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Method for Estimating Low-flow Statistics for Ungaged Streams in the Lower Hudson River Basin, New York

Charles R. Barnes
USGS

METHOD FOR ESTIMATING LOW-FLOW STATISTICS FOR UNGAGED STREAMS IN THE LOWER HUDSON RIVER BASIN, NEW YORK

By Charles R. Barnes

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DONALD PAUL HODEL, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information write to:

U.S. Geological Survey
P.O. Box 1669
Albany, New York 12201
(518) 472-3107

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CONVERSION FACTORS AND ABBREVIATIONS

The following factors may be used to convert inch-pound units to metric (International System) units.

Multiply inch-pound units	By	To obtain metric units
feet (ft)	0.3048	meter (m)
feet per mile (ft/mi)	0.1894	meter per kilometer (m/km)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
cubic feet per second (ft^3/s)	0.028232	cubic meter per second (m^3/s)
cubic feet per second per square mile [$(ft^3/s)/mi^2$]	0.01093	cubic meter per second per square kilometer [$(m^3/s)/km^2$]
inch per year (in/yr)	25.40	millimeter per year (mm/yr)

METHOD FOR ESTIMATING LOW-FLOW STATISTICS FOR UNGAGED STREAMS IN THE LOWER HUDSON RIVER BASIN, NEW YORK

By Charles R. Barnes

Abstract

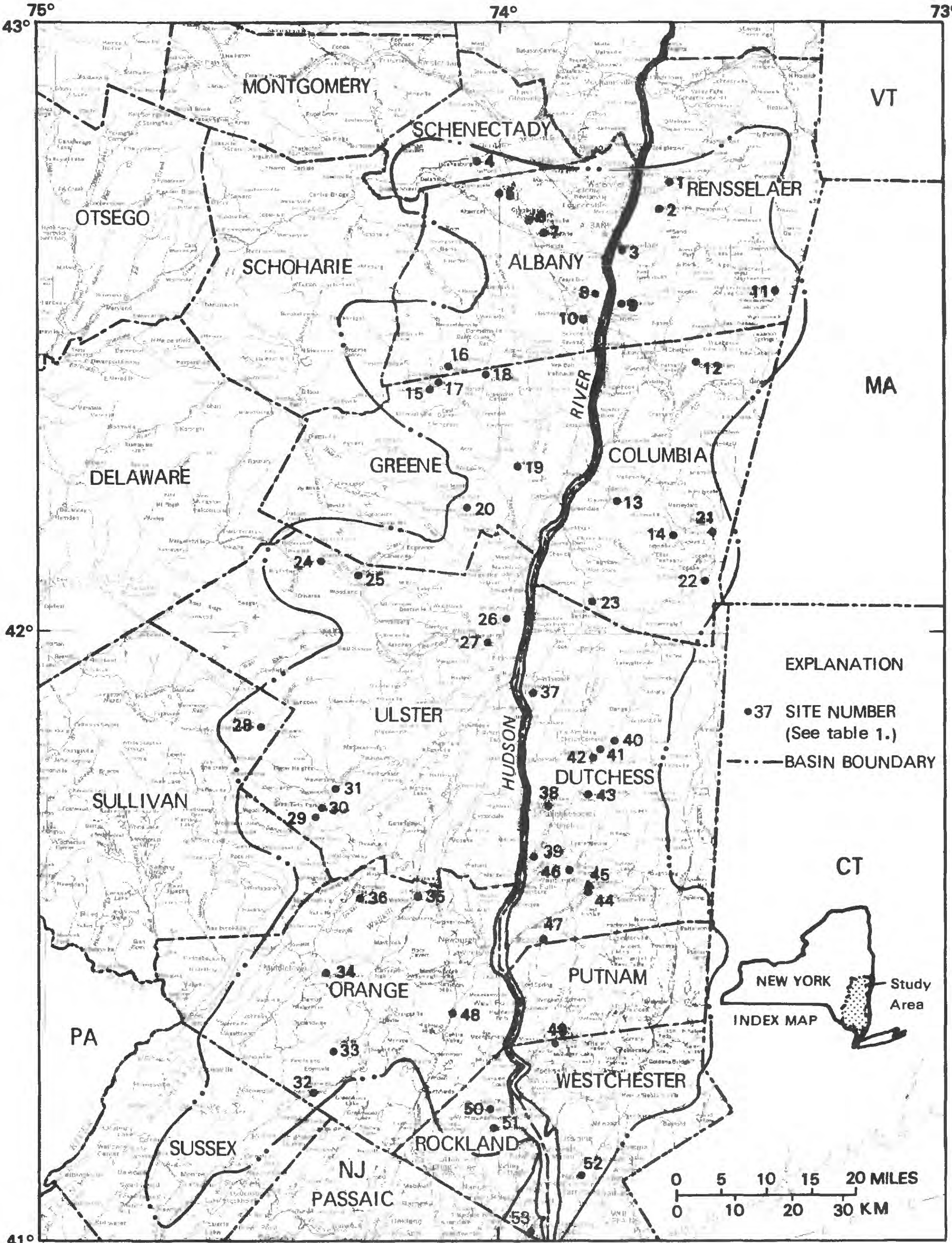
Seven-day, 10-year and 7-day, 2-year low-flow statistics were related to selected basin characteristics by multiple-regression analysis for 53 continuous and partial-record gaging sites with watershed areas of less than 100 square miles in the lower Hudson River basin. A common 20-year period of record was selected to ensure comparability of results. Results indicate that the most significant variable is the percentage of drainage basin underlain by stratified drift.

Equations yielding the lowest standard errors of estimate were obtained from regression analysis for discharge per square mile during low-flow conditions. The three significant basin characteristics needed for estimating low flow were percentage of basin underlain by stratified drift, mean basin elevation, and mean annual precipitation. The smallest standard errors for 7-day, 10-year and 7-day, 2-year low flows obtained were 51 percent of the mean and 39 percent of the mean, respectively. These equations may be used to estimate low-flow statistics for ungaged sites.

INTRODUCTION

Comprehensive planning of water supplies, analyzing the environmental and economic effects of waste discharge, and modeling stream-water quality require a knowledge of the low-flow characteristics of streams. Although no single characterization is suitable for all purposes, the low-flow index most commonly used by State and Federal agencies in designing or regulating water-supply and waste-treatment facilities is the 7-day, 10-year low flow (American Society of Civil Engineers, 1980). This index is a statistically derived value that represents the annual lowest mean streamflow over a 7-consecutive-day period that would occur on an average of once in 10 years.

Many studies have shown that low-flow characteristics are more difficult to estimate than other flow characteristics (Orsborn, 1974). Thomas and Benson (1970) studied four widely separated regions of the United States through multiple-regression techniques to relate streamflow characteristics to various drainage-basin characteristics and concluded that the basin characteristics used could provide only a rough guide to low-flow magnitudes. The U.S. Geological Survey in 1970 conducted low-flow estimation studies in 47 States; results from most States either had standard errors of estimate exceeding 100 percent or indicated that no useful relationship had been found (Riggs, 1973).



Base from U.S. Geological Survey
State Base Map, 1:500,000, 1974

Figure 1.--Location of sites used in developing low-flow equations for the lower Hudson River basin. (Site identification is given in table 1, p. 6-7.)

The major reason for difficulty in the estimating of low-flow characteristics is that base flows are derived from ground water and are dependent on the geology of a basin, which varies widely from place to place and is difficult to describe accurately.

Studies relating low flows to geologic characteristics date as far back as the mid-1940's (Cross, 1949). In some studies, regressions of low flow against basin characteristics, including geologic variables, have significantly reduced standard errors from 100 percent to about 45 percent. Some factors, for example, permeability of surficial deposits (Bent, 1971; Armbruster, 1976), streamflow recession (Bingham, 1979), and bedrock geology (Schneider, 1965; Flippo, 1982) have been used to derive indices that have improved the accuracy of low-flow estimates for ungaged streams. The use of stratified drift and till-mantled bedrock areas in a regression model developed for Connecticut watersheds (Cervione and others, 1982) has been perhaps the most successful contribution to date.

Purpose and Scope

This report describes the results of a study done in cooperation with the New York State Department of Environmental Conservation to develop a method for estimating 7-day, 10-year and 7-day, 2-year low flows for ungaged sites along streams tributary to the lower Hudson River within New York State (fig. 1) The method was developed for basins smaller than 100 mi^2, not artifically controlled during low-flow periods, and not significantly affected by urbanization. This report compares the methods and discusses the results, the standard error of estimates, and possible causes of error. A table of observed and predicted 7-day, 10-year and 7-day, 2-year low flows is included.

RELATIONSHIP BETWEEN HYDROGEOLOGIC CONDITIONS AND LOW FLOW

The lowest streamflows of the year in New York generally occur at the end of the growing season, after the period of greatest evapotranspiration. These low flows are sustained primarily by the inflow of ground water to the stream; thus, the geologic setting of the drainage basin largely determines the amount of flow during periods of no precipitation.

Ground water is present in pores or spaces between the solid mineral particles in water-bearing units. The amount of ground water that can be stored in a given area is related to the size and quantity of these spaces. The ability of a water-bearing unit to transmit ground water, measured as hydraulic conductivity, is largely dependent on the size of the spaces and their degree of interconnection. The extent to which ground water sustains streamflow is governed by such factors as infiltration capacity, ground-water-storage coefficients, hydraulic conductivity, hydraulic gradient, thickness of the water-bearing unit, and the length of stream channel in contact with the unit.

Water-bearing formations may be classified into two lithologic types, depending on their composition. One consists of consolidated rock, known as bedrock; the other consists of unconsolidated deposits that overlie the bedrock. The low storage coefficients and low hydraulic conductivity of bedrock in the lower Hudson River basin may severely limit the rate at which water is discharged to streams. In contrast, the surficial deposits, which are mainly of glacial origin, have greater storage coefficients and hydraulic conductivity and may contribute large quantities of water to streams. These deposits range from less than 1 ft to hundreds of feet in thickness. These unconsolidated deposits may be further classified as either stratified drift or till, as follows:

Stratified drift.--This material consists of sediments ranging from clay to coarse gravel that have been transported and sorted according to particle size by glacial meltwater. The sediments were deposited in distinct layers rather than in the unsorted manner found in till. Thick, coarse-grained stratified-drift deposits are the most productive water-bearing units in the lower Hudson basin owing to their relatively high hydraulic conductivities, storage coefficients, and infiltration rates.

Till.--Till is an unsorted, heterogeneous mixture of sediment ranging in particle size from clay to boulders that was deposited directly by glacial action. Although till may contain water in intergranular pores, its wide range of grain sizes allows the smaller grains to occupy the spaces between larger particles, which limits the material's ability to store or transmit water.

In a study of flow-duration curves for Connecticut streams, Thomas (1966) found low flow to be related to the percentage of the drainage basin that is overlain by stratified-drift deposits. Information on the areal distribution of stratified drift may provide a method to estimate ground-water contribution to streams during periods of low flow, which in turn may give improved estimates of low-flow statistics.

METHODS

One way to statistically define the relationship between flow characteristics and one or more independent variables is to develop an equation by multiple-regression techniques. The approach used in this study included (1) selection of appropriate gaged and partial-record sites for analysis, (2) computation of 7-day, 10-year and 7-day, 2-year low-flow statistics corresponding to a common period of record for each site, (3) measurement of physical and climatic variables to be evaluated, and (4) development of regression equations to estimate low-flow statistics of ungaged sites from measured variables.

Site-Selection Procedure

Sites reviewed for inclusion in the study were those in the lower Hudson River basin between Troy and Yonkers, N.Y. (fig. 1) at which a continuous-record gaging station had been operated for more than 8 years. Stations were eliminated if flow was affected by human activity--either by interbasin transfer, regulation, significant urbanization (more than 10 percent of the drainage area occupied with urban areas), or other societal influences. Sites with drainage areas greater than 100 mi^2 were also excluded. Only 17 stations met these criteria; one was later excluded when the common period of record was selected.

To increase the number of sites, continuous gaging stations with less than 8 years of record as well as some low-flow partial-record stations were added if they met the other criteria stated for the long-term gaging stations. The selection of partial-record stations was influenced by geographic distribution and the local surficial geology.

A total of 53 sites were used in the study--16 continuous-record sites and 37 partial-record sites. Site locations are shown in figure 1; site numbers, names, and drainage-basin characteristics are given in table 1.

Computation of 7-Day, 10-Year and 7-Day, 2-Year Low-Flow Statistics

Initially, low-flow values for the 53 sites were obtained directly from Eissler (1979). After preliminary examination, however, these values were deemed unsuitable for use in this study because they had been based on differing periods of record. For example, the early 1960's was a period of low ground-water levels and extreme low flows, whereas the mid-1970's had high ground-water levels and consequently higher-than-normal annual low flows. If low-flow values for some streams were based on one of these periods while others were based on a different period, the multiple regression analysis would not yield valid results.

The 7-day, 10-year low-flow value of an individual stream may depend on which period of record is used. For example, the 7-day, 10-year low flow for Chestnut Creek at Grahamsville (site 28 in fig. 1) calculated from 1958-68 data is 2.34 ft^3/s, whereas the value based on 1968-78 data is 4.13 ft^3/s--a 76.5 percent difference created by the use of differing periods of record.

The periods of record were reviewed, and a 20-year reference period--April 1, 1958 through March 31, 1978--was selected. This period provided the greatest number of sites and a wide range in annual flow conditions. All low-flow statistics were transformed to correspond to this reference period through techniques developed by Riggs (1982).

Low-flow statistics for long-term gaging stations with 15 or more years of record during 1958-78 were calculated, without adjustment, by the log-Pearson type III technique (Riggs, 1982). Results were checked by visual inspection of low-flow frequency curves.

If a gaging station having from 8 to 14 years of discharge records in the reference period also had climatologic and geologic characteristics similar to those at a nearby long-term station, its 7-day, 10-year low flows were obtained by a comparison of flow-duration curves. The duration curve for the station of shorter record and the curve for the corresponding period at the 20-year station were both plotted to verify that their slopes were similar. The 7-day, 10-year flows for the shorter periods, based on log-Pearson analysis, were located on each curve, and if they represented similar flow durations, the 7-day, 10-year low flow for the reference period was located on the duration curve for the abbreviated period for the station of longer record. The percent duration was noted, and the flow corresponding to that percent duration at the site of shorter record was taken as the 7-day, 10-year low-flow value.

Table 1.--Drainage-basin characteristics.

[Site locations are shown in fig. 1]

No. on fig. 1	USGS site no.	Basin	Drainage area (mi^2)	Stratified-drift area (mi^2)	Till and bedrock area (mi^2)	Surface storage area (mi^2)	Urban area (mi^2)	Slope (ft/mi)	Mean basin elevation[1] (ft)	Mean annual precipitation (in/yr)	Period of record (years)
1	1358500	Poestenkill	77.79	7.70	68.85	1.24	0.00	71	860	42	11
2	1359100	Wynantskill	29.10	7.71	20.37	1.02	.39	44	730	41	P
3	1359155	Mill Creek	13.22	3.14	10.08	.00	.00	29	310	38	P
4	1359200	Normanskill	41.17	3.41	37.32	.45	.00	41	660	34	P
5	1359340	Bozenkill	51.79	3.15	48.17	.47	.55	83	650	33	P
6	1359513	Hungerkill	8.16	7.26	0.85	0.04	0.32	37	200	32	12
7	1359517	Blockhouse Creek	1.96	1.77	.18	.00	.20	48	170	32	P
8	1359600	Vlomankill	29.77	1.43	28.33	.03	2.68	9	220	33	P
9	1359750	Moordner Kill	32.62	8.08	24.54	.00	.32	38	350	38	18
10	1359902	Coeymans Creek	35.09	2.87	31.41	.81	.00	85	650	33	8
11	1359990	East Brook	7.23	1.99	5.20	0.04	0.00	136	1,980	43	P
12	1360530	Trout Brook	4.86	.56	4.30	.00	.00	114	610	42	P
13	1361200	Claverack Creek	60.58	13.08	47.38	.12	.00	51	590	41	8
14	1361250	Taghkanic Creek	12.60	2.03	10.22	.35	.00	51	940	44	P
15	1361500	Catskill Creek	98.00	4.41	93.19	.39	.00	40	1,130	36	20
16	1361550	Ten Mile Creek	19.05	2.19	16.75	0.11	0.00	96	1,220	36	P
17	1361570	Ten Mile Creek	35.29	3.70	31.45	.14	.00	91	1,090	37	11
18	1361760	Wolf Fly Creek	6.45	.37	6.06	.01	.00	118	990	35	P
19	1362005	Bell Brook	1.31	.03	1.27	.00	.00	40	320	39	P
20	1362040	Marys Glen	.80	.00	.80	.00	.00	500	2,400	39	P
21	1362100	Roeliff Jansen	27.46	6.57	20.78	0.11	0.00	43	1,010	44	2
22	1362155	Preechey Hollow	2.53	.24	2.28	.00	.00	230	1,080	40	P
23	1362168	Fall Kill	5.02	.15	4.76	.10	.00	95	520	40	P
24	1362198	Esopus Creek	59.49	8.21	51.22	.06	.00	89	1,900	54	15
25	1362400	Stone Clove Creek	33.54	4.05	29.49	.00	.00	140	1,760	52	P

Table 1.--Drainage basin characteristics (continued).

No. on fig. 1	USGS site no.	Basin	Drainage area (mi^2)	Stratified-drift area (mi^2)	Till and bedrock area (mi^2)	Surface storage area (mi^2)	Urban area (mi^2)	Slope (ft/mi)	Mean basin elevation[1] (ft)	Mean annual precipitation (in/yr)	Period of record (years)
26	1364400	Platterkill	36.69	3.18	33.41	0.00	0.00	151	1,290	43	P
27	1364700	Sawkill	6.01	.69	5.24	.07	.00	54	490	46	P
28	1365500	Chestnut Creek	20.88	4.63	16.19	.06	.00	135	1,580	49	20
29	1366650	Sandburg Creek	56.68	11.73	42.97	1.98	.00	61	720	46	20
30	1366750	Beer Kill	43.31	1.73	40.96	.61	.00	82	770	46	P
31	1366800	Vernooykill	23.51	3.80	19.65	0.07	0.00	128	1,100	46	P
32	1368810	Wawayanda Creek	44.96	9.09	35.24	.63	.45	7	740	44	P
33	1369650	Stony Creek	2.62	.00	2.60	.02	.00	103	600	42	P
34	1370600	Crystal Brook	8.40	.08	8.23	.08	.00	22	480	42	4
35	1370800	Tin Brook	20.80	.52	19.28	1.00	.00	13	440	45	P
36	1370836	Dwaarkill	12.81	0.14	12.67	0.00	0.00	33	460	42	P
37	1372030	Fallsburg Creek	3.58	.14	3.05	.29	.00	8	250	40	P
38	1372050	Fall Kill	16.69	1.69	14.65	.25	1.60	15	300	41	P
39	1372065	Casper Creek	10.11	3.20	6.88	.03	.00	6	140	43	7
40	1372100	East Branch Wappinger Creek	33.60	6.98	26.27	.34	.00	31	590	41	6
41	1372200	Wappinger Creek	94.22	17.23	73.22	3.77	0.00	17	580	48	18
42	1372300	Little Wappinger Creek	32.90	3.48	28.29	1.12	.00	13	430	41	18
43	1372400	Great Spring	15.76	2.18	13.51	.00	.00	30	360	41	20
44	1372800	Fishkill	57.33	10.77	45.70	.86	.00	17	570	43	18
45	1372850	Whortlekill Creek	7.37	3.32	4.01	.04	.00	58	400	42	11
46	1372900	Sprout Creek	49.25	10.69	37.38	1.18	0.43	22	525	42	P
47	1372950	Clove Creek	13.06	1.40	11.49	.17	.00	75	590	43	P
48	1373690	Woodbury Creek	11.18	1.29	9.73	.16	.00	40	720	44	3
49	1374300	Peekskill Hollow	46.62	7.73	37.06	1.82	.60	80	430	48	P
50	1374440	Cedar Pond Brook	17.29	.96	15.81	.52	.62	130	410	47	3
51	1374460	South Branch Minisceongo Creek	5.83	1.80	3.59	0.43	0.00	23	470	46	P
52	1376100	Pocantico River	15.70	.84	14.60	.25	.43	31	220	48	P
53	1376270	Sparkill	4.93	1.70	3.23	.00	.41	60	200	48	8

[1] Altitude above mean sea level.

P Partial-record station.

If a suitable index station for determination of low-flow statistics through duration curves could not be found, a simple ratio of low-flow statistics was used. The 7-day, 10-year low flows were calculated for the station with 8 to 14 years of record and for a concurrent period at several long-term sites. The ratio of short-period to long-period flow statistics for the long-term sites was then used to adjust the 7-day, 10-year low flow at the site with the short record.

If a site was a low-flow partial-record station or a gaged station with fewer than 8 years of data, measured flows were correlated with concurrent daily mean flows at index stations, and the 7-day, 10-year statistics were obtained graphically as described by Riggs (1982). The 7-day, 2-year low flows were determined in a manner similar to that described above for 7-day, 10-year flows.

Computation of Drainage-Basin Characteristics

The independent variables selected for the regression analysis were basin characteristics that might influence low flows. Those that were selected represent a broad scope of indices for hydrologic, hydraulic, geologic, and meteorologic factors that could influence the quantity of low flow in a basin.

The basin characteristics selected for the study were (1) drainage areas, including separate identification of stratified-drift area, till and bedrock area, urban area, and surface-water area; (2) main-channel slope; (3) mean elevation of basin; and (4) adjusted mean annual precipitation. These terms are described below; the values used for each site are listed in table 1.

Drainage area (A).--The size of a stream's drainage area is the main factor in discharge variability among streams. Although the contributing area should be defined by the location of the ground-water divide because low flow consists predominantly of ground water, surface-water divides were used in this study. The difference is probably insignificant in most basins studied. Drainage areas, in mi^2, were computed from U.S. Geological Survey (1:24,000 scale) topographic maps.

Area of stratified drift (Sd_A).--The area of stratified drift within a basin is an index for both the ground-water-storage capacity and the potential to transmit water to the stream. Areas of stratified drift were computed, in mi^2, from maps in a variety of publications on soils and ground-water resources. (See list of additional references.) County soils maps were the major source of information. The percentage of basin area underlain by stratified drift is denoted as Sd in the equations given later in this report. Lacustrine deposits were omitted from the stratified-drift area but were included in the till and bedrock area because of their low hydraulic conductivity.

Area of till and bedrock (T_A).--Till and bedrock may decrease the potential for ground-water storage or release in a basin. The area consisting of surficial till and bedrock, in mi^2, was measured on maps in a fashion similar to that for stratified drift. The percentage of till and bedrock in a basin is denoted as T in the equations.

Area of surface storage (Ss_A).--Surface storage is that part of the total basin occupied by lakes, ponds, and marshes. Low flow can be altered by retention or release of water from surface storage. For example, surface runoff to some streams may be delayed by surface storage without the total runoff being affected, whereas surface-water storage in others may decrease low flows substantially as a result of evapotranspiration. The surface-storage area within each basin, in mi^2, was obtained from U.S. Geological Survey topographic maps. The percentage of surface storage within a basin is denoted by variable Ss in the equations.

Area of urbanization (U_A).--Urbanization may decrease the low flow in a stream by reducing infiltration and recharge to the ground-water system. Urbanization may also add to low flows if treatment-plant effluents are discharged to streams (Singh and Stall, 1974). Although attempts were made to omit basins having extensive urbanization (those over 10 percent), this variable was included because some of the basins were partly urbanized. The size of urbanized areas, in mi^2, was obtained from U.S. Geological Survey topographic maps.

Main-channel slope (S).--The index of slope used in this analysis was the average slope of the stream channel, in ft/mi, between points 10 percent and 85 percent of the distance from the gaged site to the drainage divide. Measurements needed for calculation of slope were taken from U.S. Geological Survey topographic maps.

Elevation (E).--Although elevation itself may not directly influence streamflow, it may be useful as an index to other basin characteristics not readily obtainable, such as radiation, wind, temperature, vegetation, and basin ruggedness (Dingman, 1981). The measurement of mean basin elevation is time consuming and was therefore estimated from results of a study by Langbein and others (1947) of gaged stations in the eastern United States. The resulting values were calculated as 34 percent of the range between minimum and maximum basin elevations (given on U.S. Geological Survey topographic maps) added to the minimum basin elevation. In all equations, E is expressed in hundreds of feet.

Mean annual precipitation (P).--Mean annual precipitation in a basin represents the amount of water available for potential runoff or infiltration. Mean annual precipitation was obtained from rainfall maps (fig. 2) that are based on precipitation recorded at National Weather Service stations. In subsequent equations P, is adjusted to mean annual precipitation minus 25 inches.

Selection of Equations for Regression Analysis

Multiple-regression analysis was used to define the relationship between the low-flow statistics (the dependent variable) and the selected basin characteristics (independent variables) for each site. The regression analyses were done by the "Stepwise" and "GLM" procedures as outlined in the Statistical Analysis System User's Guide (SAS Institute, 1982). The multiple regression analysis, in addition to yielding the regression constants and coefficients for the models, defines the standard error of estimate of the models and the statistical significance of each variable.

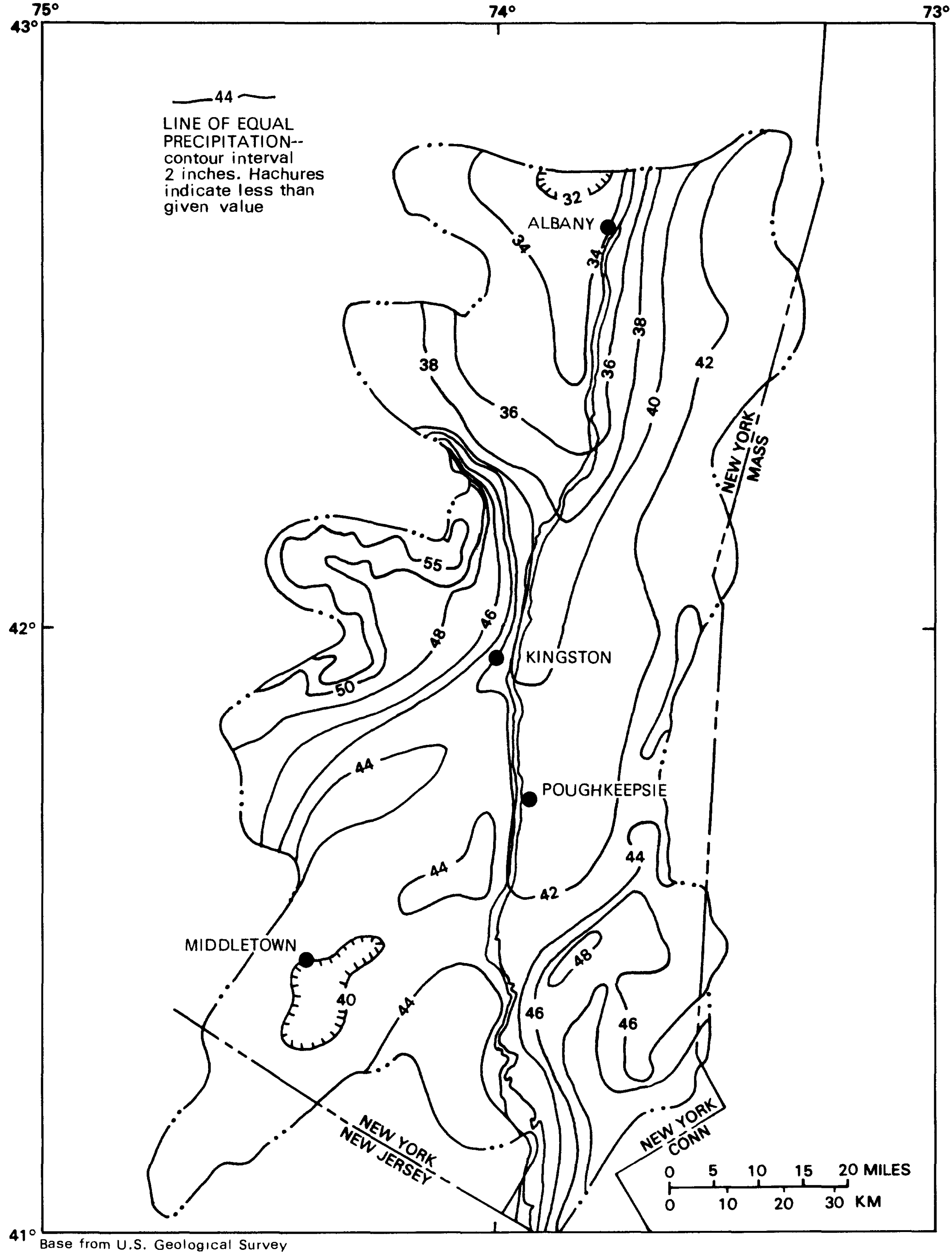


Figure 2.--Average annual precipitation in lower Hudson River basin. (Modified from Knox and Nordenson, 1954.)

Four general types of equations were used in this analysis;

$$Q_{7,t} = K_1 A^{ma} B^{mb} C^{mc} \ldots Z^{mz} \quad (1)$$

$$Q_{7,t} = K_2 (m_b B_A + m_c C_A + \ldots m_m M_A + K_3) \quad (2)$$

$$Q_{7,t} = A(q_{sm,t}) \text{ where} \quad (3)$$
$$q_{sm,t} = m_b B + m_c C + \ldots m_z Z + K_4 \quad (3a)$$

$$Q_{7,t} = A(q_{sm,t}) \text{ where} \quad (4)$$
$$q_{sm,t} = K_5 B^{mb} C^{mc} \ldots Z^{mz} \quad (4a)$$

where: $Q_{7,t}$ = mean 7-day low flow with a t-year recurrence interval, in ft^3/s,
A = area of basin,
$B, C, \ldots Z$ = basin characteristics,
$B_A, C_A, \ldots M_A$ = size of area representing given areal basin characteristic, in mi^2. For example, if B represents percentage of basin that is underlain by till and bedrock, B_A is its area, in mi^2),
$q_{sm,t}$ = mean 7-day low flow with a t-year recurrence interval, divided by area of basin, in $(ft^3/s)/mi^2$,
$m_a, m_b, \ldots m_z$ = regression coefficients defined by the regression analysis,
$K_1, K_2, \ldots K_5$ = regression parameters defined by the regression analysis.

The most significant differences among the equations are the low-flow variables used as the dependent variable. Equations 2, 3, and 3a are linear, whereas equations 1 and 4a are log-linear. (Eq. 4, although linear, uses the results of eq. 4a.) Among the linear equations, the dependent variable is the 7-day, t-year low flow in equation 2, whereas in equation 3a, the dependent variable is flow per mi^2 during 7-day, t-year flow conditions. In equations 1 and 4a, the dependent variables is the log of these variables, respectively.

ANALYSIS OF LOW FLOW AT GAGED AND PARTIAL-RECORD SITES

Past failures in developing regional equations to estimate statistics were demonstrated by the large errors encountered in the regression analysis. Application of equations that did not contain geologic variables caused a large standard error of estimate for gaged and partial-record sites in the lower Hudson River basin. For the 7-day, 10-year low flow, equation 1 was the best possible regression equation when geologic variables were excluded; that equation yielded an error of 1.16 ft^3/s, 90 percent of the mean 7-day, 10-year low flow for these sites.

Effect of Stratified Drift

The relationships between the areal extent of stratified drift and low-flow discharge was evaluated in two ways. The first was by relating discharge, in ft^3/s, to total basin area overlain by stratified drift (fig. 3A);

the second was by relating low-flow discharge per square mile, (ft3/s)/mi2, to the percentage of basin area overlain by stratified drift (fig. 3B). The two plots differ only in that the values in fig. 3B are equal to the values in fig. 3A divided by the basin area. The purpose of this comparison is to illustrate the two variables that may be optimized in the regression analysis, namely (1) the 7-day, 10-year low-flow or 7-day, 2-year low-flow discharge, or (2) the flow per square mile during these low-flow conditions.

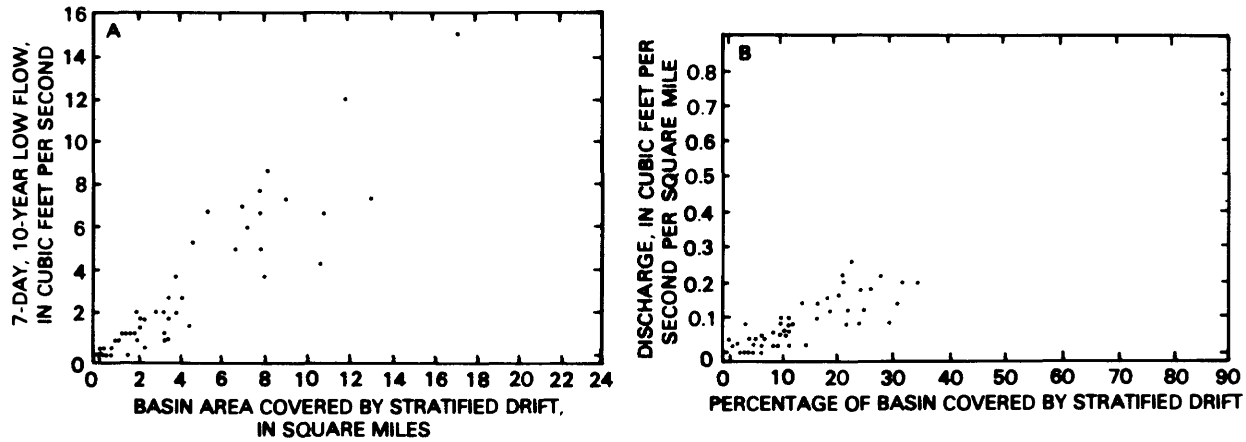


Figure 3.--Relationship of 7-day, 2-year low-flow discharge to basin area covered by stratified drift: A. With stratified-drift area expressed in square miles; B. With stratified drift expressed as percentage of drainage basin.

Results of Regression Analysis

The smallest standard errors for both the 7-day, 10-year and 7-day, 2-year low flows were obtained when the runoff per square mile was first estimated and the low-flow statistics then calculated by multiplying the areal runoff values by basin area (eq. 3).

The equations to estimate the runoff per square mile during 7-day, 10-year and 7-day, 2-year low-flow conditions were:

$$Q_{sm,10} = 0.0047Sd + 0.0013E - 0.030 \text{ and} \qquad (5)$$

$$Q_{sm,2} = 0.0070Sd + 0.0029E + 0.0021P - 0.060 \qquad (6)$$

In equation 5, which gives areal runoff during 7-day 2-year low-flow conditions, the basin percentage of stratified drift (Sd), mean elevation (E), and the adjusted mean annual precipitation (P) were statistically significant characteristics at the $\alpha < 0.1$ level. For areal runoff during 7-day 10-year low-flow conditions, only this percentage of stratified drift and mean elevation of the basin were significant. A possible explanation of the insignificance of mean annual precipitation in this regression analysis is the departure from normal precipitation patterns that accompany 7-day, 10-year low-flow periods. In addition, the significance level of mean annual precipitation may have been affected by the correlation between mean annual precipitation and elevation ($R^2 = 0.23$).

The mean areal 7-day low-flow runoff with 10-year and 2-year recurrence intervals for the 53 sites were 0.051 and 0.118 $(ft^3/s)/mi^2$, respectively. The standard error of estimate for the 10-year recurrence period was 0.023 $(ft^3/s)/mi^2$ or 45 percent of the mean value. The standard error for the 2-year recurrence period was 0.046 $(ft^3/s)/mi^2$, or 41 percent of the mean.

The residuals from the regression equations were examined for patterns that might indicate nonlinearity or circumstances for which the equation may be inappropriate. For equation 5, the residual indicated a slight tendency to underestimate when stratified drift covered less than 5 percent of the basin. Absolute values of the residuals were generally larger when the surface-storage term was less than 1 percent or the slope less than 40 ft/mi. No patterns were noted among the remaining variables within the range of values. Because surficial geology was determined from individual county maps, which may differ slightly in original interpretation, the residuals were also examined by county. Areal-runoff values for streams in Columbia County were generally overestimated, while those for Orange County were underestimated.

The absolute value of the residuals obtained in equation 6 indicated an increase in error as stratified-drift percentage increased. Because flow also increases with drift percentage, the relative error remains fairly constant, however. The absolute values of the residuals were generally smaller when surface storage exceeded 1 percent, and also among larger basins. Equation 6 underestimated values for Orange County streams.

The predicted and observed values for runoff per mi^2 are given in table 2. Where equations 5 or 6 predicted negative values, a <0.01 value was substituted.

To obtain 7-day, 10-year and 7-day, 2-year low flows, predicted runoff per mi^2 was multiplied by basin area. The resulting 7-day, 10-year low flows had a standard error of 0.63 ft^3/s or 51 percent of the mean, whereas the 7-day, 2-year low flow had a standard error of 1.06 ft^3/s or 39 percent of the mean. Predicted 7-day, 10-year and 7-day, 2-year low flows are given in table 3; the predicted values are plotted against observed values in figure 4.

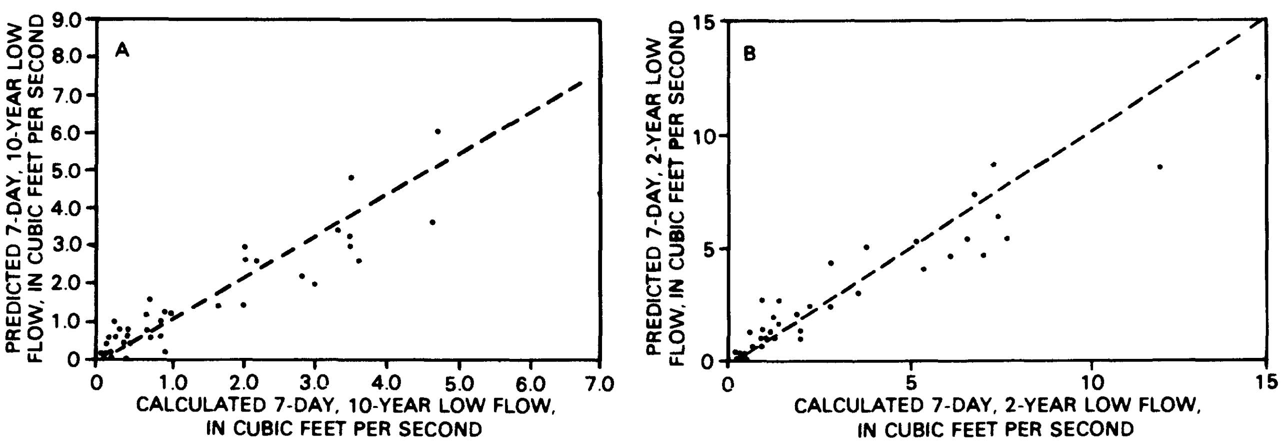


Figure 4.--Relationship between predicted and observed values for: A. 7-day, 2-year low flow from equation 6. B. 7-day, 10-year low flow from equation 5.

Table 2.--Observed and predicted discharges per square mile during 7-day, 10-year and 7-day, 2-year low flows.

[Discharges are in $(ft^3/s)/mi^2$. Locations are shown in fig. 1.]

Site no. on fig. 1	Station	7-day, 10-year discharge		7-day, 2-year discharge	
		Observed	Predicted from eq. 5	Observed	Predicted from eq. 6
1	1358500	0.035	0.028	0.097	0.069
2	1359100	.120	.104	.175	.180
3	1359155	.045	.086	.083	.143
4	1359200	.006	.017	.016	.035
5	1359340	.005	.007	.015	.017
6	1359513	.428	.393	.747	.585
7	1359517	.211	.400	.459	.595
8	1359600	.000	.000	.003	.005
9	1359750	.061	.091	.116	.151
10	1359902	.022	.017	.054	.032
11	1359990	.110	.125	.220	.228
12	1360530	.010	.032	.026	.074
13	1361200	.057	.079	.118	.142
14	1361250	.047	.058	.095	.119
15	1361500	.002	.006	.013	.026
16	1361550	.036	.040	.089	.078
17	1361570	.026	.033	.059	.069
18	1361760	.000	.010	.000	.029
19	1362005	.015	.000	.076	.000
20	1362040	.000	.001	.050	.038
21	1362100	.080	.096	.181	.176
22	1362155	.023	.028	.075	.069
23	1362168	.000	.000	.000	.008
24	1362198	.077	.059	.146	.152
25	1362400	.020	.049	.083	.132
26	1364400	.005	.027	.021	.075
27	1364700	.024	.030	.066	.078
28	1365500	.143	.095	.258	.191
29	1366650	.119	.077	.211	.150
30	1366750	.020	.001	.043	.034
31	1366800	.085	.060	.148	.129
32	1368810	.073	.075	.164	.143
33	1369650	.007	.000	.030	.000
34	1370600	.007	.000	.023	.000
35	1370800	.002	.000	.009	.012
36	1370836	.005	.002	.019	.005
37	1372030	.000	.000	.008	.006
38	1372050	.004	.022	.060	.053
39	1372065	.089	.121	.198	.204
40	1372100	.059	.076	.208	.136
41	1372200	.049	.064	.159	.133
42	1372300	.010	.025	.051	.060
43	1372400	.006	.040	.022	.081
44	1372800	.031	.066	.116	.126
45	1372850	.217	.188	.366	.303
46	1372900	.015	.079	.085	.143
47	1372950	.022	.028	.068	.069
48	1373690	.035	.034	.098	.082
49	1374300	.077	.054	.139	.117
50	1374440	.023	.002	.040	.037
51	1374460	.068	.122	.137	.214
52	1376100	.012	.005	.031	.032
53	1376270	.141	.136	.202	.237

Table 3.--Observed and predicted 7-day, 10-year and 7-day, 2-year low flows.

[Discharges are in ft^3/s. A = basin area in mi^2.]

Site no. on fig. 1	Station	7-day, 10-years low flows: Observed	7-day, 10-years low flows: Predicted from eq. 5 x A	7-day, 2-year low flows: Observed	7-day, 2-year low flows: Predicted from eq. 6 x A
1	1358500	2.80	2.18	7.60	4.40
2	1359100	3.50	3.05	5.10	2.91
3	1359155	.60	1.14	1.10	.78
4	1359200	.25	.73	.70	.71
5	1359340	.30	.38	.80	.64
6	1359513	3.50	3.21	6.10	5.92
7	1359517	.40	.78	.90	1.67
8	1359600	.01	<.01	.10	.33
9	1359750	2.00	2.99	3.80	2.00
10	1359902	.80	.60	1.90	.50
11	1359990	.80	.91	1.60	.86
12	1360530	.05	.16	.13	.29
13	1361200	3.50	4.84	7.20	4.78
14	1361250	.60	.73	1.20	1.51
15	1361500	.21	.58	1.30	1.85
16	1361550	.70	.76	1.70	.54
17	1361570	.92	1.19	2.10	1.11
18	1361760	.00	.06	.00	.11
19	1362005	.02	<.01	.10	.03
20	1362040	.00	<.01	.04	<.01
21	1362100	2.20	2.64	5.00	3.16
22	1362155	.06	.07	.19	.11
23	1362168	.00	.02	.00	.14
24	1362198	4.60	3.54	8.70	9.67
25	1362400	.70	1.66	2.80	4.47
26	1364400	.20	1.01	.80	2.08
27	1364700	.15	.18	.40	.52
28	1365500	3.00	1.99	5.40	3.36
29	1366650	6.80	4.38	12.00	7.37
30	1366750	.90	.05	1.90	2.39
31	1366800	2.00	1.42	3.50	2.43
32	1368810	3.30	3.38	7.40	4.64
33	1369650	.02	<.01	.08	.02
34	1370600	.06	<.01	.20	.20
35	1370800	.05	<.01	.20	.94
36	1370836	.07	.02	.25	.31
37	1372030	.00	<.01	.03	.12
38	1372050	.08	.37	1.00	.85
39	1372065	.90	1.23	2.00	1.37
40	1372100	2.00	2.55	7.00	2.62
41	1372200	4.70	6.04	15.00	13.24
42	1372300	.35	.85	1.70	1.79
43	1372400	.10	.63	.35	.92
44	1372800	1.80	3.80	6.70	5.14
45	1372850	1.60	1.38	2.70	1.44
46	1372900	.80	3.92	4.20	4.53
47	1372950	.30	.37	.90	.84
48	1373690	.40	.38	1.10	.82
49	1374300	3.60	2.52	6.50	6.13
50	1374440	.40	.08	.70	1.21
51	1374460	.40	.71	.80	1.19
52	1376100	.20	.07	.50	1.14
53	1376270	.70	.67	1.00	1.11

In addition to the higher standard errors (ranging from 57 to 83 percent for 7-day, 10-year low flows and 44 to 57 percent for 7-day, 2-year low flows), the other regressions developed from equations 1, 2, and 4 were rejected for unrealistic regression parameters and observed trends in the residuals.

Sources of Error

The standard error of estimate for 7-day, 10-year and 7-day, 2-year low flows estimated for the 20-year reference period from equations 5 and 6 were 51 and 39 percent, respectively. The greater relative error associated with the 7-day, 10-year estimates may simply reflect the more anomalous conditions prevailing during 7-day, 10-year low-flow periods. The errors are not large, considering that for gaging stations in the lower Hudson River basin with 10 or more years of record, Eissler (1979) calculated the standard errors of estimate of 7-day, 10-year and 7-day, 2-year low flows to be 25 and 21 percent, respectively.

Errors were also introduced as a result of other basin characteristics. The largest source of error was probably in the geologic characteristics. The demarcation between stratified drift and till is not always distinct. Also, stratified drift may contain a wide grain-size distribution, which may affect the ability to store and transmit water, and the drift may be locally unsaturated. Till and bedrock formations may vary in water-transmitting ability also. The characterizations used in these equations do not account for possibly important subsurface features nor for the thickness of the surface deposits. Differences in interpretation during preparation of the original soil maps are also a possibility.

Error in the precipitation factor can be substantial in some regions, especially the Catskill Mountain area (fig. 2). Also seasonal precipitation (June through October) or minimum precipitation with a 10-year recurrence interval may be more important than mean annual precipitation (Chang and Boyer, 1977). The errors associated with drainage area, mean elevation, and channel slope are probably less than those associated with geologic characteristics and precipitation.

PROCEDURE FOR ESTIMATING LOW-FLOW STATISTICS FOR UNGAGED SITES

Estimating 7-day, 10-year and 7-day, 2-year low flows for ungaged locations in the lower Hudson River basin requires a topographic map and a surficial geology map. The user should verify that low flow is not influenced by regulation or urbanization. Taghkanic Creek near Craryville, in Columbia County, is used here as an example.

A 1:24,000-scale geologic map of the basin is shown in figure 5. The areas overlain by stratified drift, indicated by shading, were identified from a county soil-survey map by Lewis and Kinsman (1929). The basin area was measured to be 12.6 mi^2. The area of stratified drift was measured as 2.03 mi^2, or 16.1 percent of the total basin area. The marshes and swamps occupy 0.35 mi^2, or 2.8 percent. Till occupies 10.22 mi^2 or 81 percent.

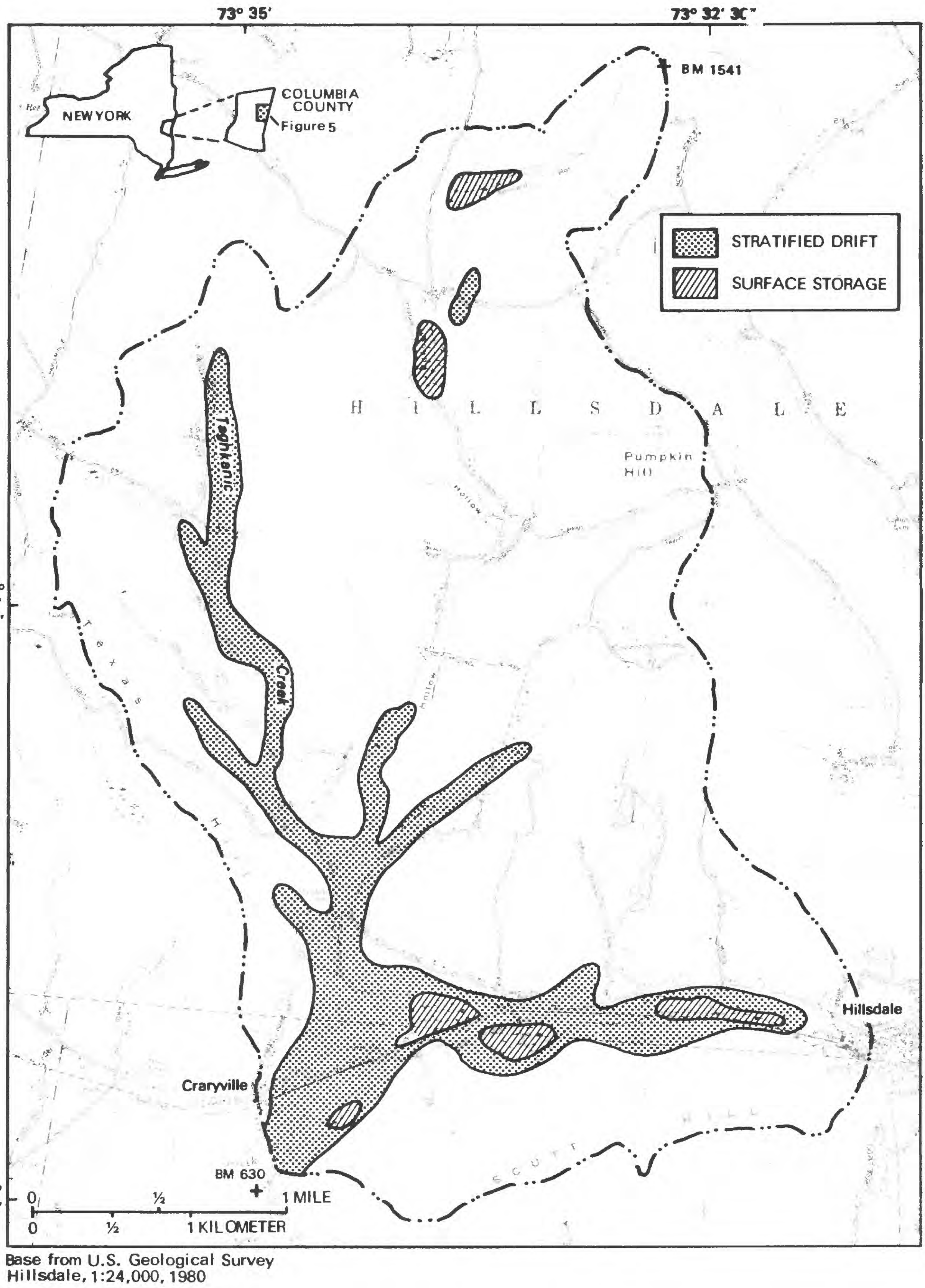


Figure 5.--Example of surficial geologic map showing delineation of stratified-drift and surface-storage areas. Location is shown in figure 1 (site 14, Taghkanic Creek near Craryville).

Mean annual precipitation (fig. 2) is about 44 inches. Elevation is 0.34 of the difference between the lowest and highest point in the basin. The lowest point is the ungaged site at 630 ft. The highest point is 1,541 ft. Thus, mean basin elevation is estimated to be 940 ft. The runoff per mi^2 during 7-day, 10-year low-flow conditions is estimated as follows:

$$Q_{sm,10} = 0.0047(Sd) + 0.0013(E) - 0.03 \qquad \text{(eq. 5)}$$

$$Q_{sm,10} = 0.0047(16.1) + 0.0013(9.4) - 0.03$$

$$Q_{sm,10} = .0578 \ (ft^3/s)/mi^2$$

and for 7-day 2-year conditions by

$$Q_{sm,2} = 0.0070(Sd) + 0.0029(E) + 0.0021(P) - 0.06 \qquad \text{(eq. 6)}$$

$$Q_{sm,2} = 0.0070(16.1) + 0.0029(9.4) + 0.0021(44-25) - 0.06$$

$$Q_{sm,2} = 0.1199 \ (ft^3/s)/mi^2$$

The 7-day, 10-year and 7-day, 2-year low flows can be estimated by multiplying these discharges by the drainage area:

$$Q_{7,10} = 0.0575 \ (ft^3/s)/mi^2 \times 12.6 \ mi^2 = 0.73 \ ft^3/s$$

$$Q_{7,2} = 0.1199 \ (ft^3/s)/mi^2 \times 12.6 \ mi^2 = 1.51 \ ft^3/s$$

SUMMARY AND CONCLUSIONS

The 7-day, 10-year and the 7-day, 2-year low flows can be estimated for any site on streams in the lower Hudson River basin that are (1) unregulated during low-flow periods and (2) not significantly affected by urbanization. The physical feature having the greatest effect on the standard error of the estimates is the percentage of basin area overlain by stratified drift.

The 7-day, 10-year and 7-day, 2-year low flows were calculated for 17 continuous-record gaging stations and for 36 low-flow partial-record stations. The calculations were based on a 20-year period of record from April 1, 1958 to March 31, 1978. The standard errors of estimate obtained are 0.62 (51 percent of mean) and 1.06 ft^3/s (39 percent of mean), respectively. Several techniques were attempted to describe the relationship between the 7-day, 10-year and 7-day, 2-year low flows and basin characteristics. Included in basin characteristics were the percentage of basin underlain by stratified drift and by till or bedrock. The equation that gave the best estimates of the 7-day, 10-year low flow is:

$$Q_{7,10} = A(0.0047 \ Sd + 0.0013 \ E - 0.030) \qquad \text{(eq. 5)}$$

and for 7-day, 2-year low flow is:

$$Q_{7,2} = A(0.0070 \ Sd + 0.0029 \ E + 0.0021 \ P - 0.060) \qquad \text{(eq. 6)}$$

where: $Q_{7,10}$ = 7-day, 10-year low flow, in ft^3/s,
$Q_{7,2}$ = 7-day, 2-year low flow, in ft^3/s,
A = drainage area, in mi^2,
Sd = percentage of drainage basin overlain by stratified drift,
E = mean basin elevation above sea level, in hundreds of feet,
P = mean annual precipitation, in inches minus 25.

Other regression equations had greater standard errors of estimate. All equations that included surficial geologic characteristics yielded lower standard errors than those that do not.

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