the 56 synoptic survey sites.

Table 1.—Mean discharge and runoff for July 18, 1981, through July 17, 1982, for 13 streamflow-gaging stations located in and near Shenandoah National Park

[mi², square miles; ft³/s, cubic feet per second; in., inches]

Map no.	Station number	Station name	Drainage area (mi²)	Mean discharge (ft³/s)	Runoff (in.)
57	01626000	South R nr Waynesboro	127	107	11.4
58	01626850	South R nr Dooms	149	149	13.6
59	01627500	South R at Harriston	212	194	12.4
6	01628060	White Oak Run nr Grottoes	1.94	2.09	14.6
7	01628150	Deep Run nr Grottoes	1.17	1.03	12.0
60	01661900	Carter Run nr Marshall	19.5	18.6	12.9
61	01662800	Battle Run nr Laurel	27.6	18.4	9.0
62	01663500	Hazel R nr Rixeyville	287	260	12.3
63	01665000	Mountain R nr Culpeper	15.9	14.9	12.8
64	01665500	Rapidan R nr Ruckersville	114	161	19.2
65	01666500	Robinson R nr Locust Dale	179	184	14
67	02032250	Moormans R nr Free Union	74.6	84.2	15.3
66	02032400	Buck Mt. nr Free Union	37.0	41.2	15.1
		Average	95.8		13.4

RUNOFF FOR SELECTED SITES

Methods of Runoff Computation

An analysis was made to select the best method for determining the runoff at the 56 water-sampling sites. From 3 to 6 discharge measurements were made at 54 of the sites during the synoptic surveys (Lynch and Dise, 1985). It was assumed that measurements would help quantify the runoff for each site and improve the accuracy over that obtained by use of an empirical relation between runoff and drainage area.

Three methods were analyzed in order to determine the one that would provide the most reliable estimate of runoff. The methods are:

1. *Graphical regression.*—This method is similar to that used for low-flow analyses (Riggs, 1972). A relation line is established by a graphical regression using the three to six miscellaneous discharge measurements and the concurrent daily mean discharges recorded at a nearby continuous-record gaging station. The recorded mean discharge for the sampling period at the gaging station is transferred through the relation line to estimate the mean discharge at the water-sampling site.

2. *Midperiod measurement.*—This method is based on the assumption that the ratio of concurrent daily mean flows of two streams near the middle of a period equals the ratio of their means for that period (Riggs, 1969). This method generally requires discharge measurements in the approximate middle of each month and on the first of the month during periods of high runoff. This method was modified for this study so that the six discharge measurements made during the synoptic survey were used. The discharge measurements are plotted against the concurrent discharges recorded at a nearby gaging station on log-log paper. A 45-degree line is drawn through the point and the recorded mean discharge at the gaging station is transferred through the 45-degree line. This provides an estimate of mean discharge at the water-sampling site. An estimate of the mean discharge for the total period is produced when combined with mean discharge values for other periods.

3. *Multiple-regression analysis.*—Multiple-regression analysis also could be performed using the data at the 13 streamflow-gaging stations. The independent variables readily available are drainage area and average flow index. An average flow index is a variable developed in an attempt to utilize the discharge measurements at the sampling sites. A previous low-flow study by Gebert (1982) demonstrated that base-flow discharge measurements, made at sites where low-flow estimates were required, are very helpful in explaining the variation in low-flow characteristics in a multiple-regression analysis. The dependent variable used in the regression analysis was the recorded runoff (Q_p) in cubic feet per second during July 18, 1981, through July 17, 1982.

The recorded streamflow data at the 13 nearby gaging stations listed in table 1 were used to evaluate the three methods. For methods 1 and 2, the recorded discharge from one site, during or near the time when water samples were obtained, was treated as if it were a miscellaneous discharge measurement. These data were related to the recorded discharge at nearby gaging stations. This was repeated for all 13 sites to obtain estimates of runoff during July 18, 1981, through July 17, 1982.

For example, the runoff for South River near Waynesboro was estimated by transferring the recorded discharge of South River near Dooms through the various relation lines established for methods 1 and 2. The runoff for South River near Dooms was then estimated by the next station in table 1, South River near Harriston. This procedure was followed sequentially for each station listed in table 1.

The equation developed from the multiple regression analysis is

$$Q_p = 0.89\ A^{1.02} \times Q_f^{0.25}.$$

The standard error of estimate for the equation is 18.4 percent. The use of Q_f was found to be of little benefit in the equation. The regression equation determined with only drainage area is

$$Q_p = 0.93\ A^{1.01}.$$

The standard error of estimate for the equation is 18.5 percent and was therefore used for the analysis.

The estimated runoff was computed for each site, by each method and compared to the recorded runoff. The results are shown in table 2.

The percent difference of the estimated runoff compared to the recorded runoff for the graphical method ranged from −28.2 to 49.5 percent, with an absolute average of 14.7 percent.

The percent difference for the midperiod method ranged from −57 to 219 percent, with an absolute average of 26.8 percent.

The estimated runoff for the multiple-regression method ranged from the recorded value from −29.6 to 48.0 percent, with an absolute average of 13.0 percent.

For method 3 the estimated runoff value ranged from 12.8 to 13.7 in. (inches) (table 2), which reflects the strong association with drainage area. The actual runoff value for these 13 stations showed considerably more variability and range from 9.0 to 19.2 in. This indicates that the regression equation does not contain the independent variables that explain much of the variability. The graphical approach, however, showed similar variability in runoff; values range from 8.36 to 20.2 in.

The graphical approach appears to incorporate the actual runoff variability more closely than the regression equations. This is probably attributable to the use of actual flow data at each site. The graphical technique was, therefore, selected as the method that provides the best representation of actual runoff.

It should be noted that the average drainage area for the 13 streamflow-gaging stations is 95.8 mi² (square miles) and the average drainage area for the 56 water-sampling sites is 3.54 mi². Because only two stations represent runoff from small drainage areas, it had to be assumed that all three methods would perform in a comparable manner for small drainage areas. The absolute average difference for the smaller drainage area may be larger than indicated in the analysis of the 13 gaging stations; this is usually the case when estimating discharge characteristics for small watersheds.

Table 2.—Recorded runoff compared to estimated runoff by three methods at 13 gaging stations

[mi², square miles; in., inches]

				Estimated runoff, by graphical method, with 6 measurements		Estimated runoff, by midperiod method		Estimated runoff, by multiple-regression equations	
Map no.	Station name	Drainage area (mi²)	Recorded runoff (in.)	(in.)	(Percent difference)	(in.)	(Percent difference)	(in.)	(Percent difference)
57	South R nr Waynesboro	127	11.4	11.8	2.8	11.0	−3.7	13.5	18.6
58	South R nr Dooms	149	13.6	13.7	.7	14.7	8.0	13.6	.2
59	South R at Harriston	212	12.4	18.6	49.5	39.6	219.0	13.6	9.9
6	White Oak Run nr Grottoes	1.94	14.6	10.5	−28.2	14.2	−2.9	12.9	−11.5
7	Deep Run nr Grottoes	1.17	12.0	8.93	−25.2	5.1	−57.0	12.8	6.8
60	Carter Run nr Marshall	19.5	12.9	12.5	−3.2	11.7	9.6	13.2	2.5
61	Battle Run nr Laurel	27.6	9.0	8.36	−7.6	8.8	2.2	13.3	48.0
62	Hazel Run nr Rixeyville	287	12.3	14.4	17.3	15.0	22.0	13.7	11.6
63	Mountain Run nr Culpeper	15.9	12.8	11.1	−12.8	12.7	0	13.2	4.1
64	Rapidan R nr Ruckersville	114	19.2	20.2	5.6	20.2	5.6	13.5	−29.6
65	Robinson R nr Locust Dale	179	14.0	15.2	8.7	14.7	5.2	13.6	−2.7
67	Moormans R nr Free Union	74.6	15.3	17.8	16.3	14.9	−2.5	13.4	−12.3
66	Buck Mt. Run nr Free Union	37.0	15.1	13.2	−12.6	13.6	−9.7	13.4	11.1
	Absolute average				14.7		26.8		13.0

Data Analysis

The runoff at a sampling site was determined from a relation line established by a graphical regression using the six miscellaneous discharge measurements and the concurrent daily mean discharge recorded at a nearby continuous-record streamflow-gaging station in the area. The mean discharge for the gaging station during July 18, 1981, through July 17, 1982, was transferred through the relation line to estimate the mean discharge at the miscellaneous site, which was then converted to runoff in inches for the period.

No estimate of runoff was made at 6 of the 56 sites because too few discharge measurements were available to define a relation. Site 46 was also dropped from the analysis when it was found that there is an undetermined amount of interbasin flow from an adjoining basin upstream from the site during periods of high flow. The runoff for the remaining 49 sites is presented in table 3. The mean discharge for the period ranged from 0.29 ft^3/s (cubic feet per second) for North Fork Moorman River tributary near Harrison (#50) to 21 ft^3/s for Rose River near Syria (#49). Runoff volume for the year (mean discharge divided by drainage area multiplied by a conversion factor), ranged from 10.9 in. at Rosson Hollow Run tributary near Etland (#37) to 38.7 in. for Staunton River near Graves Mill (#42). The average for the 49 sites is 19.0 in. The mean runoff for the same period at the 13 continuous-record gaging stations ranged from 9.0 to 19.2 in. The average for the 13 stations is 13.4 in.

The analysis showed that higher runoff values generally are associated with basins located in the central part of the Park or on streams with easterly drainage as shown in figure 2. The lowest values are associated with basins in the southern part of the Park and for streams with westerly drainage. A visual comparison of plotted runoff values and topography shows only a general relation between runoff and elevation. Runoff values were also compared to the total precipitation for the period at five Weather Service stations, but no relation was apparent. This may be attributable to the small number of rainfall stations and the fact that many of them were outside the drainage areas of the sampling sites.

Mean runoff for 7 of the 13 gaging stations shown in table 1 was determined for the period 1951–80. The runoff values and the ratio of July 18, 1981, through July 17, 1982, runoff to 1951–80 runoff is shown in table 4. Six of the stations showed that runoff during July 18, 1981, through July 17, 1982, was up to 35 percent lower than that of the long-term mean. At one site, Rapidan River near Ruckersville, runoff during 1951–80 was 6.0 percent above the long-term mean. The headwaters of the Rapidan River are in the area where the higher runoff values were found. This helps to explain some of the wide variation in runoff values for the water-quality sampling sites.

Examples of the graphical relation are shown in figure 3. The relation lines are drawn to best fit the data with more weight given to the medium-to-high discharge measurements. The straight-line relation for base-flow measurements on log-log paper has been used by hydrologists to estimate low-flow characteristics (Riggs, 1972); to a lesser extent, it has also been used as a tool for estimating peak discharges. One of the concerns in using this technique to estimate runoff is that the relation between discharge at the stations being compared is not always linear.

To evaluate the linearity of the relation determined by the graphical correlation method for estimating mean discharge, an analysis was made using the 13 gaging stations. The analysis consisted of making a log-log plot of the recorded daily discharge at two nearby streamflow-gaging stations against each other for all 365 days during the study period. A straight-line relation was evident in most instances for discharges in the medium-to-high ranges. A straight-line relation existed in some cases for the full range of flow conditions (fig. 4), but, for others, it was evident that the low-flow relation departed from the straight line established by medium to high discharges (figs. 5 and 6).

Figure 4 is an example of a good relation (low scatter of data about relation line) over the full range of flow. Figure 5 is an example of an average relation (moderate scatter of data about relation line) for the full range of flow, which is nonlinear in the upper and lower flow range. Figure 6 shows a poor relation (high scatter of data about relation line), especially in the lower flow range. The example also illustrates how the relation line was drawn through the medium-to-high flow value but not through the lower flow values. In general, because the mean lies within the straight line, the technique of using a straight-line relation line with emphasis on medium-to-high flows appears justified.

Error Analysis

The data at the 13 gaging stations was analyzed to estimate the error associated with the estimated runoff at the 49 sites as mentioned in the "Methods" section. The analyses consisted of estimating the runoff at the 13 sites by the same method used for the 49 sites.

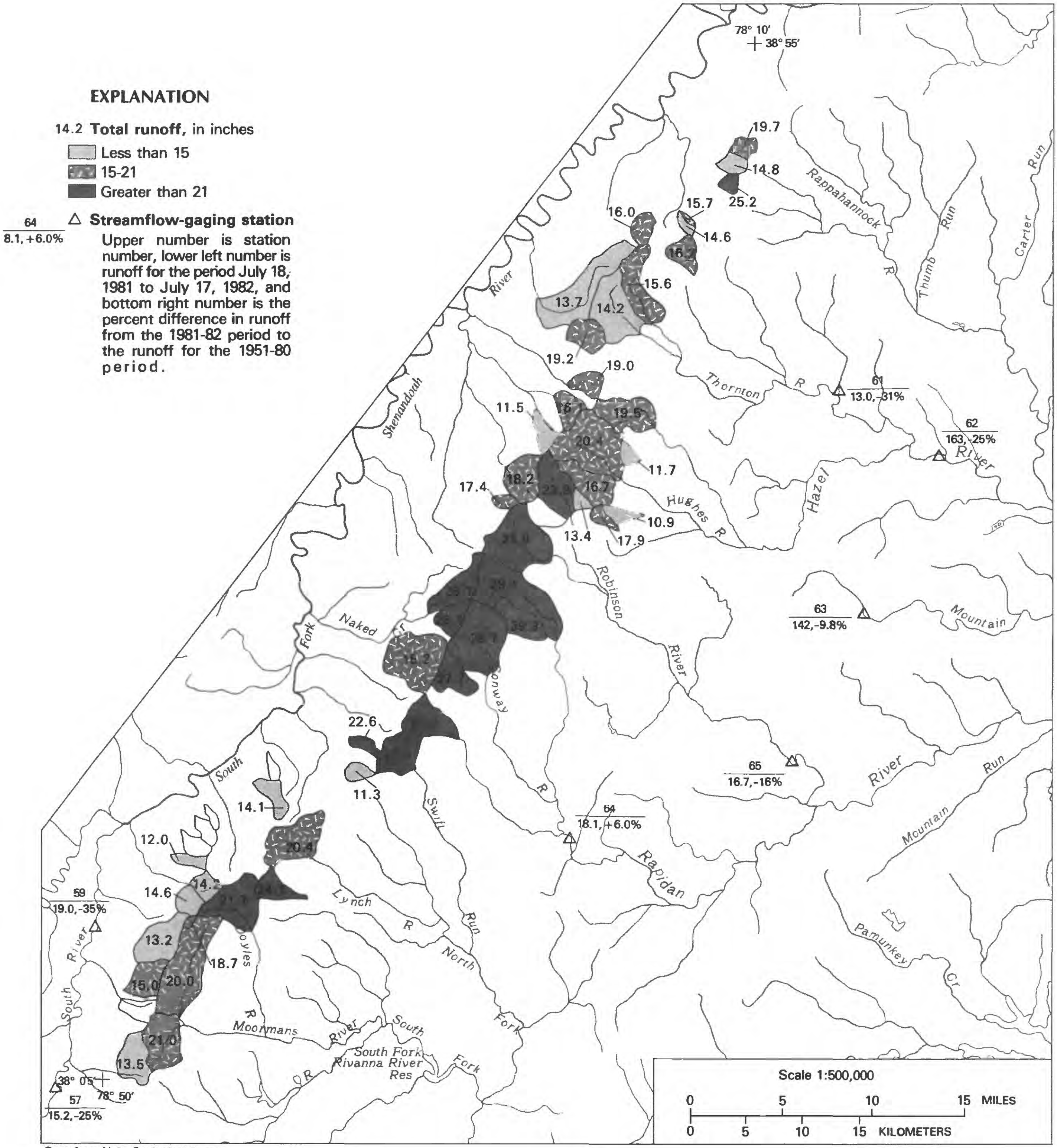
The six discharge values were used with the recorded discharge at a nearby gaging station to

Table 3.—Estimated mean discharge and runoff during July 18, 1981, through July 17, 1982, for 56 sampling stations.

[mi², square miles; ft³/s, cubic feet per second; in., inches; —, insufficient data available]

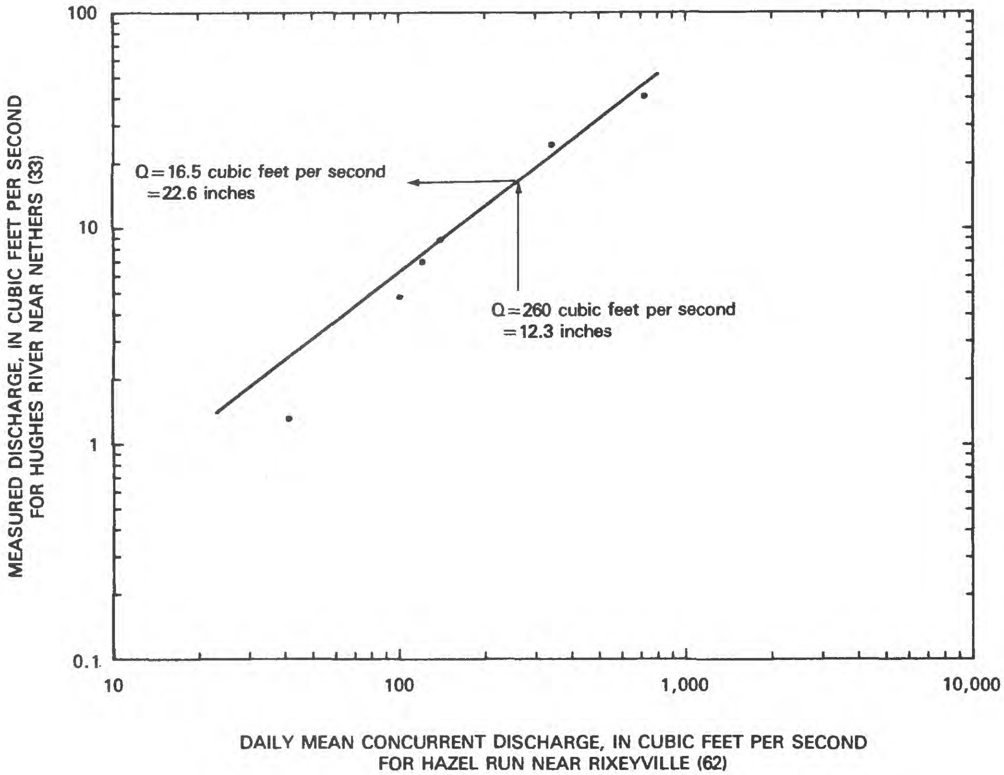
Map no.	Station number	Station name	Drainage area (mi²)	Estimated mean discharge (ft³/s)	Estimated runoff (in.)
1	01626900	Sawmill Run nr Dooms	3.62	3.6	13.5
2	01627000	Mine Branch nr Crimora	1.26	—	—
3	01627100	Meadow Run nr Crimora	3.45	3.8	15.0
4	01627400	Paine Run nr Harriston	4.92	4.8	13.2
5	01628050	Madison Run above WOR nr Grottoes	2.00	2.1	14.2
6	01628060	White Oak Run nr Grottoes	1.94	[1]2.09	14.6
7	01628150	Deep Run nr Grottoes	1.17	[1]1.03	12.0
8	01628300	Lower Lewis Run nr Lynwood	1.12	—	—
9	01628320	Lower Lewis Run trib nr Lynwood	.18	—	—
10	01628350	Upper Lewis Run nr Lynwood	1.58	—	—
11	01628530	Hangman Run nr Rocky Bar	.44	—	—
12	01628700	Twomile Run nr McGaheysville	2.17	2.25	14.1
13	01628750	Walls Run nr Rocky Bar	.60	—	—
14	01628900	Hawksbill Creek Trib nr Swift Run	1.32	1.1	11.3
15	01628910	West Swift Run at Swift Run	.96	.92	13.0
16	01629120	East Branch Naked Creek nr Jollett	4.58	8.8	26.1
17	01629130	Big Creek nr Jollett	2.43	5.2	29.1
18	01629150	South Branch Naked Creek nr Furnace	8.72	9.8	15.2
19	01629920	Little Hawksbill Creek Trib nr Ida	.78	1.0	17.4
20	01629950	East Hawksbill Creek nr Ida	4.03	5.4	18.2
21	01630100	South Fork Dry Run nr Fairview	1.53	1.3	11.5
22	01630200	North Fork Dry Run nr Thornton	2.45	2.9	16.1
23	01630542	Pass Run nr Thornton Gap	2.00	2.8	19.0
24	01630543	Rocky Branch nr Thornton	2.76	3.9	19.2
25	01630585	Jeremys Run nr Oak Hill	9.72	9.8	13.7
26	01630649	Phils Arm Run nr Browntown	.98	1.05	14.6
27	01630650	Phils Arm Trib nr Browntown	.38	.44	15.7
28	01630660	Smith Creek nr Browntown	.78	1.45	25.2
29	01630670	Greasy Run nr Browntown	1.70	2.0	16.0
30	01630680	Lands Run nr Browntown	1.38	1.5	14.8
31	01636202	Happy Creek Trib nr Glen Echo	1.51	2.20	19.7
32	01662100	Hazel River nr Nethers	5.15	7.4	19.5
33	01662150	Hughes River nr Nethers	9.92	15.0	20.4
34	01662160	Brokenback River nr Nethers	4.30	5.3	16.7
35	01662170	Rocky Run nr Nethers	1.09	.94	11.7
36	01662190	Ragged Run nr Etlan	1.14	1.50	17.9
37	01662200	Rosson Hollow Run Trib nr Etlan	1.05	.84	10.9
38	01662350	N Fork Thornton River nr Sperryville	7.28	7.6	14.2
39	01662370	Piney River nr Sperryville	5.58	6.4	15.6
40	01662480	Rush River nr Washington	2.76	3.3	16.2
41	01665260	Rapidan River nr Graves Mill	9.74	20.2	28.1
42	01665270	Staunton River nr Graves Mill	4.21	12.0	38.7
43	01665340	Conway River nr Kinderhook	9.66	20.0	28.1
44	01665343	Conway River Trib nr Kinderhook	3.62	7.4	27.7
45	01665440	South River at McMullen	4.94	8.5	23.4
46	01665710	White Oak Canyon trib nr Syria	—	[2]—	—
47	01665720	Berry Hollow trib nr Nethers	1.01	1.0	13.4
48	01665740	Robinson River near Syria	9.53	16.8	23.9
49	01665800	Rose River nr Syria	9.15	21.0	31.0
50	02031410	N Fork Moormans River Trib nr Harrison	.21	.29	18.7
51	02031500	N Fork Moormans River nr Whitehall	11.4	17.0	20.0
52	02031800	S Fork Moormans River nr Whitehall	5.56	8.5	21.0
53	02032110	Doyles River nr Browns Cove	6.44	10.3	21.7
54	02032310	Muddy Run Trib nr Boonesville	2.59	4.6	24.1
55	02032545	Ivy Creek nr Boonesville	6.11	9.2	20.4
56	02032589	Swift River at Lydia	4.80	9.0	25.4
		Average	3.5		19.0

[1]Values are recorded discharge because this is a streamflow-gaging station.
[2]Error in data, see page 5.



Base from U.S. Geological Survey
Virginia state base map,
1973, 1:500,000

Figure 2. Study area showing runoff for 50 sites for period July 18, 1981, through July 17, 1982.



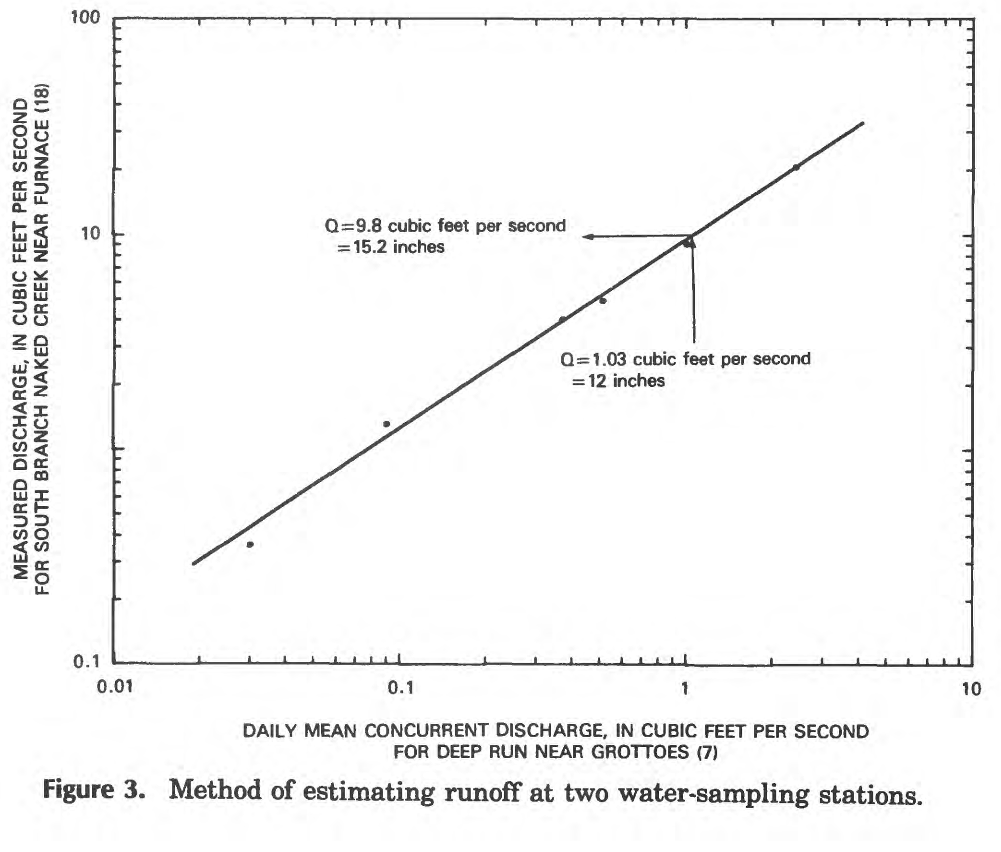


Figure 3. Method of estimating runoff at two water-sampling stations.

Table 4.—Comparison of runoff for the period July 18, 1981, through July 17, 1982, to 1951–80 for seven gaging stations located in and near Shenandoah National Park

[mi², square miles; in., inches]

Map no.	Station number	Station name	Drainage area (mi²)	Runoff July 18, 1981, through July 17, 1982 (in.)	Runoff 1951–80 (in.)	Difference[1] (percent)
57	01626000	South R nr Waynesboro	127	11.4	15.2	−25
59	01627500	South R at Harriston	212	12.4	19.0	−35
61	01662800	Battle Run nr Laurel	27.6	9.0	13.0	−31
62	01663500	Hazel R nr Rixeyville	287	12.3	16.3	−25
63	01665000	Mountain R nr Culpeper	15.9	12.8	14.2	−10
64	01665500	Rapidan R nr Ruckersville	114	19.2	18.1	+6
65	01666500	Robinson R nr Locust Dale	179	14.0	16.7	−16

[1]Percent difference in the runoff for the period July 18, 1982, through July 17, 1982, to runoff for the period 1951–80, rounded to nearest percent.

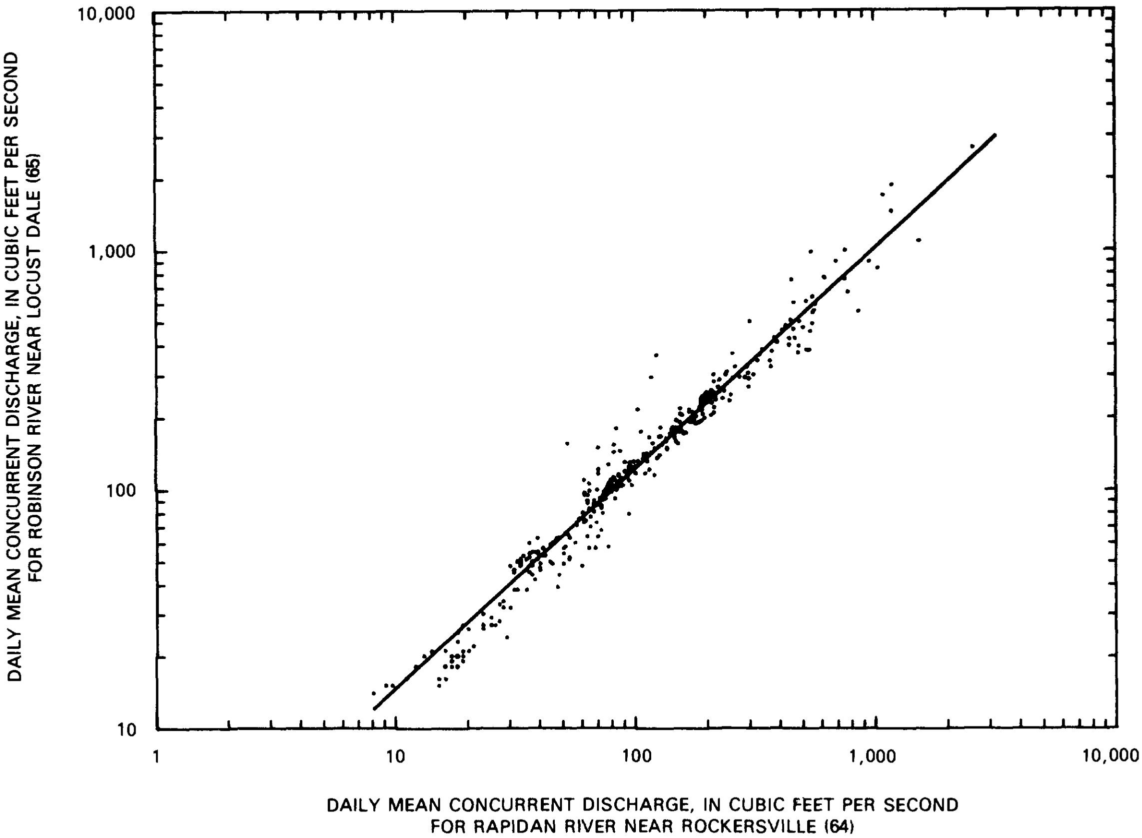


Figure 4. Example of a good relation (low scatter of data about relation line) of daily mean concurrent discharge for 365 days at two gaging stations.

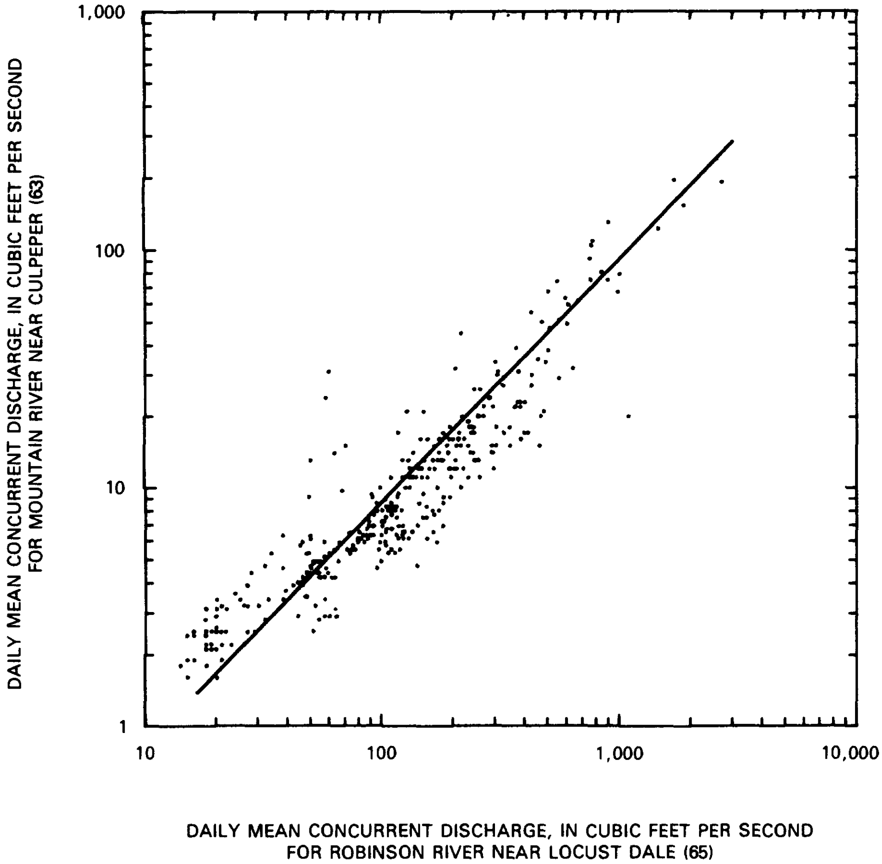


Figure 5. Example of an average relation (medium scatter of data about relation line) of daily mean concurrent discharge for 365 days at two gaging stations.

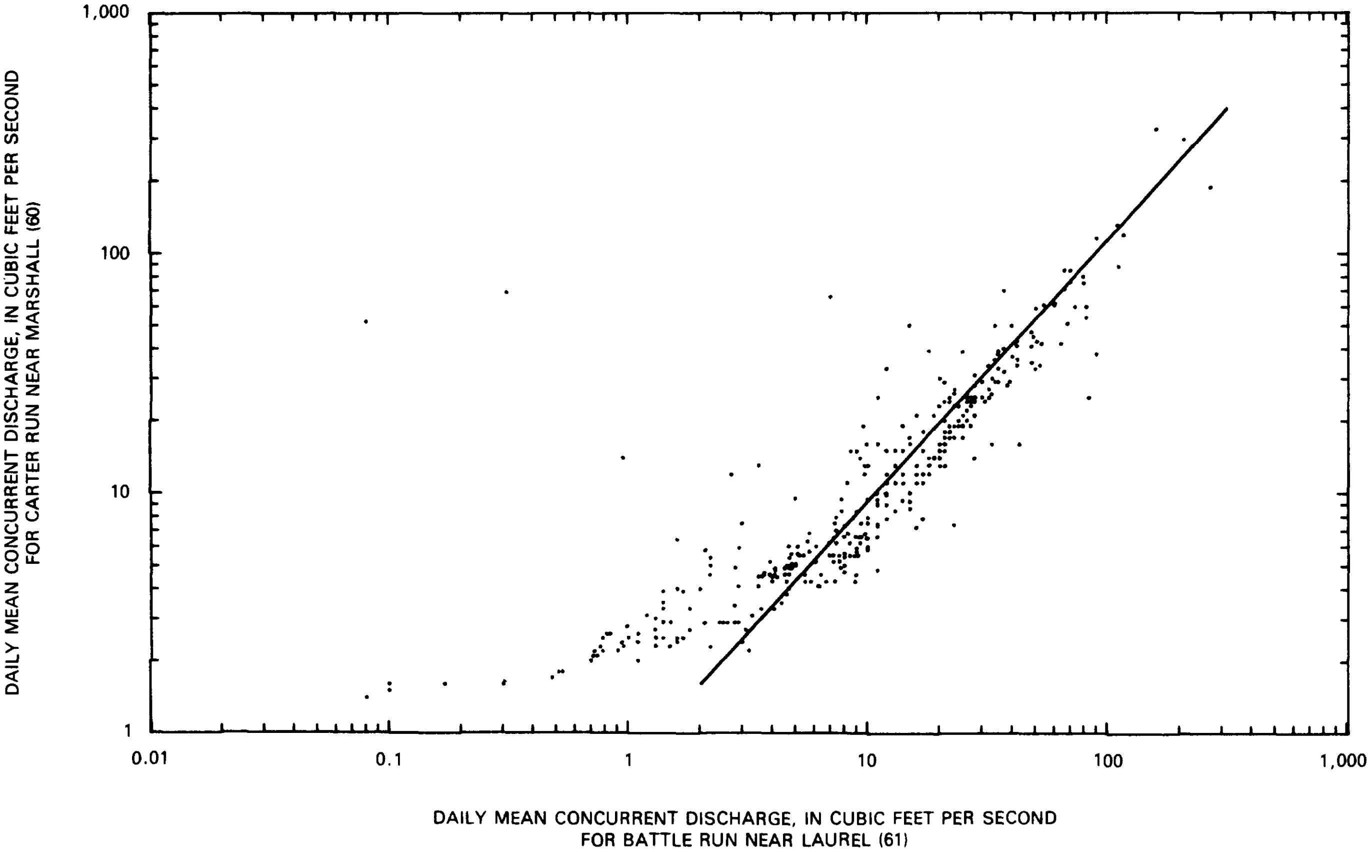


Figure 6. Example of a poor relation (high scatter of data about relation line) of daily mean concurrent discharge for 365 days at two gaging stations.

establish a relation line. Six daily streamflow values were chosen for each station on approximately the same date as the measurements were made at the 49 sites. The recorded mean discharge at the nearby gaging station was transferred through the relation line to estimate the runoff at the gaging station that was being analyzed (fig. 7). The results are shown in table 5. The estimated runoff for the relation lines developed for six measurements as compared to the recorded runoff ranged from −28.2 percent to 49.5 percent, with an absolute average of 14.7 percent. The variation in inches of runoff was −4.1 to 6.2 in., with an absolute average of 1.9 in.

The error associated with the estimated runoff at the 49 water-sampling sites is probably higher than the 14.7 percent indicated by this analysis. The 49 sites drain headwater areas of less than 10 mi^2 but the index stations drain an average area of 95.8 mi^2. For example, the percent difference between recorded and estimated runoff in table 5 can be used to show that for five gaging stations with drainage areas less than 30 mi^2 the average error is −15.4 percent, and, for the two stations with drainage areas less than 2.5 mi^2, the average error is −26.7 percent.

The runoff for these stations also was estimated by a relation line established using the 365 mean daily discharge values at both stations. The mean annual discharge at the independent gaging station was transferred through the relation line to estimate the mean annual discharge and runoff at the dependent gaging station. This provided a comparison of the accuracy of using 6 measurements and 365 measurements to the recorded mean discharge for the 13 gaging stations. These values also are shown in table 5.

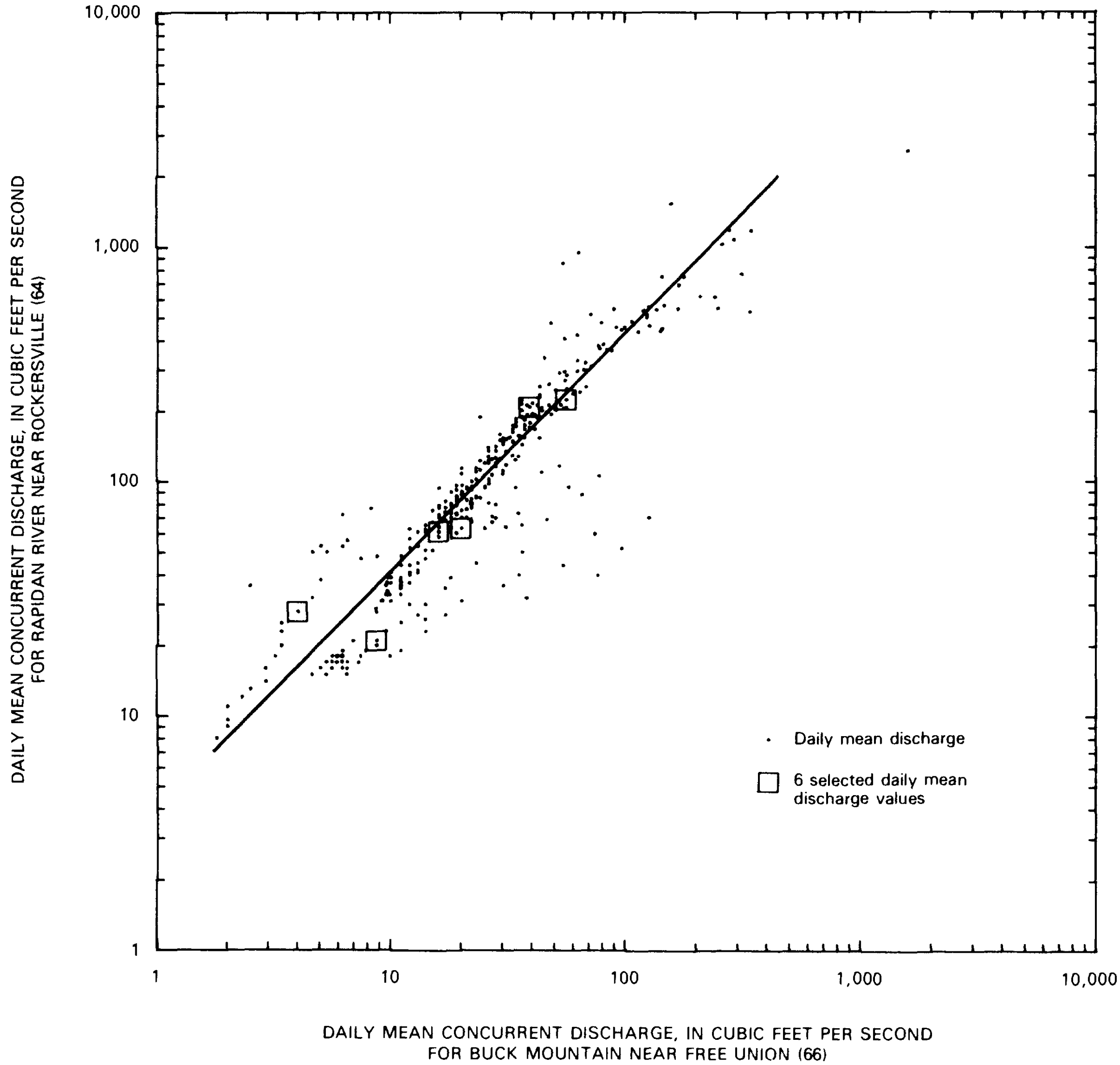


Figure 7. Comparison of methods using 6 measurements and 365 mean daily discharge values to estimate runoff.

The estimated runoff from a relation line for 365 measurements as compared to the recorded runoff ranged from −32 to 44 percent, with an absolute average of 13.3 percent (table 5).

As with the graphical method the error was large for the gaging stations with the smaller drainage areas. For the five gaging stations with drainage areas less than 30 mi² the average error is 15.7 percent and for the two stations with drainage areas less than 2.5 mi² the average error is 31.3 percent.

Assessment of Results

It was assumed before the study was started that the midperiod method, described by Riggs (1969), would probably provide the most reliable estimate of runoff. Because measurements to apply the technique exactly as described were not available, an analysis was made comparing runoff at the 13 streamflow-gaging stations.

This analysis involved estimating the runoff at each site using six measurements or daily discharge (previously described in the "Methods" section). Another estimate was prepared for each gaging station (similar to the procedure described in the "Methods" section) using a discharge measurement or daily discharge from the first of each month. Additional measurements were used for the 15th of the month for February, March, and April to improve definition of runoff during the high-flow periods. This procedure, using 15 measurements, follows the procedure described by Riggs (1969).

A comparison of estimated runoff using 6 measurements and 15 measurements to recorded runoff is shown in table 6. The percent difference for the six measurements compared to the actual runoff ranged from −57.0 to 219 percent, with an absolute average of 26.8 percent. For the 15-measurement method, the estimated values ranged from −26.0 to 179 percent, with an absolute average of 25.9 percent.

It was surprising that there was such little difference between the two methods. It was anticipated that the error would be much closer to 10 percent as previously reported by Riggs and as found by Gebert in his application of the technique to streams in Wisconsin.

An analysis of the results in table 6 shows that much of the error is associated with South River at Harriston. The estimated runoff differed from the actual runoff by 219 percent for the 6-measurement method and by 179 percent for the 15-measurement method.

It became apparent while conducting the midperiod analysis that South River near Harriston should not be used. It appeared that runoff events that were affecting South River were less pronounced on White Oak Run. Part of this is related to the large variation in size of drainage area, 212 mi², for South River compared to that of White Oak Run (1.94 mi²). Patterns of runoff and streamflow in the South River are quite different from that of other rivers in the area because South River is underlain by permeable limestone, whereas other streams in the Park drain relatively impermeable igneous rock.

The relation between discharge values at White Oak Run and South River at Harriston in the graphical method was poor, but the method provided a better estimate of the actual runoff than either of the midperiod methods.

If the South River at Harriston were removed from the comparison of methods, the absolute average difference for each method would be:

	Graphical with 6 measurements	Graphical with 365 measurements	Midperiod with 6 measurements	Midperiod with 15 measurements
Absolute average difference	11.8 percent	10.7 percent	10.7 percent	12.9 percent

Table 5.—Recorded runoff compared to estimated runoff by graphical method using 6 measurements and 365 measurements

[mi², square miles; ft/s, cubic feet per second; in., inches]

Map no.	Station name	Drainage area (mi²)	Recorded mean runoff (ft³/s)	Recorded mean runoff (in.)	Estimated mean runoff, by graphical method, with 6 measurements (ft³/s)	(in.)	(percent difference)	Estimated mean runoff, by graphical method with 365 measurements (ft³/s)	(in.)	(percent difference)	Index gaging station used for graphical correlation Map no.
57	South R nr Waynesboro	127	107	11.4	110	11.8	2.80	110	11.8	2.80	58
58	South R nr Dooms	149	149	13.6	150	13.7	.67	150	13.7	.67	59
59	South R at Harriston	212	194	12.4	290	18.6	49.5	280	17.9	44.3	6
6	White Oak Run nr Grottoes	1.94	2.09	14.6	1.50	10.5	−28.2	1.45	10.1	−30.6	7
7	Deep Run nr Grottoes	1.17	1.03	12.0	.77	8.93	−25.2	.70	8.12	−32.0	57
60	Carter Run nr Marshall	19.5	18.6	12.9	18	12.5	−3.23	18	12.5	−3.23	61
61	Battle Run nr Laurel	27.6	18.4	9.0	17	8.36	−7.61	18	8.85	−2.17	62
62	Hazel R nr Rixeyville	287	260	12.3	305	14.4	17.3	300	14.2	15.4	63
63	Mountain R nr Culpeper	15.9	14.9	12.8	13	11.1	−12.8	16.5	14.1	10.7	65
64	Rapidan R nr Ruckersville	114	161	19.2	170	20.2	5.59	180	21.4	11.8	66
65	Robinson R nr Locust Dale	179	184	14.0	200	15.2	8.70	182	13.8	−1.09	64
67	Moormans R nr Free Union	74.6	84.2	15.3	98	17.8	16.3	90	16.4	6.9	64
66	Buck Mt. nr Free Union	37.0	41.2	15.1	36	13.2	−12.6	46	16.9	11.6	67
	Absolute average	95.8					14.7			13.3	

The removal of South River makes a great reduction in the difference in both midperiod methods; all four methods then have about the same absolute average difference. Several conclusions can be drawn from this analysis when estimating runoff in this area.

1. The six-discharge values provide as accurate an estimate as the use of the more extensive data if the two general methods (graphical versus midperiod) are compared. To a certain extent, this seems to reflect good judgment in selecting periods for obtaining water-quality samples over a range of flow conditions. It would be interesting to see if six random discharge measurements would do as well.

2. The graphical method seems a somewhat superior technique for this limited comparison. It seems to provide a more reliable estimate of runoff without knowledge of geologic conditions that may influence the analysis.

SUMMARY

Runoff estimates were made for 49 sites in the Shenandoah National Park for the period July 18, 1981, through July 17, 1982. These estimates ranged from 10.9 to 38.7 in.

The higher runoff values generally were located in the central part of the Park and on the eastern side of the Blue Ridge. The lower values were in the southern part of the Park and on the western side of the Blue Ridge. A comparison of runoff values to elevation shows only a general relation. The six discharge measurements at a site were related to the concurrent daily mean discharges at a nearby gaging station and the mean flow for the subject period at the gaging station was transferred through the relation to get the estimate at the site.

Accuracy of the method was evaluated by applying it to pairs of gaging stations one of each pair being considered as having only six discharge measurements. The test indicated differences of estimated from known runoff at gaging stations that ranged from −28 to 49 percent.

Two other methods of estimating runoff from six discharge measurements were examined and found to have no advantage over the method used.

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Table 6.—Recorded runoff compared to estimated runoff by two midperiod methods at 13 gaging stations

[mi², square miles; in., inches]

				midperiod method with 6 measurements		midperiod method with 15 measurements		Index gaging station used for graphical correlation
Map no.	Station name	Drainage area (mi²)	Recorded runoff (in.)	Estimated runoff (in.)	Percent difference	Estimated runoff (in.)	Percent difference	Map no.
57	South R nr Waynesboro	127	11.4	11.0	−3.7	11.7	3.0	58
58	South R nr Dooms	149	13.6	14.7	8.0	14.1	4.0	59
59	South R at Harriston	212	12.4	39.6	219.0	34.3	179.0	6
6	White Oak Run nr Grottoes	1.94	14.6	14.2	−2.9	10.8	−26.0	7
7	Deep Run nr Grottoes	1.17	12.0	5.1	−57.0	10.7	−10.5	57
60	Carter Run nr Marshall	19.5	12.9	11.7	9.6	9.9	−23.0	61
61	Battle Run nr Laurel	27.6	9.0	8.8	2.2	9.9	1.0	62
62	Hazel Run nr Rixeyville	287	12.3	15.0	22.0	14.4	17.1	63
63	Mountain Run nr Culpeper	15.9	12.8	12.7	0	9.7	−20.4	65
64	Rapidan R nr Ruckersville	114	19.2	20.2	5.6	23.5	22.4	66
65	Robinson R nr Locust Dale	179	14.0	14.7	5.2	13.4	−4.1	64
67	Moormans R nr Free Union	74.6	15.3	14.9	−2.5	12.6	−17.9	64
66	Buck Mt. Run nr Free Union	37.0	15.1	13.6	−9.7	16.4	9.0	67
	Absolute average				26.8		25.9	