TECHNIQUE FOR ESTIMATING MAGNITUDE AND FREQUENCY OF PEAK FLOWS IN DELAWARE

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ABSTRACT

A convenient and reliable technique for estimating flood magnitudes is required for effective flood-plain management and for the efficient design of bridges, culverts, embankments, and flood-protection structures. Methods are presented for estimating peak-flow magnitudes of selected frequencies, ranging from 2 to 500 years, for all non-tidal drainage basins in Delaware. The methods were developed by generalized least-squares regression techniques using data from 74 gaged basins in and near Delaware.

The State is divided into two hydrologic regions--the Piedmont region and the Coastal Plain region. These regions correspond to the physiographic provinces of the State. Sets of equations for calculating peak discharges based on physical basin characteristics are provided for each of the hydrologic regions.

Based on the peak-flow equations, methods for estimating peak flows are presented for ungaged and gaged streams in Delaware. The methods and equations are supported by generalized least-squares analysis of basin and flood-frequency characteristics data from 74 drainage basins in and near Delaware.

In the Piedmont region, peak-flow magnitudes are estimated using drainage area, forest cover, and a basin development factor. In the Coastal Plain region, peak-flow magnitudes are estimated using drainage area, soil types A and D, forest cover, and basin relief. Standard errors of estimate for the regression equations range from 20 to 38 percent in the Piedmont region, and 26 to 39 percent in the Coastal Plain region.

INTRODUCTION

A convenient and reliable technique for estimating the magnitude and frequency of peak flows is required for effective flood-plain management and for the efficient design of bridges, culverts, and embankments. One method for estimating floods relates peak-flow characteristics to basin characteristics such as **drainage area** [1] and **forest cover**. This method was developed and applied in Delaware by Simmons and Carpenter (1978) by use of flood data through September 30, 1976.

In the present report, the U.S. Geological Survey (USGS), in cooperation with the Delaware Department of Transportation (DelDOT), has revised and extended Simmons and Carpenter's work by using the best available methods to analyze streamflow data available through September 30, 1990. The report provides estimation equations and methods for estimating peak-flow frequencies for nontidal streams in Delaware.

Background

Techniques for estimating peak-flow frequencies for Delaware streams were previously presented in reports by Tice (1968) and Cushing, Kantrowitz, and Taylor (1973). The most recent technique for estimating peak-flow frequencies in Maryland was presented by Simmons and Carpenter (1978). The earlier reports had relatively fewer data to work with when compared to the Simmons and Carpenter study, especially with respect to drainage basins under 10 mi^2. The present report updates the flood-frequency estimation technique presented by Simmons and Carpenter by including 14 years of additional data and by using the most current available analytical methods.

Purpose and Scope

The purpose of this report is to provide equations, and methods of applying them, to estimate the magnitudes of peak flows of selected frequencies on streams in Delaware. The report provides the data used in developing the estimation equations and describes methods for using the equations to estimate peak-flow discharges with recurrence intervals of 2, 5, 10, 25, 50, 100, and 500 years.

This report presents the peak-flow characteristics and basin characteristics for 74 streamflow-gaging stations in Delaware, Maryland, and Pennsylvania. The peak-flow characteristics were computed by fitting annual peak-flow data to the log-Pearson Type III distribution. With the exception of the **basin development factor**, **hydrologic soil type A**, and **hydrologic soil type D**, all basin characteristics used in this report were retrieved from the Streamflow/Basin Characteristics File in the National Water Data Storage and Retrieval System (WATSTORE). However, standard map-measurement techniques will provide acceptable estimates of basin characteristics needed to use the methods presented in the report.

This report also provides regional peak-flow-estimation equations, which are based on generalized least-squares regressions of the peak-flow and basin characteristics data from 74 streamflow-gaging stations in and near Delaware. The equations provide hydrologists, engineers, and planners with a method to estimate peak-flow magnitudes for particular recurrence intervals at ungaged stream locations in Delaware. Additionally, this report presents methods and examples for determining peak-flow estimates for locations at, near, and between streamflow-gaging stations on gaged stream reaches.

The appendix presents the results of a gaging-station network analysis presenting one set of alternatives to the current streamflow-data-collection strategy.

Description of Study Area

Delaware lies between 38°27' and 39°51' north latitude and 75°04' and 75°48' west longitude (fig. 1). The State has an irregular shape that would fit on a rectangle 40 mi wide (east-west) by 95 mi long (north-south). The State has a total area, including land and inland water, of 1,978 mi^2.

Physiographic Setting

According to Fenneman (1938), Delaware has two major physiographic provinces--the Coastal Plain and the Piedmont. A brief description of each province follows:

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[1] Words in **bold** are defined in the Glossary.

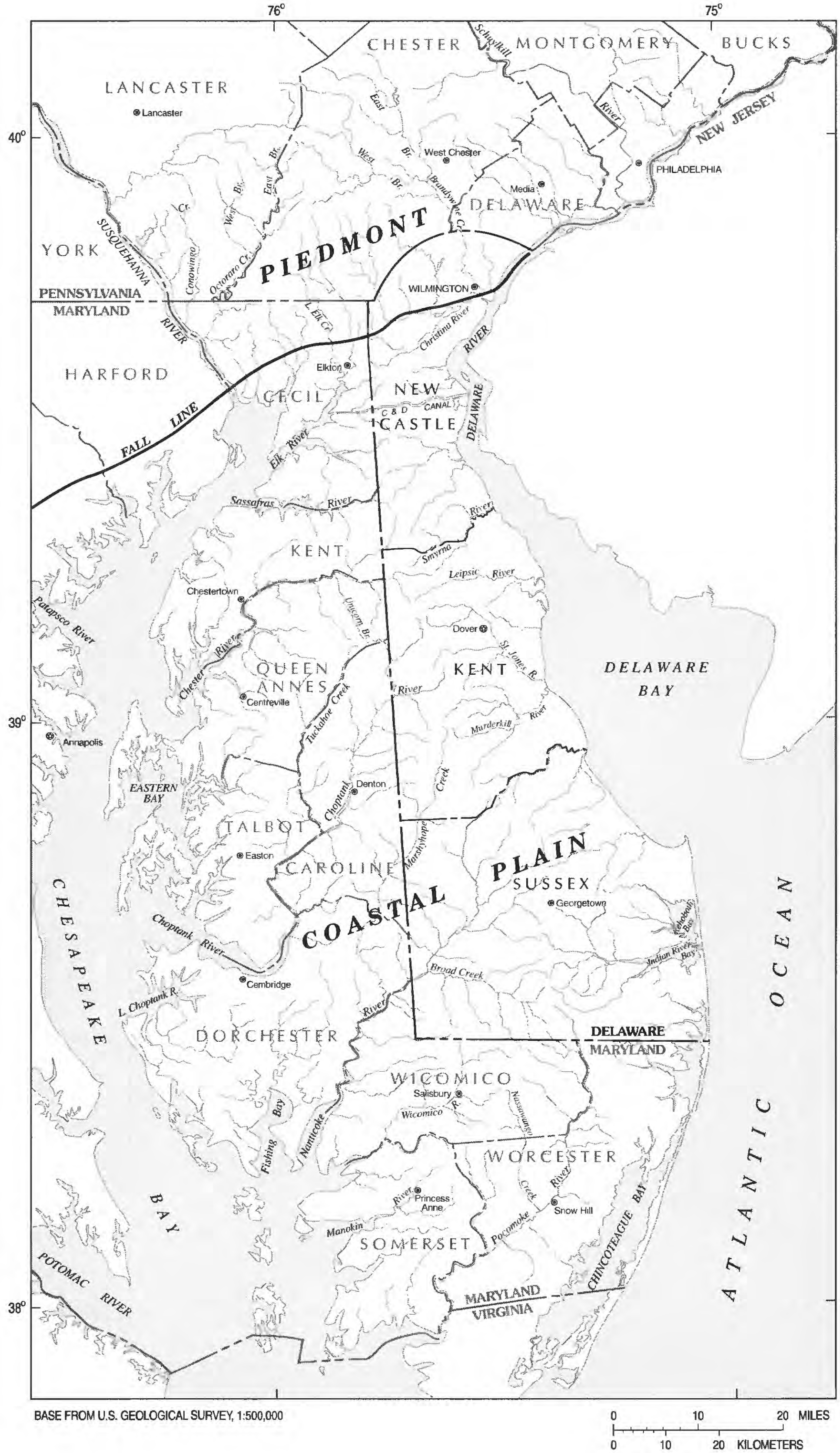

Figure 1. Study area and physiographic provinces in Delaware.

Piedmont

The Piedmont Province in Delaware, covering approximately 112 mi^2 , consists of gently rolling hills and ridges with elevations generally less than 400 ft above sea level. The province is bounded on the south by the **Fall Line**, and is drained by streams and rivers with fairly steep gradients. Streams in the Piedmont Province drain into the Delaware River.

Coastal Plain

The Coastal Plain Province is characterized by low relief, rising from sea level to slightly less than 100 ft above sea level, and is drained by small, sluggish streams. Streams and rivers in the Coastal Plain ultimately drain into the Delaware River, Delaware Bay, the Atlantic Ocean, or the Chesapeake Bay, and most are affected by tides for a considerable distance upstream from their outlets. The Coastal Plain Province in Delaware includes almost 1,866 mi^2, approximately 94 percent of the area of the State.

Acknowledgments

The Natural Resources Conservation Service is acknowledged for supplying all available natural soil group maps for the State of Delaware and surrounding parts of Maryland and Pennsylvania.

DATA COLLECTION AND ANALYSIS

Development of the technique for estimating peak-flow magnitudes for selected frequencies is based on generalized least-squares (GLS) regression analysis, which weights estimates according to the variance of observed peak-flow data at a site, and with regard to spatial correlations between streamflow-gaging-station sites. In preparation for GLS analysis, 74 streamflow-gaging stations were selected to provide the necessary basin and peak-flow characteristics data. On the basis of regression analysis and known variations in basin characteristics, two hydrologic study regions were identified, corresponding to the physiographic provinces as defined in figure 1. The distribution of streamflow-gaging stations in the hydrologic study regions is shown in figure 2. The number of stations that were chosen for inclusion in the regression analysis by hydrologic study region are listed in table 1. The following sections describe how these stations were selected, the method used to evaluate their peak-flow characteristics for various **recurrence intervals**, and the basin characteristics analyzed as potential explanatory variables.

Table 1. *Number of streamflow-gaging stations by hydrologic study region in Delaware and surrounding States*

Hydrologic study region	Number of gaging stations		
	Delaware	Maryland	Pennsylvania
Piedmont	12	7	18
Coastal Plain	21	16	0

Criteria for Station Selection

Three criteria were required for a gaged basin to be chosen and used in the regression analysis. The first criterion was that the basin had to be within the boundaries of the State of Delaware, or that the centroid of the basin had to be located within 25 mi of the State border. A summary of the number of stations and the average length of record, listed by size of drainage area, is shown in table 2. Estimates of peak flows from sites with longer periods of record have lower variances and receive greater weight in GLS analysis development of estimation equations. As in the Simmons

Table 2. *Summary of drainage area, number of streamflow-gaging stations, and average years of record used in regression analyses for Delaware*

Drainage area (square miles)	Number of gaging stations	Average years of observed record
0 - 1	5	10
1 - 2	6	11
2 - 5	13	19
5 - 10	21	24
10 - 20	7	25
20 - 50	12	33
50 - 100	7	38
100 - 200	1	43
200 - 500	2	58

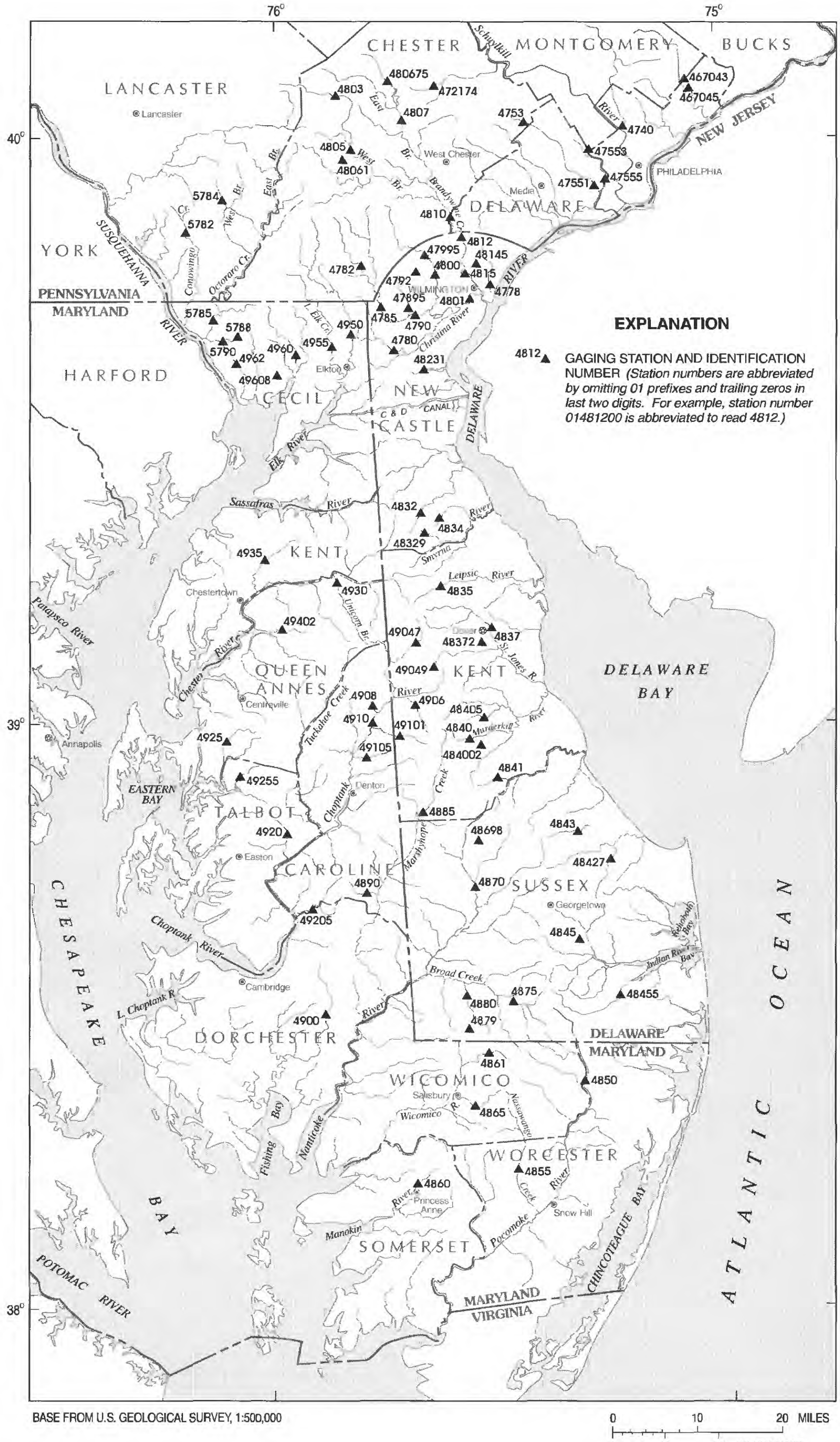

Figure 2. Location of streamflow-gaging stations in Delaware and surrounding States. (Modified from Simmons and Carpenter, 1978, Figure 1.)

and Carpenter study, the methods developed in this study are based on a broad range of drainage-basin sizes.

The second criterion for a gaged basin to be included in the analysis was that flow from the basin could not be significantly affected by either regulation or alteration of the hydrologic characteristics of the basin. Alterations in the drainage efficiency of a basin over time make the results of a peak-flow analysis for the basin less meaningful since peak-flow characteristics are determined by assuming constant basin conditions. Monotonic trends in the peak-flow records, which can indicate changing development conditions, were identified by **Kendall's tau** analysis (Helsel and Hirsch, 1992).

The third condition for a drainage basin of a stream to be included in the analysis was that the basin had to lie predominantly within a single physiographic province. This criterion was needed to avoid heterogeneity of basin characteristics caused by differences in physiography.

Application of these three criteria to the station-selection process produced a data set consisting of 74 gaging stations located in Delaware, Maryland, and Pennsylvania, which provided the necessary data for the GLS analysis. Of the 74 gaging stations used in the GLS analysis, 33 were located in Delaware, 23 in Maryland, and 18 in Pennsylvania (fig. 2).

Station Flood-Frequency Analysis

The peak-flow characteristics of each gaged basin chosen for use in the GLS analysis can be derived from the systematic record. This derivation is carried out by defining a peak-flow-frequency curve for each gaged basin to be used in the GLS analysis, as specified in "Guidelines for Determining Flood Flow Frequency" Bulletin 17B (U.S. Water Resources Council, 1981). The systematic records needed to perform peak-flow characteristic analysis for each gaged basin can be obtained from the Peak Flow File of the Water Data Storage and Retrieval System (WATSTORE) maintained at the USGS National Headquarters in Reston, Va., and are also available in the annual U.S. Geological Survey Water Resources Data reports issued for Delaware, Maryland, and Pennsylvania.

Peak-flow characteristics were determined for recurrence intervals of 2, 5, 10, 25, 50, 100, and 500 years for 74 gaged basins. These flow magnitudes were determined by fitting the log-Pearson Type III probability distribution to the observed annual peaks recorded at each station. The fitting procedure was carried out using the interactive USGS computer program ANNIE (Lumb, Kittle, and Flynn, 1990). The statistical parameters defining the distribution--(1) mean, (2) standard deviation, and (3) skew coefficient--were then used to determine the peak-flow characteristics for each gaged basin. In cases where historical flood information or outliers were encountered, adjustments were carried out in accordance with Bulletin 17B guidelines.

Deriving peak-flow characteristics by use of the methods described in Bulletin 17B is an example of an analysis where information about a statistical population (annual peak flows of a drainage basin) is inferred from the analysis of a sample (the systematic peak-flow record). Deriving the peak-flow characteristics associated with the systematic peak-flow record provides estimates of these characteristics for the entire population, not exact values. A major source of uncertainty in the case of peak-flow prediction is caused by the assumption that a station's systematic peak-flow record accurately represents the entire population of annual peak discharges at that site. This assumption introduces a time-sampling error into the analysis being performed. As previously mentioned, one advantage to using GLS regression analysis in this study is that it attempts to minimize the effect of time-sampling error by weighting the peak-flow records according to the length of systematic record available from each gaging station.

Explanatory Variable Identification

Based on the results of previous investigations, the following basin, stream, and precipitation characteristics were considered as potential explanatory variables for peak-flow prediction: (1) drainage area, (2) main channel slope, (3) **storage**, (4) forest cover, (5) 2-year, 24-hour precipitation, (6) mean annual precipitation, (7) average basin elevation, (8) gaging-station elevation, (9) **basin relief**, (10) soil type A, (11) soil type D, and (12) basin development factor.

GLS regression analysis of the selected data indicated that drainage area, forest cover, basin relief, basin development factor, and hydrologic soil types A and D were the variables most appropriate for use in the estimation equations for the two hydrologic study regions (table 3). With the exceptions of the hydrologic soil types and the basin development factor, the selected variables for each gaged basin used in the analysis were obtained from the Basin Characteristics File of the Water Data Storage and Retrieval System (WATSTORE). The procedures that can be used to determine hydrologic soil types and the basin development factor, as well as the other explanatory variables, are explained below. The user is referred to the Glossary section of this report for the definitions of each explanatory variable.

The hydrologic soil type coverage was derived from Natural Resources Conservation Service (Department of Agriculture) natural soil group maps interpreted for hydrologic soil types (Maryland Department of State Planning, 1973). These maps can be obtained by contacting any Natural Resources Conservation Service office. After determining the extent and location of soil types A and D within the selected basin, **planimeter** all of the basin subareas that exhibit soil type A and add up the areas. Divide the sum of the subarea totals by the total basin area and multiply by 100. This is the percentage of soil type A present in the basin. The percentage of soil type D is obtained using the same procedure for subareas exhibiting hydrologic soil type D.

The basin development factor can be determined by use of topographic maps and field inspection of the selected basin. After delineating the extent of the drainage basin on a topographic map of the area, divide the basin into upper, middle, and lower thirds such that each subarea contains approximately one-third of the total drainage area and the travel distance of streams in a given third are approximately equal. Note that this does not mean that travel distances of streams in different thirds of a basin are equal.

After delineating the basin and dividing it into thirds, the drainage system in each third of the basin must be evaluated in four categories: curb-and-gutter streets; storm drains (storm sewers); channel improvements; and channel linings. In performing the evaluations, a code 0 or 1 will be assigned to each category in each third of the basin. When all evaluations have been completed, the sum of all the assigned codes (a number between 0 and 12) is the value of the basin development factor. Codes are assigned as follows:

Curb-and-gutter streets.--If more than 50 percent of a basin-third subarea exhibits residential, commercial, or industrial development, individually or in combination, and if more than 50 percent of the roadways in the subarea exhibit curb-and-gutter construction, then a code 1 is assigned for that category in the subarea; otherwise, assign a code 0.

Storm drains (storm sewers).--If more than 50 percent of the secondary tributaries in a subarea exist as enclosed drainage structures, such as storm drains and storm sewers, then a code 1 is assigned to this category; otherwise, assign a code 0.

Channel improvements.--If more than 50 percent of the combined lengths of the main drainage channel and the principal tributaries exhibit improvement over natural conditions by means of straightening, enlarging, deepening and clearing, and(or) other means, then a code 1 is assigned to this category in the subarea; otherwise, assign a code 0.

Channel linings.--If more than 50 percent of the combined lengths of the main drainage channel and the principal tributaries have been lined with an impervious material, then a code 1 is assigned to this category in the subarea; otherwise, assign a code 0.

When each of the four drainage system categories has been evaluated for each third of the basin, the total of the assigned codes will be between 0 and 12. This sum is the value of the basin development factor for the entire basin.

Note that determination of drainage-system conditions should be made by field inspection when predictions are desired based on current conditions, but it is also possible to make predictions for future conditions. One example is predicting peak-flow magnitudes for future development conditions. In this case, variables such as forest cover (F) and basin development factor (BDF) could be determined from zoning maps or other planning documents.

Table 3. *Summary of statistics for variables used in regression analyses, by hydrologic study region in Delaware*

[mi^2, square mile; ft, feet; --, data not collected]

Hydrologic study region	Drainage area (mi^2)	Basin relief (ft)	Forest cover (percent)	Hydrologic soil type A (percent)	Hydrologic soil type D (percent)	Basin development factor	Storage (percent)
Piedmont	0.37 to 314	--	--	--	--	0 to 10	0.000 to 6.100
Coastal Plain	0.60 to 113	4 to 57	8 to 85	0 to 100	0 to 100	--	--

Drainage area should be planimetered from the best available topographic maps. Forest cover should be determined from the best available topographic maps as follows: Planimeter the area of the drainage basin covered by forests (shaded green on U.S. Geological Survey maps). Divide the resulting value by the drainage area and multiply by 100 to obtain a percentage value.

Basin relief can be calculated using the best available topographic maps with equally spaced grid lines superimposed over the drainage basin. Compute the arithmetic average of the elevations of 50 to 100 points within the basin at the intersections of the grid lines. Subtract the gage or outlet-point elevation from this value to obtain basin relief.

Using the procedures described above to determine values for the explanatory variables, the user can apply the following equations in order to estimate peak-flow magnitudes for various recurrence intervals.

METHODS FOR ESTIMATING MAGNITUDE AND FREQUENCY OF FLOODS

Methods developed using current analytical procedures are presented here for the estimation of flood magnitudes of selected frequencies in ungaged and gaged drainage basins. The methods presented are based, in part, on the following equations:

Piedmont region

$$Q_2 = 2.97 \times 10^5 A^{0.670}(13\text{-}BDF)^{-0.764}(ST+10)^{-2.36} \quad (1)$$

$$Q_5 = 6.88 \times 10^5 A^{0.607}(13\text{-}BDF)^{-0.548}(ST+10)^{-2.65} \quad (2)$$

$$Q_{10} = 1.08 \times 10^6 A^{0.570}(13\text{-}BDF)^{-0.398}(ST+10)^{-2.83} \quad (3)$$

$$Q_{25} = 1.73 \times 10^6 A^{0.531}(13\text{-}BDF)^{-0.223}(ST+10)^{-3.03} \quad (4)$$

$$Q_{50} = 2.33 \times 10^6 A^{0.507}(13\text{-}BDF)^{-0.105}(ST+10)^{-3.16} \quad (5)$$

$$Q_{100} = 3.05 \times 10^6 A^{0.485}(13\text{-}BDF)^{0.004}(ST+10)^{-3.27} \quad (6)$$

$$Q_{500} = 5.30 \times 10^6 A^{0.440}(13\text{-}BDF)^{0.237}(ST+10)^{-3.52} \quad (7)$$

Coastal Plain region

$$Q_2 = 134A^{0.549}(F+10)^{-0.662}(SA+10)^{-0.394}(SD+10)^{0.334}BR^{0.430} \quad (8)$$

$$Q_5 = 306A^{0.511}(F+10)^{-0.840}(SA+10)^{-0.424}(SD+10)^{0.392}BR^{0.552} \quad (9)$$

$$Q_{10} = 596A^{0.490}(F+10)^{-0.940}(SA+10)^{-0.438}(SD+10)^{0.409}BR^{0.584} \quad (10)$$

$$Q_{25} = 1{,}440A^{0.467}(F+10)^{-1.06}(SA+10)^{-0.447}(SD+10)^{0.418}BR^{0.593} \quad (11)$$

$$Q_{50} = 2{,}770A^{0.452}(F+10)^{-1.15}(SA+10)^{-0.446}(SD+10)^{0.422}BR^{0.590} \quad (12)$$

$$Q_{100} = 5{,}230A^{0.439}(F+10)^{-1.25}(SA+10)^{-0.439}(SD+10)^{0.425}BR^{0.584} \quad (13)$$

$$Q_{500} = 21{,}500A^{0.410}(F+10)^{-1.47}(SA+10)^{-0.411}(SD+10)^{0.428}BR^{0.564} \quad (14)$$

where

Q_2, Q_5,...,Q_{500} are the peak discharges for floods with recurrence intervals of 2 years, 5 years,..., 500 years;

A is the drainage area, in square miles;
BDF is the basin development factor, 0 to 12;
ST is the storage (lakes, ponds, and swamps), in percent;
F is the forest cover, in percent;
SA is the hydrologic soil type A, in percent;
SD is the hydrologic soil type D, in percent; and
BR is the basin relief, in feet.

Note that in the equations for the 100- and 500-year recurrence intervals for the Piedmont region, the exponent associated with BDF is positive. This does not mean that peak-flow values at these recurrence intervals can be decreased by increasing basin development. There is no statistically significant relation between BDF and flow for these recurrence intervals, so the exponents are not the result of physical relations between basin and peak-flow characteristics. However, BDF is included in all Piedmont region equations to maintain consistency within the equation set.

Flow values calculated by use of the equations are in units of cubic feet per second. Conversion to other measurement systems can be performed by applying the appropriate transformation factor to the equation result.

Magnitude Estimation Method for Ungaged Streams

Peak-discharge magnitude estimates can be made for ungaged streams within the hydrologic study regions shown in figure 1 using the preceding equations. The estimates obtained using the equations will be accurate within the limits given in the Accuracy and Limitations section if the input variables are measured or known with reasonable accuracy.

Demonstration of the Estimation Method for Ungaged Streams

The following example is presented to demonstrate the proper use of the estimation equations. An estimate of peak discharge for a site on any ungaged stream in Delaware can be obtained by following the procedure used in the example.

Problem 1: Estimate the 50-year discharge on Double Run at Road 105 east of Woodside, Del., 39°03'43" north latitude and 75°31'58" west longitude.

1. Determine in which region the drainage basin is located (fig.2) to determine which equation (1-14) should be used;

   Region: Coastal Plain region.

   Use equation 12. Drainage area, forest cover, basin relief, and hydrologic soil types A and D are required for use in this equation.

2. Determine drainage area. Outline the drainage basin above Road 105 on the best available topographic map(s) and use a planimeter to determine the area of the basin.

   $A = 2.25\ mi^2$.

3. Determine forest cover. On the topographic map(s), use a planimeter to determine the forested area within the drainage basin; express this number as a percentage of the drainage area.

   Forest cover area: $0.84\ mi^2$.

   $F = (0.84/A) \times 100 = (0.84/2.25) \times 100 = 37$ percent.

4. Determine basin relief. Select 50 to 100 evenly spaced points within the drainage basin using the grid method. Find the arithmetic average of the elevations of these points and subtract the elevation of the outlet point of the basin.

   Average basin elevation: 4,839/94 = 51 ft.

   BR = 51-31 = 20 ft.

5. Determine hydrologic soil types A and D. Locate the basin on plate(s) 1-3. Use a planimeter to determine the area of the basin exhibiting hydrologic soil type A. Also determine the area exhibiting hydrologic soil type D. Divide each of these areas by the total drainage basin area and multiply by 100.

Area exhibiting soil type A: $0.007\ mi^2$
Area exhibiting soil type D: $0.759\ mi^2$

$SA = (0.007/2.25) \times 100 = 0.3 = 0$ percent;
$SD = (0.759/2.25) \times 100 = 33.7 = 34$ percent.

6. Determine peak discharge. Using equation 12,

$$Q_{50} = 2{,}770A^{0.452}(F+10)^{-1.15}(SA+10)^{-0.446}(SD+10)^{0.422}BR^{0.590}.$$

By substitution,

$$Q_{50} = 2.770(2.25)^{0.452}(47)^{-1.15}(10)^{-0.446}(44)^{0.422}(20)^{0.590};$$

$$Q_{50} = 494 \text{ ft}^3/\text{s}.$$

The boundary between the Piedmont and Coastal Plain regions is not a drainage divide, so it is possible that a drainage basin may lie in both regions. When a basin lies in more than one region, the discharge for the basin is computed twice, as if the basin were entirely within each region. A weighted average discharge is then calculated--the weighting factors being the percentages of the total basin area falling in each region.

Sensitivity Analysis of Explanatory Variables

A certain amount of error is inherent in the determination of explanatory variable values, and occasionally the user of the estimation equation might be more interested in obtaining an approximate estimate immediately rather than taking the time to develop the best possible flow estimate. In either case, it would be helpful to know how much error is introduced into the prediction by use of an inexact variable value. So that the user may quantify the effect of measurement error, a method of determining the sensitivity of an estimation equation to variation in the values of its explanatory variables is presented.

After determining the region in which the site is located and which estimation equation is appropriate, the sensitivity of the equation to variations in the values of its variables can be determined as follows:

1. Make an estimate of the value of the variable of interest.
2. Multiply the estimate by the appropriate factor; if interested in the effect of increasing the variable's value by 10 percent, multiply by 1.1.
3. If necessary, add or subtract the prescribed constant from each value.
4. Raise the value to the exponent for that variable.
5. Divide the adjusted quantity by the quantity resulting from the original estimate.
6. Subtract one from the resulting ratio and multiply by 100.

The result of this procedure is the percentage of change in the result of the estimation equation because of a specified variation in the chosen variable's value. This procedure can be repeated for variations of any magnitude in the same variable and for other variables of interest in the same equation.

Caution should be used when estimating the value of a variable that will have a constant added or subtracted to it before being raised to the appropriate exponent. In these cases, the magnitude of the estimated value will affect the percentage of change calculated for the equation result. When dealing with a variable that does not have a constant added or subtracted before exponentiation, the estimated value of the variable does not matter, as long as it remains above zero.

For example, consider the drainage basin identified in Problem 1. Using equation 12, the 50-year recurrence-interval flow for that basin was estimated to be 494 ft ^{3}/s. This estimate was calculated using measured values of 2.25 mi^2 for drainage area, 37 percent for forest cover, 0 and 34 percent for hydrologic soil types A and D, respectively, and 20 ft for basin relief. To determine the effect of error in measuring these values, use the following procedure. (For example, finding the effect of a 10-percent overestimate of the area of the drainage basin.)

1. The original estimate of the drainage basin area is

   $A = 2.25$ mi^2

2. Increasing this value by 10 percent,

   $A = 1.1 \times 2.25 = 2.48$ mi^2.

3. No constant is added to this variable in equation 12.
4. $2.48^{0.452} = 1.51$.
5. $(2.48^{0.452})/(2.25^{0.452}) = 1.51/1.44 = 1.045$.
6. $(1.045-1) \times 100 = 4.5$ percent.

A 10-percent increase in the estimate of the drainage area results in an increase of 4.5 percent in the flow estimate, Q_{50} = 516 ft^3 /s. The effect of a 10-percent increase in the estimate of forest cover can be determined as follows.

1. Originally, F = 37 percent.
2. F = 1.1x37 = 40.7 = 41.
3. Add the constant indicated in equation 12, 41+10 = 51.
4. $51^{-1.15}$ = 0.0109.
5. $(51^{-1.15})/(47^{-1.15})$ = (0.0109/0.0119) = 0.910.
6. (0.910-1)x100 = -9.0 percent.

A 10-percent increase in the estimate of forest cover results in a decrease of 9.0 percent in the flow estimate, Q_{50}= 450 ft^3/s.

In this example, overestimating either drainage area or forest cover by 10 percent could have a significant impact on the peak-flow estimate. The sensitivity to error in the estimates of the other explanatory variables can also be calculated by following the general procedure described above. The procedure can be used to estimate the effect of any percentage of error in the measurement for any variable in any of the equations (1-14).

Accuracy and Limitations

One measure of the accuracy of the results of the estimation equations is called the standard error of estimate. The standard error of estimate is a measure of how well the estimated peak flows agree with actual peak flows. The standard error of estimate is derived from the model error, which measures the inability of the estimation equations to provide peak estimates that match observed peak records. Another measure of equation accuracy, the standard error of prediction, is derived from two quantities--the model error, and the sampling error, which is an estimate of the inability of the observed peak records to describe the actual peak-flow characteristics of a stream.

The standard errors of estimate and the standard errors of prediction for equations 1 through 14 are presented in table 4. The relation of observed and estimated flow values for the 100-year recurrence interval for the Piedmont region is shown in figure 3.

Table 4. *Standard errors of estimate and standard errors of prediction for estimation equations, by hydrologic study region in Delaware*

[Values are given in percent; standard errors of prediction are in parentheses]

Recurrence interval (years)	Standard errors, by hydrologic study region	
	Piedmont	Coastal Plain
2	21 (23)	39 (43)
5	20 (23)	36 (41)
10	21 (25)	33 (40)
25	24 (28)	30 (38)
50	27 (31)	29 (38)
100	30 (35)	27 (38)
500	38 (45)	26 (39)

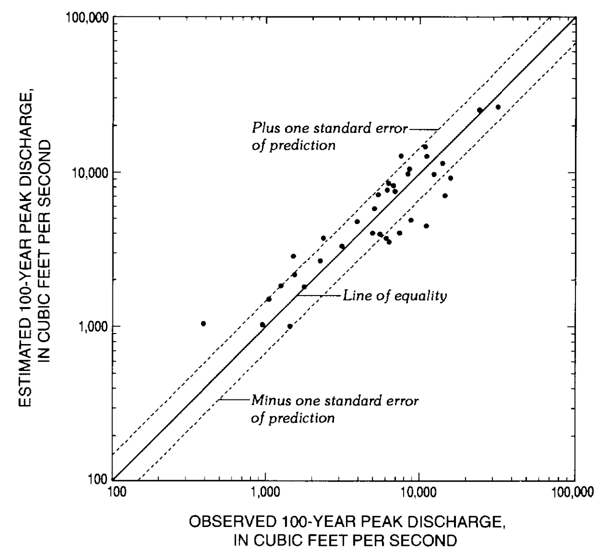

Figure 3. Relation of observed to estimated 100-year peak discharges for the Piedmont region in Delaware.

About 68 percent of the predicted values should fall within one standard error of the corresponding observed values if the data distribution is approximately normal. Likewise, about 95 percent of the data points should fall within two standard errors.

Another measure of the accuracy of the estimation equations is the equivalent years of record. The equivalent years of record is an estimate of the number of years of record needed at a given site to produce flood-magnitude estimates with an accuracy equal to that of the estimation equations. The equivalent years of record is derived from a relation between the standard error of estimate and the measure of variability of the observed flood-magnitude data used to develop the equations. The values of the equivalent years of record for the estimation equations are shown in table 5. Since the estimating capability available from 1 or 2 years of record is poor, the accuracy of a given estimation equation may be somewhat higher than indicated in cases where the equivalent years of record value is low, equal to 1 or 2 years. The concept of equivalent years of record as a measure of equation accuracy, however, is valid for longer periods of record.

A perspective of the magnitudes of recorded floods in and around Delaware is shown in figures 4a and 4b. These data are included to provide a perspective on the magnitude of peak flows that have occurred in the past. The data consist of a compilation of the most extreme floods recorded at the 74 gaging stations used in this analysis expressed in units of cubic feet per second per square mile. These data are available from the U.S. Geological Survey's Water Resources Data series.

In addition to knowing the accuracy that can be expected from the estimation equations, understanding some of the limitations that apply to their use is also important. The range of basin characteristics used to develop the estimation equations for each study region are listed in table 3. The standard errors of estimate presented as measures of accuracy are only valid for sites whose characteristics lie within the appropriate ranges. The estimation equations should not be used for sites having one or more characteristics that are outside the range(s) used to develop the equations. Also, the equations are not applicable at sites that are affected by (1) peak-flow regulation by dams;(2) tidal marshes; or (3) excavation, mining, or landfill activities.

Table 5. *Equivalent years of record for estimation equations, by hydrologic study region in Delaware*

Recurrence interval (years)	Equivalent years of record, by hydrologic study region	
	Piedmont	Coastal Plain
2	6	3
5	12	6
10	15	10
25	18	17
50	19	23
100	19	30
500	18	45

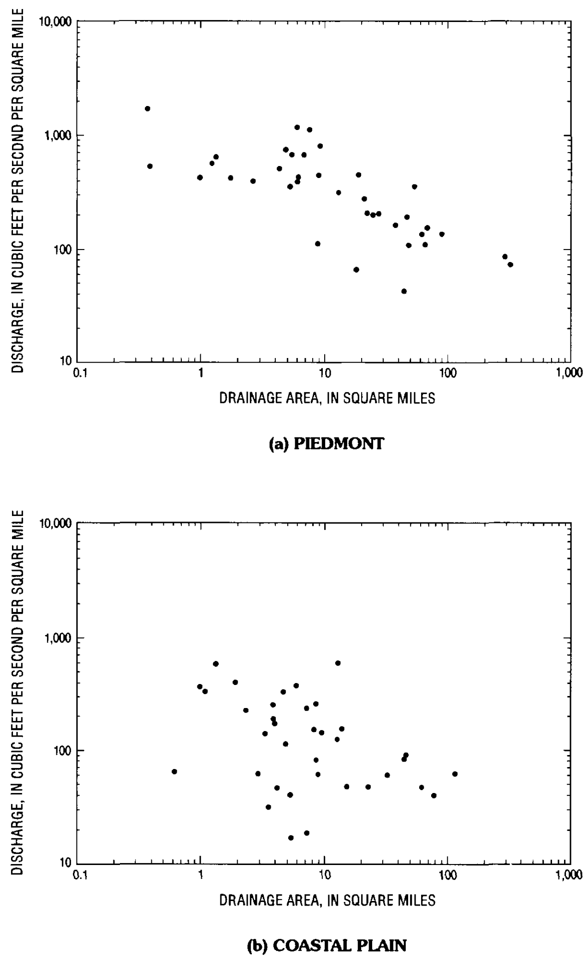

Figure 4. Relation of maximum unit discharge to drainage area for hydrologic regions: (a) Piedmont, and (b) Coastal Plain in Delaware and surrounding states.

Magnitude Estimation Method for Gaged Streams

The estimation equations can also be used to estimate peak flows at locations on gaged streams. Methods for making such estimates are presented in this section for instances when the selected site is at a gaged location, near a gaged location, and between two gaged locations.

Estimation Method for a Site at a Gaged Location

When a peak-flow estimate is needed at a gaged location, the estimate is derived from a weighted average of the flow obtained using an estimation equation and the flow obtained from analysis of the observed data. The weighting factors are the equivalent years of record associated with the estimation equation (table 5) and the years of record at the gaged location.

The discharge derived from the observed data can be obtained from table 6 (at end of report) for all stations used in the study, along with the number of years of record for each station. After retrieving the derived discharge and years of record for a selected site, computing the flow from the estimation equation, and finding the appropriate equivalent years of record, the following equation is used to obtain the peak-flow estimate at the site:

$$Q_w = \frac{Q_g N_g + Q_r N_r}{N_g + N_r} \qquad (15)$$

where

Q_w is the log of the weighted peak-flow estimate at the gaged location;
Q_g is the log of the discharge at the gaged location for the selected recurrence interval, derived from the observed data (table 6);
Q_r is the log of the discharge computed by using the estimation equation for the selected recurrence interval;
N_g is the number of years of record associated with the gaged location (table 6); and
N_r is the number of equivalent years of record for the selected estimation equation (table 5).

The following example demonstrates the application of the procedure just described:

Problem 2: Estimate the 100-year flood at streamflow-gaging station 01480100, Little Mill Creek at Elsmere, Del.

1. Obtain the discharge for a 100-year recurrence interval for Little Mill Creek at the gaged location from table 6;

$$Q_g = \log(7{,}310 \text{ ft}^3/\text{s}) = 3.8639.$$

2. Obtain drainage area, basin development factor, and storage from table 6;
   $A = 6.70 \text{ mi}^2$;
   $BDF = 5$;
   $ST = 0.164$ percent.

3. Compute the discharge for the 100-year recurrence interval at the gaged location using equation 6 (Piedmont region);

$$Q_{100} = 3.05 \times 10^6 \, A^{0.485} (13\text{-}BDF)^{0.004} (ST+10)^{-3.27}.$$

By substitution,

$$Q_{100} = 3.05 \times 10^6 (6.70)^{0.485} (8)^{0.004} (10.164)^{-3.27};$$

$$Q_{100} = 3{,}940 \text{ ft}^3/\text{s}.$$

$$Q_r = \log(Q_{100}) = \log(3{,}940 \text{ ft}^3/\text{s}) = 3.5955.$$

4. Obtain the number of observed years of record at the gaged location from table 6;

$$N_g = 18 \text{ years}.$$

5. Obtain the number of equivalent years of record for equation 6 from table 5;

$$N_r = 19 \text{ years}.$$

6. From equation 15, the weighted discharge at the gaged location is:

$$Q_w = \frac{Q_g N_g + Q_r N_r}{N_g + N_r}$$

By substitution,

$$Q_{w'} = \frac{(3.8639 \times 18) + (3.5955 \times 19)}{18 + 19}$$

$$Q_{w'} = 3.7261$$

The weighted peak-flow estimate is $10^{3.7261}$, which is 5,320 ft^3/s.

Estimation Method for a Site Near a Gaged Location

When a peak-flow estimate is required at an ungaged site, but the drainage area does not differ by more than 50 percent from that of a gaged location on the same stream, the following procedure is recommended for determining the estimate.

1. Use the procedure described in the previous section to obtain the weighted peak-flow estimate, $Q_{w'}$.

2. Determine the weighted average between the weighted peak-flow estimate, $Q_{w'}$, and the discharge, Q_r, calculated by using the estimation equation as follows:

$$R = \frac{Q_{w'}}{Q_r} \qquad (16)$$

where

R is the ratio of the weighted peak-flow estimate to the discharge calculated by using the estimation equation; and
$Q_{w'}$ and Q_r are as defined in the previous section.

The ratio R is then scaled, based on the difference in drainage area between the ungaged site and the gaged location, to apply to the selected ungaged site, by use of the following equation:

$$R_{w'} = R - \frac{2|A_g - A_u|}{A_g}(R-1) \qquad (17)$$

where

$R_{w'}$ is the ratio R scaled to account for the difference in drainage areas between the selected site and the gaged location on the same stream;
R is as defined in equation 16;
A_g is the drainage area at the nearby gaged location; and
A_u is the drainage area at the selected ungaged site.

3. Calculate the discharge at the ungaged site using the appropriate estimation equation by the procedure described in Problem 1. Using this computed discharge and the weighted ratio $R_{w'}$, the final weighted peak-flow estimate can be obtained from the following equation:

$$Q_f = R_{w'} \times Q_u \qquad (18)$$

where

Q_f is the log of the final weighted peak-flow estimate at the selected ungaged site on the gaged stream;
$R_{w'}$ is as defined in equation 17; and
Q_u is the log of the discharge at the selected ungaged site, calculated from the appropriate estimation equation.

If a peak-flow prediction is needed at an ungaged site on a gaged stream, but the drainage area of the selected site differs by more than 50 percent from that of the gaged location, the appropriate estimation equation should be used to obtain the estimate by the procedure used in Problem 1.

The following example demonstrates the application of the procedure just described.

Problem 3: Estimate the 100-year flood on Little Mill Creek at New Rd., Elsmere, Del., 39° 44' 17" north latitude and 75° 36' 29" west longitude.

1. Determine the drainage area associated with ungaged site;

$A = 3.55$ mi^2. Drainage area size is within 50 percent of the gaged drainage area,

$A_g = 6.70$ mi^2.

2. Obtain the logarithm of the discharge for a 100-year recurrence interval for Little Mill Creek at the gaged location, and the weighted discharge at the gaged location as in Problem 2;

$$Q_{r} = \log(3{,}940 \text{ ft}^3/\text{s}) = 3.5955;$$

$$Q_{w} = \log(5{,}320 \text{ ft}^3/\text{s}) = 3.7261.$$

3. Determine the ratio of the weighted discharge to the discharge from the estimation equation using equation 16;

$$R = 3.7261/3.5955 = 1.036.$$

4. Determine the weighted ratio using equation 17;

$$R_{w'} = 1.036 - [(2|6.70 - 3.55|)/6.70] \times (1.036 - 1);$$

$$R_{w'} = 1.002.$$

5. Obtain drainage area, basin development factor, and storage for the ungaged site using standard measurement methods;

$A = 3.55$ mi^2;
BDF = 3;
ST = 0.142 percent.

6. Compute the discharge for the 100-year recurrence interval at the ungaged site using equation 6 (Piedmont region);

$$Q_u = \log(3.05\text{x}10^6 A^{0.485}(13\text{-BDF})^{0.004}(\text{ST}+10)^{-3.27}).$$

By substitution,

$$Q_u = \log(3.05\text{x}10^6(3.55^{0.485})(10)^{0.004}(10.142)^{-3.27});$$

$$Q_u = \log(2{,}920 \text{ ft}^3/\text{s}) = 3.4654.$$

7. Determine the logarithm of the final weighted peak-flow estimate at the ungaged site using equation 18;

$$Q_f = 1.002 \times 3.4654 = 3.4723.$$

The final weighted peak-flow estimate is $10^{3.4723}$, which is 2,970 ft^3/s.

Estimation Method for a Site Between Gaged Locations

In the case where a peak-flow estimate is required for a site which is located between two gaged locations on a stream, the estimate may be obtained by use of the procedure presented for calculating estimates for a site at a gaged location with the following procedural alteration.

Since the site is ungaged, a direct determination of Q_g for the selected recurrence interval from the observed data is not possible. However, there are gaged locations upstream and downstream from the selected site. To obtain the interpolated value for Q_g for use in equation 15, use the following procedure:

1. On log paper, plot the peak-flow discharge for the selected recurrence interval against the drainage area (table 6) for the two adjacent gaged locations.

2. Draw a line between these two points and find the point on the line which corresponds to the drainage area associated with the selected site.

3. Determine the discharge associated with this point.

This discharge value may be used in equation 15 in place of Q_g.

The value for N_g is also not obtainable in this case. A value may be calculated, however, by finding an arithmetically weighted average of the periods of record for the upstream and downstream locations, using the difference in the two drainage areas as the weighting factor. The calculation can be made using the following equation:

$$N_g = \frac{N_{gd}|A_{gu} - A_u| + N_{gu}|A_{gd} - A_u|}{A_{gd} - A_{gu}} \qquad (19)$$

where

N_g and A_u are as previously defined;
N_{gd} is the number of years of record at the downstream gage location;
A_{gu} is the drainage area at the upstream gage location;
N_{gu} is the number of years of record at the upstream gage location; and
A_{gd} is the drainage area at the downstream gage location.

Once these values of Q_g and N_g have been calculated, the peak-flow estimate for the selected ungaged site may be obtained using equation 15.

SUMMARY AND CONCLUSIONS

This report presents a convenient and reliable technique for estimating peak-flow discharges for streams in Delaware. The State was divided into two study regions--the Piedmont and the Coastal Plain--based on its hydrologic characteristics. Analyses of basin characteristics and peak-flow data from 74 streamflow-gaging stations revealed that drainage area, forest cover, basin relief, basin development factor, and hydrologic soil types A and D are the explanatory variables that provide the best estimation equations for peak flow across the State.

The accuracy of the estimation equations is described by the standard error of estimate. For the equations presented in this report, the standard error of estimate ranges from 20 to 39 percent. Methods are presented that explain the use of the estimation equations with regard to sites on ungaged and gaged streams, and are valid for use in the estimation of peak-flow discharges throughout the State of Delaware, excepting those streams whose flow is significantly affected by tides or by other conditions as outlined in the Accuracy and Limitations section. Adherence to the guidelines set forth in the Accuracy and Limitations section will ensure satisfactory results from the equations within the appropriate standard errors of estimate.

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Table 6. *Basin characteristics and observed flood-frequency characteristics for selected streamflow-gaging stations in Delaware*

[mi^2, square miles; ft, feet; %, percent; -----, data not determined; * Flood-frequency data are weighted estimates based on observed ard synthetic flood-frequency curves; + Flood-frequency data based on flood-frequency curves derived from truncated observed record to elimin?te time trend; # Flood-frequency data adjusted for historical flood information]

Station no.	Years of record	Basin characteristics: Drainage area (mi^2)	Basin relief (ft)	Basin development factor	Storage (%)	Soil type A (%)	Soil type D (%)	Forest cover (%)
01467043	16	1.20	106	6	0.000	-----	-----	19
01467045	18	42.8	184	4	.000	-----	-----	7
01472174	16	5.98	160	0	.000	-----	-----	14
01474000	24	64.0	239	6	.000	-----	-----	11
01475300	18	5.15	117	2	.000	-----	-----	26
01475510	27	37.4	210	4	.000	-----	-----	18
01475530	17	4.78	205	6	.000	-----	-----	6
01475550	26	22.0	195	8	.000	-----	-----	3
01477800 +	45	7.46	253	6	.000	-----	-----	12
01478000	48	20.5	173	4	.070	-----	-----	19
01478200	31	12.7	261	0	.000	-----	-----	11
01478500	24	66.7	301	0	.073	-----	-----	19
01478950 *	7	6.04	219	2	.050	-----	-----	25
01479000	50	89.1	333	0	.090	-----	-----	23
01479200 *	10	4.19	141	3	.000	-----	-----	9
01479950 *	10	.38	167	0	.000	-----	-----	27
01480000	48	47.0	259	0	.822	-----	-----	18
01480100	18	6.70	105	5	.164	-----	-----	14
01480300	31	18.7	149	0	.000	-----	-----	18
01480500	30	45.8	355	0	.350	-----	-----	25
01480610	27	2.57	185	0	.000	-----	-----	23
01480675	24	8.57	160	0	6.100	-----	-----	27
01480680	12	17.8	260	0	3.030	-----	-----	30
01480700	25	60.6	258	0	.990	-----	-----	19
01481000	71	287	320	0	.160	-----	-----	45
01481200 *	10	.97	201	0	.310	-----	-----	43
01481450	10	.37	44	10	.000	-----	-----	11
01481500	44	314	401	0	.170	-----	-----	18
01482310 *	10	1.07	45	-----	-----	0	0	9
01483200 *	39	3.85	45	-----	-----	0	22	43
01483290 *	10	1.30	21	-----	-----	0	0	17
01483400 *	10	.60	18	-----	-----	0	0	26
01483500 *	33	9.35	43	-----	-----	0	25	21
01483700	33	31.9	43	-----	-----	0	31	46
01483720 *	10	2.3	27	-----	-----	0	0	20
01484000 #	28	13.6	35	-----	-----	25	54	35
01484002 *#	10	.97	25	-----	-----	100	0	28
01484050 *	9	3.29	31	-----	-----	0	0	16
01484100 *	33	2.83	17	-----	-----	41	59	45
01484270 *	15	6.10	33	-----	-----	90	5	57
01484300	22	7.08	35	-----	-----	93	3	54
01484500 *	48	5.24	21	-----	-----	26	74	51
01484550 *	15	8.78	25	-----	-----	2	98	46
01485000	41	60.5	30	-----	-----	2	97	30
01485500	41	44.9	34	-----	-----	8	83	85

Flood-frequency characteristics							
Peak discharge, in cubic feet per second, for indicated recurrence interval in years							Station no.
2	5	10	25	50	100	500	
280	471	623	844	1,030	1,230	1,790	01467043
2,770	3,990	4,920	6,230	7,310	8,470	11,700	01467045
640	1,310	1,930	2,920	3,820	4,890	8,080	01472174
3,710	4,660	5,300	6,150	6,800	7,450	9,110	01474000
658	1,030	1,310	1,690	2,000	2,330	3,180	01475300
2,870	4,210	5,160	6,400	7,360	8,340	10,800	01475510
770	1,470	2,160	3,390	4,610	6,180	11,700	01475530
2,530	3,590	4,330	5,300	6,060	6,840	8,770	01475550
1,860	3,150	4,360	6,400	8,390	10,900	19,100	01477800 +
1,770	2,590	3,200	4,020	4,680	5,370	7,170	01478000
1,040	1,750	2,350	3,270	4,090	5,030	7,770	01478200
3,000	4,600	5,860	7,700	9,250	11,000	15,800	01478500
844	1,650	2,340	3,420	4,370	5,460	8,580	01478950 *
3,660	5,250	6,430	8,060	9,390	10,800	14,600	01479000
550	970	1,340	1,920	2,450	3,070	4,960	01479200 *
43	81	121	196	276	383	796	01479950 *
2,180	3,080	3,740	4,650	5,380	6,170	8,230	01480000
931	1,720	2,510	3,740	5,410	7,310	14,200	01480100
1,290	2,690	4,200	7,080	10,200	14,400	30,700	01480300
1,810	3,340	4,770	7,150	9,430	12,200	21,300	01480500
350	654	924	1,360	1,750	2,220	3,640	01480610
241	432	600	869	1,120	1,410	2,310	01480675
648	848	988	1,180	1,320	1,480	1,870	01480680
3,140	5,260	7,090	9,980	12,600	15,700	25,000	01480700
6,660	10,200	12,900	17,000	20,400	24,200	35,000	01481000
100	208	321	526	741	1,030	2,090	01481200 *
240	366	471	629	770	930	1,410	01481450
7,320	11,500	15,100	20,700	25,800	31,900	50,200	01481500
141	266	374	544	695	869	1,380	01482310 *
134	275	408	631	842	1,100	1,910	01483200 *
143	258	371	568	767	1,020	1,920	01483290 *
24	36	47	66	85	108	192	01483400 *
223	461	697	1,100	1,520	2,040	3,820	01483500 *
474	824	1,100	1,500	1,830	2,180	3,140	01483700
158	296	425	643	852	1,110	1,950	01483720 *
289	565	803	1,170	1,500	1,870	2,940	01484000 #
18	29	40	60	79	105	198	01484002 *#
64	134	209	356	516	733	1,610	01484050 *
53	87	120	175	231	300	542	01484100 *
27	36	43	53	61	69	91	01484270 *
35	55	73	100	126	156	250	01484300
62	107	150	225	301	397	737	01484500 *
273	413	547	781	1,020	1,320	2,410	01484550 *
659	947	1,190	1,580	1,930	2,330	3,580	01485000
512	827	1,070	1,410	1,690	2,000	2,800	01485500

Table 6. *Basin characteristics and observed flood-frequency characteristics for selected streamflow-gaging stations in Delaware*---Continued

Station no.	Years of record	Basin characteristics: Drainage area (mi^2)	Basin relief (ft)	Basin development factor	Storage (%)	Soil type A (%)	Soil type D (%)	Forest cover (%)
01486000	40	4.80	17	-----	-----	0	98	57
01486100 *	10	4.1	20	-----	-----	6	74	77
01486980 *	10	5.28	12	-----	-----	0	58	68
01487000	47	75.4	36	-----	-----	5	24	40
01487900 *	9	3.47	4	-----	-----	0	89	44
01488500	45	43.9	28	-----	-----	0	100	29
01489000	41	7.10	29	-----	-----	0	49	33
01490000	30	15.0	18	-----	-----	5	39	50
01490600 *#	10	8.4	22	-----	-----	3	97	48
01490800	10	3.9	25	-----	-----	0	70	29
01491000	43	113	56	-----	-----	8	64	35
01491010 *#	10	1.9	16	-----	-----	3	97	28
01491050	10	3.8	17	-----	-----	2	36	25
01492000	32	5.85	53	-----	-----	8	20	26
01492050	11	8.4	39	-----	-----	0	13	23
01492500	30	8.09	44	-----	-----	0	21	32
01492550	11	4.6	41	-----	-----	4	20	14
01493000	42	22.3	57	-----	-----	3	40	43
01493500	40	12.7	45	-----	-----	1	9	8
01494000	13	12.5	51	-----	-----	0	42	24
01495000 #	59	52.6	329	0	.053	-----	-----	14
01495500	10	26.8	292	0	0.065	-----	-----	23
01496000	36	24.3	265	0	.094	-----	-----	22
01496080	10	1.7	174	0	.025	-----	-----	96
01496200	24	9.03	160	0	.019	-----	-----	17
01578200	27	8.71	190	0	.000	-----	-----	23
01578400	19	5.98	182	0	.000	-----	-----	22
01578800 *	10	1.3	78	0	.184	-----	-----	12
01579000 *	22	5.31	128	0	.077	-----	-----	22

Flood-frequency characteristics							
Peak discharge, in cubic feet per second, for indicated recurrence interval in years							Station no.
2	5	10	25	50	100	500	
131	232	317	445	556	682	1,040	01486000
90	144	192	272	347	439	743	01486100 *
41	59	74	97	117	141	212	01486980 *
567	1,010	1,420	2,090	2,730	3,510	6,010	01487000
77	108	142	204	272	370	746	01487900 *
881	1,700	2,380	3,410	4,300	5,290	8,030	01488500
241	563	885	1,440	1,990	2,660	4,830	01489000
225	361	471	633	771	925	1,360	01490000
208	356	491	715	931	1,190	2,070	01490600 *#
187	341	484	723	952	1,230	2,140	01490800
1,640	2,920	3,990	5,640	7,090	8,750	13,500	01491000
70	149	230	376	525	717	1,400	01491010 *#
74	179	311	606	972	1,530	4,180	01491050
266	532	807	1,310	1,840	2,530	5,070	01492000
96	197	307	519	752	1,070	2,340	01492050
216	469	732	1,210	1,710	2,350	4,630	01492500
126	278	459	838	1,290	1,940	4,820	01492550
294	507	676	921	1,130	1,350	1,950	01493000
363	793	1,270	2,180	3,190	4,570	9,960	01493500
463	827	1,170	1,740	2,300	3,000	5,300	01494000
2,790	4,720	6,370	8,940	11,200	13,900	21,900	01495000 #
1,690	2,520	3,240	4,380	5,410	6,640	10,400	01495500
1,500	2,360	3,050	4,100	5,020	6,060	9,050	01496000
277	494	679	965	1,220	1,510	2,360	01496080
1,100	2,190	3,220	4,960	6,640	8,690	15,400	01496200
496	921	1,340	2,100	2,870	3,870	7,420	01578200
612	1,270	2,000	3,440	5,040	7,270	16,200	01578400
364	556	725	1,030	1,340	1,750	3,210	01578800 *
720	1,350	1,980	3,130	4,350	6,000	12,200	01579000 *

GLOSSARY

Basin development factor: An index of development based upon improvements to the basin drainage system.

Basin relief: The difference between the gage or outlet point elevation and the average basin elevation, where all elevations are referenced to sea level.

Drainage area: The planar area of a drainage basin.

Fall Line. The line marking the point on each stream where the flow descends from the Piedmont to the Coastal Plain in Delaware.

Forest cover: The part of a drainage basin where land use is defined as forest.

Hydrologic soil type A: Soils having high infiltration rates even when thoroughly wetted.

Hydrologic soil type D: Soils having very slow infiltration rates when thoroughly wetted.

Kendall's tau. A measure of the strength of the monotonic relation between annual peak-flow values and their temporal position in the station record.

Planimeter. An instrument for measuring the area of a plane figure by tracing its boundary line.

Recurrence interval. The average number of years between occurrences of an annual peak flow greater than or equal to a specified magnitude.

Storage: The part of a drainage basin which exists as a lake, pond, or swamp.

APPENDIX

ANALYSIS OF THE STREAMFLOW-GAGING-STATION NETWORK

One measure of the accuracy of the estimation equations presented in this report is the standard error of prediction. The standard error of prediction associated with each estimation equation was presented in table 4. The smaller the standard error of prediction, the more accurate the results from an equation are expected to be. Therefore, it is a point of interest to determine how the standard error of prediction for equations in the various study regions may be reduced. One way of making this determination is by network analysis.

The standard error of prediction is directly dependent upon two types of error--model error and sampling error. Model error refers to the error that is present because of the inability of the current best set of explanatory variables in an equation to fully account for all factors affecting peak-flow discharge at a site. Sampling error refers to the inability of the observed flow data to define with complete accuracy the peak-flow discharge for a given recurrence interval at a site. The model error can be affected by using a different set of explanatory variables in an equation. The sampling error can be affected by the accuracy of the data collected, errors associated with auto-correlation and correlation with other gages, and the number and (or) location of gaging-station sites in the data set used to develop the estimation equation.

Since the analysis methods used in this study have already minimized the model error by choosing the set of explanatory variables on the basis of their statistical significance and utilizing them to develop the current estimation equations, it is not possible to predict further reductions in the model error using the methods and data available. However, by randomly specifying potential new gaging-station sites (fig. 5) and allowing the GLS analysis package to estimate the error associated with each site, it is possible to estimate the change that may occur in the sampling error because of changes in the number and location of gaging stations in operation.

According to Carpenter and others (1987), an analysis of the streamflow-gaging-station network of Delaware indicated that none of the active stations in the State should be considered for discontinuation. The analysis took a number of data-use classes into account, including regional hydrology, hydrologic systems, project operation, hydrologic forecasts, water-quality monitoring, and research, as well as other miscellaneous uses. The results of the network analysis conducted as part of this study indicate agreement with Carpenter's conclusions.

In order to determine if the standard error of prediction for each study region could be reduced appreciably, potential gaging-station sites were selected at random in each region. By constraining the analysis such that all gaging stations currently active in the network must remain active, and using a 10-year planning horizon, the following estimates were made.

In the Piedmont region, reductions in the average sampling error of 35 percent and 35 percent for the 2-year and 100-year recurrence-interval estimates, respectively, could be achieved by activating two of the potential gaging-station sites for the region. Because of the relative magnitudes of the sampling errors and the model errors in this region, however, the effect of the additional stations would be a reduction of 3.5 percent and 5.6 percent in the magnitudes of the standard error for the 2-year and 100-year recurrence-interval equations, respectively.

In the Coastal Plain region, reductions in the average sampling error of 51 percent and 48 percent for the 2-year and 100-year recurrence-interval estimates, respectively, could be achieved by activating four of the potential gaging-station sites for the region. The result of these alterations in the gaging-station network for this region would be to reduce the magnitude of the standard errors of prediction by 6.1 percent for the 2-year recurrence-interval equation, and by 16.2 percent for the 100-year recurrence-interval equation.

These estimates are based on the general statistical relations between sampling error and station location and length of record in flood-estimation applications, a set of potential

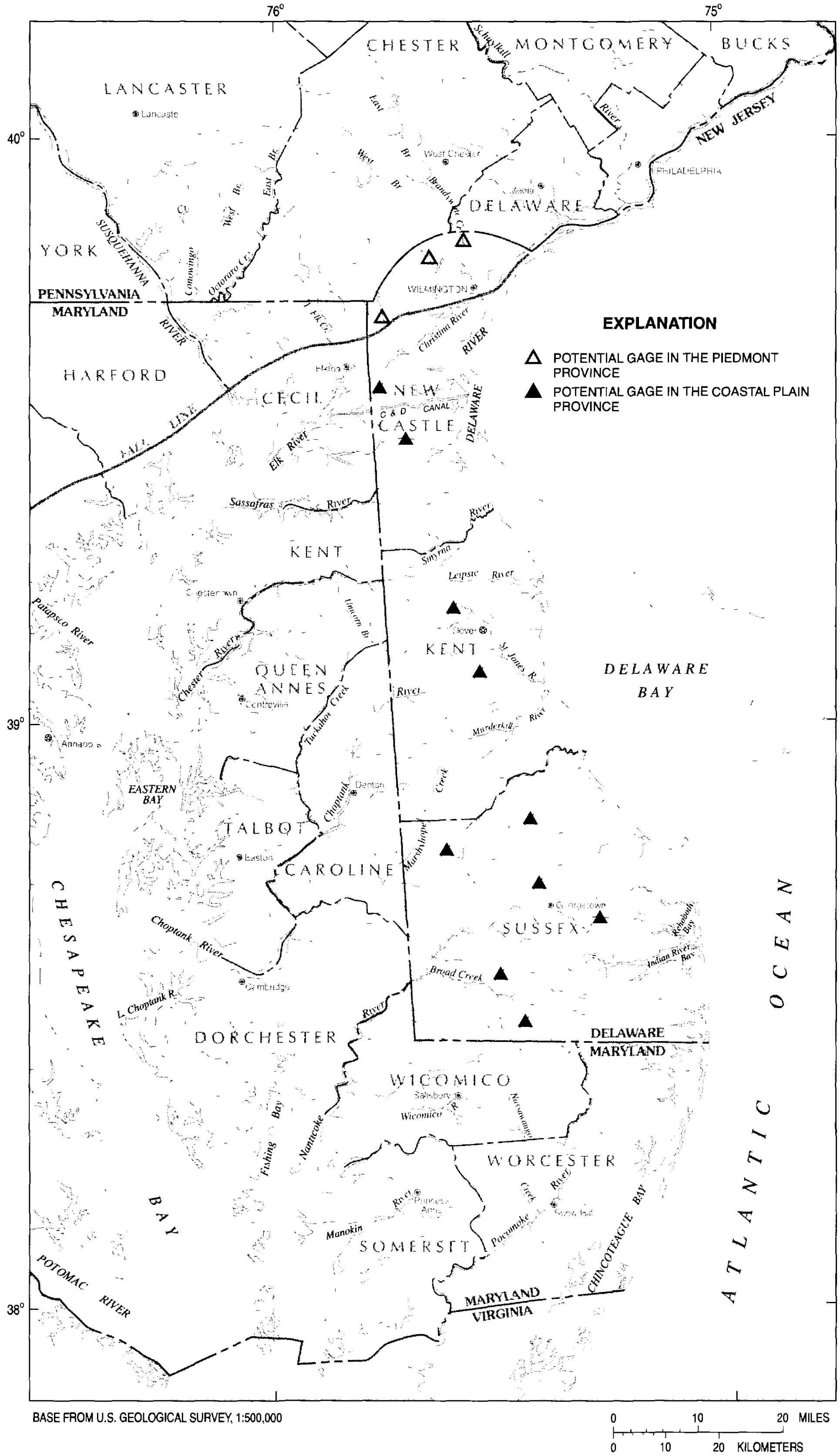

Figure 5. Location of potential gaging-station sites in Delaware.

gaging-station sites selected at random within each hydrologic study region by the author, an assumption of comparable gage-record accuracy, and estimated errors of auto-correlation and inter-correlation. The analysis assumed that the cost of operation was the same for all stations.

While the conclusions drawn from the data should, in theory, be similar, the results of network analyses for the various study regions would change to some extent if a different set of potential gaging-station sites were selected. Thus, what has been presented here is one of many possible interpretations using the data available, and further investigation in this area may be desirable. The results of this analysis indicate, however, that average sampling errors, and thus standard errors of prediction, for a region may be appreciably reduced by the addition of new gaging stations to the network.

CONVERSION FACTORS, ABBREVIATIONS, AND VERTICAL DATUM

Multiply	By	To obtain
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
cubic foot per second per square mile [$(ft^3/s)/mi^2$]	0.01093	cubic meter per second per square kilometer

Sea Level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929--a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level datum of 1929.