Technique For Estimating Depths Of 100-Year Floods In Pennsylvania

U.S. GEOLOGICAL SURVEY
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TECHNIQUE FOR ESTIMATING DEPTHS OF 100-YEAR FLOODS IN PENNSYLVANIA

By Herbert N. Flippo, Jr.

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Plate [in pocket]

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CONVERSION FACTORS AND ABBREVIATIONS

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

Multiply inch-pound unit	By	To obtain metric unit
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile $(ft^3/s)/mi^2$	0.01093	cubic meter per second per square kilometer $(m^3/s)/km^2$
foot (ft)	0.3048	meter (m)
foot per second (ft/s)	0.3048	meter per second (m/s)
inch (in.)	25.40	millimeter (mm)
mile (mi)	1.609	kilometer (km)
square foot (ft^2)	0.0929	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)

TECHNIQUE FOR ESTIMATING DEPTHS OF 100-YEAR FLOODS IN PENNSYLVANIA

By Herbert N. Flippo, Jr.

ABSTRACT

Techniques are developed for estimating 100-year flood depths in natural channels of unregulated Pennsylvania streams that drain less than 2,200 square miles. Equations and graphs are presented relating the depth of the 100-year flood above median stage to drainage area in five defined hydrologic areas in the State. Another graph defines the relation between drainage area and median depth of flow over the low point of riffles. Thus, 100-year depths on riffles can be estimated by summing depth values derived from two simple relations.

INTRODUCTION

Maps showing areas of potential flood hazards are useful tools in flood-plain management. Preparations of such maps usually entails the estimation of flood depths, for a chosen recurrence interval, along stream channels or other paths of flow. Most commonly, flood profiles that correspond to 100-year flood depths along principal stream channels are developed to define, for mapping purposes, the spatial distribution of high-water elevations. The resultant map of 100-year flood boundaries delineates those areas having a probability of about 1 in 100 of being flooded in any year.

Purpose and Scope

The purpose of this report is to present a method, using simple relations, to estimate 100-year depths of floods in natural channels of unregulated streams in Pennsylvania.

The depth of the 100-year flood above median stage--the stage corresponding to median (50th percentile) flow--can easily be estimated for unregulated streams throughout Pennsylvania. Mathematical relations, in which drainage area is the only independent variable, are provided for making such estimates for streams in five hydrologic areas. The range of application in three areas is from 1 to 2,200 mi^2 (square miles). The lower limit of applicability in the other two areas is also 1 mi^2; however, the upper limits are 325 and 560 mi^2, which approximates the areas of the largest drainage basins therein. A graph is provided for estimating median depth.

TECHNIQUE FOR ESTIMATING 100-YEAR FLOOD DEPTHS

Method of Analysis

The relation of flood depth to flood discharge, as developed by Leopold and Maddock (1953), is of the form:

$$d = cQ^f, \quad (1)$$

where d is the average cross-sectional depth, Q is the discharge for a given probability of occurrence, and c and f are constants. Flippo (1977 and 1982) has shown that for probabilities of occurrence in the range of 0.5 to 0.01 for an annual event--corresponding to recurrence intervals of 2 to 100 years--there is a high correlation between unregulated flood discharges and drainage area for most streams in Pennsylvania. Consequently, for this study the equation of Leopold and Maddock was revised to a depth-predictive equation for unregulated streams of the form:

$$D_{100} = cA^f, \quad (2)$$

in which: A is the area of the drainage basin, D_{100} is the depth of the 100-year flood above the stage of median flow, and c and f are constants for the 100-year flood.

Relations between flood depth and drainage area were developed in this study using graphical methods. Data on the depths, in feet, of 100-year floods above median stream stages were regressed against drainage areas (A, in square miles) for 281 gaging stations on essentially unregulated streams. Regionalization procedures (Riggs, 1973) were used to minimize regression errors for five hydrologic areas (A-E), which are delineated on the map of plate 1. Gaging stations for which the stage-discharge relations are affected by channelization, or by backwater from bridges or other hydraulic controls, were omitted from this analysis. The drainage basins for several gaging stations lie in more than one hydrologic area. Each of these stations was grouped with those stations that served to define the hydrologic area in which the gage lies. Locations of the gaging stations are shown in plate 1.

Results of the regressions are summarized in table 1 and figure 1. Data on drainage area, stages for median flow and the 100-year flood, and the depth of the 100-year flood above median stage are given in table 2. Owing to uncertainties in the definition of median-flow and 100-year-flood stages, computed depths of 100-year floods above median stages are less accurate than the hundredths-of-a-foot precision shown in this table.

Median stream stages (table 2) are those gage heights that correspond to median flows at the respective gaging stations. Median flows for continuous-record stations were determined by magnitude-frequency analyses of daily mean discharges. Median flows at crest-stage partial-record stations were estimated from median-flow/drainage-area ratios for nearby continuous-record stations. Stage-discharge relations were used to translate the median flows into corresponding stream stages.

Table 1.--Summary of equations for estimating 100-year flood depth

[ft, feet; mi^2, square miles]

Hydrologic area	Equation	[1]N	Areal means D_{100} (ft)	Areal means [2]A (mi^2)	Applicable range in [2]A (mi^2)	Standard error (percent)
A	[3] $D_{100} = 1.80\ A^{.380}$	15	7.19	38.2	1 - 325	24
B	$D_{100} = 6.50\ A^{.167}$	55	12.21	43.5	1 - 2,200	22
C	$D_{100} = 3.72\ A^{.241}$	155	9.80	55.7	1 - 2,200	25
D	$D_{100} = 2.31\ A^{.252}$	27	6.52	61.5	1 - 2,200	16
E	$D_{100} = 2.87\ A^{.261}$	29	7.52	40.0	1 - 560	28

[1] Number of gaging stations for which depth and drainage-area values were used in regression analysis. The arithmetic averages of these N values are the "areal means".

[2] A = Drainage area above site, in square miles.

[3] D_{100} = Depth of 100-year flood above median stage, in feet.

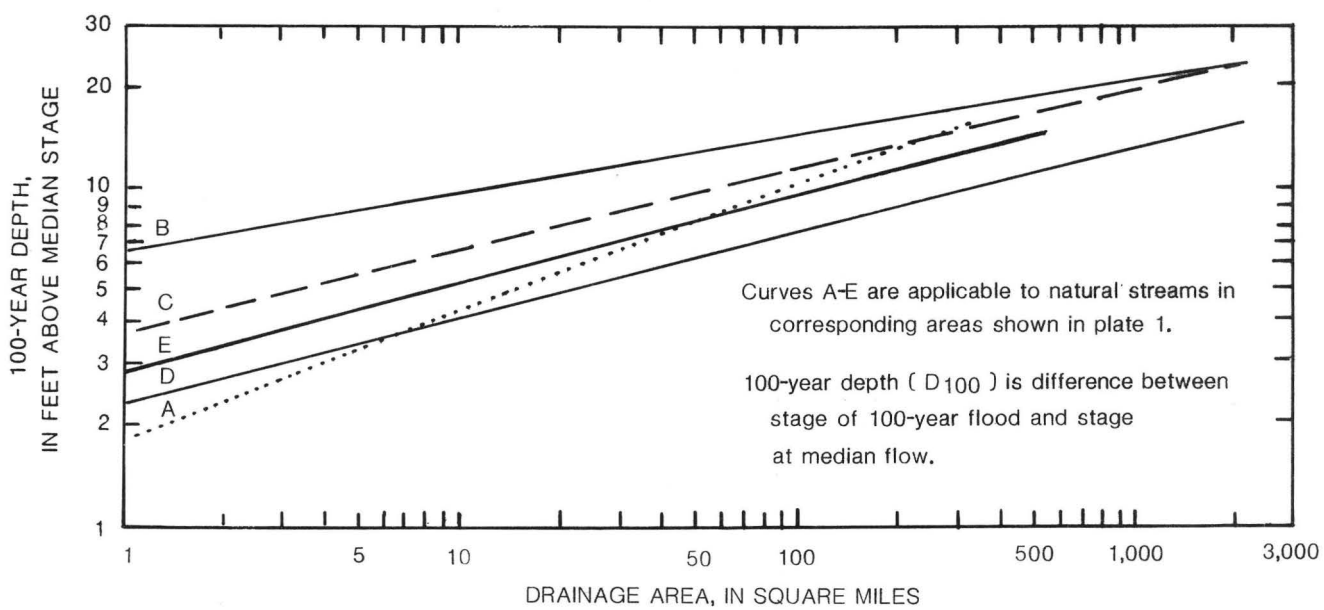

Figure 1.--Relation between 100-year flood depth and drainage area in five hydrologic areas.

Stages for 100-year floods are those gage heights that correspond to 100-year instantaneous peak discharges. Station estimates of 100-year-flood discharges were computed through use of procedures set forth by the U.S. Water Resources Council, as revised by the Hydrology Subcommittee, Interagency Advisory Committee on Water Data (1982). Final estimates of 100-year-flood discharges were developed by weighting each station estimate with a regional estimate, as computed from a regional regression equation developed by Flippo (1982, table 3). The weighting procedure (Flippo, 1977, Appendix D) weights the two 100-year estimates in proportion to the number of annual peaks used to compute the station estimate and the equivalent years of record for the applicable regional regression equation.

Gaging stations for which there are fewer than 10 unregulated annual peak discharges of record, or for which the stage-discharge relation is not representative of natural hydraulic control in the channel, or for which the drainage area exceeds 2,200 mi^2, were not considered in this depth analysis.

A graph of drainage area versus median depth was prepared to facilitate the estimation of total 100-year depth. This graph (fig. 2) resulted from the least-squares fitting of median-depth values for 151 of the 281 gaging stations listed in table 2. Median-depth values were determined by subtracting the measured stage at the low point of the riffle that forms the low-water hydraulic control at the gaging station ("point of zero flow") from the stage at median flow (table 2). Only those measurements of riffle low points that were consistent with the stage-discharge relations used in the preparation of table 2 were considered. No reliable riffle measurements were available for many gage sites, including most partial-record stations. Riffle measurements for many other sites were unsuitable for this analysis, because the low-water controls are artificial structures.

Table 2.--Summary of gaging-station data

[°, degrees; ', minutes; mi^2, square miles; ft, feet; ft^3/s, cubic feet per second]

Station number	Station name	Latitude (°,')	Longitude (°,')	Drainage area (mi^2)	Median flow Stage (ft)	Median flow Discharge (ft^3/s)	100-year flood Stage (ft)	100-year flood Discharge (ft^3/s)	Depth of 100 year flood above median stage (ft)
	AREA A								
01431680	Mill Brook near Paupack	41 23	75 14	4.84	3.92	2.6	6.75	616	2.83
01432500	Shohola Creek near Shohola	41 27	74 55	83.6	2.05	120	8.25	6,000	6.20
01438300	Vandermark Creek at Milford	41 20	74 48	5.36	1.52	2.8	4.20	668	2.68
01439500	Bush Kill at Shoemakers	41 05	75 02	117	1.75	160	10.05	10,800	8.30
01440300	Mill Creek at Mountainhome	41 10	75 16	5.84	3.01	3.6	7.65	2,380	4.64
01440400	Brodhead Creek near Analomink	41 05	75 13	65.9	1.94	75	11.90	13,200	9.96
01441000	McMichaels Creek at Stroudsburg	40 59	75 12	65.3	2.55	81	11.30	7,440	8.75
01442500	Brodhead Creek at Minisink Hills	40 60	75 09	259	2.89	320	17.85	45,100	14.96
01446600	Martins Creek near East Bangor	40 54	75 12	10.4	1.70	6.2	5.10	3,040	3.40
01447500	Lehigh River at Stoddartsville	41 08	75 38	91.7	.96	120	13.58	19,500	12.62
01447720	Tobyhanna Creek near Blakeslee	41 05	75 36	118	2.68	160	15.80	14,800	13.12
01448000	Lehigh River at Tannery	41 02	75 46	322	2.00	440	19.20	41,200	17.20
01448500	Dilldown Creek near Long Pond	41 02	75 33	2.39	1.24	3.1	4.37	851	3.13
01449360	Pohopoco Creek at Kresgeville	40 54	75 30	49.9	3.36	70	14.20	6,460	10.84
01450500	Aquashicola Creek at Palmerton	40 48	75 36	76.7	3.53	98	12.80	9,920	9.27
	AREA B								
01427650	North Branch Calkins Creek near Damascus	41 42	75 10	7.02	2.25	3.7	9.15	1,530	6.90
01428500	Delaware River near Barryville, NY	41 31	74 59	2,020	3.17	1,800	26.40	130,000	23.23
01429000	West Branch Lackawaxen River at Prompton	41 35	75 20	59.7	1.53	63	12.40	10,200	10.87
01429500	Dyberry Creek near Honesdale	41 38	75 16	64.6	1.73	50	16.70	16,100	14.97
01430000	Lackawaxen River near Honesdale	41 34	75 15	164	1.10	160	20.60	28,000	19.50
01430500	Lackawaxen River at West Hawley	41 28	75 11	206	1.78	200	20.10	31,600	18.32
01431000	Middle Creek near Hawley	41 29	75 13	78.4	.75	63	18.10	12,500	17.35
01431500	Lackawaxen River at Hawley	41 28	75 10	290	2.28	240	21.97	42,500	19.69
01451000	Lehigh River at Walnutport	40 45	75 36	889	2.81	1,400	19.70	90,390	16.89
01451800	Jordan Creek near Schnecksville	40 40	75 38	53.0	2.93	45	14.20	9,480	11.27
01453000	Lehigh River at Bethlehem	40 37	75 23	1,279	2.15	1,600	30.20	110,300	28.05
01458900	Tinicum Creek near Ottsville	40 28	75 08	14.7	1.07	5.7	9.80	10,230	8.73
01459500	Tohickon Creek near Pipersville	40 26	75 07	97.4	1.32	37	12.50	21,200	11.18
01465500	Neshaminy Creek near Langhorne	40 10	74 57	210	1.18	120	21.52	42,300	20.34
01465770	Poquessing Creek at Trevose Road, Philadelphia	40 08	75 00	5.08	1.50	3.5	9.20	2,900	7.70
01465780	Poquessing Creek above Byberry Cr, Philadelphia	40 04	74 59	13.2	1.71	6.3	12.70	5,830	10.99
01465785	Walton Run at Philadelphia	40 05	75 00	2.17	2.41	1.2	11.40	1,850	8.99
01465790	Byberry Creek at Chalfont Road, Philadelphia	40 05	74 59	5.34	1.89	3.4	13.30	2,960	11.41
01465795	Byberry Creek at Grant Avenue, Philadelphia	40 04	75 00	7.13	2.40	3.7	13.70	4,760	11.30
01465798	Poquessing Creek at Grant Ave., Philadelphia	40 03	74 59	21.4	2.92	11	15.25	10,500	12.33
01467042	Pennypack Creek at Pine Road, Philadelphia	40 05	75 04	37.9	3.10	34	12.48	7,590	9.38
01467043	Stream 'A' at Philadelphia	40 05	75 04	1.20	9.75	.67	16.00	1,200	6.25
01467045	Pennypack Creek below Veree Road, Philadelphia	40 05	75 03	42.8	3.98	35	15.20	8,960	11.22
01467048	Pennypack Creek at Rhawn Street, Philadelphia	40 03	75 02	49.8	2.39	40	13.00	11,400	10.61
01467050	Wooden Bridge Run at Philadelphia	40 03	75 01	3.35	3.22	1.6	13.45	2,960	10.23
01467086	Tacony Creek at County Line, Philadelphia	40 03	75 07	16.6	2.27	14	13.50	6,920	11.23
01467089	Frankford Creek at Torresdale Ave., Philadelphia	40 00	75 06	33.8	3.71	23	15.55	11,600	11.84

Table 2.--Summary of gaging-station data--Continued

[°, degrees; ', minutes; mi^2, square miles; ft, feet; ft^3/s, cubic feet per second]

Station number	Station name	Latitude (°,')	Longitude (°,')	Drainage area (mi^2)	Median flow: Stage (ft)	Median flow: Discharge (ft^3/s)	100-year flood: Stage (ft)	100-year flood: Discharge (ft^3/s)	Depth of 100-year flood above median stage (ft)
	AREA B--Continued								
01467500	Schuylkill River at Pottsville	40 41	76 11	53.4	2.73	65.0	14.50	9,470	11.77
01468500	Schuylkill River at Landingville	40 38	76 08	133	3.21	180	19.80	17,900	16.59
01469500	Little Schuylkill River at Tamaqua	40 48	75 58	42.9	2.29	49	10.99	7,520	8.70
01470500	Schuylkill River at Berne	40 31	75 60	355	5.23	430	18.82	42,000	13.59
01471000	Tulpehocken Creek near Reading	40 22	75 59	211	1.57	200	17.10	19,600	15.53
01471510	Schuylkill River at Reading	40 20	75 56	880	3.13	940	28.60	71,000	25.47
01471980	Manatawny Creek near Pottstown	40 16	75 41	85.5	2.12	59	13.60	10,400	11.48
01472000	Schuylkill River at Pottstown	40 14	75 39	1,147	2.22	1,200	28.00	88,000	25.78
01472157	French Creek near Phoenixville	40 09	75 36	59.1	4.58	54	15.50	16,100	10.92
01473000	Perkiomen Creek at Graterford	40 14	75 27	279	1.47	160	20.30	48,600	18.83
01473100	Zacharias Creek near Skippack	40 12	75 22	7.27	4.45	7.4	10.80	10,200	6.35
01473120	Skippack Creek near Collegeville	40 10	75 26	53.7	1.55	28	18.30	21,400	16.75
01473900	Wissahickon Creek at Fort Washington	40 07	75 13	40.8	1.90	24	17.60	7,150	15.70
01473950	Wissahickon Creek at Bells Mill Rd., Philadelphia	40 05	75 14	53.6	3.34	37	13.70	9,720	10.36
01473980	Wissahickon Creek at Livezey Lane, Philadelphia	40 03	75 13	59.2	1.53	41	8.60	10,500	7.07
01474000	Wissahickon Creek at mouth, Philadelphia	40 01	75 12	64.0	2.23	44	10.85	11,200	8.62
01475300	Darby Creek at Waterloo Mills near Devon	40 01	75 25	5.15	1.54	5.2	8.70	3,340	7.16
01475510	Darby Creek near Darby	39 56	75 16	37.4	1.53	47	11.74	8,860	10.21
01475530	Cobbs Creek at U.S. Highway 1, Philadelphia	39 59	75 17	4.78	2.29	3.7	12.20	5,490	9.91
01475550	Cobbs Creek at Darby	39 55	75 15	22.0	1.46	9.0	11.50	7,400	10.04
01476000	Crum Creek at Woodlyn	39 53	75 21	33.3	2.31	18	11.22	5,150	8.91
01476030	Little Crum Creek at Michigan Ave., Swarthmore	39 54	75 20	1.15	2.30	.85	10.80	1,160	8.50
01476500	Ridley Creek at Moylan	39 54	75 24	31.9	1.43	31	13.10	7,920	11.67
01477000	Chester Creek near Chester	39 52	75 25	61.1	2.86	55	22.90	18,200	20.04
01478200	Middle Branch White Clay Creek near Landenberg	39 47	75 48	12.7	3.41	8.85	15.50	6,340	12.09
01480610	Sucker Run near Coatesville	39 58	75 51	2.57	2.00	2.2	10.90	2,660	8.90
01480617	West Branch Brandywine Creek at Modena	39 58	75 48	55.0	3.08	56	16.10	14,600	13.02
01481000	Brandywine Creek at Chadds Ford	39 52	75 36	287	1.79	270	17.00	26,100	15.21
	AREA C								
01516500	Corey Creek near Mainsburg	41 47	77 01	12.2	1.68	3.4	9.69	4,370	8.01
01516800	Manns Creek near Mansfield	41 49	77 06	3.01	2.92	.85	10.00	1,130	7.08
01517000	Elk Run near Mainsburg	41 49	76 58	10.2	.51	2.9	5.67	3,470	5.16
01518000	Tioga River at Tioga	41 54	77 08	282	1.61	120	19.28	51,680	17.67
01518500	Crooked Creek at Tioga	41 54	77 09	122	2.61	31	17.40	20,250	14.79
01520000	Cowanesque River near Lawrenceville	41 59	77 09	298	7.22	78	18.50	48,200	11.28
01531250	North Branch Sugar Creek tributary near Columbia Cross Roads	41 50	76 50	8.83	1.69	2.5	6.82	3,320	5.13
01532000	Towanda Creek near Monroeton	41 42	76 28	215	7.03	110	18.90	52,500	11.87
01532200	South Branch Towanda Creek at New Albany	41 35	76 26	13.3	2.67	9.0	11.10	3,770	8.43
01532850	Middle Branch Wyalusing Creek tributary near Richardville	41 52	76 00	5.67	3.96	3.7	7.80	2,180	3.84
01533250	Tuscarora Creek near Silvara	41 42	76 07	11.8	2.75	7.8	8.62	3,130	5.87
01533500	North Branch Mehoopany Creek near Lovelton	41 32	76 09	35.2	2.47	21	9.95	14,500	7.48
01533800	Butler Creek at Gibson	41 48	75 39	7.38	2.44	4.5	8.30	2,820	5.86

Table 2.--Summary of gaging-station data--Continued

[°, degrees; ', minutes; mi^2, square miles; ft, feet; ft^3/s, cubic feet per second]

Station number	Station name	Lati-tude (°,')	Longi-tude (°,')	Drainage area (mi^2)	Median flow		100-year flood		Depth of 100-year flood above median stage (ft)
					Stage (ft)	Discharge (ft^3/s)	Stage (ft)	Discharge (ft^3/s)	
	AREA C--Continued								
01533950	South Branch Tunkhannock Creek near Montdale	41 34	75 39	12.6	1.25	5.7	7.30	3,290	6.05
01534000	Tunkhannock Creek near Tunkhannock	41 33	75 54	383	2.01	240	14.60	42,600	12.59
01537500	Solomon Creek at Wilkes-Barre	41 14	75 57	15.7	1.64	13	10.90	2,970	9.26
01538000	Wapwallopen Creek near Wapwallopen	41 04	76 06	43.8	1.56	40	10.64	4,970	9.08
01538800	Huntington Creek near Pikes Creek	41 19	76 09	4.94	4.78	3.3	11.40	2,070	6.62
01539000	Fishing Creek near Bloomsburg	41 05	76 26	274	2.44	250	15.60	34,000	13.16
01539500	Little Fishing Creek at Eyers Grove	41 05	76 31	56.5	1.75	37	10.30	6,720	8.55
01540000	Fishing Creek at Bloomsburg	41 00	76 28	355	3.35	400	20.00	35,700	16.65
01540200	Trexler Run near Ringtown	40 51	76 17	1.77	1.27	.94	5.60	672	4.33
01541000	West Branch Susquehanna River at Bower	40 54	78 41	315	5.08	255	18.45	26,800	13.37
01541308	Bradley Run near Ashville	40 31	78 35	6.77	1.61	8.2	5.50	1,690	3.89
01541500	Clearfield Creek at Dimeling	40 58	78 24	371	3.60	280	18.80	26,450	15.20
01542000	Moshannon Creek at Osceola Mills	40 51	78 16	68.8	.97	64	15.50	5,840	14.53
01542720	Wilson Run at Penfield	41 13	78 35	8.34	1.30	4.3	6.50	1,070	5.20
01543000	Driftwood Br Sinnemahoning Creek at Sterling Run	41 25	78 12	272	1.25	180	14.02	38,100	12.77
01543500	Sinnemahoning Creek at Sinnemahoning	41 19	78 05	685	2.63	470	25.08	74,400	22.45
01544450	Germania Branch at Germania	41 39	77 39	2.40	.49	1.22	5.10	693	4.61
01544500	Kettle Creek at Cross Fork	41 29	77 50	136	2.01	96	15.00	20,200	12.99
01545600	Young Womans Creek near Renovo	41 23	77 41	46.2	1.88	33	9.30	7,230	7.42
01547800	South Fork Beech Creek near Snow Shoe	41 02	77 54	12.2	1.21	15.3	6.60	1,850	5.39
01547950	Beech Creek at Monument	41 07	77 42	152	6.00	170	18.00	13,500	12.00
01548020	Bull Run near Loganton	41 00	77 20	1.99	5.54	2.43	10.80	544	5.26
01548500	Pine Creek at Cedar Run	41 31	77 27	604	2.12	360	14.88	55,600	12.76
01549000	Pine Creek near Waterville	41 19	77 23	750	1.82	550	18.70	64,000	16.88
01549500	Blockhouse Creek near English Center	41 28	77 14	37.7	1.40	24	10.60	8,020	9.20
01549700	Pine Creek below Little Pine Creek near Waterville	41 16	77 19	944	2.37	510	20.92	92,600	18.55
01549780	Larrys Creek at Cogan House	41 25	77 10	6.80	1.11	4.0	6.63	1,860	5.52
01550000	Lycoming Creek near Trout Run	41 25	77 02	173	2.00	130	19.85	25,300	17.85
01551000	Grafius Run at Williamsport	41 15	77 01	3.14	.77	1.5	4.10	1,460	3.33
01552000	Loyalsock Creek at Loyalsockville	41 20	76 54	443	3.83	370	14.36	81,600	10.53
01552100	Mill Creek near Warrensville	41 20	76 58	11.9	.24	7.0	6.60	3,100	6.36
01552500	Muncy Creek near Sonestown	41 21	76 32	23.8	2.00	24	9.00	8,780	7.00
01553600	East Branch Chillisquaque Creek near Washingtonville	41 05	76 39	9.48	1.72	2.5	11.10	4,710	9.38
01555000	Penns Creek at Penns Creek	40 52	77 03	301	2.08	240	13.89	26,400	11.81
01555500	East Mahantango Creek near Dalmatia	40 37	76 55	162	1.99	110	19.50	24,600	17.51
01555800	McDonald Run near East Freedom	40 23	78 26	1.54	1.45	1.9	5.90	512	4.45
01556000	Frankstown Branch Juniata River at Williamsburg	40 28	78 12	291	2.95	190	22.90	24,500	19.95
01556400	Sandy Run near Bellwood	40 34	78 21	5.58	1.98	6.9	6.80	1,420	4.82
01556500	Little Juniata River at Tipton	40 38	78 18	93.7	2.05	82	12.00	10,500	9.95
01557100	Schell Run at Tyrone	40 40	78 15	1.68	1.24	2.1	4.64	570	3.40
01557500	Bald Eagle Creek at Tyrone	40 41	78 14	44.1	.53	38	7.50	6,270	6.97
01558000	Little Juniata River at Spruce Creek	40 37	78 08	220	2.20	200	17.10	28,000	14.90
01559000	Juniata River at Huntingdon	40 29	78 01	816	1.79	590	20.23	58,000	18.44
01559500	Standing Stone Creek near Huntingdon	40 31	77 58	128	1.47	76	11.45	9,890	9.98
01559700	Buffalo Run tributary near Manns Choice	39 59	78 37	5.28	.37	1.6	6.30	1,700	5.93
01560000	Dunning Creek at Belden	40 04	78 30	172	1.75	89	14.05	19,500	12.30
01560500	Dunning Creek at Yount	40 03	78 28	191	1.43	89	21.70	27,100	20.27

Table 2.--Summary of gaging-station data--Continued

[°, degrees; ', minutes; mi^2, square miles; ft, feet; ft^3/s, cubic feet per second]

Station number	Station name	Lati-tude (°,')	Longi-tude (°,')	Drainage area (mi^2)	Median flow Stage (ft)	Median flow Discharge (ft^3/s)	100-year flood Stage (ft)	100-year flood Discharge (ft^3/s)	Depth of 100-year flood above median stage (ft)
	AREA C--Continued								
01561000	Brush Creek at Gapsville	39 57	78 15	36.8	2.25	21.0	11.00	7,330	8.75
01562000	Raystown Branch Juniata River at Saxton	40 13	78 16	756	1.88	400	21.71	59,000	19.83
01562500	Great Trough Creek near Markleton	40 21	78 08	84.6	1.59	42	8.45	8,100	6.86
01563500	Juniata River at Mapleton Depot	40 24	77 56	2,030	3.39	1,200	34.06	126,600	30.67
01563800	Elders Branch near Hustontown	40 05	78 03	3.46	3.96	1.05	9.85	829	5.89
01564500	Aughwick Creek near Three Springs	40 13	77 55	205	3.26	90	19.80	26,900	16.54
01565920	Lick Run near East Waterford	40 21	77 39	8.38	2.70	4.2	10.40	2,720	7.70
01566000	Tuscarora Creek near Port Royal	40 31	77 25	214	3.62	110	21.15	22,300	17.53
01567500	Bixler Run near Loysville	40 22	77 24	15.0	2.91	7.5	10.40	8,820	7.49
01568000	Sherman Creek at Shermans Dale	40 19	77 10	200	1.48	130	20.40	34,500	18.92
01569000	Stony Creek near Dauphin	40 23	76 55	33.2	1.57	38	11.87	6,310	10.30
01569340	Newburg Run at Newburg	40 08	77 33	5.29	1.65	3.7	6.91	3,000	5.26
01572000	Lower Little Swatara Creek at Pine Grove	40 32	76 23	34.3	1.31	30	10.50	4,260	9.19
01572900	Reeds Creek near Ono	40 24	76 33	8.63	1.42	5.4	9.90	3,780	8.48
01573000	Swatara Creek at Harper Tavern	40 24	76 35	337	1.99	310	21.50	43,300	19.51
01573500	Manada Creek at Manada Gap	40 24	76 43	13.5	1.70	14	11.00	4,190	9.30
01574000	West Conewago Creek near Manchester	40 05	76 43	510	3.17	230	21.16	56,900	17.99
01574500	Codorus Creek at Spring Grove	39 53	76 51	75.5	2.20	43	14.00	14,500	11.80
01575000	South Branch Codorus Creek near York	39 55	76 45	117	1.18	68	20.30	23,000	19.12
01575500	Codorus Creek near York	39 57	76 45	222	2.32	120	23.00	25,700	20.68
01576320	Stony Run at Reamstown	40 13	76 08	3.55	.60	2.6	9.20	1,720	8.60
01576500	Conestoga River at Lancaster	40 03	76 17	324	3.50	240	20.78	36,900	17.28
01577500	Muddy Creek at Castle Fin	39 46	76 19	133	3.57	120	22.80	22,000	19.23
01577940	Broad Creek tributary at Whiteford, MD	39 42	76 22	.77	.01	.58	3.00	378	2.99
01578200	Conowingo Creek near Buck	39 51	76 12	8.71	2.41	6.6	11.50	3,850	9.09
01578400	Bowery Run near Quarryville	39 54	76 07	5.98	2.51	4.5	9.90	5,870	7.39
01600700	Little Wills Creek at Bard	39 56	78 40	10.2	5.80	3.1	11.00	3,000	5.20
01601000	Wills Creek below Hyndman	39 49	78 43	146	2.30	60	13.10	15,700	10.80
01613050	Tonoloway Creek near Needmore	39 54	78 08	10.7	3.06	4.5	11.60	1,990	8.54
01619000	Antietam Creek near Waynesboro	39 43	77 36	93.5	3.30	88	15.10	8,270	11.80
03007800	Allegheny River at Port Allegany	41 49	78 18	248	2.97	275	23.00	24,200	20.03
03008000	Newell Creek near Port Allegany	41 54	78 21	7.79	2.55	5.5	6.60	3,920	4.05
03009680	Potato Creek at Smethport	41 49	78 26	160	2.92	190	17.15	16,800	14.23
03010500	Allegheny River at Eldred	41 58	78 23	550	3.80	450	26.50	45,000	22.70
03010655	Oswayo Creek at Shinglehouse	41 57	78 12	98.7	4.21	96	19.00	11,500	14.79
03023000	Cussewago Creek near Meadville	41 40	80 13	90.2	2.45	45	15.55	4,800	13.10
03028000	West Branch Clarion River at Wilcox	41 35	78 42	63.0	1.83	64	12.65	8,420	10.82
03029000	Clarion River at Ridgway	41 25	78 44	303	2.93	310	22.20	30,100	19.27
03029200	Clear Creek near Sigel	41 19	79 05	8.67	2.91	5.4	8.95	1,400	6.04
03029500	Clarion River at Cooksburg	41 20	79 13	807	3.10	800	18.60	52,100	15.50
03031780	Mill Creek near Brockway	41 15	78 50	2.12	1.90	1.6	8.20	496	6.30
03031950	Big Run near Sprankle Mills	40 60	79 05	7.38	2.04	5.4	6.94	1,430	4.90
03032500	Redbank Creek at St. Charles	40 60	79 24	528	3.75	400	19.00	39,900	15.25
03034000	Mahoning Creek at Punxsutawney	40 56	79 01	158	1.82	135	18.30	16,400	16.48
03034500	Little Mahoning Creek at McCormick	40 50	79 07	87.4	2.00	68	14.60	8,050	12.60
03035000	Mahoning Creek near Dayton	40 54	79 14	321	2.65	260	14.00	21,100	11.35
03038000	Crooked Creek at Idaho	40 39	79 21	191	2.83	120	17.30	16,500	14.47
03039000	Crooked Creek at Crooked Creek Dam	40 43	79 31	278	1.45	160	19.50	22,000	18.05

Table 2.--Summary of gaging-station data--Continued

[°, degrees; ', minutes; mi^2, square miles; ft, feet; ft^3/s, cubic feet per second]

Station number	Station name	Latitude (°,')	Longitude (°,')	Drainage area (mi^2)	Median flow: Stage (ft)	Median flow: Discharge (ft^3/s)	100-year flood: Stage (ft)	100-year flood: Discharge (ft^3/s)	Depth of 100-year flood above median stage (ft)
	AREA C--Continued								
03039200	Clear Run near Buckstown	40 03	78 50	3.68	2.46	3.3	6.90	683	4.44
03040000	Stonycreek River at Ferndale	40 17	78 55	451	3.06	310	18.08	44,300	15.02
03041000	Little Conemaugh River at East Conemaugh	40 21	78 53	183	1.14	136	12.20	23,200	11.06
03041500	Conemaugh River at Seward	40 25	79 02	715	2.79	660	22.27	70,600	19.48
03042000	Blacklick Creek at Josephine	40 28	79 11	192	3.69	170	14.20	25,600	10.51
03042170	Stoney Run at Indiana	40 37	79 10	4.39	2.20	3.35	11.20	852	9.00
03042200	Little Yellow Creek near Strongstown	40 34	78 57	7.36	3.11	5.5	7.80	2,360	4.69
03042500	Two Lick Creek at Graceton	40 31	79 10	171	2.34	130	15.88	23,100	13.54
03043000	Blacklick Creek at Blacklick	40 28	79 12	390	3.80	340	14.60	38,300	10.80
03045000	Loyalhanna Creek at Kingston	40 18	79 20	172	2.60	150	13.80	21,700	11.20
03045500	Loyalhanna Creek at New Alexandria	40 24	79 26	265	3.10	210	19.10	26,400	16.00
03047500	Kiskiminetas River at Avonmore	40 32	79 28	1,723	4.30	1,600	38.50	127,500	34.20
03049000	Buffalo Creek near Freeport	40 23	79 42	137	1.47	77	13.05	13,000	11.58
03049800	Little Pine Creek near Etna	40 31	79 56	5.78	.46	2.7	5.20	1,630	4.74
03070500	Big Sandy Creek at Rockville, WV	39 37	79 42	200	4.90	212	18.40	23,500	13.50
03071000	Cheat River near Pisgah, WV	39 36	79 47	1,354	5.50	1,740	28.70	114,000	23.20
03072000	Dunkard Creek at Shanopin	39 46	79 58	229	1.82	81	14.80	19,400	12.98
03072590	Georges Creek at Smithfield	39 48	79 48	16.3	2.38	8.4	12.80	2,390	10.42
03072840	Tenmile Creek near Clarksville	40 00	80 03	133	1.37	75	8.90	17,900	7.53
03072880	Browns Creek near Nineveh	39 56	80 17	17.5	3.14	6.8	12.40	3,860	9.26
03073000	South Fork Tenmile Creek at Jefferson	39 55	80 04	180	1.52	58	19.00	14,500	17.48
03074300	Lick Run near Hopwood	39 52	79 42	3.80	1.56	3.3	4.70	824	3.14
03074500	Redstone Creek at Waltersburg	39 59	79 46	73.7	.62	52	13.09	6,950	12.47
03078000	Casselman River at Grantsville, MD	39 42	79 08	62.5	1.65	64	9.70	7,060	8.05
03078500	Big Piney Run near Salisbury	39 44	79 03	24.5	2.10	15	7.90	5,570	5.80
03079000	Casselman River at Markleton	39 52	79 14	382	1.86	310	12.80	34,900	10.94
03080000	Laurel Hill Creek at Ursina	39 49	79 19	121	1.40	140	11.00	11,500	9.60
03081000	Youghiogheny River below Confluence	39 50	79 22	1,029	2.57	1,200	18.60	58,800	16.03
03082200	Poplar Run near Normalville	40 01	79 26	9.27	2.40	9.1	8.35	1,880	5.95
03082500	Youghiogheny River at Connellsville	40 01	79 36	1,326	2.92	1,500	19.60	73,000	16.68
03083000	Green Lick Run at Green Lick Reservoir	40 06	79 30	3.07	.57	2.5	3.35	1,250	2.78
03083600	Gillespie Run near Sutersville	40 14	79 49	4.04	.67	2.1	7.90	1,130	7.23
03084000	Abers Creek near Murrysville	40 27	79 43	4.39	1.62	2.2	7.90	1,520	6.28
03084500	Turtle Creek at Trafford	40 23	79 46	55.9	1.15	33	11.70	7,000	10.55
03085500	Chartiers Creek at Carnegie	40 24	80 06	257	1.40	152	14.90	16,500	13.50
03086100	Big Sewickley Creek near Ambridge	40 36	80 10	15.6	3.30	7.6	10.10	2,610	6.80
03100000	Shenango River near Turnersville	41 31	80 28	152	5.80	78	16.50	10,600	10.70
03101000	Sugar Run at Pymatuning Dam	41 30	80 28	9.34	.44	2.6	6.53	2,530	6.09
03102500	Little Shenango River at Greenville	41 25	80 23	104	1.57	59	14.20	8,550	12.63
03103000	Pymatuning Creek near Orangeville	41 19	80 29	169	2.35	63	12.50	9,620	10.15
03104000	Shenango River at Sharon	41 14	80 31	608	3.00	300	20.40	30,400	17.40
03104500	Shenango River at New Castle	41 00	80 21	792	2.14	380	16.50	31,100	14.36
03106000	Connoquenessing Creek near Zelienople	40 49	80 15	356	1.82	190	16.10	20,860	14.28
03108000	Raccoon Creek at Moffatts Mill	40 38	80 20	178	1.86	84	12.50	13,400	10.64
03111150	Brush Run near Buffalo	40 12	80 24	10.3	2.23	3.7	9.90	2,260	7.67
04213040	Raccoon Creek near West Springfield	41 57	80 27	2.53	1.67	1.3	8.70	602	7.03
04213200	Mill Creek at Erie	42 06	80 05	9.16	8.67	5.6	13.70	1,930	5.03

Table 2.--Summary of gaging-station data--Continued

[°, degrees; ', minutes; mi^2, square miles; ft, feet; ft^3/s, cubic feet per second]

Station number	Station name	Lati-tude (°,')	Longi-tude (°,')	Drainage area (mi^2)	Median flow		100-year flood		Depth of 100-year flood above median stage (ft)
					Stage (ft)	Discharge (ft^3/s)	Stage (ft)	Discharge (ft^3/s)	
	AREA D								
01542810	Waldy Run near Emporium	41 35	78 18	5.24	3.47	2.7	6.80	945	3.33
03011800	Kinzua Creek near Guffey	41 56	78 43	46.4	2.45	45	9.15	6,360	6.70
03012500	Allegheny River near Kinzua	41 51	79 00	2,179	8.40	2,100	20.20	65,500	11.80
03015000	Conewango Creek at Russell	41 56	79 08	816	3.38	880	13.00	24,300	9.62
03015080	Akeley Run near Russell	41 56	79 06	9.64	.43	9.5	4.70	1,150	4.27
03015280	Jackson Run near North Warren	41 54	79 14	12.8	1.98	11.8	5.55	1,110	3.57
03015390	Hare Creek near Corry	41 56	79 39	12.3	3.40	11.5	7.05	2,300	3.65
03015500	Brokenstraw Creek at Youngsville	41 51	79 19	321	2.40	280	13.50	17,000	11.10
03017500	Tionesta Creek at Lynch	41 36	79 03	233	1.60	235	11.35	15,600	9.75
03017800	Minister Creek near Truemans	41 37	79 09	10.8	.65	9.5	5.20	1,150	4.55
03019000	Tionesta Creek at Nebraska	41 28	79 23	469	1.38	390	10.68	20,000	9.30
03020440	West Branch Caldwell Creek near Grand Valley	41 46	79 34	4.37	5.82	4.0	9.40	640	3.58
03020500	Oil Creek at Rouseville	41 29	79 42	300	2.45	260	11.60	19,100	9.15
03021350	French Creek at Wattsburg	42 01	79 47	92.0	3.97	110	13.75	9,240	9.78
03021410	West Branch French Creek near Lowville	42 05	79 51	52.3	3.90	60	11.10	6,370	7.20
03021500	French Creek at Carters Corners	41 57	79 53	208	2.93	180	13.20	20,000	10.27
03021700	Little Conneautee Creek near McKean	41 56	80 05	3.60	1.35	2.2	4.82	893	3.47
03022500	French Creek at Saegerstown	41 43	80 09	629	3.25	510	17.75	26,000	14.50
03022540	Woodcock Creek at Blooming Valley	41 41	80 03	31.1	5.96	29.4	11.60	3,080	5.64
03023500	French Creek at Carlton	41 28	80 01	998	1.72	830	15.15	31,700	13.43
03024000	French Creek at Utica	41 26	79 57	1,028	3.00	920	15.35	32,000	12.35
03025000	Sugar Creek at Sugarcreek	41 26	79 53	166	2.82	135	12.50	11,400	9.68
03025200	Patchel Run near Franklin	42 15	79 51	5.69	3.04	5.2	5.88	1,140	2.84
03026500	Sevenmile Run near Rasselas	41 38	78 35	7.84	2.04	7.0	5.73	3,250	3.69
03029400	Toms Run at Cooksburg	41 20	79 13	12.6	1.38	7.9	5.50	1,140	4.12
03104760	Harthegig Run near Greenfield	41 11	80 20	2.26	1.17	.82	4.00	560	2.83
03106500	Slippery Rock Creek at Wurtemburg	40 53	80 14	398	1.28	250	13.30	21,300	12.02

Table 2.--Summary of gaging-station data--Continued

[°, degrees; ', minutes; mi^2, square miles; ft, feet; ft^3/s, cubic feet per second]

Station number	Station name	Latitude (°,')	Longitude (°,')	Drainage area (mi^2)	Median flow Stage (ft)	Median flow Discharge (ft^3/s)	100-year flood Stage (ft)	100-year flood Discharge (ft^3/s)	Depth of 100-year flood above median stage (ft)
	AREA E								
01451500	Little Lehigh Creek near Allentown	40 35	75 29	80.8	2.26	55.0	13.30	14,000	11.04
01452000	Jordan Creek at Allentown	40 37	75 29	75.8	2.87	58	10.53	13,300	7.66
01452300	East Branch Monocacy Creek near Bath	40 43	75 22	5.35	1.96	.85	7.25	1,490	5.29
01452500	Monocacy Creek at Bethlehem	40 38	75 22	44.5	2.34	36	10.17	5,660	7.83
01454600	Polk Valley Run at Hellertown	40 34	75 20	2.14	1.65	.35	5.40	857	3.75
01470720	Maiden Creek trib. at Lenhartsville	40 34	75 53	7.46	2.36	4.8	7.72	2,550	5.36
01470756	Maiden Creek at Virginville	40 31	75 53	159	2.48	153	18.40	15,500	15.92
01470779	Tulpehocken Creek near Bernville	40 25	76 10	66.5	2.08	79	13.15	9,300	11.07
01470960	Tulpehocken Creek at Blue Marsh Dam near Reading	40 22	76 01	175	2.71	150	13.87	17,800	11.16
01472174	Pickering Creek near Chester Springs	40 05	75 38	5.98	2.46	6.1	5.61	4,720	3.15
01480300	West Branch Brandywine Creek near Honey Brook	40 04	75 52	18.7	1.35	12	11.50	8,480	10.15
01480500	West Branch Brandywine Creek at Coatesville	39 59	75 50	45.8	3.98	46	11.90	13,630	7.92
01480675	Marsh Creek near Glenmoore	40 06	75 45	8.57	1.62	7.9	7.10	2,020	5.48
01480680	Marsh Creek near Lyndell	40 04	75 44	17.8	2.23	13	9.30	3,240	7.07
01480800	East Branch Brandywine Creek at Downingtown	40 00	75 42	81.6	.50	56	11.40	9,690	10.90
01546500	Spring Creek near Axemann	40 53	77 48	87.2	2.43	61	7.03	4,460	4.60
01547100	Spring Creek at Milesburg	41 56	77 47	142	2.64	150	13.60	8,790	10.96
01547200	Bald Eagle Creek below Spring Creek at Milesburg	40 57	77 47	265	.89	220	10.93	15,300	10.04
01547700	Marsh Creek at Blanchard	41 04	77 36	44.1	2.54	21	7.39	5,730	4.85
01548000	Bald Eagle Creek at Beech Creek Station	41 04	77 34	559	2.21	430	15.51	28,650	13.30
01553050	White Deer Hole Creek near Elimsport	41 07	77 04	18.2	4.84	22	11.83	4,200	6.99
01553130	Sand Spring Run near White Deer	41 04	77 05	4.93	3.01	6.4	5.75	1,630	2.74
01565000	Kishacoquillas Creek at Reedsville	40 39	77 35	164	2.53	110	15.00	13,200	12.47
01565700	Little Lost Creek near Oakland Mills	40 36	77 19	6.52	4.47	2.9	8.80	1,630	4.33
01566500	Cocolamus Creek near Millerstown	40 34	77 07	57.2	2.17	34	9.82	7,520	7.65
01570000	Conodoguinet Creek near Hogestown	40 15	77 01	470	1.80	350	14.83	24,700	13.03
01571500	Yellow Breeches Creek near Camp Hill	40 13	76 54	216	1.35	200	16.20	13,700	14.85
01573086	Beck Creek near Cleona	40 19	76 29	7.87	3.61	5.2	10.20	3,280	6.59
01603500	Evitts Creek near Centerville	39 47	78 39	30.2	1.44	14	6.55	4,890	5.11

[1] Additional information on the locations and records of active gaging stations is given in Water Resources Data for Pennsylvania (U.S. Geological Survey, 1984).

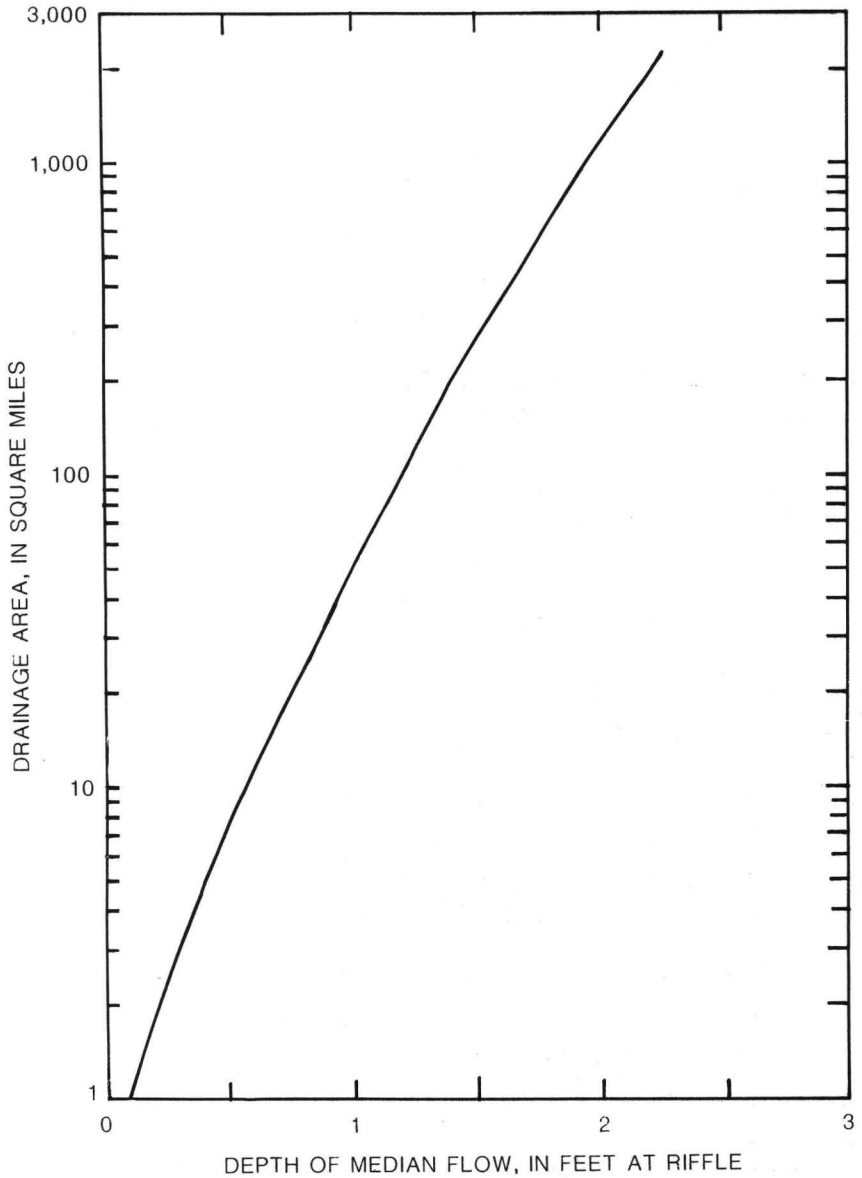

Figure 2.--Relation between drainage area and median depth of flow on riffle.

Application of Results

Determinations of total flood depth are required if flood-inundation maps are to be prepared or if profiles are to be plotted to show flood depth over the streambed. The procedure for estimating the depth of the 100-year flood above median stage, at a given site on a stream, is as follows:

1. Determine the drainage area, in square miles, of the basin above the site of interest.

2. Determine the hydrologic area for the site from plate 1.

3. Compute the 100-year flood depth (D_{100}) from the appropriate areal equation (table 1) or, alternatively, from the appropriate graph in figure 1.

In order to determine the total 100-year depth at the site of interest, it is necessary to add the depth at median stage to the D_{100} depth, as determined by the above procedure. The depth at median stage can be estimated from figure 2, which is of statewide applicability.

Elevations of the 100-year flood at, or in the vicinity of, the site of interest can be determined by adding the total 100-year depth to the elevation of the streambed at its lowest point on natural riffles. Elevations for such riffle points are best determined by spirit- or electronic-level surveys. High-quality contour maps with contour intervals of 2 feet or less can provide adequate elevation control for flood profiling or mapping of most small, steep-gradient streams.

Flood profiles and maps of lesser accuracy can be developed from 7-1/2 minute U.S. Geological Survey topographic maps, which are available for all of Pennsylvania at contour intervals of 10 or 20 feet. It is commonly assumed that elevations of median stages coincide with the elevations of contour lines where they cross a stream. Thus, depths (D_{100}) estimated from figure 1 can be added to contour elevations to estimate 100-year-flood elevations at the points of contour crossings. Elevations for flood profiles that are developed in this manner can be no more accurate than the topographic map used. Third-order leveling at several localities in Pennsylvania has shown that position errors for these contour lines commonly exceed a quarter of a contour interval, and some may exceed half of a contour interval.

Accuracy and Limitations

The accuracy of each flood-depth equation (table 1) was measured by comparing the 100-year depth computed through use of the equation with observed depths (table 2) at gaged sites in the delineated (pl. 1) hydrologic areas. Standard errors of estimate for the five equations range from 16 to 28 percent, as shown in table 1. Two out of three depth (D_{100}) estimates can be expected to be in error by no more than the standard error of the equation used.

The depth equations should be applied only for drainage areas that fall within the size ranges shown in table 1. Each applicable range closely matches the range of drainage-area values used in the respective regression. The upper limits of the applicable ranges for areas A and E (325 and 560 mi^2, respectively) approximate those of the largest unregulated streams in these two areas. Most streams that drain more than 2,200 mi^2--the upper limit of the applicable ranges for areas B, C, and D--are regulated.

Depth estimates for sites whose basins lie in more than one of the delineated hydrologic areas (pl. 1) can be proportioned according to the fraction of basin within each area.

The depth equations should not be applied for streams that have been channeled or are highly regulated. The equations should not be used for streams that drain urbanized areas or for those that have more than 15 percent of their drainage controlled by reservoirs, ponds, or swamps. This suggested limit on the percentage of controlled area is based on studies by Aron and

Kibler (1981, fig. 5-3). Their studies show the reduction in 100-year discharge resulting from 15 percent of controlled area is usually in the range of 5 to 13 percent. The corresponding range in percent of reduction in flood depths will be somewhat less. The relationship for area A incorporates the moderating effects of ponds and swamps on 100-year flood depths in streams that drain the small watersheds that are typical of the Pocono Mountain area.

A constriction or a hydraulic structure, such as a bridge, culvert, or dam, will usually cause a backwater condition on the upstream side of the constriction or structure. The 100-year depth in the reach of backwater will usually exceed that predicted through use of figure 2 and the areal equation of table 1.

The standard error of the median-depth relation (fig. 2) is 0.25 ft. About two-thirds of median-depth estimates made through use of this figure will be in error by less than that amount; however, about 90 percent of measured median depths for drainage areas of less than 10 mi^2 are within 0.25 ft of the depths indicated by figure 2. For drainage areas greater than 10 mi^2, about 96 percent of median-depth estimates will be in error by less than two standard errors of estimate, or 0.50 ft. Median-depth relations for the five individual hydrologic areas (pl. 1) showed no significant deviation from figure 2, which is based on all available riffle-depth data for the group of gaging stations (table 2).

SUMMARY

Estimates of 100-year flood depth on the riffles in a natural, unregulated Pennsylvania stream can be made by using two relations presented in this report.

Standard errors of estimate for the relations between 100-year depths above median stage and drainage area range from 16 to 28 percent for the five delineated hydrologic areas. An additional error of less than 0.25 ft is typical for estimates of the median-depth component of 100-year depths on riffles.

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