Effects of Land Use and Retention Practices on Sediment Yields in the Stony Brook Basin, New Jersey

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1798-L

Prepared in cooperation with the New Jersey State Departments of Environmental Protection and of Agriculture

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By LAWRENCE J. MANSUE *and* PETER W. ANDERSON

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EFFECTS OF LAND USE AND RETENTION PRACTICES ON SEDIMENT YIELDS IN THE STONY BROOK BASIN, NEW JERSEY

By Lawrence J. Mansue and Peter W. Anderson

ABSTRACT

The average annual rate of suspended-sediment discharge of the Stony Brook at Princeton, N.J. (44.5 square miles) is about 8,800 tons, or 200 tons per square mile. Annual yields within the basin, which is in the Piedmont Lowlands section of the Piedmont physiographic province in west-central New Jersey, range from 25 to 400 tons per square mile. Storm runoff that transports suspended materials in excess of a ton carries 90 percent of the total suspended-sediment discharge from the basin. Observations of particle-size distributions indicate that the suspended material carried during storms is 55 percent silt, 40 percent clay, and 5 percent sand.

A trend analysis of sediment records collected at Princeton between 1956 and 1970 indicated an increase in suspended-sediment discharge per unit of water discharge during 1956–61. From early 1962 to late 1967, sediment trends were difficult to interpret owing to complicating factors, such as reservoir construction, urbanization, and extreme drought. After 1967, yields decreased.

Variations in sediment yields during the study are attributed to the integrated influence of several factors. A 2.9 percent decrease in croplands and an increase of 5.1 percent in idle and urban land use probably produced a net increase in sediment yields. Construction of seven sediment-retention reservoirs under Public Law 566 resulted in temporary increases in sediment yields. However, based on a trap-efficiency investigation at 1 site, the combined effect of operation of these 7 reservoirs is estimated to result in a 20 percent reduction in sediment discharge from the basin. Other factors that influence the noted decrease include reduction in yields during 5 years of drought, 1962–66, and reduced construction and development during the latter part of the study period resulting from a general economic slowdown.

INTRODUCTION

Sediment is an important but often overlooked aspect of stream quality. It degrades water quality for nearly every water use. Sediment affects the heat balance in streams, shades out aquatic plants, abrades constructions in stream channels, and interferes with the life process of aquatic organisms. Deposited in channels, lakes, reservoirs, ditches, or pipelines, sediment reduces storage and transport capacity, smothers bottom organisms, and changes the aquatic habitat. In flooded areas, it may severely damage buildings and their contents, crops, highways, drainage ditches, and other land features. In highly industrialized and urban areas, sediment may carry surface-adsorbed nutrient materials, pesticides and other toxins, or pathogenic micro-organisms.

As part of its continuing evaluation of the Nation's water resources, the U.S. Geological Survey has cooperated with several State and Federal agencies in the investigation of stream-sedimentation characteristics in New Jersey. The purpose of this report is to present the findings of one such investigation on the Stony Brook basin in west-central New Jersey.

The original objective of the investigation was to determine the suspended-sediment load transported from the basin into Carnegie Lake. In order to meet this objective, daily measurements of suspended-sediment concentration were made at Princeton. On the basis of these measurements and daily water-discharge records, daily, monthly, and annual loads of suspended sediment to the lake were computed.

The objective was modified shortly after inception of the project to include an investigation of the basin's hydrology in relation to land-use and land-management practices. Special emphasis in the modified investigation was placed on the influence and efficiency of reservoir development by the U.S. Soil Conservation Service (USSCS) under Public Law 566 (P.L. 566) in reducing sediment yield from the basin. Measurements of sediment discharge at Princeton in the modified project were to define long-term variations in sediment yield due to gradual urbanization in the basin and to the construction of several P.L. 566 reservoirs. Periodic measurements of sediment concentrations at five subbasin sampling sites were made during storms to define the yields from these areas.

Daily sediment-discharge records were collected from the outfall of one P.L. 566 retention reservoir, Baldwin Lake near Pennington. These records and periodic measures of the changes in the reservoir capacity were used to determine its trap efficiency.

In addition to sediment analyses, additional samples were randomly collected and analyzed for chemical constituents at most of the sampling sites. A brief discussion of the results of these analyses is presented at the end of this report.

All records collected during the project were published annually in the Geological Survey's Water-Supply Paper series titled "Quality of Surface Water in the United States." In addition, since 1964 the records also have been released in annual basic-data releases titled "Water Resources Data for New Jersey—Part 2. Water Quality Records." Distribution of these latter reports is limited as they are designed primarily for rapid release of data to meet local needs.

PREVIOUS INVESTIGATIONS

In 1956, several local agencies, including the Mercer and Hunterdon County Soil Conservation Districts and the Stony Brook-Millstone Watersheds Association requested assistance through the USSCS under the Watershed Protection and Flood Prevention Act (P.L. 566). Detailed improvements were suggested to control sedimentation and flooding in the Stony Brook basin. Subsequently, a watershed plan was prepared for the construction of nine P.L. 566 reservoirs, for channel improvements, and for other conservation practices in the basin. Implementation of this plan, that since has been revised or modified several times, was begun in 1956.

Recognizing the needs for information to define the long-term effects of the work plan, this cooperative investigation of sedimentation in the basin was begun in 1956 by the predecessor of the present New Jersey State Department of Environmental Protection, Division of Water Resources, and the U.S. Geological Survey, at the request of Princeton University and the Stony Brook-Millstone Watersheds Association. During 1962–67, funding for the cooperative project was provided by the State Department of Agriculture, State Soil Conservation Committee. Subsequently, the Division of Water Resources returned as the principal cooperating agency. Preliminary results of the cooperative investigation between the State and the U.S. Geological Survey, in addition to the annual publication of basic data, were reported by George (1963), Anderson and George (1966), Anderson and McCall (1968), and Mansue (1970).

George summarized results from the period 1956–59 and made preliminary observations on sediment transport by streams in the basin. He reported that the greater part of annual suspended-sediment discharges occur during the nongrowing season. Soil conservationists concluded from this fact that more efficient cover-crop practices were needed to reduce soil erosion from farmlands during nonproductive periods. George also concluded that urban expansion and reservoir construction produced higher-than-average suspended-sediment yields in the basin between 1956 and 1959. He inferred that land-use changes that exposed soils created temporary conditions contributing to excessive stream sedimentation. George also reported that on several occasions construction of bridges, reservoirs, or pipelines in or near the stream channel contributed to temporarily high sediment yields in this basin. This trend toward increased sediment yield in the basin from urbanization and construction was shown by George (1963, p. 42) to expand after 1957. That is, the amount of sediment for a given rate of runoff increased significantly.

Anderson and McCall (1968) included a brief discussion of this project in an article on urbanization's effect on sediment yields in the State. Mansue (1970) more recently discussed sediment yields in the Stony Brook basin, as affected by land-use and retention practices. In addition, Anderson and George (1966, p. 37–40), as part of a reconnaissance of the water-quality characteristics of New Jersey's streams, presented brief discussions of the sediment characteristics of this basin.

ACKNOWLEDGMENTS

The authors acknowledge the guidance, support, and advice received from the following persons, without whose assistance the study could not have been accomplished: Mr. Phillip Alampi, Secretary, State Department of Agriculture; Mr. C. M. Pike, Director, State Division of Water Resources; Messrs. G. F. Walton, M. W. Crooks, and S. R. Race, successive Executive Secretaries of the State Soil Conservation Committee, and Mr. G. R. Shanklin, former Director and Chief Engineer, State Division of Water Policy and Supply.

Appreciation is acknowledged to representatives of the Stony Brook-Millstone River Watersheds Association, in particular, Paul M. Van Wegen, former President, and M. W. Crooks, G. F. Walton, R. W. Thorsell, and I. R. Walker, successive Executive Directors, for their advice, support, and guidance in the conduct of the project and for their assistance in coordinating the services of several resident observers throughout the watershed.

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STONY BROOK BASIN

The Stony Brook is a major headwater tributary of the Millstone River. It drains 47.8 sq mi (square miles) and flows into Carnegie Lake near the east edge of Princeton (fig. 1).

This part of New Jersey has a fairly mild climate. Based on National Weather Service records for Trenton, the nearest city having continuous climatologic records, while winter temperatures may occasionally drop to 0°F (—17.8° Celcius), the average daily temperature during the coldest month, January, is 33°F (0.6°C). The average daily temperature in July, the warmest month, is 76°F (24.4°C). The growing season ranges from 190 to 240 days and averages 218 days. Distribution of precipitation throughout the watershed seems nearly uniform, both in time and place. For comparison, a tabulation of average precipitation during 1956–70 and the normal monthly and annual precipitation in the State's northern and southern climatologic divisions and for Trenton are presented in table 1. The basin is in the boundary area between the two divisions.

PHYSIOGRAPHY

The basin lies on the east edge of the Piedmont Lowland section of the Piedmont physiographic province (fig. 1). Anderson and

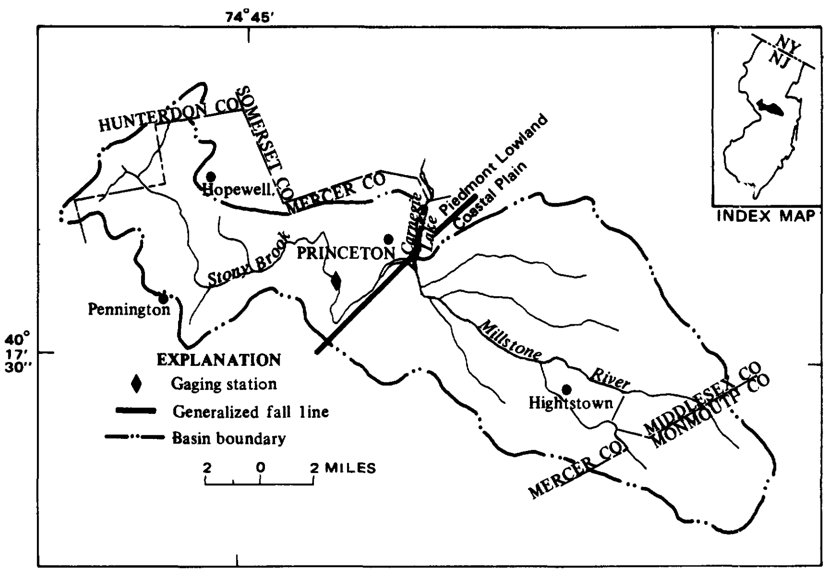


FIGURE 1.—Map of upper Millstone River basin showing generalized physiographic boundary.

TABLE 1.—*Average annual and normal precipitation, in inches, at Trenton and in the State's northern and southern climatologic divisions*

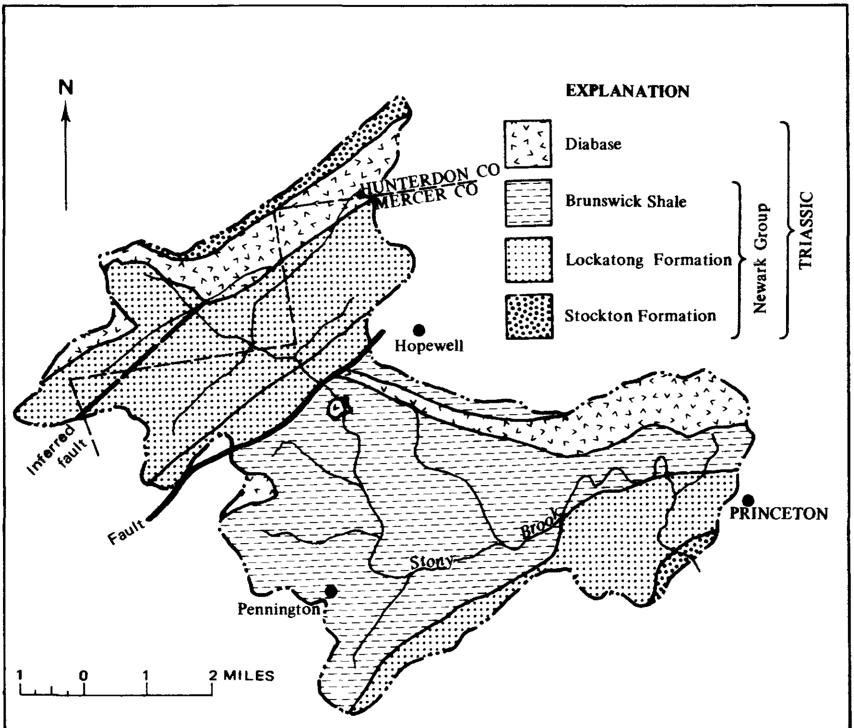
[Based on National Weather Service records]

Year	Trenton	Northern division	Southern division
	Average		
1956	43.65	46.78	48.68
1957	28.79	38.72	33.73
1958	45.46	49.97	55.95
1959	41.30	44.43	42.84
1960	40.91	48.46	45.00
1961	45.67	44.35	46.39
1962	44.02	41.68	44.31
1963	30.41	33.95	36.03
1964	35.44	34.63	37.73
1965	32.73	30.54	28.39
1966	39.57	40.00	41.27
1967	46.27	46.29	45.83
1968	37.48	41.63	38.79
1969	45.59	46.83	47.25
1970	33.83	41.01	39.16
	Normal		
Jan	3.10	3.47	3.45
Feb	2.59	2.92	2.99
Mar	3.84	4.10	4.09
Apr	3.21	3.91	3.45
May	3.62	4.07	3.78
June	3.60	4.01	3.62
July	4.18	4.65	4.37
Aug	4.77	4.91	5.06
Sept	3.50	4.06	3.79
Oct	2.84	3.42	3.35
Nov	3.16	3.88	3.74
Dec	2.87	3.56	3.26
Annual	41.28	46.96	44.95

George (1966, p. 37) described this province as producing the highest sediment yields in nonurban areas of the State. The general topography is rolling to hilly. Elevations range from 560 feet near Hopewell to 53 feet at Princeton. More than three-fourths of the land slopes are classified between 0 and 6 percent grade (Stony Brook-Millstone River Watersheds Association, 1956, p. 3).

The basin is underlain (Bascom and others, 1909) by sedimentary members of the Newark Group—that is, the Stockton Formation, Lockatong Formation, and Brunswick Shale—and by intrusive diabase (fig. 2). The Stockton Formation, the oldest unit of the Newark Group in this area, is exposed over approximately 5 percent of the basin. It is composed generally of varicolored sandstone, arkose, and scattered thin red shale. The Lockatong Formation, which underlies approximately 32 percent of the basin, is a hard dark argillite that includes some thin-bedded sandstone. The youngest formation of the Newark Group exposed is the Brunswick Shale, which underlies approximately 48 percent. It consists of soft red shale that locally includes a few layers of sandstone. Diabase is exposed along the northeast edge of the upper part of the basin, along the northern divide between Hopewell and Princeton, and at two points north of Pennington. Because of its greater resistance to weathering, the diabase forms the highlands of much of the northern border. Approximately 15 percent is underlain by diabase.

Soils vary in physical character and in depth (U.S. Soil Conserv. Service, 1953). Those developed from the Stockton Formation are primarily sandy and silt loams ranging in thickness from less than 24 inches to very deep; those from the Lockaton Formation are generally silty loams, ranging in thickness from 20 to more than 36 inches; those from the Brunswick Shale are generally silty loams, ranging in thickness from less than 12 to 36 inches; and those from diabase are silt loams ranging from thin to thick. Even though the soils are generally thin in the diabase highlands, when exposed they may yield rather large quantities of sediment. The red shale which underlies much of the basin is



From U.S. Geological Survey (1967)

FIGURE 2.—Generalized geologic map of the Stony Brook basin.

a potentially high sediment yielder where silty and a low yielder where sandy.

LAND USE

The land-use distribution above Princeton as well as in several subbasins, as reported by George (1963, p. 17–18), is given in table 2. The sample values for the gaged area were reported by George to compare favorably to those reported earlier by Palmer and others (1957).

A comparison was made between the aerial photographs obtained in 1957 by the USSCS and those by the U.S. Geological Survey in 1969. Changes noted were field checked; a planimeter was used to determine acreage; and the land usage, as of 1970, was tabulated in table 2. The same land-use categories used by George are given in this report, with the following exception: Because grass, hay, and pasture have similar erosion characteristics, these categories were combined.

TABLE 2.—*Land use, in percentage of area, as measured in 1957 and 1970 in the Stony Brook basin and selected subbasins*

	Woodland		Cropland		Grass, hay, and pasture		Idle		Urban	
	1957	1970	1957	1970	1957	1970	1957	1970	1957	1970
Stony Brook at Princeton (44.5 sq mi)	32.2	32.5	18.3	15.4	25.1	22.6	10.7	11.2	13.7	18.3
Woodsville Brook at Woodsville (1.86 sq mi)	20.0	21.6	17.0	1.6	42.0	42.0	12.0	21.2	8.9	13.5
Baldwin Creek at Pennington (1.92 sq mi)	25.6	26.1	22.6	16.7	7.6	7.6	6.0	9.4	8.3	10.3
Stony Brook near Hopewell (2.57 sq mi)	71.4	72.6	2.4	2.4	9.5	8.9	7.1	6.6	9.5	9.6
Honey Branch near Rosedale (4.02 sq mi)	21.0	18.3	22.0	19.6	41.1	33.6	8.9	10.3	6.9	18.1
Stony Brook at Glenmoore (17.6 sq mi)	40.9	42.1	15.5	11.7	22.6	21.9	12.8	14.0	8.1	10.1

Woodlands constitute 32 percent of the land area. These lands are principally in the northern and western parts of the basin. There has been a negligible net change in these lands since 1957. However, some areas idle in 1957 are now (1970) wooded, whereas some wooded areas in 1957 are now in another land-use classification.

Much of the land is used for farming, about 43 percent in 1957 and 38 percent in 1970. In 1957, poultry, dairy, and cattle farms were scattered throughout the basin, but primarily in the western part. These farms nearly disappeared by 1970 and were replaced by "cash-crop" farming; that is the growing of soy beans, small grains, and corn without sufficient crop rotation. This type of farming probably creates greater erosion problems than previous types (H. B. Slayback, U.S. Soil Conserv. Service, oral commun., 1970).

Most of the 5-percent net decrease in farmland is reflected by a similar increase in urban areas. The 18-percent urban land use exists mainly in the southeast, in the Princeton area, and in the northwest, near Hopewell (fig. 1). Increased urban usage is greatest in the eastern part of the basin. This can be attributed chiefly to the development of housing and research facilities in the Princeton area.

About 11 percent of the land is classified as idle (1970). The net change from 1957 in this use is an approximate 0.5 percent increase. Much of this idle land is in abandoned submarginal farms along the northwest divide or in vacant lands west of Princeton. Some of this land exists as an interim phase between the change from farmland to suburban-residential use.

In the northern headwaters area near Hopewell, land that was classified as idle in 1957 seems to have been farmed previously. In 1970 these areas were primarily woodland. This change is attributed to less suitable soil for farming.

Within the Honey Branch subbasin, nearly 3 percent of the woodland area was converted either to idle or urban classifications owing to construction of a retention reservoir and housing. Urbanization in this subbasin increased 11 percent, primarily in areas that previously (1957) had been classified under the grass, hay, and pasture category.

SEDIMENTATION

Stony Brook and Millstone River were impounded in 1907 to create Carnegie Lake (fig. 1) for use by Princeton University for recreation. Extending about 3.5 miles, the lake has an average width of over 500 feet. The upper Millstone River enters the lake about 2 miles above the dam. The lake's original storage capacity was 1,355 acre-feet (422 million gallons).

Sediment accumulation in the lake became a problem within a few years after impoundment. The University found it necessary in 1927 to dredge a channel from the boathouse in the upper end (Stony Brook) of the lake to deep water in the center. The upper 1.5 miles of the lake was again extensively dredged between 1937 and 1939. Permanent cross-section monuments were established in 1950 on each side of the lake at 2,000-foot intervals throughout its length. Results of a survey in 1950 (Moore and others, 1952) indicated a total deposition of 410 acre-feet of sediment, including dredged materials, since the original impoundment. Results of a survey in 1959 (U.S. Soil Conserv. Service, 1959) indicated that the total sediment accumulation had increased to 459 acre-feet. Another survey in 1968 (Praeger and others, 1968) reported that 651 acre-feet of material would have to be removed to restore the original hard bottom.

Moore and others (1952, p. 19) estimated that 1.3 percent of the total sediment accumulated in Carnegie Lake before 1950 was contributed by Millstone River and 98.7 percent by Stony Brook. Results of their investigations suggest that permeable soils, low stream gradients, and the presence of several dams in the upper Millstone River basin minimize the sediment contributed by this river system.

STONY BROOK AT PRINCETON

Because of its greater sediment contribution, Stony Brook was chosen by the cooperating agencies for intensive investigation. Daily measurements of suspended-sediment discharge of Stony Brook were begun in January 1956 in order to define the sources of suspended-sediment discharge from the basin and to evaluate any trend in sediment discharge over an extended period. Between January 1956 and June 1970, more than 127,000 tons of suspended sediment was transported from the basin at an average annual discharge of 200 tons per sq mi.

Streamflow- and sediment-duration curves (fig. 3) were prepared to evaluate the distribution of daily data with respect to time. Note that high streamflow, suspended-sediment concentration, and sediment discharge represent only a small percentage of the total time period. For example, although days when more than 100 tons of sediment was transported occurred only 2.5 percent of the time during the 1956–70 period, these days accounted for 88 percent of the sediment load. Conversely, though days of low suspended-sediment discharge are frequent, the total sediment discharge during these times of minimum streamflow is small.

Another application of duration curves is in the determination of the percentage of time that a particular parameter equaled or exceeded or, conversely, was less than an indicated value. For example, the median streamflow, that equaled or exceeded 50 percent of the time, is 18.5 cfs (cubic feet per second); median suspended-sediment concentration is 5.6 mg/l (milligrams per liter); and median suspended-sediment discharge is 0.24 ton per day. Similarly, values for other frequencies of occurrence can be described.

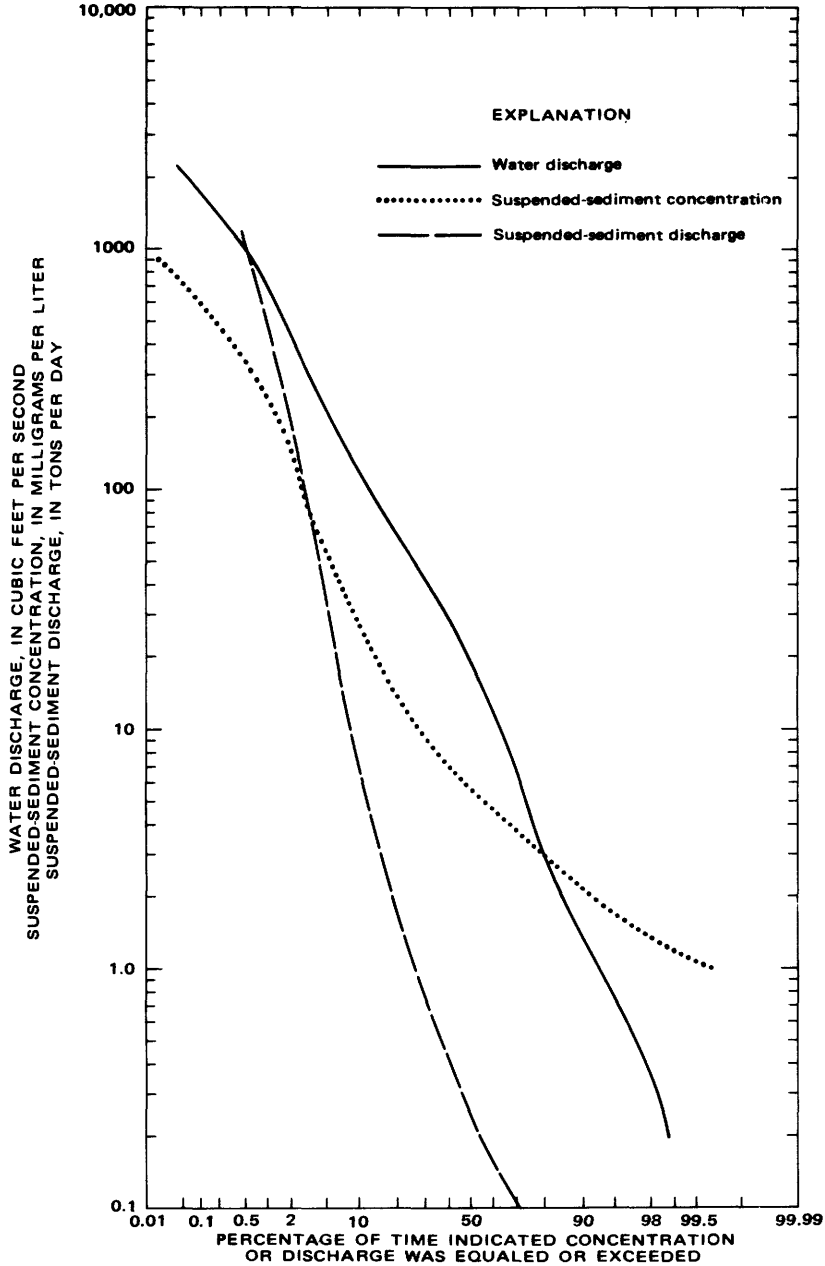


FIGURE 3.—Frequency distribution of mean daily streamflow, suspended-sediment concentration, and suspended-sediment discharge, Stony Brook at Princeton, 1956–70.

The seasonal and annual variations of the suspended-sediment load transported from the basin are shown in table 3. Generally, low sediment loads are concurrent with low streamflows from August to October, with higher loads in the remaining months. Although moving averages tend to dampen extremes of short-term fluctuations in the chronologic sequence of the parameter analyzed, the plot illustrated in figure 4 shows that the decreased quantity and intensity of storms and resultant low streamflows during the 1962–66 drought resulted in sediment discharges being reduced considerably. One of the few beneficial environmental effects of drought is the reduction of the amount of soil erosion and stream sedimentation—undoubtedly related to the reduction in the number and intensity of storms. Based on the annual loads at Princeton (table 3), sediment discharges were reduced nearly tenfold between 1961 and 1965.

MULTIPLE-REGRESSION ANALYSIS

For most streams, there is a close relation between the rate of sediment discharge and that of storm runoff (Colby, 1956). If the

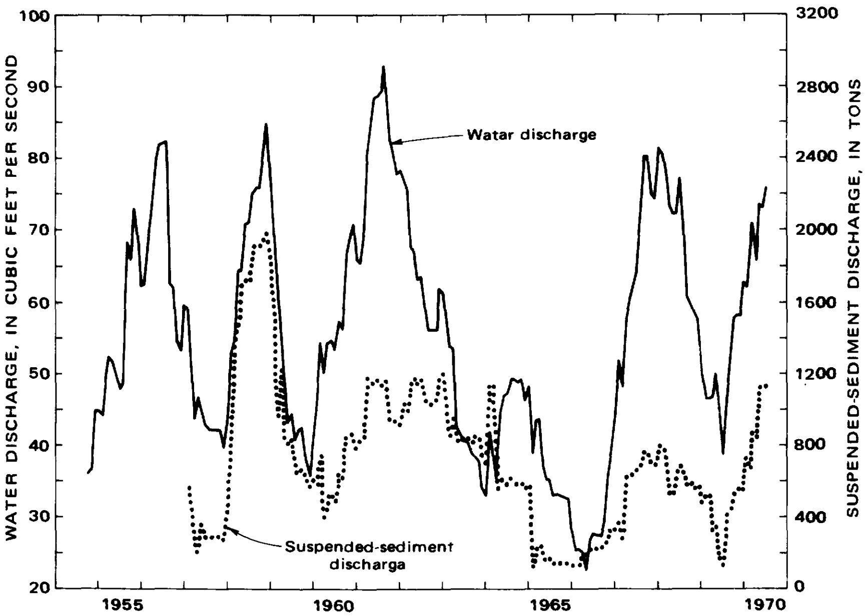


FIGURE 4.—Trend analysis, as shown by 12-month moving averages, of streamflow and sediment discharge, Stony Brook at Princeton.

TABLE 3.—*Suspended-sediment discharges, in tons, Stony Brook at Princeton, 1956–70*

Year	Jan.	Feb.	Mar.	Apr.	May	June	July
1956	----	1,985	3,019	591	551	65.6	5.6
1957	141	303	149	2,399	3.5	2.1	.2
1958	4,230	7,512	978	4,954	233	3.1	2,239
1959	777	695	4,051	240	8.5	194	7.5
1960	489	2,470	57	1,578	19	16	1,666
1961	941	2,592	4,090	1,350	161	6.3	1,426
1962	2,078	2,295	5,829	1,652	74	80	33
1963	178	77	7,245	108	111	25	18
1964	5,400	107	171	824	16	6.6	248
1965	56	1,200	290	51	6.1	1.7	2.7
1966	14	1,280	978	50	393	4.9	.8
1967	350	208	5,314	40	542	184	434
1968	244	85	2,344	113	2,060	682	2.3
1969	715	44	230	202	101	11	3,653
1970	23	2,360	120	3,347	23	181	----

Year	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1956	1.2	2.0	0.7	127	345	-----
1957	.5	2.2	.9	7.4	2,776	5,785
1958	26	5.7	359	701	679	21,920
1959	192	40	2.2	91	1,024	7,322
1960	17	2,647	56	130	248	9,393
1961	200	136	3.0	23	193	11,121
1962	125	28	86	1,460	549	14,299
1963	17	259	.5	211	71	8,319
1964	1.7	4.8	5.1	1.7	138	6,923
1965	1.9	11	2.1	.3	1.4	1,625
1966	.2	214	884	85	146	4,050
1967	858	5.1	274	21	1,227	9,457
1968	2.2	1.5	21	47	107	5,709
1969	168	1,155	190	19	2,214	8,701
1970	----	----	----	----	----	-----

availability or transportability of these sediments changes, the relation of sediment to water discharge also may change. As each storm is unique, each having different meteorologic, hydrologic, and areal cover patterns, the data can be assembled, logically, on a single storm basis. An analysis of data from a large number of storms is simplified by use of a digital computer, as many variables would be necessary to define the transport of sediment.

The most comprehensive method for analysis of data is through a multiple-regression analysis. Such an analysis was made on the Princeton data to obtain the best fit of several variables (independent) that affect the transport of suspended sediment (dependent variable) for given storms. A multiple regression of the following mathematical form was used:

$$Y = b_0 + b_1 X_1 + b_2 X_2 + \ldots b_n X_n$$

where constants b_0 to b_n are the partial-regression coefficients; Y, the estimated dependent variable; and X_1 to X_n, the independent variables.

The following regression models, which are basically those discussed by Guy (1964), were used to define predictive equations:

$$\log S_L = b_0 + b_1 \log Q_t \quad (1)$$
$$\log S_L = b_0 + b_1 \log Q_w \quad (2)$$
$$\log C = b_0 + b_1 \log Q_t \quad (3)$$
$$\log C = b_0 + b_1 \log Q_w \quad (4)$$
$$\log C = b_0 + b_1 \log P_n \quad (5)$$
$$\log C = b_0 + b_1 \log Q_w + b_2 \log P_n \quad (6)$$
$$\log C = b_0 + b_1 \log Q_w + b_2 \log P_n + b_3 \log Q_a \quad (7)$$
$$\log C = b_0 + b_1 \log Q_w + b_2 \log P_n + b_3 \log Q_a + b_4 \log Q_b \quad (8)$$
$$\log C = b_0 + b_1 \log Q_w + b_2 \log P_n + b_3 \log Q_a + b_4 \log Q_b + b_5 A_t \quad (9)$$
$$\log C = b_0 + b_1 \log Q_w + b_2 \log P_n + b_3 \log Q_a + b_4 \log Q_b + b_5 A_t + b_6 T_m \quad (10)$$

where S_L is the suspended-sediment load for a storm, in tons; C, the mean sediment concentration for a storm, in milligrams per liter; Q_t, the surface runoff due to the storm, in cfs-days (cubic feet per second-days); Q_w, the net water discharge due to the storm, in cfs-days; P_n, the peak rate of water discharge minus the base flow, in cubic feet per second; Q_a, the antecedent streamflow at the beginning of the storm, in cubic feet per second; Q_b, the base flow during the storm, in cfs-days; A_t, the normal daily air temperature during the storm, in degrees Fahrenheit; and T_m, the accumulative time since the first storm, in tenths of a month.

Many hydrologic and climatologic variables affect the sediment transported from a basin. Using a multiple-regression analysis, one can evaluate from the correlation coefficients the most useful variables for determination of the optimum mathematical expression. The search for useful variables is reported to be limitless (Guy, 1964, p. 22). However, many of these variables are of little use as an independent variable. This is due to either low correlation, poor quality of the data, or high intercorrelation with other variables. In addition, significance of a variable as an independent quantity is reported to vary from basin to basin (Guy, 1964, p. 42–46).

Some variables were not used because data are either not available or are inaccessible in usable form. For example, precipitation intensity in the study area is difficult to evaluate and often is too inaccurately determined for an effective measure of storm intensity. Thus, the peak-flow rate of the storm-streamflow hydrograph (fig. 5) was used as a partial measure of precipitation intensity. High intercorrelation was found between peak-flow rates and other hydrologic variables. This is due to the antecedent streamflow (Q_a) and the base flow (Q_b) being included in the value of the total peak streamflow (P_t). The intercorrelation was reduced by subtracting the estimated base flow from total streamflow at

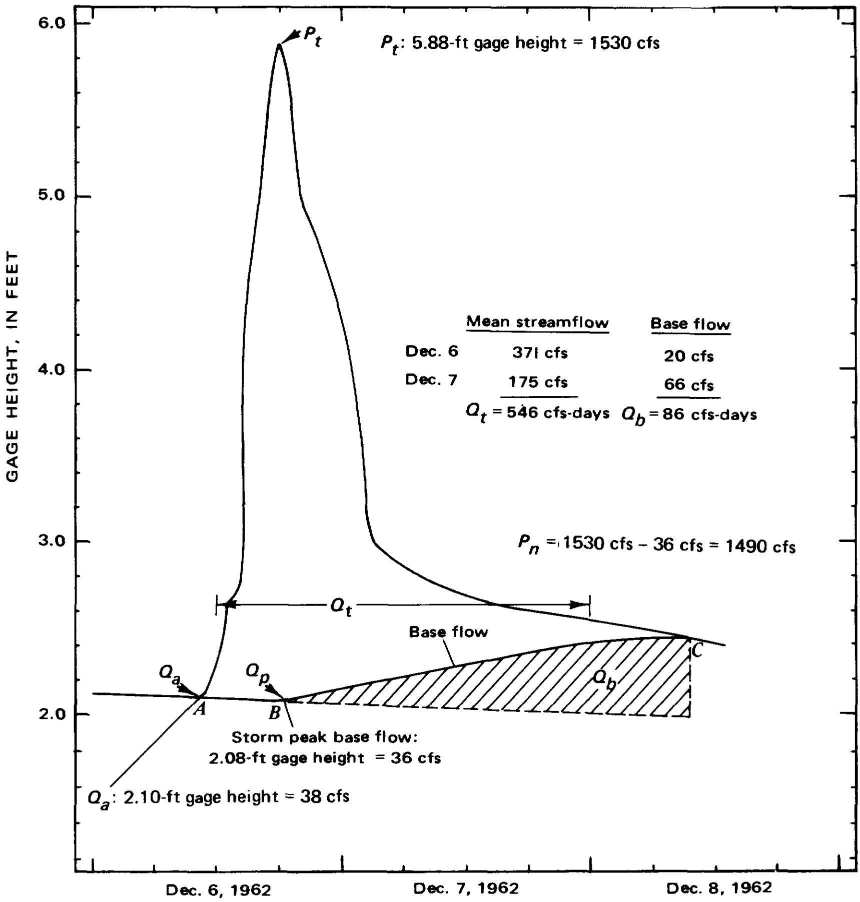


FIGURE 5.—Representative storm hydrograph, Stony Brook at Princeton.

the time of each peak. Consequently, the net peak-storm streamflow (P_n) was used to partly represent the storm intensity.

Base flow was determined from hydrographs (fig. 5) in a manner similar to that described in Davis and DeWiest (1967, p. 30–32). This technique involved extending the dry-weather recession curve (that is, the flow recession curve preceding the storm to the time of the peak flow *A* to *B* in fig. 5). From this point of intersection (*B*), a line is drawn at an angle of 30° to its intersection (*C*) with the storm's recession curve. Base flow was subtracted from the streamflow to obtain the direct runoff from each storm. Likewise, the net storm peak was derived by subtracting the base flow at point *B* from the streamflow peak.

A measure of the seasonal variation of sediment was needed. Assignment of arbitrary numbers to months of the year was found to be indefinite. As seasonal variation reflects climatic variation, some measure of this variation could logically be used. Daily normal air temperatures(U.S. Weather Bureau, 1963) were chosen, as their partial-regression coefficients agreed well with those of the mean daily air temperatures during storms. Soil temperatures also were tried, but air temperatures produced higher correlation coefficients than soil-temperature data.

Storms with sediment loads of less than 1 ton per day were not considered for the regression analysis. Also, storms in which streamflow hydrographs had nearly equal double peaks were not used. Between January 1956 and June 1970, there were 354 major storms that met these criteria, during which 90 percent of the total sediment load was transported.

Standard error of estimate was used in selecting the mathematical model best fitting the data. The smaller the value of the standard error of estimate, the better the model describes the suspended-sediment discharge from the basin. The standard errors of estimate for the 10 regression models (p. L14) are: 0.412, 0.377, 0.337, 0.320, 0.292, 0.293, 0.291, 0.271, 0.268, and 0.260 log units, respectively. It is evident that as additional variables are added to the model an improvement is made in its ability to describe the dependent variable. Model 5 produced a relatively low standard error of estimate (0.294 log units), with the least number of variables. Little improvement was made by the addition of antecedent flow, base flow, temperature, or time trend in the regression analyses.

The net peak discharge was found to be the most significant independent variable, and the magnitude of the time trend the least significant for describing sediment variations. The partial-regression coefficient, a measure of the interdependent variable correlation with the dependent variable, for the time of the storm was found to be negative; that is, the sediment concentration decreases with increasing time of the storm. This can be interpreted as indicating a long-term reduction in storm-sediment concentration. The daily normal air temperature, a measure of seasonal effects, also varied inversely with sediment concentration. The high degree of negative intercorrelation between air temperature and seasonal storm periods unquestionably produced the relation that is observed here.

The regression constants for each of the 10 models using the 1956–70 storm data are listed in the following table.

Model	b_0	b_1	b_2	b_3	b_4	b_5	b_6
1	—2.0837	1.5633					
2	—1.5349	1.4343					
3	.6491	.4353					
4	.7293	.4309					
5	.4768	.4836					
6	.4580	—.1508	0.6253				
7	.4880	—.1146	.6195	—0.0737			
8	.5948	.1014	.5765	.2908	—0.5481		
9	.8521	.0	.6627	.2523	—.5560	—0.0036	
10	.8854	.0	.6362	.1995	—.4567	—.0027	—0.0014

These constants can be used to predict the suspended-sediment concentration, given knowledge of the other parameters.

Model 2 is a regression of the two variables used for a unit rate of sediment-transport curve. A plot of this regression is illustrated in figure 6. It does not seem that the observed sediment data for any of the years of record plots above or below the line of regression. Therefore, a trend cannot be detected in this illus-

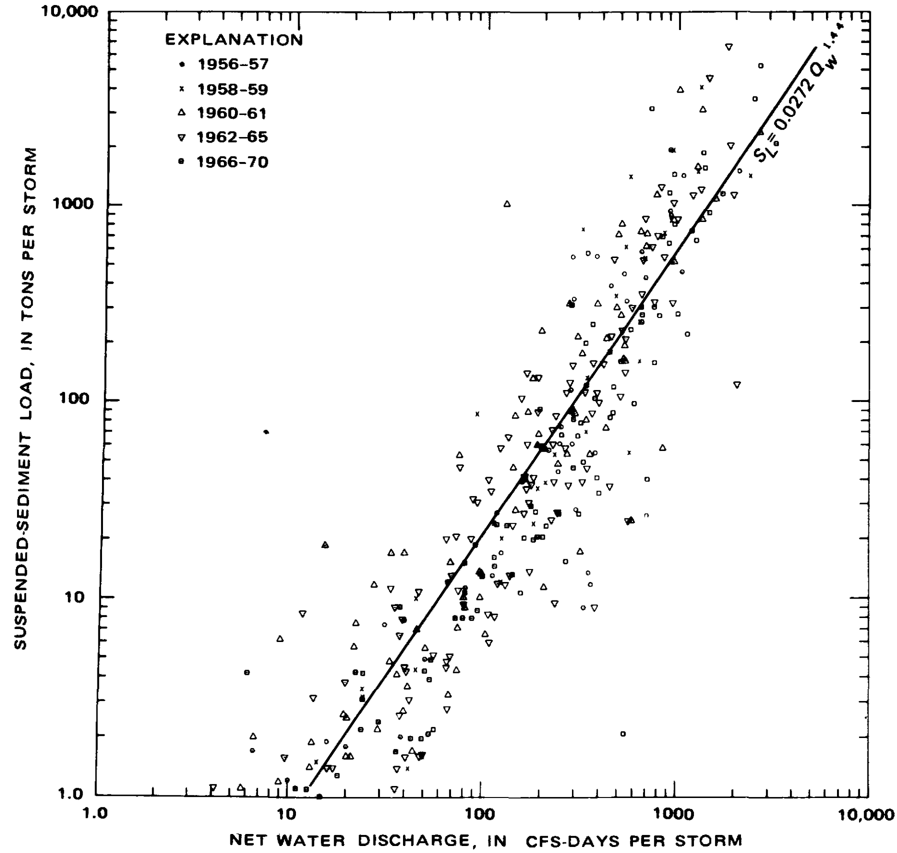


FIGURE 6.—Suspended-sediment transport curve based on storm runoff, Stony Brook at Princeton.

tration. Consequently, another method of analysis must be considered. Note also that in areas above 1,000 cfs-days this linear-regression analysis seems to be an inaccurate predictive model. Sediment-load values predicted are generally lower than those observed. A nonlinear expression would probably be of greater use for prediction.

DOUBLE-MASS-CURVE ANALYSIS

Another technique, that involving a double-mass curve, also has been used (Guy, 1957) for studying trends in sediment yield and in detecting the effect of watershed practices on sediment yield. A double-mass curve (Searcy and Hardison, 1960) is a plot of the cumulative observed data for one variable against the cumulative observed or calculated data for another variable. The plot will be a straight line when variations in both parameters are proportional; the slope of the line will represent the constant of proportionality between the quantities. Each break in slope represents a point in time at which a change has occurred in the relation between the two quantities analyzed.

A double-mass curve of net storm runoff and suspended-sediment discharge at Princeton is illustrated in figure 7. The parameters plotted are those used in model 2. Several breaks in slope can be seen. For example, the slope changed in late 1957. This is in agreement with an earlier observation by George (1963, p. 69), who concluded that urban expansion and reservoir construction produced temporarily high average sediment yields from 1957 to 1959. Large breaks in the curve, such as those in 1959, 1962, 1964, 1967, and 1970, are difficult to explain. Similar patterns (H. P. Guy, written commun., 1972) have been observed on other streams and seem to occur at the time of rather drastic (nonseasonal) weather changes, especially rather large storms. The breaks illustrated seem to concur with the first major storm subsequent to the spring thaw.

Interpretation of the data on this curve is complicated further by at least two factors: (1) the construction of several sediment retention reservoirs during 1958–70 and (2) an extreme drought during 1962–66.

If the drought is ignored and if the slope during the early years, 1956–61, is compared with that subsequent to the drought, 1967–70, then the following observations can be made. From 1956 to 1961, the slope of the curve is 1.03; from 1967 to 1970, it is 0.80. This suggests an overall change in the relation of about 22 percent. However, four of seven retention reservoirs were completed in the early period and only one during the later period. The change in slope may reflect the reduction in temporarily high sediment yields due to reservoir construction.

Figure 7 indicates that the proportionality between water and sediment discharges changes with time. However, which of the two parameters caused the variation in the proportionality? In order to answer this question a double-mass-curve analyses of observed data against values derived from model 10 was made and illustrated in figure 8. Model 10 was chosen, as it is the most accurate in predicting sediment transport. Also, variations in sediment concentration, rather than load that includes both streamflow and sediment, can be considered. In effect, this illustration indicates periods in which the observed concentrations are higher or lower than the average, as derived by regression analysis, for the entire period of record.

Note the six periods of relatively consistent slopes during 1956–58, 1959, 1960–62, 1963–66, 1967, and 1968–70. These periods of consistent slope are almost concurrent with similar periods in

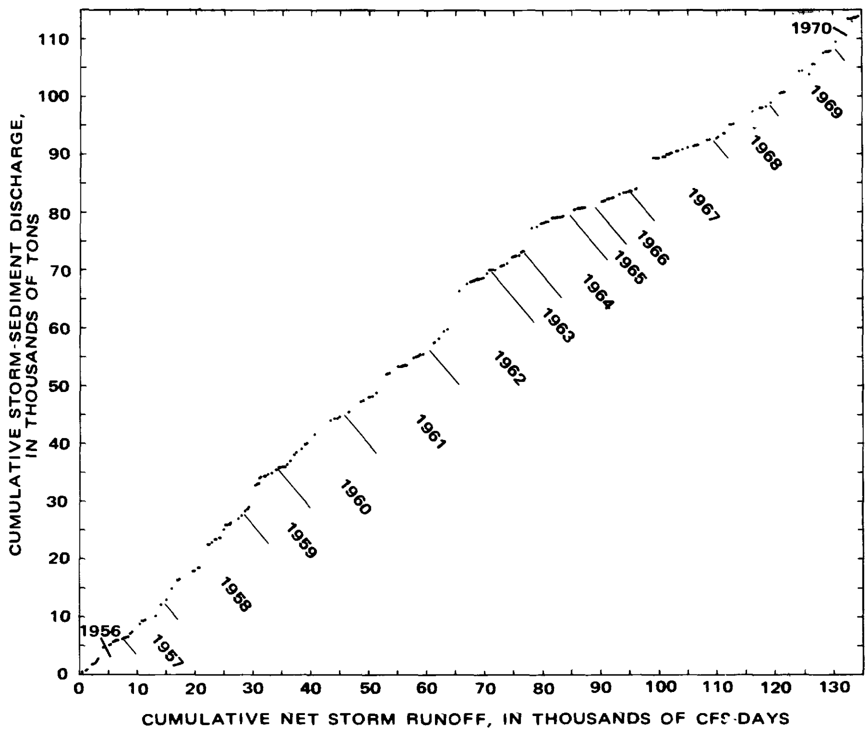


FIGURE 7.—Double-mass relation of net storm runoff and storm suspended-sediment discharge, Stony Brook at Princeton.

figure 7. Consequently, it is concluded that changes in proportionality are related, at least, to variations in sediment concentrations and not entirely to variations in water yield. Also, note that observed sediment concentrations were higher than average during 1958–59, 1962–66, and 1968–70 and that they were lower than average during 1960–61 and 1967. The periods of higher than average sediment concentration is coincident with retention reservoir construction in the basin. For example, three reservoirs (table 5) were completed between 1959 and 1960, three were completed between 1962 and 1964, and one in 1969. The higher yields

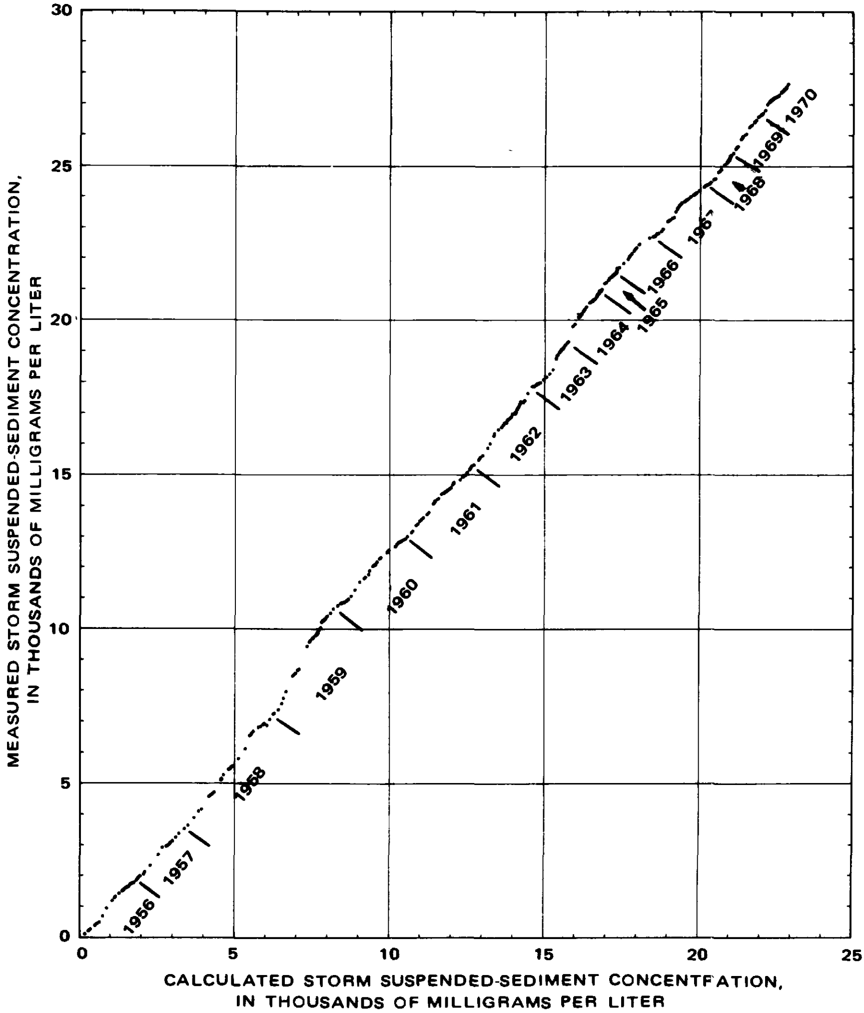


FIGURE 8.—Double-mass-curve relation of observed and calculated storm-sediment concentrations, Stony Brook at Princeton.

observed during 1958–59, 1962–66, and 1968–70 may be explained partly by earth moving in and near the stream channel from the construction of these reservoirs.

SUBBASIN-SEDIMENT YIELD

Five sediment-sampling locations were established within the basin at which sediment-load data were collected during storm-runoff. The period of record is listed in table 4. Measurements were made in order to identify areas yielding abnormally high or low quantities of sediment. The location of these sites and the drainage area above each location is shown in figure 9.

Storm data collected at these intermittent sampling sites are summarized and compared graphically (fig. 10) with similar data collected at Princeton. These plots show that the average sediment load per square mile transported by the Stony Brook near Hopewell, Honey Branch, and Stony Brook at Glenmore are less than that carried at Princeton. The loads from Baldwin Creek generally exceed those at Princeton below 7 tons per sq mi and are less that those at Princeton above 7 tons per sq mi. Woodsville Brook is transporting a greater load per square mile than Stony

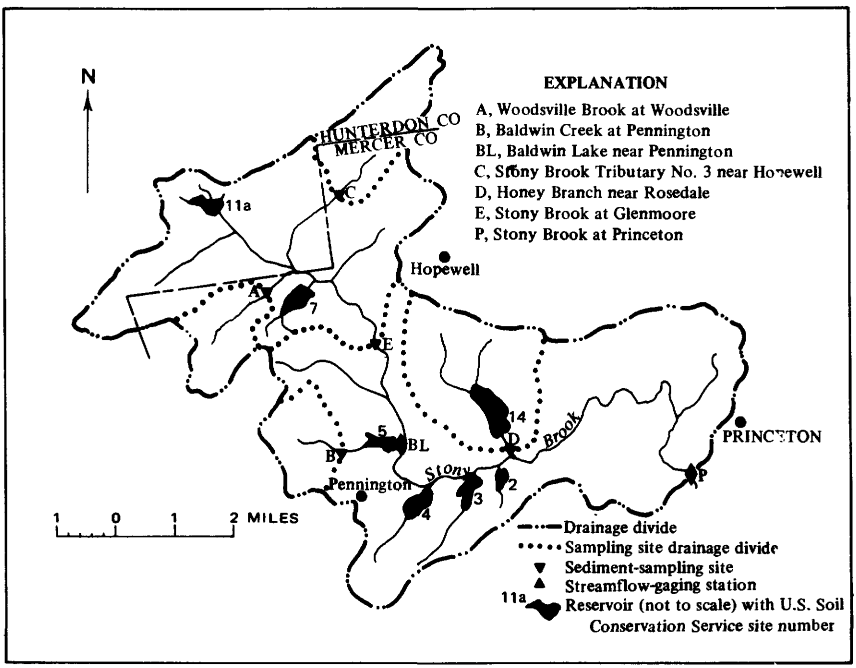


FIGURE 9.—Map showing location of subbasin sediment-sampling stations and sediment-retention reservoirs.

Brook at Princeton. However, data collected to date at this latter sampling site define the relation in only a small region of the graph and, thus, may be insufficient, for valid interpretation.

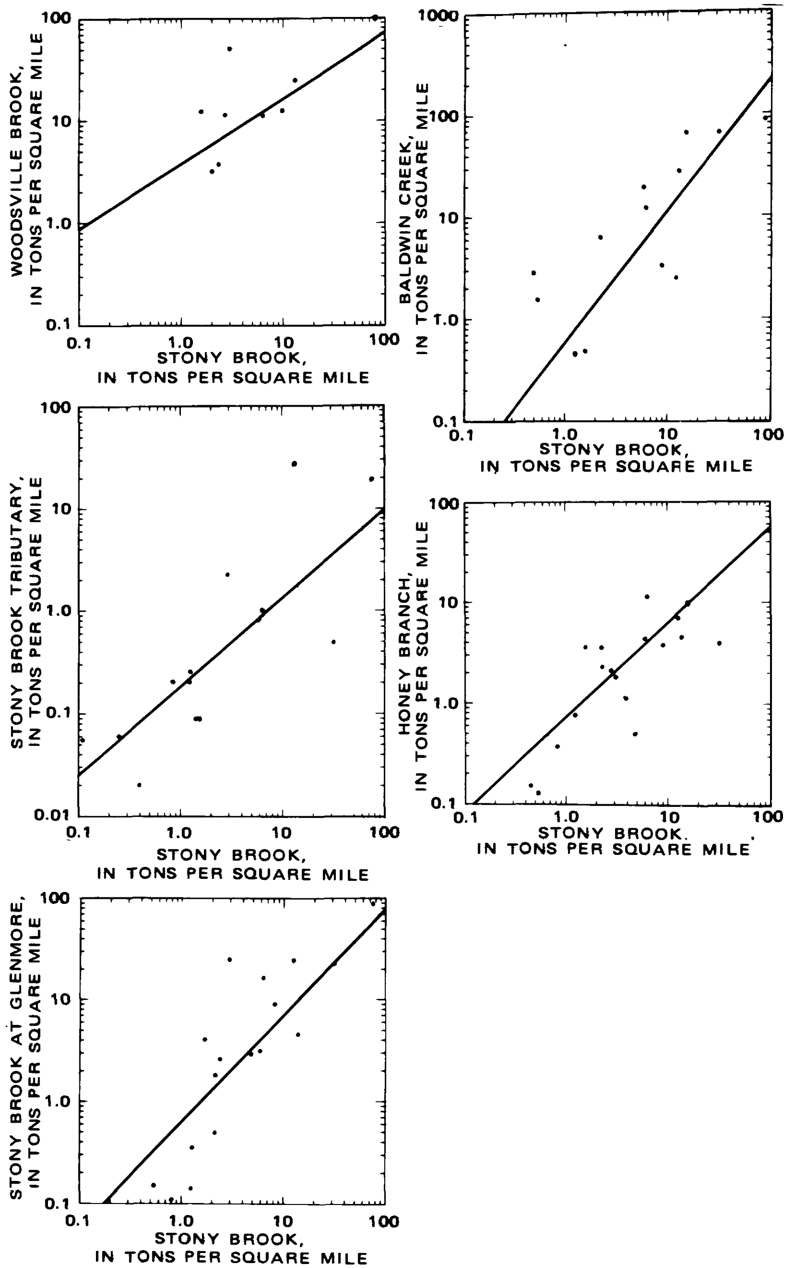


FIGURE 10.—Sediment-load relation between subbasin sampling stations and Stony Brook at Princeton.

Using graphs similar to those in figure 10, George (196[illegible]) determined the percentage of load yielded by each subbasin to the amount at Princeton (table 4). Storm-load samples collected after George's study plot in a manner similar to those he reported. Consequently, no change in this correlation was considered. Total suspended-sediment load at Princeton during January 1956 to June 1970 was about 127,000 tons, or 8,800 tons per year. Applying the percentage values listed to the average annual suspended-sediment discharge at Princeton results in a computed annual-sediment discharge for each subbasin. These results, which are summarized in table 4, range from roughly 25 to 400 tons per sq mi and compare well with the earlier estimates of Anderson and George (1966, p. 38) for this physiographic province.

Note that the highest yield, 405 tons per sq mi, was observed on Baldwin Creek (fig. 9, site B). This basin mainly drains the Brunswick Formation (fig. 2). Conversely, the lowest yield, 28.4 tons per sq mi, was observed on Stony Brook tributary No. 3, which principally drains diabase rock. Other subbasin sampling sites also were chosen to be representative of underlying geologic formations. For example, Honey Branch mainly drains the Brunswick Formation, Woodsville Brook the Lockatong Formation, and the Stony Brook at Glenmore a composite of the Stockton and Lockatong Formations and diabase rocks.

TABLE 4.—*Computed average annual suspended-sediment discharge of Stony Brook subbasins*

Subbasin	Period of record	Percentage of Princeton load	Suspended-sediment discharge	
			Tons	Tons per sq mi
Stony Brook at Glenmoore (17.6 sq mi)	1956–59, 1970	28.7	2,990	169
Honey Branch near Rosedale (4.02 sq mi)	1956–59, 1969	5.4	560	139
Stony Brook Tributary No. 3 near Hopewell (2.57 sq mi)	1956–57, 1970	.7	73	28
Baldwin Creek at Pennington (1.92 sq mi)	1956–59, 1968	7.5	779	405
Woodsville Brook at Woodsville (1.86 sq mi)	1956–58, 1970	4.9	509	273

SEDIMENT-RETENTION RESERVOIRS

Seven small reservoirs were constructed in the basin by the USSCS between 1958 and 1969. Each reservoir was designed to retain a large amount of the transported sediments normally carried downstream. The location of these sites is shown in figure 9.

A listing of the storage, drainage area, and approximate completion date is given in table 5. The drainage area above these reservoirs is 14.2 sq mi, or roughly 25 percent of the basin's drainage area. The USSCS estimated that these reservoirs would reduce the amount of sediment transported from the entire basin by 61 percent (M. P. Crooks, written commun., 1960).

TABLE 5.—*Descriptive data on retention reservoirs*

Site (fig. 9)	Reservoir name	Storage (acre-ft)	Drainage area (acres)	Percent of basin drainage area	Completion date
2	Willow Lake	16	256	0.89	Aug. 1959
4	Curliss Lake	107	1,088	3.82	Sept. 1960
7	Hunt Lake	43	422	1.48	Sept. 1960
11A	Amwell Lake	47	595	2.09	Jan. 1962
5	Baldwin Lake	77	1,609	5.69	Jan. 1964
14	Honey Lake	125	2,260	7.94	Dec. 1964
3	Johnson Lake	69	932	3.27	Oct. 1969

One of these P.L. 566 retention reservoirs, Baldwin Lake, was selected for a sediment-trap efficiency investigation. This lake (site 5, fig. 9), built in 1960 and modified slightly in 1962, is about 1 mile north of Pennington. Daily records of suspended-sediment discharge were collected at the lake overflow outlet (drainage area 2.52 sq mi) between October 1962 and July 1969. Monthly and annual sediment loads at this station are summarized in table 6. In addition, storm-sediment data were collected at a point upstream from the lake, drainage area of 1.92 sq mi.

As part of the trap-efficiency study, topographic surveys of the lake bottom were completed in 1960 and 1964. Because the lake was drained and modified in 1962, comparison of these surveys cannot be used to define the lake's trap efficiency accurately. The USSCS currently (1972) plans similar surveys periodically, at least every 5 years. Upon completion of additional surveys, it will be possible to determine the volume of sediment deposited in the reservoir. However, it is possible to estimate the lake's trap efficiency by the techniques described in the next paragraph.

Computations, based on 1962–69 records, indicate a sediment discharge from Baldwin Lake of about 117 tons per year, or an annual sediment yield downstream of approximately 46 tons per sq mi. When compared to the average annual yield of Baldwin Creek before reservoir construction (about 433 tons per sq mi), a reservoir-trap efficiency of 89 percent is indicated. Assuming all P.L. 566 reservoirs are equally efficient, the result should be a reduction in sediment yield into Carnegie Lake of about 20 percent. However, a greater percentage reduction would be expected,

TABLE 6.—*Suspended-sediment discharges, in tons, Baldwin Creek at Baldwin Lake, near Pennington*

Year	Jan.	Feb.	Mar.	Apr.	May	June	July
1962	---	---	---	---	---	---	---
1963	6.1	17.7	34.2	1.0	0.3	.1	0.0
1964	31.7	5.6	5.9	12.8	1.4	.0	1.1
1965	2.7	13.8	14.3	2.8	.2	.0	.0
1966	.8	50.7	20.4	.5	3.5	.3	.0
1967	21.1	7.7	91.8	2.0	7.7	1.0	15.7
1968	6.4	2.7	58.4	2.1	50.9	27.2	.1
1969	8.4	1.8	47.0	4.0	1.2	.4	32.2

Year	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1962	----	----	0.0	9.5	8.4	----
1963	0.0	0.0	.0	11.6	2.6	73.6
1964	.0	.0	.3	.5	15.2	74.5
1965	.7	.5	.2	.1	.2	35.5
1966	.0	3.3	40.2	1.8	4.3	125.8
1967	16.4	.9	1.5	1.3	71.6	238.7
1968	.0	.0	.0	1.3	4.5	153.6

as these reservoirs are in areas of potentially high sediment yields. These computations assume that the period of sediment-discharge records from Baldwin Lake are representative of the average, that the average annual yield from the basin before construction has not significantly changed, and that all reservoirs are equally efficient. Also, the average-annual yield for the Baldwin Creek basin before reservoir construction was developed on the basis of comparatively few storm data. The 89 percent reduction value may be high in that the period of sediment-discharge records (1962–69) on Baldwin Lake includes 5 years of extreme drought (1962–66), with resultant lower than normal sediment discharges.

As these reservoirs fill with sediment their efficiency can be expected to decrease. Also, because a stream has a certain inherent capacity to carry sediments, some material from the channel and banks will be picked up by the stream below these reservoirs, reducing the reported efficiency of the reservoirs. In addition, as additional areas of the basin are urbanized, an increase in impervious areas will result in increased runoff and cause channel enlargement. This will probably result in increased sediment transport below the P.L. 566 reservoirs.

SEDIMENT-PARTICLE SIZE

Analyses were made on several occasions to determine the particle-size distribution of suspended sediments in Stony Brook. Samples were collected during periods when direct runoff constituted most of the flow and when suspended-sediment concentrations were relatively high. As most of the sediment is transported during storms, these samples closely represent the size distribution of a large percentage of the suspended sediment transported annually.

Samples of suspended sediment collected at Princeton and analyzed for particle-size distribution were compared by relating each size distribtuion to its corresponding water discharge and then grouping the discharge into three ranges by using the streamflow duration curve in figure 4: those discharges expected to be equaled or exceeded 0.1 percent of the time or less; those expected between 0.1 and 1.0 percent of the time; and those expected between 1.0 and 10 percent of the time. The average particle-size distributions for these three streamflow duration ranges are illustrated in figure 11. The American Geophysical Union's classification of particle size is used in this illustration (Lane and others, 1947).

Comparison of the curves in this illustration indicate some interesting variations in particle size with changing flow frequency. Amounts of material in each class of samples collected during flow duration of less than 0.1 percent and 0.1–1.0 percent are approximately identical; roughly 40 percent clay, greater than 55 percent silt, and minor amounts of sand. Distributions at durations of 1.0–10 percent have higher clay sizes (50 percent) and lower silt sizes (45 percent). Clay and silt predominate in all samples and make up 96–99 percent of this suspended-material transported. Transport of sand sizes increases somewhat at lower duration, that is, at higher flows.

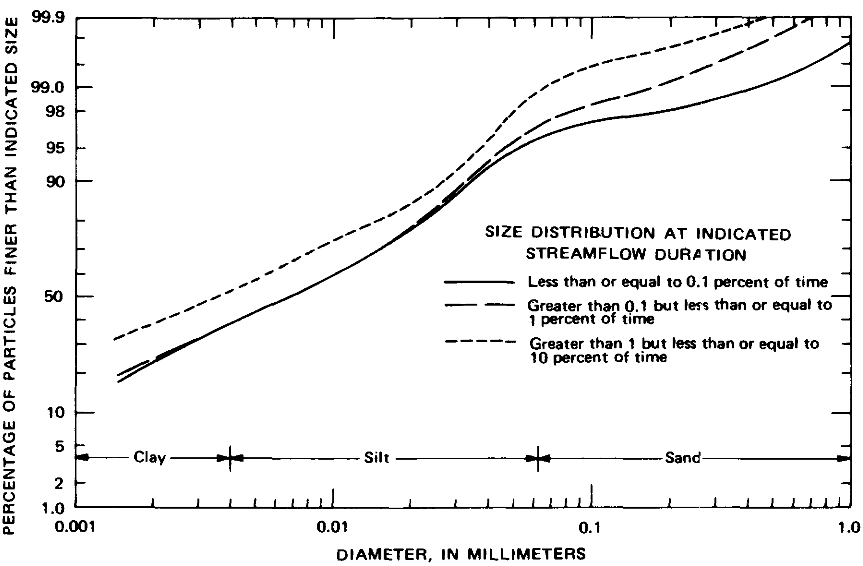


FIGURE 11.—Average particle-size distribution of suspended sediment, Stony Brook at Princeton.

In addition, samples of lakebed material were collected in April 1959 at several points for subsequent particle-size analysis. The purpose of this sampling was to determine downstream variation in particle-size composition of the lake-deposited sediments. Results of these analyses are shown in table 7. The first two distributions listed in the table represent sediments composited from bed samples collected in Carnegie Lake above confluence with the Millstone River. The second pair of distributions represent lakebed samples collected below the river confluence. There is little difference between particle-size distributions for the two pairs of samples.

TABLE 7.—*Particle-size distribution of sediments deposited in Carnegie Lake at Princeton*

	Percentage of sample finer than indicated size (mm)						
	Clay		Silt		Sand		
	0.002	0.004	0.008	0.016	0.032	0.062	0.125
Above confluence	16	26	48	63	88	97	99
	15	29	47	65	80	90	92
Below confluence	11	24	45	62	81	97	99
	10	23	37	54	67	87	90

Praeger, Kavanagh, and Waterbury (1968) reported analyses of material collected in January 1968 from the "upper" and "lower" layers of Carnegie Lake. The percentage of material in each soil class is:

	Clay	*Silt*	*Sand*
Upper layer	25	70	5
Lower layer	22	72	6

These compare closely to those collected in April 1959 (table 7).

Average particle-size composition of suspended-sediment samples collected from Stony Brook at Princeton indicates 3 percent sand, 53 percent silt, and 44 percent clay. The average composition of sediments deposited in Carnegie Lake (table 7) was found to be 7 percent sand, 68 percent silt, and 25 percent clay. These data show slightly higher percentages of sand (which may be due to high sand content in sediments transported by the Millstone River, which drains Coastal Plain sediments) and somewhat smaller percentages of clay in the deposited sediments. Some of the very fine sediments transported into the reservoir are probably not deposited, but are carried over the dam. In part, this explains the differences between the composition of the suspended and deposited sediments.

CHEMICAL QUALITY

In general, streams draining the basin are similar in chemical characteristics. The alkaline earths, calcium and magnesium, are the predominant cations, making up 70–90 percent of the total. Calcium-magnesium hardness usually ranges in pH from 6.7–8.1. The waters are neutral to alkaline, ranging in pH from 6.7–8.1. Anions associated with strong acids, sulfate, chloride, fluoride, and nitrate, predominate, making up 50–70 percent of the total. Of these, sulfate is found in larger amounts. This may be attributed to weathering of gypsum and red shale. Alkalinity, almost always bicarbonate, makes up the remaining 30–50 percent of the total anions. Dissolved solids generally range from 100 to 250 mg/l.

Results of six spectrographic analyses of water samples collected at Princeton for trace elements were recently reported by Anderson (1970). A summary of the maximum and minimum value observed in these samples for several elements is listed below. In addition to those listed, the following elements were

Element	*Range* ($\mu g/l$)
Aluminum	15 –900
Barium	25 – 70
Boron	29 – 90
Chromium	.3– 4.0
Copper	2.0– 28
Lead	.7– 7.0
Lithium	.4– 5.0
Molybdenum	.0– 3.0
Nickel	3.0– 7.0
Rubidium	1.0– 7.0
Strontium	60 –320
Titanium	1.0– 19
Vanadium	.0– 6.0

sought, but were not observed in analyzable quantities: beryllium, bismuth, cadmium, cobalt, gallium, germanium, silver, tin, zinc, and zirconium. In general, iron concentrations were less than 500 μg/l (micrograms per liter) and manganese less than 150 μg/l. Comparison of these analytical results with others in the State produced no anomalies.

In addition to chemical and spectrographic analyses of water samples, special samples were collected in the fall of 1967 and the spring of 1968. Water and bed-material samples were collected at the gaging station and at three points in Carnegie Lake. The samples were analyzed for 10 chlorinated hydrocarbon pesticides, and the results are summarized in table 8. The data indicate the presence of several chlorinated hydrocarbon insecticides.

TABLE 8.—*Pesticide analyses of water and bed samples collected from Stony Brook and Carnegie Lake at Princeton, 1967–68*

Date	Aldrin	DDD	DDE	DDT	Dieldrin	Endrin	Heptachlor	Lindane
WATER SAMPLES [Results in micrograms per liter]								
01–4010.00 Stony Brook at Princeton, N.J.								
09-15-67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
05-20-68	.00	.01	.01	.03	.01	.00	.00	.01
Carnegie Lake at Princeton, N.J. (boathouse)								
09-15-67	0.00	0.02	0.00	0.02	0.01	0.00	0.00	0.00
05-20-68	.00	.04	.08	.25	.00	.00	.00	.00
Carnegie Lake at Princeton, N.J. (below Millstone River confluence)								
09-15-67	0.00	0.01	0.00	0.00	0.03	0.00	0.00	0.00
05-20-68	.00	.03	.05	.01	.20	.00	.00	.00
Carnegie Lake at Princeton, N.J. (0.25 mile above dam)								
09-15-67	0.00	0.01	0.00	0.01	0.03	0.00	0.00	0.00
05-20-68	.00	.01	.02	.01	.10	.00	.00	.01
BED SAMPLES [Results in micrograms per kilogram]								
01–4010.00 Stony Brook at Princeton, N.J.								
09-15-67	0.00	5.0	2.0	20	0.00	0.00	0.00	0.00
05-20-68	.00	2.0	.5	5.0	.00	.00	.00	.00
Carnegie Lake at Princeton, N.J. (boathouse)								
09-15-67	0.00	115	3.0	45	0.00	0.00	0.00	0.00
05-20-68	.00	200	15	75	.00	.00	.00	.00
Carnegie Lake at Princeton, N.J. (below Millstone River confluence)								
09-15-67	0.00	110	2.0	25	0.00	0.00	0.00	0.00
05-20-68	.00	45	6.0	11	.00	.00	.00	.00
Carnegie Lake at Princeton, N.J. (0.25 mile above dam)								
09-15-67	0.00	55	3.0	15	0.00	0.00	0.00	0.00
05-20-68	.00	40	4.0	8.0	.00	.00	.00	.00

The water-phase data indicate the presence of the DDT and its metabolites, DDD and DDE and some dieldrin and lindane. Concentrations seem to be slightly higher in samples collected in the spring than those in the fall, perhaps indicating an input from agricultural usage.

The bed-material data indicate only the presence of the DDT family. Data collected during the spring show concentrations at one site (boathouse) increasing in the amount of DDT-type compounds in relation to fall samples, while decreasing at the other three sites. The reason for this is unclear, but may be related to sampling techniques or bed movement. Values in the Carnegie Lake samples represent an average concentration greater than one thousand times the levels observed in the water phase for the DDD and DDT components. The high concentrations of DDD may result from the degradation of DDT. These data indicate a situation where DDT entered the water medium at a time in the past, but ended up in the sediments as a persistent residue. There undoubtedly has been a buildup over a time period, but the absence of previous data precludes any quantitative conclusion.

SUMMARY AND CONCLUSIONS

The Stony Brook basin drains part of the Piedmont Lowland section of the Piedmont physiographic province in west-central New Jersey. This section has been described (Anderson and George, 1966) as the State's heaviest nonurban sediment producer. Cooperating agencies determined that it was necessary to identify the source, magnitude, and trend of sediment transported in and from the basin and to describe the effect of land-management practices, urban growth, and development of seven P.L. 566 retention reservoirs on the sediment yield from the basin.

Observation of sediment yield at Princeton (table 3) and at 5 subbasin sampling sites (table 4) range from roughly 25 to 400 tons per sq mi. During 1956–70, about 127,000 tons of suspended sediment was transported by Stony Brook into Carnegie Lake at an annual rate of about 8,800 tons, or 200 tons per sq mi. About 90 percent of this material, which consists of 40 percent clay, 55 percent silt, and 5 percent sand, was carried during storms that transported at least 1 ton of suspended sediment from the basin.

Land use has changed in two prominent ways: an increase in the percentage of idle land and cash-crop farming and an increase in urbanization. Based on surveys made in 1957 and 1970, there was a 0.5 percent net increase of idle land, nearly a 5 percent decrease in farmlands, and a 4.6 percent increase in urban land. Increases in idle areas were mainly in the northwestern part of the basin. Farmlands have decreased over the entire basin, but mostly in the western part. The basin is being urbanized throughout, but somewhat more rapidly south of Hopewell and west of Princeton.

Trend analyses indicate that a greater suspended-sediment load was transported by the Stony Brook at Princeton during the earlier years of this investigation (1956–61) than during the more recent years (1967–70). Also, in a multiple-regression analysis of the same data, the partial-regression coefficient for a particular storm was found to be negative, thus indicating that sediment concentration decreased with increasing period of sediment record. These analyses can be interpreted as evidence of a trend toward decreasing sediment load per unit discharge with time.

An upward trend in sediment discharge at Princeton, during the early period investigated (1956–61), is probably the consequence of farming, highway construction, reservoir construction, and urbanization. Earth moving related to highway and reservoir construction and to developing urban areas is a potential source of higher sediment yields. Similarly, the continued reworking of the land surface by farming together with a general lack of cover-crop practices, particularly in areas where cash-cropping prevails, also is a potential source of increased erosion and sediment transport. Construction of three of seven P.L. 566 sediment-retention reservoirs prior to 1961 exposed soils to erosion and increased the potential for sediment transport. The influence of these and other factors probably explains the upward trend noted in the 1956–61 period.

During the later period (1967–70), sediment discharge per unit water discharge decreased. The decrease can be attributed to several factors. Exposure of soils through earth moving associated with construction and during developmental phases of urban areas generally results in temporary high sediment yields. When this stage has passed, an area becomes relatively stable and sediment yields become lower. An economic slowdown in construction and urban development during this period certainly contributed to this downward trend. Also, while temporary local increases in sediment yields can be attributed to the construction of one P.L. 566 sediment-retention reservoir in 1968–69, the combined operation of six completed reservoirs, based on a trap-efficiency study of one, Baldwin Lake, is estimated to reduce sediment discharge at Princeton by 20 percent.

Interpretation of trends in sediment discharge during 1962–66 is extremely difficult, complicated by the installation of three reservoirs, continued land-use changes, and a drought. Although it was not possible to separate the influences of reservoir construction and urbanization, they undoubtedly produced higher than normal sediment yields. Concurrently, sediment discharges at Princeton were reduced almost tenfold, from 11,121 tons in 1961 to 1,625 tons in 1965, during the drought. The total effect of these factors complicated the interpretation of sediment trends.

The drought is over, as is the economic slowdown. Whether the downward trend in sediment discharge continues remains to be determined. It seems likely, however, that completion of the sediment-detention reservoirs, together with the technical knowledge now available for sediment and erosion control, will work together for reduction of sediment discharge.

Calcium sulfate type water predominates in the basin's streams. Dissolved-solids content ranges from 100 to 250 mg/l, hardness from 75 to 200 mg/l, and pH from 6.7 to 8.1. Spectrographic analyses indicate trace amounts of aluminum, barium, boron, chromium, copper, iron, lead, lithium, manganese, molybdenum, nickel, rubidium, strontium, titanium, and vanadium in addition to those elements routinely measured in chemical analyses, including sodium, potassium, calcium, magnesium, bicarbonate, sulfate, chloride, and nitrate. Results of analyses for 10 chlorinated hydrocarbon insecticides also are given. In general, higher amounts of these insecticides, principally members of the DDT family, were observed in water during a spring sampling period, perhaps indicating agricultural input, and in the bottom sediments during both spring and fall samplings, indicating that pesticides are persistent in bottom sediments. However, dredging, scouring during high-flow periods, or other disturbance of bed materials are likely to move bottom sediments.

REFERENCES

Anderson, P. W., 1970, Occurrence and distribution of trace elements in New Jersey streams: New Jersey Div. of Water Policy and Supply, Water Resources Circ. 24, 24 p.

Anderson, P. W., and George, J. R., 1966, Water-quality characteristics of New Jersey streams: U.S. Geol. Survey Water-Supply Paper 1819–G, 48 p.

Anderson, P. W., and McCall, J. E., 1968, Urbanization's effect on sediment yield in New Jersey: Jour. Soil and Water Conserv., v. 23, no. 4, p. 142–144.

Bascom, F., and others, 1909, Description of the Trenton quadrangle [New Jersey-Pennsylvania]: U.S. Geol. Survey Geol. Atlas, Folio 167.

Colby, B. R., 1956, Relationship of sediment discharge to streamflow: U.S. Geol. Survey open-file rept., 170 p.

Davis, S. N., and DeWiest, R. J. M., 1967, Hydrogeology: New York, John Wiley and Sons, 463 p.

George, J. R., 1963, Sedimentation in the Stony Brook basin, New Jersey, 1956–59: U.S. Geol. Survey open-file rept., 71 p.

Guy, H. P., 1957, The trend of suspended-sediment discharge of the Brandywine Creek at Wilmington, Delaware, 1947–55: U.S. Geol. Survey open-file rept., 55 p.

——— 1964, Analysis of storm-period variables affecting stream sediment transport: U.S. Geol. Survey Prof. Paper 462–E, 46 p.

Lane, E. W., and others, 1947, Report of the subcommittee on sediment terminology: Am. Geophys. Union Trans., v. 28, no. 6, p. 936–938.

Mansue, L. J, 1970, Sediment yields as affected by land use and retention practices: Am. Soc. Agr. Engrs., Proc. Annual Meeting.

Moore, W. R., Ferris, H. J., and Koszchyn, J., 1952, Report on sedimentation in Carnegie Lake, Princeton, New Jersey: U.S. Soil Conserv. Service Rept. SCS–TP–109, 20 p.

Palmer, A. C., and others, 1957, A regional planning plot study of the Millstone watershed: Rutgers Plan. Service, 83 p.

Praeger, Kavanagh, and Waterbury, 1968, Supplementary report of proposed restoration of Carnegie Lake, Princeton, New Jersey: New York, Praeger, Kavanagh, and Waterbury Consultants, 13 p.

Searcy, J. K., and Hardison, C. H., 1960, Double-mass curves, U.S. Geol. Survey Water-Supply Paper 1541–B, p. 31–66.

Stony Brook-Millstone Watersheds Association and other Sponsoring Organications, 1956, Work plan agreements for the Stony Brook watershed: Stony Brook-Millstone Watersheds Association, 45 p.

U.S. Geological Survey, 1967, Engineering geology of the northeast corridor, Washington, D.C., to Boston, Massachusetts, Bedrock geology: U.S. Geol. Survey Misc. Geol. Inv. Map I–514–A, Sheet 3.

U.S. Soil Conservation Service, 1953, Land-capability class (New Jersey): U.S. Dept. Agriculture, Sheet nos. 1–7.

——— 1959, Report of sedimentation study on Carnegie Lake, Princeton, New Jersey: U.S. Dept. Agriculture, 3 p.

U.S. Weather Bureau, 1963, Climatography of the United States: U.S. Dept. of Commerce, no. 84, p. 181.

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