UNITED STATES

DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

EXCEEDANCE PROBABILITY - DEPTH RELATIONSHIPS OF FLOODS FOR MARYLAND STREAMS WEST OF CHESAPEAKE BAY

Open-File Report 78-171

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By W. J. Herb

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FOR MARYLAND STREAMS WEST OF CHESAPEAKE BAY

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ABSTRACT

A procedure is outlined for estimating the depths of floods of specified exceedance probabilities for Maryland streams west of the Chesapeake Bay. Data required for use of the estimating procedure are the stream's location in one of three flood-depth regions and the drainage area. Regression equations developed for depth estimation of the 50-, 20-, 10-, 2-, and 1-percent floods have standard errors of estimate of 19 to 25 percent for Region I, 22 to 36 percent for Region II, and 19 to 24 percent for Region III.

INTRODUCTION

Techniques are available which allow hydrologists or hydraulic engineers to estimate flood depths for a particular stream reach. The more commonly used technique requires an estimate of the selected flood magnitude. The flood depth is then computed by theoretical hydraulic principles. This traditional approach requires knowledge of the flood characteristics of the stream in order to estimate the magnitude of the flood discharge, a detailed onsite survey, and a series of complex office computations. This paper presents the results of a study which investigated a simple, low-cost alternative for flood-depth estimation which may be useful where considerations of human life or valuable property are not involved.

Conversion of Measurement Units

The following factors may be used to convert the U.S. customary units published in this report to metric units.

Multiply U.S. customary unit	By	To obtain metric unit
foot	0.3048	meter
square mile	2.590	square kilometer

METHOD OF STUDY

The relationship between flood depth and drainage area at selected exceedance probabilities was examined for 46 streams which had gaging station records at least 10 years in length. The streams are in the Ohio, Potomac, Susquehanna, Patapsco, Patuxent, Gunpowder, and St. Marys River basins. Gaging station locations are shown in figure 1.

Flood-frequency analyses were performed on annual peak discharges through the 1975 water year for gaging stations on the selected streams. Each gaging-station record was analyzed according to the U.S. Geological Survey's interpretation of the Water Resources Council's (1976) guidelines for determination of floodflow frequency.

Flood discharges, in cubic feet per second, at exceedance probabilities of 50, 20, 10, 2, and 1 percent were calculated for each gaging station. The 50-percent (0.5) flood has a 50-percent chance of being exceeded in a given year. The 20-percent (0.2) flood has a 20-percent chance of being exceeded in a given year. The 10-, 2-, and 1-percent floods are defined in a similar manner. The 50-, 20-, 10-, 2-, and 1-percent floods correspond to "recurrence intervals" or "T-year floods" of 2, 5, 10, 50, and 100 years, respectively. The stage corresponding to the selected flood-peak discharge was determined from the most recent rating table or curve (stage-discharge relationship). Because stage is referred to an arbitrary datum at each gaging station, rather than the streambed, it was necessary to develop a relationship between stage and flow depth.

Thomas (1964) defined the stage of the channel bottom by subtracting the average water depth at median flow (50-percent duration) from the median-flow stage. Median flows for the current Maryland investigation were taken from data presented by Walker (1971). Median-flow stages were determined from the most recent stage-discharge relation, and median-flow depths were averaged from recent discharge measurement notes. Bed stages were then determined by subtracting the average median-flow depths from the median-flow stages. Flood depths at selected exceedance probabilities (table 1) were calculated by subtracting the bed stage from the selected flood stage.

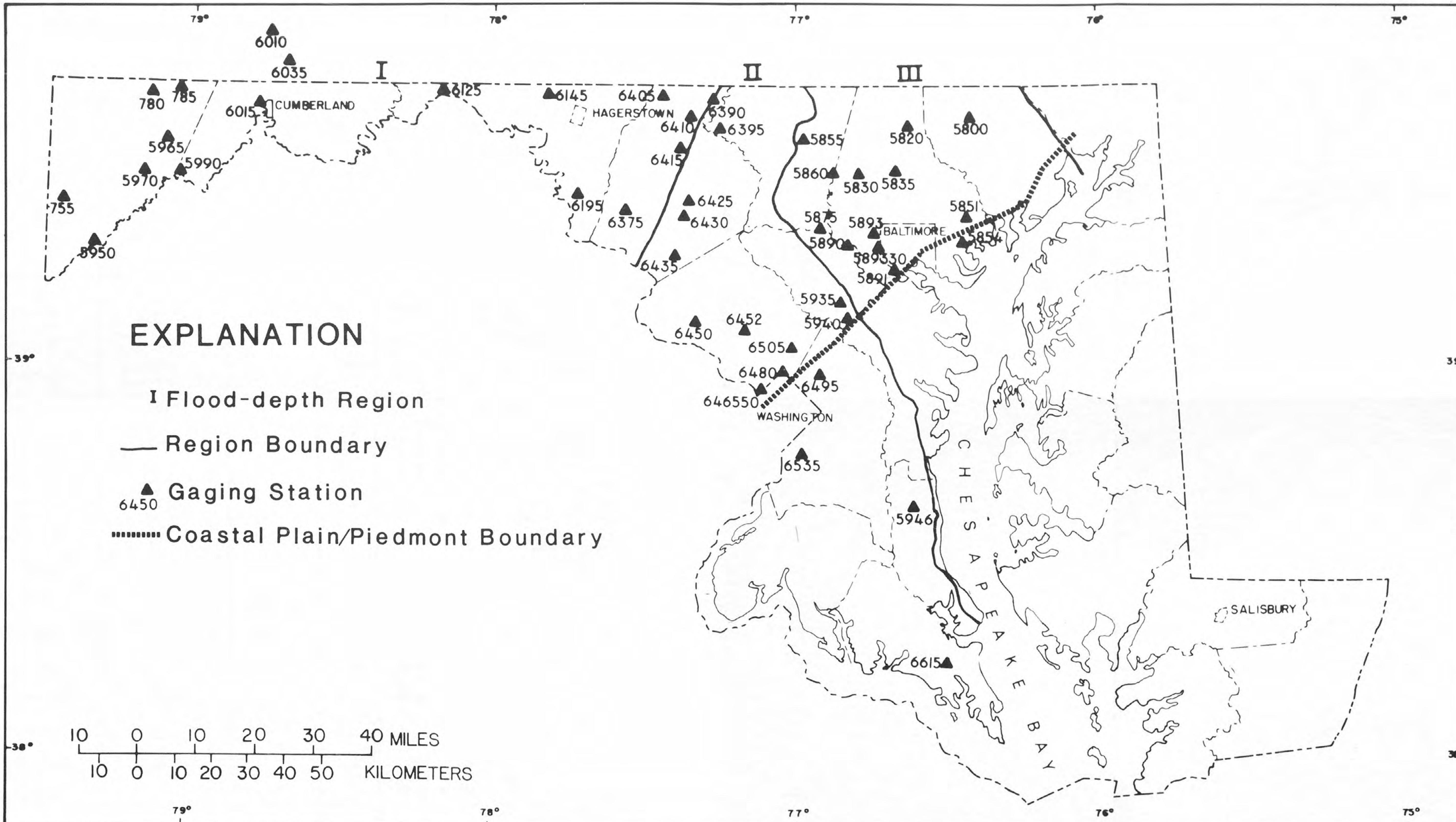

Figure I.-- Location of gaging stations and flood-depth region boundaries.

TABLE 1.--Drainage areas, regions, and flood depths at selected exceedance probabilities for streamflow stations used in this report.

Station No.	Drainage area (square miles)	Region	Exceedance probability (percent)				
			50	20	10	2	1
			Flood depths (feet)				
01580000	94.4	III	7.8	10.5	12.6	15.8	16.9
01582000	52.9	III	7.0	9.4	11.7	19.1	23.1
01583000	2.1	III	3.0	3.4	3.7	4.2	4.5
01583500	59.8	III	5.6	8.8	11.3	17.4	20.3
01585100	7.6	III	3.9	8.3	9.8	12.4	13.6
01585400	1.97	III	3.1	4.9	6.0	8.8	10.7
01585500	3.3	III	2.8	3.5	4.0	5.7	7.1
01586000	56.6	III	6.9	9.7	11.5	15.2	17.0
01587500	64.4	III	6.5	11.3	14.9	23.5	27.6
01589000	285	III	5.6	8.9	12.5	23.4	28.9
01589100	2.5	III	2.8	3.5	3.9	4.8	6.4
01589300	32.5	III	5.2	8.2	10.8	17.8	20.6
01589330	5.5	III	5.7	7.8	9.3	11.5	12.6
01593500	38.0	II	7.3	9.0	10.1	13.5	17.6
01594000	98.4	II	7.8	10.0	11.8	16.4	18.8
01594600	3.8	II	4.6	6.4	7.1	8.3	8.9
01595000	73.0	I	5.6	6.4	6.9	7.9	8.3
01596500	49.1	I	3.7	4.5	5.0	6.4	7.1
01597000	16.7	I	3.2	3.8	4.2	5.3	5.8
01599000	72.4	I	5.5	7.3	8.6	13.7	14.4
01601000	146	I	6.0	7.2	8.0	9.9	10.6
01601500	247	I	6.1	7.8	9.1	12.5	14.9

TABLE 1.--Drainage areas, regions, and flood depths at selected exceedance probabilities for streamflow stations used in this report--Continued.

Station No.	Drainage area (square miles)	Region	Exceedance probability (percent)				
			50	20	10	2	1
			Flood depths (feet)				
01603500	30.2	I	3.1	3.7	4.2	5.9	6.9
01612500	16.9	I	5.6	6.7	7.6	10.0	11.0
01614500	494	I	8.2	10.2	11.7	16.0	18.5
01619500	281	I	4.8	7.2	9.0	13.9	16.2
01637500	66.9	I	5.0	7.5	9.5	12.0	13.7
01639000	173	II	16.3	16.9	18.6	22.4	24.0
01639500	102	II	8.5	11.5	13.0	16.4	17.8
01640500	5.9	I	3.0	4.1	5.0	7.5	8.8
01641000	18.4	I	2.8	3.5	4.0	5.0	5.2
01641500	7.3	I	1.9	2.4	2.7	3.7	4.2
01642500	82.3	II	6.6	9.1	10.8	13.4	14.8
01643000	817	II	15.4	19.2	22.3	28.6	31.4
01643500	62.8	II	6.3	8.7	10.4	14.3	16.5
01645000	101	II	6.2	7.7	8.6	12.2	15.0
01645200	3.7	II	5.5	5.9	6.1	6.7	6.9
01646550	4.1	II	3.3	4.2	4.8	6.3	7.9
01648000	62.2	II	6.4	9.3	10.0	13.0	15.3
01649500	72.8	II	4.0	6.0	7.1	9.3	10.6
01650500	21.1	II	7.0	8.4	9.2	11.5	12.7
01653500	16.7	II	5.0	6.3	7.0	8.6	9.1
01661500	24.0	II	6.6	9.1	10.2	12.7	14.1

TABLE 1.--Drainage areas, regions, and flood depths at selected exceedance probabilities for streamflow stations used in this report--Continued.

Station No.	Drainage area (square miles)	Region	Exceedance probability (percent)				
			50	20	10	2	1
			Flood depths (feet)				
03075500	134	I	5.5	7.1	8.1	10.9	11.4
03078000	62.5	I	4.4	5.4	6.2	8.0	8.8
03078500	24.5	I	4.0	4.9	5.8	7.4	8.0

Regression of the flood depth for a 1-percent exceedance-probability flood on the log (base 10) of drainage area for all 46 streams produced the relationship:

$$d_1 = 6.63 \, (\log DA) + 3.29 \qquad (1)$$

where

d_1 is the depth of the 1-percent flood in feet above the streambed, and

DA is the drainage area in square miles.

The standard error of estimate for equation 1 is 37 percent.

Residuals (the differences between the actual flood depths and the flood depths computed from equation 1) were calculated for each of the 46 streams and plotted on a map. A definite geographic trend was apparent from this analysis. Flood depths for streams in the western part of the study area were overestimated, and for streams in the eastern part of the study area the flood depths were underestimated.

The above analysis, combined with a subsequent residual analysis, indicated that the study area should be divided into three flood-depth regions (fig. 1). This approach produced three sets of regression data. These sets contained data from 17 stations in Region I, 16 stations in Region II, and 13 stations in Region III.

The regressions of flood depth on the log of drainage area for the three separate regions produced a series of equations which are listed in table 2. The regression lines are shown graphically in figures 2, 3, and 4.

Note: An examination of residuals for Coastal Plain stations in Region II indicated that flood depths for these streams were considerably overestimated using figure 3 or table 2. Because there are too few Coastal Plain stations to develop a separate relationship, the depth determined from figure 2 should be reduced by 30 percent to provide more realistic estimates of Coastal Plain flood depths. This correction was determined by plotting Coastal Plain data points on a graph with the regression line, and selecting a reduction factor which would approximately center the regression line on the Coastal Plain data points. Because of this approximation, Coastal Plain flood-depth estimates are not considered as reliable as those for the remainder of the State. The Coastal Plain boundary is shown on figure 1.

TABLE 2.--Regression equations and standard errors of estimate for flood-depth prediction equations for Regions I, II, and III.

Equation	Standard error (percent)
Region I	
$d_{50} = 2.35 (\log DA) + 0.59$	21
$d_{20} = 3.11 (\log DA) + 0.47$	19
$d_{10} = 3.63 (\log DA) + 0.45$	20
$d_{2} = 4.96 (\log DA) + 0.68$	24
$d_{1} = 5.98 (\log DA) - 0.01$	25
Region II	
$d_{50} = 4.02 (\log DA) + 0.84$	36
$d_{20} = 4.88 (\log DA) + 1.37$	26
$d_{10} = 5.79 (\log DA) + 1.11$	25
$d_{2} = 7.75 (\log DA) + 0.88$	22
$d_{1} = 8.70 (\log DA) + 0.93$	22
Region III	
$d_{50} = 1.96 (\log DA) + 2.49$	24
$d_{20} = 3.22 (\log DA) + 3.56$	20
$d_{10} = 4.54 (\log DA) + 3.74$	19
$d_{2} = 8.82 (\log DA) + 3.57$	19
$d_{1} = 9.64 (\log DA) + 4.12$	21

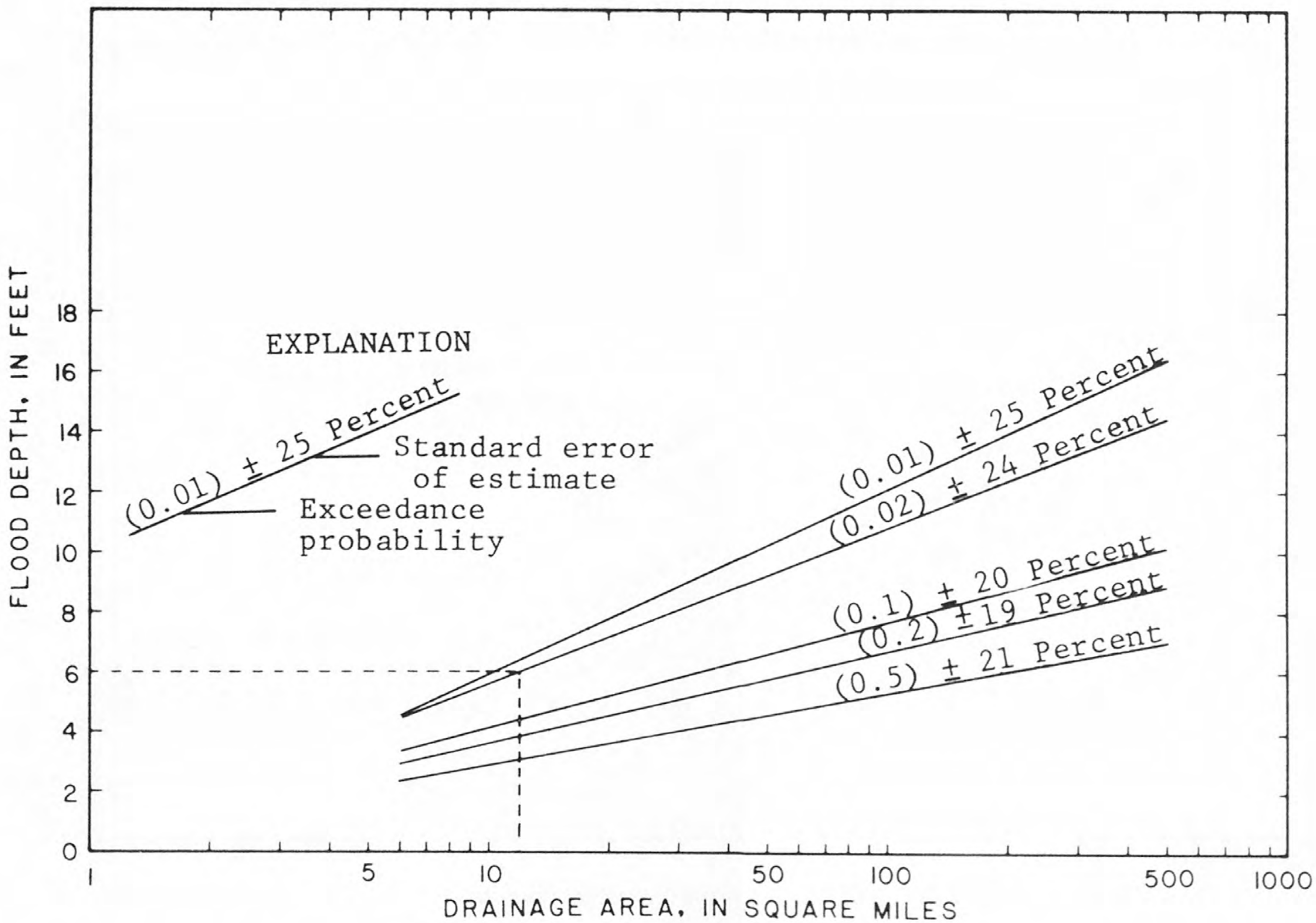

Figure 2.-- Depth of flood discharges of specified exceedance probabilities for various basin sizes in Region I.

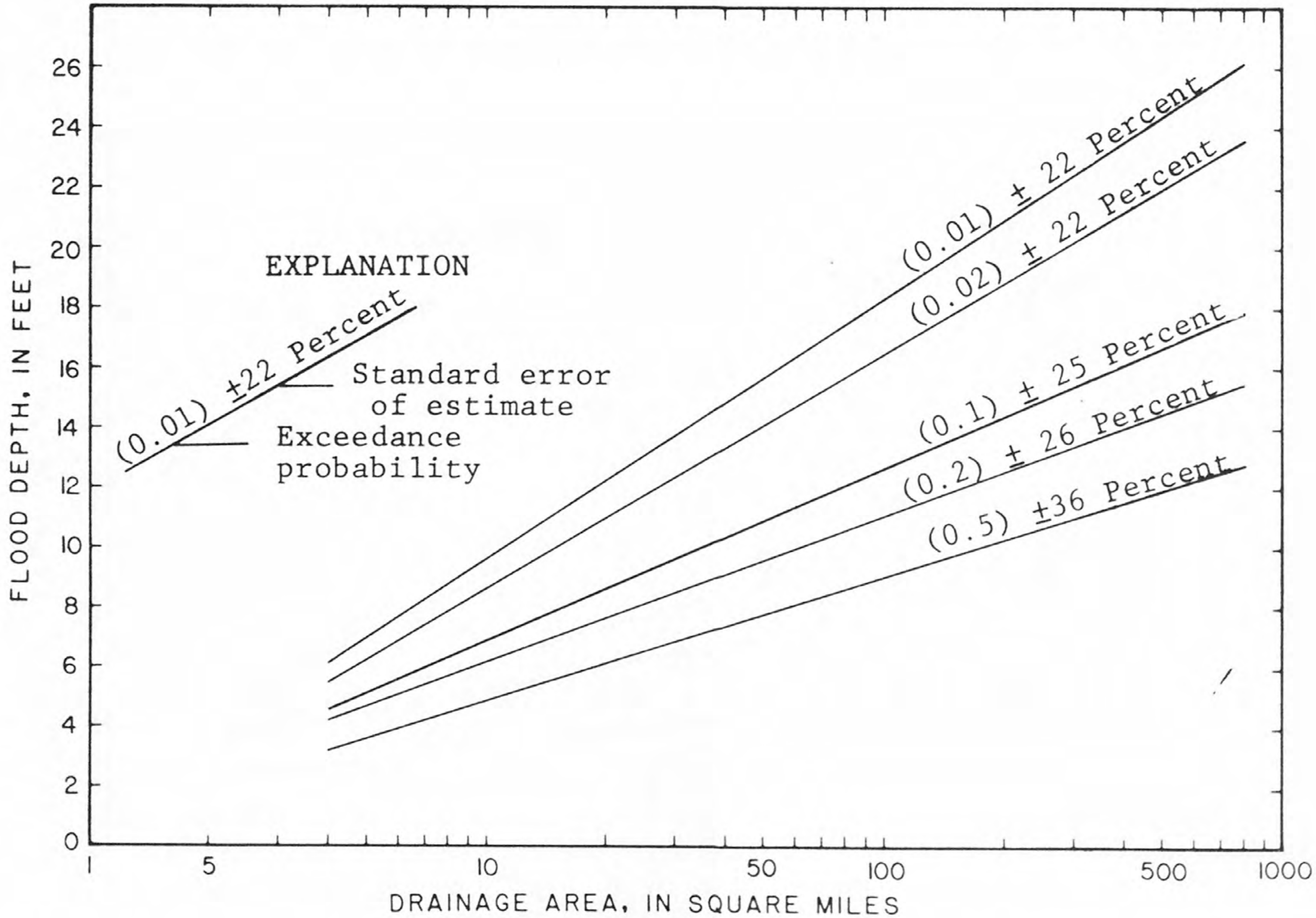

Figure 3.-- Depth of flood discharges of specified exceedance probabilities for various basin sizes in Region II .

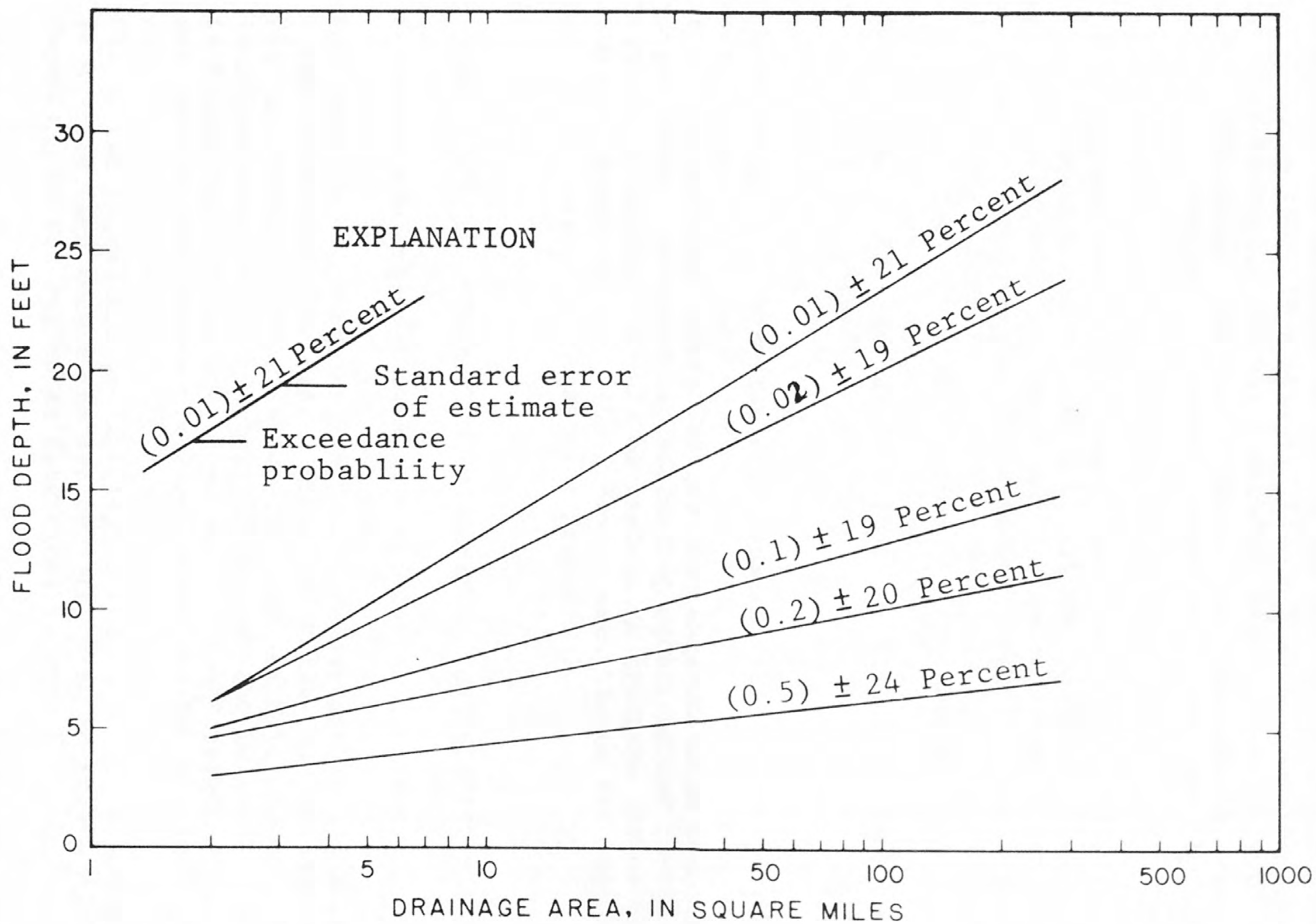

Figure 4.-- Depth of flood discharges of specified exceedance probabilities for various basin sizes in Region III.

Each regression line in figures 2, 3, and 4, and each regression equation in table 2 has an associated standard error of estimate. The standard error of estimate indicates the scatter of data points about the regression line. For example, figure 4 shows that the 2-percent flood depth in Region III has a standard error of estimate of ± 19 percent. This means that two-thirds of the flood depths used in the regression fall within 19 percent of the value indicated by the regression line.

Although the standard errors of estimate are relatively large for all exceedance-probability floods in all regions when using only drainage area in the regression analyses, the inclusion of additional variables did not significantly reduce the standard errors. Other parameters examined included channel width at median flow and channel cross-sectional area at median flow. A similar study in Virginia (Miller, 1977) demonstrated that the inclusion of main-channel slope, main-channel length, and percentage of forested area included with the drainage area in the regression did not significantly improve the 1-percent flood-depth estimate.

When using the regression equations in table 2, or the regression lines in figures 2, 3, and 4, the user is cautioned not to apply the relation with drainage areas outside the range of those established in the regressions. For example, estimating equations and curves for streams within Region I should be limited to drainage basins between 6 and 500 mi^2 (square miles). The drainage area limits for Region II are 4 to 800 mi^2 and are 2 to 300 mi^2 for Region III.

PROCEDURE FOR DETERMINING THE DEPTH OF THE SELECTED FLOOD

1. Determine the drainage area at the point of interest.

2. Determine in which region the point of interest lies. Region I, encompassing the Blue Ridge, Ridge and Valley, and Appalachian Plateau physiographic provinces, is west of U.S. Highway 15. Stream locations east of U.S. Highway 15 through the Patuxent River basin are in Region II. Stream locations east of the Patuxent River basin and west of the Susquehanna River or Chesapeake Bay are in Region III.

3. Choose the exceedance probability of the flood for which the depth is desired, and locate the appropriate curve in figure 2, 3, or 4 depending on the region as determined in step 2.

4. Using figure 2, 3, or 4, determine the flood depth that corresponds to the drainage area determined in step 1.

If the water surface elevation of the selected flood is desired, determine the average streambed elevation and add that value to the results of step 4.

DISCUSSION

Prior to the application of the estimating procedures presented in this report, some of the inherent limitations should be understood. The outlined procedures provide only estimates of the various flood depths. The variability of natural streamflow dictates that at times there will be wide departures from the computed relationships. Depths determined from the relationships given in table 2 and figures 2, 3, and 4 have a 50-percent chance of being too high and a 50-percent chance of being too low. The probability of underestimating the flood depth for the sample population can be reduced to about one in six by adding the proper regional standard error of estimate to the value determined from figures 2, 3, and 4 and using the total as the flood-depth estimate.

Because the relationships were developed for channel reaches in the vicinity of gaging stations, any attempt to estimate flood depths for unusually wide or narrow channel reaches will be subject to additional error. The selected relationships should not be used for estimating flood depths on streams whose peak flows are controlled by dams or ponds or streams where basin urbanization may have significantly increased the magnitude of the flood runoff for a chosen exceedance-probability flood.

Flood-depth data computed by the outlined procedures can be used to delineate potential flood-prone areas on topographic maps. Because most topographic maps are referred to a sea-level datum, it is usually necessary to relate the streambed elevation to sea level. The elevation (referred to sea level) of the streambed can be determined by leveling from a point of known elevation using standard surveying procedures, or by estimation from a topographic map. The elevation of the flood-water surface is determined by adding the chosen flood depth to the streambed elevation.

EXAMPLE

A rod-and-gun club has property bordering Cherry Creek in Garrett County, Maryland. The club members would like to build several small trout hatchery ponds along the stream, but are concerned about the possibility of flood damage. Therefore, the club is interested in knowing how far above the stream to locate the ponds.

1. An examination of topographic maps shows that Cherry Creek drains an area of about 12 mi^2 above the proposed hatchery site.

2. Because Garrett County is west of U.S. Highway 15, Cherry Creek is in flood-depth Region I.

3. The club members decide that they want to locate the ponds above the elevation of a flood with a 1 chance in 50 of being exceeded in a given year (2-percent flood).

4. Because Cherry Creek is in Region I, the use of figure 2 is required. A drainage area of 12 mi^2 was located on the horizontal scale of figure 2 and a vertical line was extended upward to intersect the 2-percent exceedance-probability line. From that point a horizontal line was extended to the left to intersect the vertical (depth) scale. The intersection with the depth scale shows 6.0 ft (feet) as the estimated depth of the 2-percent flood.

5. Therefore, the club members should build their ponds at least 6.0 ft above the average streambed elevation to have a 50-50 chance of avoiding a flood with an exceedance probability of 2 percent. However, the members are cautious and to increase their chances of avoiding the 2-percent flood, they follow the procedure outlined in the discussion and increase the flood-depth estimate by 24 percent (the standard error of estimate) to arrive at a new flood depth estimate of 7.4 ft. Constructing the ponds 7.4 ft above the bed elevation should give the club a 5 to 1 chance of avoiding a 2-percent flood.

CONCLUSIONS

Residual analysis indicates that there are three flood-depth regions in Maryland west of the Chesapeake Bay. Each region has unique relationships between drainage area and flood depths at selected exceedance probabilities. Regression equations defining these relationships have standard errors of estimate ranging from 19 percent to 36 percent. The procedures used in this investigation and outlined in this report should provide adequate low-cost estimates of the depths of floods at specified exceedance probabilities when used within the specified limitations.

SELECTED REFERENCES

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