FLOOD-DISCHARGE PROFILES OF SELECTED STREAMS IN ROCKLAND COUNTY, NEW YORK

By Richard Lumia

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CONVERSION FACTORS AND ABBREVIATIONS

The following factors may be used to convert inch-pound units of measurement in this report to International Systems of Units (SI).

Multiply inch-pound unit	By	To obtain SI unit
	Length	
inch (in.)	25.40	millimeter (mm)
	0.0254	meter (m)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow	
cubic foot per second (ft^3/s)	0.0283	cubic meter per second (m^3/s)
	Slope	
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)

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ABSTRACT

Flood-discharge profiles of 10 streams in Rockland County at six recurrence intervals ranging from 2 to 100 years are presented. Synthetic flood-frequency estimates were derived for each of nine rainfall-runoff sites from calibrated models; observed flood-frequency estimates were derived for three sites having long-term discharge records. A variance-weighting technique was applied to weight the synthetic flood-frequency estimates with the observed (gaged) estimates and with estimates computed for each site from regional regression equations. For ungaged locations on the 10 streams, flood-frequency relationships were derived from regional regression equations previously developed for New Jersey streams. Regional analysis indicated the most significant basin characteristics to be drainage area, streambed slope, storage, and amount of impervious cover. A method for refining (weighting) flood-frequency estimates for selected ungaged locations near rainfall-runoff and (or) long-term gaged sites is given. This report explains analytical methods, describes basin characteristics at several locations along each stream, and gives a table of peak discharges for the six recurrence intervals at 13 gaging stations. The profiles enable rapid determination of flood discharge at all locations on these streams having a drainage area greater than 1 square mile.

INTRODUCTION

Rockland County, in southeastern New York, has experienced severe flooding on several streams. The U.S. Geological Survey, in cooperation with the Rockland County Drainage Agency, used available data to analyze flooding along 10 streams in the county and to develop flood-discharge profiles (flood discharge at successive locations along the stream) at recurrence intervals of 2, 5, 10, 25, 50, and 100 years. This report presents the results of that study.

Purpose and Scope

The objectives of this study were to (1) describe procedures for estimating flood-magnitude and frequency at rainfall-runoff sites, at gaged sites, and at ungaged locations; (2) describe techniques for refining (weighting) flood-discharge estimates; and (3) develop flood-discharge profiles for the six recurrence intervals for the 10 streams studied.

This report presents flood-discharge profiles for seven major streams and three of their tributaries and describes the methods of computation. From these profiles, the magnitude and frequency of flooding at any location along these streams with a drainage area exceeding 1 mi2 can readily be determined. An appendix listing basin characteristics at selected locations along each stream, and a table of flood-discharge estimates for sites on each stream, are included.

Description of Area

Rockland County, a triangular 180-mi^2 area in southeastern New York State, is bounded on the east by the Hudson River, on the northwest by Orange County, and on the southwest by New Jersey (fig. 1).

The county's population in 1970 was 229,900 (Rockland County Planning Board, 1974) and had increased to 259,550 by 1980 (U.S. Bureau of Census, oral commun., 1981). The population is distributed among 5 towns and 13 villages. Principal physiographic features are the Hudson River, numerous lakes and swamps, and the Palisades and Ramapo mountain ranges.

The climate is humid continental. Average annual precipitation is 48 inches with fairly uniform distribution throughout the year. Coastal storms occur throughout the year, and severe thunderstorms are common during summer.

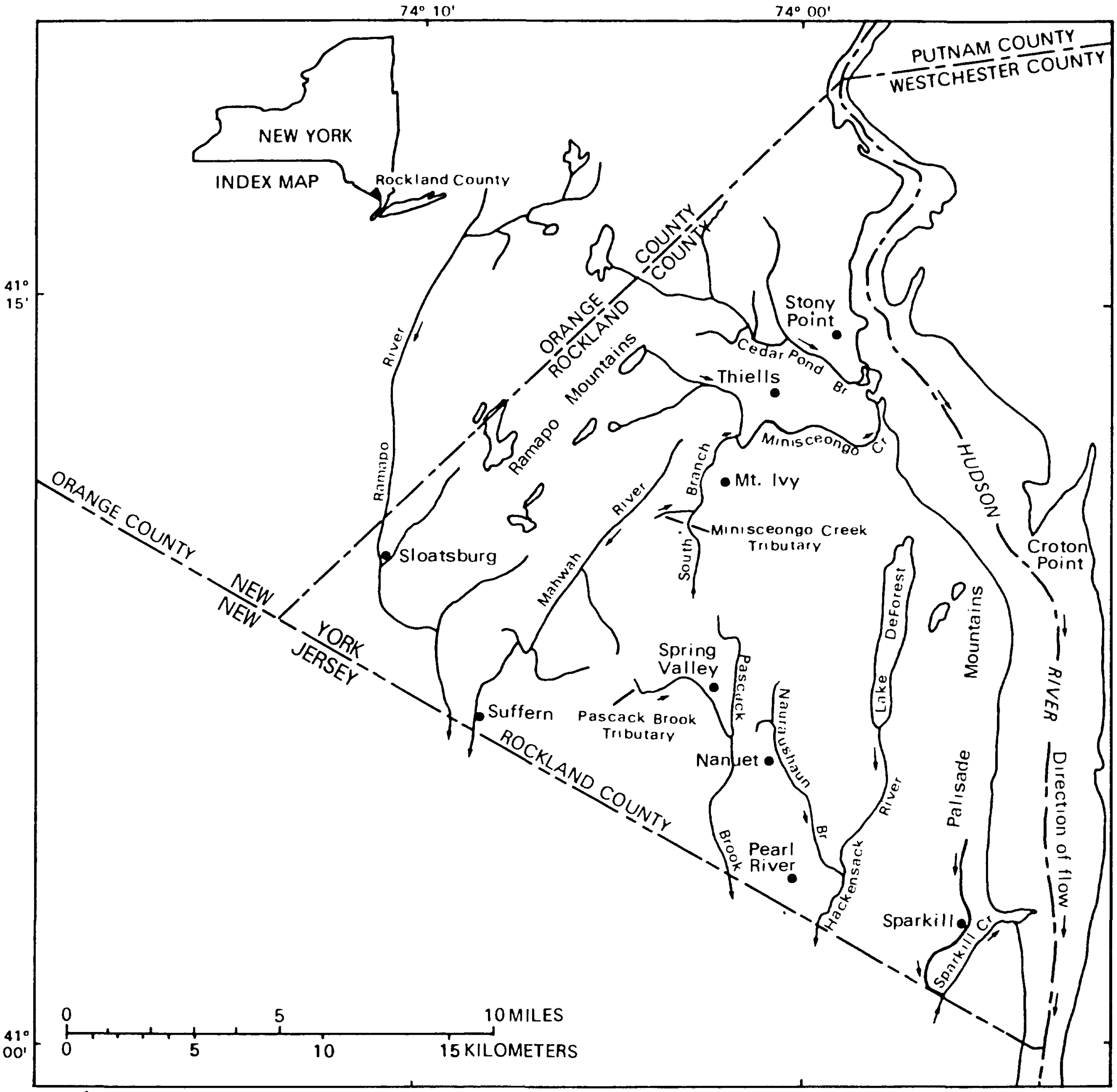
Approximately one-third of Rockland County is drained by eastward-flowing streams that are tributary to the Hudson River; the remainder of the county is drained by southward-flowing streams entering the Hackensack and Passaic River systems of New Jersey (fig. 1). The names of the 10 streams studied, the drainage area, and period of record of each gaged site are listed in table 1. Locations of the streams are shown in figure 1 and in plate 1; plate 1 also shows locations of gage sites and river-mile points used to construct the final flood-discharge profiles (p. 19-26).

Most of Rockland County is underlain by crystalline bedrock mantled by unconsolidated materials. The soil cover includes three types of deposits.--local stream and lake deposits of sand, gravel, silt, and clay; stratified deposits of sand and gravel, distributed primarily along the major stream valleys; and an unstratified and poorly sorted mixture ranging from clay particles to large boulders. The unstratified and poorly sorted material forms the soil cover in most of the county.

Previous Studies

Regional flood-frequency equations for New York and New Jersey are given in U.S. Geological Survey reports described below.

Zembrzuski and Dunn (1979) described techniques for estimating magnitude and frequency of floods on rural, unregulated streams in New York. The discharges presented herein (based on the New Jersey equations) are preferred over those calculated by the 1979 New York methods because (1) the 1979 analyses apply to rural basins, whereas many of the Rockland County basins are extensively urbanized; (2) analyses of flood-frequency estimates computed from the 1979 equations for rural Rockland County streams indicate a significant bias that resulted from the equations' failure to account for basin storage, which is a significant factor in many Rockland County basins; (3) few Rockland



Base from U.S. Geological Survey
State base map, 1974

Figure 1.--Location of streams in study area. (Modified from Lumia, 1982.)

County gaging stations were used in the 1979 regression analyses; and (4) much additional information became available for this study.

The flood-frequency equations for New Jersey streams (Stankowski, 1974) were used in the Rockland County analysis because (1) they include percentages of lakes, ponds and swamps, and impervious cover within each watershed; (2) they are based partly on data from streams common to New Jersey and Rockland County; and (3) Rockland County is geologically similar to parts of northern New Jersey.

Table 1.--Drainage area and period of record of gaged sites on 10 Rockland County streams.

[Stream locations are shown in figure 1; site locations are shown on plate 1.]

Stream name and site number[1]	Drainage area (mi^2)	Period of record
MAJOR STREAMS		
Cedar Pond Brook		
01374440 at Stony Point	17.3	1960-68
Minisceongo Creek		
01374480 at Thiells	15.1	1960-62 (1977-79)[2]
Sparkill Creek		
01376280 at Sparkill	10.7	1960-68 (1975-79)[2]
Nauraushaun Brook		
01376842 at Nanuet	2.12	(1975-79)[2]
01376855 at Pearl River	5.97	(1975-79)[2]
Pascack Brook		
01377260 near Pearl River	8.39	(1975-79)[2]
Ramapo River		
01387250 at Sloatsburg[3]	60.1	1956, 60-63, (1975-79)[2]
01387500 at Mahwah, N.J.	118	1962-current
Mahwah River		
01387450 near Suffern	12.3	1959-current (1975-79)[2]
TRIBUTARY STREAMS		
South Branch Minisceongo Creek tributary		
01374456 near Mt. Ivy	0.90	(1976-79)[2]
South Branch Minisceongo Creek		
01374454 near Mt. Ivy	1.84	--
01374458 at Mt. Ivy	5.19	(1976-79)[2]
01374460 at Letchworth Village	5.80	1960-76
Pascack Brook tributary		
01377196 at Spring Valley	3.89	(1977-79)[2]

[1] Numbers represent U.S. Geological Survey gaging-station designation.
[2] Period of operation as rainfall-runoff site.
[3] Rainfall-runoff model not used in this study.

METHOD of STUDY

The flood-discharge profiles presented herein are a result of a detailed flood-frequency analysis of data on the 10 streams studied. The analysis was based on records from nine rainfall-runoff sites with 4 to 5 years of data (table 1), three gaged sites with 10 or more years of discharge data, and regional regression equations developed by Stankowski (1974). The flood-frequency estimates for each recurrence interval were derived for gaged and ungaged sites by the following procedures:

(1) Recording-gage sites:

a. Nine rainfall-runoff sites.--"Synthetic" flood-frequency estimates were computed through previously calibrated models (Lumia, 1982) that were used in conjunction with long-term rainfall data;

b. Three gaged sites (including two of the above sites).--"Observed" flood-frequency estimates were computed from the long-term record of annual peak discharges;

c. The 10 sites in (a) and (b) above.--Additional flood-frequency estimates were computed from regional regression equations (Stankowski, 1974);

The estimates computed in steps a, b, and c above were then combined through variance-weighting techniques to produce "best" weighted estimates for each recording site.

(2) Selected ungaged locations (6 to 13 on each stream).--In general, computations were made for every stream mile above mouth or county line. For locations having no nearby recording site, flood-frequency estimates were computed from the regional regression equations of Stankowski (1974). For ungaged locations near recording sites (1a and 1b above), flood-frequency estimates were refined through a drainage-area-weighting procedure.

The final weighted flood-frequency estimates described above were then plotted against stream mile to form the final flood-discharge profiles (figs. 2A-2J). The basin characteristics measured at recording sites and selected ungaged locations are given in the appendix. A detailed discussion of the above procedures and methods is presented below.

FLOOD-FREQUENCY ESTIMATES

Flood-frequency analyses define the relationship of flood-peak magnitude to exceedance probability or recurrence interval. Exceedance probability is the percent chance that a flood of given magnitude will be exceeded in any one year; recurrence interval is the reciprocal of exceedance probability and is the average number of years between occurrences. For example, a flood having an exceedance probability of 0.01 (1 percent) has a recurrence interval of 100 years. Recurrence intervals imply no regularity of occurrence; a 100-year flood might be exceeded in two or more consecutive years or it might not be exceeded in a 100-year period.

Estimates of flood frequency at several locations along each of the 10 streams (table 1) were made for 2-, 5-, 10-, 25-, 50-, and 100-year recurrence intervals. Analyses were limited to sites having a drainage area greater than 1 mi^2 except station 01374456 (South Branch Minisceongo Creek Tributary near Mt. Ivy), which has a drainage area of 0.90 mi^2. Flood-frequency estimates were derived by the procedures given on the preceding page; the procedures and techniques used to compute and weight the estimates are described below.

Flood-Frequency Estimates for Rainfall-Runoff Sites

An analysis was made to define flood-frequency relationships for rainfall-runoff sites. Rainfall-runoff models were calibrated for nine sites (table 1) by Lumia (1982), and the models were used in conjunction with long-term rainfall data to generate a long-term record of synthetic peak discharges at each location. The synthetic peak-discharge data were obtained through the U.S. Army Corps of Engineers HEC-1 model (1973).

Long-term, unit (60-minute interval) storm rainfall data for a 59-year period (1920-78) were obtained from the National Weather Service. The data were recorded at a station in Central Park in New York City, the site nearest Rockland County (about 14 mi away) having sufficient recorded unit rainfall data. An interpolation procedure was used to reduce the unit rainfall to 30-minute values. The applicability of Central Park rainfall data to Rockland County was investigated by comparing hourly rainfall data recorded in Central Park during 76 storms during 1945-51 with concurrent records from Spring Valley in Rockland County (fig. 1). Storm intensites of 1, 3, 6, 12, and 24 hours, and total storm rainfalls at the two sites, were statistically compared. The frequency distributions for each intensity were similar, which suggests that for long-term analysis, rainfall at the Central Park gage is representative of that within Rockland County.

Unit-rainfall data from the storms associated with the 7 to 10 largest daily rainfalls each year were used with the models to generate 7 to 10 peak discharges for each year at the nine sites. The 7 to 10 largest rainfalls each year were chosen to ensure that the storm causing the annual maximum discharge at each site would be included. The computed annual maximum peaks were fitted to a log-Pearson Type III distribution to calculate synthetic flood-frequency data for each of the nine sites. Guidelines suggested by the Interagency Advisory Committee on Water Data (U.S. Geological Survey, 1983) were followed in developing these synthetic flood-frequency estimates.

Variance of flood-frequency estimates represents the amount of dispersion of the annual peak discharges around their mean and is equivalent to the square of the standard deviation. The synthetic flood-frequency relationships tend to exhibit a loss of variance because of the models' smoothing effect in the calibration process. A watershed is subject to many secondary factors that represent a part of the variance in the observed data that cannot be reproduced by the model. Kirby (1975) suggests a method for adjusting the synthetic frequency estimates to account for this loss of variance; this method was applied to the standard deviation of the log-Pearson Type III distribution of synthetic annual peak discharges at the nine modeled sites as follows:

$$I_V' = \frac{I_V}{r} \qquad (1)$$

where: I_V' = standard deviation of logarithms of synthetic annual peak discharges adjusted for loss of variance,
I_V = unadjusted standard deviation of logarithms of synthetic annual peak discharges, and
r = correlation coefficient between observed and simulated peak discharges from model calibration.

The use of I_V' to compute variances of the synthetic flood-frequency estimates is discussed in the section "Weighting of Flood-Frequency Estimates for Rainfall-Runoff and Long-term Gaged Sites."

Flood-Frequency Estimates for Long-Term Gaged Sites

Three of the streams studied had sites with 10 or more years of peak discharge record; "observed" flood-frequency estimates were developed for these sites from guidelines suggested in Bulletin 17B of the Interagency Advisory Committee on Water Data (U.S. Geological Survey, 1983). The recorded annual peak discharges were fitted to a log-Pearson Type III distribution after the station and regional (generalized) skews were weighted, as described in Bulletin 17B. The details of analysis at each site are discussed below.

South Branch Minisceongo Creek at Mt. Ivy.--Peak-discharge data were recorded at Letchworth Village (station 01374460) for 17 years (1960-76). These observed annual peak-discharge values were adjusted for drainage area and transferred upstream to the Mt. Ivy site (01374458) and were then combined with the Mt. Ivy annual peak-flow data (1976-79). These combined data (1960-79) were used in a log-Pearson Type III analysis to obtain an "observed" flood-frequency relationship.

Mahwah River near Suffern.--This site (01387450) had 22 years of peak-discharge data (1959-80) and was also operated as a rainfall-runoff gage during 1975-79. The recorded annual peak discharges (1959-80) were used in a log-Pearson Type III analysis to obtain an "observed" flood-frequency relationship for this site.

Ramapo River at Sloatsburg.--This site (01387250) had 10 years of peak-discharge data. A two-station comparison procedure, as outlined in Bulletin 17B (U.S. Geological Survey, 1983), was used to compute the flood-frequency relationship for this site. A 57-year record (1923-79) of annual peaks at the Ramapo River near Mahwah, N.J. gage (01387500, drainage area 118 mi^2) was used in a regression analysis with the Sloatsburg record to adjust the logarithmic mean and standard deviation of the 10-year Sloatsburg record. The adjustment was then used to extend the short-term record and compute an "observed" flood-frequency relationship for the Sloatsburg site. On the basis of an equivalent-years-of-record procedure suggested in Bulletin 17B, the accuracy of the Sloatsburg estimates computed from the adjusted statistics is equivalent to that which would result from a 44-year record of observed peaks. The equivalent-years-of-record procedure reflects the accuracy of the adjusted mean, but Bulletin 17B recommends that the computed equivalent years also be used as an estimate of the equivalent years of record for the various exceedance-probability floods. The two-station comparison was used in place of the rainfall-runoff model developed for the Sloatsburg site (Lumia, 1982) because the basin is relatively large (60.1 mi^2) and rainfall over the basin highly variable.

Flood-frequency estimates for the rainfall-runoff and long-term gaged sites were also computed by the regional regression equations (Stankowski, 1974); these estimates were weighted with those obtained by the other methods, as discussed below.

Weighting of Flood-Frequency Estimates for Rainfall-Runoff and Long-Term Gaged Sites

The flood-frequency estimates computed for rainfall-runoff and long-term gaged sites were weighted by a procedure described by the Interagency Advisory Committee on Water Data, Bulletin 17B (U.S. Geological Survey, 1983, p. 8-1), which states:

> "If two independent estimates are weighted inversely proportional to their variance, the variance of the weighted average is less than the variance of either estimate."

The variance-weighting procedure was applied to flood-frequency data for rainfall-runoff sites and long-term gaged sites as described below.

Rainfall-Runoff Sites

For these nine sites, the variance-weighting technique was applied as follows:

$$\log Q_W = \frac{\log Q_S\ (V_R) + \log Q_R\ (V_S)}{(V_R + V_S)} \qquad (2)$$

where: Q_W = weighted flood-discharge estimate for the site,
Q_S = synthetic flood-discharge estimate for the site,
Q_R = regional regression flood-discharge estimate for the site,
V_S = variance of the synthetic estimate, in log units, and
V_R = variance of the regression estimate, in log units.

The variances of the regional regression equations (V_R) ranged from 0.041 (2-year flood) to 0.051 (100-year flood), in log units. The variances of the log-Pearson Type III estimates (V_S) based on the synthetic annual peaks were computed according to a formula given by Hardison (1971):

$$V_S = \frac{(RI_v)^2}{N} \qquad (3)$$

where: R = factor relating standard error of a T-year flood to I_V and N; R is a function of skewness (Hardison, 1971, table 2),
I_V = index of variability equal to standard deviation of logarithms of annual peak discharges (obtained from the log-Pearson Type III frequency distribution for each site), and
N = number of annual events.

To compute more accurately the variance of the synthetic annual peak discharges, an adjustment was made to N in equation 3 in accordance with two studies of rainfall-runoff modeling and associated errors in resulting flood-frequency estimates (Thomas, 1982; Lichty and Liscum, 1978). The adjusted values of N, termed equivalent years of record (N'), are shown below:

Recurrence interval (years)	Equivalent years of record N' (years)
2	6
5	11
10	14
25	18
50	20
100	20

N' gives a more realistic indication of the time sampling error in the synthetic estimates and provides for a better appraisal of their accuracy. Incorporating this adjustment and substituting I_V' from equation 1 for I_V, equation 3 becomes:

$$V_S = \frac{(RI_V')^2}{N'} \qquad (4)$$

Variances of the synthetic flood-frequency estimates for each recurrence interval were then computed from equation 4. Average variance of the synthetic flood-frequency estimates at the nine previously modeled sites ranged from 0.009 (2-year flood) to 0.021 (100-year flood), in log units. This translates to a range in standard error of 22 percent (2-year flood) to 34 percent (100-year flood). At each rainfall-runoff site not having additional gaged data (total of 10 or more years of recorded peak discharges), weighted flood-discharge estimates (Q_W) were computed for each recurrence interval through equation 2 and are listed in table 2.

Long-Term Gaged Sites

For the three sites having 10 or more years of recorded peak discharges, the weighting technique was applied as follows:

South Branch Miniscongo Creek at Mt. Ivy (01374458) and Mahwah River near Suffern (01387450).--Three flood-frequency relationships were computed for each of these sites from synthetic data, long-term gaged data, and the regression equations of Stankowski (1974). The final weighted estimates (Q_W) were derived by simultaneously weighting the "synthetic" estimates (Q_S), the regional regression estimates (Q_R), and the long-term gage ("observed") estimates (Q_G) by the following equation:

$$\log Q_W = \log Q_S(a) + \log Q_R(b) + \log Q_G(c) \qquad (5)$$

where: $a = \dfrac{V_R V_G}{V_S V_R + V_R V_G + V_S V_G}$

$b = \dfrac{V_S V_G}{V_S V_R + V_R V_G + V_S V_G}$

$c = \dfrac{V_S V_R}{V_S V_R + V_R V_G + V_S V_G}$

Q_G = long-term gaged ("observed") flood-discharge estimate for the site,
V_G = variance of the long-term gaged estimate, in log units.

Ramapo River at Sloatsburg (01387250).--The weighted flood-frequency estimates for this site (Q_W) were computed by weighting the long-term gage ("observed") estimates (Q_G), determined through the two-station comparison, with the regional regression estimates (Q_R) by the following equation:

$$\log Q_W = \frac{\log Q_G(V_R) + \log Q_R(V_G)}{(V_G + V_R)} \qquad (6)$$

Comparison of Final Estimates

Final flood-discharge estimates at the six recurrence intervals for each recording gage site are listed in table 2. No consistent pattern of differences between Q_S and Q_R values is apparent. Q_G values are generally larger than corresponding Q_S or Q_R values and may be a combined result of (1) the period of record at gaged sites used to compute statistics for the log-Pearson analyses, (2) the smoothing effect during the rainfall-runoff modeling process, and (3) the data used for the regression analysis, as discussed by Stankowski (1974). Because only two of the sites (01374458 and 01387450) listed in table 2 include discharge values Q_S, Q_R, and Q_G, a detailed analysis of the discharge differences was not feasible.

Flood-Frequency Estimates for Ungaged Locations

An attempt was made to develop flood-frequency relationships for selected ungaged locations on the 10 streams studied by developing regional regression relationships from data from rainfall-runoff sites and long-term gaged sites. No useful relationships were found, however, because of the small sample size (10 sites) and significant range in basin-characteristic values at the sites. Therefore, estimates were made based on regional regression equations developed by Stankowski (1974).

Table 2.--Flood-discharge estimates at selected recurrence intervals for sites in Rockland County, N.Y.

[Site locations are given in plate 1; dashes indicate no data available for computation.]

Station number	Station name	Recurrence interval (years)	Flood discharge[1] cubic feet per second			
			Q_S	Q_R	Q_G	Q_W
01374440	Cedar Pond Brook at Stony Point	2	---	559	---	559
		5	---	886	---	886
		10	---	1,260	---	1,260
		25	---	1,710	---	1,710
		50	---	2,090	---	2,090
		100	---	2,590	---	2,590
01374454	South Branch Minisceongo Creek near Mt. Ivy	2	---	209	---	209
		5	---	313	---	313
		10	---	424	---	424
		25	---	576	---	576
		50	---	693	---	693
		100	---	853	---	853
01374456	South Branch Minisceongo Creek tributary near Mt. Ivy	2	31	32	---	31
		5	47	52	---	48
		10	58	72	---	60
		25	76	103	---	80
		50	90	128	---	97
		100	107	160	---	119
01374458[2]	South Branch Minisceongo Creek at Mt. Ivy	2	75	113	129	110
		5	107	175	191	159
		10	131	241	235	194
		25	167	331	293	241
		50	197	409	337	284
		100	230	501	383	334
01374480	Minisceongo Creek at Thiells	2	586	374	---	553
		5	858	588	---	818
		10	1,070	828	---	1,030
		25	1,370	1,120	---	1,330
		50	1,620	1,370	---	1,570
		100	1,900	1,670	---	1,840
01376280	Sparkill Creek at Sparkill	2	418	420	---	418
		5	610	631	---	613
		10	759	860	---	773
		25	973	1,150	---	998
		50	1,150	1,380	---	1,190
		100	1,350	1,680	---	1,430

[1] Q_S, computed from rainfall-runoff model data (synthetic estimates);
Q_R, computed from regional regression equations;
Q_G, computed from observed (gaged) peak discharges; and
Q_W, computed from weighting Q_S, Q_R, and (or) Q_G.

[2] Q_G estimates based on data from 01374460.

[3] Q_G estimates based on data from 01387500.

Table 2.--Flood-discharge estimates at selected recurrence intervals for sites in Rockland County, N.Y. (continued).

Station number	Station name	Recurrence interval (years)	Flood discharge cubic feet per second Q_S	Q_R	Q_G	Q_W
01376842	Nauraushaun Brook at Nanuet	2	154	202	---	162
		5	222	300	---	233
		10	273	403	---	294
		25	344	544	---	377
		50	401	650	---	453
		100	463	790	---	547
01376855	Nauraushaun Brook at Pearl River	2	944	384	---	828
		5	1,360	561	---	1,230
		10	1,650	749	---	1,490
		25	2,040	989	---	1,870
		50	2,330	1,180	---	2,110
		100	2,640	1,410	---	2,340
01377196	Pascack Brook tributary at Spring Valley	2	424	214	---	379
		5	590	319	---	539
		10	709	431	---	655
		25	872	578	---	808
		50	1,000	691	---	923
		100	1,140	833	---	1,040
01377260	Pascack Brook near Pearl River	2	906	432	---	813
		5	1,290	634	---	1,180
		10	1,570	849	---	1,450
		25	1,950	1,120	---	1,810
		50	2,250	1,340	---	2,050
		100	2,570	1,600	---	2,320
01387250[3]	Ramapo River at Sloatsburg	2	---	779	1,180	1,160
		5	---	1,200	2,130	2,060
		10	---	1,670	3,000	2,860
		25	---	2,220	4,410	4,070
		50	---	2,750	5,730	5,090
		100	---	3,360	7,320	6,240
01387450	Mahwah River near Suffern	2	509	318	522	501
		5	779	488	945	822
		10	990	674	1,330	1,080
		25	1,300	910	1,960	1,440
		50	1,550	1,120	2,550	1,730
		100	1,840	1,380	3,270	2,060
01387500	Ramapo River at Mahwah, N.J.	2	---	2,000	2,610	2,590
		5	---	3,020	4,440	4,360
		10	---	4,180	6,040	5,890
		25	---	5,430	8,590	8,210
		50	---	6,610	10,900	10,200
		100	---	8,010	13,700	12,400

Locations Without Nearby Gaged Sites

A multiple regression analysis was used by Stankowski (1974) to develop relationships between the T-year flood discharges (T = 2-, 5-, 10-, 25-, 50-, and 100-year recurrence intervals) and basin characteristics. The analysis revealed that the significant characteristics were drainage area, main-channel slope, surface storage (in lakes, ponds, swamps), and percentage of manmade impervious cover. The regional regression equations developed by Stankowski (1974) are:

$$Q_2 = 25.6\ A^{0.89}\ S^{0.25}\ St^{-0.56}\ I^{0.25} \quad (7)$$
$$Q_5 = 39.7\ A^{0.88}\ S^{0.26}\ St^{-0.54}\ I^{0.22} \quad (8)$$
$$Q_{10} = 54.0\ A^{0.88}\ S^{0.27}\ St^{-0.53}\ I^{0.20} \quad (9)$$
$$Q_{25} = 78.2\ A^{0.86}\ S^{0.27}\ St^{-0.52}\ I^{0.18} \quad (10)$$
$$Q_{50} = 104\ A^{0.85}\ S^{0.26}\ St^{-0.51}\ I^{0.16} \quad (11)$$
$$Q_{100} = 136\ A^{0.84}\ S^{0.26}\ St^{-0.51}\ I^{0.14} \quad (12)$$

where: Q_T = peak discharge for T-year recurrence interval, in cubic feet per second.
A = drainage area, in square miles.
S = main-channel slope, in feet per mile, defined as the average slope of the main channel between points 10 and 85 percent of the distance upstream from the runoff site to the watershed boundary.
St = surface storage index, in percent of drainage area occupied by lakes, ponds, and swamps and increased by 1.00 percent.
I = index of manmade impervious cover, in percentage of total area.

The standard error of estimate for the regression equations ranged from 48 to 54 percent. The applicability and limitations of the equations, methods to estimate percent manmade impervious cover, and methods of assessing the effects of urbanization on flood-peak discharges are also discussed by Stankowski (1974).

Basin characteristics were measured above each of several points (generally every river mile above the mouth or county line) along each stream studied. Drainage area, main-channel slope, and surface storage (percent area occupied by lakes, ponds, and swamps) were obtained from U.S. Geological Survey 7 1/2-minute topographic maps; percent area containing manmade impervious cover was estimated from Land Use and Natural Resource Inventory of New York (LUNR) maps (New York State Economic Development Board, 1976) and the most recent topographic maps. Data on these basin characteristics above selected points along each stream are presented in the appendix; these are the most recent data available and supersede those given by Lumia (1982).

Flood discharges at selected ungaged locations along each stream were computed for each recurrence interval from basin-characteristics data (see appendix) through the appropriate regression equation. Further refinement of some of these estimates is described in the following section.

Locations Near Gaged Sites

For selected ungaged locations having a drainage area less than one-half or greater than twice the drainage area at a rainfall-runoff or long-term gaged site on the stream, flood-frequency estimates were computed from the regional regression equations (Stankowski, 1974), as discussed in the previous section. For ungaged locations having a drainage area within one-half to twice the drainage area at a rainfall-runoff or long-term gaged site on the stream, the regression estimates were modified by the following procedure (Zembrzuski and Dunn, 1979):

(1) Flood magnitude at the ungaged location (Q_U) was computed from the regional regression equations (Stankowski, 1974);
(2) The ratio (K_G) of the weighted discharge (Q_W) to the regression discharge (Q_R) was computed from the discharge values for the rainfall-runoff or long-term gaged sites on the stream (table 2);
(3) The weighted ratio for the ungaged location was computed as follows:

a. locations downstream from the gaged site:

$$K_U = (K_G - 1)\frac{(2A_G - A_U)}{A_G} + 1$$

b. locations upstream from the gaged sites:

$$K_U = (K_G - 1)\frac{(2A_U - A_G)}{A_G} + 1$$

where: K_U = ratio of the weighted discharge to the regression discharge at the ungaged location,
A_U = drainage area above the ungaged location, and
A_G = drainage area above the rainfall-runoff or long-term gaged site.

(4) From Q_U obtained in step 1 and K_U obtained in step 3, the weighted discharge (Q_{UW}) at the ungaged location was computed as:

$$Q_{UW} = K_U \times Q_U \qquad (15)$$

These refined flood-frequency estimates for ungaged locations near rainfall-runoff or long-term gaged sites were used to develop the final flood-discharge profiles, except for Ramapo River. The final profiles for Ramapo River were developed from the weighted estimates of flood discharge (Q_W) at the Ramapo River gaging stations at Sloatsburg (01387250) and at Mahwah, N.J. (01387500). These estimates were used in conjunction with estimates from Mahwah River (enters Ramapo River just upstream from station 01387500) to develop the flood-discharge profiles for the Ramapo River.

FLOOD-DISCHARGE PROFILES

Flood-discharge profiles, showing flood discharge at successive river miles above mouth or county line, at the six recurrence intervals are presented in figures 2A-2J. Each profile depicts the downstream progression (from right to left) of flood discharges with 2-, 5-, 10-, 25-, 50-, and 100-year recurrence intervals. Locations of major road crossings, gaging stations, tributaries, swamps or ponds, and county lines are indicated on the profiles and on plate 1. Also shown on plate 1 are river-mile location points above the mouth or county line, shown as the horizontal axis in the profiles. River-mile locations and road crossings were determined from U.S. Geological Survey 7.5-minute topographic maps.

The flood-discharge profiles presented in figure 2 were derived from the final weighted discharges (Q_W) of recording gage sites listed in table 2, discharges at ungaged locations computed through the regional regression equations (Stankowski, 1974), and computed discharges at ungaged locations near gaged sites. Basin characteristics listed in the appendix were used in applying the regression equations. The discharge at each recurrence interval was plotted at selected river-mile locations (and at gaged points), and straight lines drawn between the points.

Some of the profiles show downstream decreases in discharge along certain reaches; these result from storage of storm runoff in swamps, ponds, or lakes in the basin. The increases in discharge at tributaries were estimated from a regional relationship of drainage area to discharge, which was developed from the discharges computed for each recurrence interval at selected locations on the 10 study streams.

The profiles can be used to estimate flood discharges of recurrence intervals from 2 to 100 years at any location having a drainage area exceeding 1.0 mi^2 along the 10 streams studied.

SUMMARY AND CONCLUSIONS

Flood-frequency estimates at recurrence intervals of 2, 5, 10, 25, 50, and 100 years were computed for several locations along each of 10 streams in Rockland County.

For rainfall-runoff sites, calibrated models (Lumia, 1982) were used in conjunction with long-term (59 years) rainfall data to generate synthetic flood-frequency estimates. For gaged sites with 10 or more years of discharge record, "observed" flood-frequency estimates were computed. Additional estimates for both rainfall-runoff and long-term gaged sites, were made from regional regression equations (Stankowski, 1974) based on drainage area, slope, storage, and percentage of impervious cover. A variance-weighting technique was used to compute weighted "best" flood-frequency estimates for each gaged site.

Flood-frequency estimates for selected ungaged locations, were also computed from regional regression equations (Stankowski, 1974). The estimates for ungaged locations near rainfall-runoff or long-term gaged sites were refined through a drainage area weighting procedure.

The flood-discharge profiles, showing discharge at successive river miles above mouth or county line, at the six recurrence intervals, based on the final flood-frequency estimates for all gaged sites and ungaged locations evaluated, are included. Increased flow at tributaries was estimated through a regional drainage-area discharge relationship. These profiles enable rapid determination of flood discharge at any location having a drainage area exceeding 1.0 mi^2 on any of the 10 streams.

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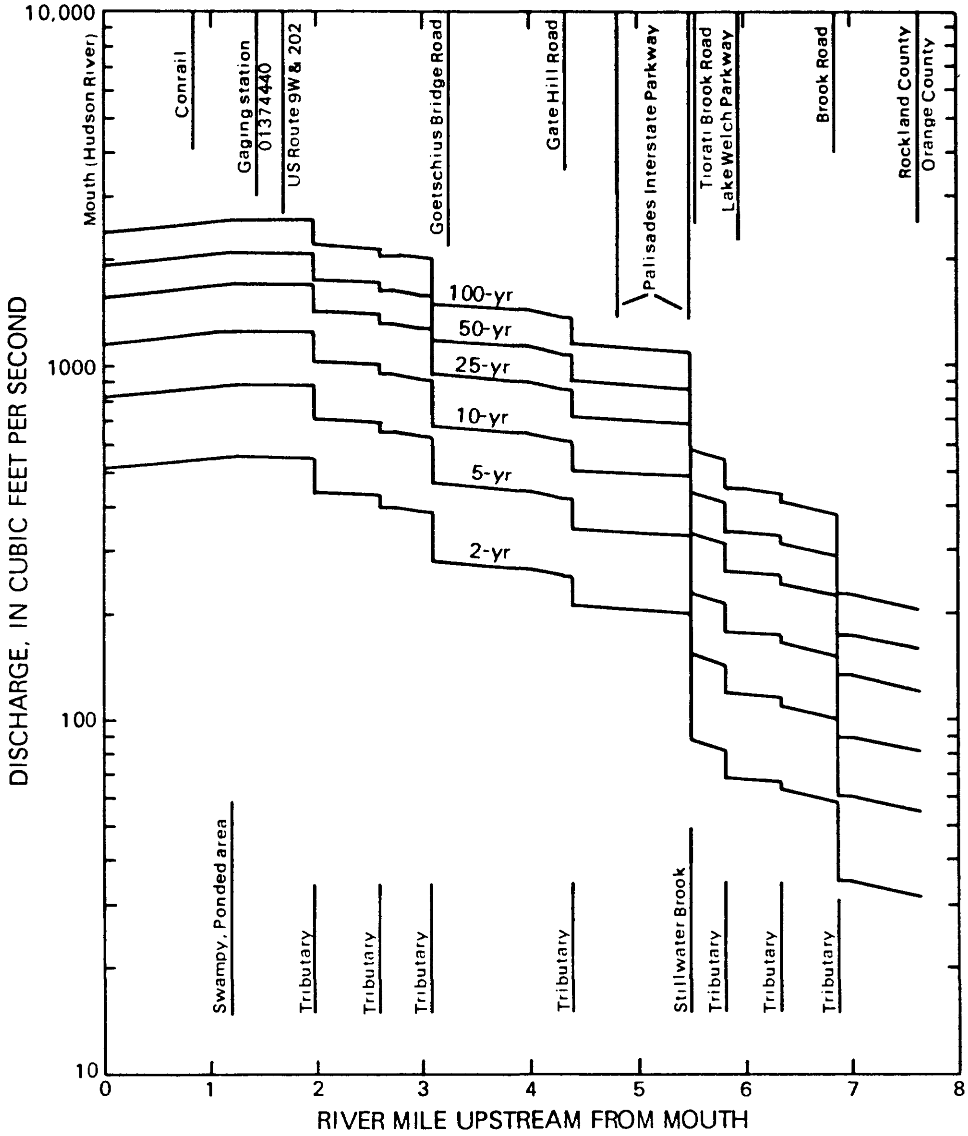

Figure 2A.--Flood-discharge profiles of Cedar Pond Brook.

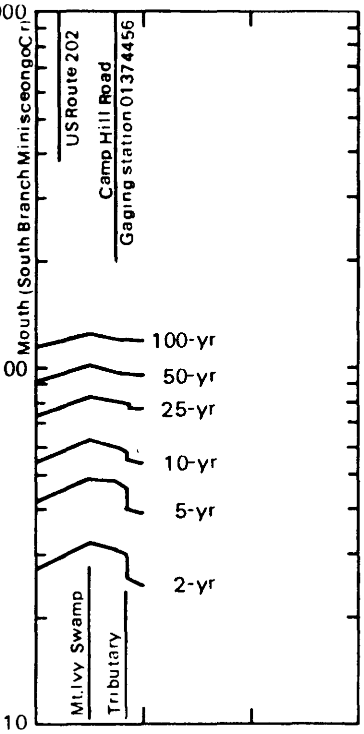

Figure 2B

Flood-discharge profiles of South Branch Minisceongo Creek Tributary.

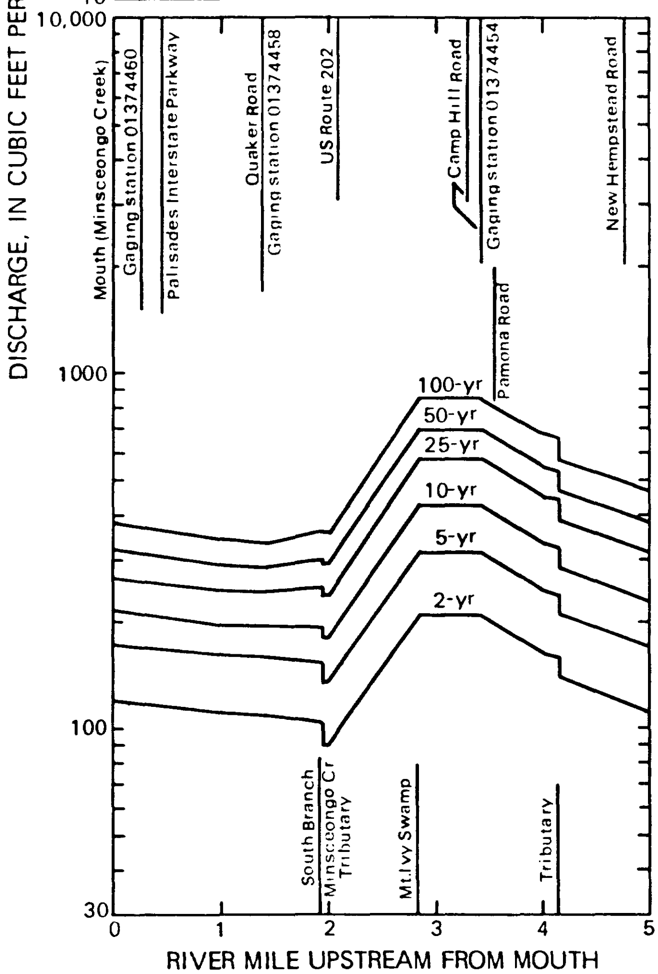

Figure 2C

Flood-discharge profiles of South Branch Minisceongo Creek.

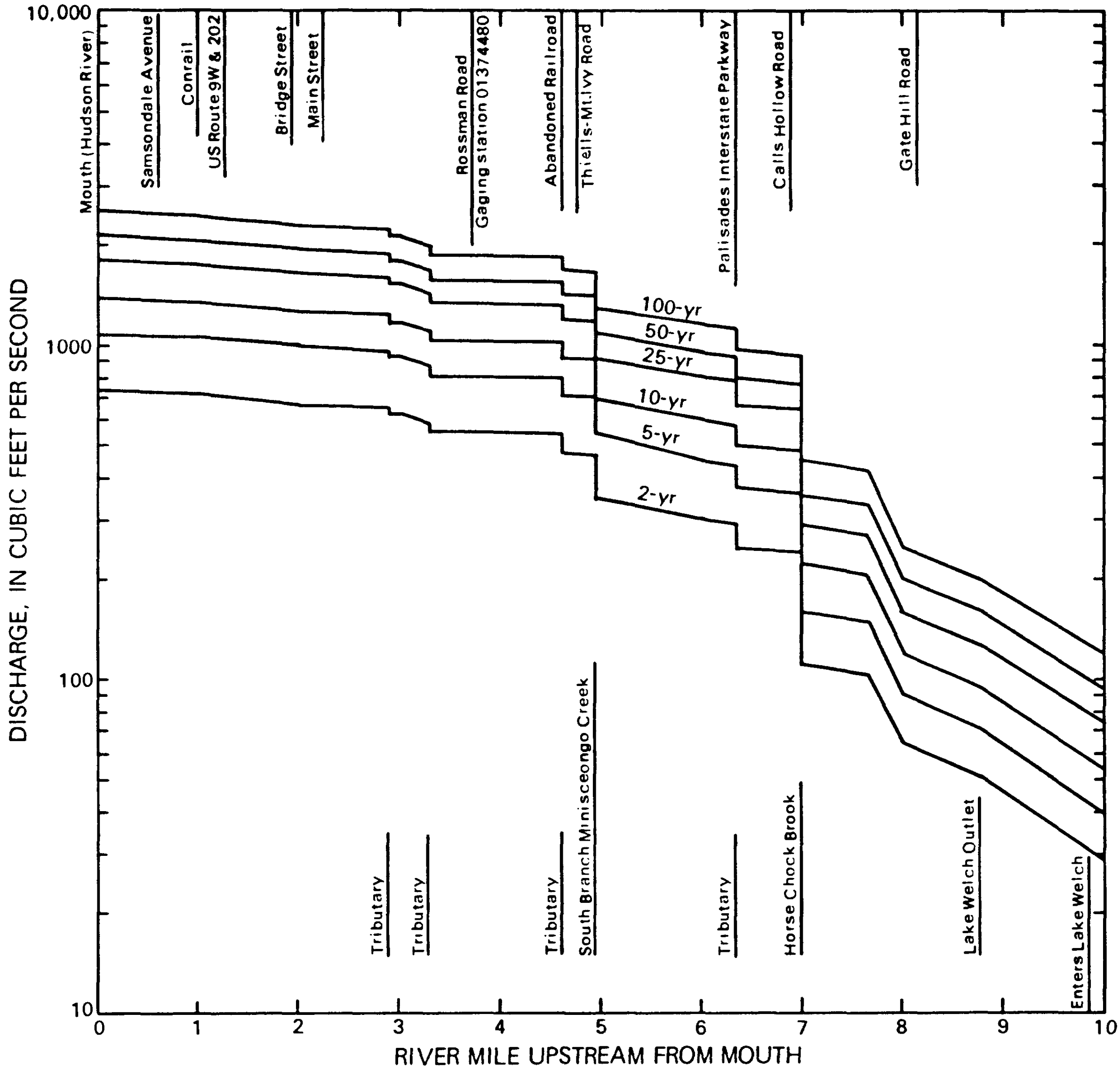

Figure 2D.--Flood-discharge profiles of Minisceongo Creek.

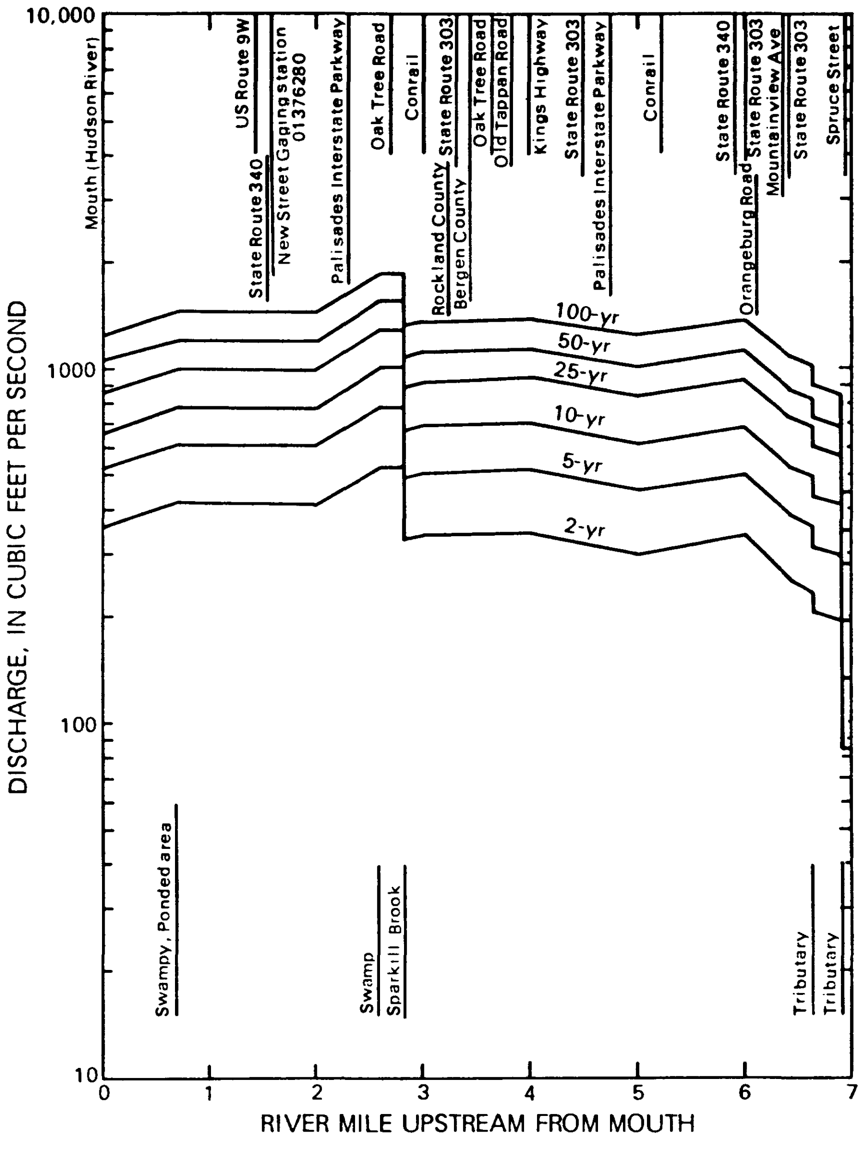

Figure 2E.--Flood-discharge profiles of Sparkill Creek.

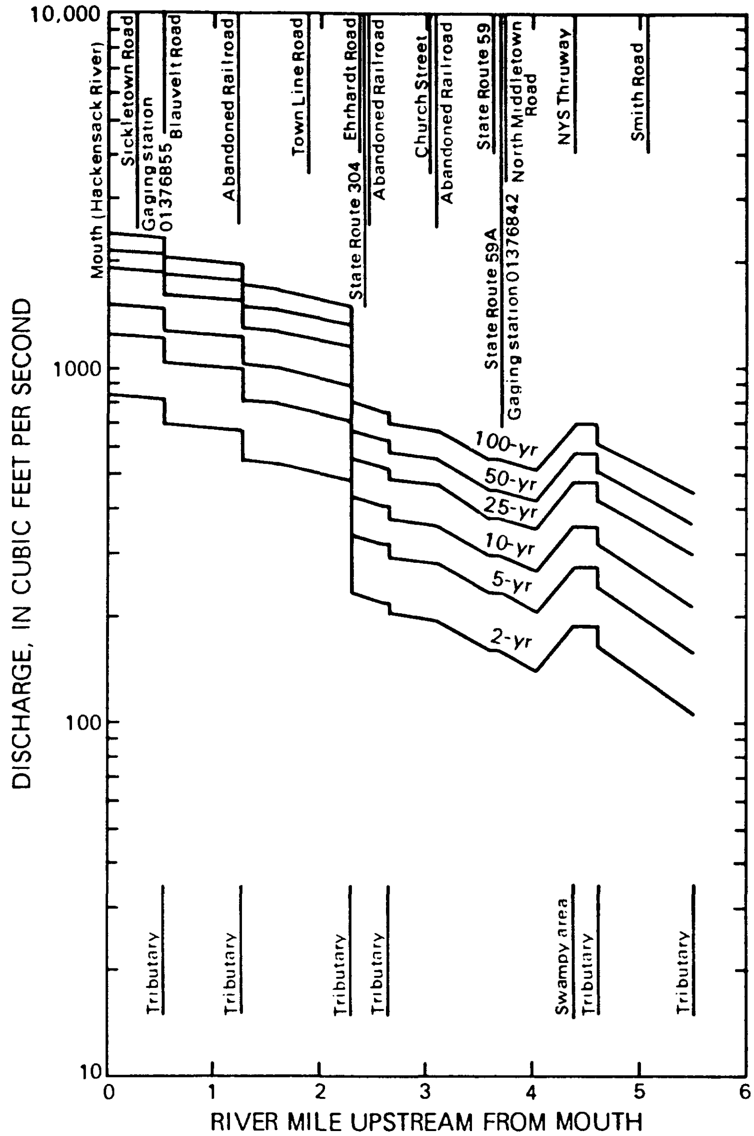

Figure 2F.--Flood-discharge profiles of Nauraushaun Brook.

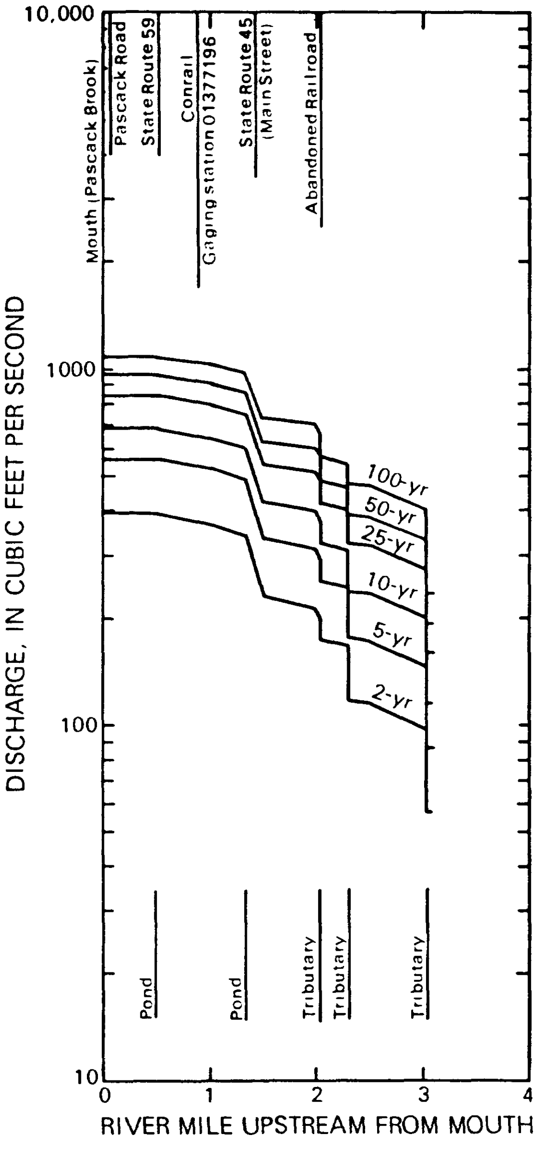

Figure 2G.--Flood-discharge profiles of Pascack Brook Tributary.

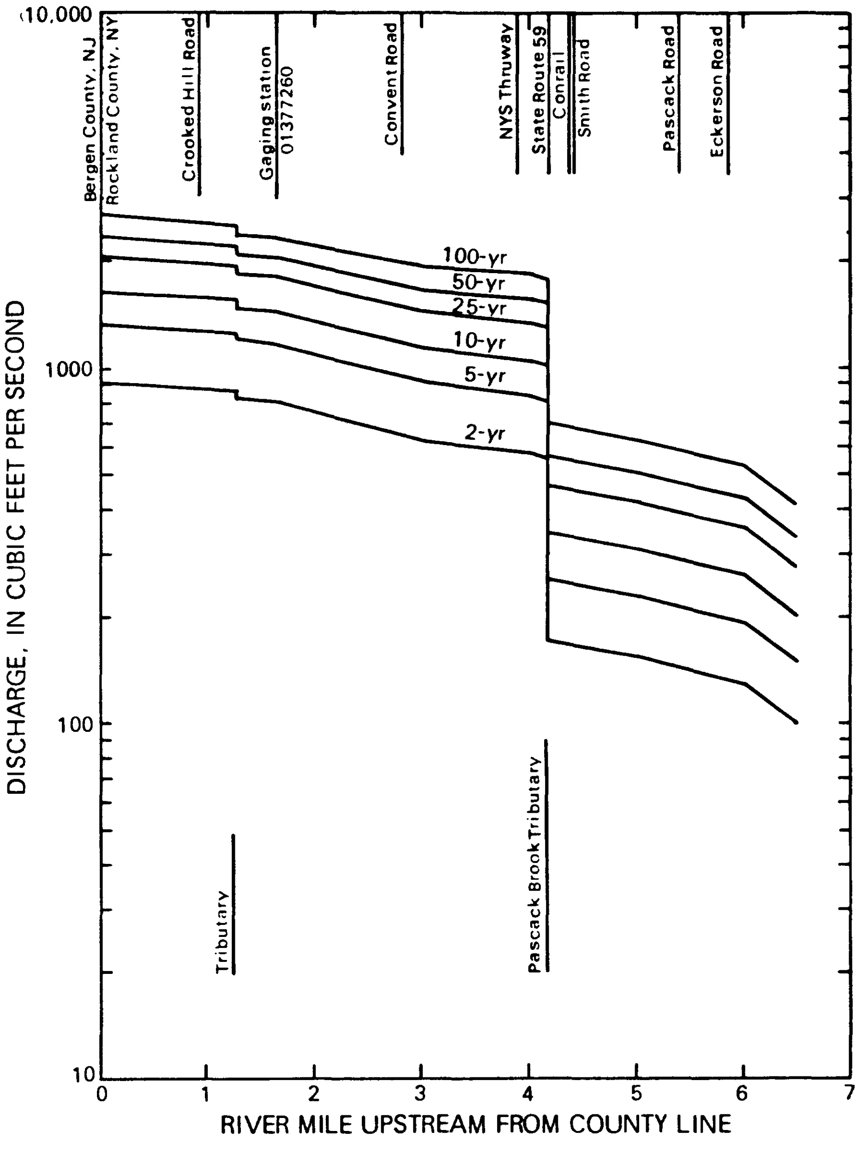

Figure 2H.--Flood-discharge profiles of Pascack Brook.

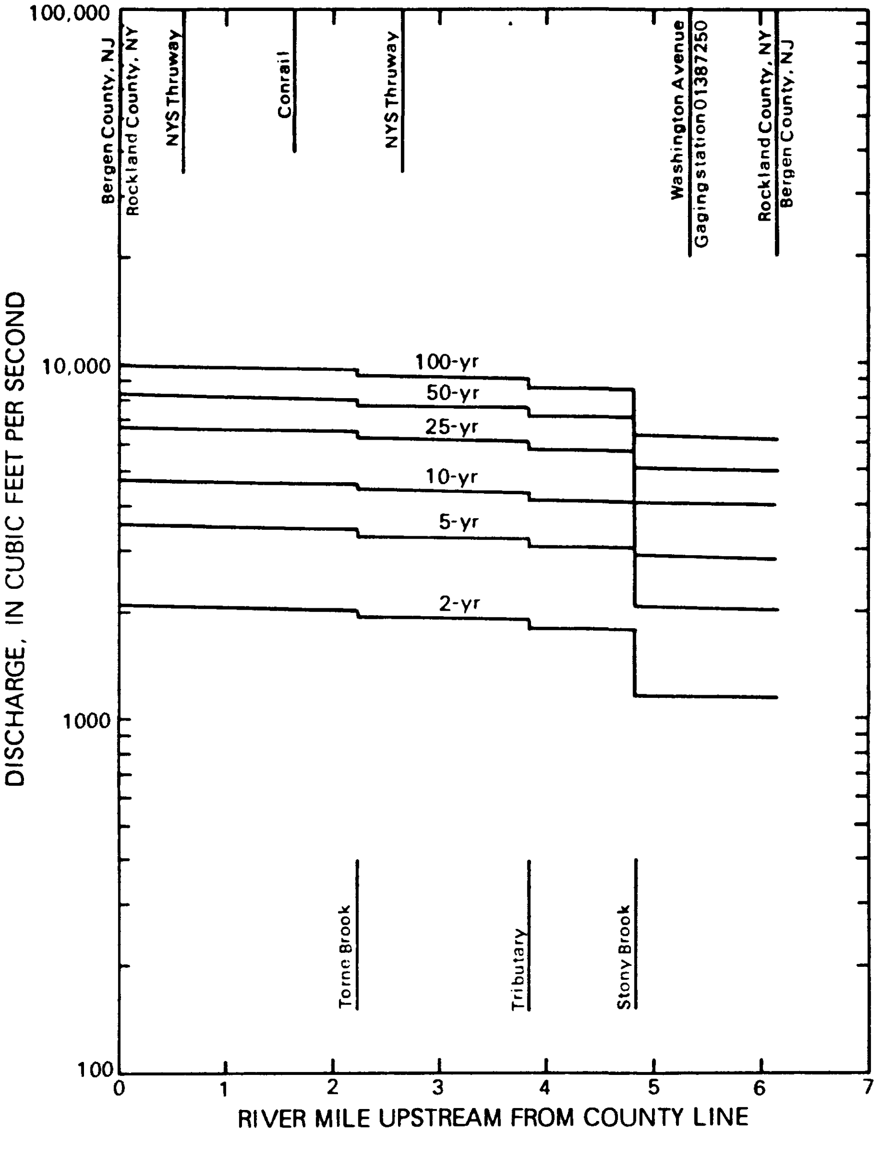

Figure 2I.--Flood-discharge profiles of Ramapo River.

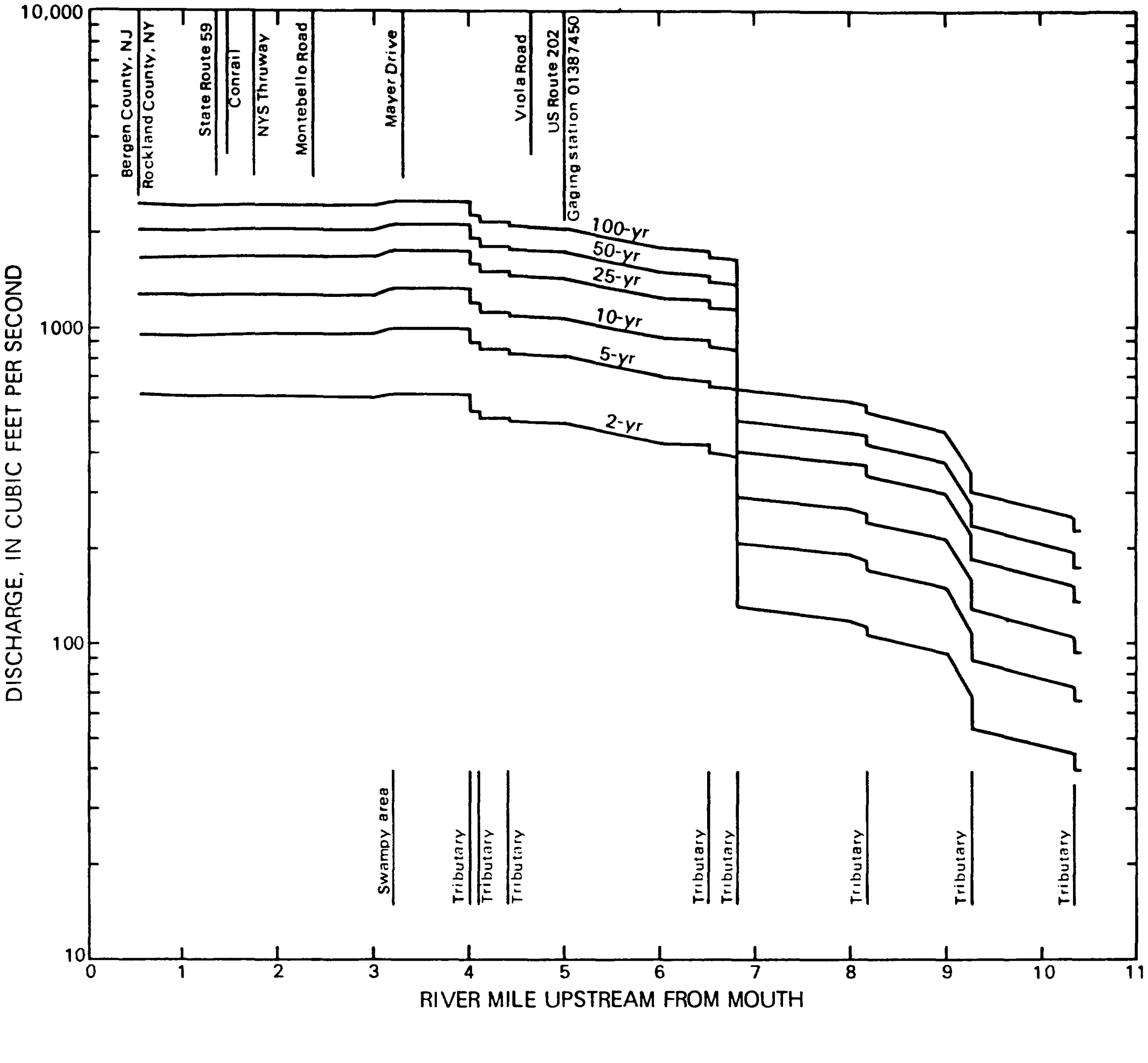

Figure 2J.--Flood-discharge profiles of Mahwah River.

APPENDIX

Basin Characteristics at Selected Locations on 10 Rockland County Streams

The following letter designations and their meaning are used in column headings in the tables of basin characteristics that follow this explanation.

A = Drainage area, in square miles.--Area of a basin (watershed upstream from the site of interest), delineated on a 7.5-minute U.S. Geological Survey topographic maps and determined by planimetering the basin outline.

P = Mean annual precipitation, in inches.--Mean annual precipitation determined from a rainfall map (Zembrzuski and Dunn, 1979) based on precipitation data from 1931-60.

L = Stream length, in miles.--Distance up the channel from site of interest to basin divide, determined from 7.5- or 15-minute maps.

S = Main channel slope, in feet per mile.--Difference in elevation (ft) between points 10 percent and 85 percent of distance up channel from site of interest to the basin divide, divided by distance, in miles, between the two points, determined from 7.5- or 15-minute maps.

St = Storage, in percent.--Percentage of total drainage area shown as lakes, ponds, and swamps, determined from 7.5- or 15-minute topographic maps by grid sampling or planimetering.

I = Manmade impervious cover, in percent.--Percentage of basin covered by buildings, streets, and paved parking lots.

A. Cedar Pond Brook
B. South Branch Minisceongo Creek Tributary
C. South Branch Minisceongo Creek
D. Minisceongo Creek
E. Sparkill Creek
F. Nauraushaun Brook
G. Pascack Brook Tributary
H. Pascack Brook
I. Ramapo River
J. Mahwah River

CEDAR POND BROOK

Stream mile (upstream from mouth)	Characteristic					
	A (square miles)	P (inches)	L (miles)	S (feet per mile)	St (percent)	I (percent)
8.00	1.64	46.5	1.4	224	28.7	1.1
7.00	2.73	47.0	2.4	130	19.8	0.7
6.00	4.62	47.0	3.4	168	11.9	.4
5.50	5.37	47.0	3.9	182	10.6	.3
5.00	9.07	47.0	4.4	192	8.3	1.2
4.31	10.6	47.0	5.1	194	7.4	1.3
4.00	11.0	47.0	5.4	195	7.1	1.3
3.00	15.1	47.5	6.4	180	5.8	1.3
2.75	15.4	47.5	6.7	177	5.7	1.4
2.00	16.2	47.5	7.4	168	5.7	1.8
1.45 (01374440)	17.3	47.5	8.0	157	5.3	3.5
1.00	17.4	47.5	8.4	145	5.4	3.6
0.0	17.8	48.0	9.4	127	6.0	3.7

SOUTH BRANCH MINISCEONGO CREEK TRIBUTARY

Stream mile (upstream from mouth)	Characteristic					
	A (square miles)	P (inches)	L (miles)	S (feet per mile)	St (percent)	I (percent)
1.50	0.29	48.0	0.5	282	0.0	14.6
1.00	0.47	48.0	1.0	150	8.5	12.7
0.75 (01374456)	0.90	48.0	1.3	108	11.1	9.0
0.50	0.97	48.0	1.5	80.9	10.3	9.0
0.0	1.10	48.0	2.0	63.8	15.4	8.1

SOUTH BRANCH MINISCEONGO CREEK

Stream mile (upstream from mouth)	A (square miles)	P (inches)	L (miles)	S (feet per mile)	St (percent)	I (percent)
	Characteristic					
5.00	0.54	48.0	0.9	206	0.0	15.6
4.00	1.39	48.0	1.9	105	.7	16.4
3.42 (01374454)	1.84	48.0	2.5	83.3	.5	15.2
3.00	2.04	48.0	2.9	58.5	.5	15.4
2.00	3.45	48.0	3.9	41.1	11.0	11.4
1.94	4.55	48.0	4.0	41.1	12.1	10.6
1.39 (01374458)	5.19	48.0	4.5	33.7	12.5	10.9
1.00	5.38	48.0	4.9	28.3	12.1	11.0
0.0	5.88	48.0	5.9	23.2	11.1	10.6

MINISCEONGO CREEK

Stream mile (upstream from mouth)	A (square miles)	P (inches)	L (miles)	S (feet per mile)	St (percent)	I (percent)
	Characteristic					
10.00	1.10	48.0	2.3	55.8	20.9	1.0
8.78	2.74	48.0	3.5	35.6	30.3	1.3
8.00	3.09	48.0	4.3	50.6	26.9	1.1
7.00	3.64	48.0	5.3	135	22.8	1.2
6.00	7.25	48.0	6.3	144	14.3	2.0
5.00	8.11	48.0	7.3	133	12.9	2.1
4.93	14.0	48.0	7.4	132	12.1	5.7
4.00	15.0	48.0	8.3	119	11.5	6.4
3.72 (01374480)	15.1	48.0	8.6	116	11.4	6.5
3.00	17.3	48.0	9.3	113	10.1	6.6
2.00	18.4	48.0	10.3	108	9.7	7.4
1.00	19.3	48.0	11.3	108	9.3	8.4
0.0	19.8	48.0	•12.3	106	9.2	9.0

SPARKILL CREEK

Stream mile (upstream from mouth)	Characteristic					
	A (square miles)	P (inches)	L (miles)	S (feet per mile)	St (percent)	I (percent)
7.00	0.63	48.0	1.6	267	0.0	2.2
6.41	1.67	48.0	2.2	188	.0	8.1
6.00	2.22	48.0	2.6	148	.0	12.5
5.00	3.76	48.0	3.6	95.9	1.3	10.5
4.00	4.71	48.0	4.6	66.8	1.3	13.2
3.00	5.58	48.0	5.6	55.4	2.0	14.0
2.84	5.60	48.0	5.7	52.7	2.1	14.0
2.83	9.41	48.0	5.7	52.7	1.9	13.7
2.00	10.4	48.0	6.6	45.6	4.0	13.1
1.54 (01376280)	10.7	48.0	7.0	42.4	3.9	13.0
1.00	11.3	48.0	7.6	37.5	4.0	12.7
0.0	11.5	48.0	8.6	20.2	4.2	12.7

NAURAUSHAUN BROOK

Stream mile (upstream from mouth)	Characteristic					
	A (square miles)	P (inches)	L (miles)	S (feet per mile)	St (percent)	I (percent)
5.60	0.21	48.0	1.1	159	0.0	21.6
4.60	1.57	48.0	2.1	104	.6	23.8
4.05	1.74	48.0	2.7	80.6	1.7	23.8
3.70 (01376842)	2.12	48.0	3.0	74.6	1.4	25.6
3.60	2.14	48.0	3.1	70.8	1.4	25.6
2.60	2.70	48.0	4.1	55.9	1.1	27.8
1.60	4.59	48.0	5.1	49.2	2.0	29.2
0.60	5.59	48.0	6.1	38.6	2.3	27.2
0.30 (01376855)	5.97	48.0	6.4	40.4	2.2	29.2
0.0	6.00	48.0	6.7	42.9	2.2	29.1

PASCACK BROOK TRIBUTARY

Stream mile (upstream from mouth)	A (square miles)	P (inches)	L (miles)	S (feet per mile)	St (percent)	I (percent)
	Characteristic					
3.50	0.28	48.0	1.2	95.3	7.1	36.7
3.00	1.20	48.0	1.6	113	3.3	27.0
2.50	1.49	48.0	2.2	93.2	3.3	28.5
2.00	2.95	48.0	2.6	85.4	6.1	27.0
1.50	3.08	48.0	3.2	75.4	5.8	27.0
1.35	3.70	48.0	3.3	72.2	4.9	29.0
1.00	3.86	48.0	3.7	71.2	4.9	29.2
0.90 (01377196)	3.89	48.0	3.8	69.8	4.9	29.3
0.50	4.10	48.0	4.2	65.1	4.6	30.1
0.0	4.19	48.0	4.6	62.5	4.8	32.3

PASCACK BROOK

Stream mile (upstream from county line)	A (square miles)	P (inches)	L (miles)	S (feet per mile)	St (percent)	I (percent)
	Characteristic					
7.00	0.35	48.0	1.0	80.7	2.8	17.8
6.00	1.26	48.0	2.0	61.0	0.8	18.2
5.00	1.79	48.0	3.0	48.5	1.1	18.9
4.18	2.38	48.0	3.9	52.2	1.7	16.8
4.17	6.57	48.0	3.9	52.2	4.0	26.7
4.00	6.69	48.0	4.0	52.3	3.9	26.7
3.00	7.32	48.0	5.0	46.2	3.6	26.8
2.00	8.10	48.0	6.0	39.0	3.2	26.2
1.64 (01377260)	8.39	48.0	6.4	37.4	3.1	26.2
1.00	9.31	48.0	7.0	37.6	2.8	25.0
0.0	9.93	48.0	8.0	37.6	2.6	24.9

RAMAPO RIVER

Stream mile (upstream from county line)	Characteristic A (square miles)	P (inches)	L (miles)	S (feet per mile)	St (percent)	I (percent)
6.15	58.3	44.0	16.9	17.5	8.4	3.7
6.00	58.5	44.0	17.0	17.5	8.4	3.7
5.33 (01387250)	60.1	44.0	17.7	16.7	8.5	3.7
5.00	60.3	44.0	18.0	16.5	8.5	3.7
4.82	60.4	44.5	18.2	16.4	8.5	3.8
4.81	78.8	44.5	18.2	16.4	9.0	3.1
4.00	79.4	45.0	19.0	16.4	9.0	3.1
3.00	85.7	45.0	20.0	17.1	9.0	3.1
2.00	90.2	45.5	21.0	17.2	8.6	2.9
1.00	91.1	45.5	22.0	17.4	8.5	3.0
0.61	93.1	46.0	22.4	17.5	8.5	3.0
0.0	93.7	46.0	23.0	17.6	8.4	3.1

MAHWAH RIVER

Stream mile (upstream from mouth)	Characteristic A (square miles)	P (inches)	L (miles)	S (feet per mile)	St (percent)	I (percent)
11.00	0.34	48.0	0.6	167	0.0	1.7
10.00	2.09	48.0	1.6	83.9	9.1	1.9
9.00	3.81	48.0	2.6	67.3	8.7	3.8
8.00	5.27	48.0	3.6	47.0	8.3	4.1
7.00	6.29	48.0	4.6	32.4	7.8	3.6
6.00	11.3	48.0	5.6	31.6	5.4	6.3
5.00 (01387450)	12.3	48.0	6.6	28.3	5.1	6.4
4.00	16.0	48.0	7.6	27.1	4.1	6.5
3.00	16.8	48.0	8.6	21.5	4.1	6.8
2.00	20.4	48.0	9.6	19.9	4.4	7.9
1.00	20.8	48.0	10.6	18.1	4.5	8.3
0.64	21.1	48.0	10.9	18.4	4.4	8.6