TECHNIQUES FOR ESTIMATING FLOOD-DEPTH FREQUENCY RELATIONS FOR STREAMS IN WEST VIRGINIA

By J. B. Wiley

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CONVERSION FACTORS AND ABBREVIATIONS

Readers who prefer to use metric (International System) units rather than inch-pound units in this report can make conversions using the following factors:

Multiply inch-pound unit	By	To obtain metric unit
Foot (ft)	0.3048	Meter (m)
Square mile (mi^2)	2.590	Square kilometer (km^2)

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

DEFINITION OF TERMS

Baseline depth: The difference between river stages at the point of zero flow and at the 50-percent flow duration.

Flood depth: The difference between river stages at the 50-percent flow duration and at the flood-flow frequency.

Mean basin elevation: Determined by placing a transparent grid over the drainage area outlined on a topographic map. A uniform grid size such that 20 to 80 grid intersections fall within the basin boundary is needed. Mean basin elevation is the arithmetic mean ground elevation determined at all of the grid intersections that fall within the basin.

Natural control: A rock ledge outcrop or relatively stable riffle or gravel bar found on a streambed and controls streamflow.

Point of zero flow: The lowest measurable elevation on a streambed that controls flow. In this report, the lowest measurable point at a naturally occurring control is used.

TECHNIQUES FOR ESTIMATING

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ABSTRACT

Multiple-regression analyses are applied to data from 119 U.S. Geological Survey streamflow stations to develop equations that estimate baseline depth (depth of 50-percent flow duration) and 100-year flood depth on unregulated streams in West Virginia. Drainage basin characteristics determined from the 100-year flood-depth analysis were used to develop 2-, 10-, 25-, 50-, and 500-year regional flood-depth equations. Two regions with distinct baseline-depth equations and three regions with distinct flood-depth equations are delineated. Drainage area is the most significant independent variable found in the analysis except for flood-depth determinations in the central and northern areas of the state where mean basin elevation also is significant. The equations are applicable to any unregulated site in West Virginia where values of independent variables are within the range evaluated for the region. Examples of inapplicable sites include those in reaches below dams, within and directly upstream from bridge or culvert constrictions, within encroached reaches, in karst areas, and where streams flow through lakes or swamps.

INTRODUCTION

Many engineering projects are located within or adjacent to flood-hazard areas. Some examples are bridge and highway construction, building of industrial and private dwellings, flood-dike projects, and flood-prone area mapping. Hydrologic and hydraulic analyses, including extensive river basin surveys and complex hydrographic computations, are required for some projects. However, many of these projects could use a less detailed and less costly method of analysis, such as regionalized equations for estimating flood depths of selected return intervals.

The U.S. Geological Survey, in cooperation with the West Virginia Department of Highways, has developed a method for estimating flood-depth frequency relations for ungaged stream sites in West Virginia. Basin characteristics and streamflow data are regressed to regionalize and develop estimating equations. This report presents procedures, equations, and graphical solutions to estimate 2-, 10-, 25-, 50-, 100- and 500-year flood depths applicable on unregulated streams in West Virginia.

The relation between stream depth and streamflow will change as flow overtops the main channel (bankfull) and encroaches the floodplain. "Bankfull" flows normally occur at a nearly constant flood frequency within a specific hydrologic region. In order to define flood-depth regions, which may be different from flood-flow regions, regional differences in "bankfull" depth must be apparent. The "bankfull" depth above the point of zero flow varies throughout a region partially because of irregular geometries of natural low-water controls. The effect of these irregular geometries within a region can be reduced by referencing depth to a specific water surface. The water surface for the 50-percent flow duration was used in this study. The depth corresponding to this flow above the point of zero flow is referred to as baseline depth (figure 1). The flood depth is the depth between baseline and the flood water surface (flood elevation).

DATA SELECTION

Three U.S. Geological Survey streamflow stations in Ohio and 116 in West Virginia were selected for this study (fig. 2). All streamflow stations met the following selection criteria: (1) a minimum of 5 years of continuous streamflow record, (2) no significant streamflow regulation, and (3) a well-defined stage-discharge relation. A record length of 10 years is desired, but sufficient numbers of small drainages with this record length were not available.

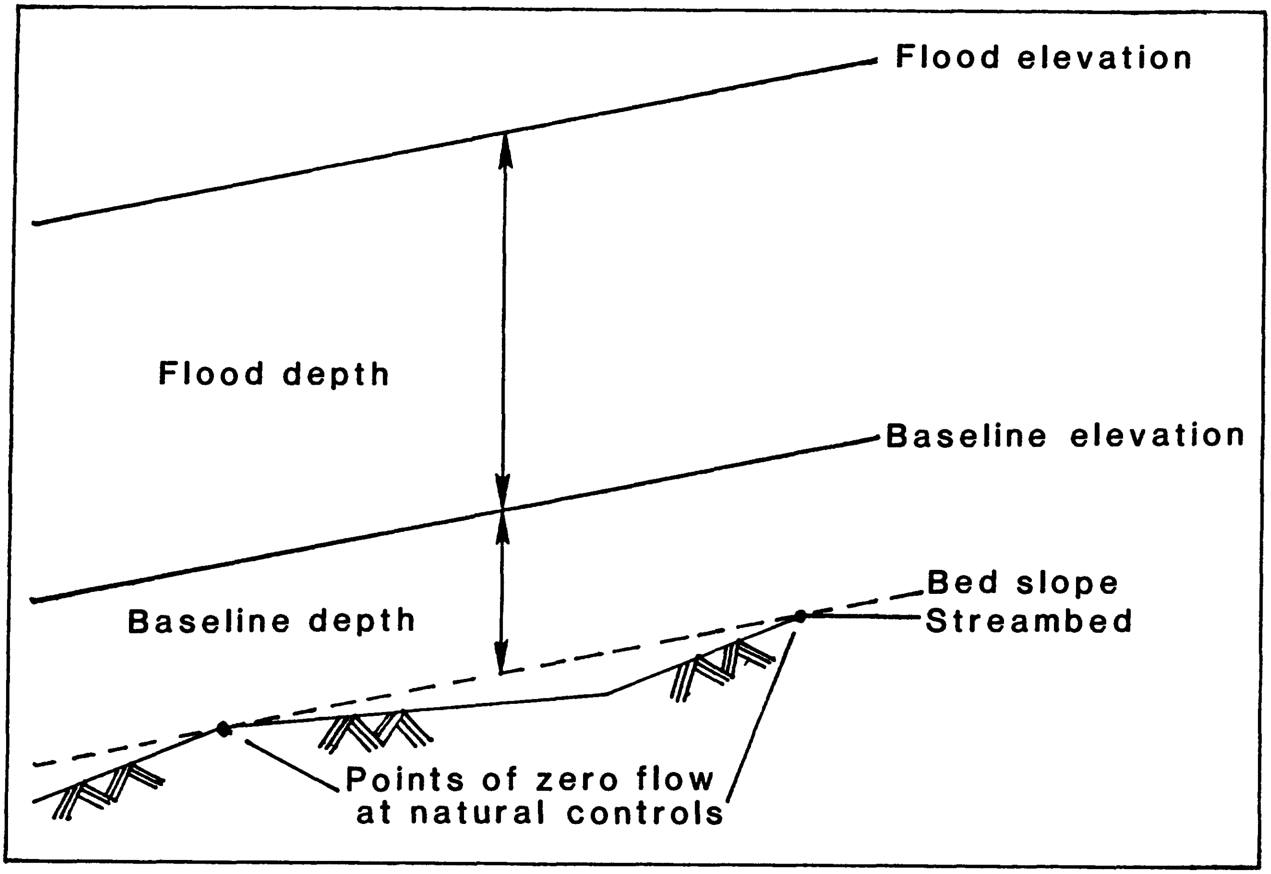

Figure 1.--Relations among point of zero flow, baseline depth, and flood depth.

Basin characteristics for stations were obtained from the Basin Characteristics File of the U.S. Geological Survey's National Water Data Storage and Retrieval System (WATSTORE). Basin-characteristic data include: (1) drainage area, (2) main channel slope, (3) stream length, (4) mean basin elevation above sea level, (5) forest cover, (6) 50-percent flow duration, and (7) 2-, 10-, 25-, 50-, 100-, and 500-year flood-flow frequencies.

Stage data were obtained from streamflow-station stage-discharge curves. Flow depths were determined for (1) the 50-percent flow duration, (2) 2-, 10-, 25-, 50-, 100-, and 500-year flood-flow frequencies, and (3) the point of zero flow.

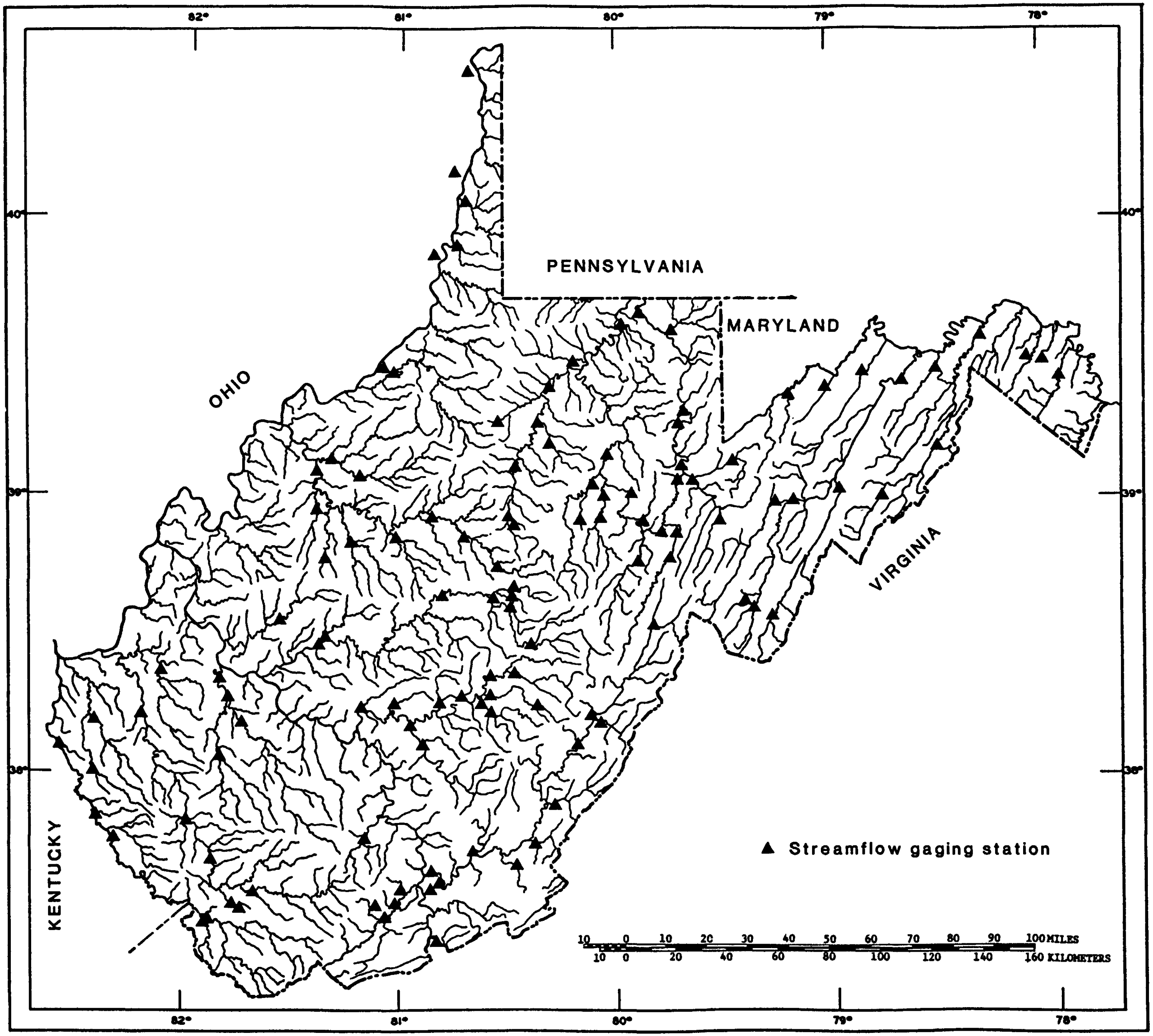

Figure 2.--Location of selected streamflow stations in West Virginia.

DEVELOPMENT OF EQUATIONS FOR ESTIMATING FLOOD DEPTHS

Regionalized equations are developed for estimating baseline depth and 100-year flood depth. Equation development follows methods described by Riggs (1973) and uses SAS[1] correlation (CORR) and general linear model (GLM) procedures (SAS Institute, Inc., 1982). The following steps were followed to develop regional equations:

1. Correlation analysis, data plots, and transformed data plots were used to identify independent variables to consider for regression.

2. Multiple linear regression techniques were used to develop an equation; only those independent variables that significantly increased the coefficient of determination (R^2) and reduced the standard error of estimates were included.

3. Regression residuals from the equation were plotted on an area map. The plot was examined for grouping on the basis of the magnitude of residuals. Considering the residual groups, geology, and topography regional boundaries were constructed. Each region was then analyzed by the procedures outlined in steps one and two.

Independent variables used in the 100-year flood-depth equations were used to develop 2-, 10-, 25-, 50-, and 500-year regional flood-depth equations.

Baseline-Depth Analysis

Baseline-depth analysis divided the State into East and West Regions (fig. 3). The regional equations, R^2 values, standard errors of estimates, number of data pairs, and ranges of drainage area are shown in table 1. The equations are shown graphically in figure 4.

Note that the equation with the greater R^2 value and lower standard error is for the East Region (table 1). This difference probably reflects uniformity of stream channel geometries. Streams in the East Region generally are wide and shallow, whereas streams in the West Region are more variable. Also, stream drainages in the East Region are primarily trellis, whereas those in the West Region are primarily dendritic.

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[1]Use of trade names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

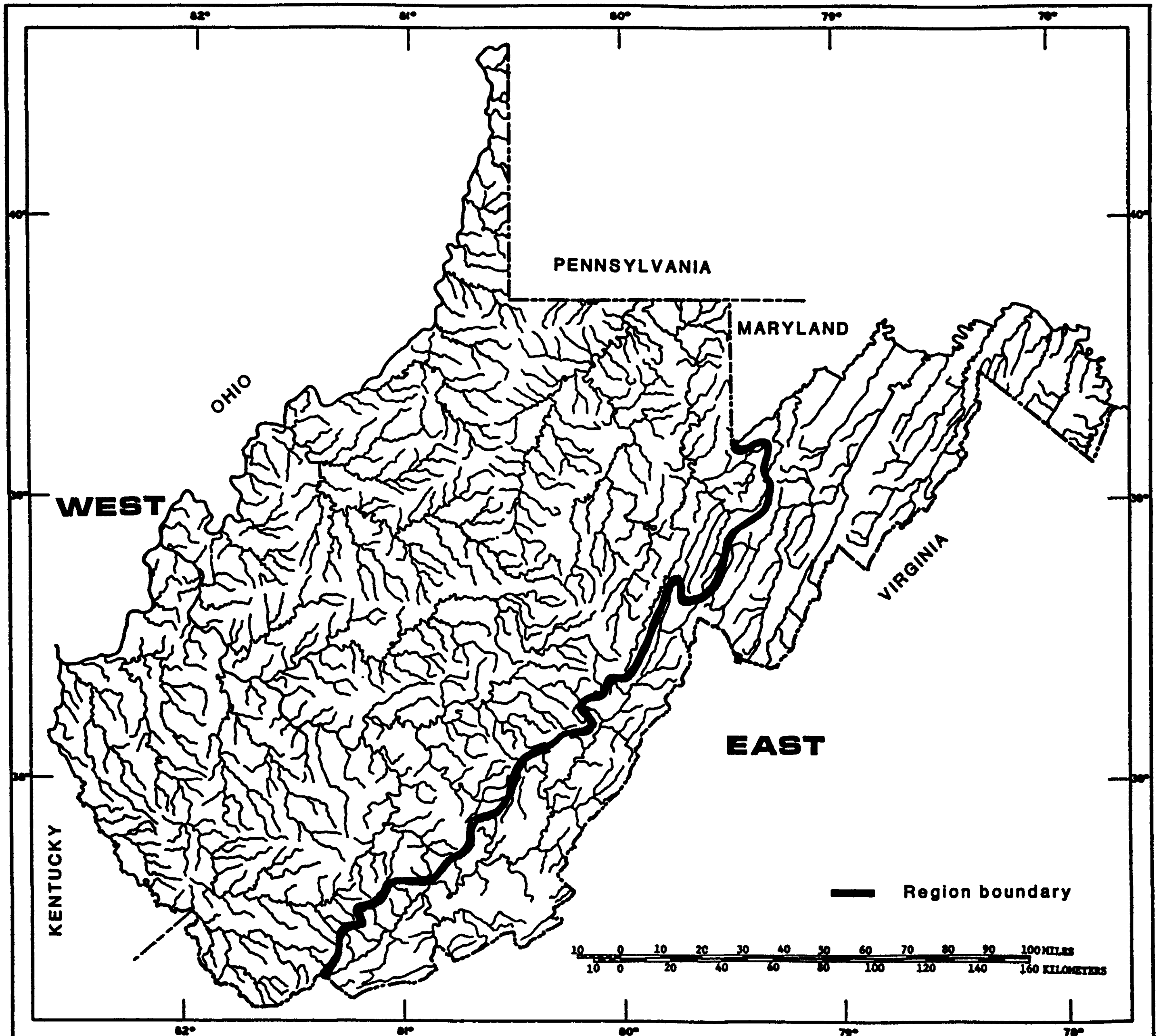

Figure 3.--Regions for baseline-depth equations in West Virginia.

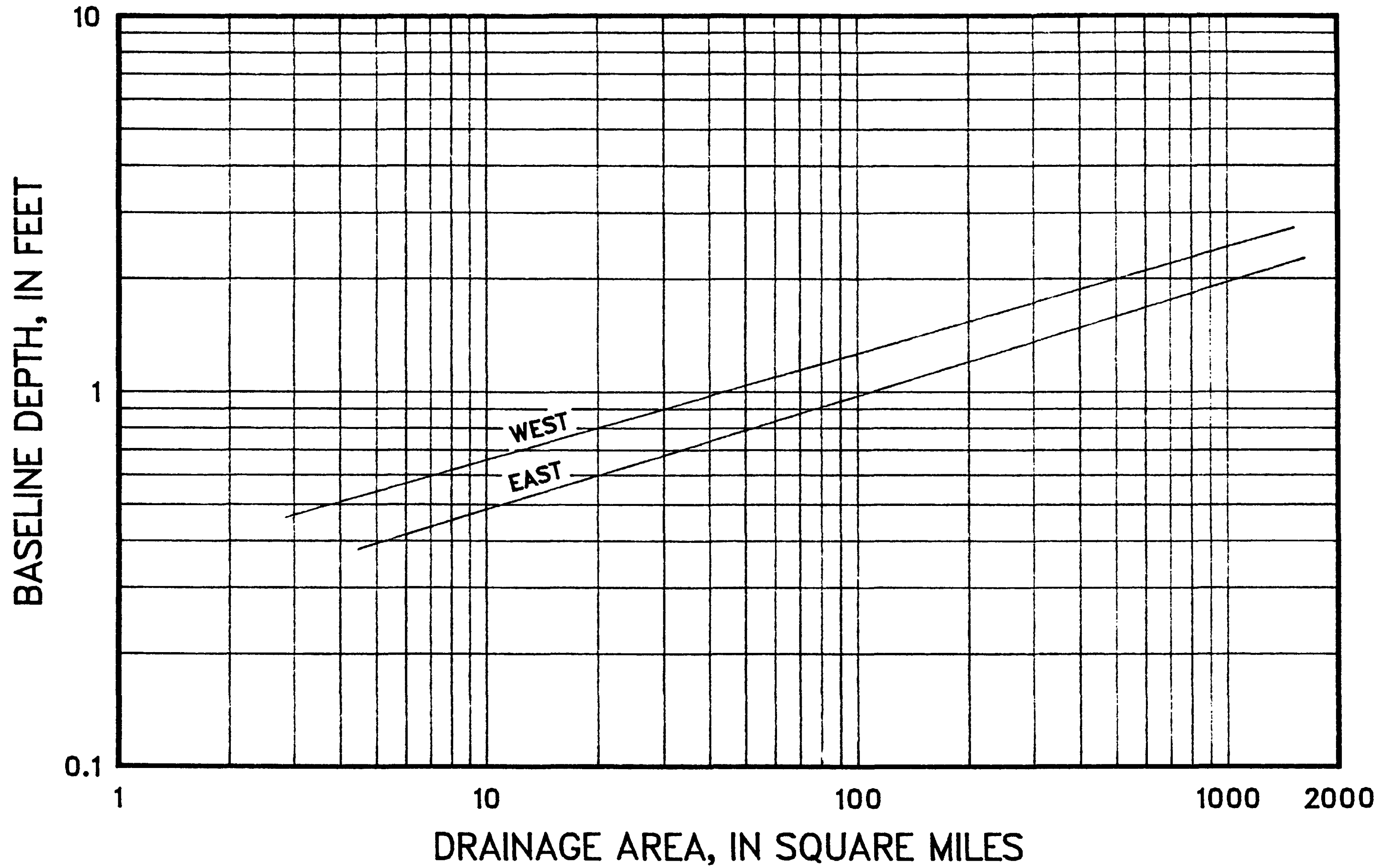

Figure 4.--Regional baseline-depth relations.

Table 1.--Regionalized baseline-depth equations and statistics

[BASE is the baseline depth, in feet; and AREA is the contributing drainage area, in square miles]

Geographic region	Equation	Coefficient of determination	Standard error of estimate, in percent	Number of data pairs	Range of drainage area, in square miles
EAST	BASE = 0.238 $AREA^{0.305}$	0.79	22	33	4.55-1,619
WEST	BASE = 0.343 $AREA^{0.284}$	.69	29	86	2.82-1,515

Table 2.--Regionalized flood-depth equations and statistics

[D(n) is the flood depth in feet for (n)-year flood discharge; AREA is the contributing drainage area in square miles; and ELEV is the mean basin elevation above sea level.]

Geographic region	Equation	Coefficient of determination	Standard error of estimate, in percent	Number of data pairs	Range of drainage area, in square miles	Range of mean basin elevation above sea level
North	D2 = 1.63 $AREA^{0.305}$	0.60	37	68	2.82-1,515	880-3,950
	D2 = 68.1 $AREA^{0.309}$ $ELEV^{-0.493}$	.72	30	64		
	D10 = 2.49 $AREA^{0.287}$	.56	38	68		
	D10 = 130 $AREA^{0.291}$ $ELEV^{-0.522}$	.72	29	64		
	D25 = 2.93 $AREA^{0.280}$	.54	40	68		
	D25 = 150 $AREA^{0.283}$ $ELEV^{-0.519}$	.70	30	64		
	D50 = 3.22 $AREA^{0.277}$	.54	39	68		
	D50 = 149 $AREA^{0.279}$ $ELEV^{-0.504}$	.69	30	64		
	D100 = 3.54 $AREA^{0.274}$	.52	40	68		
	D100 = 148 $AREA^{0.275}$ $ELEV^{-0.490}$	.66	32	64		
	D500 = 4.34 $AREA^{0.263}$	.49	41	68		
	D500 = 145 $AREA^{0.262}$ $ELEV^{-0.459}$	.61	34	64		
South	D2 = 1.83 $AREA^{0.336}$	.70	34	18	7.34-1,507	
	D10 = 2.52 $AREA^{0.364}$	.79	29			
	D25 = 2.87 $AREA^{0.367}$	.81	28			
	D50 = 2.99 $AREA^{0.375}$	.82	27			
	D100 = 3.39 $AREA^{0.368}$	.82	28			
	D500 = 3.89 $AREA^{0.371}$	.80	29			
East	D2 = 1.11 $AREA^{0.340}$	.78	26	33	4.55-1,619	
	D10 = 1.78 $AREA^{0.321}$	.77	25			
	D25 = 2.15 $AREA^{0.314}$	.74	27			
	D50 = 2.47 $AREA^{0.306}$	.71	28			
	D100 = 2.79 $AREA^{0.299}$	.67	30			
	D500 = 3.60 $AREA^{0.287}$	.59	34			

Flood-Depth Analysis

The 100-year flood-depth analysis divided the State into three Regions--North, South, and East (fig. 5). The 100-year flood-depth equations, R^2 values, standard errors of estimate, number of data pairs, ranges of drainage area, and range of mean basin elevation above sea level (only in North Region), are shown in table 2. The equations that use only drainage area as the independent variable are shown graphically in figures 6-8.

Consider the flood-depth equations in the South and the East Regions shown in table 2. Examination of table 2 indicates that R^2 values increase and standard errors decrease for equations as the average return period of floods increases for the South Region, and that the opposite trend is apparent for equations applicable in the East Region. This trend probably reflects different channel geometries; streams in the East Region generally have wide-sloping floodplains, whereas streams in the South Region are generally confined by steep valley walls.

For the North Region, flood-depth equations that use only drainage area as the independent variable have R^2 values that range from 0.49 to 0.60 and standard errors from 37 to 40 percent. Addition of mean basin elevation to the equation for the North Region increased the R^2 values to between 0.61 and 0.71 and reduced the standard error to between 28 and 34 percent. Mean basin elevation was not available for four of the stations. Channel geometry in the North Region is highly variable. The northwestern part of the North Region is similar to the East Region and the southeastern part is similar to the South Region. Mean basin elevation generally increases from northwest to southeast in the North Region.

The 2-, 10-, 25-, 50-, and 500-year regional flood-depth equations are developed by using independent variables obtained from the 100-year flood-depth analysis. The regional equations, and statistics described above, are shown in table 2 and the equations that use drainage area as the independent variable are shown graphically in figures 6, 7, and 8.

Two independent variables--drainage area and mean basin elevation above sea level--are necessary for the North Region to satisfy the criteria presented in item two of the "Development of Equations for Estimating Flood Depths" section. However, equations that use only drainage area as the independent variable are also given (table 2) since these are adequate for some users.

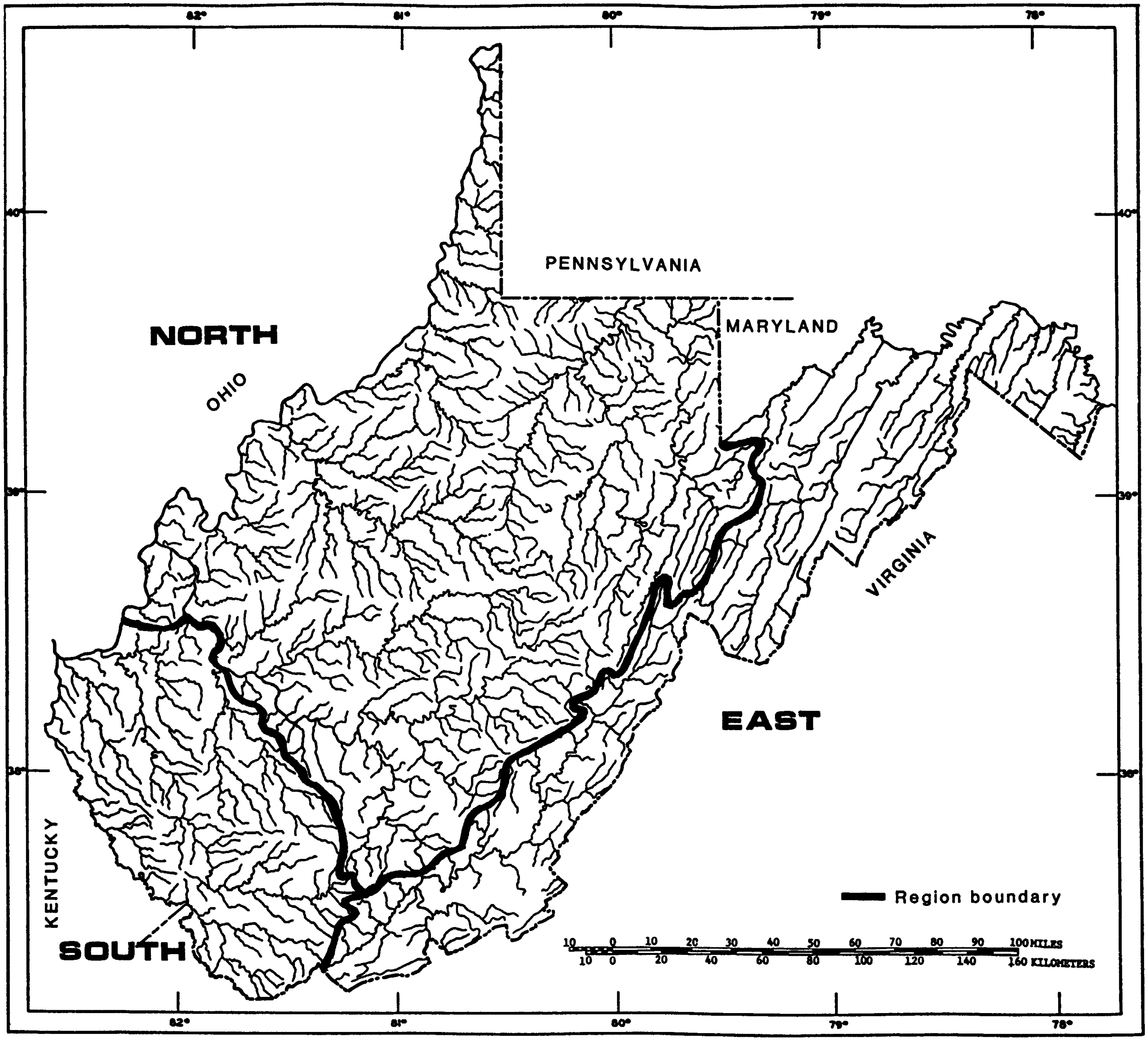

Figure 5.--Regions for flood-depth equations in West Virginia.

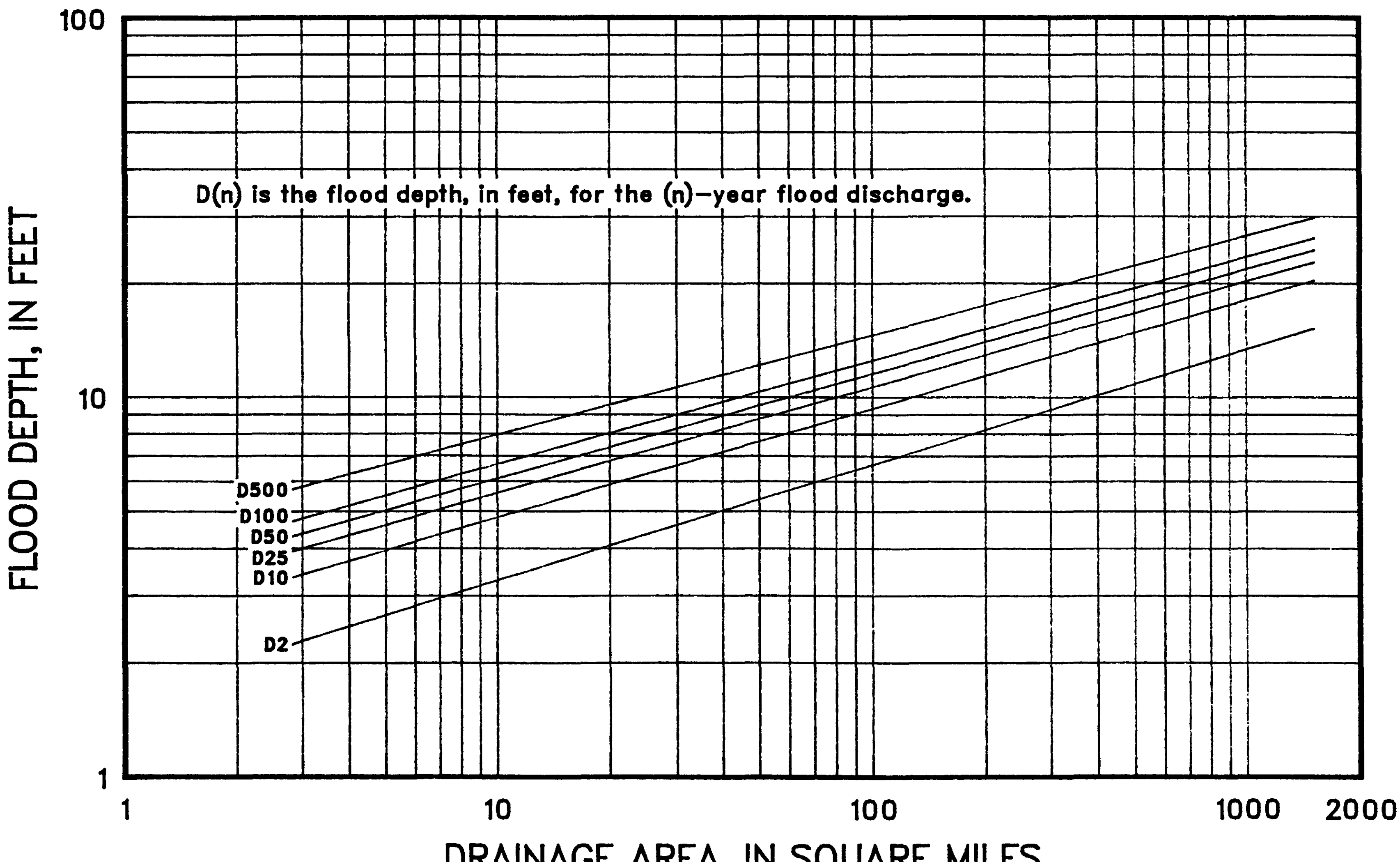

Figure 6.--North Region flood-depth relations.

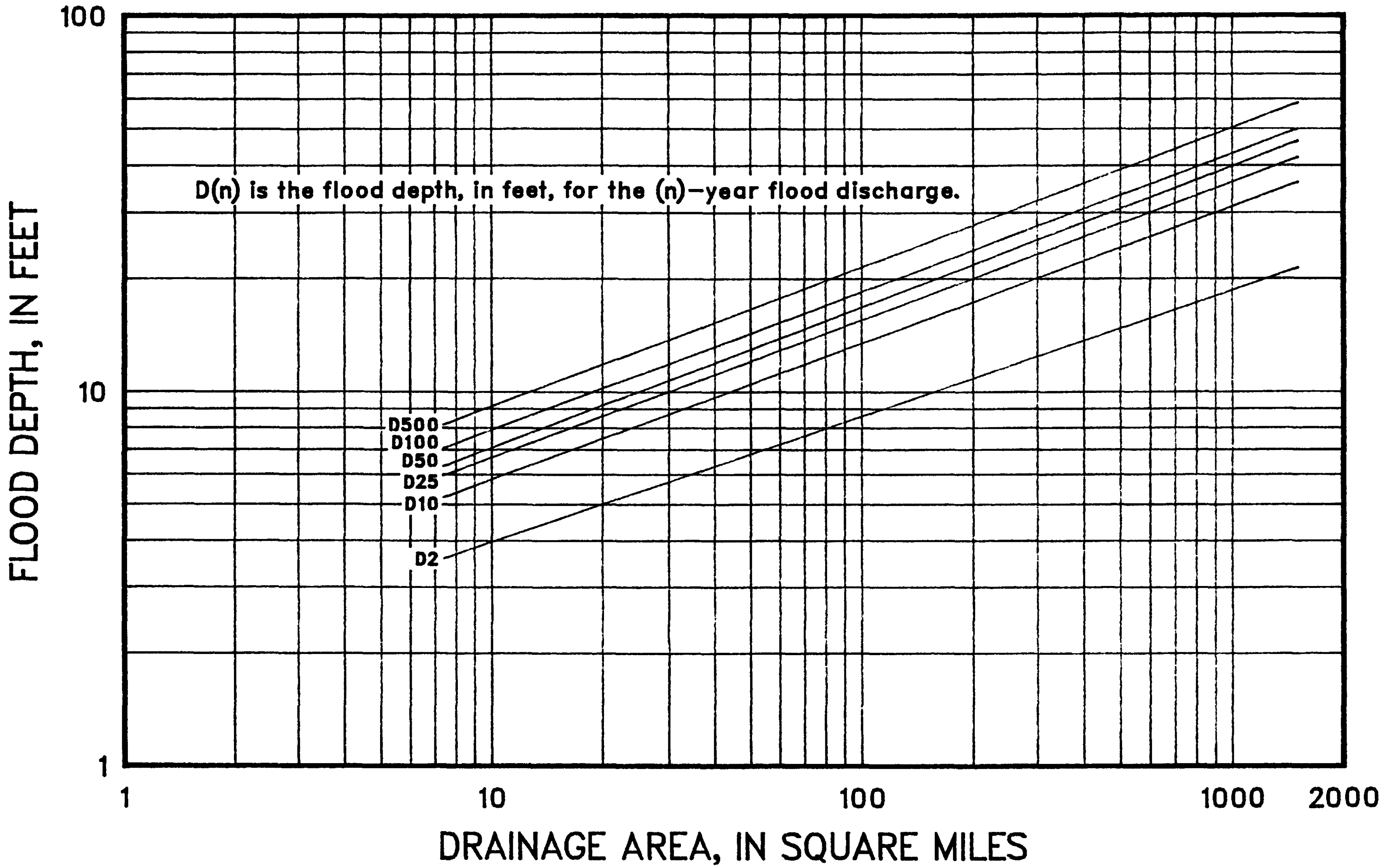

Figure 7.--South Region flood-depth relations.

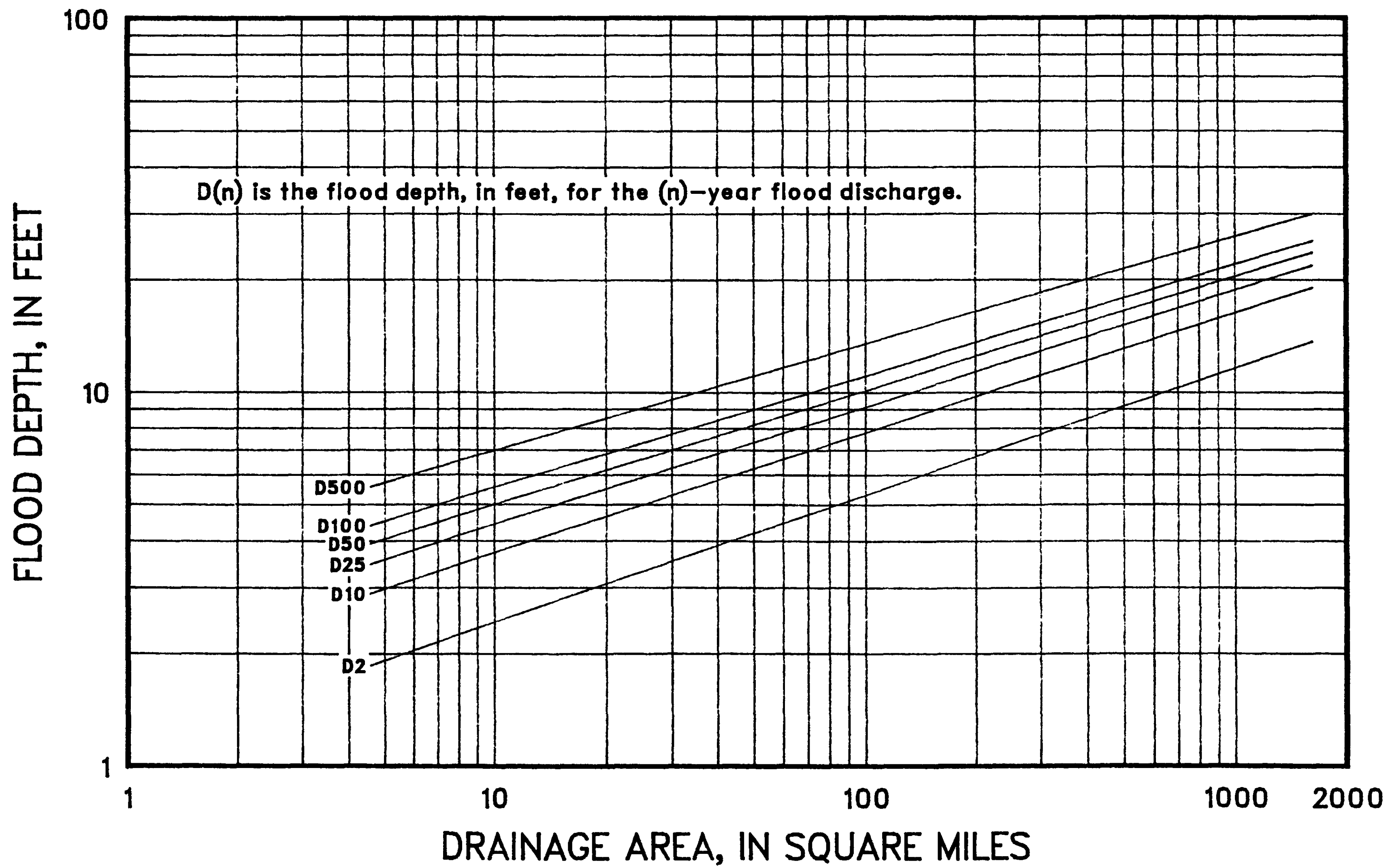

Figure 8.--East Region flood-depth relations.

APPLICATION OF FLOOD-DEPTH FREQUENCY EQUATIONS

Flood depths can be computed by equations or determined from regional curves. The elevation corresponding to such depths requires some site specific information. This information may be obtained by either of two methods. The first method described requires an on-site inspection to determine the elevation of the natural control. The second method requires no field visit; however, this method may result in a less accurate determination of baseline depth.

Field-Investigation Method

The first method for determining flood elevation follows:

1. Locate and mark the site on a topographic map and locate the site in the field.

2. If the site is at a natural control, then follow "a" directions below. Otherwise, find natural controls upstream and downstream from the site and follow "b" directions below.

3. a. Determine lowest elevation of control by using level survey methods.

   b. Determine lowest elevation of upstream and downstream controls by using level survey methods.

4. a. Determine contributing drainage area, in square miles, at location.

   b. Determine contributing drainage area, in square miles, at upstream and downstream locations.

5. a. Determine baseline-depth region in which basin is located from figure 3.

   b. Determine baseline-depth region in which basin is located from figure 3.

6. a. Solve regional baseline-depth equation from table 1 for location or read depths from regional baseline-depth curve of figure 4.

   b. Solve regional baseline depth equation from table 1 for upstream and downstream locations or read depths from regional baseline-depth curve of figure 4.

7. a. Add baseline depth to lowest elevation of control; the sum is baseline elevation.

   b. Add baseline depth to respective lowest elevation of controls for upstream and downstream locations; the sums are baseline elevations at those locations. Determine baseline elevation at desired site by interpolating between baseline elevations at upstream and downstream locations.

8. Determine flood-depth region in which basin is located from figure 5.

9. If the basin is in the North Region, decide if mean basin elevation will be determined (see 100-year Flood-Depth Analysis).

10. Solve regional flood-depth equation from table 2 or read depth from regional flood-depth curve (fig. 6, 7, or 8).

11. Add flood depth to baseline elevation; the sum is flood elevation.

Topographic-Map Method

The second method for determining flood elevation (requiring no field visit) is as follows:

1. Locate and mark the site on a topographic map.

2. If a contour line crosses the stream at the site, the contour-line elevation is assumed to be equivalent to baseline elevation. Otherwise, locate the first contour line crossings upstream and downstream from the site. The contour-line elevations are assumed equivalent to baseline elevations. Determine baseline elevation at desired site by interpolating between baseline elevations at upstream and downstream contour-line crossings.

3. Determine contributing drainage area in square miles at the site.

4. Determine flood-depth region in which basin is located from figure 5.

5. If the basin is in the North Region, decide if mean basin elevation will be determined (see 100-Year Flood-Depth Analysis).

6. Solve regional flood-depth equation from table 2 or read depth from regional curve (fig. 6, 7, or 8).

7. Add flood depth to baseline elevation; the sum is flood elevation.

ACCURACY AND LIMITATIONS OF EQUATIONS

Adding flood depth to baseline elevation introduces additional error sources. The magnitude of these errors affects estimates of the 2-, 10-, and 25-year floods more than estimates of the 50-, 100-, and 500-year floods.

National standards for vertical control on U.S. Geological Survey topographic maps requires that no more than 10 percent of the elevations of well-defined test points interpolated from contours be in error more than half the contour interval (Steger, 1982, pp. 15-16). This may affect the accuracy of the baseline elevation if topographic-map elevations have been used.

Limitations for use of equations:

1. Applicable only to stream sites in West Virginia.

2. Not applicable to sites on regulated streams, within encroached areas, bridge constrictions, or where streams flow through lakes or swamps.

3. Not applicable in karst areas.

4. Values of independent variables need to be within the range of values used to develop the regional equations.

SUMMARY

Depths of the 50-percent flow duration, and depths of floods for various recurrence intervals were defined at 119 sites from gaging-station records. These data and basin characteristic data were used to develop equations for estimating such depths at ungaged sites.

Regression procedures are used to develop baseline-depth (depth of 50-percent flow duration) and 100-year flood-depth equations. Drainage basin characteristics determined for the 100-year flood-depth equations were used to develop 2-, 10-, 25-, 50-, and 500-year regional flood-depth equations.

Two Regions--East and West--are delineated from the baseline-depth analysis. Drainage area is the only significant independent variable in the analysis. Channel geometries of streams in the East Region are more uniform than those in the West Region. The uniformity of stream-channel geometry probably is the reason why baseline-depth equations for the East Region had larger R^2 values and smaller standard errors of estimates.

The 100-year flood-depth analysis resulted in the delineation of three Regions--North, South, and East. Drainage area is the only significant independent variable in the analysis for the South and East regions. The equations for the North Region include basin elevation as an additional signficant independent variable. Streams in the East Region generally have wide-sloping floodplains, whereas streams in the South Region are generally confined by steep valley walls; this is probably the reason why R^2 values increase and standard errors decrease for the equations as the average return period between floods increases for the South Region, and the opposite trend is apparent in the East Region. Mean basin elevation generally increases from northwest to southeast in the North Region.

Two methods of applying the equations to make estimates of flood elevations at an ungaged site are given. Estimating equations are not applicable on streams outside of West Virginia, on regulated streams, or where the values of independent variables are not within the range evaluated for the region.

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