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SUSPENDED-SEDIMENT YIELDS OF NEW JERSEY COASTAL PLAIN STREAMS DRAINING INTO THE DELAWARE ESTUARY

By

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ABSTRACT

Suspended sediment transported by streams draining into the Delaware estuary and Bay from New Jersey is related to areal variations in geology, physiography, and land use. It is estimated that sediment contribution from the Delaware River mainstem is 700,000 tons per year; that of streams draining the Inner Coastal Plain, 200,000 tons per year; and that of streams draining the Outer Coastal Plain, 9,000 tons per year. Thus, of the approximate 910,000 tons per year transported into the Delaware estuary and Bay, roughly 20 percent is contributed by the Coastal Plain tributaries.

INTRODUCTION

An investigation was begun in 1965 by the U.S. Geological Survey in cooperation with the U.S. Army, Corps of Engineers, Philadelphia District to meet the Corps' need for information on sediment transport in the Delaware River basin in relation to the maintenance of navigable channels in the river's estuarine areas. Sediment records were needed by the Corps to identify the principal sources and amounts of suspended sediment transported by New Jersey tributary streams into these estuarine areas.

In order to meet the project's objective, a daily sediment-sampling program at streamflow-gaging stations on Crosswicks Creek, Cooper River, Maurice River, and Raccoon Creek was established. Because of protracted drought, which resulted in unusually low sediment discharges, the period of data collection at these daily stations was extended. Upon reviewing these records, three partial-record stations were established on the Pennsauken, Big Timber, and Mantua Creeks in 1970 to complete the areal coverage. Records at two additional stations, Delaware River at Trenton and McDonalds Branch in Lebanon State Forest, collected as part of other cooperative projects were available also for use in this study.

The purpose of this report is to summarize sediment data collected at selected stream-sampling sites in southern New Jersey. Computations of excepted average annual yields at each sampling site were made and utilized to estimate the annual yield at ungaged sites. Similar data currently are being compiled for streams draining Pennsylvania and Delaware. It is planned to report on the combined information at a later date in the Geological Survey's Water-Supply Paper series.

DEFINITION OF TERMS

Terms related to water-quality and hydrologic data, as used in this report, are defined as follows:

Bed load or sediment discharged as bed load is the discharge of the shifting portion of fragmented alluvial material that moves close to the streambed and is not in suspension.

Cubic foot per second (cfs, CFS) is the rate of discharge representing a volume of 1 cubic foot passing a given point during 1 second and is equivalent to 7.48 gallons per second or 448.8 gallons per minute.

Daily-record station is a particular site where continuous streamflow or once-daily water-quality data are collected or calculated systematically over a period of years for use in hydrologic analyses.

Discharge is the volume of water (or more broadly, total fluids), that passes a given point within a given period of time.

Mean discharge is the arithmetic mean of individual daily mean discharges during a specific period.

Instantaneous discharge is the discharge at a particular instant of time.

Drainage area of a stream at a specified location is that area, measured in a horizontal plane, enclosed by a topographic divide from which direct surface runoff from precipitation normally drains by gravity into the river above the specified point.

Gaging station is a particular site on a stream, canal, lake, or reservoir where systematic observations of gage height or discharge are obtained.

Milligrams per liter (mg/l, MG/L) is a unit for expressing the concentration of constituents in solution. Concentration of suspended sediment is expressed in milligrams per liter, and is based on the weight of sediment per liter of water-sediment mixture. Sedimentation methods (pipet, bottom-withdrawal tube, visual-accumulation tube) determine fall diameter of particles in either distilled water (chemically dispersed) or in native water (the river water at the time and point of sampling) (Guy, 1969).

Partial-record station is a particular site where limited streamflow or water-quality data are collected systematically over a period of years for use in hydrologic analyses.

Particle size is the diameter, in millimeters (mm), of suspended sediment or bed material determined either by sieve or sedimentation methods.

Particle-size classification, used in this report agrees with recommendations made by the American Geophysical Union Subcommittee on Sediment Terminology. The classification is as follows:

Clay:	Between 0.00024 and 0.004 mm.
Silt:	Between 0.004 and 0.062 mm.
Sand:	Between 0.062 and 2.0 mm.
Gravel:	Between 2.0 and 64.0 mm.

The particle-size distributions given in this report are not necessarily representative of the particles in transport in the stream. Most of the organic matter is removed, and the sample is subjected to mechanical and chemical dispersion before analysis in distilled water. Chemical dispersion is not used for native-water analysis (Guy, 1969).

Sediment is solid material that originates mostly from disintegrated rocks and is transformed by, suspended in, or deposited from water; it includes chemical and biochemical precipitates and decomposed organic material such as humus. The quantity, characteristics, and cause of the occurrence of sediment in streams are influenced by environmental factors. Some major factors are degree of slope, length of slope, soil characteristics, land usage, and quantity and intensity of precipitation.

Suspended sediment is the sediment that at any given time is maintained in suspension by the upward components of turbulent currents or that exists in suspension as a colloid.

Suspended-sediment concentration is the velocity-weighted concentration of suspended sediment in the sampled zone (from the water surface to a point approximately 0.3 feet above the bed) expressed as milligrams of dry sediment per liter of water-sediment mixture (mg/l).

Suspended-sediment discharge is the rate at which dry weight of sediment passes a section of stream or is the quantity of sediment, as measured by dry weight, or by volume, that is discharged in a given time. The rate, expressed in tons per day, is computed by multiplying cfs times mg/l times 0.0027.

Tons per day is the quantity of a substance in solution or suspension that passes a stream section during a 24-hour period.

GENERAL FEATURES OF STUDY AREA

The Delaware River and its tributary streams drain an area of 12,765 sq. mi. (square miles). That part of the basin in New Jersey, 2,345 sq. mi., is divided into two physiographic provinces (Parker and others, 1964) with markedly different topographic, geologic, and hydrologic characteristics. The two provinces are the Appalachian Highlands and Atlantic Plain (fig. 1). The Fall Line or boundary between these two provinces runs in nearly a straight line passing through Trenton and New Brunswick. The Appalachian Highlands is generally forested and characterized by ridges and valleys, plateaus, and mountains. The rock formations are structurally complex. Most streams have moderate to steep slopes. The Delaware River at Trenton represents the combined drainage into the estuary of streams draining this province. The Coastal Plain is an area of low relief lying southeast of the Fall Line. It consists of deposits of sand and gravel, silt, and unconsolidated clay overlying a buried bedrock. Its surface slopes gently, generally not exceeding 5-6 feet per mile. Stream-channel gradients are very flat, and at many places tidewater extends for considerable distances inland. The basin's drainage divide is within 10-30 miles of the mainstem Delaware River. Streams west of the divide drain into the Delaware River basin; those east, directly into the Atlantic Ocean.

SUSPENDED-SEDIMENT DISCHARGE

Suspended-sediment records were collected at five daily and four partial-record sampling sites (fig. 2) in the study area. Collection and analysis of samples were made in accordance with techniques described by Guy (1969) and Guy and Norman (1970). Descriptive material about sampling sites is presented on table 1.

Samples at daily stations were collected periodically when flows were uniform; at 2-hour intervals during storms, when flows were increasing rapidly; and at 4-6 hour intervals during periods of decreasing flow. Individual sample concentrations were plotted against time, and mean daily sediment concentrations were computed from these graphs. Mean daily concentration and streamflow were used to determine sediment discharge except for periods of rapidly changing flow, when a method of subdivision was used to compute sediment discharges.

Samples at partial-record stations normally were collected during high flows and occasionally during low flows. Sediment discharges were computed using streamflows estimated from water stage-discharge relations.

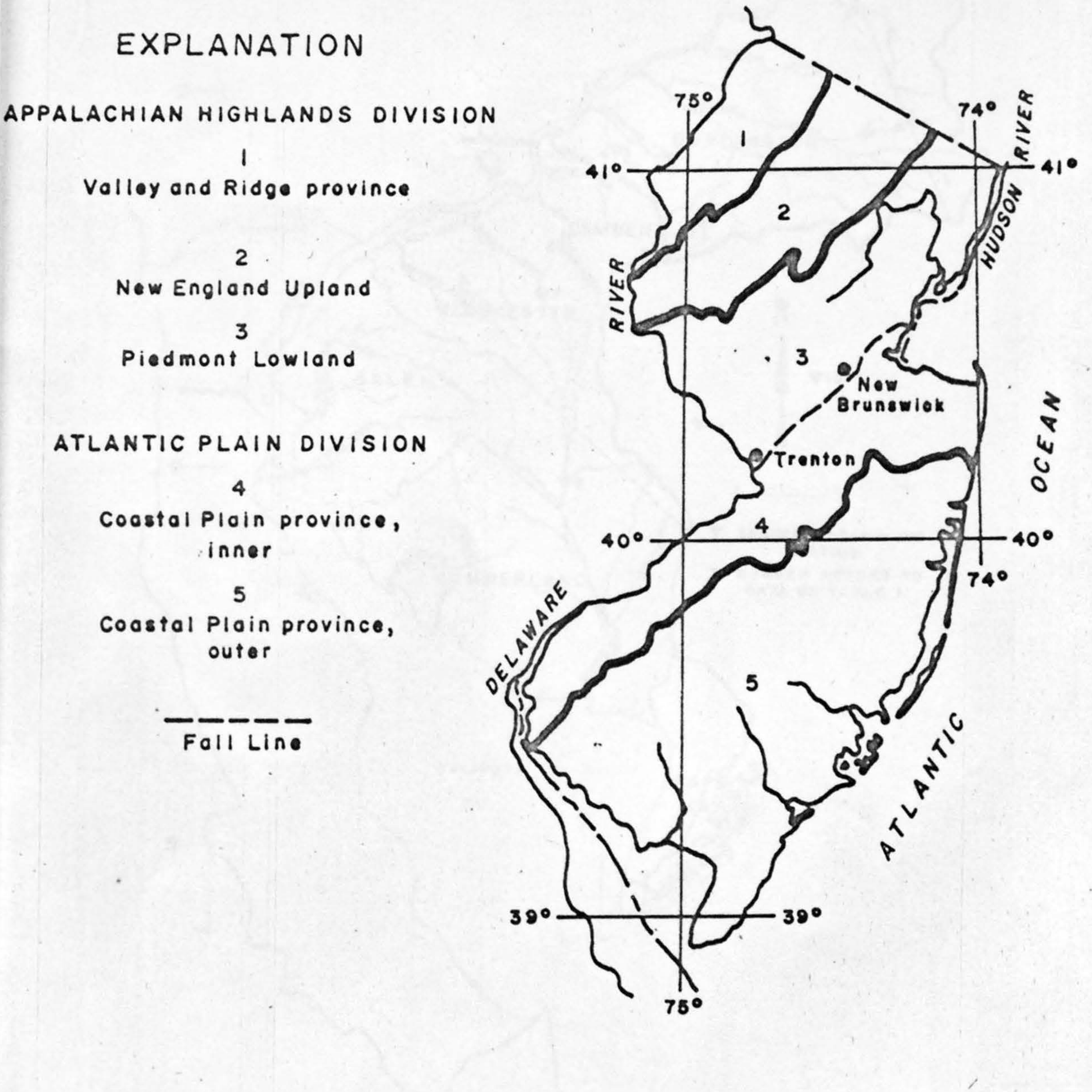

Figure 1.--Physiographic divisions of New Jersey, based on a map by Rogers (1955).

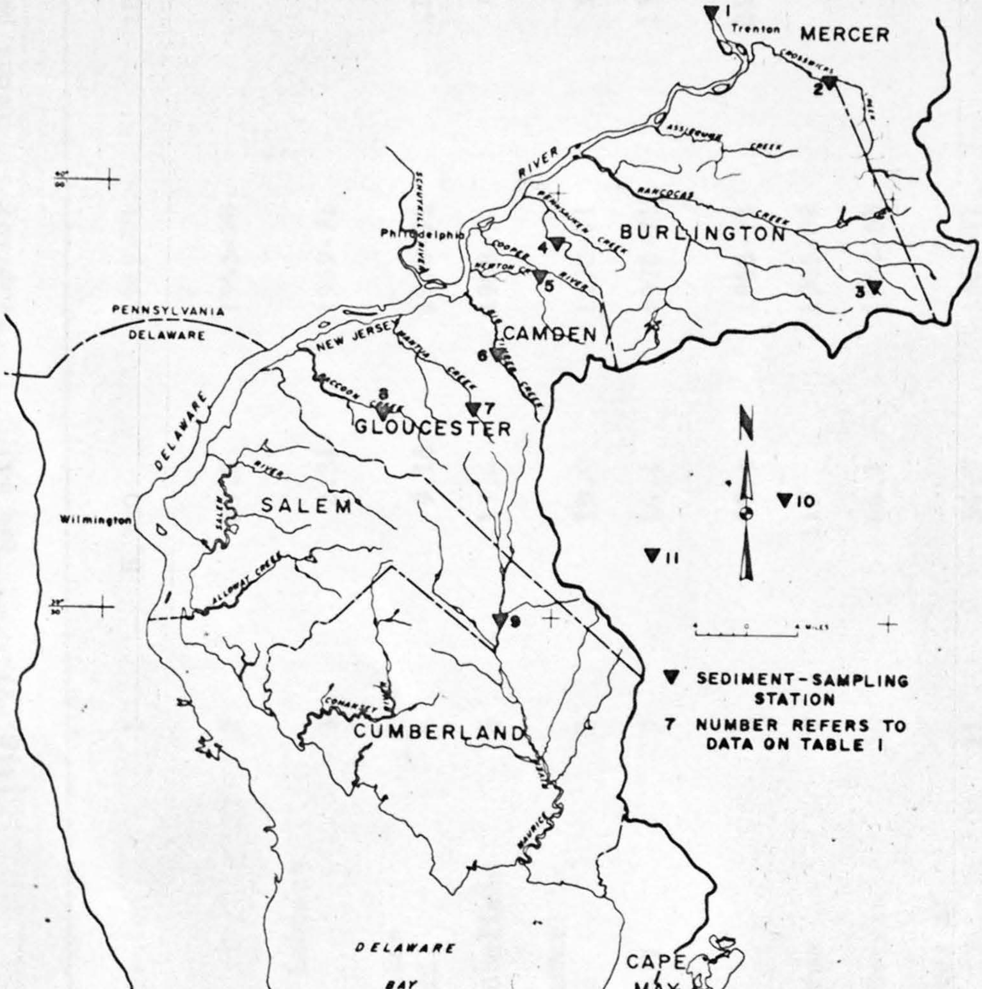

Figure 2.--Location of sediment-sampling stations in southern New Jersey.

Table 1.--Description of suspended-sediment sampling stations on the Delaware River at Trenton and on New Jersey Coastal Plain tributaries.

Station ident. no.	Stream and location	Map no. (fig. 2)	Drainage area (sq mi)	Period of sampling	Sediment yield (tons per sq mi)
01463500	Delaware River at Trenton	1	6,780	1949-71	104
01464500	Crosswicks Creek at Extonville	2	83.6	1965-70	94
01466500	McDonalds Branch in Lebanon State Forest	3	2.31	1969-71	5
01467080	South Branch Pennsauken Creek at Cherry Hill	4	9.16	1970-71	210
01467150	Cooper River at Haddonfield	5	17.4	1968-71	78
01467350	South Branch Big Timber Creek at Blackwood	6	19.0	1970-71	37
01475020	Mantua Creek at Sewell	7	14.4	1970-71	130
01477120	Raccoon Creek near Swedesboro	8	29.9	1966-71	210
01411500	Maurice River at Norma	9	113	1965-68	9
01409400	Mullica River near Batsto	10	46.1	1964-65	9
01411000	Great Egg Harbor River at Folsom	11	56.3	1965-71	6

Transport curves, which define the relation between streamflow nd sediment discharges, were developed for each station listed in able 1. Curves for Coastal Plain tributaries, based on plots of nstantaneous streamflow and sediment measurements, are illustrated on igure 3.

Sediment-transport and flow-duration curves were used, in general, to compute expected average annual sediment discharge using a technique described by Miller (1951). An example of the computational procedure is shown in table 2. Two assumptions are made in this method: (1) that the sediment-transport and flow-duration curves represent long-term relations; and (2) that the observed suspended-sediment discharge has the same relation to the concurrent flow measurement as that of the mean daily sediment and water discharge. Using this method, an expected average annual sediment load can be computed. The advantage is that only short periods of record are necessary.

Estimated annual yields (table 1) at the sediment stations were computed as follows:

1. The value of 104 tons per sq. mi. for the Delaware River at Trenton was computed by averaging observed annual sediment discharges. The 22 years of record (1949-70) at this station includes periods of major flooding, such as that which occurred in August 1955, and drought, 1962-66. The length of record and variability of flow are considered sufficient for computation of a long-term annual yield.

2. Sediment yields at other continuous streamflow-gaging stations were determined using streamflow-duration (Laskowski, 1970) and sediment-transport (fig. 3) curves.

3. Sediment yields at partial-record gaging stations were developed in a manner similar to that described in item 2 above, with the following exception. Flow durations were estimated by correlation of flow measured at the sampling site with long-term discharges observed at a nearby continuous gaging station.

In addition to the determination of sediment concentration and discharge, the particle-size distribution of sediments in selected samples was determined. Samples were collected generally near the peak of direct runoff. 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.

Tabulations of basic data on sediment concentration, sediment discharge, and particle-size analyses are reported by the U.S. Geological Survey (1966-72).

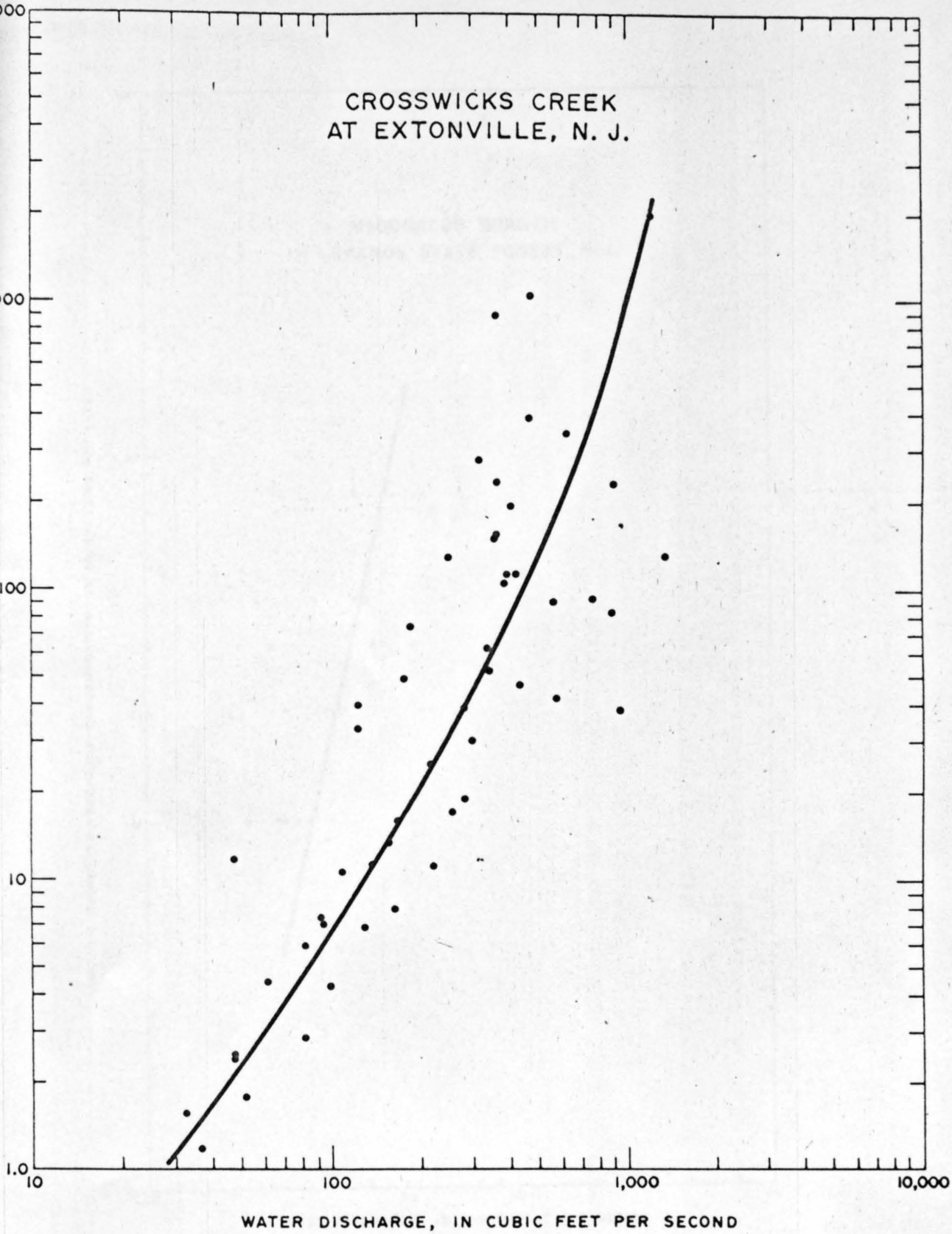

Figure 3.--Suspended-sediment transport curves for southern New Jersey sampling sites.

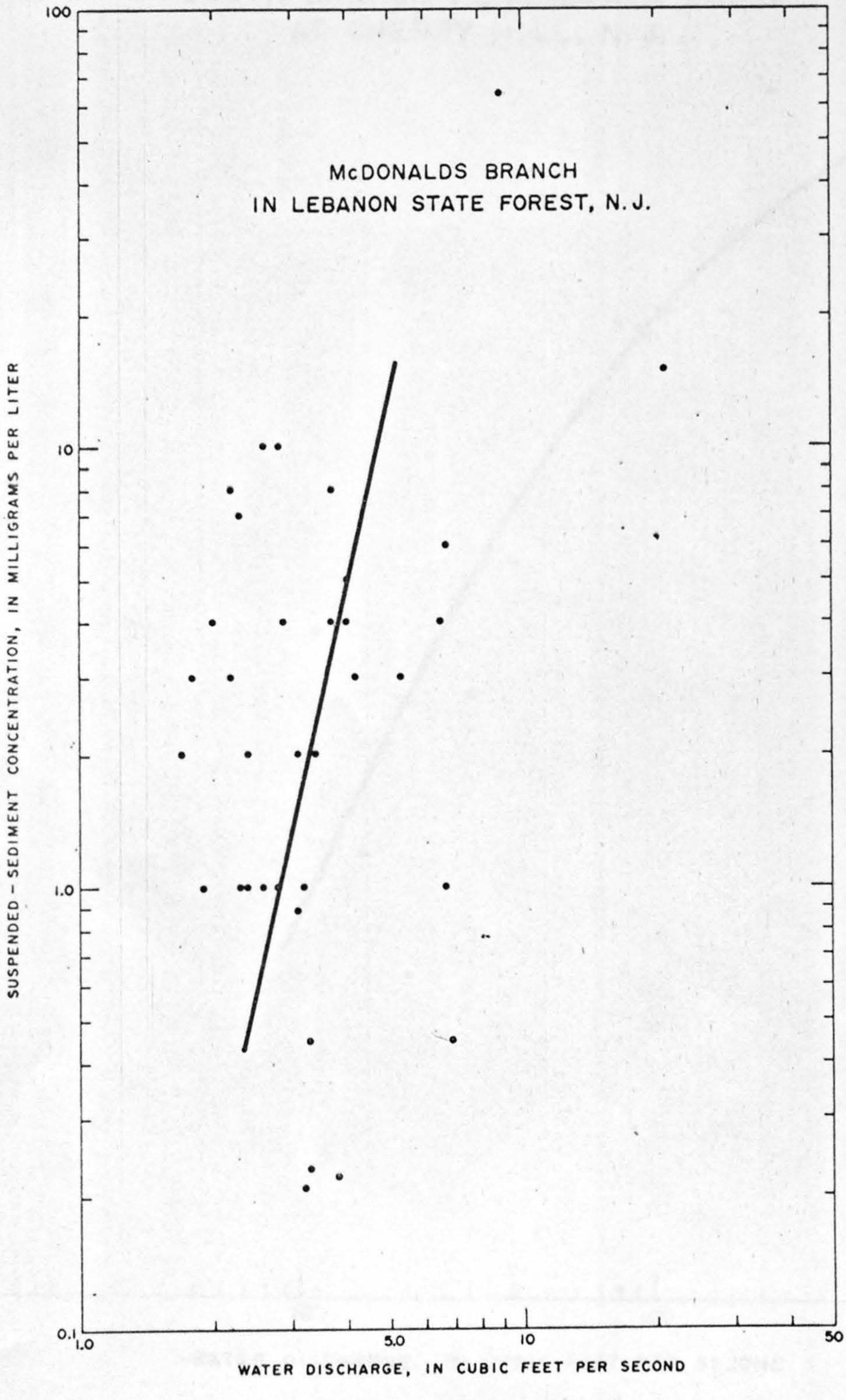

Figure 3.--Suspended-sediment transport curves for southern New Jersey sampling sites--Continued.

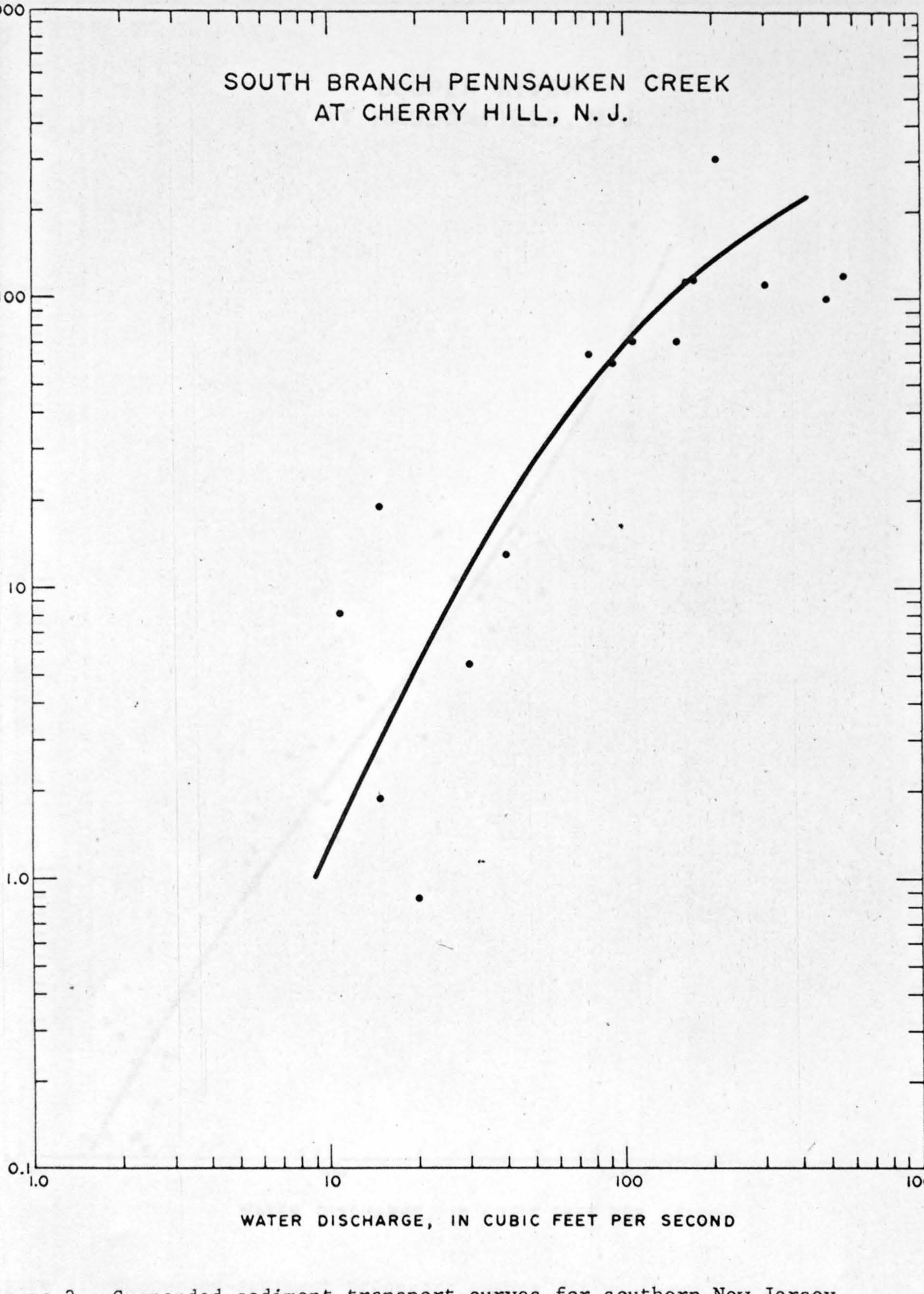

Figure 3.--Suspended-sediment transport curves for southern New Jersey sampling sites--Continued.

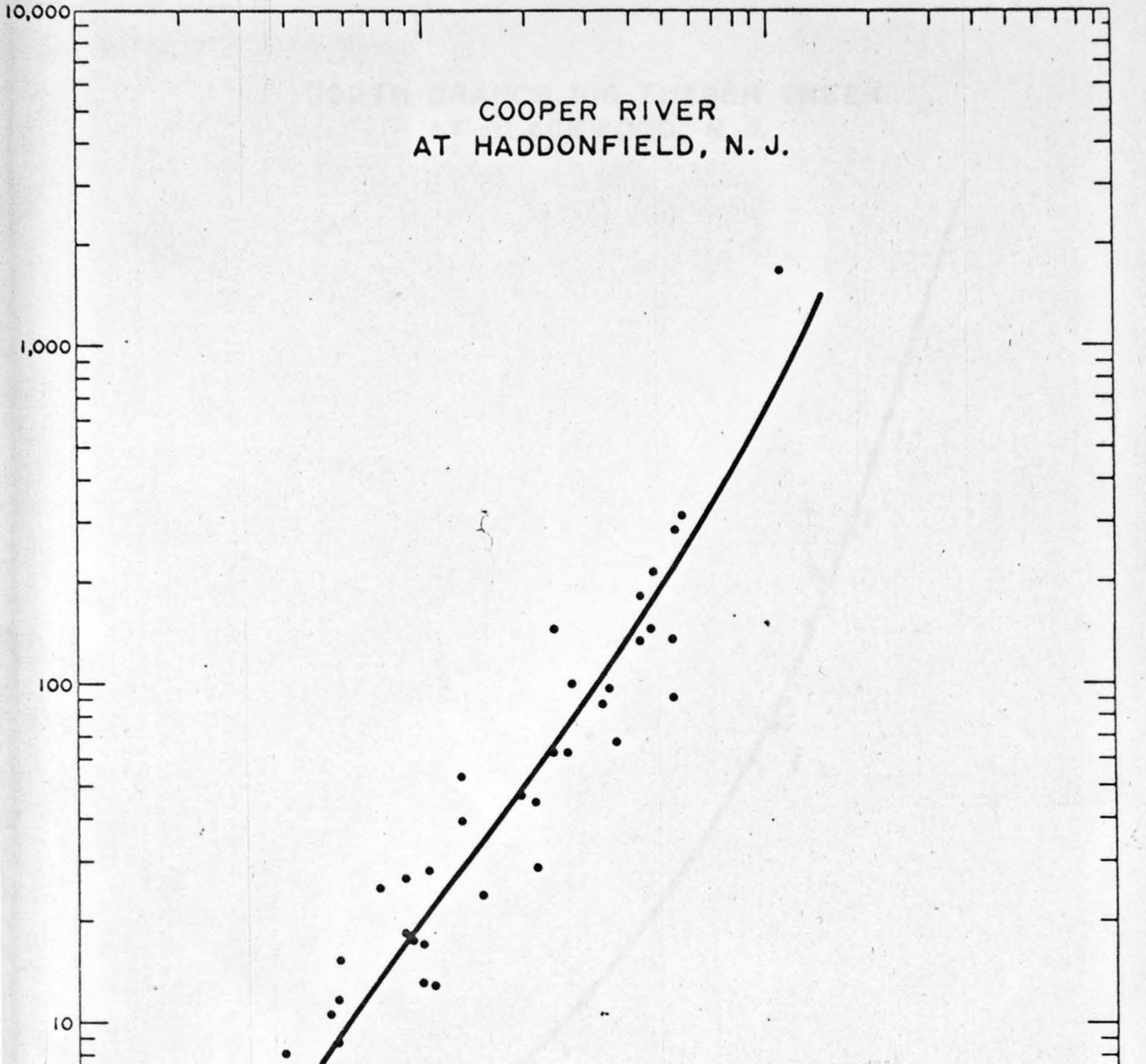

Figure 3.--Suspended-sediment transport curves for southern New Jersey sampling sites--Continued.

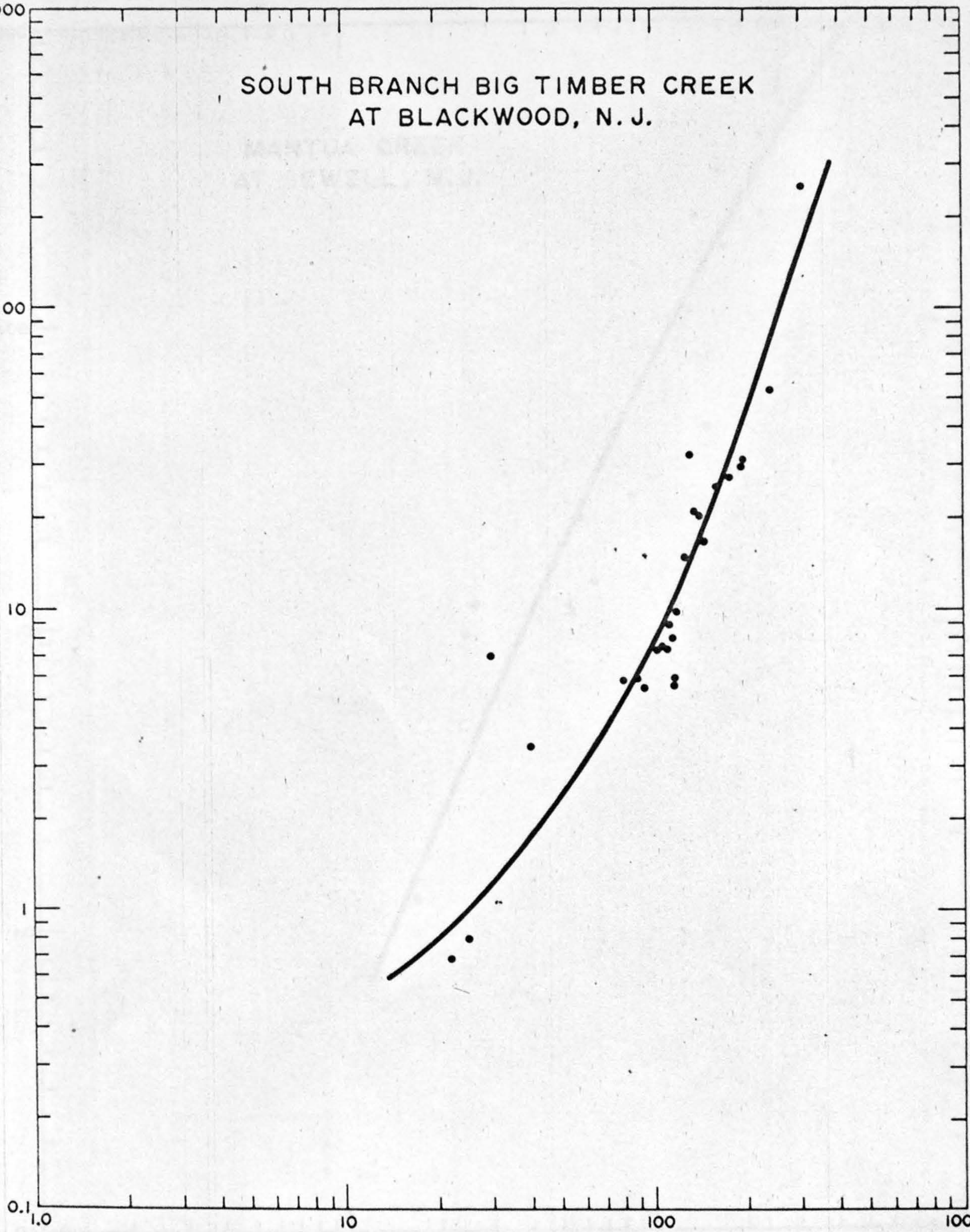

Figure 3.--Suspended-sediment transport curves for southern New Jersey sampling sites--Continued.

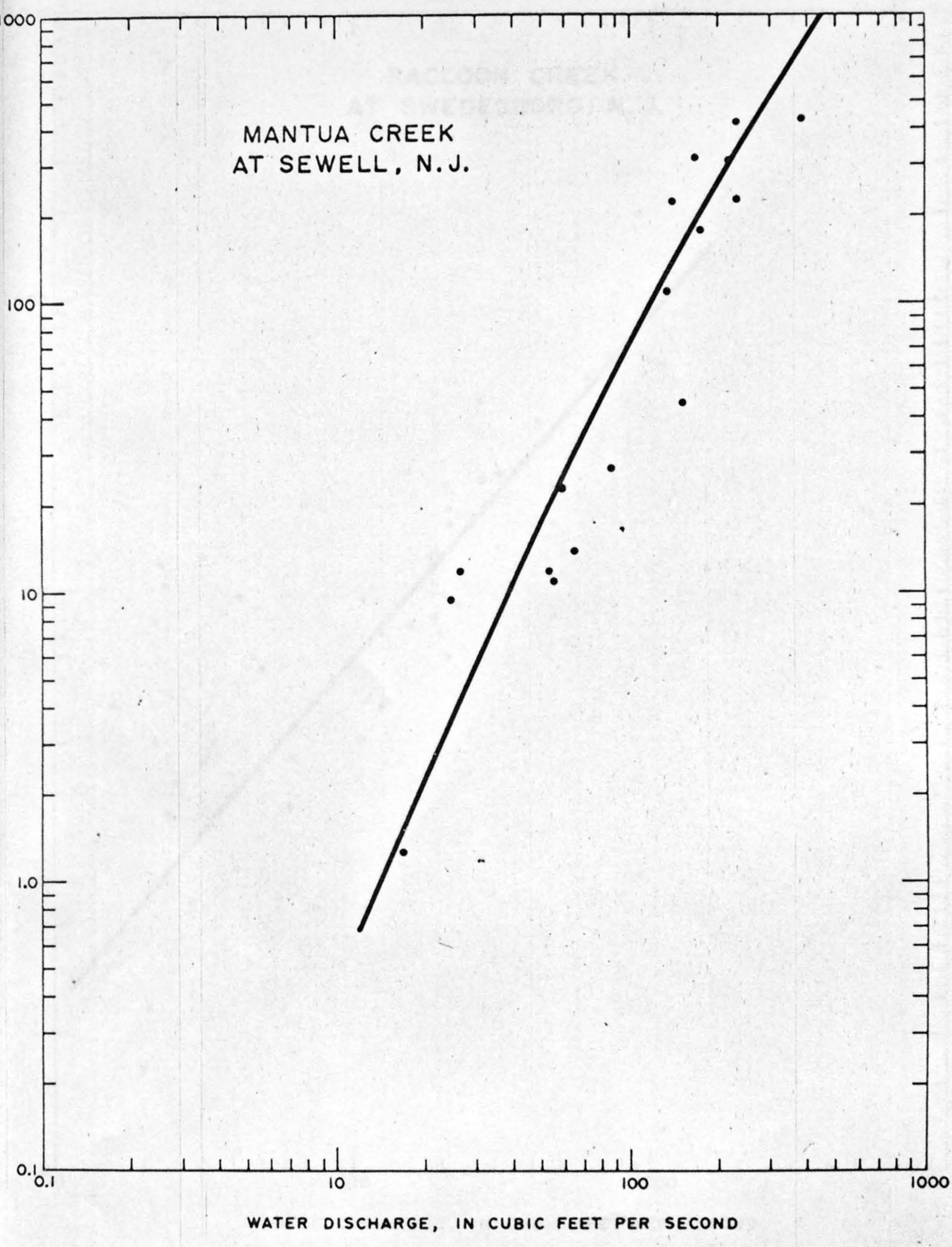

Figure 3.--Suspended-sediment transport curves for southern New Jersey sampling sites--Continued

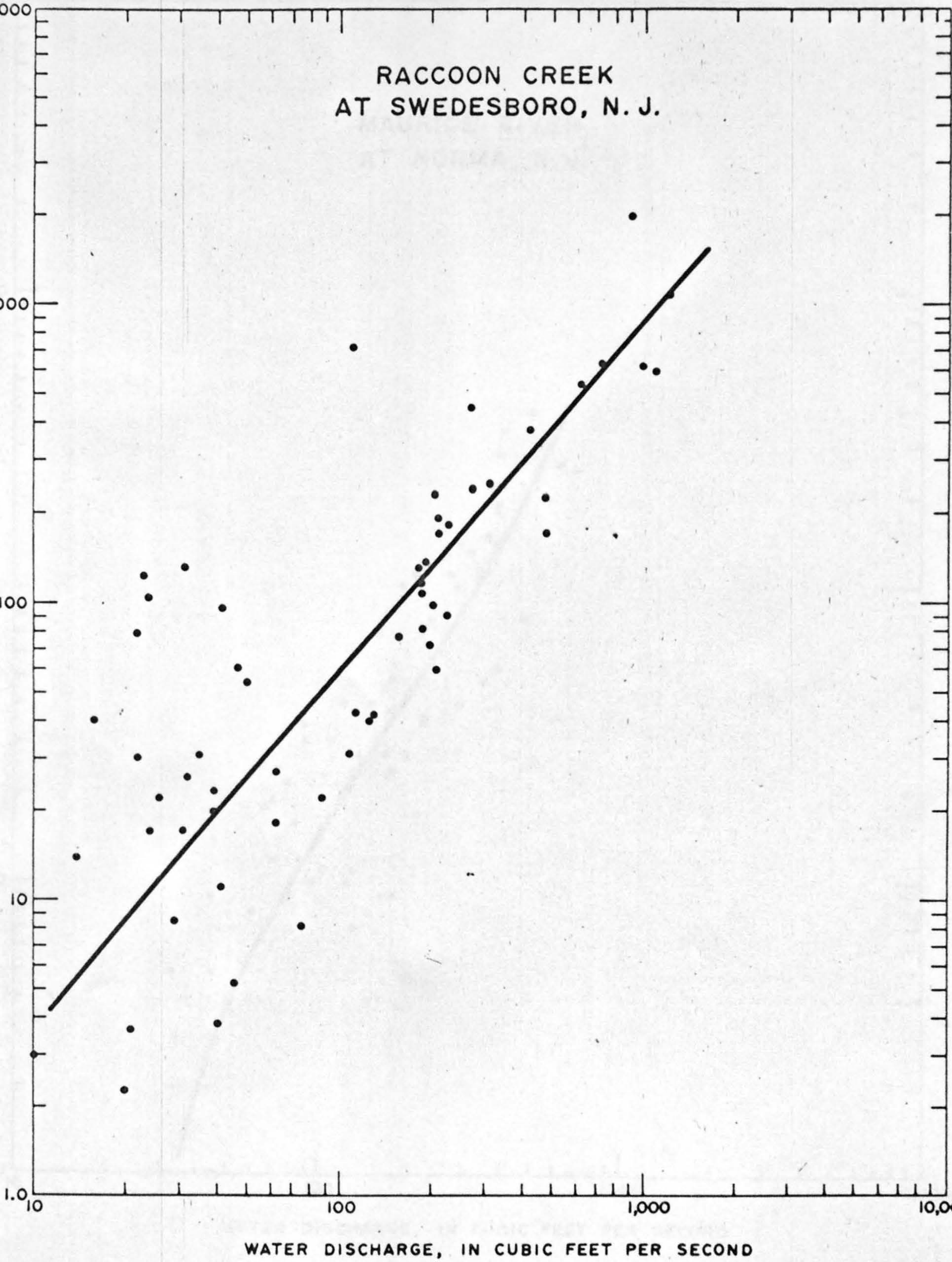

Figure 3.--Suspended-sediment transport curves for southern New Jersey sampling sites--Continued.

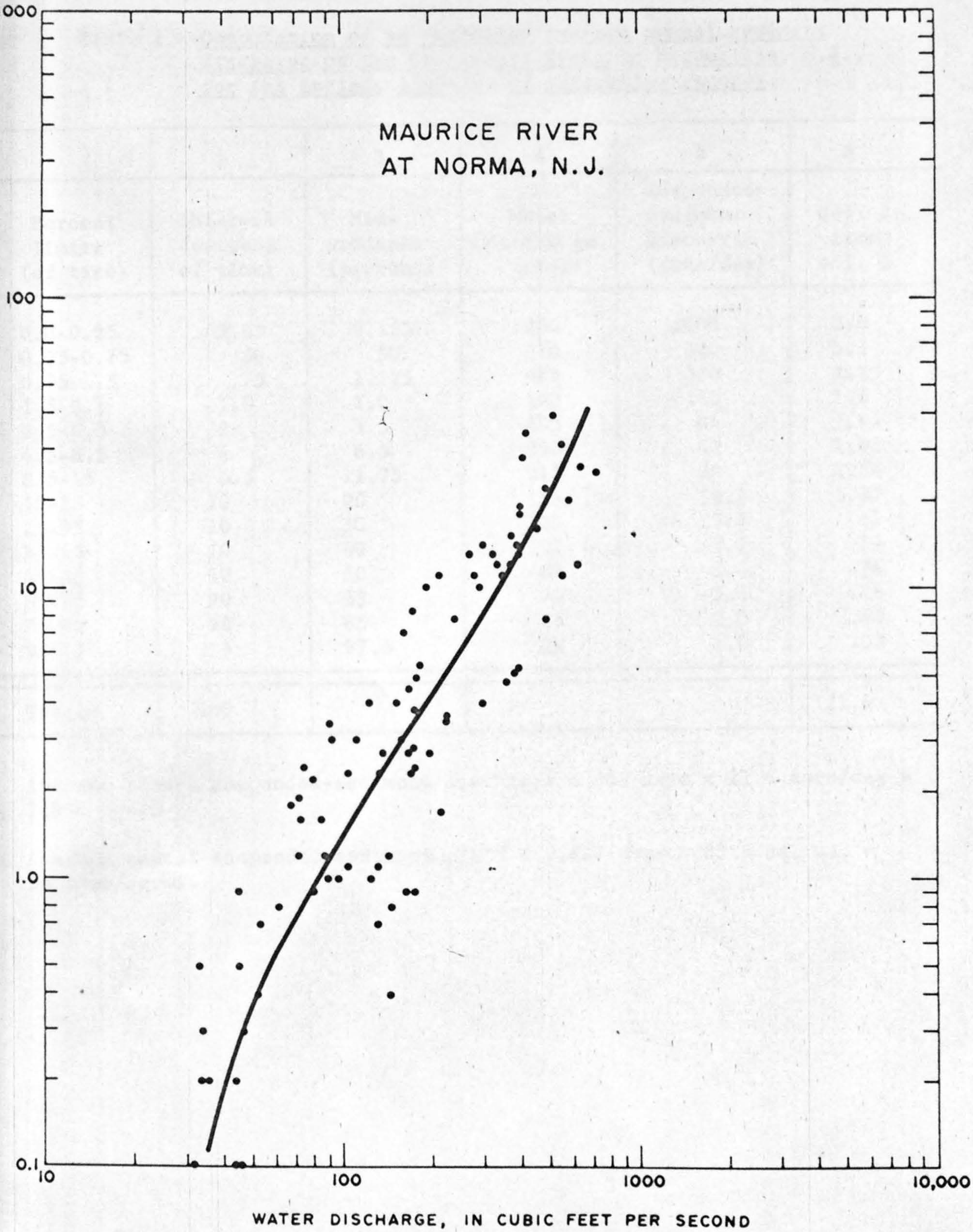

Figure 3.--Suspended-sediment transport curves for southern New Jersey sampling sites--Continued.

Table 2.--Computation of an estimated average annual sediment discharge on the Crosswicks Creek at Extonville, N.J., for the period, 1940-70, of streamflow records.

1	2	3	4	5	6
Percent limits (of time)	Interval (percent of time)	Mid-ordinate (percent)	Water discharge (cfs)	Suspended-sediment discharge (tons/day)	Col. 2 times col. 5
0.0-0.25	0.25	0.125	1200	2000	5.0
0.25-0.75	.50	.50	870	620	3.1
0.75-1.5	.75	1.125	685	300	2.25
1.5-2.5	1.0	2.0	540	160	1.6
2.5-4.5	2	3.5	405	84	1.64
4.5-8.5	4	6.5	290	42	1.68
8.5-15	6.5	11.75	215	24	1.56
15-25	10	20	155	13.7	1.37
25-35	10	30	122	9.3	.93
35-45	10	40	103	7.1	.71
45-55	10	50	88	5.4	.54
55-75	20	65	70	3.8	.76
75-95	20	85	45	2.0	.40
95-100	5	97.5	28	1.0	.05
Totals	100				21.6

Average annual suspended-sediment discharge = 365 days x 21.6 tons/day = 7,880 tons.

Average annual suspended-sediment yield = 7,880 tons / 83.6 sq. mi. = 94 tons/sq.mi.

Particle-size distribution of suspended sediment collected at four sampling sites are shown in figure 4. Each curve represents the average particle-size distribution of samples collected. The size distribution of the sampled stations are tabulated on table 3. A comparison of the data presented (table 3) indicate a variation in distribution within samples collected on the mainstem and those collected in Coastal Plain tributaries. The particle-size distribution at Trenton is mostly silt (53 percent), whereas clay is the dominant size in the Coastal Plain streams, ranging from 52-65 percent. Sand sizes range from 8-20 percent in the Coastal Plain streams and make up 4 percent of the distribution at Trenton.

Generally, a sample concentration of 100 mg/l is required for particle-size analyses. Streams in the Outer Coastal Plain rarely reach this concentration; therefore, only a few such samples can be obtained over a period of years. Only one sample, that on the Maurice River, was collected during the period of study. Analysis of this sample indicated particle-size distribution was as follows: 68 percent clay, 29 percent silt, and 3 percent sand.

SEDIMENT-YIELD VARIATIONS

Variations in sediment yields from Coastal Plain tributaries of the Delaware River are related to several environmental factors. Those notable are the physiographic subdivision in which the drainage area is contained, the degree and type of cultural development, and the geologic and soil characteristics of the surface of the drainage basin and stream channel.

The Coastal Plain has been subdivided by several investigators on the basis of geographic, geologic, physiographic, geomorphic, and soil characteristics. Rogers (1955, p. 10-12) subdivided it into two zones. He termed one the Outer Coastal Plain, the other the Inner Coastal Plain. These zones were based on geologic and geographic classifications; the major difference between them is the predominance of stratified deposits of sand and silt, with lesser amounts of clay and gravel in the Outer Coastal Plain. The Inner Coastal Plain consists of various sequences of silt, sandy clay, clay, and sand, with silt and sandy clay predominating. More recently, Owens and Minard (1960) mapped the Coastal Plain into three physiographic subprovinces: an Outer Lowland with altitudes rarely exceeding 50 feet; a broad Inner Upland with altitudes as great as 400 feet; and a narrow Inner Lowland with altitudes generally averaging about 150 feet. Their classification was based mainly on topographic characteristics. The boundary between the Inner and Outer Coastal Plain of Rogers and the Inner Lowland and Inner Upland of Owens and Minard is somewhat similar, except that the boundary established by Rogers is generally closer to the drainage divide between streams draining into the Delaware River and those that drain into the Atlantic Ocean.

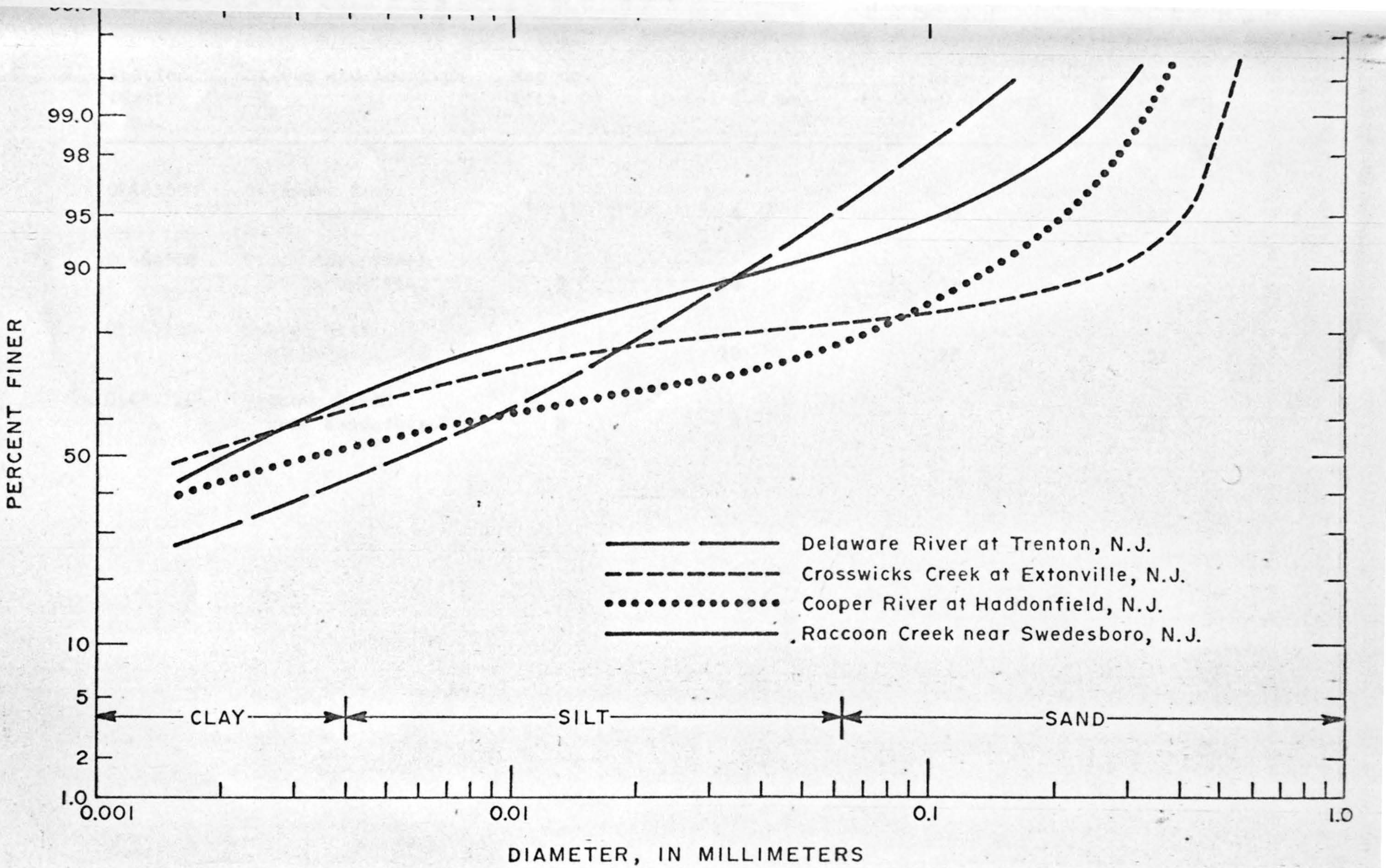

Figure 4.--Average particle-size distribution of suspended material samples at various stations.

Station ident. no.	Stream and location	Map no. (fig. 2)	Sand (0.062-2.0 mm)	Silt (0.004-0.062 mm)	Clay (<0.004 mm)
01463500	Delaware River at Trenton	1	4	53	43
01464500	Crosswicks Creek at Extonville	2	20	19	61
01467150	Cooper River at Haddonfield	5	20	28	52
01477120	Raccoon Creek near Swedesboro	8	8	27	65

In an attempt to regionalize sediment yields, a comparison was made between sediment records (table 1) and subprovince boundaries developed by these investigators. The boundary developed by Rogers, which is shown on figure 5 as a dotted line, was selected as being more indicative of variations in sediment yield.

Streams draining the Outer Coastal Plain (fig. 5), represented by sampling sites on McDonalds Branch (site 3), Mullica River (site 10), Great Egg Harbor River (site 11), and Maurice River (site 9), are estimated to yield less than 10 tons per sq. mi. annually of sediments in suspension. Estimated sediment yields obtained at two of the above sampling sites (10 and 11), which are located outside the basin, were included on table 1 to support values derived at nearby sites (3 and 9) within the basin.

Some of the factors that influence sediment yields in the Outer Coastal Plain are: (1) extremely low relief and stream gradients; (2) predominately heavy coarse-grained sandy surface materials, which promote infiltration; and (3) generally a dense cover of vegetation. These three factors inhibit erosion-producing overland runoff.

Suspended-sediment yields may vary also from basin-to-basin as a consequence of cultural activities, such as farming, highway construction, and urbanization. For example, in the Crosswicks Creek basin, the yield at the sampling site was computed as 94 tons per sq. mi. annually. Although there is some farming and very little urbanization, forested areas are probably greater in this basin than in other Inner Coastal Plain basins. This higher percentage of woodlands may account for the moderate suspended-sediment yields indicated. Another explanation for the lower measured yields is that about 40 percent of the drainage basin above the sampling site drains the Outer Coastal Plain.

Sediment data were collected on the North Branch Rancocas Creek at Mount Holly; however, records collected to date (1972) are of insufficient longevity for computation purposes. It seems that sediment yields in this basin resemble those in the Crosswicks, in that land-use characteristics are similar.

Land use in the Pennsauken Creek and Cooper River basins is predominately urban. There is a small amount of farming and some wooded areas in these basins. Higher sediment yields from the Pennsauken Creek probably result mainly from earth moving related to highway construction and exposure of soils for the construction of new housing in developing urban areas. The exposure of soil during development phases probably produces a temporary high sediment yield. In contrast, this developing stage has passed in the Cooper River basin, and the urban growth in this area is now relatively stable. This stability is probably reflected in the lower sediment yield and in the lesser scatter noted on the sediment-transport curve (fig. 3, p. 12).

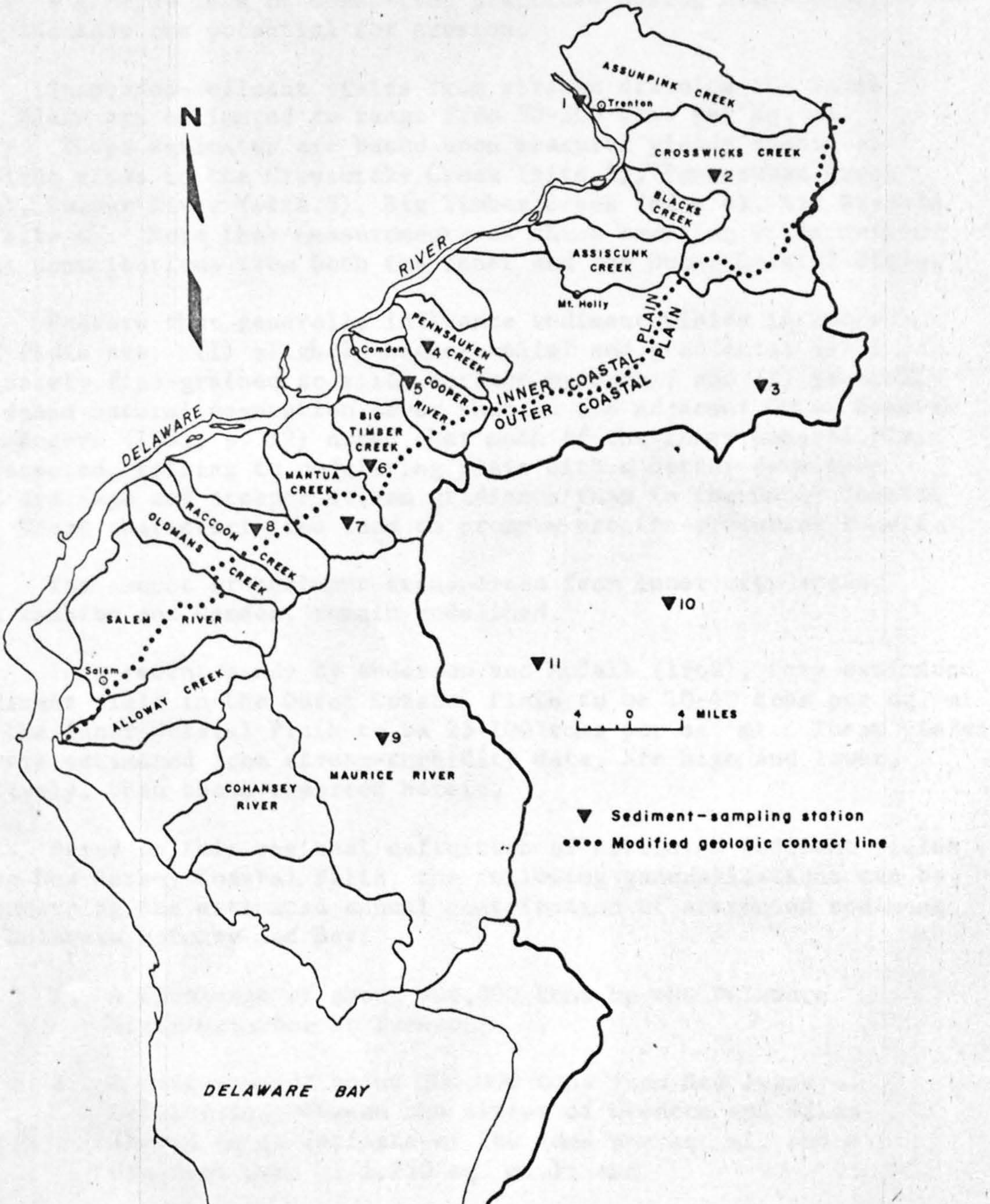

Figure 5.--Drainage basin boundaries of New Jersey streams draining to estuarine areas of the Delaware River and modified geologic contact line (after Rogers, 1955).

Farming is the predominate land use in the Raccoon and upper Mantua Creek basins. Some urban development continues in the lower Mantua Creek basin, but very little exists in the Raccoon Creek basin. Both basins contain fairly large amounts of wooded areas, but not nearly as much as found in the Rancocas and Crosswicks Creek basins. The continued reworking of the land surface by farming exposes soils to erosion. A general lack of cover-crop practices during high-runoff periods increase the potential for erosion.

Suspended-sediment yields from streams draining the Inner Coastal Plain are estimated to range from 50-300 tons per sq. mi. annually. These estimates are based upon measured yields (table 1) at sampling sites in the Crosswicks Creek (site 2), Pennsauken Creek (site 4), Cooper River (site 5), Big Timber Creek (site 6), and Raccoon Creek (site 8). Note that measurements at these sampling sites reflect sediment contributions from both the Inner and the Outer Coastal Plain.

Factors that generally influence sediment yields in Inner Coastal Plain are: (1) slightly higher relief and gradients; (2) a predominately fine-grained to silty surface material; and (3) generally a less dense natural vegetation cover than in the adjacent Outer Coastal Plain. Rogers (1955, p. 12) noted that much of the Inner Coastal Plain is a dissected, rolling to undulating plain with a better developed surface drainage and steeper stream gradients than in the Outer Coastal Plain. These characteristics tend to promote erosion-producing runoff.

The amount of sediment transported from inner city areas, such as Trenton and Camden, remain undefined.

In a recent study by Anderson and McCall (1968), they estimated the sediment yield in the Outer Coastal Plain to be 10-40 tons per sq. mi. and in the Inner Coastal Plain to be 25-100 tons per sq. mi. These yields, which were estimated from stream-turbidity data, are high and lower, respectively, than those reported herein.

Based on this regional definition of estimated sediment yields from the New Jersey Coastal Plain, the following generalizations can be made concerning the estimated annual contribution of suspended sediment to the Delaware estuary and Bay:

1. A discharge of about 700,000 tons by the Delaware River mainstem at Trenton;

2. A discharge of about 200,000 tons from New Jersey tributaries between the cities of Trenton and Salem (based on an estimate of 160 tons per sq. mi. and a drainage area of 1,250 sq. mi.); and

3. A discharge of about 8,000 tons from New Jersey tributaries between the cities of Salem and Cape May (based on an estimate of 9 tons per sq. mi. and a drainage area of about 875 sq. mi.).

In total, it is estimated that about 910,000 tons of suspended material annually enter the Delaware estuary and Bay from these three regions. This value does not include an estimate of materials transported along the streambed. Parker and others (1964, p. 160) indicate that bed load would account for 10 percent of the total sediment load transported in the Delaware River basin. Thus, it is estimated that 90,000 tons of bed material annually enter the Delaware estuary and Bay from the Delaware River mainstem and from the New Jersey Coastal Plain.

The estimates given above represent values produced by accepted techniques; however, these estimates should be qualified for the following reasons:

1. Few streamflow-gaging stations in the area have a period of record (10 years or more) sufficient for the calculation of flow-frequency information.

2. Low density and areal distribution of sampling sites (less than one per tributary) prevented more accurate estimation of yields for each entire tributary.

3. Most of the data were collected during periods of normal or below normal streamflow; thus, definition of the sediment-transport curves at high flows was imprecise.

However, it is probable that a longer and more intensive data-collection program would only slightly improve the accuracy of the estimated contribution by Coastal Plain streams.

SUMMARY AND CONCLUSIONS

The suspended-sediment discharge from streams that drain into the Delaware estuary and Bay from New Jersey were measured to determine areas of high sediment yield. Estimated annual yields range from 10 to 300 tons per sq. mi. and are dependent upon geologic and land-use characteristics of the drainage basin.

Long-term sediment records collected on the Delaware River at Trenton indicates an expected annual suspended-sediment yield of 100 tons per sq. mi. Particle-size analysis (fig. 4) of samples collected during storms at this sampling site indicates that the suspended sediments are composed of approximately 43 percent clay, 53 percent silt, and 4 percent sand.

Streams that flow into the Delaware estuary south of Trenton (fig. 1) drain the Coastal Plain. Streamflow-duration-analyses and sediment-transport curves were used to estimate the annual sediment yields transported by these tributaries. Streams draining the Outer Coastal Plain (fig. 5) are estimated to yield less than 10 tons per sq. mi. annually. Factors that influence this low yield are an extremely low relief, predominantly heavy coarse-grained sandy surface material, a lack of urban development, and a dense cover of vegetation. Streams draining the Inner Coastal Plain are estimated to yield from 50 to 300 tons per sq. mi. annually. Factors that influence the higher yields are a better developed surface drainage, steeper stream gradients, fine-grained to silty surface materials, and generally a less dense natural vegetation cover than in the adjacent Outer Coastal Plain. In general, high yields are observed in heavily farmed or in developing urban areas and low yields in heavily forested, or stabilizing urban areas. An approximate average of the particle-size analyses of suspended material collected during high runoff periods from stations in the Inner Coastal Plain indicated that sediments from these areas consist of 59 percent clay, 25 percent silt, and 16 percent sand.

About 910,000 tons of suspended sediment is transported annually from the Delaware River mainstem and Coastal Plain streams into the Delaware estuary and Bay. In addition, about 90,000 tons of bed material is transported by these two sources into the Delaware estuary and Bay. Approximately 20 percent of the suspended load is contributed by New Jersey Coastal Plain tributaries.

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