BASE FLOW OF 10 SOUTH-SHORE STREAMS, LONG ISLAND, NEW YORK, 1976-85, AND THE EFFECTS OF URBANIZATION ON BASE FLOW AND FLOW DURATION

By Anthony G. Spinello and Dale L. Simmons

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CONVERSION FACTORS AND ABBREVIATIONS

Multiply	by	To obtain
	Length	
inch (in.)	25.4	millimeter
inch (in.)	2.54	centimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
foot per mile (ft/mi)	0.1894	meter per kilometer
	Area	
acre	0.4047	hectare
square mile (mi^2)		square kilometer
	Flow	
cubic foot per second (ft^3/s)	28.32	liter per second
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
million gallons per day (Mgal/d)	0.0438	cubic meter per second

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Abstract

Hydrograph-separation techniques were used to quantify the 1976-85 base flows of 10 continuously gaged streams on the south shore of Long Island. Base flow is the water that enters a stream channel as discharge from the ground-water reservoir--the "fair-weather" flow of the stream. Base flow during 1948-52, the last 5 years before extensive urban development, constituted about 95 percent of the total annual stream discharge, but in 1976-85, it averaged 14 percent in streams in a highly urbanized, sewered area; 79 percent in streams in a less urbanized, more recently sewered area; 88 percent at streams in a suburban area in which sanitary sewerage is nearly complete; and 96 percent at streams in an unsewered area where development is minimal.

A major cause of base-flow decreases on Long Island has been a lowering of the water table as a result of urbanization. The principal factors that cause this lowering include a decrease in the amount of permeable (unpaved) area, the routing of storm runoff directly to streams through storm sewers, and sanitary sewers, all of which intercept recharge and prevent it from entering the ground-water system. Water-level declines and the attendant losses of base flow are minimized in areas where stormwater is routed to recharge basins.

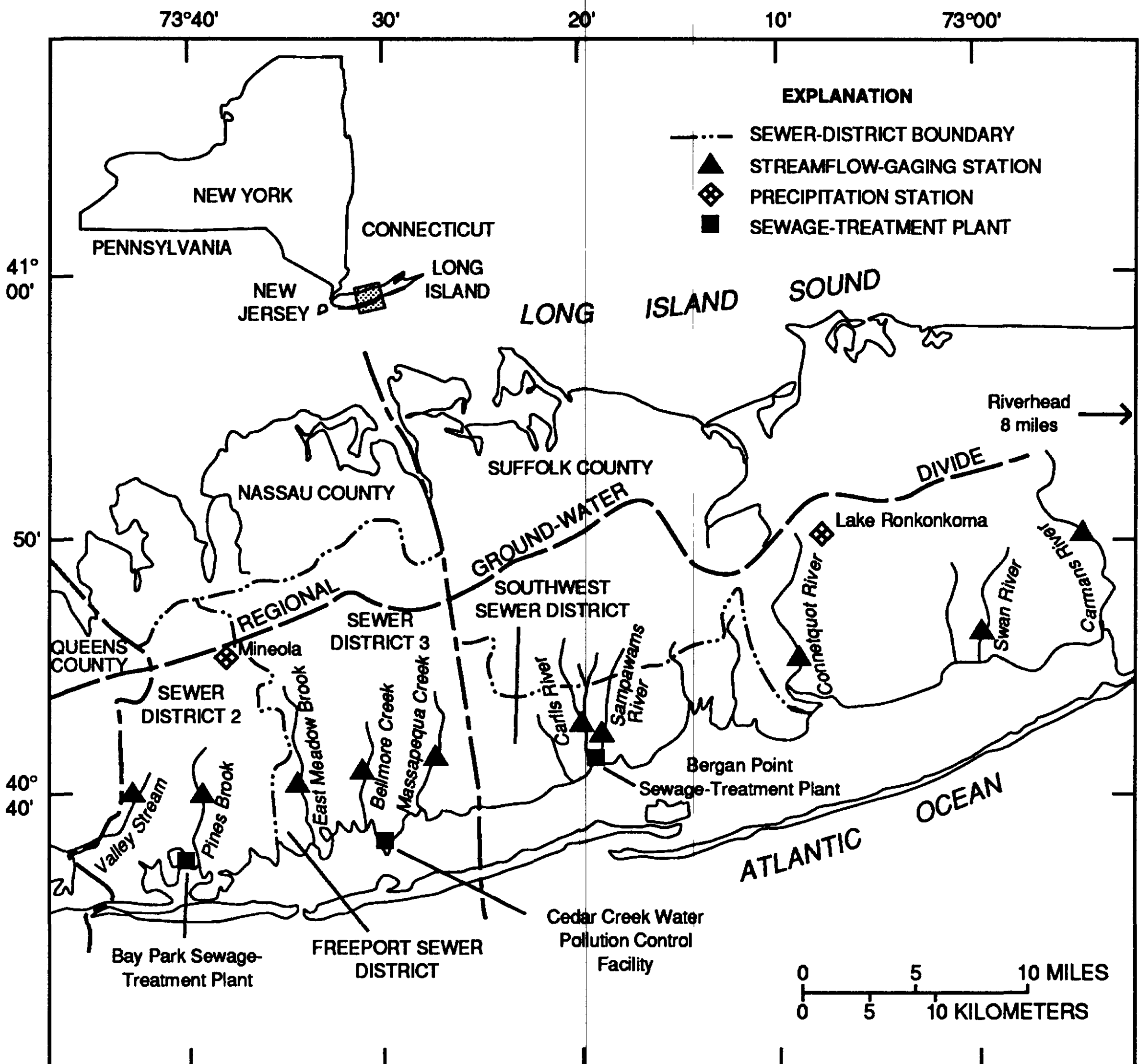
Flow-duration analysis shows that urbanization also causes an increase in the magnitude and frequency of high flows and in the flow variability of each stream. These effects currently are seen as far east as Carlls River in southwestern Suffolk County. Double-mass-curve analysis shows that a new base-flow equilibrium has been reached at the three westernmost streams studied.

INTRODUCTION

Streams in the highly permeable glacial outwash deposits on the south shore of Long Island (fig. 1) that are in areas largely unaffected by urban development derive about 95 percent of their total flow from ground-water discharge (base flow); the remainder of the flow consists of direct runoff from storms (Pluhowski and Kantrowitz, 1964). Because the streams function as ground-water drains, small fluctuations in ground-water levels may cause large fluctuations in stream discharge (Garber and Sulam, 1976).

Progressive eastward urbanization on Long Island since the 1940's has been accompanied by (1) a large-scale increase in impermeable land-surface area and construction of storm sewers to convey storm runoff directly to stream channels, both of which decrease the infiltration of precipitation to the water table and increase the flow of streams during storms; and (2) construction of sanitary sewers, which discharge wastewater to the bays or ocean surrounding the island through sewage-treatment plants rather than returning it to the ground-water system through cesspools and septic tanks. These effects have caused ground-water levels to decline, and this, in turn, has decreased ground-water discharge to streams and diminished streamflow during dry weather (base flow).

Declines in ground-water levels and stream base flow as a result of urbanization have been documented by Sawyer (1963), Franke (1968), Seaburn (1969), Garber and Sulam (1976), Pluhowski and Spinello (1978), Sulam (1979), Prince (1981), Reynolds (1982), and Simmons and Reynolds (1982). The most recent of these investigations quantified the changes in streamflow characteristics only through 1975; since that time, however, construction of sanitary



Base from U.S. Geological Survey, 1:250,000 scale.
Hartford, 1962; New York, 1957; Providence, 1947

Figure 1.--Locations of the 10 streams studied.

sewers has been completed in Nassau County Sewer District 3 in southeastern Nassau County, and hookups are underway in the Southwest Sewer District in southwestern Suffolk County (fig. 1). The effects of these and other urbanization-related activities on patterns of streamflow on Long Island since 1975 have not been previously documented.

Purpose and Scope

This report quantifies the annual base flow of all 10 continuously gaged streams on the south shore of Long Island for each year from 1976 through 1985. Three graphical methods of streamflow analysis--hydrograph separation, double-mass-curve analysis, and flow-duration-curve analysis--are used to compare current flows with those before urbanization and to illustrate the nature and magnitude of streamflow changes that have occurred since the 1940's. Three 5-year time periods were chosen for comparison of base-flow and flow-duration data. The first period, 1948-52 (index period), represents hydrologic conditions in the drainage basins before extensive urban development; the second, 1971-75, represents the streams' response from 1948-52 to 1972-75 (23 years) to changes caused by urbanization; and the last represents the period of further adjustment of streamflow to changing hydrologic conditions from 1971-75 to 1981-85 (10 years).

Acknowledgments

Paul Heisig, of the U.S. Geological Survey office in Syosset, N.Y., performed the statistical analysis of precipitation data. Ernest F. Rossano and Ronald J. Busciolano, U.S. Geological Survey, Syosset, prepared the computer program that produced the 3-year running-average base-flow hydrographs.

DESCRIPTION OF STREAMS

Stream valleys on the south shore of Long Island are broad, straight, and shallow and generally follow the courses established by meltwater channels during glacial retreat. These streams are widely spaced, have few or no tributaries, and have gentle gradients that average 10 ft/mi (Cohen and others, 1968).

The high permeability of the outwash sand and gravel, as well as the flat terrain, enable precipitation to infiltrate almost immediately. Before urbanization, about 95 percent of annual streamflow consisted of water from the upper glacial aquifer (Franke and McClymonds, 1972); the remaining 5 percent consisted of direct runoff. Thus, the streams function as ground-water drains, and streamflow during dry weather is determined by ground-water levels adjacent to the stream channel (Pluhowski and Kantrowitz, 1964).

All 10 continuously gaged streams on the south shore were included in this study. These streams and their drainage area, average daily discharge, and period of record, which ranges from 32 to 49 years, are listed in table 1. The average daily discharge ranges from 2.23 ft^3/s at Valley Stream, the smallest and westernmost stream, to 38.5 ft^3/s at Connetquot River, the largest stream studied. Stream locations are shown in figure 1.

Valley Stream and Pines Brook flow through the most highly urbanized part of western Nassau County. The construction of sanitary sewers in this area began in 1953 and was completed in 1964. Bellmore and Massapequa Creeks are farther east in Nassau County, where urbanization is less extensive (Cohen and others, 1968). Here, hookups to wastewater-treatment facilities were completed in 1989. East Meadow Brook roughly parallels the border between the two Nassau County sewer districts.

Carlls River and Sampawams Creek flow through southwestern Suffolk County, an area of primarily suburban development, where construction of sanitary sewers that currently receive about 65 percent of domestic wastewater is virtually complete. Connetquot River, just outside the eastern border of the Southwest Sewer District, is surrounded by State parkland. Swan River and Carmans River are in a largely suburban area that has no sanitary sewers. Carmans River is surrounded by town and county parkland.

Table 1.--Mean daily discharge of the 10 streams studied

[Locations are shown in fig. 1; SWSD, Suffolk County Southwest Sewer District]

Stream name	Stream-flow-gaging-station number	Sewer district	Approximate drainage area (square miles)	Average daily discharge (cubic feet per second)	Period of continuous record
NASSAU COUNTY					
Valley Stream	01311500	2	4.5	2.23	July 1954-Sept. 1985
Pines Brook	01311000	2	10	3.68	Dec. 1936-Sept. 1985
East Meadow Brook	01310500	2 and 3	31	14.3	Jan. 1937-Sept. 1985
Bellmore Creek	01310000	3	17	10.0	Sept. 1937-Sept. 1985
Massapequa Creek	01309500	3	38	11.1	Dec. 1936-Sept. 1985
SUFFOLK COUNTY					
Carlls River	01308500	SWSD	35	26.6	Oct. 1944-Sept. 1985
Sampawams Creek	01308000	SWSD	23	9.71	Oct. 1944-Sept. 1985
Connetquot River	01306500	unsewered	24	38.5	Oct. 1943-Sept. 1985
Swan River	01305500	unsewered	8.8	12.7	Oct. 1946-Sept. 1985
Carmans River	01305000	unsewered	71	24.2	June 1942-Sept. 1985

FACTORS THAT AFFECT BASE FLOW

The principal factors that affect ground-water levels on Long Island, and, in turn, control the amount of ground water that discharges to streams, are (1) precipitation, (2) the use of storm sewers and recharge basins, and (3) the use of sanitary sewers. Each of these factors and its effect on stream base flow is described below.

Precipitation

Mean annual precipitation on Long Island ranges from about 40 in. on the south shore of Nassau County to about 51 in. in the island's central region, near Lake Ronkonkoma (fig. 1), and has a long-term mean of 44 in. islandwide (Cohen and others, 1968). Precipitation patterns on Long Island are described in detail by Miller and Frederick (1969).

Under predevelopment conditions, an increase in precipitation causes ground-water levels to rise and surface runoff to increase, which increases both the base-flow and direct-runoff components of streamflow. The ratio between these two components of total stream discharge does not change significantly, however, except during storms of unusually long duration or high intensity (Ku and Simmons, 1986). Similarly, a decrease in precipitation causes a reduction in both base flow and direct runoff but, again, causes little change in the ratio between them. This is because the runoff-to-precipitation ratio depends primarily on the physical characteristics of the drainage basin rather than on precipitation.

As a part of this study, precipitation data were analyzed statistically to examine the possibility that spatial or temporal variations in precipitation might be a major factor in the observed changes in streamflow patterns. Figure 2 shows total annual precipitation at precipitation-measurement stations in Mineola and Riverhead (fig. 1) for 1948-85. Annual precipitation at Mineola ranged from 27.27 to 69.64 in. during this period; that at Riverhead ranged from 30.99 to 65.46 in. A paired t-test showed no statistical difference at the 95-percent confidence level between mean precipitation at these two stations.

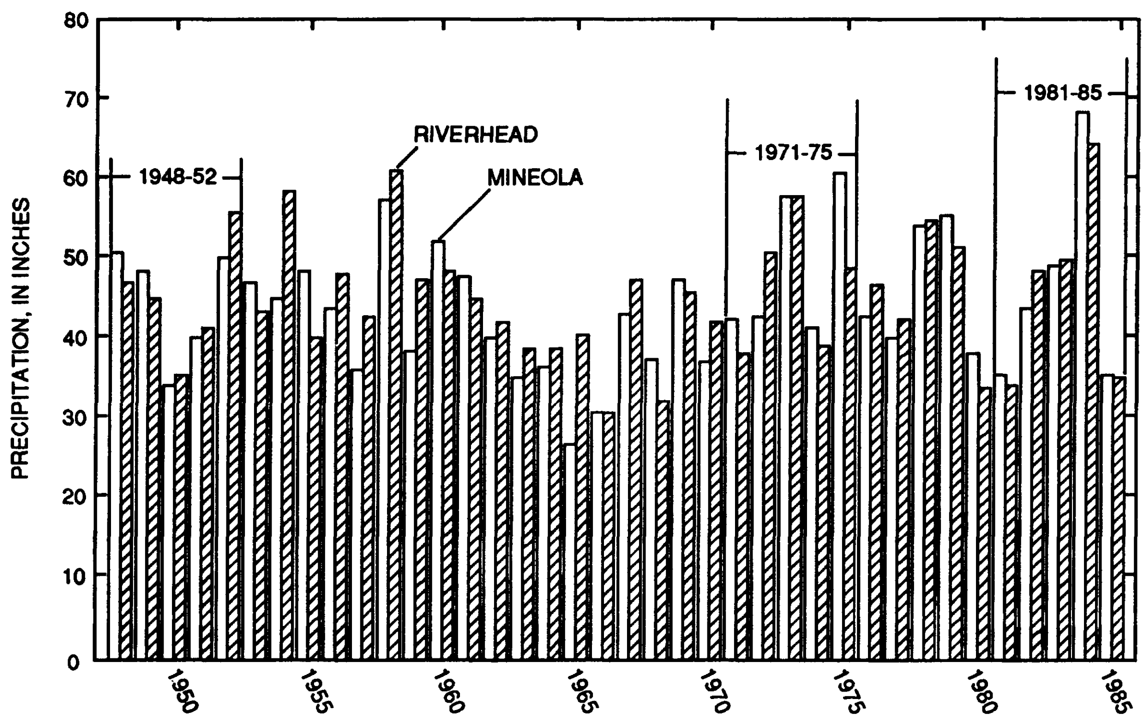


Figure 2.--Annual precipitation at Mineola and Riverhead, 1948-85. (Locations are shown in fig. 1.)

Total and mean annual precipitation at Mineola and Riverhead during the three 5-year periods chosen for comparison of base-flow and flow-duration data are shown in table 2. (See section on methods of streamflow analysis.) A Kruskal-Wallis test for analysis of variance among small populations of data with a non-normal distribution showed no statistical difference at the 95-percent confidence level in precipitation among these three time intervals at either Mineola or Riverhead.

Table 2.--Total and mean annual precipitation at Mineola and Riverhead during 1948-52, 1971-75, and 1981-85

[Values are in inches]

	Mineola		Riverhead	
Time period	Total	Mean	Total	Mean
1948-52	229.20	45.84	222.78	44.56
1971-75	248.69	49.74	237.44	47.49
1981-85	238.40	47.68	237.40	47.48

Recharge Basins

Rapid eastward urbanization on Long Island since the 1940's, with the attendant construction of highways, houses, shopping centers, industrial parks, and streets and sidewalks in previously undeveloped or agricultural areas, has caused a decrease in the amount of land surface through which precipitation can infiltrate. The increased amount of impervious surface has, in turn, caused a twofold water-management problem--an increased volume of urban storm runoff from paved areas and a consequent loss of ground-water recharge. To eliminate the need for costly trunk storm sewers to carry storm runoff to coastal waters and to minimize the loss of recharge, excavation of shallow stormwater-collection basins known as recharge basins was begun in 1935 to retain the runoff and allow it to infiltrate to the underlying aquifers (Pluhowski and Spinello, 1978). The conveyance of storm runoff to these basins through storm sewers enables efficient disposal of storm runoff and replenishment of the ground water (Ku and Simmons, 1986).

Most of the recharge basins on Long Island are unlined, open pits that range in area from 0.1 to 30 acres; the average is 1.5 acres. Most are about 10 ft deep, but some are as deep as 40 ft (Seaburn and Aronson, 1973). Long Island today has more than 3,000 such basins--more than 800 in eastern Nassau County and the remainder in western Suffolk County (fig. 3). According to Aronson and Seaburn (1974), 91 percent of these basins are dry within 5 days after a 1-inch rainfall. Those that hold water for longer periods either intersect the water table, are excavated in till or moraine of low permeability rather than in outwash deposits, or are clogged by sediment and debris.

Under predevelopment conditions, about 50 percent of the average annual precipitation on Long Island infiltrated the soil and recharged the ground-water reservoir (Aronson and Seaburn, 1974); the rest was lost through evapotranspiration or became runoff to tidewater. At present, however, much of the precipitation falls on impervious surfaces and becomes runoff, thereby decreasing the amount of natural recharge.

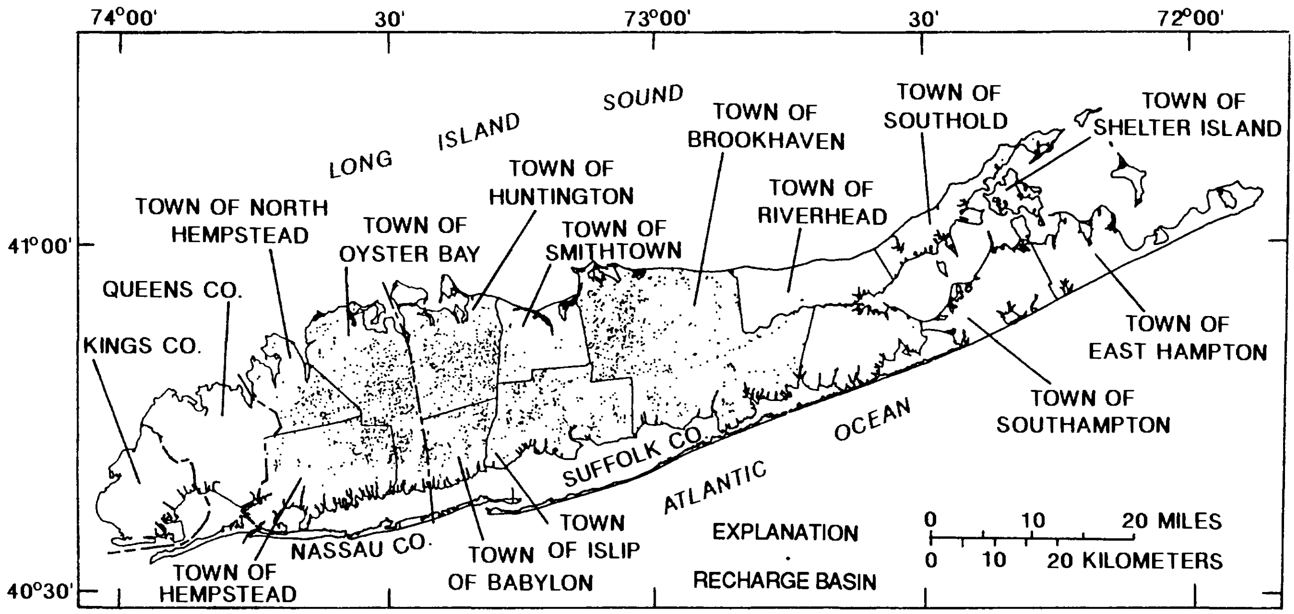


Figure 3.--Locations of recharge basins in Nassau and Suffolk Counties in 1969. (From Seaburn and Aronson, 1973, fig. 2.)

Most recharge now results from infiltration of precipitation through remaining pervious areas, such as lawns and other open spaces, and from infiltration of storm runoff through recharge basins. More than 10 percent of the area in Nassau and Suffolk Counties drains to recharge basins. In these areas, ground-water recharge from precipitation probably exceeds recharge under predevelopment conditions (Seaburn and Aronson, 1974), especially during the growing season (H. F. H. Ku, U.S. Geological Survey, written commun., 1988). In addition, some of the water used for domestic and industrial purposes returns to the ground-water system through cesspools, septic tanks, leaching basins, and recharge wells; some of the water used to irrigate lawns returns to the water table by infiltration.

Since the early 1960's, many storm sewers have been constructed in southern Nassau County and southwestern Suffolk County, where the population increase has been most rapid (Pluhowski and Spinello, 1978). The use of recharge basins there is impractical, however, because the water table there is less than 20 ft below land surface (Koszalka, 1975). Therefore, most of the storm runoff in this area is conveyed directly to streams, which increases the runoff component and decreases (by reducing ground-water recharge) the base-flow component of stream discharge.

Sanitary Sewers

Before the first large-scale sewage-treatment plant on Long Island began operation in the 1950's, domestic and industrial waste was discharged into the ground through individual septic systems, except in the few villages that had their own treatment systems; these plants also discharged effluent into the ground. Only the village of Freeport in south-central Nassau County (fig. 1) had a sewage system that discharged effluent to tidewater.

Initial planning for sanitary sewers in Nassau County began in response to (1) the need to protect the ground-water reservoir from contamination, (2) increasing commercial and industrial development, and (3) the failure of aging private sewage-disposal units. Today, sanitary sewers convey wastewater from residences and commercial and industrial facilities to sewage-treatment plants that discharge the treated effluent to the ocean. Figure 1 shows the areas served by Nassau County Sewage-Disposal Districts 2 and 3 and Suffolk County's Southwest Sewer District; rates of effluent discharge from each of the three sewage-treatment facilities are illustrated in figure 4 and listed in table 3.

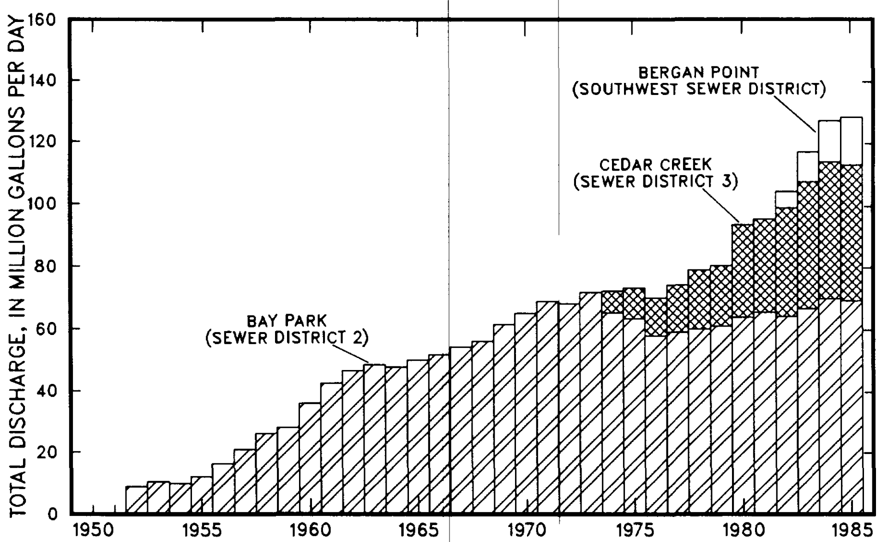


Figure 4.--Annual discharge from Bay Park, Cedar Creek, and Bergan Point sewage-treatment plants, 1952-85.

Sewer District 2 in western Nassau County has been in operation since 1952. Effluent from the Bay Park Sewage Treatment Plant (fig. 1) increased from 8.8 Mgal/d in 1952 to 68.8 Mgal/d in 1985 (R. M. Alvey, Nassau County Department of Public Works, written commun., Jan. 25, 1988), except for a temporary decline beginning in the mid-1970's, when the Cedar Creek Water Pollution Control Plant (fig. 1) in adjacent Sewer District 3 began operation. Discharge from the Bay Park facility has now returned to the levels of the early 1970's.

Sewer District 3, in eastern Nassau County, began operation in 1974, when discharge from the Cedar Creek Water Pollution Control Plant was 7.1 Mgal/d. This amount had increased to 43.5 Mgal/d by 1985 (R. M. Alvey, Nassau County Department of Public Works, written commun., Jan. 25, 1988).

Suffolk County's Southwest Sewer District began treating wastewater in 1982, when discharge from the Bergan Point facility (fig. 1) was 5.3 Mgal/d. By 1985, the amount had increased to 15.5 Mgal/d (Steven Cary, Suffolk County Department of Health Services, oral commun., Jan. 27, 1988). Therefore, the total loss of ground water through sanitary sewers in the three major sewer districts on the south shore of Long Island in 1985 was 127.8 Mgal/d, more than a 14-fold increase over the 1952 value of 8.8 Mgal/d. (Discharge from six smaller sewage-treatment plants on the south shore of Long Island was 11.2

Mgal/d in 1985 (B. J. Schneider, Nassau County Department of Public Works, written commun., Dec. 15, 1988).) Discharge from the Southwest Sewer District is expected to increase for several years as additional homeowners complete their hookups to the sanitary-sewer system.

Table 3.--Annual discharge from Bay Park, Cedar Creek, and Bergan Point sewage-treatment plants, 1952-85

[Values are in million gallons per day]

Year	Bay Park[1] (Sewer District 2)	Cedar Creek[1] (Sewer District 3)	Bergan Point[2] (Southwest Sewer District)
1952	8.8		
1953	10.5		
1954	9.9		
1955	12.1		
1956	16.3		
1957	20.9		
1958	26.1		
1959	28.0		
1960	35.8		
1961	42.4		
1962	46.5		
1963	48.4		
1964	47.7		
1965	49.9		
1966	51.6		
1967	54.0		
1968	55.9		
1969	61.3		
1970	64.9		
1971	68.7		
1972	68.0		
1973	71.7		
1974	65.0	7.1	
1975	63.2	9.9	
1976	57.7	12.1	
1977	58.8	15.2	
1978	59.9	18.9	
1979	60.7	19.5	
1980	63.6	29.6	
1981	65.2	29.8	
1982	63.9	34.7	5.3
1983	66.4	40.6	9.6
1984	69.6	43.7	13.4
1985	68.8	43.5	15.5

[1] R. M. Alvey, Nassau County Department of Public Works, written commun., Jan. 25, 1988.

[2] Steven Cary, Suffolk County Department of Health Services, oral commun., Jan. 27, 1988.

Although sanitary sewers help to protect ground-water quality by removing a large volume of wastewater that would otherwise be returned to the aquifer, they also reduce recharge and thereby cause a decline in ground-water levels. Garber and Sulam (1976) showed that water levels in Sewer District 2 had declined an average of nearly 7 ft below those in unsewered parts of Long Island, and Sulam (1979) reported that water levels in Sewer District 2 had reached a new equilibrium by the early 1970's, after an average decline of 9 ft.

Pluhowski and Spinello (1978) reported a corresponding decrease in the average base flow of East Meadow Brook (fig. 1) from 91.2 percent of annual streamflow in 1949 to 64.8 percent in 1974. They also indicated that the ground-water contribution to streamflow at East Meadow Brook had declined 45 percent during 1965-74 as a result of both sanitary and storm sewers and attributed 75 percent of this loss of base flow to the effect of sanitary sewers.

METHODS OF STREAMFLOW ANALYSIS

To compare the flow patterns of Long Island's south-shore streams before development with those in 1976-85, base-flow hydrographs, double-mass curves, and flow-duration curves generated from stream-discharge records were used to determine base-flow discharge and to examine loss of base flow and changes in flow duration. These methods of streamflow analysis are described below.

Hydrograph Separation

A hydrograph represents the temporal distribution of flow in a stream at a given location. According to Chow (1964), it can be regarded as an expression of the physiographic and climatic characteristics that determine the relation between rainfall and runoff in a particular drainage basin. Thus, the hydrograph curve shows the changes in discharge at the point of measurement through a specified time, and the shape of the curve reflects the basin's hydrologic characteristics.

A hypothetical stream hydrograph that represents the sum of direct storm runoff and base flow is shown in figure 5. The curve consists of three segments--the approach segment AB, the rising segment BC, and the recession segment CDE. During and immediately after a storm, base flow and direct runoff increase, peak, and decrease at differing rates. Because base flow rises and recedes more slowly than direct runoff, base flow on Long Island commonly peaks 1 to 2 days after runoff does.

Section DE of segment CDE is the ground-water (or base-flow) recession curve, which illustrates the decrease in ground-water contribution to the stream after the rainfall. When plotted on semilogarithmic paper, this segment generally approximates a straight line whose slope resembles the slope of the approach segment of the next hydrograph peak.

Hydrograph separation (or base-flow separation) is the division of the discharge hydrograph (plotted on semilogarithmic paper) into two parts, one representing the base-flow component of streamflow and the other representing the direct-runoff component. Because the exact location of the line that separates these flow components is impossible to determine, several empirical procedures have been developed for the purpose of hydrograph analysis (Chow, 1964).

According to Chow (1964, p. 14-11), a simple way to separate the base-flow component from the direct-runoff component of a hydrograph is to draw a straight line from the point of rise (B in fig. 5) to an arbitrary point on the lower part of the recession segment (D). For the purpose of this report, this method was modified to give a curve to the base-flow separation line, as shown in figure 5. The arbitrary point on the recession segment at which the base-flow-separation line rejoins the hydrograph (and discharge is again equal to base flow) was taken to be the point of inflection at which the slope of the recession segment begins to more closely resemble base-flow recession than direct-runoff recession.

Hydrographs of daily mean flow at each of the 10 streams listed in table 1 for each year from 1976 through 1985 were separated into base-flow and direct-runoff components by the method described above, and daily mean base-flow values for each year were totaled to obtain annual mean base flow for each stream. Annual mean base flow was then divided by annual mean discharge to obtain the percent base flow. Base-flow data prior to 1976 were obtained from Pluhowski and Spinello (1978), Simmons and Reynolds (1982), and Reynolds (1982).

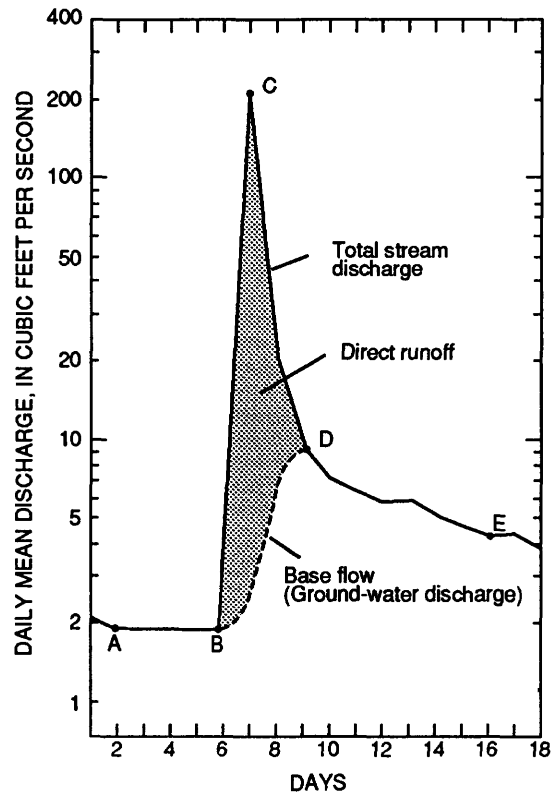


Figure 5.--Hydrograph components and method of base-flow separation.

Double-Mass-Curve Analysis

The double-mass curve is a graphical-statistical method of analysis that is described in detail by Searcy and Hardison (1960). The theory of the double-mass curve is that a graph of the cumulation of one quantity against the cumulation of another quantity during the same period is a straight line if the data are proportional. The slope of the line represents the constant of proportionality between the quantities. A departure of the curve from the slope established by the early data points indicates a change in the relation between the two variables, which in streamflow analysis can be caused by changes in the physical characteristics of the drainage basin that affect the relation. Thus, the double-mass curve can be used to detect the magnitude and time of occurrence of changes that affect only one of the two variables, or changes that affect both variables unequally.

Double-mass curves were prepared in the following way. First, the years 1948-52 were chosen as an "index period" to represent the streams' base-flow characteristics before urbanization and sanitary sewers. Nine of the streams have discharge records that extend back to 1948; Valley Stream's record begins in 1955. Carmans River, the easternmost of the 10 streams studied, was chosen as an "index stream" to represent relatively constant predevelopment conditions and as a control for variations in such factors as precipitation, ground-water gradient, transmissivity, and size of drainage basin.

Base-flow values, in percent of annual mean discharge (herein referred to as percent base flow), were cumulated for each of the 10 streams for each year from 1948 through 1985. For each of the nine streams from Valley Stream in the west to Swan River in the east, cumulative percent base flow was plotted against cumulative percent base flow at Carmans River, the index stream, to yield nine double-mass curves.

For each of these nine streams, a ratio was calculated by dividing the average percent base flow for 1948-52 by average percent base flow at Carmans River for the same period. This ratio was used to calculate "expected percent base flow"--that is, the percent base flow that would have occurred without urbanization--for each stream for each year thereafter (1953-85). The cumulative expected percent base flow for each year at each stream was then plotted against cumulative percent base flow at Carmans River. For each stream, the difference between the two curves represents the cumulative loss of base flow that has resulted from changes in the physical characteristics of its drainage basin.

Because the first full year of discharge data at Valley Stream is 1955, the 1948-52 base-flow ratio for adjacent Pines Brook was used to calculate the expected percent base flow of Valley Stream. Because a second gaging station was established on Bellmore Creek in 1958, making pre-1959 discharge data inconsistent with post-1959 data, the index-period base-flow ratio calculated for adjacent Massapequa Creek was used to calculate expected percent base flow at Bellmore Creek. Because pre-1960 base-flow data for Swan River are unavailable, the 1948-52 base-flow ratio for adjacent Connetquot River was used to calculate the expected percent base flow of Swan River. Percent base flow during years of missing data was estimated by averaging percent base-flow values of the stream in question for the immediately preceding and succeeding years.

Flow-Duration-Curve Analysis

The flow-duration curve is a cumulative-frequency curve that shows the percentage of time that specified discharges were equaled or exceeded during a given time period. It depicts the flow characteristics of a stream throughout the range of discharge without regard to the chronological sequence of flow values and is applicable only to the specific period for which data were analyzed. The curve provides a means for studying the flow characteristics of streams and for comparing streams with one another by integrating the effects of natural factors (such as climate, topography, and geology) that affect stream discharge with the effects of man-induced changes in the drainage basins. The construction and interpretation of flow-duration curves are discussed in detail by Searcy (1959).

Searcy (1959) states that a steeply sloping flow-duration curve denotes flow that is derived largely from direct runoff, and therefore is highly variable, whereas a flattened curve indicates a large component of ground water or surface-water storage, which tends to distribute the flow evenly. The magnitude and frequency of high flows depend chiefly on such factors as climate, topography, and vegetation, whereas the magnitude and frequency of low flows depend largely on basin geology (in undeveloped areas) or degree of urbanization. A flat slope at the lower end of the curve indicates a large amount of aquifer storage, and a steep slope indicates a negligible amount. Therefore, the lower end of the curve is useful for study of the effect of urbanization on base flow.

Three flow-duration curves, each for a different time interval, were developed for each of the 10 streams to indicate changes in flow characteristics over time. These curves were prepared through a computer program from daily stream-discharge data for the 5-year periods 1948-52, 1971-75, and 1981-85.

EFFECTS OF URBANIZATION ON BASE FLOW AND FLOW DURATION

Results of streamflow analysis of the 10 south-shore streams by means of hydrograph separation, double-mass-curve analysis, and flow-duration-curve analysis to determine base-flow discharge and to examine loss of base flow and changes in flow duration are described below.

Base-Flow Discharge

Annual mean base-flow values for each of the 10 streams for each year from 1976 through 1985 are presented in table 4A; the base-flow percentage of annual mean flow for each stream is given in table 4B and is plotted against time (1976-85) in figure 6.

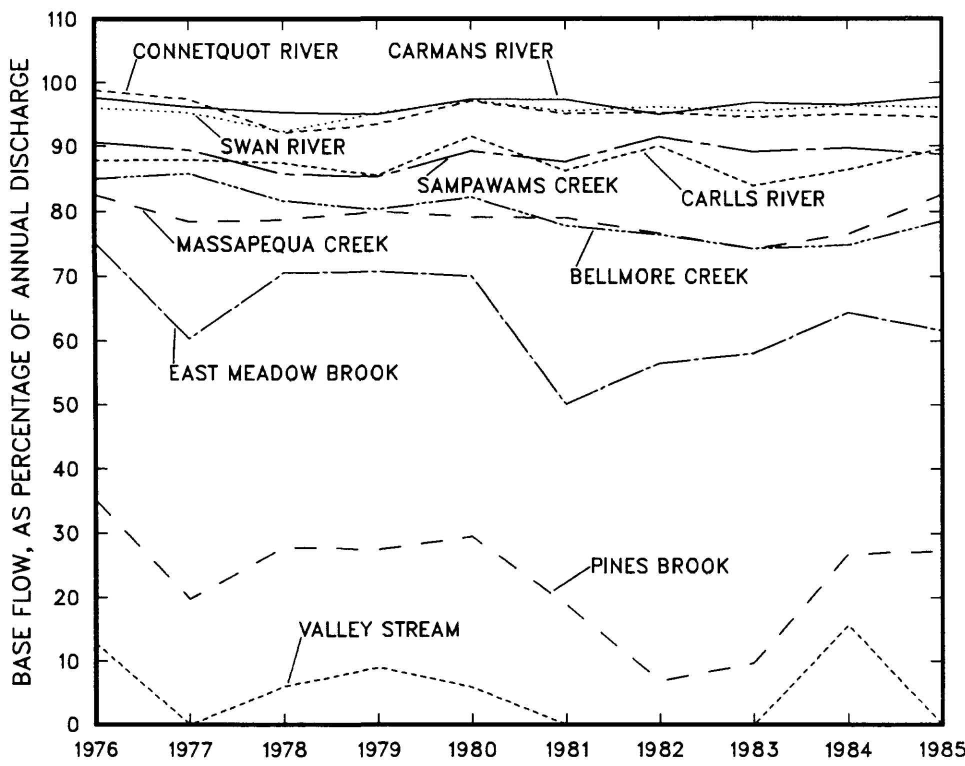


Figure 6.

Base flow of the 10 south-shore streams as percentage of total annual discharge, 1976-85.

Table 4B shows that the annual mean base flows of Valley Stream and Pines Brook, both in Sewer District 2, a highly developed area that has been completely sewered since the early 1960's, ranged from 0 to 35.2 percent during the 10-year study period. Annual mean base flow of East Meadow Brook, the next stream to the east, which flows parallel to the border between Sewer Districts 2 and 3, is intermediate between that of streams in each of these two districts. Annual mean base flow of East Meadow Brook ranged from 50 to 75 percent of total flow during the study period.

Base flow of Bellmore and Massapequa Creeks, both of which are in Sewer District 3 (an area that was urbanized less extensively and sewered later than Sewer District 2 to the west), ranged from 74 to 86 percent of the streams' total annual flow during the 10-year period. Annual mean base flow of Carlls River and Sampawams Creek, in Suffolk County's Southwest Sewer District, ranged from 83 to 92 percent, and annual mean base flow of Connetquot, Swan, and Carmans Rivers, in an unsewered area to the east that is largely unaffected by urban development, ranged from 92 to 99 percent of the total annual streamflow during the period studied.

Table 4.--Annual mean base flow of the 10 south-shore streams, 1976-85

[Locations are shown in fig. 1; total flow in B. is base flow plus direct runoff]

Stream name	Water year[1] 1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	Mean
A. DISCHARGE, IN CUBIC FEET PER SECOND											
Valley Stream	0.15	0	0.09	0.13	0.04	0	0	0	0.44	0	0.08
Pines Brook	.83	.28	.85	.92	.62	.17	.10	.19	1.29	.39	.56
East Meadow Brook	11.5	5.02	14.2	14.7	10.5	2.86	4.46	5.90	13.3	4.67	8.71
Bellmore Creek	9.14	6.41	12.0	10.2	9.41	3.97	3.51	4.06	8.87	3.32	7.09
Massapequa Creek	9.53	6.84	13.1	15.2	10.2	5.03	6.05	6.37	13.1	4.76	9.02
Carlls River	25.9	19.5	34.8	31.9	27.8	19.1	23.7	22.0	32.9	19.9	25.8
Sampawams Creek	9.17	6.20	10.3	11.6	10.1	5.86	8.95	8.83	13.8	8.54	9.34
Connetquot River	42.5	34.8	42.8	49.0	46.8	28.8	34.2	36.2	49.9	32.9	39.8
Swan River	12.6	11.1	13.9	16.4	13.7	9.08	11.9	13.5	17.8	11.9	13.2
Carmans River	27.1	21.8	30.9	35.8	31.7	19.6	20.0	26.3	35.5	28.6	27.7
B. PERCENTAGE OF TOTAL FLOW											
Valley Stream	12.8	0	6.0	9.0	5.9	0	0	0	15.7	0	4.9
Pines Brook	35.2	19.8	27.9	27.5	29.5	18.9	6.9	9.7	26.8	27.3	23.0
East Meadow Brook	75.2	60.3	70.5	70.7	70.0	50.1	56.5	58.0	64.4	61.6	63.7
Bellmore Creek	85.0	85.8	81.6	80.3	82.2	77.8	76.4	74.3	74.8	78.5	79.7
Massapequa Creek	82.5	78.4	78.7	80.0	79.1	79.0	76.6	74.2	76.5	82.6	78.8
Carlls River	87.8	87.9	87.4	85.5	91.5	86.2	90.0	83.9	86.4	89.5	87.6
Sampawams Creek	90.6	89.4	85.7	85.3	89.2	87.6	91.4	89.1	89.7	88.7	88.7
Connetquot River	98.8	97.4	92.1	93.4	97.1	95.1	95.3	94.5	95.0	94.5	95.3
Swan River	96.0	95.3	92.3	95.2	97.2	95.5	96.2	95.4	96.4	96.1	95.6
Carmans River	97.6	96.2	95.3	95.0	97.4	97.3	95.0	96.8	96.5	97.7	96.5

[1] A water year is the 12-month period that begins on October 1 and ends on September 30. It is designated by the year in which it ends.

The values given in table 4B and plotted in figure 6 indicate that base flow during 1976-85 averaged (1) less than 25 percent at Valley Stream and Pines Brook; (2) 64 percent at East Meadow Brook; (3) 75 to 80 percent at Bellmore and Massapequa Creeks; (4) 85 to 90 percent at Carlls River and Sampawams Creek; and (5) greater than 95 percent at Connetquot, Swan, and Carmans Rivers. This trend clearly reflects the sewerage history in these five areas. Comparison of figures 1 and 6 reveals that this pattern corresponds to the locations of the streams. The lowest values are in the westernmost part, in Sewer District 2 (Valley, Pines); the next lowest are between Sewer Districts 2 and 3 (East Meadow Brook); the next are in Sewer District 3 (Bellmore, Massapequa); the next are in the Suffolk County Southwest Sewer District (Carlls, Sampawams); and the highest are in an unsewered area (Connetquot, Swan, Carmans). This correlation indicates that the use of sanitary sewers, with the attendant decrease in volume of recharge and lowering of water levels, is one of the most important human-induced influences on stream base flow on Long Island.

The bar graphs in figures 7 and 8 present these data in historical perspective. Figure 7 shows annual mean base flow (in cubic feet per second) of each of the 10 streams for each year for which base-flow data are available; figure 8 shows the same information expressed as the percentage of annual mean discharge that consists of base flow. These illustrations show that base-flow values at Valley Stream and Pines Brook plummeted in the late 1950's and early 1960's and have remained low as a result of the lowered water table and increase in direct runoff that resulted from the increasing use of storm sewers and sanitary sewers. This effect was accentuated by below-normal precipitation during 1962-66 (Cohen and others, 1969). The declines in base flow were progressively smaller and occurred later to the east; declines were not noted for the three streams in the unsewered area (Connetquot, Swan, and Carmans Rivers).

Figure 9 (p. 20) is a series of bar graphs that illustrate the relation between annual mean base flow and annual mean discharge at each stream for each year for which base-flow data are available. Table 5 (p. 22) shows the mean annual base flow of the 10 south-shore streams, both in cubic feet per second and as percentage of total stream discharge, during three 5-year periods: 1948-52, 1971-75, and 1981-85. As indicated above, the first period (index period) represents hydrologic conditions in the drainage basins before urban development; the second represents the streams' response from 1948-52 to 1972-75 (23 years) to changes caused by urbanization; and the last represents the period of further adjustment of streamflow to changing hydrologic conditions from 1971-75 to 1981-85 (10 years).

Both figure 9 and table 5B indicate a trend toward a decreasing ratio of base flow to discharge, both geographically (from east to west) and with time. Table 5A indicates a decrease of more than 25 percent in base flow between the predevelopment period and 1971-75 at each of the three streams in Nassau County for which index-period data can be evaluated (Pines Brook, East Meadow Brook, and Massapequa Creek). Little or no decrease in base flow between 1971-75 and 1981-85 is seen at the three westernmost streams (Valley Stream, Pines Brook, and East Meadow Brook), but base flow at Bellmore and Massapequa Creeks decreased 48 and 21 percent, respectively, during this time. No streams in Suffolk County experienced a significant trend in base-flow volume over the three time periods.

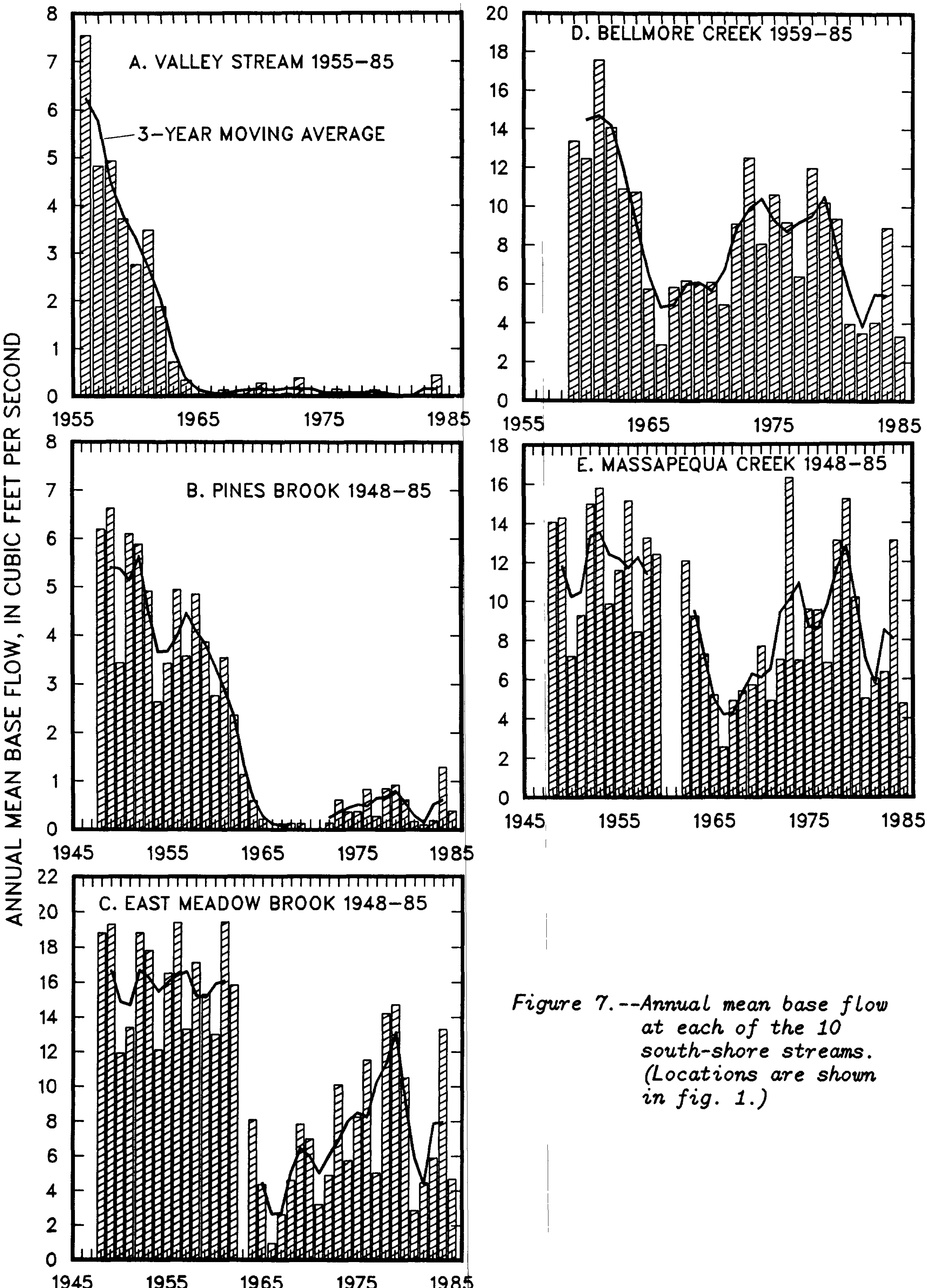


Figure 7.--Annual mean base flow at each of the 10 south-shore streams. (Locations are shown in fig. 1.)

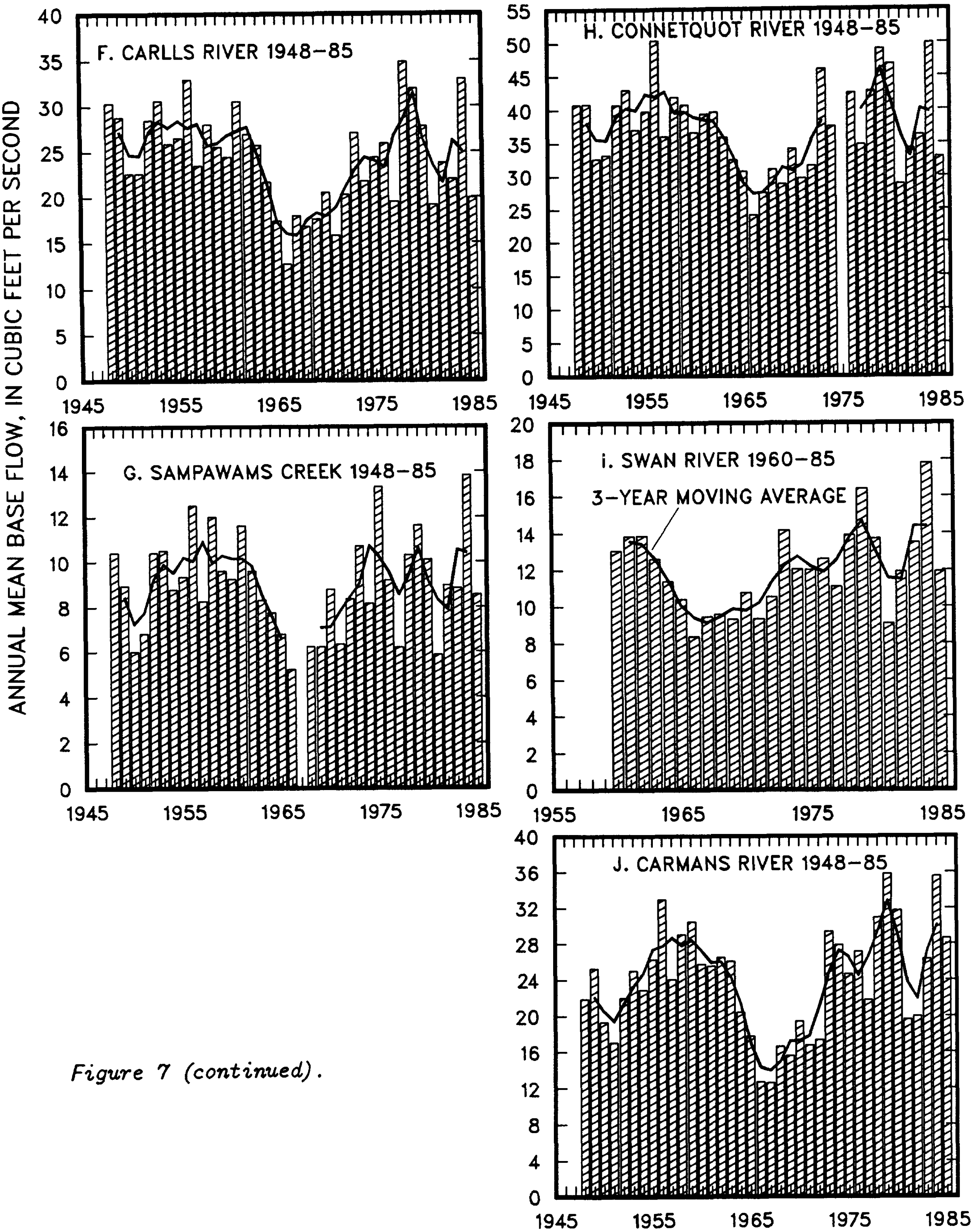


Figure 7 (continued).

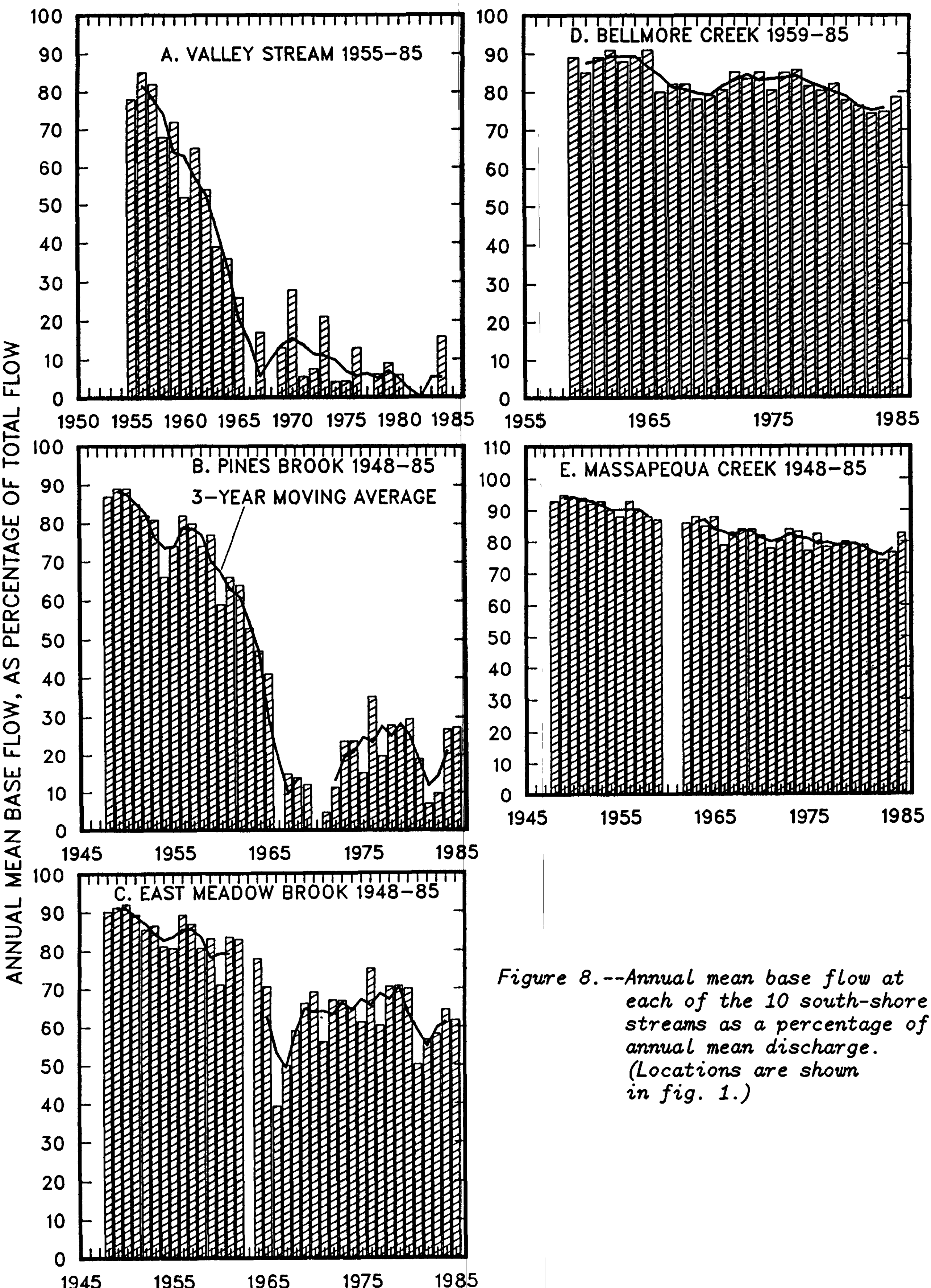


Figure 8.--Annual mean base flow at each of the 10 south-shore streams as a percentage of annual mean discharge. (Locations are shown in fig. 1.)

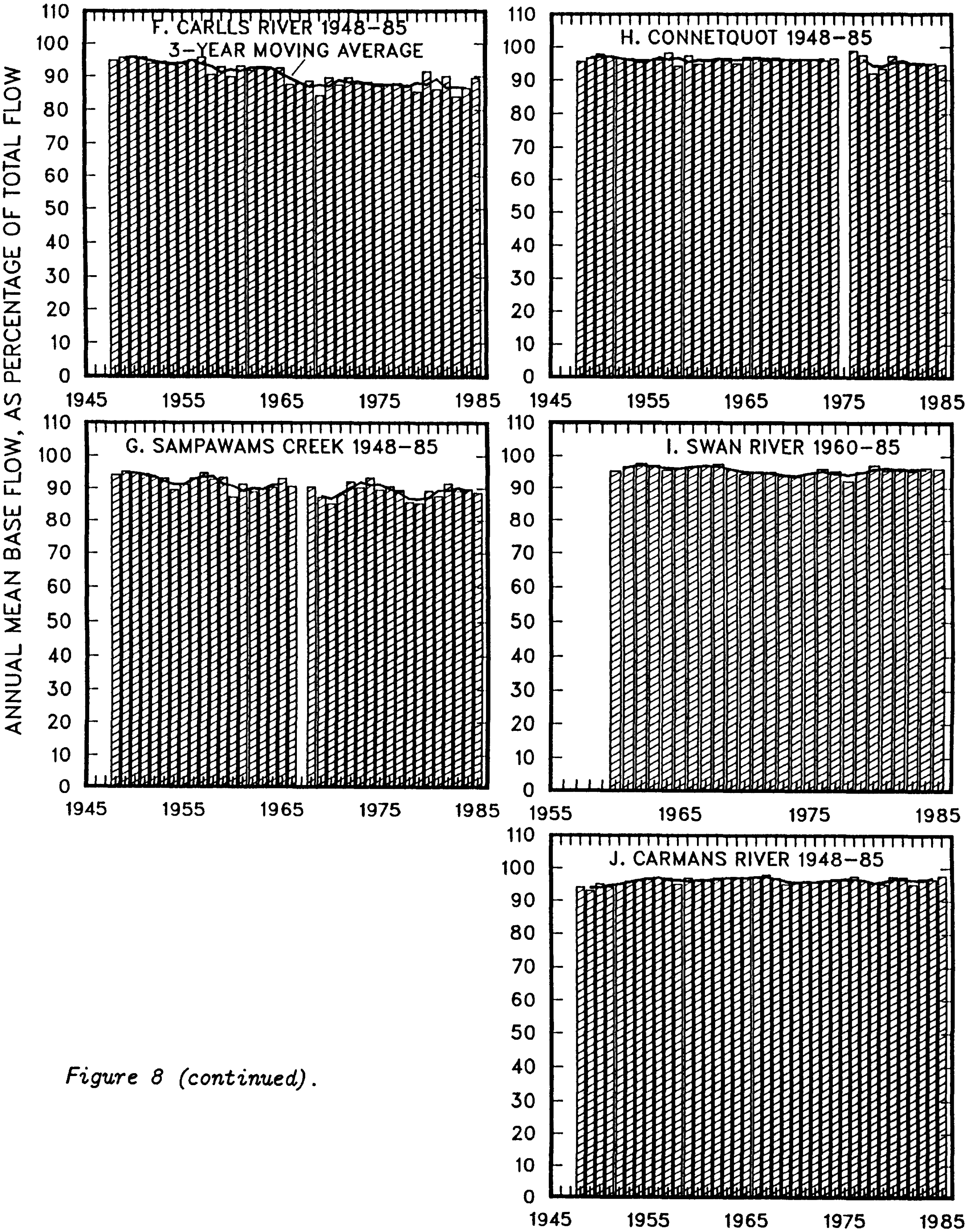


Figure 8 (continued).

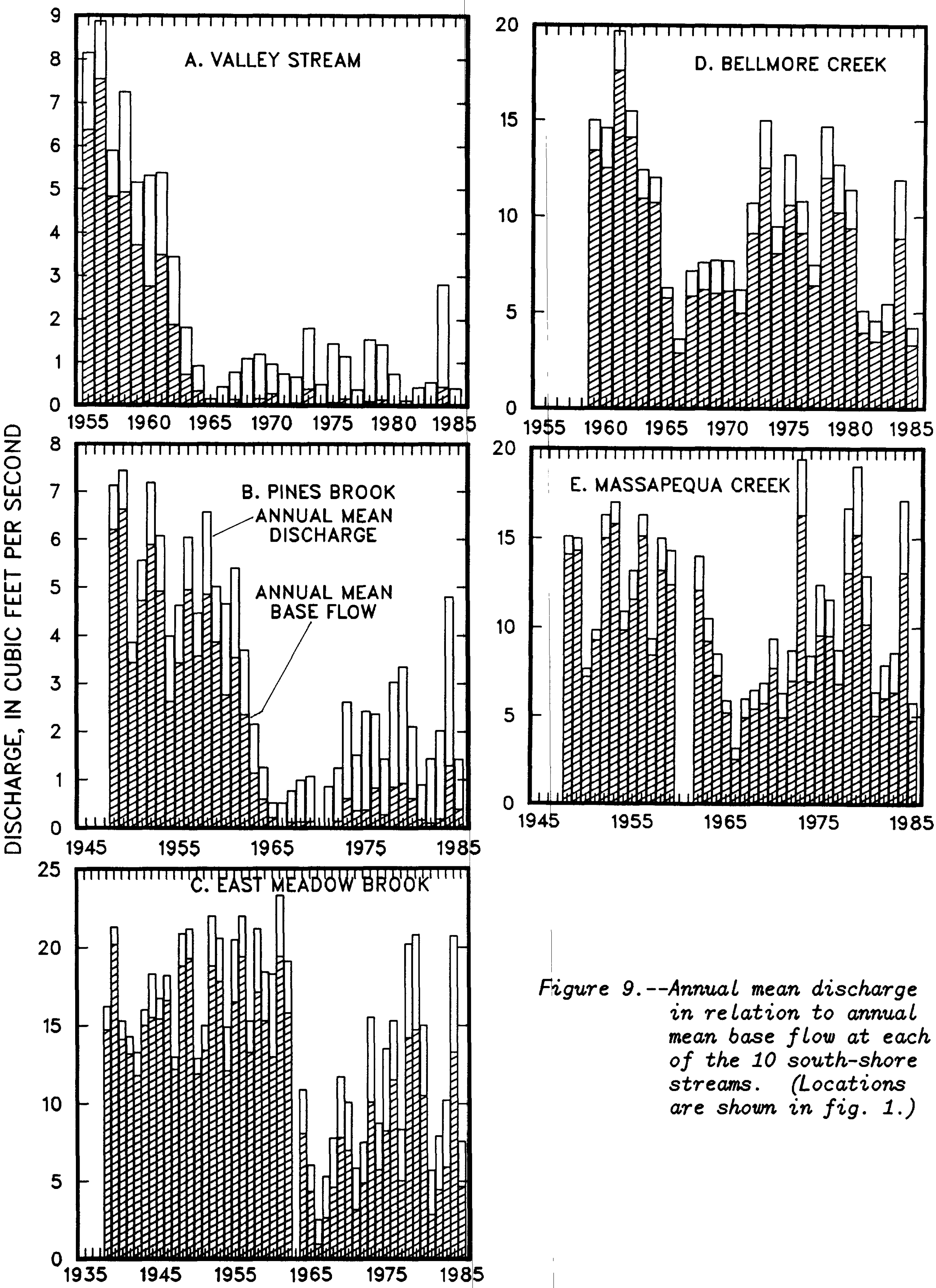


Figure 9.--Annual mean discharge in relation to annual mean base flow at each of the 10 south-shore streams. (Locations are shown in fig. 1.)

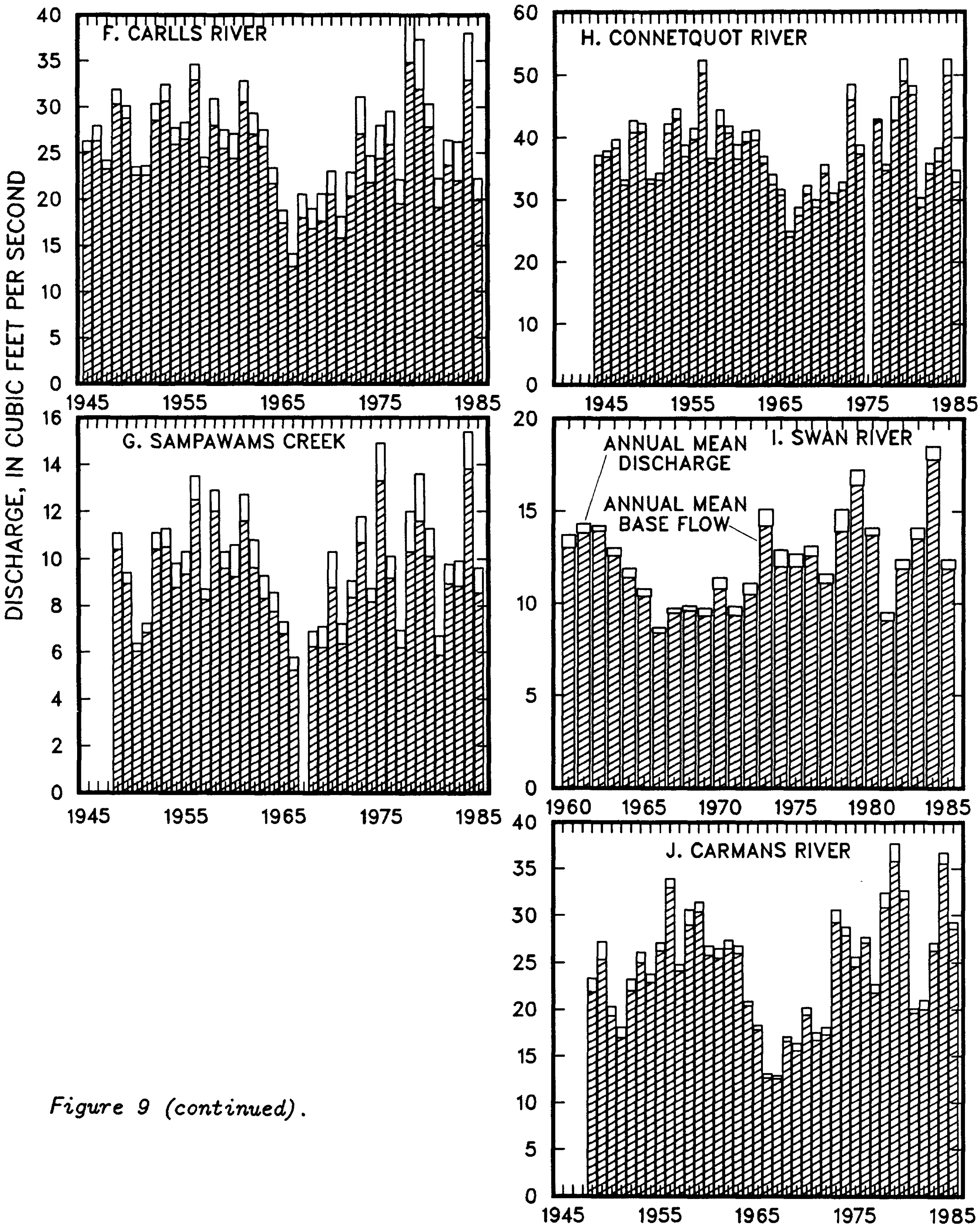


Figure 9 (continued).

Although percent base flow in the streams in urbanized, sewered areas decreased, percent base flow in streams that flow through areas that are largely undeveloped fluctuated little from year to year. For example, percent base flow in the three streams in the unsewered area (Connetquot, Swan, and Carmans Rivers) changed little despite several years of severely diminished precipitation during the 1962-66 drought (fig. 8). In contrast, percent base flow in streams in highly developed, sewered areas decreased significantly during the 1962-66 drought, indicating that percent base flow is noticeably responsive to variations in precipitation only when the natural hydrologic regime has been altered. Therefore, urbanization has not only caused the base flow of streams to decline, but has caused an increase in its sensitivity to variations in precipitation and has caused the streams to become "flashy"--that is, to become subject to wide changes in discharge over relatively short periods of time.

Table 5.--Mean annual base flow of the 10 south-shore streams during 1948-52, 1971-75, and 1981-85

[Locations shown in fig. 1]

Stream name	A. Cubic feet per second			B. Percentage of total discharge		
	1948-52	1971-75	1981-85	1948-52	1971-75	1981-85
Valley Stream	[1]--	0.11	0.09	[1]--	8.4	3.1
Pines Brook	5.37	0.30	0.43	86.4	15.7	17.9
East Meadow Brook	16.4	6.43	6.24	89.7	63.2	58.1
Bellmore Creek[2]	8.74	9.06	4.75	83.2	83.0	76.4
Massapequa Creek	12.0	8.95	7.06	93.6	80.6	77.8
Carlls River	26.6	21.9	23.5	95.2	88.1	87.2
Sampawams Creek	8.53	9.37	9.20	94.4	90.7	89.3
Connetquot River	37.6	[3]36.2	36.4	96.7	[3]96.2	94.9
Swan River	[4]--	11.6	12.8	[4]--	94.4	95.9
Carmans River	21.1	23.2	26.0	94.2	96.1	96.7

[1] No data. Gaging station not established until 1954.
[2] Second gaging station established on Bellmore Creek tributary in 1959; base-flow values before this date cannot be compared with those measured subsequently.
[3] No record for 1975; base-flow value derived from 1971-74 base-flow data.
[4] No data. Base-flow data before 1960 unavailable.

Base-Flow Loss

Double-mass curves of actual percent base flow at each of the nine streams in relation to actual percent base flow at the index stream (Carmans River) are compared with double-mass curves of expected percent base flow at each of the nine streams against actual percent base flow at the index stream in figure 10. In each plot, the difference between the two curves represents the cumulative base-flow loss, as a percentage of annual mean discharge, that has resulted from changes in the physical characteristics of the drainage basin.

Cumulative percent base flow at Valley Stream and Pines Brook, both in the highly urbanized area that has been served by sanitary sewers since the 1950's, is much lower than would be expected had urbanization not occurred, particularly from 1965 on (figs. 10A, 10B). The trend in cumulative percent base flow at East Meadow Brook just to the east (fig. 10C) is similar but not as pronounced as at Valley Stream and Pines Brook.

Figures 10D-10I indicate a progressive eastward decreasing departure from expected base-flow values at each of the six remaining streams. The break in slope that characterizes the double-mass curves of the three westernmost streams (figs. 10A-10C) is absent among the eastern streams.

The double-mass curves in figure 10 indicate that base-flow loss is greatest in streams in the area that is most heavily urbanized and has been urbanized and sewered the longest (Sewer District 2) and is least in streams

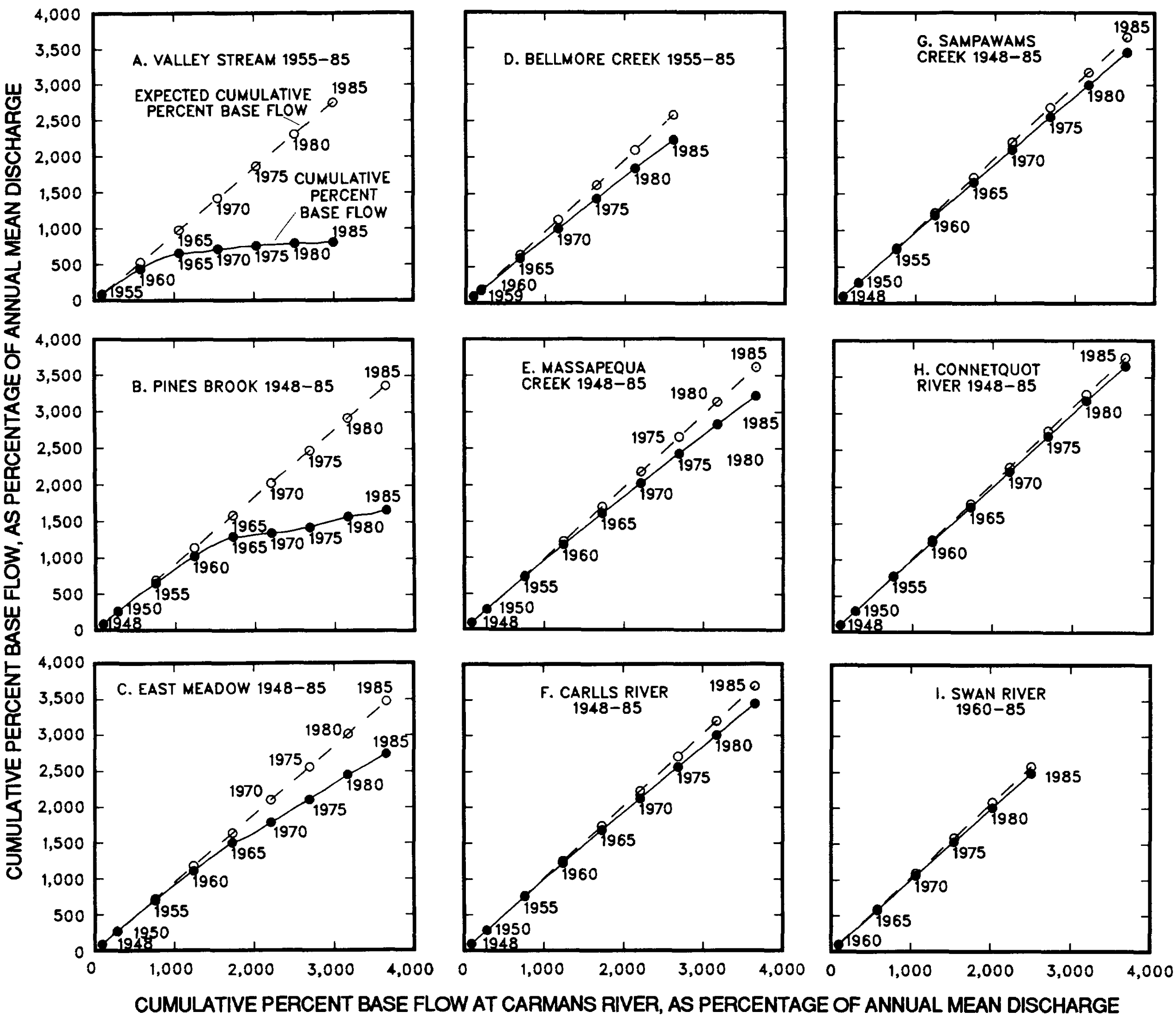


Figure 10.--Cumulative percent base flow at Carmans River in relation to that at each of the other nine streams. (Locations are shown in fig. 1.)

in the unsewered and least urbanized area east of the Suffolk County Southwest Sewer District. The difference between base-flow loss from streams in Sewer District 2 and loss from streams in Sewer District 3 (fig. 1) is accentuated by the difference in the density of recharge basins (fig. 11). Where recharge basins are sparse, as in southwestern Nassau County, most storm runoff is routed directly to streams and discharges to tidewater. Where the density of recharge basins is high, as in southeastern Nassau County, most storm runoff is routed to the basins, where it infiltrates and percolates through the unsaturated zone to the ground-water reservoir. This ground water eventually discharges to streams and thereby helps to maintain the base-flow component of streamflow between storms.

Recharge-basin density in southwestern Suffolk County is similar to that in southeastern Nassau County (fig. 3); differences between base-flow decreases in these two areas result primarily from the effects of sanitary sewers and, therefore, are correspondingly smaller than differences between base-flow decreases in southwestern Nassau County (Sewer District 2) and southeastern Nassau County (Sewer District 3).

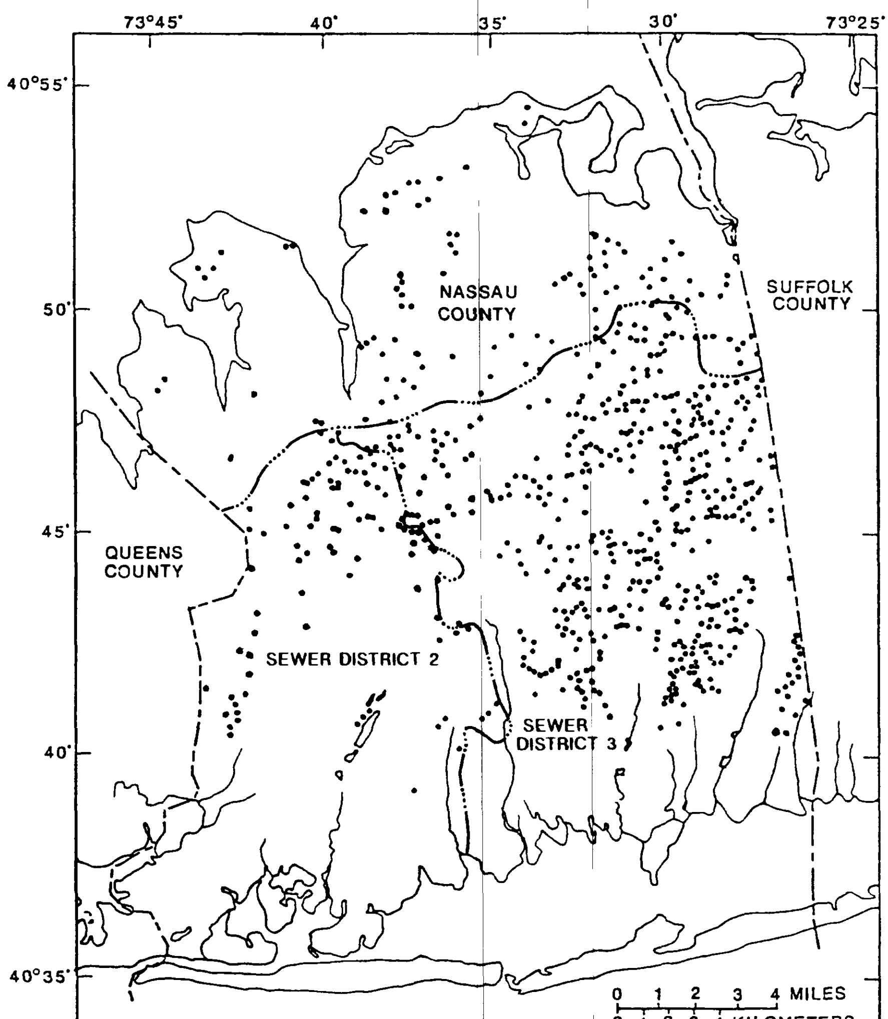


Figure 11.--Locations of recharge basins in Nassau County in 1987.

Of the nine double-mass curves shown in figure 10, only those for Valley Stream, Pines Brook, and East Meadow Brook show a discernible break in slope during the time period examined (1955-85 for Valley Stream, 1948-85 for Pines Brook and East Meadow Brook). In each plot, this break occurs in or around 1965 and is followed by a relatively straight line with a flattened slope that represents a new constant of proportionality between the cumulative percent base flow of the stream and the cumulative percent base flow at Carmans River. This indicates that the base-flow patterns of the three westernmost streams have reached a new equilibrium after a period of adjustment to lowered ground-water levels.

Flow Duration

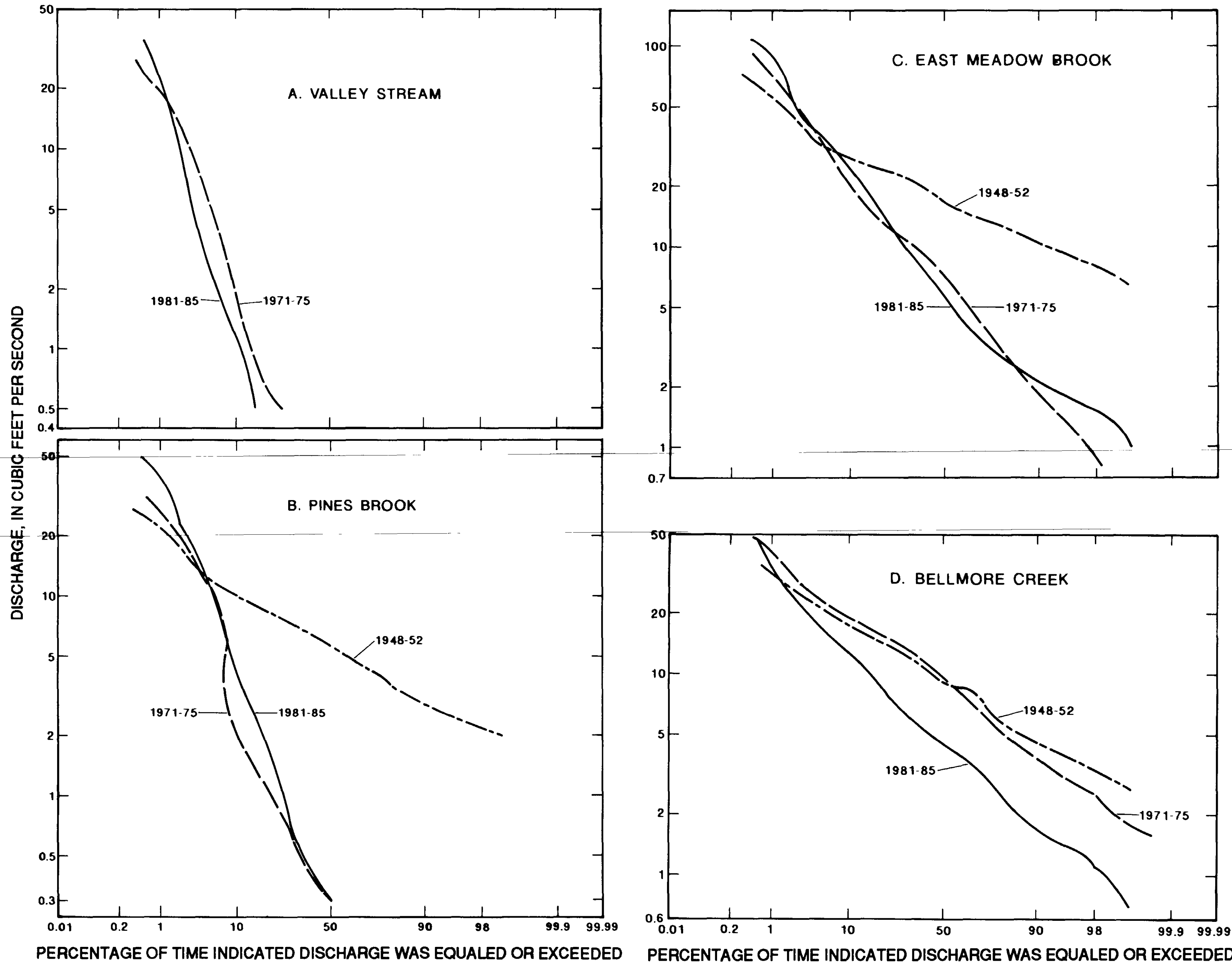
Flow-duration curves for each of the 10 streams during each of the three time periods (two for Valley Stream) are plotted in figure 12 (A through J). Without the influence of urbanization, flow-duration curves for Long Island streams would have a relatively flat slope (Prince, 1981) (as does the curve for Carmans River during 1948-52 (fig. 12J)), which reflects the small range in discharge and a large base-flow contribution. The graphs in figure 12 clearly show the extent to which these characteristics have been altered by urbanization, from west to east.

High Flow and Low Flow

Table 6A lists the discharge at 1-percent and 98-percent duration for each stream during each of the three time periods; these values were determined from the flow-duration curves in figure 12. Table 6B shows the percent change in these values for each stream from the index period to each of the two later periods.

Valley Stream and Pines Brook.--The flow-duration curve for Pines Brook (fig. 12B) for 1948-52 has a relatively steep upper slope but tends to flatten out at the lower end, indicating a large ground-water contribution to the stream during this period. High flows had already become variable by 1952 as a result of the paving of previously permeable surfaces and the routing of stormwater directly to the streams. In contrast, flow-duration curves for Valley Stream and Pines Brook (figs. 12A and 12B) during 1971-75 and 1981-85 are nearly vertical, indicating virtually no ground-water contribution to streamflow and an extremely variable high discharge that is determined entirely by precipitation. Comparison of the Valley Stream curve for 1971-75 with that for 1981-85 shows that, during the intervening 10 years, high flows increased in magnitude and frequency; flow at 1-percent duration increased 15 percent during this time, from 20 to 23 ft^3/s (table 6A). Flow at 98-percent duration was zero during both periods.

Flow at 1-percent duration in Pines Brook (fig. 12B) increased from 22 to 28 ft^3/s from the index period (1948-52) to 1971-75. Although low flows were similar (no flow) during the two later periods, high discharges increased in magnitude and frequency from 1971-75 to 1981-85; flow at 1-percent duration increased from 28 to 40 ft^3/s. This represents increases of 27 percent and 82 percent for 1971-75 and 1981-85, respectively, above flow at 1-percent duration during the index period, whereas flow at 98-percent duration decreased 100 percent and remained at zero during both later periods.


A. VALLEY STREAM
1981-85
1971-75
B. PINES BROOK
1948-52
1971-75
1981-85
C. EAST MEADOW BROOK
1948-52
1981-85
1971-75
D. BELLMORE CREEK
1948-52
1981-85
1971-75
DISCHARGE, IN CUBIC FEET PER SECOND
PERCENTAGE OF TIME INDICATED DISCHARGE WAS EQUALED OR EXCEEDED
PERCENTAGE OF TIME INDICATED DISCHARGE WAS EQUALED OR EXCEEDED

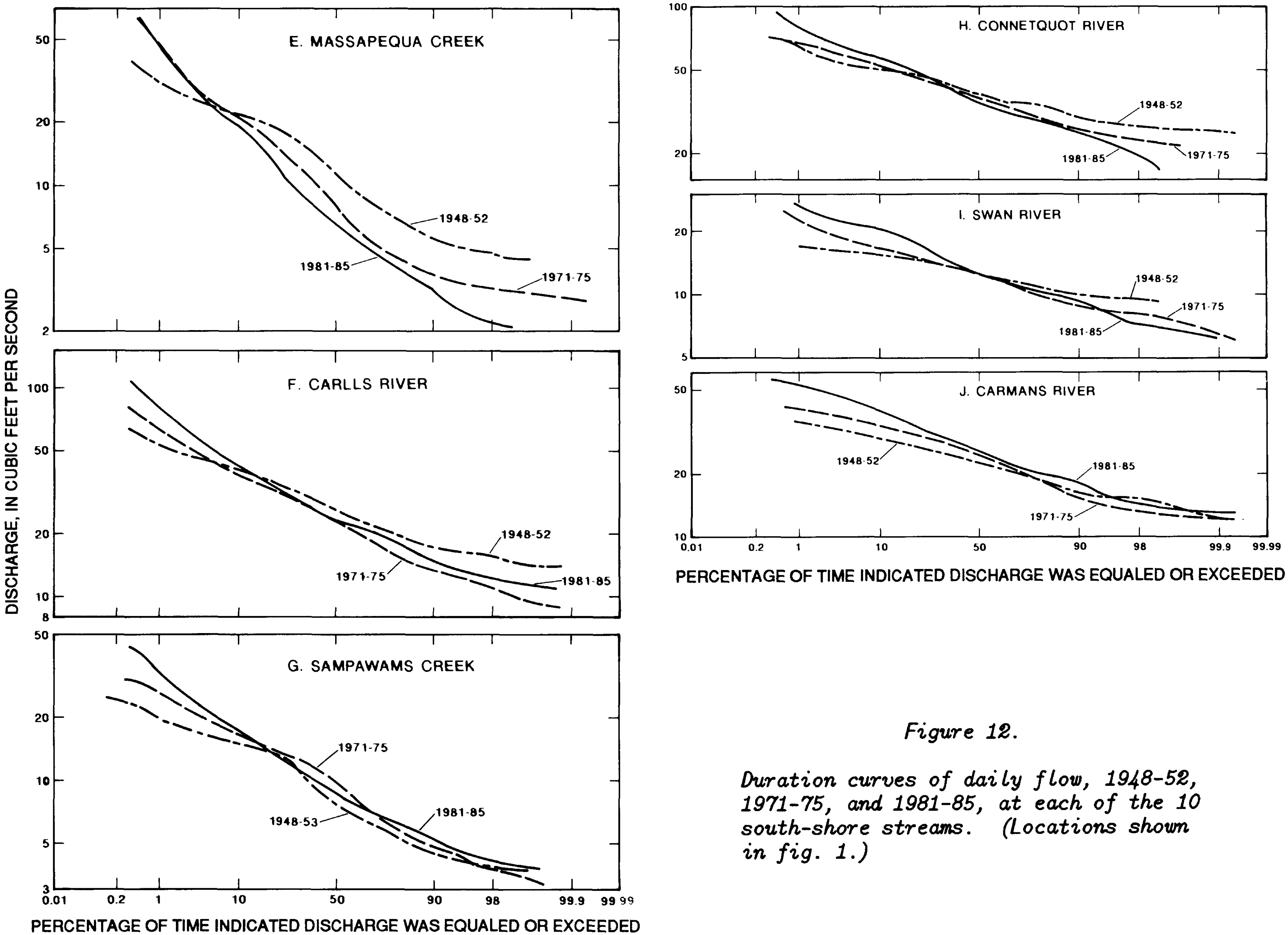


Figure 12.

Duration curves of daily flow, 1948-52, 1971-75, and 1981-85, at each of the 10 south-shore streams. (Locations shown in fig. 1.)

East Meadow Brook.--Duration curves of flow in East Meadow Brook (fig. 12C) show that flow at 1-percent duration increased 35 percent from the index period to 1971-75 (54 to 73 ft^3/s), and an additional 32 percent from 1971-75 to 1981-85 (73 to 90 ft^3/s), whereas flow at 98-percent duration decreased sharply from 8.1 ft^3/s in 1948-52 to 0.9 ft^3/s in 1971-75 (89 percent), then recovered slightly, but not significantly (8 percent), to 1.5 ft^3/s by 1981-85.

East Meadow Brook's flow-duration curves for 1971-75 and 1981-85 have a moderately steep slope and are roughly parallel to each other, but both are much steeper than the index-period curve. They illustrate a continuing and comparatively even increase in the magnitude and frequency of high flows from the index period to 1971-75 and from 1971-75 to 1981-85. Most of the adjustment of low flow in this stream to the effects of urbanization occurred during the 2 decades after the index period, however, and little additional change occurred from 1971-75 to 1981-85.

Bellmore Creek.--The flow-duration curve for the index period at Bellmore Creek (fig. 12D) cannot be compared with the curves for the two later time periods because a second gaging station was established on a tributary to the stream in 1959. Flow at 98-percent duration declined 58 percent (from 2.6 to 1.1 ft^3/s) from 1971-75 to 1981-85, however; flow at 1-percent duration also decreased slightly (15 percent) from 41 to 35 ft^3/s.

Although both the high and low ends of the Bellmore Creek flow-duration curve for 1971-75 are moderately steep, those for 1981-85 are even steeper, indicating an increase in the variability of stream discharge and a decrease in the ground-water contribution to streamflow during the interval between these two time periods, as well as a decline in the base-flow contribution that occurred later than that which occurred at East Meadow Brook.

Massapequa Creek.--The flow-duration curve for Massapequa Creek (fig. 12E) indicates a decline in flow at 98-percent duration from the index period to 1971-75 (4.7 to 3.2 ft^3/s, or 32 percent) and from 1971-75 to 1981-85 (3.2 to 2.2 ft^3/s, or 21 percent). Flow at 1-percent duration at Massapequa Creek increased by more than 50 percent from the index period to 1971-75 (31 to 49 ft^3/s, or 58 percent), then declined slightly, by less than 10 percent, to 46 ft^3/s by 1981-85.

Virtually all of the change in flow at 1-percent duration in Massapequa Creek had occurred by 1971-75, whereas the change in flow at 98-percent duration is comparatively evenly divided between the two time intervals since the index period.

Carlls River.--At Carlls River (fig. 12F), flow at 1-percent duration increased from 55 to 65 ft^3/s (18 percent) from the index period to 1971-75, and from 65 to 83 ft^3/s (an additional 33 percent) from 1971-75 to 1981-85; the high-flow distribution also became more variable with time (steeper slope at upper end of curve). Flow at 98-percent duration decreased from 16 to 11 ft^3/s (31 percent) between the index period and 1971-75, then recovered slightly, to 12 ft^3/s (6 percent), by 1981-85. The slope of the lower end of the curves for all three time periods is relatively flat, indicating that streamflow is still maintained by a significant ground-water contribution, even though changes have occurred as a result of urbanization in western Suffolk County.

Sampawams Creek.--The flow-duration curves for Sampawams Creek (fig. 12G) show that the flow duration changed more in the high-discharge region than in the low-discharge region from the index period to 1981-85. Flow at 1-percent duration increased 30 percent, from 20 to 26 ft^3/s, from the index period to 1971-75, and an additional 30 percent, to 32 ft^3/s, by 1981-85. In contrast, flow at 98-percent duration was exactly the same during 1971-75 as that during the index period (3.8 ft^3/s) and had increased only slightly (11 percent, to 4.2 ft^3/s) by 1981-85, indicating that low flows had not yet been substantially affected by urbanization at Sampawams Creek, although the increased paving of permeable surfaces and the use of storm sewers had caused changes in high discharges.

Connetquot River.--Flow at 98-percent duration in Connetquot River (fig. 12H) decreased from 27 ft^3/s during the index period to 24 ft^3/s in 1971-74 (1975 flow data unavailable), and to 20 ft^3/s in 1981-85. This represents successive decreases of 11 and 15 percent from the index period to 1971-75 and from 1971-75 to 1981-85, respectively. Flow at 1-percent duration increased little (65 to 67 ft^3/s, or 3 percent) from the index period to 1971-75 but increased to 82 ft^3/s by 1981-85--a flow that was 26 percent greater than the

Table 6.--Flow-duration data for the 10 south-shore streams

[Dashes indicate no data; locations shown in fig. 1]

Stream name	1948-52 1-percent duration	1948-52 98-percent duration	1971-75 1-percent duration	1971-75 98-percent duration	1981-85 1-percent duration	1981-85 98-percent duration
A. FLOW, IN CUBIC FEET PER SECOND						
Valley Stream	--	--	20	0	23	0
Pines Brook	22	2.2	28	0	40	0
East Meadow Brook	54	8.1	73	.9	90	1.5
Bellmore Creek[1]	33	3.3	41	2.6	35	1.1
Massapequa Creek	31	4.7	49	3.2	46	2.2
Carlls River	55	16	65	11	83	12
Sampawams Creek	20	3.8	26	3.8	32	4.2
Connetquot River	65	27	[2]67	[2]24	82	20
Swan River	17	9.5	23	8.1	27	7.3
Carmans River	36	15	41	13	52	14
B. PERCENT CHANGE IN FLOW FROM 1948-52 VALUES						
Valley Stream[3]			--	--	--	--
Pines Brook			27	-100	82	-100
East Meadow Brook			35	- 89	67	- 81
Bellmore Creek[1]			--	--	--	--
Massapequa Creek			58	- 32	48	- 53
Carlls River			18	- 31	51	- 25
Sampawams Creek			30	0	60	11
Connetquot River			[2]3.1	[2]- 11	26	- 26
Swan River			35	- 15	59	- 23
Carmans River			14	- 13	44	- 6.7

[1] Second gaging station established on Bellmore Creek tributary in 1959; flow-duration values before this date cannot be meaningfully compared with those thereafter.

[2] No record for 1975; flow-duration value derived from 1971-74 flow data.

[3] Gaging station established in 1954.

flow at 1-percent duration during the index period. In addition, both the upper and lower ends of the 1981-85 curve are steeper than those of the other curves, indicating increasing variability of discharge.

Swan River.--The flow-duration curves for Swan River (fig. 12I) show that high discharges increased slightly but steadily; flow at 1-percent duration increased from 17 ft^3/s during the index period to 23 ft^3/s in 1971-75 and to 27 ft^3/s in 1981-85. These values represent successive increases of 35 and 24 percent, respectively. Flow at 98-percent duration decreased from 9.5 to 8.1 ft^3/s (15 percent) by 1971-75, and then to 7.3 ft^3/s (an additional 8 percent) by 1981-85. Each curve for this stream, like each curve for Connetquot River, is slightly but noticeably steeper than the curve for the previous time period, indicating a small but consistent increase in variability of discharge.

Carmans River.--Flow-duration curves for Carmans River (fig. 12J), the easternmost stream, also show a consistent increase in flow at 1-percent duration, but this change became much more pronounced during the interval between 1971-75 and 1981-85. Flow at 1-percent duration first increased from 36 to 41 ft^3/s from the index period to 1971-75, and then to 52 ft^3/s by 1981-85. These values represent successive increases of 14 and 30 percent, respectively, over flow at 1-percent duration during the index period. Flow at 98-percent duration showed little change--decreasing from 15 to 13 ft^3/s from the index period to 1971-75, and then increasing to 14 ft^3/s by 1981-85--a decrease of 13 percent followed by a 7-percent recovery. This indicates that the base flow of Carmans River was still stable, constant, and well maintained by ground water.

Streamflow Patterns

In addition to the preceding quantitative analysis, the flow-duration curves shown in figure 12 allow a qualitative evaluation of the changes in streamflow patterns at each of the 10 study streams since the index period. Although no data for Valley Stream are available for the index period, the curves for 1971-75 and 1981-85 for this stream are nearly vertical, indicating that flow is extremely variable and depends entirely on runoff from storms. The steepness of the upper ends of the curves for these two time periods indicates great variability in high flows, whereas the steepness of the lower ends indicates the absence of ground-water contribution to the stream. Although sewer installation in this westernmost drainage area was completed more than 20 years ago, and little change has occurred in the drainage basin since 1971-75, minute additional adjustments in streamflow from 1971-75 to 1981-85 are evident--high flows became still higher and more variable, and low flows became lower and more variable.

At Pines Brook, high flows increased appreciably from 1971-75 to 1981-85. Low flows, by contrast, decreased markedly through 1971-75 (100 percent) and remained at zero flow thereafter.

Flow in East Meadow Brook has followed a similar pattern, although the stream continued to receive sufficient ground water during 1981-85 to maintain base flow between storms, except during short periods of unusually low precipitation. The flow pattern of East Meadow Brook, which runs along the border between Nassau County Sewer Districts 2 and 3, was sufficiently changed by lowered ground-water levels caused by sewers to the west to resemble, in subdued form, the adjustment pattern of Pines Brook, whose drainage basin is in the center of Sewer District 2.

Although flow at 1-percent duration in Bellmore Creek, also in Sewer District 2, changed little from 1971-75 to 1981-85, high flows became more variable, as indicated by the increased slope of the upper end of the flow-duration curve for 1981-85. Low flows at Bellmore Creek became both lower and more variable, and most of the change occurred during the interval from 1971-75 to 1981-85. Massapequa Creek's flow-duration curves show a similar pattern, except that the decline in low flow was slightly greater from the index period to 1971-75 than during the ensuing decade.

Duration curves of flow at the five easternmost streams are similar. High flows became slightly higher and more variable with time, whereas low flows decreased only slightly from predevelopment flows, except at Sampawams Creek, where low flow actually increased slightly.

In summary, the curves for the three westernmost streams--Valley Stream, Pines Brook, and East Meadow Brook--are similar. The shapes of these curves indicate that these streams had completed most of the adjustment to urbanization and sanitary sewering in Nassau County Sewer District 2 by the mid-1970's, although minor changes continued even decades after the urbanization process was largely completed in 1964.

The curves for Bellmore Creek and Massapequa Creek, to the east in Nassau County Sewer District 3, also resemble each other. These curves indicate that high flows at Bellmore Creek increased little from 1971-75 to 1981-85, but that low flows declined significantly during this interval. At Massapequa Creek, almost all of the increase in high flows occurred during the interval from the index period to 1971-75, whereas increases in low flows occurred evenly through both time intervals.

The curves for the five easternmost streams--Carlls River, Sampawams Creek, Connetquot River, Swan River, and Carmans River--also are similar. At these streams, increases in high flows were consistent through time, whereas low-flow changes formed no clear trend. Among these curves, those for Carlls River and Sampawams Creek clearly show increasing variability of high discharges, whereas high flows at Connetquot, Swan, and Carmans Rivers increased overall but showed little change in slope.

These results indicate that (1) among the flow characteristics of streams on the south shore of Long Island, high flow is the first variable to be affected by urbanization, probably because it is affected directly by the increase in storm runoff from paved surfaces and storm sewers; (2) low flow responds to the lowering of ground-water levels, which occurs late in the urbanization process; (3) small but quantifiable changes in stream-discharge patterns may persist at least two decades after urbanization is largely complete; and (4) decreases in low flow have occurred as far east as Carlls River in recently sewered southwestern Suffolk County, and (5) flow at 1-percent duration increased by 26 to 82 percent from the index period to 1981-85 at the eight streams for which index-period data can be evaluated.

SUMMARY AND CONCLUSIONS

Under predevelopment conditions, streams on the south shore of Long Island derived about 95 percent of their total flow from ground water; direct runoff from storms constituted the remainder (Pluhowski and Kantrowitz, 1964). Because the streams function as ground-water drains, small fluctuations in ground-water levels commonly cause large variations in stream discharge (Garber and Sulam, 1976).

Characteristics of urbanization on Long Island that have affected storm runoff and ground-water levels include (1) an increase in impermeable (paved) area, (2) construction of storm sewers that convey storm runoff to streams or to recharge basins, and (3) diversion of wastewater to sanitary sewers that discharge to the south-shore bays after treatment rather than returning it to the ground-water system through septic tanks and other individual wastewater-disposal units. The net effect of these changes has been (1) a decline in ground-water levels and a corresponding reduction in ground-water discharge to streams, and (2) an increase in high flows and variability of flow in streams.

Results of hydrograph separation show that during 1976-85, the annual base flow of streams in heavily urbanized Nassau County Sewer District 2 averaged 14 percent of the total flow; base flow of streams in Nassau County Sewer District 3, to the east, averaged 79 percent; base flow in Suffolk County Southwest Sewer District averaged 88 percent; and base flow at streams in an unsewered area of Suffolk County averaged 96 percent. This correlation between the percent base flow and the locations of the streams indicates that the installation of sanitary sewers, which results in decreased recharge and thus lowered ground-water levels, is one of the major causes of base-flow declines on Long Island.

Double-mass-curve analysis confirms that base-flow loss is greatest at streams in Sewer District 2--the area that is most heavily urbanized and has been urbanized and sewered for the longest time--and is least in streams in the unsewered part of south-central Suffolk County, where urbanization is least. Base-flow loss resulting from sanitary sewers is attenuated in areas where the density of recharge basins is high. Double-mass curves indicate that the three westernmost streams--Valley Stream, Pines Brook, and East Meadow Brook--have reached equilibrium with the new hydrologic regime caused by the physical changes that accompany urbanization and sewerage in the drainage basins, whereas streams east of East Meadow Brook had not reached equilibrium by 1981-85.

Flow-duration-curve analysis documents the increased variability of high and low flows and indicates that, in the south-shore streams, (1) high flow is the first variable to be affected by urbanization, probably because it responds to the increase in direct runoff caused by the paving of formerly permeable surfaces and the routing of this water directly to streams; (2) low-flow decreases follow the lowering of ground-water levels caused by use of sanitary sewers and, therefore, occur late in the urbanization process; (3) small but quantifiable changes in stream-discharge patterns can persist as long as two decades after urbanization is virtually complete; (4) increases in flow at 1-percent duration ranged from 26 to 82 percent from the index period (1948-52) to 1981-85 at all eight streams for which index-period data can be evaluated; and (5) reductions in low flow have occurred as far east as Carlls River in the recently sewered part of southwestern Suffolk County.

The net effect of urbanization on streamflow on the south shore of Long Island is (1) a decrease in base flow, (2) an increase in high flow, and (3) an increase in flow variability. These effects have reached at least as far east as Carlls River in southwestern Suffolk County. Undesirable changes in streamflow patterns appear to be mitigated by the use of recharge basins, which increase recharge of the ground-water reservoir with stormwater runoff and thereby help to maintain ground-water levels and stream base flow.

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