Dimensionless Unit Hydrograph for the Delmarva Peninsula

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The Soil Conservation Service uses a dimensionless unit hydrograph to develop storm hydrographs for hydrologic evaluation of small watersheds and for hydrologic design of conservation measures. An average dimensionless unit hydrograph has been used extensively nationwide with reasonable success. However, in flatlands such as the Atlantic coastal plains, stream gauge analysis indicates that another shaped dimensionless unit hydrograph that is significantly different from the average should be used. An average dimensionless unit hydrograph for coastal flatlands was developed by using the techniques in the U.S. Army Corps of Engineers HEC-1 computer program. An average C_p value for the Snyder unit hydrograph was determined from seven events on four streams. The flatland unit hydrograph was then used to generate peakflow frequency curves with reasonable success at the four stream gauge sites plus one additional site.

The Soil Conservation Service (SCS) uses a dimensionless unit hydrograph to develop storm hydrographs for hydrologic evaluation of small watersheds and hydrologic design of soil and water resource management practices. These practices include both agricultural and urban stormwater management.

An average dimensionless unit hydrograph has been used extensively by the SCS throughout the country with reasonable results. However, in certain unique areas such as the Delmarva Peninsula of the Atlantic coastal plain, the observed storm hydrographs from stream gauges indicate that the hydrograph shape in this area is significantly different from that of the average SCS unit hydrograph.

A dimensionless unit hydrograph that is representative of some of the flat topography has been developed and is currently being used by SCS personnel in the Delmarva Peninsula. This paper describes the technique used to develop the Delmarva unit hydrograph.

WATERSHED DESCRIPTION

As part of the Atlantic Coast Flatwoods major land resource area, the Delmarva Peninsula has local relief of less than 3 m (10 ft) with considerable available surface storage in swales and depressions. Although many soils require drainage before they can be used for crops, crops grown on some of the sandy soils need irrigation during droughts. The mean annual precipitation is 117 cm (46 in.), including 38 cm (15 in.) of snowfall (*1*).

The four watersheds studied are widely distributed geographically and have at least 20 years of continuous stream gauge records (Figure 1). These watersheds have drainage areas of approximately 12–155 km² (5–60 mi²). The average land slopes of 2 to 5 percent or less are typical of the Delmarva Peninsula.

BACKGROUND

The standard SCS unit hydrograph was derived from natural unit hydrographs of watersheds varying widely in size and geographic location (*2*). However, most of these watersheds are in the Midwest where local relief may be 15–30 m (49–98 ft) with little or no surface storage. Since these physical characteristics are not typical of those in the Delmarva Peninsula, a unit hydrograph unique to the watershed characteristics of the study area was developed.

In the standard SCS unit hydrograph, shown in Figure 2, 37.5 percent of the volume is under the rising side. The peak rate of flow equation for this standard SCS hydrograph is

$$q_p = \frac{2.08QA}{T_p} \quad \left(\frac{484QA}{T_p}\right) \tag{1}$$

where

- q_p = peak discharge in cubic meters per second (cubic feet per second);
- Q = volume of runoff in centimeters (inches);
- A = drainage area in square kilometers (square miles); and
- T_p = time to peak in hours.

The constant, 2.08, is a shape and unit conversion factor. Later reference to this factor will be as a dimensionless unit hydrograph peak factor. This constant can be converted to the percent of volume under the rising side of the hydrograph by multiplying by 18.

The dimensionless form of a unit hydrograph, where the axes are q/q_p and T/T_p, is used in the SCS Computer Program for Project Formulation—Hydrology (TR-20) (*3*). The TR-20 computer program has the capability of developing a flood hydrograph given the rainfall histogram, watershed characteristics (T_c, drainage area, and curve number), and a dimen-

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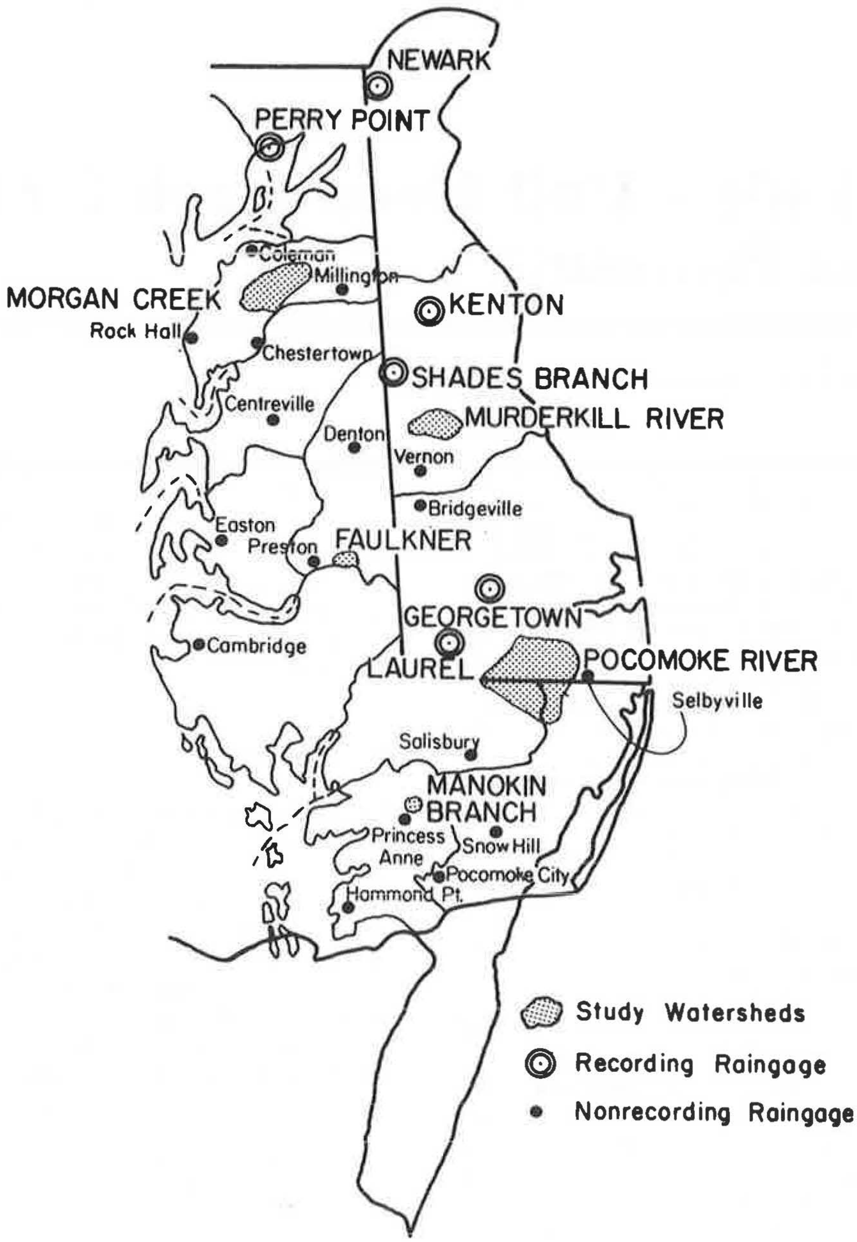

FIGURE 1 Locations of watersheds and climatological stations.

sionless unit hydrograph. The TR-20 computer program cannot be used to develop unit hydrographs.

BASIC DATA

Rainfall and runoff data were obtained for three storms on two agricultural watersheds and two storms on two other watersheds (Table 1). Locations of the watershed and climatological stations are shown in Figure 1. A total of 10 flood hydrographs were used to develop the dimensionless unit hydrograph. Two additional storms on the Murderkill River watershed were used during the verification portion of the study. The rainfall and runoff data used were compiled and published by the National Weather Service (NWS) and U.S. Geological Survey (USGS). The data were used in 1-hour intervals. The closest available recording precipitation gauges were used. Nonrecording precipitation gauges within a 32-km (20-mi) radius of the watershed were used to weight the total rainfall volume. With the exception of the September 1960 storm on the Pocomoke River, 3 cm (1.2 in.) or more of runoff occurred for each event.

ANALYSIS

The computer model selected for this study is the Flood Hydrograph Package (HEC-1) (*4*). Selection was based on the model's capability of developing a unit hydrograph given a rainfall histogram, a recorded flood hydrograph, and the watershed characteristics. The unit hydrograph is computed by the Clark method by using two unit hydrograph variables

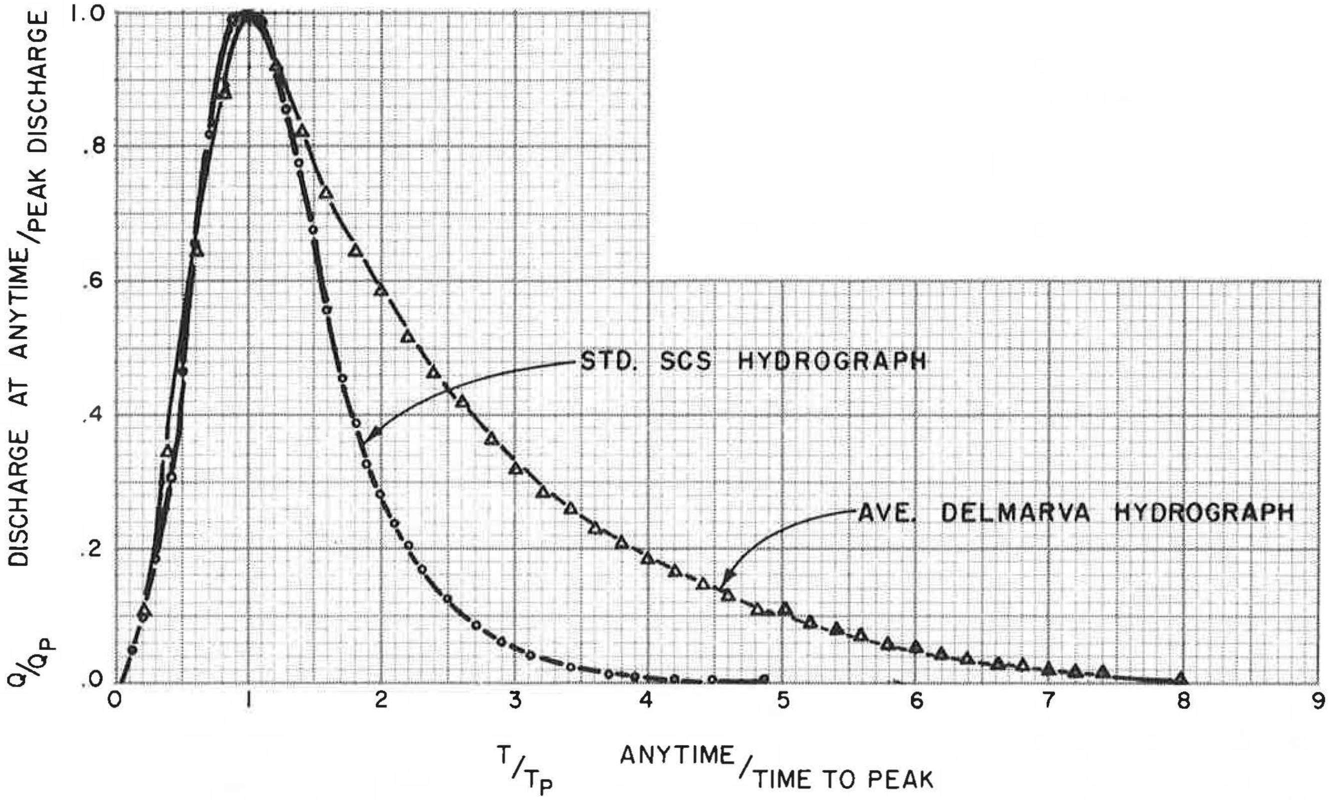

FIGURE 2 Dimensionless unit hydrographs.

TABLE 1 WATERSHED CHARACTERISTICS AND SELECTED FLOODS

			Flood Runoff Data					
			Aug. 12–13, 1955		Aug. 24–26, 1958		Sept. 11–12, 1960	
Watershed	Drainage Area (km^2)	Land Slope (%)	Peak (m^3/sec)	Volume (cm)	Peak (m^3/sec)	Volume (cm)	Peak (m^3/sec)	Volume (cm)
Faulkner Branch at Federalsburg, Md.	18.4	2	12.2	4.85	11.9[a]	5.84	18.4	6.48
Manokin Branch near Princess Anne, Md.	12.4	2	6.54	4.88	—	—	5.18[a]	3.76
Morgan Creek near Kennedyville, Md.	32.9	5	17.6	3.10	23.3	3.43	43.6[a]	5.72
Pocomoke River near Williards, Md.	157.0	2	17.5	3.20	—	—	5.80	0.66

[a]Not used in developing average Delmarva dimensionless unit hydrograph.

and four loss-rate variables as calibration coefficients. Full optimization of all six variables was performed. In a few cases, the results were improved by specifying starting values for the optimization of these variables.

Originally, it was planned to use the procedure described in the HEC-1 Users Manual to individually fix each loss-rate variable and then reiterate the computations until all variables were selected. After finishing two of these iterations, however, it was recognized that only optimized loss-rate variables and no average unit hydrograph would be obtained. Therefore, HEC-1 was used to compute a unit hydrograph and Snyder's coefficient (C_p) for each storm (see Table 2).

The mean value of C_p was 0.40 with a standard deviation of 0.18. The seven unit hydrographs with C_p values within approximately one standard deviation of 0.40 were selected for averaging. These unit hydrographs could not be readily averaged because they were tabulated by using different intervals. The seven unit hydrographs were made dimensionless and averaged to obtain a unique dimensionless unit hydrograph with a dimensionless unit hydrograph peak factor of

TABLE 2 HEC-1 OPTIMIZATION RESULTS

	C_p by Storm Year		
Location of Stream Gauge	1955	1958	1960
Morgan Creek	0.45	0.41	0.78[a]
Faulkner Branch	0.34	0.23[a]	0.44
Manokin Branch	0.52	—	0.09[a]
Pocomoke River	0.33	—	0.42

[a] Not used in developing average dimensionless unit hydrograph. Mean C_p (n = 10) is 0.40; standard deviation, 0.17. Mean C_p (n = 7) is 0.42; standard deviation, 0.06.

1.22 (284). This average dimensionless unit hydrograph can be used as input in TR-20. SCS has developed a relationship between T_p and time of concentration (T_c) for the unit hydrograph.

$$T_p = \frac{D}{2} + 0.6\ T_c \tag{2}$$

where

T_p = time to peak of unit hydrograph in hours,
D = duration of rainfall excess in hours, and
T_c = time of concentration in hours.

This relationship was developed from analysis of hydrographs from small watersheds.

The TR-20 computer program generates the flood hydrograph by convolution of the incremental unit hydrographs. Time of concentration is a user-defined variable in the TR-20 computer program. This procedure of flood hydrograph development provided reasonable results. The simulated and actual storm hydrographs are shown in Figures 3–6.

VERIFICATION

Although the TR-20 computer program is not intended to reproduce an historic event, it was used to determine if the average Delmarva unit hydrograph gave better results than the standard SCS unit hydrograph. The hydrographs are shown in Figures 3–6 and the peak discharges are shown in Table 3. The peak discharge obtained using the average Delmarva unit hydrograph more nearly approximates the observed peak discharge in every case except one.

Using the actual computed unit hydrograph for each storm improved the results for only two of the seven storms that were used to develop the average Delmarva unit hydrograph.

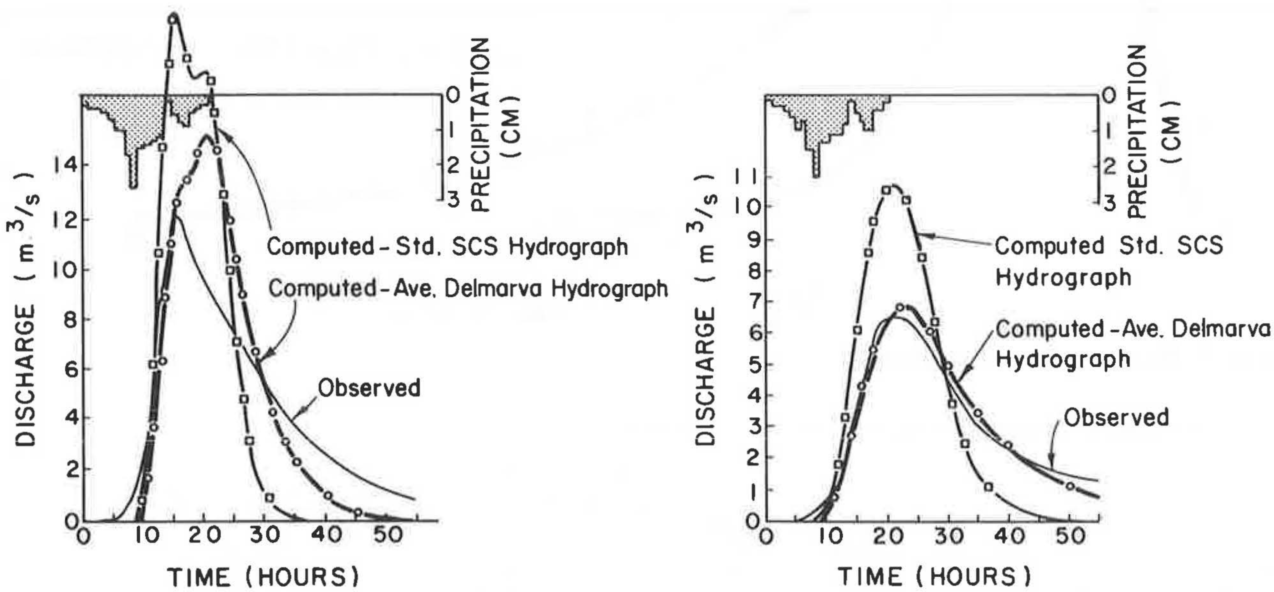

FIGURE 3 Actual storm hydrographs: *Left*, 1955 storm, Faulkner Branch; *right*, 1955 storm, Manokin Branch.

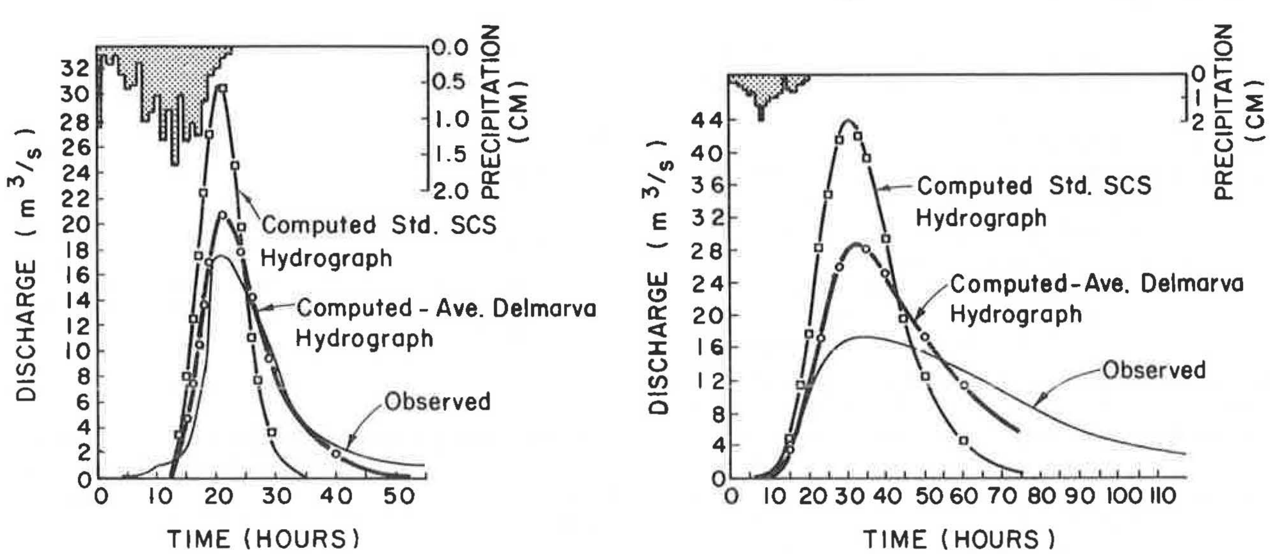

FIGURE 4 Actual storm hydrographs: *Left*, 1955 storm, Morgan Creek; *right*, 1955 storm, Pocomoke River.

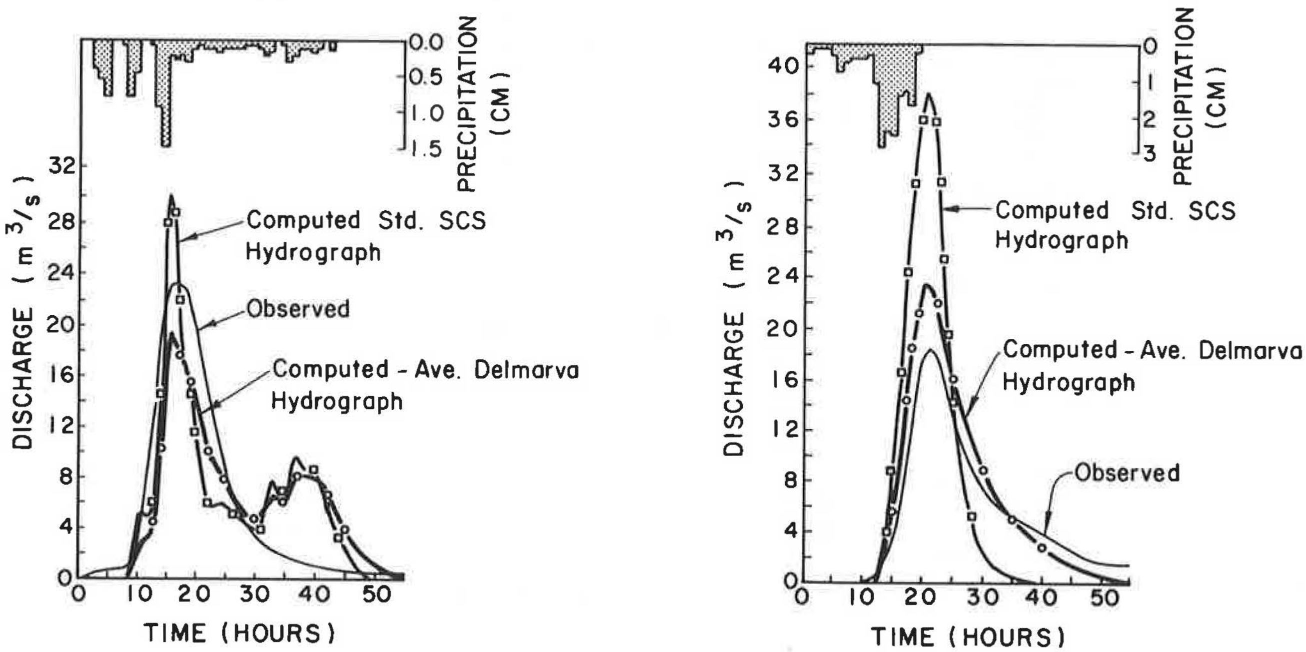

FIGURE 5 Actual storm hydrographs: *Left*, 1958 storm, Morgan Creek; *right*, 1960 storm, Faulkner Branch.

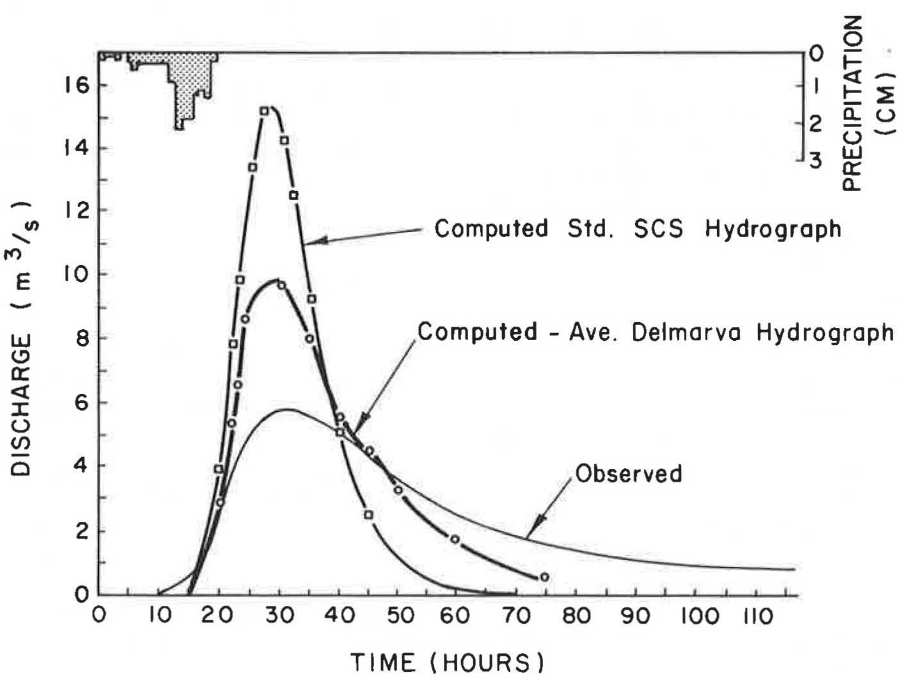

FIGURE 6 Actual storm hydrographs: 1960 storm, Pocomoke River.

TABLE 3 PEAK DISCHARGES FOR HISTORIC EVENTS

	Storm Peak Discharge (m^3/sec)			
Watershed	Observed	Actual Hydrograph[a]	Average Delmarva Hydrograph[a]	Standard SCS Hydrograph[a]
Faulkner Branch				
1955	12.2	14.2	15.3	20.1
1958[b]	11.9	—	18.7	29.4
1960	18.4	24.1	23.5	38.5
Manokin Branch				
1955	6.54	7.93	6.80	10.8
1960[b]	5.18	—	23.80	27.5
Morgan Creek				
1955	17.6	21.8	21.0	31.1
1958	23.3	22.1	19.5	30.6
1960[b]	43.6	—	28.0	45.0
Pocomoke River				
1955	17.5	25.2	28.7	43.6
1960	5.80	9.91	9.91	15.3
Murderkill River				
1960[b]	22.8	—	34.5	58.3
1967[b]	58.9	—	75.3	129.0

[a] TR-20 results.
[b] Not used in developing average Delmarva dimensionless unit hydrograph.

The maximum variation of peak discharges using the average Delmarva unit hydrograph and the actual storm unit hydrograph was 14 percent. This value indicates that the average Delmarva hydrograph provides results as reasonable as those from the actual hydrograph.

The TR-20 computer program was used to compute a peak flow frequency curve for each station studied. The TR-20 uses standard hydrograph generation techniques and 24-hour precipitation values for selected return periods (i.e., 2-, 10-, 25-, 50-, 100-year) to determine peak flows at selected return periods. As shown in Figures 7 and 8, the peak flow frequency curves computed by the average Delmarva hydrograph are much closer to the peak flow frequency curves published by Simmons and Carpenter (5) than are the curves computed by the standard SCS hydrograph.

These comparisons indicate that in most cases the average Delmarva hydrograph still produces peak discharges that are higher than those observed. These values are to be expected since the Type II rainfall distribution was used. Type II is a maximized distribution based on design considerations rather than on meteorological factors (*6*). To provide unbiased results, the TR-20 models were not calibrated against either the actual storm hydrographs or the USGS peak flow frequency curves. Thus, the estimated times of concentration and runoff curve numbers used may not be representative, which may account for part of the differences. In addition, the hydraulic rating curves developed by SCS for the Pocomoke River appear to be significantly different from those of USGS. The reasons for the difference were never determined. However, it appears that different downstream conditions were assumed.

Data from two storms on the Murderkill River Watershed, a watershed not used for development of the average Delmarva hydrograph, provided an independent validation of results. Figure 9 shows that the computed peak discharges are within 20 percent of those observed. The computed hydrograph shape for the single burst storm on September 11–12, 1960 matches the observed hydrograph shape very closely. The lack of similarity of hydrograph shapes for the August 3–4, 1967 storm is probably due to the inapplicability of the TR-20 computer program to multiple burst storms and the variation between actual rainfall on the watershed and rainfall recorded at the climatological stations. The peak flow frequency curves for the Murderkill River (Figure 10) also indicate the superior performance of the average Delmarva hydrograph.

CONCLUSIONS

Use of the Delmarva dimensionless unit hydrograph will allow more accurate hydrologic evaluation of small watersheds and, therefore, more appropriate design of conservation practices and structures, including stormwater management practices on the Delmarva Peninsula. However, other factors such as rainfall distribution, runoff potential (as reflected in the runoff curve number), and watershed characteristics, such as the time of concentration, also must be accurately estimated to obtain reasonable results.

This same approach is being used for development of dimensionless unit hydrographs for the entire Atlantic coastal plain. The study was extended to the coastal plain region of New Jersey. However, the variability in the available data precluded the development of a dimensionless unit hydrograph for New Jersey.

McCuen and Bondelid (*7*) analyzed the same flood events for the same stream gauges on the Delmarva Peninsula by another technique. They assumed that the proportion under

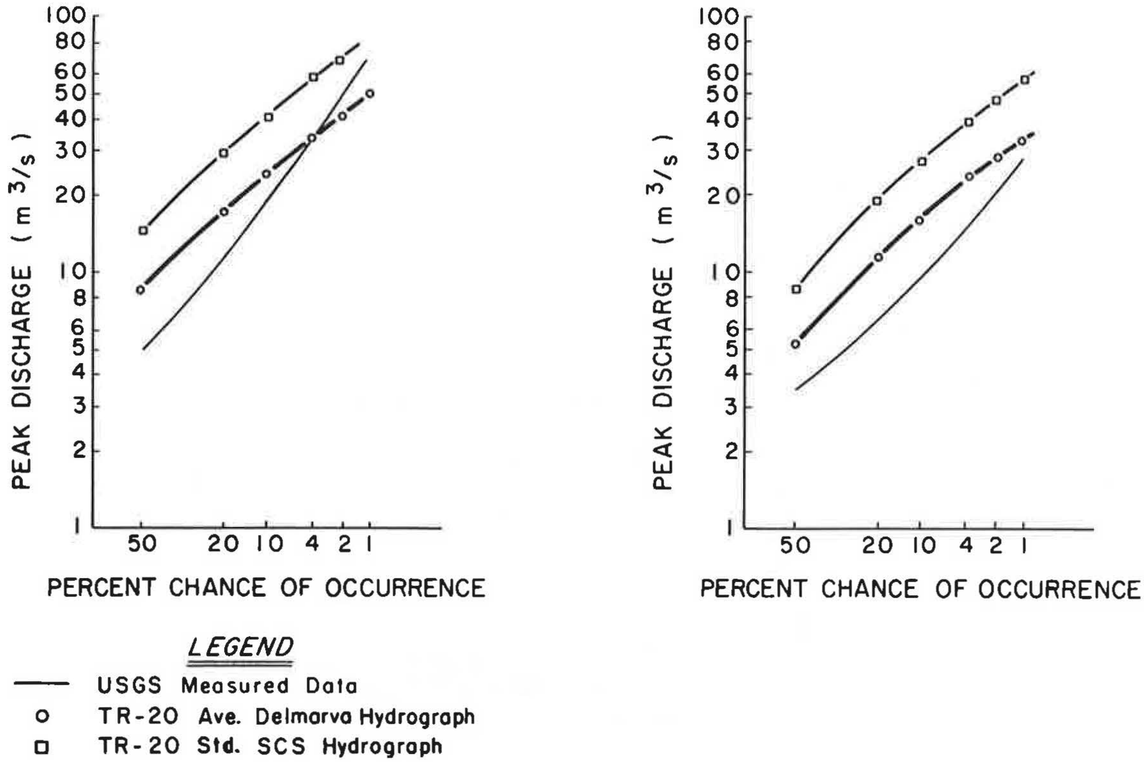

FIGURE 7 Peak flow frequency curves: *Left*, Faulkner Branch; *right*, Manokin Branch.

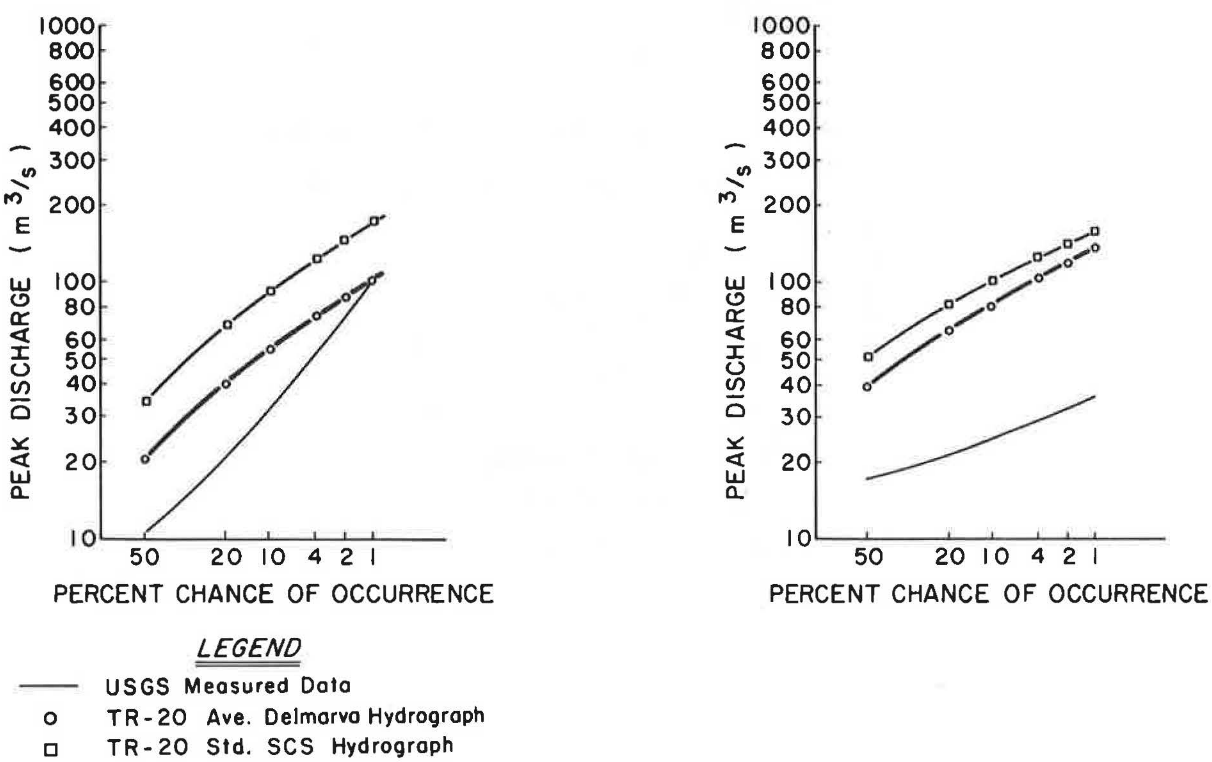

FIGURE 8 Peak flow frequency curves: *Left*, Morgan Creek; *right*, Pokomoke River.

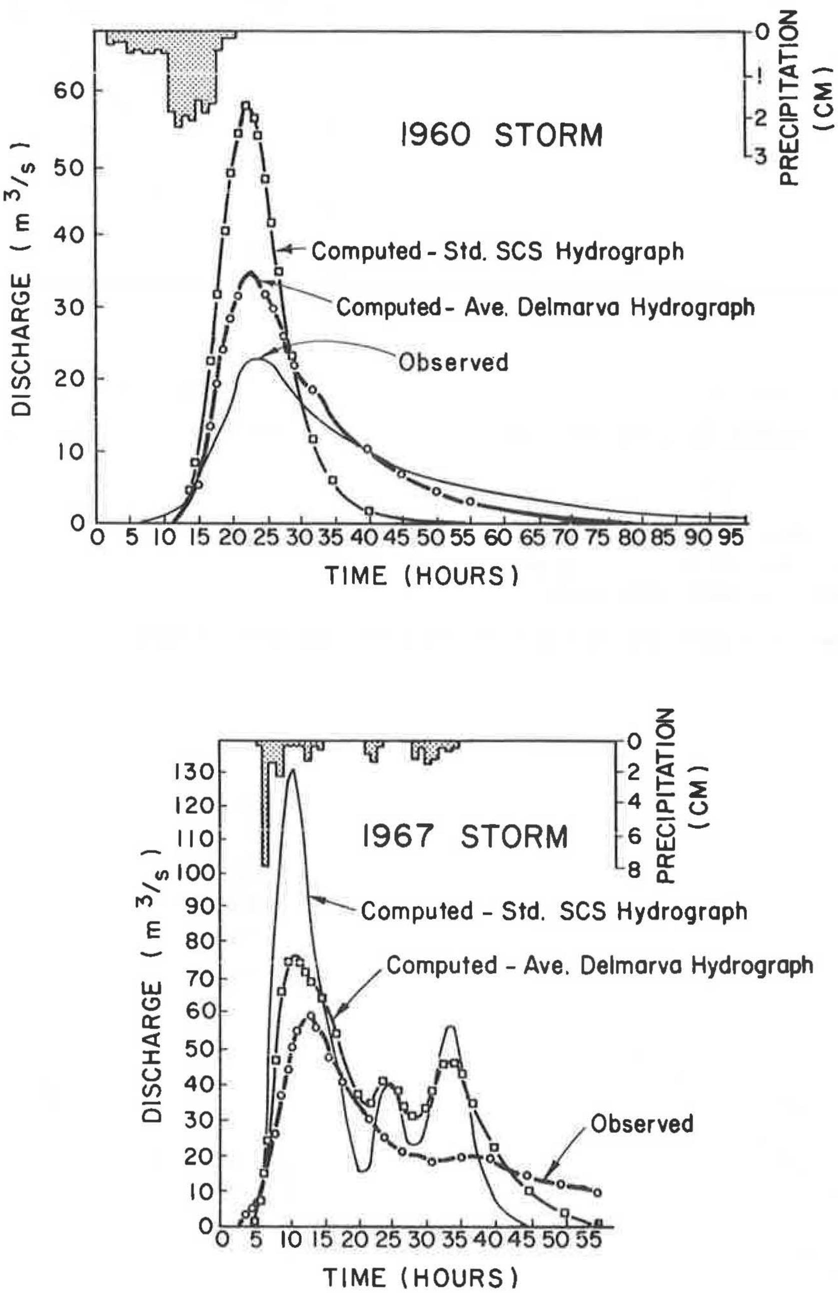

FIGURE 9 Actual storm hydrographs: Murderkill River.

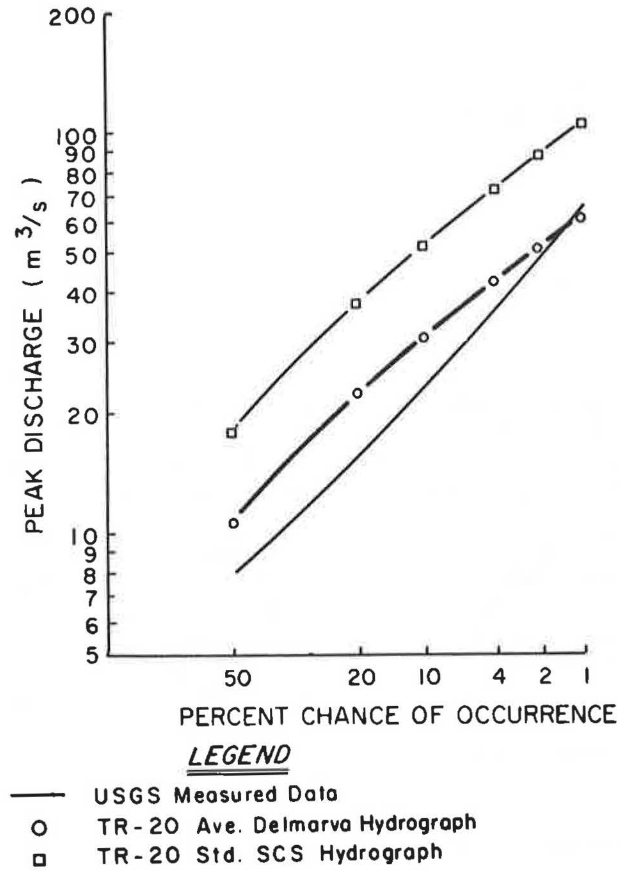

FIGURE 10 Peak flow frequency curves: Murderkill River.

the rising limbs of the time area curve and the dimensionless unit hydrograph are equal. Their conclusions are consistent with the conclusions of this paper: that a standard factor of 2.08 was too large for coastal watersheds.

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