Fluvial Sediment in Ohio

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 2045

Prepared in cooperation with the Ohio Department of Natural Resources and the Ohio Environmental Protection Agency

Fluvial Sediment in Ohio

By PETER W. ANTTILA *and* ROBERT L. TOBIN

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 2045

Prepared in cooperation with the Ohio Department of Natural Resources and the Ohio Environmental Protection Agency

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1978

UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, *Secretary*

GEOLOGICAL SURVEY

W. A. Radlinski, *Acting Director*

Library of Congress Cataloging in Publication Data
Anttila, Peter W

Fluvial sediment in Ohio.
(Geological Survey water-supply paper ; 2045)
Bibliography: p.
1. Sediments (Geology)—Ohio. 2. Sediment transport—Ohio. I. Tobin, Robert L., joint author. II. Ohio. Dept. of Natural Resources. III. Ohio. Environmental Protection Agency. IV. Title. Series: United States. Geological Survey. Water-supply paper ; 2045.
QE471.2.A57 551.3'04'09771 77-608033

For sale by Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

Stock Number 024-001-03068-3

CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS

Factors for converting English units to the International System of Units (SI) are given below. However, in the text the metric equivalents are shown only to the number of significant figures that correspond to the values of the English units.

Multiply English units	*By*	*To obtain SI units*
inches (in)	25.40	millimeters (mm)
feet (ft)	0.3048	meters (m)
acre-feet (acre-ft)	0.001233	cubic hectometers (hm^3)
square miles (mi^2)	2.590	square kilometers (km^2)
cubic feet per second (ft^3/s)	0.02832	cubic meters per second (m^3/s)
tons (short)	0.9072	tonnes (t)
tons per square mile per year [($tons/mi^2$)/yr]	0.3503	tonnes per square kilometer per year [(t/km^2)/yr]
pounds per cubic foot (lb/ft^3)	16.02	kilograms per cubic meter (kg/m^3)

FLUVIAL SEDIMENT IN OHIO

By Peter W. Anttila and Robert L. Tobin

ABSTRACT

Characteristics of fluvial sediment in Ohio streams and estimates of sediment yield are reported. Results are based on data from several daily record stations and 5 years of intermittent record from a 38-station network.

Most of the sediment transported by Ohio streams is in suspension. Mean annual bedload discharge, in percentage of mean annual suspended-sediment discharge, is estimated to be less than 10 percent at all but one of the sediment stations analyzed. Duration analysis shows that about 90 percent of the suspended sediment is discharged during 10 percent of the time. Concentration of suspended sediment averages less than 100 milligrams per liter 75 percent of the time and less than 50 milligrams per liter 50 percent of the time.

Suspended sediment in Ohio streams is composed mostly of silt and clay. Sand particle content ranges from 1 to 2 percent in northwestern Ohio to 15 percent in the east and southeast.

Sediment yields range from less than 100 tons per square mile per year (35 tonnes per square kilometer per year) in the northwest corner of Ohio to over 500 tons per square mile per year (175 tonnes per square kilometer per year) in the southern part, in Todd Fork basin, lower Paint Creek basin, and the Kentucky Bluegrass area. Yield from about 63 percent of Ohio's land area ranges from 100 to 200 tons per square mile per year (35 to 70 tonnes per square kilometer per year).

INTRODUCTION

Fluvial sediment is widely recognized as a pollutant of surface waters. Erosion, transport, and deposition of sediment present significant economic and environmental problems. These problems include land erosion, esthetic damage to surface waters, filling or scouring of stream channels, cost of removal of sediment from municipal and industrial water supplies, sediment deposition in reservoirs and harbors, and floodwater damage due to sediment. The economic aspects of these and other problems are discussed by Maddock (1969b). Another problem of increasing importance is the sorption on sediment of toxic metals, pesticides and other toxic organic compounds, nutrients, and radionuclides. These sorbed substances create a potential hazard to public health when transported into a water supply or concentrated in a depositional area.

It is physically and economically impractical to eliminate fluvial sediment. Instead, sediment problems are controlled by adequate conservation and management of surface water and land resources. To provide such management requires information about the quantity and characteristics of fluvial sediment. In Ohio, this information is of extreme value because of the significant role of surface waters in the economic welfare of the State.

In October 1969, the U.S. Geological Survey, in cooperation with the Ohio Department of Natural Resources, established a fluvial-sediment-inventory network to provide sufficient data so that quantities and characteristics of fluvial sediment could be defined on a statewide basis. In 1970 the cooperation with the U.S. Geological Survey was transferred to the Ohio Environmental Protection Agency. The network consisted of 39 streamflow stations that met the following criteria: wide geographical distribution, drainage area of 85 mi^2 (220 km^2) or more, representation of major soil associations, and unregulated flow conditions. Sediment and related data were collected on an intermittent basis at each station for the 5-year period, October 1969 to September 1974. Data collection included suspended-sediment samples, bed-material samples, water discharges, and water temperatures.

The primary purpose of this report is to present a summary and interpretation of the fluvial-sediment data collected from the inventory network and from historical and concurrent investigations of the cooperative water-resources program of the U.S. Geological Survey in Ohio. Summaries include: time durations of concentration and discharge of suspended sediment, particle-size distributions of suspended sediment and bed material, and basin sediment yields.

As its secondary purpose, this report describes relevant methodology, concepts, and definitions relating to fluvial sediment. Because interpretive reports on fluvial sediment in Ohio are sparse, these subjects are included for the benefit of water managers and planners who may use the information contained herein.

The basic data used in this study (not presented in this report) are published in the U.S. Geological Survey publication, "Water Resources Data for Ohio, Part 2. Water Quality Records," for water years 1964–73; prior to the 1963 water year, in the U.S. Geological Survey Water-Supply Paper series, "Quality of Surface Waters of the United States, Parts 3 and 4. Ohio River Basin and St. Lawrence River Basin."

This report was prepared by the U.S. Geological Survey in cooperation with the Ohio Environmental Protection Agency. Acknowledgment is made to personnel of the Miami Conservancy District for their assistance in the collection of data in the Great Miami River basin.

FLUVIAL-SEDIMENT CONCEPTS

Fluvial sediment, as defined by Colby (1963, p. VI), is "sediment that is transported by, or suspended in, water or that has been deposited in beds by water." Concepts of fluvial sediment as they pertain to the objectives of this report, are discussed briefly in this section. Readers are referred to Colby (1963) and Guy (1970a) for a comprehensive summary on concepts and for an adequate listing of published literature.

Sediment is fragmental material that originates mostly from disintegrated rocks and includes chemical and biochemical precipitates and decomposed organic material such as humus. The fragmental material becomes fluvial sediment when it is entrained in water by sheet or channel erosion. Another source of fluvial sediment, although not one considered significant in Ohio, is sediment transported by air (eolian sediment) and deposited in surface waters.

Erosion by water is generally classified into two types: sheet erosion and channel erosion. Sheet erosion removes sediment rather uniformly from an area. Included is erosion by the many small rivulets that are formed by minor concentrations of flow. Channel erosion results from concentrated flow of water. Gullying, valley trenching, streambed erosion, and streambank erosion are types of channel erosion. Beds and banks of streams are eroded when the flowing water has the capability of transporting additional sediment. The pertinent hydraulic variables affecting sediment transported by a stream are: mean velocity, depth, slope, width, and channel-flow resistance. Of these variables, mean velocity is the best available index of the rate of sediment transport (Maddock, 1969a, p. 2). Channel erosion is usually evident below reservoirs, where the relatively sediment-free effluent will degrade an unprotected stream channel as it attempts to satisfy its sediment-transport capacity.

The quantity of sediment delivered to a stream is dependent upon a combination of active and passive forces acting on the watershed. Table 1 is a summary, modified from Guy (1970a, p. 11), of the factors affecting erosion and transport of sediment

TABLE 1.—*Factors affecting erosion and transport of sediment from land surface*

[From Guy 1970a]

Major factors	Elements	Influence of elements on soil erosion
Agents and characteristics causing active forces		
Climate	Rainfall-runoff (intensity and duration).	Raindrop splash erosion: Breaks down aggregates, dislodges and disperses soil, and thereby seals the surface and increases precipitation excess. Imparts turbulence to sheet flow causing movement of larger particles. Flow erosion: Physical force due to pressure difference and impact of water dislodges, disperses, and transports. Intensity and duration affect rate of runoff after infiltration capacity is reached.
	Temperature	Alternate freezing and thawing: Expands soil, increases moisture content, and decreases cohesion. Thus, dislodgment, dispersion, and transport are facilitated.
	Wind	Pressure difference and impact: Dislodges because force produces pressure difference and (or) impact.
Gravity		Elements of mass wasting: for example, slow-flowage types such as soil creep, rock creep, and rock-glacier creep; Rapid-flowage types such as mudflow, landslides, and rockslides.
Agents and characteristics causing passive forces		
Soil character	Properties of the soil mass.	Granulation: Affects force required for dislodgment and transport. Stratification: Stratum of lowest porosity and permeability controls infiltration rate through overlying layers. Porosity: Determines waterholding capacity. Affects infiltration and runoff rates. Permeability: Determines percolation rate. Affects infiltration and runoff rates. Volume change and dispersion properties: Soil swelling loosens and disperses soil and thereby reduces cohesion and facilitates dislodgment and transport. Moisture content: Moisture reduces cohesion and lengthens erosion period by increasing the period of precipitation excess. Frost susceptibility: Determines intensity of ice formation and affects porosity, moisture content, and reduction in strength.
	Properties of the soil constituents.	Grain size, shape, and specific gravity: Determines force needed for dislodgment and transport against force of gravity.
Topography	Slope	Orientation: Determines effectiveness of climatic forces. Degree of slope: Affects energy of flow as determined by gravity. Length of slope: Affects quantity or depth of flow. Depth and velocity affect turbulence. Both velocity and turbulence markedly affect erosion and transport.
Soil cover		Vegetative cover: All vegetative cover, whether alive or dead, protects the land surface in proportion to interception of raindrops by canopy and retardation of flow erosion through decreasing velocity of runoff, increasing soil porosity, and for live plants, increasing soil moisture-holding capacity through the process of transpiration. Nonvegetative cover: Open surfaces result in a minimum of surface protection and therefore maximum splash erosion, reduced infiltration, increased runoff, and maximum erosion. A paved surface affords maximum surface protection with zero erosion and highly efficient runoff and transport characteristics.

from the land surface. Of all the forces given in table 1, rainfall is the most dynamic and consequently the most significant.

Sediment in streams is transported in suspension (suspended load) or by being rolled, skipped, or slid along the streambed (bedload). The suspended load consists of fine sediment that usually travels at the velocity of the stream and that is held in suspension by the upward components of turbulent currents or by colloidal forces. The source of the fine material that is delivered to most streams is sheet erosion, rather than channel erosion. In Ohio, sheet erosion is considered to be the principal source of suspended sediment.

Bedload consists of coarser sized sediment that comes from the bed and banks of the stream. Particles moving as bedload remain close to the streambed, usually within a few grain diameters for uniform sediment (Colby, 1963, p. 12). Size, shape, and weight of a particle and the flow pattern near the bed determine the probability of a particle to move as bedload. Unlike the fine particles, which usually travel from the point of erosion to places far downstream, bedload particles move sporadically and are deposited throughout the length of the stream.

Sediment deposition in water is dependent upon particle-fall velocity and the previously discussed transporting capability of the body of water. Fall velocity of a particle is dependent upon the difference in density between the particle and the water, the viscosity of the water, and the size, shape, and flocculation of the particles. Flocculation is dependent upon the size, shape, and composition of the particles and on the turbulence and chemical properties of the water (Colby, 1963, p. 31).

Fluvial sediments are generally deposited in lakes or reservoirs, coastal areas, estuaries, harbors, stream channels, or flood plains. In Ohio, the principal deposit areas are the harbors and bays of Lake Erie and inland reservoirs and lakes.

DESCRIPTION OF FACTORS AFFECTING EROSION AND TRANSPORT OF SEDIMENT IN OHIO

The active and passive factors affecting erosion and transport of sediment given in table 1 have been described in State reports on water and soil resources. Because literature is abundantly available, only a brief summary of these factors is given in this report for ease in understanding the interpretations contained in later sections.

ACTIVE FACTORS

The climate of Ohio is essentially continental. Average annual temperatures range from 49.5° F (9.7° C) in the northeast to 57° F (13.9° C) in the southern extremity (Ohio Division of Water, 1962). The growing season (temperatures greater than 32.0° F (0° C)) varies considerably according to latitude and proximity to Lake Erie. The longest growing season is about 200 days on the lake shore, and the shortest is less than 150 days in the northeastern valleys of the Ohio River drainage. Dates of first and last freezing temperatures vary from September 30 to November 6 and from April 15 to May 18, respectively (Pierce, 1959).

Annual precipitation averages 38 in (970 mm) with a range of 36 in (910 mm) in the north to 41 in (1,040 mm) in the south. Intensity and duration of rainfall increases from the northeast corner to the southwest corner of the State. The 2-year, 24-hour rainfall intensity ranges from 2.2 to 3.0 in (56 to 76 mm) (U.S. Weather Bureau, 1961), and the 2-year, 2-day rainfall total ranges from 2.7 to 3.5 in (69 to 89 mm) (U.S. Weather Bureau, 1964). Two-year recurrence interval values are derived from frequency analyses of annual values and are representative of the mean annual values. Highest intensities generally occur as local thunderstorms that have an annual frequency of 40 to 50. Rainfall is greatest in the spring (about 4 in (100 mm) in April) and least in the fall (about 2.5 in (64 mm) in October).

Runoff averages about 13 in (330 mm) per year, with a range of 8 in (203 mm) in an area of the northwest to 18 in (457 mm) in areas in the southeast and northeast (Ohio Division of Water, 1962). Floods are more prevalent in the spring but may occur during any season.

Gravity is probably not a significant erosive factor in Ohio except possibly for occasional debris slides in strip mine and major construction areas.

PASSIVE FACTORS

A description of the passive factors affecting erosion and transport of sediment would include summaries on physiography, geology, soils, and land cover. In order to eliminate a lengthy discussion of these individual factors, this report will use the major land-resource area classification of the U.S. Soil Conservation Service. Austin (1965, p. 1) has defined major land-resource areas to be areas of geographically associated land-resource units, usually of several thousand acres, that are characterized by similar patterns of soil, climate, water resources, land use, and type of farming.

There are 156 major land-resource areas, of which eight are represented in Ohio (fig. 1). Table 2, modified from U.S. Department of Agriculture (1971, p. 9), summarizes the characteristics of Ohio's major land-resource areas. Information from the Ohio Division of Lands and Soil (1973) and from Austin's report (1965) was incorporated into table 2.

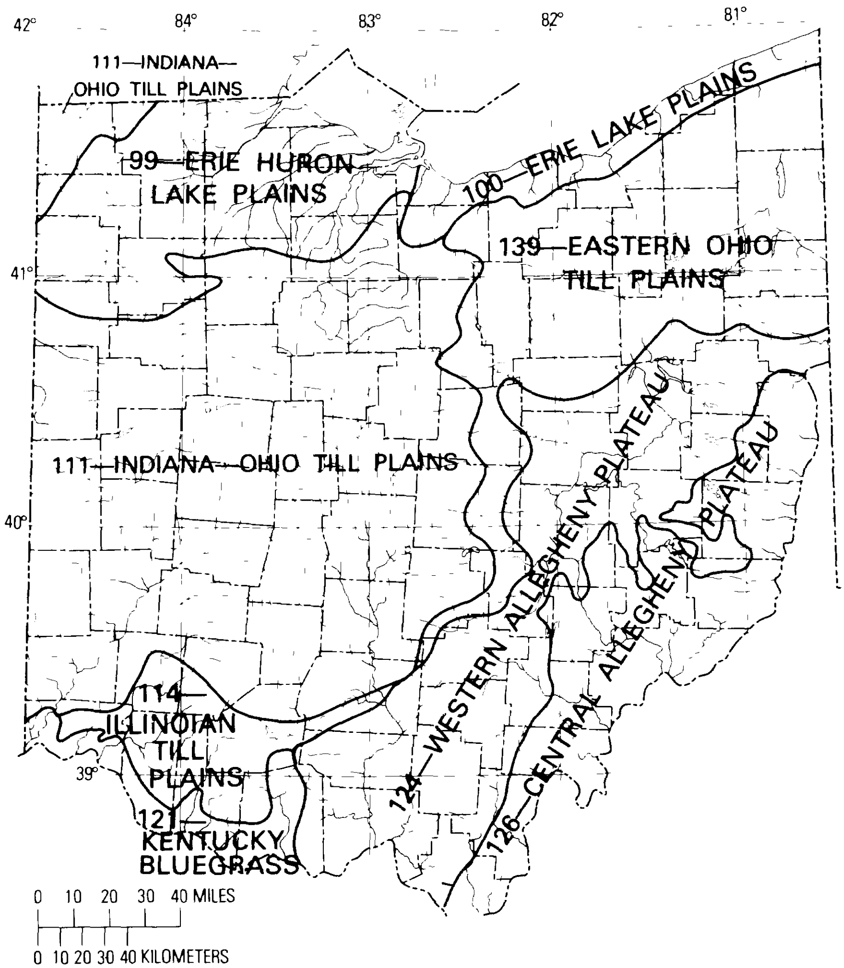


FIGURE 1.—Major land-resource areas in Ohio, as described in table 2 (from U.S. Department of Agriculture, 1971).

TABLE 2.—*Characteristics of major land-resource areas in Ohio*

[Modified from U.S. Department of Agriculture, 1971]

Major land-resource area Nos.		Percentage of Ohio in major land-resource areas
99	Erie Huron Lake Plains Calcareous lacustrine materials Huntsville Haney Paulding soils Predominately farm land, northwest cash grain and livestock farming. Nearly level; local relief (average variation between adjacent low and high land surface), only a few feet.	10.1
100	Erie Lake Plains Acid lacustrine materials Lorain, Caneadea, Elnora soils Mostly semi-urban; crops are specialized to northeast. Nearly level to sloping plain. local relief, a few feet.	2.4
111	Indiana and Ohio Till Plains Glacial limestone materials Crosby, Brookston, Miamian, Blount, Pewamo, Morley, and Fox soils Predominately western cash grain crop farming. Gently sloping but broken in places by hilly moraines, kames, and outwash terraces; local relief, mainly a few feet to a few tens of feet.	37.0
114	Illinoian Till Plains Gray flats and silts over till material Clermont, Avonburg, Rossmoyne soils Mostly cash grain and livestock farming with some woodland in sloping areas. Narrow ridgetops with steep slopes to ridges and valley sides; local relief, a few feet to tens of feet on ridgetops with stream valleys one to several hundred feet below adjoining uplands.	4.3
121	Kentucky Bluegrass Residual limestone hills Eden and Bratton soils Farming predominately livestock with tobacco principal cash crop; includes urban Cincinnati area. Undulating to rolling plain; local relief, few tens of feet.	2.1
124	Western Allegheny Plateau Residual sandstone and shale materials Muskingum, Wellston, Gilpin, and Rarden soils About one-fifth is cropland, one-fifth pasture, and two-fifths woodland, and some strip mining of coal. Level narrow valley floors, rolling ridgetops and hilly to steep ridge slopes; local relief, one to several hundred feet.	16.8
126	Central Allegheny Plateau Residual sandstone and red shale materials Gilpin, Upshur, Guernsey, Westmore soils Mostly pasture and woodland with strip mining common in some areas. Level narrow valleys and narrow rolling ridgetops separated by long steep slopes; local relief, in hundreds of feet.	10.8
139	Eastern Ohio Till Plains Glacial, sandstone, and shale materials Rittman, Mahoning, Plateau, Canfield and Chili soils Three-fifths dairy and small grain farms and one-fifth urban. Gentle to strong dissected plateau with narrow but not deeply incised stream valleys; local relief, one to tens of feet.	16.5

INVESTIGATIONS

Before the 39-station inventory network was established in October 1969, fluvial-sediment investigations consisted primarily of reservoir-accumulation studies and collection of suspended-sediment data from several daily record stations. Most daily stations were located on principal streams. Data from these stations include daily suspended-sediment discharges, daily sediment concentration, and particle-size distributions. The historical data were insufficient for a statewide evaluation because of a lack of data for the subbasins of the principal drainages and for smaller streams tributary to the Ohio River and Lake Erie.

The cooperative fluvial-sediment program of the U.S. Geological Survey in Ohio began in April 1950, with establishment of a daily sediment station on the Maumee River at Waterville, Ohio. The program quickly expanded, and by the end of 1952, 13 daily stations were in operation. Continuous record of 10 years or more is available for 6 of 30 daily stations which had been operated in Ohio before the date of this report. Most of the short-term stations were operated for specific hydrologic projects or were designed for long-term operation and were discontinued because of budget constraints. Table 3 contains a list of the 30 daily fluvial-

TABLE 3.—*Daily fluvial sediment stations in Ohio*

Station No.	Station name	Drainage area (mi^2)	Drainage area affected by regulation (mi^2)	Period of daily record
03139000	Killbuck Creek at Killbuck	462	None	10/1962— 9/1969
03144500	Muskingum River at Dresden	5,993	4,276	10/1952— 9/1974
03155900	Hocking River Subwatershed No. 1 near Hooker.	1.04	1.04	5/1956— 9/1962
03159500	Hocking River at Athens	943	72.5	10/1956— 9/1965
03219500	Scioto River near Prospect	567	None	4/1951— 9/1953
03228500	Big Walnut Creek at Central College.	190	None during period	10/1951— 9/1953
03229000	Alum Creek at Columbus	189	None	10/1960— 9/1965
03234000	Paint Creek near Bourneville	807	None	10/1956— 9/1962
03234500	Scioto River at Higby [1]	5,131	2,011	10/1953— 9/1974
03237280	Upper Twin Creek at McGaw [2]	12.8	None	10/1969— 9/1973
03239000	Little Miami River near Selma	48.9	None	9/1952— 9/1958
03239500	North Fork Little Miami River near Pitchin.	28.9	None	8/1952— 9/1958
03240000	Little Miami River near Oldtown	129	None	8/1952— 9/1958
03240500	North Fork Massie Creek at Cedarville.	28.9	None	7/1954— 9/1958
03241000	South Fork Massie Creek near Cedarville.	17.1	None	7/1954— 9/1958
03241500	Massies Creek at Wilberforce	63.2	None	9/1952— 9/1958
03244000	Todd Fork near Roachester	219	None	9/1952— 9/1958
03261500	Great Miami River at Sidney	541	99.8	10/1967— 9/1975
03261950	Loramie Creek near Newport	152	77.7	10/1967— 9/1975
03265000	Stillwater River at Pleasant Hill	503	None	10/1963— 9/1975
03267800	Mad River at Eagle City [3]	307	None	10/1965— 9/1969
03270500	Great Miami River at Dayton [4]	2,511	2,434	10/1951— 9/1953
04193500	Maumee River at Waterville	6,330	Insignificant	4/1950— date
04195500	Portage River at Woodville	428	None	10/1950— 9/1956
04198000	Sandusky River near Fremont	1,251	None	10/1950— 9/1956
04201500	Rocky River near Berea [2]	267	Insignificant	7/1969— current year
04206000	Cuyahoga River at Old Portage	404	205	3/1972— current year
04207200	Tinkers Creek at Bedford	83.9	None	3/1972— 6/1972
•				10/1974— current year
04208000	Cuyahoga River at Independence [3]	707	205	10/1950— current year
04209000	Chagrin River at Willoughby [2]	246	None	7/1969— current year

[1] 1,734 mi^2 affected by regulation prior to April 1968.
[2] Selected days only.
[3] Flow affected by diversion.
[4] Flood flow regulated.

sediment stations, with their period of record. The 39-inventory-network stations are listed in table 4.

The location of each station is shown in figure 2. Data from the inventory network were obtained by intermittent sampling (8 to 20 times per year) of suspended sediment and annual sampling of bed material. The sampling of suspended sediment was designed

TABLE 4.—*Fluvial sediment inventory network stations in Ohio (Intermittent data)*

Station No.	Station name	Drainage area (mi²)	Period of water discharge record (water year)
03109500	Little Beaver Creek near East Liverpool	496	1916–current year
03110000	Yellow Creek near Hammondsville	147	1941–current year
03111500	Short Creek near Dillonvale	123	1942–current year
03114000	Captina Creek at Armstrongs Mills	134	1927–35, 1959–current year
03115400	Little Muskingum River at Bloomfield	210	1959–current year
03116200	Chippewa Creek at Easton	146	1961–current year
03117500	Sandy Creek at Waynesburg	253	1939–current year
03123000	Sugar Creek above Beach City Dam, at Beach City.	169	1945–current year
03137000	Kokosing River at Millwood	455	1922–74
03144000	Wakatomika Creek near Frazeysburg	140	1937–current year
03146000	North Fork Licking River at Utica	116	1940–48, 1970–current year
03159540	Shade River near Chester	156	1966–current year
03202000	Raccoon Creek at Adamsville	585	1916–35, 1939–current year
03223000	Olentangy River at Claridon	157	1947–current year
03228805	Alum Creek at Africa	122	1964–current year
03230500	Big Darby Creek at Darbyville	534	1922–35, 1939–current year
03230800	Deer Creek at Mount Sterling	228	1967–current year
03232000	Paint Creek near Greenfield	249	1927–35, 1940–56, 1967–current year
03237500	Ohio Brush Creek near West Union	387	1927–35, 1941–current year
03238500	Whiteoak Creek near Georgetown	222	1924–35, 1940–current year
03246200	East Fork Little Miami River near Marathon	195	1969–current year
03262700	Great Miami River at Troy	926	1963–current year
03264000	Greenville Creek near Bradford	193	1931–current year
03267000	Mad River near Urbana	162	1926–31, 1940–current year
03271800	Twin Creek near Ingomar	197	1963–current year
03272800	Sevenmile Creek at Collinsville	120	1961–72
04185000	Tiffin River at Stryker	410	1922–28, 1941–current year
04186500	Auglaize River near Fort Jennings	332	1921–35, 1941–current year
04189000	Blanchard River near Findlay	346	1924–35, 1941–current year
04191500	Auglaize River near Defiance	2,318	1916–current year
04196000	Sandusky River near Bucyrus	88.8	1926–35, 1939–51, 1964–current year
04196800	Tymochtee Creek at Crawford	229	1965–current year
04197000	Sandusky River near Mexico	774	1924–35, 1939–current year
04199000	Huron River at Milan	371	1951–current year
04199500	Vermilion River near Vermilion	262	1951–current year
04200500	Black River at Elyria	396	1945–current year
04212000	Grand River near Madison	581	1923–35, 1939–current year
04212500	Ashtabula River near Ashtabula	121	1925–35, 1940–47, 1951–current year
04213000	Conneaut Creek at Conneaut	175	1923–35, 1951–current year

to obtain adequate definition at each station for all flow conditions. The number of samples collected, therefore, varied annually and among stations. Data from station 03228805, Alum Creek at Africa, were not included in this report because of the effects from upstream construction of a multipurpose dam during most of the collection period.

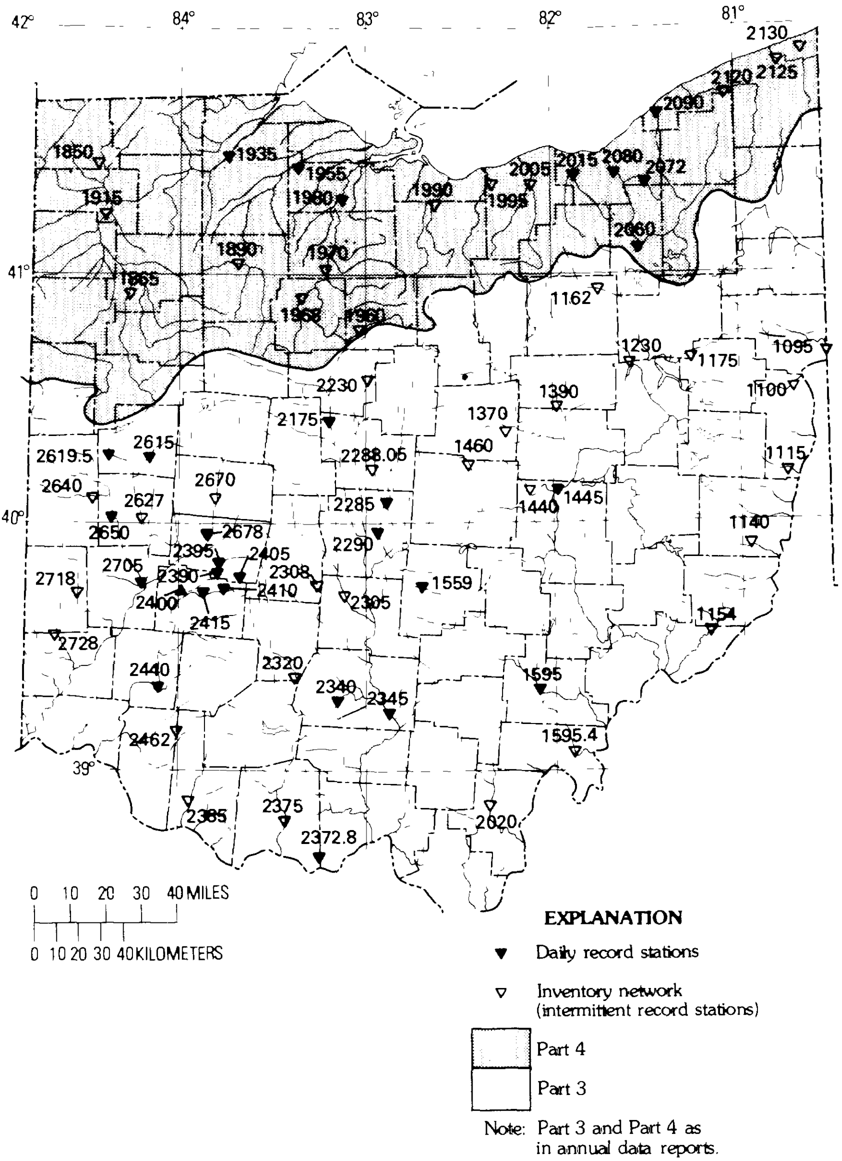


FIGURE 2.—Location of fluvial sediment stations in Ohio.

COLLECTION AND LABORATORY METHODOLOGY

The fluvial-sediment data used in this report were determined from samples of suspended sediment and bed material. Samples were collected by standard methods and with equipment developed by the Federal Inter-Agency Sedimentation Project (F.I.A.S.P.) of the Inter-Agency Committee on Water Resources. A listing of F.I.A.S.P. reports describing methods and equipment is contained in the Inter-Agency Report Catalog (F.I.A.S.P., 1974). Guy and Norman (1970) have summarized and condensed much of the information contained in the F.I.A.S.P. reports.

All samples were analyzed at the U.S. Geological Survey sediment laboratory in Columbus, Ohio, by standard methods, as described by Guy (1969).

Suspended-sediment samples used in this study are considered representative of the average water-sediment mixture for the flow condition at the station for the time of sampling. Samples were depth-integrated by using a US DH–48 depth integrating sampler during low flow and a US D–49 or a US DH–59 depth-integrating sampler for higher flows. "A depth-integrating sampler is designed to accumulate a water-sediment sample from a stream vertical at such a rate that the velocity in the nozzle at point of intake is always, as nearly as possible, identical with the immediate stream velocity while running the vertical at a uniform speed." (F.I.A.S.P., 1952, p. 22.) Depth-integrating samplers do not sample the entire depth of flow. Samplers, depending on the location of the nozzle, will sample a water column to within 3 to 5 in (76 to 127 mm) of the bottom of the column. Lateral distribution of sediment was measured by averages or composites of depth-integrated samples taken at centroids of equal increments of discharge in the cross section of the stream. Multivertical sampling was discontinued and replaced by single vertical samples for flow conditions in which the lateral distribution of sediment was uniform.

Concentration of suspended sediment is equal to the ratio of the dry weight of sediment to the volume of the water-sediment mixture and is reported in milligrams per liter (mg/L). Concentrations were determined in the laboratory by a decanting, filtering, drying, and weighing procedure. Concentrations by this procedure are computed as a weight to weight ratio and are expressed in parts per million. Parts per million is subsequently converted to mg/L using the assumptions that water density is 1.0 gram per milliliter and specific gravity of sediment is 2.65. The conversion factor is equal to unity for concentrations less than 8,000 mg/L. The concentrations determined from depth-integrated samplers are considered discharge-weighted mean concentrations because the sediment collected is proportional to the sediment discharged in the sampled section of flow. Subsequent discussion concerning the analysis of concentration data will be based entirely on discharge-weighted mean concentrations. This point is emphasized because concentration is frequently reported as a time-weighted mean value. A discharge-weighted mean sediment concentration for a given time interval represents the concentration that would be obtained if the total water discharge and total sediment discharge for the time interval were uniformly mixed.

Particle-size distribution of suspended sediment was determined in percentage by dry mass for selected samples by the sieve and bottom-withdrawal-tube methods. The sand fractions were defined by wet sieving. The finer size fractions (silt and clay) were defined by the bottom-withdrawal method, using a settling medium of distilled water with an added dispersing agent. The dispersed settling medium is used to minimize the formation of floccules, so that the results represent "standardized conditions."

Bed material was sampled for particle-size analysis. Samples were collected using a US BMH–53 bed-material sampler (or a scooping can) for wadable streams and a US BMH–60 bed-material sampler for deeper streams. Material larger than very coarse gravel (greater than 64 millimeter diameter) was not sampled. A field approximation was made of the representation of the unsampled material. At a given cross section the number of verticals sampled varied with the lateral distribution of the bed-material size. Stations with a uniform lateral distribution of bed-material size were represented by sampling at only one vertical.

The size distribution of samples by mass was determined in percentage by the dry-sieve method. Size fractions were classified from very fine sands to coarse gravel. Size distribution of the finer material (silt and clay) was not determined. Average textural composition of the streambed at a station was evaluated by incorporating particle-size distributions from samples, field approximations of coarser material, and percentage of bedrock. Size classifications for both suspended sediment and bed material are based on the recommendations of Lane and others (1947, p. 937). The classifications are itemized in table 5.

TABLE 5.—*Classification of sediment particle size in metric and English units*

[Modified from Lane and others, 1947]

Class name	Metric units		English units—feet
	Millimeters	Micrometers	
Very coarse gravel	64 -32	-----------	0.210 -0.105
Coarse gravel	32 -16	-----------	0.105 -0.0525
Medium gravel	16 - 8	-----------	0.0525 -0.0262
Fine gravel	8 - 4	-----------	0.0262 -0.0131
Very fine gravel	4 - 2	-----------	0.0131 -0.00656
Very coarse sand	2.0 - 1.0	2000 -1000	0.00656 -0.00328
Coarse sand	1.0 - 0.50	1000 - 500	0.00328 -0.00164
Medium sand	0.50 - 0.25	500 - 250	0.00164 -0.000820
Fine sand	0.25 - 0.125	250 - 125	0.000820 -0.000410
Very fine sand	0.125 - 0.062	125 - 62	0.000410 -0.000205
Coarse silt	0.062 - 0.031	62 - 31	0.000205 -0.000103
Medium silt	0.031 - 0.016	31 - 16	0.000103 -0.0000512
Fine silt	0.016 - 0.008	16 - 8	0.0000512-0.0000256
Very fine silt	0.008 - 0.004	8 - 4	0.0000256-0.0000128
Coarse clay	0.004 - 0.0020	4 - 2	----------------
Medium clay	0.0020- 0.0010	2 - 1	----------------
Fine clay	0.0010- 0.0005	1 - 0.5	----------------
Very fine clay	0.0005- 0.00024	0.5- 0.24	----------------

SUSPENDED-SEDIMENT CONCENTRATION

The amount of suspended sediment in a stream is dependent upon the factors given in table 1. Usually, the peak concentration of sediment at a given stream location will precede slightly or coincide with the peak water discharge. Such is true for Ohio, as indicated by continuous-concentration curves drafted from daily sediment data. The variation of concentration with storm runoff is illustrated in figure 3, which shows advanced and simultaneous sediment-concentration graphs plotted with their water-discharge hydrographs for station 03265000, Stillwater River at Pleasant Hill, Ohio.

The advanced concentration graph reflects a basinwide abundance of sediment that was readily available for transport. Suggested sources of this sediment include: (1) loose soil particles on the land; (2) previously eroded sediment deposited on milder slopes before reaching a stream channel; (3) deposits in small drainage ditches; and (4) stream-channel deposits of aggregates formed of floccules of clay and fine-size silt, or coarser size silt. The stream-channel deposits are caused by reductions in stream velocity which occur at meanders and sections upstream from channel constrictions.

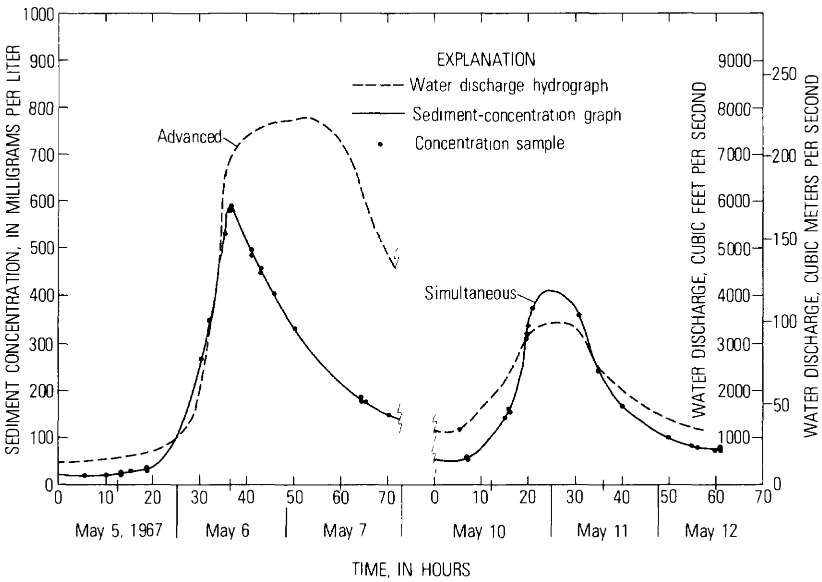


FIGURE 3.—Advanced and simultaneous sediment concentration graph plotted with water discharge hydrograph for station, 03265000, Stillwater River at Pleasant Hill, Ohio.

The simultaneous graph shows the results of a subsequent but smaller storm runoff, which began 72 hours after the peak water discharge for the May 5–7 runoff. Because the previous storm runoff had substantially reduced the supply of sediment readily available for transport, the rate of erosion varied more directly with rate of runoff; that is, more runoff delivered more sediment to the stream.

The peak concentration of sediment may lag behind the peak flow. Lag in concentration can occur when concentrations of suspended material originating far upstream enter downstream segments coincidental with locally receding conditions having relatively low sediment concentrations.

At a specific time the concentration of suspended sediment will vary in areal distribution for a given cross section. Lateral and vertical variation involve the coarse material, which is transported in accordance with the characteristics of flow in the section. Fine material is usually dispersed throughout the section. An example of the variation of concentration with depth for different particle-size groups is shown in figure 4 for the Missouri River at Kansas City, Mo. A later discussion in the report will show that the particle-size distributions of suspended sediment in Ohio are mostly silt and clay; therefore, the instantaneous concentration within a given cross section will be fairly uniform.

The variability of suspended-sediment concentrations among Ohio streams and the variability with time are represented by daily duration tables 6 and 7. Duration values of a parameter are determined from a duration curve, or frequency curve, that shows the percentage of time during which specified values of the pa-

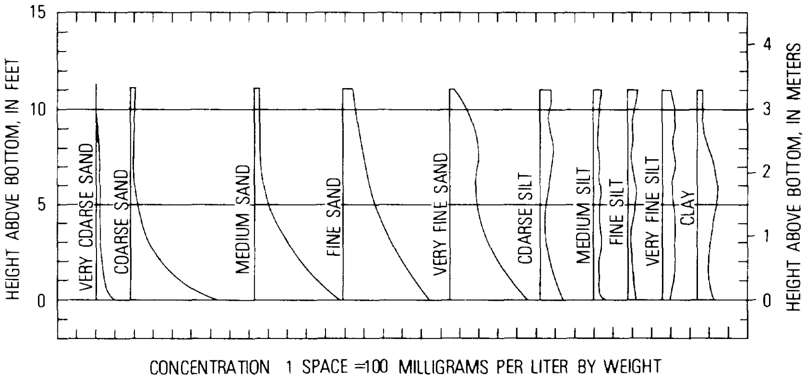


FIGURE 4.—Concentration of suspended sediment for different particle-size groups at a sampling vertical in the Missouri River at Kansas City, Mo. (Guy, 1970a).

rameter are equaled or exceeded for a given period of time. Table 6 contains the duration and maximum values of discharge-weighted mean concentrations for daily record stations.

Sediment-duration data from the inventory network stations in table 7 were not determined from duration curves of daily concentration and sediment-discharge values. The latter are synthesized data computed from a method that uses the daily water-discharge duration curve and an instantaneous suspended-sediment transport curve. Description of this method is given in the section on sediment discharge. It is emphasized that table 7 data are restricted. Users should be familiar with the analytical method and applied assumptions.

TABLE 6.—*Daily duration table of water discharge, discharge-weighted mean sediment concentration, and suspended-sediment discharge for daily sediment record stations in Ohio*

Station No.	Parameter [1]	Water year	Percent of time indicated value of parameter was equaled or exceeded								Maximum daily value
			1	5	10	15	50	75	90	99	
03139000	Q_w	1963–69	2600	1330	870	365	135	64	42	28	37200
	C		390	220	145	91	50	19	8	2	2500
	Q_s		2400	630	275	65	14	4.4	1.8	.6	121000
03159500	Q_w	1960–65	8500	3500	2100	850	250	110	68	38	31200
	C		570	258	145	45	14	7	4	1	1330
	Q_s		9000	2650	840	99	8.8	2.3	1.3	.2	44000
03229000[2]	Q_w	1961–65	1950	620	300	95	29	9.4	4.8	2.2	11600
	C		670	210	107	46	23	14	8	2	1120
	Q_s		3000	320	68	8.0	1.5	.4	.2	.1	13400
03234000	Q_w	1957–62	7000	3250	2050	900	320	95	50	23	22200
	C		1250	410	180	78	40	20	10	4	2630
	Q_s		20000	3100	820	130	24	5.6	3.2	1.5	77900
03234500	Q_w	1960–73	35000	18000	11500	4800	2000	940	580	360	122000
	C		900	370	220	95	39	19	12	5	4170
	Q_s		54000	14000	6200	1150	200	54	22	5	35200
03240000	Q_w	1953–58	720	310	200	98	41	18	12	7.4	3810
	C		370	130	73	39	22	9.0	3	-----	5050
	Q_s		580	80	29	7.5	2.1	.6	.2	<.05	13600
03244000	Q_w	1953–58	2700	960	490	170	61	9.5	2.1	.3	8760
	C		1700	560	190	50	19	8	4	1	3720
	Q_s		9000	1100	180	17	1.7	.3	.09	<.05	53000
03265000	Q_w	1964–73	4700	1800	980	370	135	54	30	14	13200
	C		600	215	106	42	23	12	6	2	2360
	Q_s		5400	900	235	30	7.6	2.2	.8	.2	21400
03267800	Q_w	1966–69	1450	660	460	290	210	155	120	86	3780
	C		840	160	98	58	27	15	10	4	3080
	Q_s		3000	250	81	34	15	7.0	4.2	1.4	10400
04193500	Q_w	1960–73	38000	21000	13000	4900	1400	470	240	108	79000
	C		580	280	170	70	35	18	8	3	2250
	Q_s		50000	15000	5800	860	115	24	7.4	2.2	174000
04195500	Q_w	1951–56	4650	1900	1000	265	57	12	5.7	2	8740
	C		550	270	120	49	23	9	4	1	1270
	Q_s		5500	1220	340	23	1.9	.5	.2	.1	27900
04198000	Q_w	1951–56	10000	4500	2450	730	140	43	23	13	17700
	C		660	270	170	64	23	9	3.3	1	1500
	Q_s		14000	3000	1100	105	8.0	1.4	.4	.2	47000
04208000	Q_w	1960–73	4900	2650	1850	980	420	190	135	92	10700
	C		1300	480	260	87	37	21	14	7	5120
	Q_s		11000	2800	970	200	43	12	6.3	2.4	51400

[1] Q_w = Water discharge, in cubic feet per second.
C = Discharge-weighted mean sediment concentration, in milligrams per liter.
Q_s = Suspended-sediment discharge, in tons per day.
[2] Affected by highway construction during period of record.

TABLE 7.—*Daily duration table of water discharge and the corresponding estimated discharge-weighted mean sediment concentration and estimated suspended-sediment discharge for inventory network sediment stations in Ohio (water years 1946–70)*

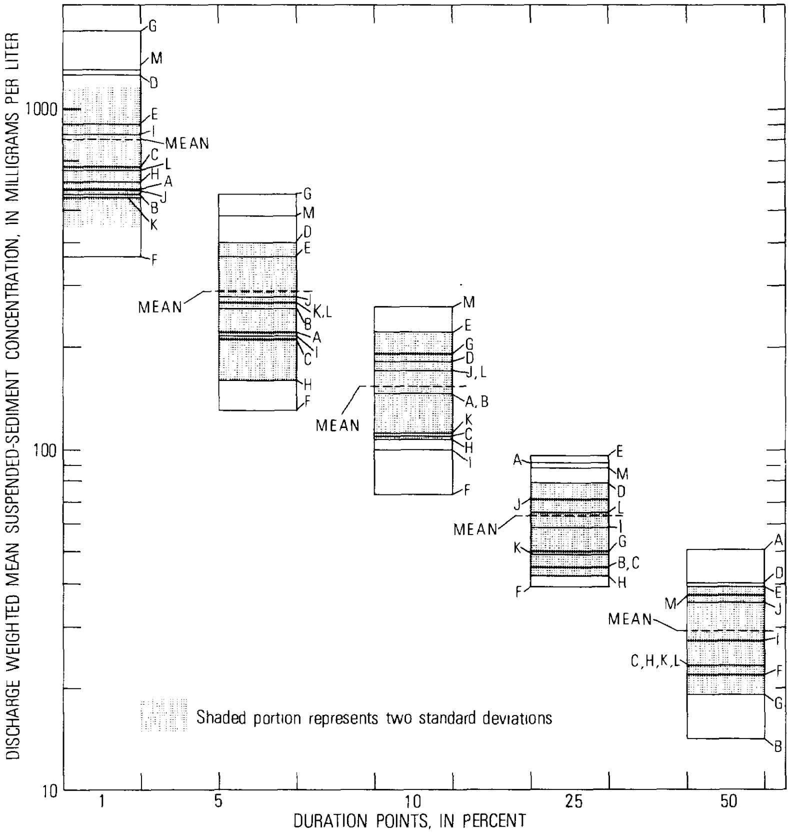
Station No.	Parameter[1]	Percent of time indicated value of parameter was equaled or exceeded							
		0.1	1	5	10	25	50	75	90
03109500	Q_w	10400	3970	1750	1160	560	200	82	46
	C	1900	306	65	30	7	7	7	7
	Q_s	53500	3280	305	93	10	3.6	1.5	0.84
03110000	Q_w	3000	1300	580	380	172	60	20	8.3
	C	1520	405	114	58	11	6	3	2
	Q_s	12300	1420	178	60	5.3	1	.18	.05
03111500	Q_w	2000	785	410	252	140	62	30	19
	C	1950	585	254	136	64	134	29	11
	Q_s	10500	1240	281	92	24	22	2.3	.56
03114000	Q_w	3900	1580	660	410	185	60	10	1.7
	C	1550	315	68	29	6	7	--	--
	Q_s	16300	1340	120	32	2.8	1.1	.27	.06
03115400	Q_w	5850	2750	1070	640	275	74	9.2	1.2
	C	671	259	79	41	12	12	13	14
	Q_s	10600	1920	227	71	8.7	2.5	.33	.05
03116200	Q_w	2400	1200	620	320	115	36	16	10
	C	345	235	163	113	43	40	38	37
	Q_s	2230	760	272	97	13	3.9	1.6	.99
03117500	Q_w	4100	1850	910	610	290	115	48	30
	C	693	213	74	41	16	12	10	8
	Q_s	7680	1060	182	67	13	3.8	1.2	6.7
03123000	Q_w	3400	1290	540	320	128	43	17	9.3
	C	542	268	142	97	37	35	33	32
	Q_s	4980	932	207	84	13	4	1.5	.80
03137000	Q_w	11800	4400	1750	1080	480	200	96	66
	C	1500	332	81	39	8	7	7	6
	Q_s	47900	3940	382	112	10	3.9	1.7	1.1
03144000	Q_w	3400	1300	530	320	160	58	19	9.7
	C	768	353	83	27	11	8	6	5
	Q_s	7050	1240	118	23	4.6	1.3	.32	.14
03146000	Q_w	3500	1640	495	240	93	33	11	5.8
	C	492	230	69	34	12	14	17	20
	Q_s	4650	1020	93	22	2.9	1.2	.52	.31
03159540	Q_w	4000	2340	700	345	135	38	7.5	2.7
	C	1210	687	191	90	11	13	15	17
	Q_s	13100	4340	361	84	4	1.3	.30	.12
03202000	Q_w	11400	4900	2650	1750	680	190	51	18
	C	215	111	68	49	9	5	3	1
	Q_s	6600	1460	488	232	16	2.4	.34	.07
03223000	Q_w	3700	1700	700	355	112	32	7.4	3
	C	645	283	110	54	21	27	--	--
	Q_s	6440	1300	208	51	6.4	2.3	.71	.34
03230500	Q_w	12000	4850	1900	1100	410	130	45	22
	C	1700	533	161	80	20	23	27	30
	Q_s	55100	6980	825	237	22	8.2	3.3	1.8
03230800	Q_w	5120	2070	715	445	177	64	23	8.8
	C	1990	495	97	47	42	30	21	15
	Q_s	27500	2770	187	56	20	5.1	1.3	.35
03232000	Q_w	5900	2250	970	575	210	61	13	3.6
	C	2060	428	108	46	18	13	9	6
	Q_s	32900	2600	283	72	10	2.2	.30	.06
03237500	Q_w	17500	6400	1850	900	320	92	20	4.3
	C	2250	748	193	88	49	34	22	14
	Q_s	106000	12900	962	213	43	8.5	1.2	.16
03238500	Q_w	9400	3800	1100	500	130	36	8.8	2.2
	C	1350	587	188	91	27	26	24	23
	Q_s	34200	6020	558	123	9.6	2.5	.57	.13
03246200	Q_w	9350	3400	880	390	138	35	8.2	1.3
	C	544	325	163	108	64	32	15	6
	Q_s	13700	2980	388	114	24	3	.34	.02
03262700	Q_w	16500	8000	4000	2000	700	250	100	58
	C	775	350	163	76	28	21	16	14
	Q_s	34500	7550	1760	411	53	14	4.4	2
03264000	Q_w	4150	1900	690	390	168	72	34	21
	C	1250	437	111	52	30	23	18	15
	Q_s	14000	2240	208	54	14	4.4	1.6	.84

TABLE 7.—*Daily duration table of water discharge and the corresponding estimated discharge-weighted mean sediment concentration and estimated suspended-sediment discharge for inventory network sediment stations in Ohio (water years 1946–70)*—Continued

Station No.	Parameter[1]	Percent of time indicated value of parameter was equaled or exceeded							
		0.1	1	5	10	25	50	75	90
03267000	Q_w	2200	800	360	260	160	96	63	46
	C	2370	401	99	56	30	19	14	10
	Q_s	14100	866	96	39	13	5	2.3	1.3
03271800	Q_w	8350	2650	870	410	158	52	20	10
	C	1950	479	123	49	24	16	11	9
	Q_s	44100	3430	288	54	10	2.3	.62	.24
03272800	Q_w	5500	1400	460	250	100	36	12	6.5
	C	1540	607	285	188	8	12	18	23
	Q_s	22900	2300	354	127	2.2	1.2	.58	.40
04185000	Q_w	4800	2500	1350	850	320	107	37	20
	C	70	71	72	73	75	77	80	81
	Q_s	908	481	264	168	65	22	8	4.4
04186500	Q_w	6000	3000	1300	675	215	67	27	16
	C	640	399	226	145	35	44	53	59
	Q_s	10400	3240	794	264	20	8	3.9	2.6
04189000	Q_w	6100	3050	1200	620	170	43	17	8.3
	C	631	362	172	101	36	21	24	26
	Q_s	10400	2980	556	169	16	2.8	1.1	.59
04191500	Q_w	33000	18800	8900	4900	1450	360	75	33
	C	702	414	205	117	46	39	31	28
	Q_s	62600	21000	4930	1550	181	37	6.4	2.5
04196000	Q_w	2100	1090	370	180	65	19	5.2	3
	C	783	417	147	74	30	15	7	7
	Q_s	4440	1230	147	36	5.3	.77	.10	.04
04196800	Q_w	4250	1980	940	480	102	20	2	.25
	C	775	451	266	165	41	33	24	18
	Q_s	8890	2410	674	214	11	1.8	.13	.01
04197000	Q_w	11000	6200	3000	1500	470	137	43	22
	C	677	435	248	145	22	23	24	24
	Q_s	20100	7280	2010	588	27	8.3	2.7	1.4
04199000	Q_w	8000	3800	1280	610	220	64	23	13
	C	2750	919	185	62	14	5	7	7
	Q_s	59400	9420	640	102	8.2	.95	.41	.25
04199500	Q_w	6500	3000	1060	550	165	43	10	2.4
	C	2230	753	175	70	15	12	10	9
	Q_s	39100	6100	501	104	6.0	1.4	.28	.06
04200500	Q_w	8300	4150	1400	730	220	53	17	9.1
	C	1010	475	146	72	21	11	6	5
	Q_s	22600	5320	551	141	13	1.5	.29	.11
04212000	Q_w	10700	6300	3000	1950	710	170	31	11
	C	450	227	87	50	12	11	11	10
	Q_s	13000	3860	704	262	22	5.1	.88	.30
04212500	Q_w	4000	1600	680	410	150	39	4.7	.50
	C	448	138	46	24	9	5	2	1
	Q_s	4840	594	84	26	3.5	.53	.03	.00
04213000	Q_w	5600	2650	1170	700	260	86	24	11
	C	1110	373	114	54	9	7	5	4
	Q_s	16700	2670	359	102	6.3	1.6	.34	.13

[1] Q_w = Water discharge in cubic feet per second.
C = Discharge-weighted mean sediment concentration, in milligrams per liter, estimated by method using daily water-discharge duration curve and instantaneous suspended-sediment rating curve.
Q_s = Suspended-sediment discharge, in tons per day, estimated by method using daily water-discharge duration curve and instantaneous suspended-sediment rating curve.

Figure 5 shows a graphical comparison of concentrations from the daily stations for the 1, 5, 10, 25, and 50-percent duration points. Using these stations as an index for Ohio, one could con-



EXPLANATION

Symbol	Station No	Location
A	03139000	Killbuck Creek at Killbuck
B	03159500	Hocking River at Athens
C	03229000	Alum Creek at Columbus
D	03234000	Paint Creek near Bourneville
E	03234500	Scioto River at Higby
F	03240000	Little Miami River near Oldtown
G	03244000	Todd Fork near Roachester
H	03265000	Stillwater River at Pleasant Hill
I	03267800	Mad River at Eagle City
J	04193500	Maumee River at Waterville
K	04195500	Portage River at Woodville
L	04198000	Sandusky River near Fremont
M	04208000	Cuyahoga River at Independence

FIGURE 5.—Discharge-weighted mean sediment concentrations at selected duration points.

clude that 75 percent of the time suspended-sediment concentration is below 100 mg/L, and 50 percent of the time concentrations are below 50 mg/L. The highest concentrations for the daily stations occurred in the Cuyahoga River, Todd Fork, and Paint Creek basins. The latter two are adjacent basins in the southeastern part of the Indiana and Ohio Till Plains (Major Land-Resource Area (MLRA) 111), whereas, the Cuyahoga River is in the Eastern Ohio Till Plains (MLRA 139). The characteristics of these basins are quite similar, with steeper stream gradients and more rugged topography than the other 10 basins.

Relatively high concentrations in Todd Fork are not sustained, as the concentration equaled or exceeded 25 percent of the time is below the average for the 13 stations. The lower concentrations at the higher duration points for Todd Fork are typical for smaller basins, where the concentration of sediment is more dependent on basinwide storms, whereas major tributaries are the major influence on sustaining flow and concentration in large basins. Except for the 10- and 25-percent duration values, the concentration at Sandusky River near Fremont represents the median of the 13 stations. Lowest concentrations occurred in the Little Miami River near Oldtown and the Stillwater River at Pleasant Hill. Both basins are in gently sloping areas of the Indiana and Ohio Till Plains (MLRA 111).

SUSPENDED-SEDIMENT DISCHARGE

The terms "load" and "discharge" are sometimes used synonymously in relation to fluvial sediment. Load is a less specific term that commonly designates the amount of sediment carried by a particular mode of transport, such as, suspended load, bedload. Sediment discharge is defined as the time rate at which the dry weight of sediment passes a section of a stream. Suspended-sediment discharge (Q_s), expressed in tons per day, is easily computed using the discharge equation

$$Q_s = kQ_wC$$

where

k = conversion factor of 0.0027
Q_w = water discharge in cubic feet per second (ft^3/s)
C = discharge-weighted mean concentration in milligrams per liter (mg/L)

If Q_s is expressed in metric tons (tonnes) and Q_w is in cubic meters per second (m^3/s), k is equal to 0.0864.

Q_s is commonly referred to as the measured sediment discharge. The difference between the total sediment discharge and the measured sediment is termed "unmeasured sediment discharge." The unmeasured discharge is the rate of sediment moving as bedload plus that part of the suspended sediment discharged in the unsampled zone (explained previously in methodology), but not represented in the sampled zone. The unmeasured suspended-sediment discharge is applicable when the concentration in the unsampled zone exceeds the sampled concentration. This difference in concentration, as previously shown in figure 4, is due to the presence of coarser particles that are in suspension but that are not uniformly dispersed. The lack of coarse particles in suspension (see discussions on concentration and particle size) in Ohio streams infers that measured sediment discharge is usually equal to the suspended-sediment discharge in Ohio streams.

DAILY RECORD STATIONS

Daily suspended-sediment discharge is calculated using the discharge equation, $Q_s = kQ_wC$, with C determined from a continuous concentration curve, which is defined by sample concentrations. Because the concentration determined from this curve is actually a time-weighted concentration, daily sediment discharge, for days with fluctuating water discharge and sediment concentration, is calculated by subdividing the day into selected time intervals and summing the sediment discharges, computed by the discharge equation, for each time interval.

Duration values of daily suspended-sediment discharge are given in table 6 for daily record stations. These values indicate the variability of daily sediment discharge at each station during the indicated period of record. The relation between water discharge and suspended-sediment discharge can be shown in table 8, which gives the percentage of total suspended-sediment discharge and percentage of total water discharge for both water and sediment duration values. Table 8 shows that sediment at the daily stations is storm influenced and is transported in a short period of time. An average of the daily station data shows that 89 percent of the total sediment discharge occurs in 10 percent of the time and is transported by 51 percent of the total water discharge. An average of percentages in table 8 reveals that 41 percent of the total suspended-sediment discharge is contributed by sediment discharges that are equaled or exceeded 1 percent of the time. Water discharges, equaled or exceeded 1 percent of the time, however, transported 37 percent of the total sediment discharge. This indicates that high sediment discharges are not always transported by the highest water discharges, and, furthermore, this shows peak sediment concentration preceding peak water discharge in Ohio streams during appreciable runoff.

TABLE 8.—*Percentages of total water discharge and suspended-sediment discharge contributed by daily discharges that equal or exceed selected duration values at daily record stations*

Station No. and period of record	Parameter [1]	Percent of total water (or) suspended-sediment discharges for indicated percentages of time: 1	5	10	25	50	75	90
03139000	a	18.4	38.0	52.0	74.7	90.4	96.8	99.1
(1963–69).	b	15.4	32.7	48.3	72.1	87.0	94.8	98.2
	c	58.8	77.4	86.2	95.4	98.8	99.8	<100
	d	53.9	70.1	81.1	93.3	98.0	99.4	99
03159500	a	15.8	39.9	55.0	78.6	93.6	97.6	99.4
(1960–65).	b	12.9	37.7	54.7	78.5	92.7	96.6	97.7
	c	32.7	72.6	88.5	98.0	99.8	99.9	<100
	d	25.3	67.0	86.1	97.6	99.7	99.9	<100
03229000	a	25.8	53.0	69.6	86.4	96.0	99.1	99.8
(1960–65).	b	24.2	53.3	69.0	85.4	95.0	99.0	99.4
	c	52.6	88.4	95.7	98.9	99.8	<100	<100
	d	48.4	84.5	94.1	98.4	99.7	99.9	<100
03234000	a	14.2	35.9	51.8	76.8	92.6	98.3	99.6
(1957–62).	b	13.0	33.6	49.1	73.3	90.4	98.0	98.9
	c	45.7	81.2	91.5	97.7	99.4	99.9	<100
	d	41.7	74.5	86.8	96.4	99.2	99.8	99.9
03234500	a	8.8	30.3	48.4	71.9	88.8	96.6	99.0
(1960–73).	b	9.2	28.0	44.4	70.6	87.9	96.1	98.8
	c	33.2	66.6	81.4	95.0	98.9	99.8	<100
	d	22.2	56.8	76.7	93.1	98.6	99.7	99.9
03240000	a	14.7	34.6	48.3	70.7	88.6	96.7	99.0
(1953–58).	b	13.0	32.4	44.1	67.3	85.6	94.7	97.0
	c	60.2	83.9	89.8	96.1	99.0	99.8	<100
	d	56.4	81.6	87.5	94.9	98.3	99.6	99.9
03244000	a	21.2	47.4	63.3	83.6	96.1	99.6	<100
(1953–58).	b	15.8	44.1	60.7	81.3	94.6	99.0	99.9
	c	51.5	89.4	97.0	99.5	99.9	100	100
	d	47.8	84.7	92.6	98.8	99.8	<100	100
03267800	a	8.1	20.8	30.3	51.3	68.6	81.9	93.9
(1966–69).	b	7.4	18.8	29.4	45.5	68.2	86.1	94.1
	c	50.2	79.5	85.8	91.9	97.0	99.1	99.7
	d	39.0	75.4	82.0	90.0	93.6	96.2	98.7
03265000	a	18.0	41.9	58.6	79.0	92.9	98.0	99.5
(1964–73).	b	13.6	39.5	55.8	77.4	91.2	97.2	99.1
	c	39.8	81.4	91.9	97.8	99.4	99.9	<100
	d	34.7	75.2	90.0	96.8	99.2	99.8	<100
04193500	a	11.4	35.0	55.3	79.3	94.2	98.5	99.6
(1960–73).	b	9.4	33.7	52.3	78.3	93.4	98.3	99.5
	c	28.7	66.8	84.0	96.3	99.4	99.9	<100
	d	24.4	63.2	83.5	95.8	99.3	99.9	<100
04195500	a	14.7	46.9	65.9	88.8	97.4	99.6	99.9
(1951–56).	b	14.9	45.8	64.2	87.5	96.5	98.6	99.3
	c	39.0	79.9	92.5	99.1	99.9	<100	100
	d	27.5	74.7	90.3	99.0	99.8	<100	100
04198000	a	13.6	44.3	64.1	87.0	97.1	99.3	99.8
(1951–56).	b	11.3	42.0	60.8	85.2	96.2	98.5	99.5
	c	33.2	74.8	89.1	98.4	99.9	<100	100
	d	27.9	70.1	87.1	98.1	99.8	<100	100
04208000	a	7.6	25.1	39.4	65.1	85.8	95.6	98.2
(1960–73).	b	6.6	23.9	36.0	61.2	84.8	95.3	97.8
	c	32.8	70.1	83.2	94.6	98.7	99.7	99.9
	d	25.9	58.8	74.2	89.6	97.7	99.6	99.9
Average for	a	14.8	37.9	54.0	76.4	90.9	96.7	99.0
stations.	b	12.8	35.8	51.4	74.1	89.5	96.3	98.4
	c	40.8	77.8	89.0	96.8	99.2	99.8	<100
	d	36.6	72.0	85.5	95.5	98.7	99.6	99.9

[1] a = Percent of total water discharge contributed by water discharges equaled or exceeded indicated percentage of time.
b = Percent of total water discharge occurring with suspended-sediment discharges equaled or exceeded indicated percentage of time.
c = Percent of total suspended-sediment discharge contributed by suspended-sediment discharges equaled or exceeded indicated percentage of time.
d = Percent of total suspended-sediment discharge occurring during water discharges equaled or exceeded indicated percentage of time.

Sediment records must be extended to a long period representative of average conditions to obtain the mean annual suspended-sediment discharge. The 25-water-year period, 1946–70, was selected as the base period for this report. A method, described by Dawdy and Matalas (1964, chap. 8, p. 70), to test the homogeneity of variance by means of the chi-square distribution, was applied to five long-term-record streamflow stations in Ohio to evaluate the selected base period. The number of years of record for those five stations ranges from 39 to 57 years and averages 46 years. The variance of annual mean water discharge was tested. The hypothesis that the variance for the 25-year period and the variance for the remaining years of station record were homogeneous was accepted at the 1-percent level of confidence for each of the five stations.

The selected base period is also desirable because continuous water-discharge data were collected during the period at many of the daily and inventory network stations. Except for three stations in the Little Miami River basin, mean annual sediment discharge was estimated for daily stations with a minimum of 5 years of sediment record and with a continuous discharge record during the 1946–70 base period.

A slight modification of Nelson's (1970) least squares relation between the logarithms of annual sediment, Q_{sa}, and an independent variable, Kn, was used to estimate mean annual sediment discharge at daily suspended-sediment stations. The modification occurs in the variable, Kn. Nelson (1970) computed Kn as the multiple product of annual mean water discharge, annual peak water discharge, and the factor 10^{-6}. This Kn provided a good least squares relationship for streams in the State of Washington, where a large part of the annual sediment discharge is transported during the day of peak water discharge.

In Ohio annual peak discharge is not as significant in its contribution to the annual sediment discharge. Major runoff is more frequent in Ohio. One can expect a yearly average of three significant times of runoff in a given stream basin. Kn was modified to include the influence of other runoff by setting it equal to the multiple product of annual mean water discharge, the sum of the peak water discharges above a base discharge, and the factor 10^{-6}. The base discharge is defined as discharge that on the average is not exceeded more than three times a year. Only peaks from independent runoff are considered in determining Kn. Figure 6 shows the least squares relation for station, 04195500, Portage River at Woodville, Ohio. Mean annual sediment discharge is computed as

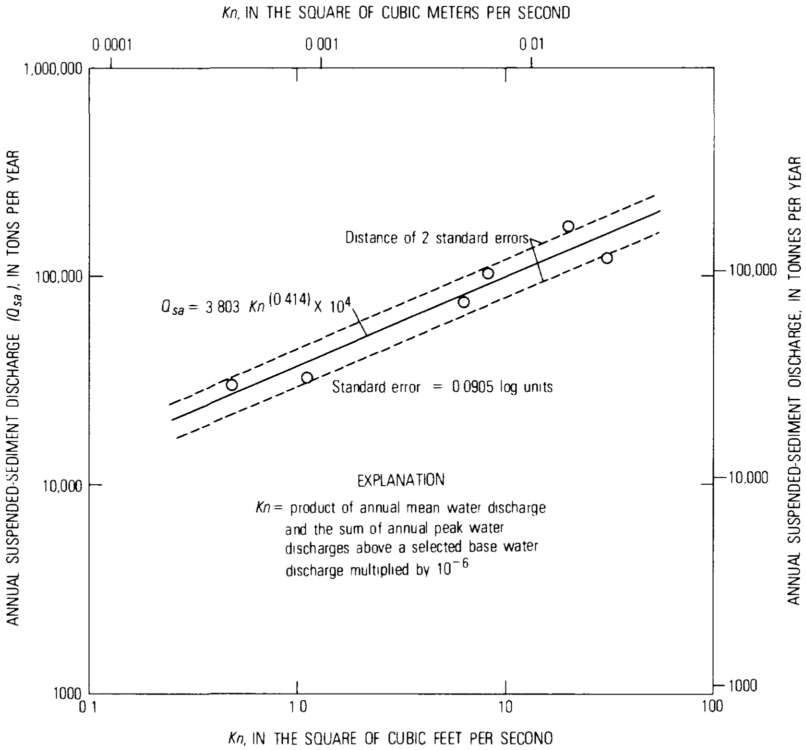


FIGURE 6.—Least squares relation of annual suspended-sediment discharge to *Kn* for station 04195500, Portage River at Woodville, Ohio.

the mean of the 25 annual sediment discharges which were determined from the least squares relation using the annual values of *Kn*. The least squares equation, standard error of estimate, mean annual water discharge, and the 25-year mean annual sediment discharge for the daily stations are listed in table 9. The standard error is expressed as a percentage of the calculated value and is defined as the limit above and below the calculated value within which 67 percent of measured values of annual sediment discharge occur.

Stations, 03240000, 03241500, and 03244000, in the Little Miami River basin, did not have a complete water discharge record for the base period. Mean annual sediment discharge for the period of water discharge record (water years 1953–73, for each station) was adjusted to the base period using the following method:

TABLE 9.—*Daily record station summary of mean annual water discharge and suspended-sediment discharge for base period, water years 1946–70, and mean annual suspended-sediment discharge for period of station record*

[Least squares equation of Q_{sa} versus Kn is included]

Station No.	Years of record	Least squares equations $Q_{sa} = a\ (Kn)^b\ 10^1$ *a*	*b*	Standard error (percent)	Mean annual water discharge for 1946–70 (ft³/s)	Mean annual suspended-sediment discharge for 1946–70 (tons/yr)	Mean annual suspended-sediment discharge for period of record (tons/yr)
03139000	7	3.514	0.534	31	402	77500	82400
03159500	9	6.594	.347	15	935	193000	183000
03234000	6	4.893	.481	21	790	294000	288000
03234500	20	19.35	.290	24	4510	1210000	1190000
03240000	6	1.766	.385	32	104	16400	12700
03241500	6	2.463	.543	12	57.5	12200	9490
03244000	6	5.882	.383	17	217	137000	123000
03261500	6	4.012	.315	38	466	77600	86500
03265000	10	3.802	.338	37	440	91500	82900
04193500	23	2.740	.679	34	4910	1180000	1190000
04195500	6	3.803	.414	21	312	78900	90000
04198000	6	4.959	.422	20	957	235000	227000
04208000	23	5.550	.661	28	790	207000	214000

Step 1. A mean annual sediment discharge was computed from the least squares equation using the mean Kn for the period of flow record.

Step 2. A ratio equal to the Kn for the base period divided by the mean Kn for the period to be adjusted was computed from a nearby water discharge record station with a complete record.

Step 3. A mean Kn for the base period of the sediment station was computed by multiplying the mean Kn for the period of record by the ratio computed in step 2.

Step 4. A mean annual sediment discharge was computed from the least squares equation using the computed Kn (step 3) for the base period.

Step 5. A ratio equal to mean annual sediment discharge in step 4 divided by mean annual sediment discharge from step 1 was computed.

Step 6. Mean annual sediment discharge for the period of record was computed as the mean of the computed annual sediment discharges for the period of flow record.

Step 7. Mean annual sediment discharge for the base period was determined by multiplying mean annual sediment discharge for the period of flow record (step 6) by the ratio computed in step 5.

INVENTORY NETWORK STATIONS

Mean annual suspended-sediment discharge can be computed from short-term intermittent sampling by a method that employs an instantaneous sediment-transport curve and a flow-duration curve for a long period of record.

Sediment-transport curves have been described and analyzed in detail by Colby (1956). An instantaneous sediment transport curve is prepared by plotting simultaneous instantaneous suspended-sediment discharges and water discharges on logarithmic coordinates. The instantaneous suspended-sediment discharges are calculated in tons per day by the discharge equation $Q_s = 0.0027\ Q_w C$.

Except for two stations, the plotted points indicated that the transport curves for an inventory network station could be defined by two least squares relations: one relation used for high discharges and the second for the lower discharges. The change between the least squares relations occurred about the 25-percent flow duration point for 79 percent of the stations. The change in the relation for the other stations ranged from the 12.5-percent flow duration value to the 39.0-percent flow duration value. A single least squares relation was fitted to all the plotted points for the other two stations. Addition of the square of the logarithm of instantaneous water discharge to the linear least squares relation added no significance to any of the relations.

Figures 7 to 14 show graphically the least squares relations for each of the network stations. These relations are considered applicable for discharges equal to or less than the 0.1-percent flow duration value. The sediment transport curves for water discharges greater than the 0.1-percent duration value could not be defined during the 5-year collection period. In fact, discharges during the 5 years never exceeded the 0.1-percent duration value at most stations. Extending the least squares relation to include the higher water discharges is unrealistic.

For example, consider extending the transport curve for station 03137000, Kokosing River at Millwood, Ohio (fig. 8). The curve value of suspended-sediment discharge for the maximum daily water discharge of 30,600 ft^3/s is 535,000 tons per day, which yields a discharge-weighted mean sediment concentration of 6,480 mg/L. The duration table (table 6) for daily stations strongly indicates that a concentration of this magnitude is not probable in the Kokosing River basin. Further justification for not extending the least squares relation for water discharges greater than the 0.1-percent duration value has been shown in table 8, where the highest sediment discharges do not always occur with the highest water discharges. Comparison of the maximum daily mean concentration and the mean concentration of the maximum daily water discharge reveals that the latter concentration was substantially less (averaging 37 percent of the maximum daily concentration for the 13 stations) at the stations listed in table 6.

Flow duration values for the base period are given in table 7. Complete water discharge data were available during the base period for 45 percent of the stations. Duration values for the

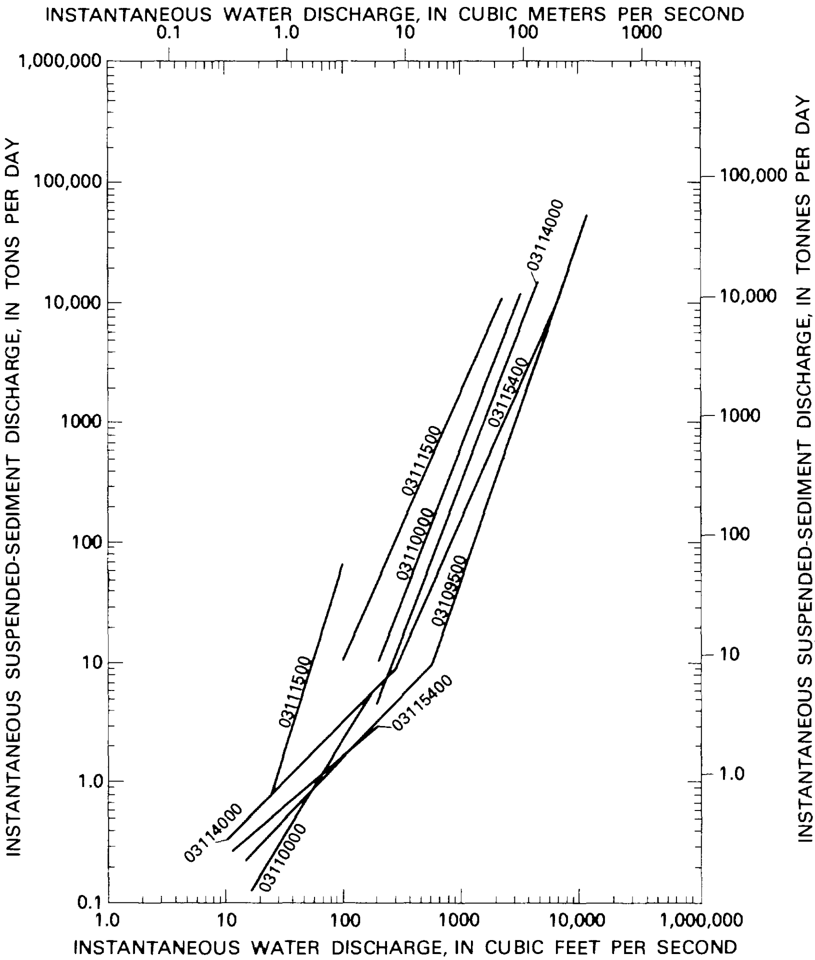


FIGURE 7.—Instantaneous suspended-sediment transport curves for inventory network stations on streams tributary to the Ohio River between the Shenango River and the Muskingum River.

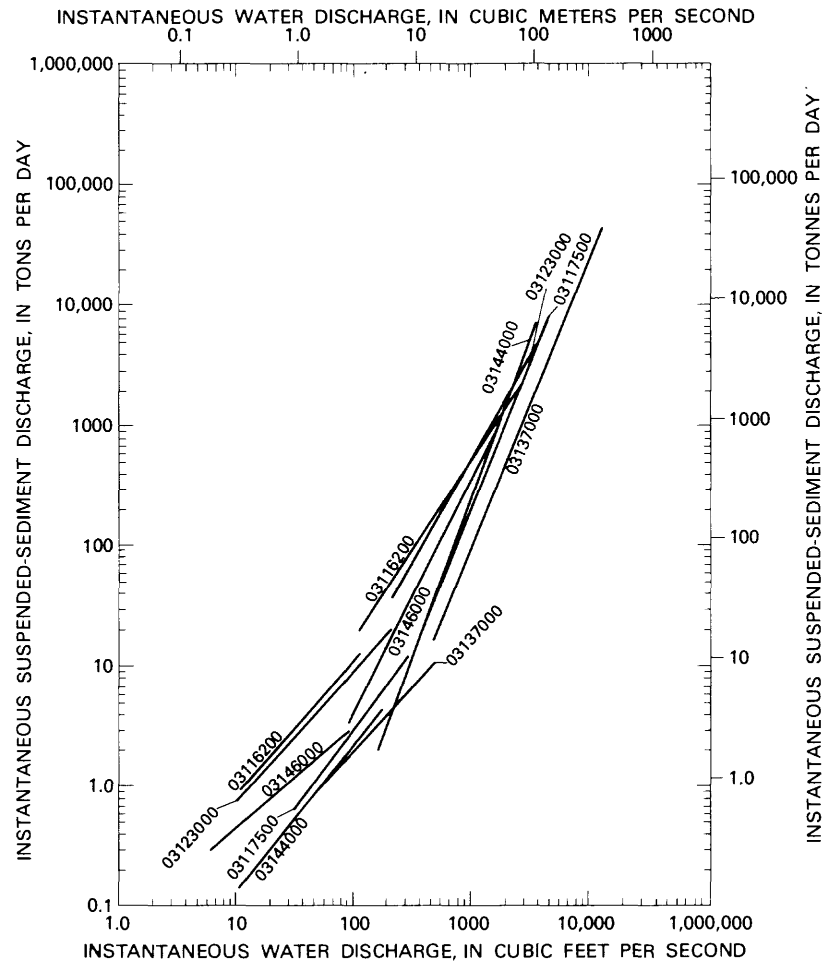


FIGURE 8.—Instantaneous suspended-sediment transport curves for inventory network stations on streams in the Muskingum River basin.

period of flow record for the other stations were adjusted to the base period by the method described by Cross and Hedges (1959).

The method to compute the 25-year mean annual suspended-sediment discharge is illustrated in table 10 by the computation for station 03137000, Kokosing River at Millwood, Ohio:

1. Water discharges (column 2) equaled or exceeded for selected percentages of time (column 1) are determined from the flow-duration curve for the base period. Intervals between succeeding percentages of time (column 5) are smaller at

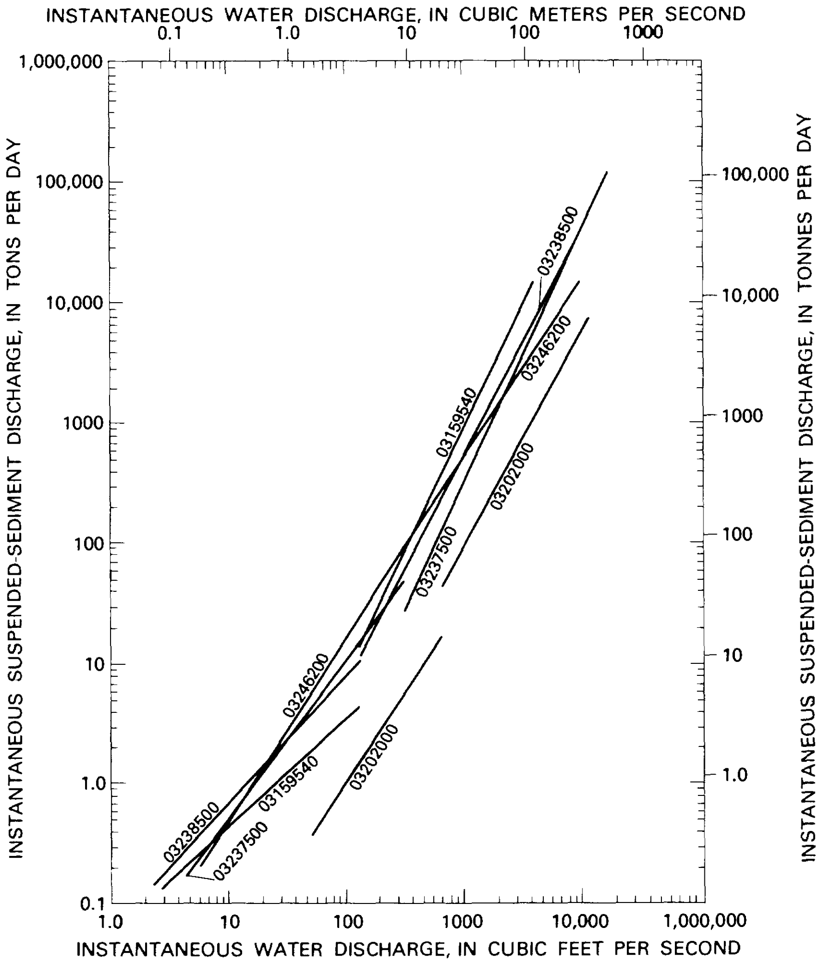


FIGURE 9.—Instantaneous suspended-sediment transport curves for inventory network stations on streams tributary to the Ohio River between the Muskingum River and the Great Miami River, excluding the Scioto River basin.

the lower percentages because of the large differences in discharge between them. Note especially the large difference between the maximum daily discharge, 0.01-percent duration value, and the discharge for the 0.1-percent value. For several stations there was considerable difference between the maximum and second highest daily discharges. The selection of percentages of time are evaluated by computing the mean annual flow as follows:

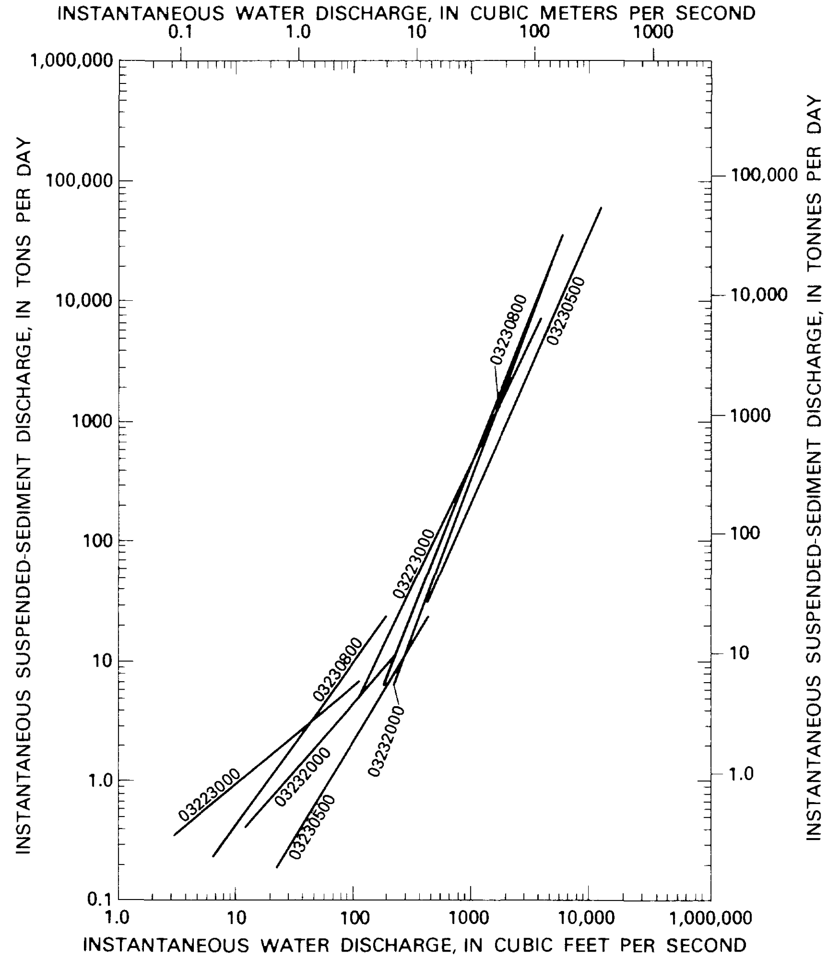


FIGURE 10.—Instantaneous suspended-sediment transport curves for inventory network stations on streams in the Scioto River basin.

a. Except for the 0.01 and 0.02 percentages, the mean discharges for each interval of time are computed as the average of the discharges at the limits of each interval. The mean discharges for the 0.01 and 0.02 percentages are the maximum and second highest daily mean discharges, respectively. (One day represents 0.01 percent of the 25-year period.)
b. The mean discharges are multiplied for each interval by the percentage interval. These products are listed in column 6.

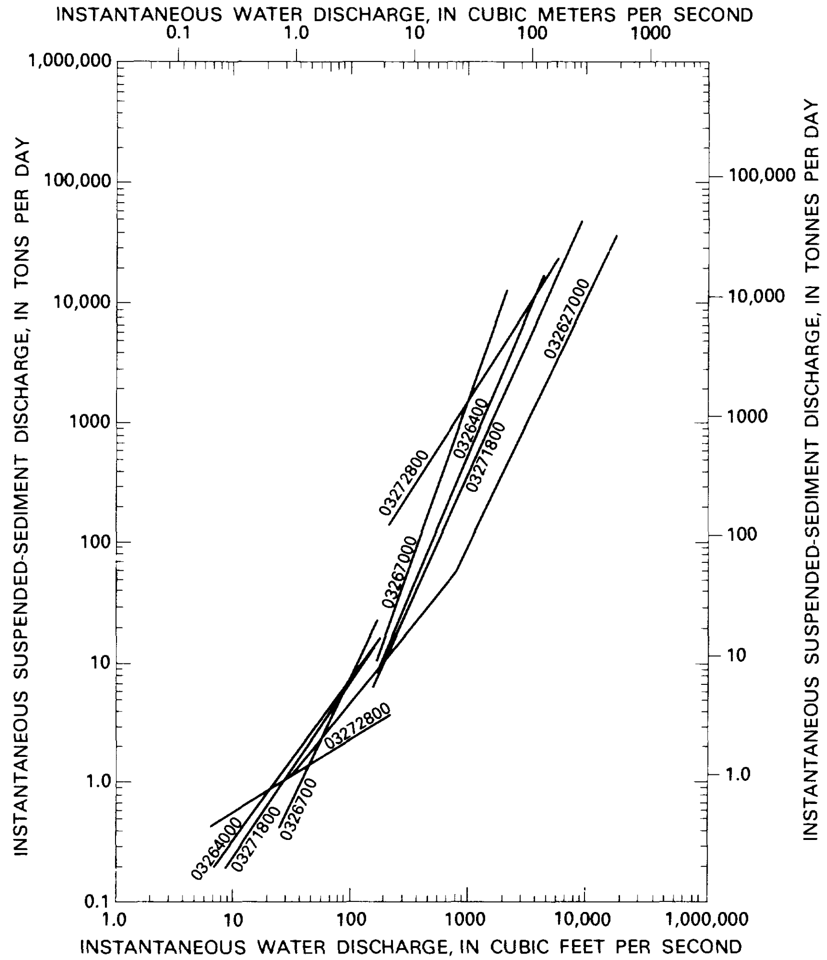


FIGURE 11.—Instantaneous suspended-sediment transport curves for inventory network stations on streams in the Great Miami River basin.

c. Mean annual flow is equal to the sum of the products divided by 100.

d. If water discharge records were collected during the base period, the computed mean annual flow is compared to the true mean annual flow (computed mean of the annual means). The percentages are changed, if necessary, so that the difference between the computed and true mean is less than 5 percent of the true value. The computed value of 487 ft^3/s for station 03137000 is

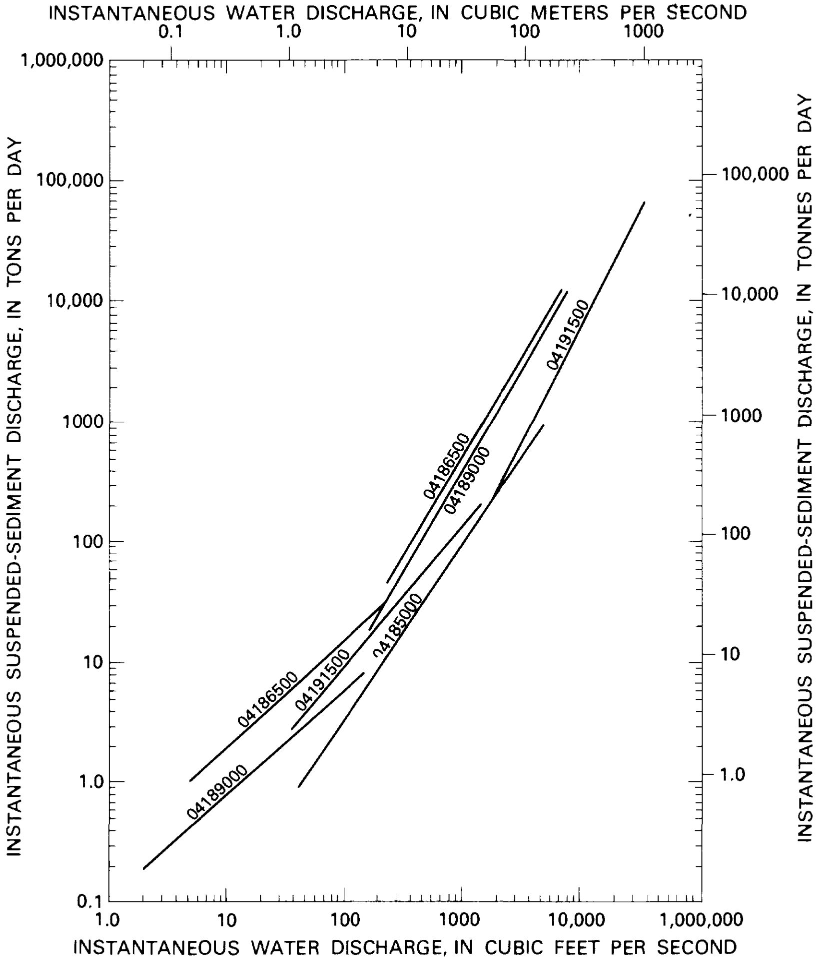


FIGURE 12.—Instantaneous suspended-sediment transport curves for inventory network stations on streams in the Maumee River basin.

well within 5 percent of the true mean annual flow of 479 ft^3/s.

2. Sediment discharges (column 3) are determined from the least squares lines, figure 15, for all discharges in column 2 that are equal to or less than the 0.1 percent discharge. For station 03137000 sediment discharges that were exceeded 25 percent of the time but were less than the discharges exceeded 0.1 percent of the time were determined from the line represented by the equation, $Q_s = [2.34(Q_w)^{2.53}]10^{-6}$.

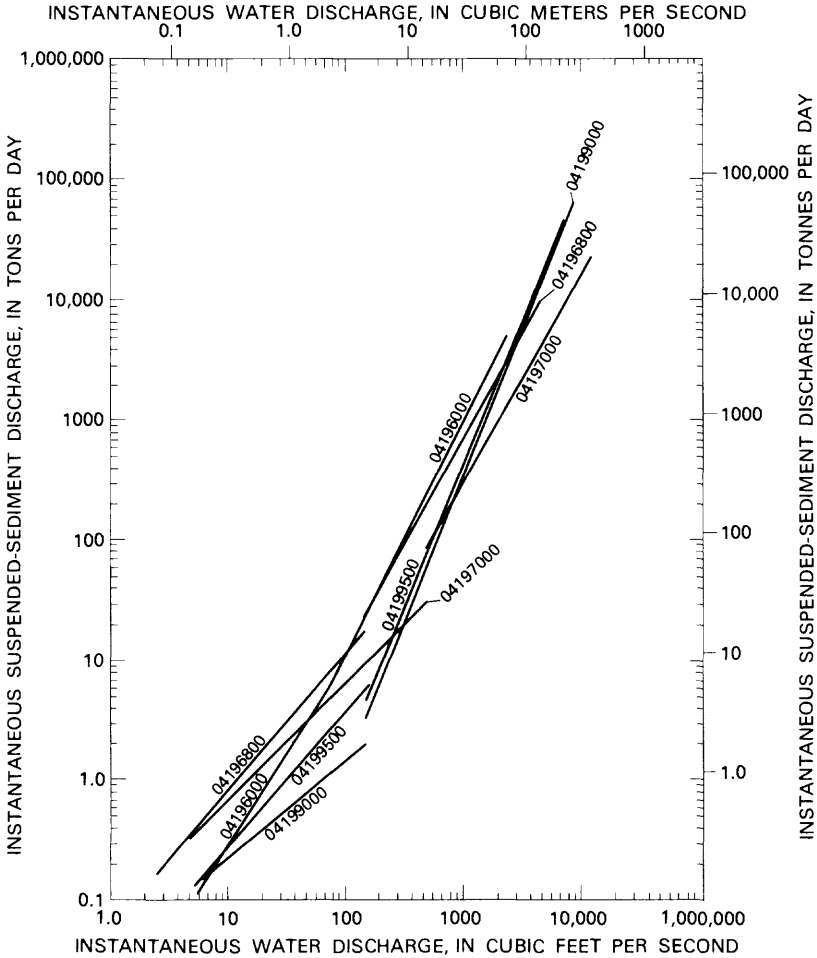


FIGURE 13.—Instantaneous suspended-sediment transport curves for inventory network stations on streams tributary to Lake Erie from and including the Sandusky River to the Vermilion River.

Sediment discharges equal to or less than the 25-percent duration discharge were computed from the relation, $Q_s = [1.03(Q_w)^{1.12}]10^{-2}$. Sediment discharges exceeded 0.1 percent of the time were computed by the discharge equation, $Q_s = 0.0027\ Q_w C$, using an estimated value of C. The estimated concentration was based on sediment records from nearby daily stations and the distribution of sample concentrations during the 5-year collection period.

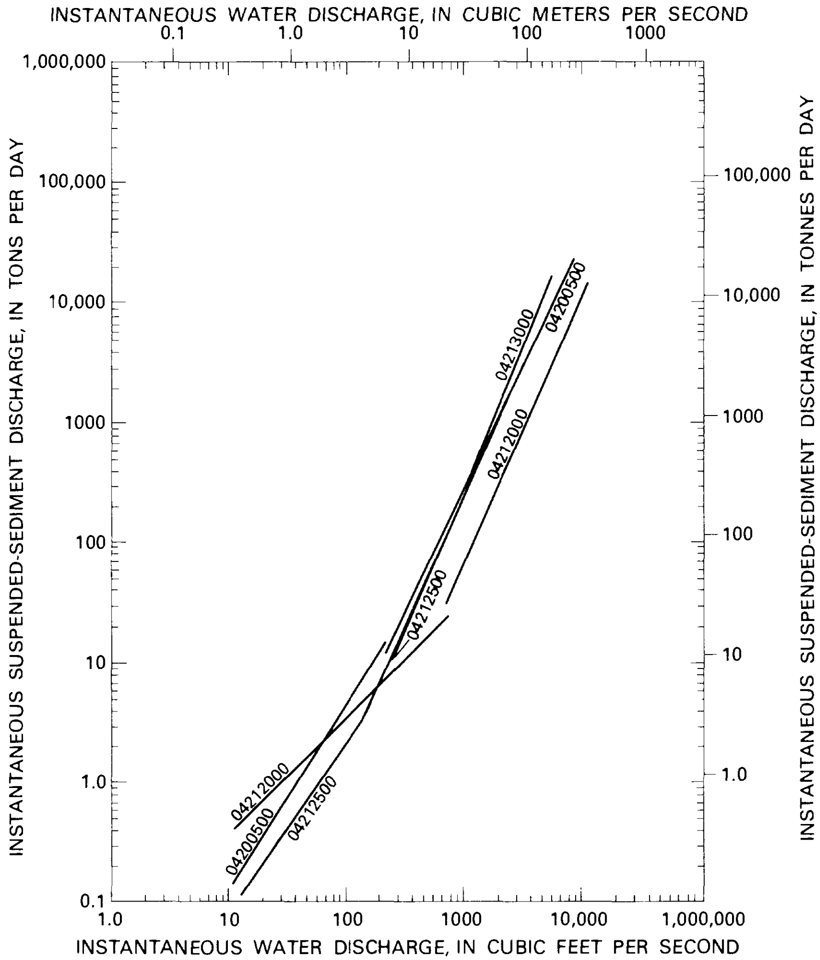


FIGURE 14.—Instantaneous suspended-sediment transport curves for inventory network stations on streams tributary to Lake Erie from and including the Black River to Conneaut Creek.

3. Concentrations (column 4) are determined for the other percentages of time by using the values in columns 2 and 3 and solving the discharge equation for C.
4. The mean sediment discharge for each time interval was computed as described previously in step 1a, except for the discharges exceeded 0.1 percent of the time, which are computed by the discharge equation using the mean water discharge for the percentage intervals.

TABLE 10.—*Computation of mean annual suspended-sediment discharge for station, 03137000, Kokosing River at Millwood, Ohio*

Percentage of time	Water discharge equaled or exceeded (ft^3/s)	Suspended-sediment discharge (tons/day)	Discharge-weighted concentration (mg/L)	Interval between succeeding percentages of time	Water discharge multiplied by time interval (ft^3/s)	Suspended sediment multiplied by time interval (tons)
0.01	30600	82620	1000	0.01	306	826
0.02	23000	62100	1000	0.01	230	621
0.05	15000	40500	1000	0.03	570	1539
0.10	11800	47933	1504	0.05	670	1809
0.18	8200	19069	861	0.08	800	2680
0.35	6700	11433	632	0.17	1266	2593
0.65	5500	6936	467	0.30	1830	2755
1.00	4400	3942	332	0.35	1732	1904
1.30	3700	2542	254	0.30	1215	972
2.00	3000	1494	184	0.70	2345	1413
3.00	2400	849	131	1.00	2700	1172
3.90	2000	535	99	0.90	1980	623
5.00	1750	382	81	1.10	2062	504
7.70	1300	180	51	2.70	4118	758
10.00	1080	112	39	2.30	2737	336
12.60	880	67	28	2.60	2548	233
16.30	720	40	21	3.70	2960	198
20.40	590	24	15	4.10	2686	132
25.00	480	10	8	4.60	2461	80
30.90	390	8.3	8	5.90	2566	56
42.30	260	5.3	8	11.40	3705	77
50.00	200	3.9	7	7.70	1771	35.
75.00	96	1.7	7	25.00	3700	71
90.00	66	1.1	6	15.00	1215	21
100.00	34	.5	6	10.00	500	8

Mean annual flow (ft^3/s) = 487
Mean daily suspended-discharge (tons per day) 214
Mean annual suspended-sediment discharge (tons per year) 78200

5. The mean sediment discharge for each interval was multiplied by the percentage interval (column 7).
6. The mean daily sediment discharge was computed as the sum of the products in column 6 divided by 100.
7. The mean annual sediment discharge, in tons, for the base period is equal to the mean daily sediment discharge multiplied by 365.24 days.

The duration values for sediment discharge and sediment concentration in table 7 were taken from columns 3 and 4, respectively, of the computation of mean annual sediment discharge for the inventory network stations. The mean annual suspended-sediment discharge, the computed mean annual flow, and the true mean water discharge (if available) for the inventory network stations are listed in table 11.

The average percentages of total water discharge and total suspended sediment discharge, that respective water and sediment discharges equaled or exceeded given duration values, are given in table 12 for the inventory network stations. The 12 percent of

TABLE 11.—*Mean annual values, water years 1946–70, for inventory network stations*

Station No.	Mean annual suspended-sediment discharge (tons year)	True mean [1] annual water discharge (ft³/s)	Computed mean [2] annual water discharge (ft³/s)
03109500	68200	486	490
03110000	26100	152	155
03111500	30000	115	117
03114000	30400	--	172
03115400	33700	--	266
03116200	19300	--	130
03117500	23900	252	255
03123000	21500	132	135
03137000	78200	479	487
03144000	21800	144	147
03146000	16500	--	120
03159540	53200	--	167
03202000	39700	614	623
03223000	24200	--	147
03230500	120000	453	457
03230800	45100	--	191
03232000	53900	--	226
03237500	213000	440	450
03238500	102000	244	248
03246200	51000	--	211
03262700	135000	--	817
03264000	34800	180	183
03267000	22300	141	142
03271800	72500	--	211
03272800	49100	--	125
04185000	22800	304	309
04186500	64900	278	279
04189000	51700	245	251
04191500	373000	1760	1750
04196000	17700	--	82.0
04196800	47200	--	166
04197000	140000	576	584
04199000	134000	--	291
04199500	93900	--	232
04200500	84400	306	310
04212000	69700	680	690
04212500	12200	--	158
04213000	42700	--	275

[1] Mean of annual means for 1946–70 water years.
[2] Computed from flow duration curve.

total sediment discharge, contributed by sediment discharges that were exceeded 0.1 percent of the time, represents the sediment discharge not computed from a least squares relation. The percentages in table 12 compare favorably with those given in table 8 for the daily stations. Note especially, that the percentages of sediment discharge in table 12 agree more favorably with the corresponding percentages for the sediment discharge duration values (parameter c in table 8). For example, an average of 89 percent of the suspended sediment and 54 percent of the water was discharged in 10 percent of the time at the daily stations, while the respective average percentages at the inventory network stations were 92 and 58. The implied agreement between the percentages

TABLE 12.—*Average percentages of total water discharge and total suspended-sediment discharge at various time duration percentages for the inventory network stations, Ohio, 1946–70*

Type of discharge	Percent of total discharge for indicated time duration percentages							
	0.1	1.0	5.0	10	25	50	75	90
Water discharge	3.3	16.8	42.2	58.5	80.3	93.6	98.5	99.7
Suspended-sediment discharge	12.2	52.6	82.4	91.5	97.2	99.2	99.8	99.9

for daily stations and inventory network stations indicates that the method of computation is satisfactory for Ohio streams.

PARTICLE SIZE OF SUSPENDED SEDIMENT

Established particle-size distributions of suspended sediment in streams are helpful in defining the soil characteristics of their respective drainage basins. Major changes or shifts in the particle-size distribution may indicate changing basin conditions.

Particle-size data are necessary in the design and control of stream impoundments. Compaction rates of entrapped sediment within these impoundments are related to the amount and size distribution of the sediment transported by the streams (F.I.A.S.P., 1943). Size information also is important in the design and operation of water-treatment facilities. Treatment-plant operations can be overloaded and (or) made costly by excessive clay and sand.

Entire biological populations have been reduced, eliminated, or altered because of shifts in the amount or type of transported sediment (McKee and Wolf, 1971). Photosynthetic activity of aquatic flora, being directly related to available light energy, is especially sensitive to the light scattering concentrations of suspended silt and clay. Benthic (bottom dwelling) organisms are vulnerable, not only to the sediment concentrations in the water, but also to sediment changes in the streambed.

Transport of sorbed substances, such as trace metals, organic material, and nutrients on the surfaces of suspended sediments has been well documented (Sayre and others, 1963). As a sediment particle is broken down into progressively smaller fragments, the total surface area increases according to the approximation $A=1/d$, in which A is the total surface area of a given weight of sediment and d is the mean particle diameter. Thus, for a given sediment concentration, the percentages of silt, and especially, clay, would be an important factor in the quantification of the real or potential total transport capabilities of a stream. In addition, if estimates of total sediment discharge for a stream are to be made, the relationship between the clay-silt-sand fraction of the suspended load and the particle-size distribution of the bed material is essential.

A total of 490 particle-size analyses were determined for Ohio's streams for the period of October 1969 through September 1974 (1970–74 water years). Efforts were made to sample randomly flows greater than the 20 percent flow duration. The results of the analyses, summarized percentages of clay, silt, and sand, are presented in table 13. Both ranges and averages are included, as percentage fluctuations may vary greatly at a given station depending on season, storm, and basin characteristics. The average percentages of clay, silt, and sand are plotted on a triangular coordinate graph (fig. 15) and display a general State grouping in the clay and clay-silt phase.

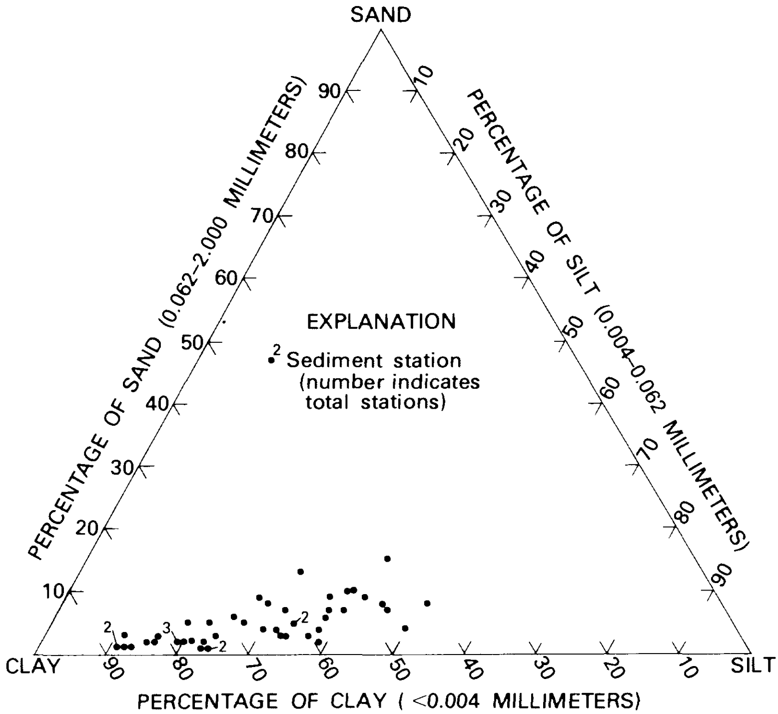


FIGURE 15.—Average suspended-sediment particle-size distributions, by percentages, for the daily and inventory network stations, water years 1970–74.

TABLE 13—*Summary of particle-size analyses of suspended sediment (water years 1970–74)*

Station No.	Number of samples	Discharge range in ft³/s	Discharge range Percent duration	Sediment concentration range (mg/L)	Clay (<0.004 mm) Range	Clay (<0.004 mm) Average	Silt (0.004–0.062 mm) Range	Silt (0.004–0.062 mm) Average	Sand (0.062–2.0 mm) Range	Sand (0.062–2.0 mm) Average
03109500	6	3220–650	1–21	58–1030	39–64	55	29–54	38	2–10	7
03110000	6	2180–219	0.3–95	39–1930	36–72	50	27–45	40	1–19	10
03111500	7	2230–295	0.1–8	280–3490	37–52	43	36–45	42	6–26	15
03114000	9	1530–495	1–8	47–373	47–66	56	32–45	38	2–14	6
03115400	8	6720–305	0.1–20	29–1090	33–62	47	26–59	46	3–13	7
03116200	10	1430–76	0.5–30	83–1680	49–86	66	12–44	30	1–10	4
03117500	10	2370–406	0.5–17	74–464	39–67	56	23–47	31	6–22	13
03123000	9	2060–450	0.3–7	87–1080	40–89	61	7–51	34	1–9	5
03137000	9	8710–2370	0.2–3	134–919	41–58	51	33–47	39	3–20	10
03144000	10	5640–57	0.04–50	49–974	39–69	54	29–48	37	1–29	9
03144500	17	24500–1460	--	156–3720	44–62	53	29–50	40	0–18	7
03146000	10	6620–736	0.01–3	95–1080	33–83	64	13–57	27	2–20	9
03159540	9	3670–214	0.1–15	101–1300	48–68	60	29–48	37	0–4	2
03202000	7	4660–606	1–28	41–305	53–69	61	26–43	32	3–16	7
03223000	9	2880–524	0.2–7	196–1030	51–92	77	7–43	21	0–6	2
03230500	9	7710–470	0.3–22	93–1460	61–86	76	13–37	23	0–7	1
03230800	9	3960–1030	0.1–3	87–1480	64–89	78	11–34	20	0–4	2
03232000	10	4450–668	0.2–8	63–2180	60–87	75	11–37	23	1–4	2
03234500	14	46400–10300	--	228–2510	42–93	64	7–51	32	0–8	4
03237500	7	7210–1130	1–8	245–992	34–76	59	22–63	39	1–3	2
03238500	9	7670–1280	0.2–4	175–2270	41–78	63	21–50	34	0–9	2
03246200	9	5490–209	0.4–17	62–758	58–89	77	10–40	21	0–4	2
03261500	18	6010–519	--	109–2030	53–92	79	8–45	19	0–4	2
03261950	19	2620–114	--	95–1220	64–95	82	4–34	16	0–10	2
03262700	11	11300–2780	0.2–8	153–1240	51–83	69	13–38	25	1–14	6
03264000	8	2650–562	0.5–6	185–770	55–83	73	16–44	24	0–4	2
03265000	18	7300–1550	--	189–2950	63–91	79	8–34	19	0–4	1
03267000	8	2470–332	0.08–5	58–4240	53–74	64	23–41	33	1–10	3
03271800	7	6630–422	0.2–10	245–1130	56–86	73	13–34	22	1–10	5
03272800	9	2970–204	0.3–12	297–1760	35–86	63	13–40	29	0–33	8
04185000	9	1770–397	3–21	55–199	76–93	86	6–22	11	1–5	2
04186500	10	5890–245	0.1–23	90–1180	79–96	87	4–20	12	0–4	1
04189000	10	5500–574	0.1–11	128–1070	78–96	88	4–21	11	0–2	1
04191500	10	31900–2100	0.1–19	67–794	81–93	88	6–16	11	0–4	1
04193500	17	70000–13200		231–1340	61–93	83	6–39	15	0–5	2

04196000	10	2160–272	0.1–7	146–1340	60–91	79	8–36	19	0–4	2
04196800	9	4540 406	0.07–11	118–1500	78–94	86	5 22	13	0–2	1
04197000	10	12300–516	0.05–23	130–913	70–90	82	9–29	16	1–4	2
04199000	8	7460–450	0.1–13	106–1980	64–89	76	10–27	19	1–12	5
04199500	8	4250–679	0.4–8	87–1440	41–83	68	17–44	27	0–15	5
04200500	8	5520–996	0.5–8	70–1230	49–85	75	13–49	24	0–2	1
04201500	13	6160–60	--	60–2080	45–88	61	11–46	34	1–18	5
04208000	21	8130–880	--	132–2360	29–86	49	14–55	42	0–26	9
04209000	22	8760–475	--	202–6820	30–62	41	37–60	51	0–17	8
04212000	10	6140–1590	1–13	35–324	41–73	58	25–50	38	2–9	4
04212500	7	1940–230	0.7–18	13–305	33–68	47	16–57	45	2–16	7
04213000	7	2380–610	1–12	55–539	34–56	46	41–62	50	1–8	4

Average clay percentages and their related drainage areas are grouped and mapped in figure 16. A general geographic pattern is evident, with high clay content dominating the streams of north-

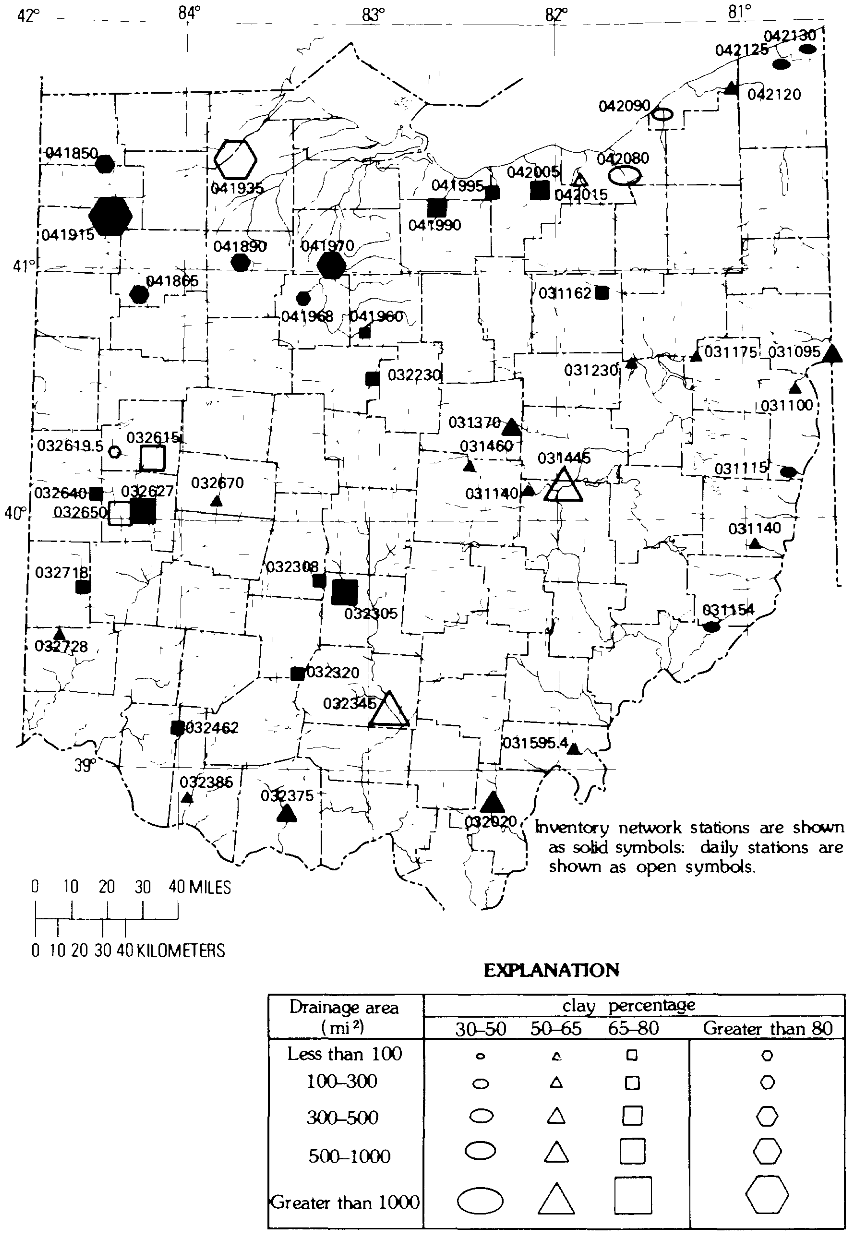


FIGURE 16.—Average percentages of clay in suspended sediment at daily and inventory network stations for water years 1970–74.

western Ohio. Decreases in the percentage of clay, coincidental with increases in silt and sand, occur in the eastern and southeastern parts of the State and, to a lesser degree, in the southern part.

Highest average clay fractions (88 percent) were observed at station, 04191500, Auglaize River near Defiance, and 04189000, Blanchard River near Findlay. Average silt was highest (50–51 percent) in the northeastern part of the State, in the Chagrin and Conneaut River basins. Sand was generally a minor constituent of the suspended sediments, averaging from 1 to 2 percent in the northwestern quarter of Ohio, increasing up to 8 percent southward to the Ohio River, and to 15 percent in the east and southeastern highlands. Highest concentrations of sand (13–15 percent) were recorded at 03117500, Sandy Creek at Waynesburg and 03111500, Short Creek near Dillonvale, respectively.

Attempts to relate particle size to concentration, sediment discharge, and (or) slope gradient were generally nonproductive. Regression analyses of three daily record stations did demonstrate some statistically significant relationships between particle size and concentration or sediment discharge. However, these regressions varied from station to station and were deemed inconclusive for statewide applications.

Data from the inventory network stations were insufficient for a statistical evaluation. However, the plotted data did suggest a tendency of increasing silt percentage versus sediment discharge in eastern Ohio. Further analyses would require additional data in a multiple regression utilizing other variables as soil, vegetation, and cultural patterns.

A cause and effect interpretation of particle-size data on a basin-by-basin basis is beyond the scope of this report. However, some regional relationships between the clay-silt-sand percentages and the major land-resource areas (fig. 1) are probable. Although not shown, the general bedrock geology would also have a great influence on sediment distributions, especially in the unglaciated highlands of southeastern Ohio, where Paleozoic shale, sandstone, and limestone beds are widely exposed.

BED MATERIAL

Bed material was observed and (or) analyzed at all inventory network stations during the 5-year sampling period. Samples were taken once annually during the low-flow conditions of early fall. The average textural composition of the stream channel bed at inventory network stations is presented in table 14. Bed-material analyses for several of the daily stations used in estimating total sediment discharge are included. Bed-material data are restricted for the daily stations. Inventory network stations with 90 percent or more bedrock or gravel composition were only sampled once during the 5-year collection period.

TABLE 14.—*Average textural composition of streambeds at inventory network stations and selected daily stations*

Station No.	Number of samplings used	Percentage of bed material			Cobbles, boulders, or bedrock	Remarks
		Silt <0.062 mm	Sand 0.062–2.0 mm	Gravel 2.0–64.0 mm		
03109500	1	0	<1	<1	99	
03110000	5	<1	14	26	60	
03111500	4	9	24	67	0	
03114000	5	0	4	46	50	
03115400	4	12	46	42	<1	
03116200	4	16	80	4	0	
03117500	5	0	32	68	0	
03123000	1	2	14	84	0	
03137000	1	0	9	61	30	
03139000	0	--	--	--	0	Field observation.
03144000	1	0	<1	<1	99	
03146000	1	10	25	40	25	
03159500	0	0	<1	<1	99	Field observation.
03159540	4	2	25	73	0	
03202000	3	2	96	2	0	
03223000	3	36	57	7	0	
03229000	--	--	--	--	--	Not evaluated.
03230500	1	2	31	67	0	
03230800	5	0	6	44	50	
03232000	5	0	8	17	75	
03234000	1	4	49	47	0	
03234500	2	6	48	46	0	
03237500	2	0	12	88	0	
03238500	3	0	<1	4	95	
03240000	0	--	--	--	0	Field observation.
03241500	0	--	--	--	0	Field observation.
03244000	0	--	--	--	>95	Field observation.
03246200	1	0	12	15	73	
03261500	1	1	6	43	50	
03262700	1	14	84	2	0	
03264000	3	23	66	11	0	
03265000	1	1	37	62	0	
03267000	2	0	6	94	0	
03271800	4	0	22	68	10	
03272800	5	0	16	84	0	
04185000	3	42	54	4	0	
04186500	2	<1	1	4	95	
04189000	1	0	11	9	80	
04191500	1	0	3	47	50	
04193500	0	0	0	0	100	Field observation.
04195500	1	<1	56	43	0	
04196000	4	0	1	4	95	
04196800	1	0	<1	9	90	
04197000	4	0	8	42	50	
04198000	0	0	<5	--	>95	Field observation.
04199000	3	<1	25	69	5	
04199500	3	<1	3	16	80	
04200500	1	0	<1	<1	99	
04208000	1	<1	<1	4	95	One measurement.
04212000	2	<1	3	46	50	
04212500	1	<1	3	46	50	
04213000	5	0	1	4	95	

Sediments of gravel size or larger, bedrock, or both accounted for a minimum of 65 percent of the bed material in all but ten of the inventory network stations (fig. 17). Of these eight, sand was the major constituent, with the highest (96 percent) recorded in Raccoon Creek at Adamsville. Note that part of the material analyzed as sand for these eight stations is consolidated clay particles, which do not break down to their primary size in the dry sieve method. The maximum average silt percentage (42 percent) occurred at station 04185000, Tiffin River at Stryker in northwestern Ohio.

Mean channel slope versus the percentage of bed-material, gravel size or larger, for all inventory network stations is plotted in figure 18. Interpretation of the data is difficult; however, some apparent grouping does occur for those stations having a slope of 0.0011 or greater. The lack (less than 25 percent) of fine sediments in these streams reflects limited basin supplies of fine-sized sediments. Conversely, the ample supply of fine sediments at

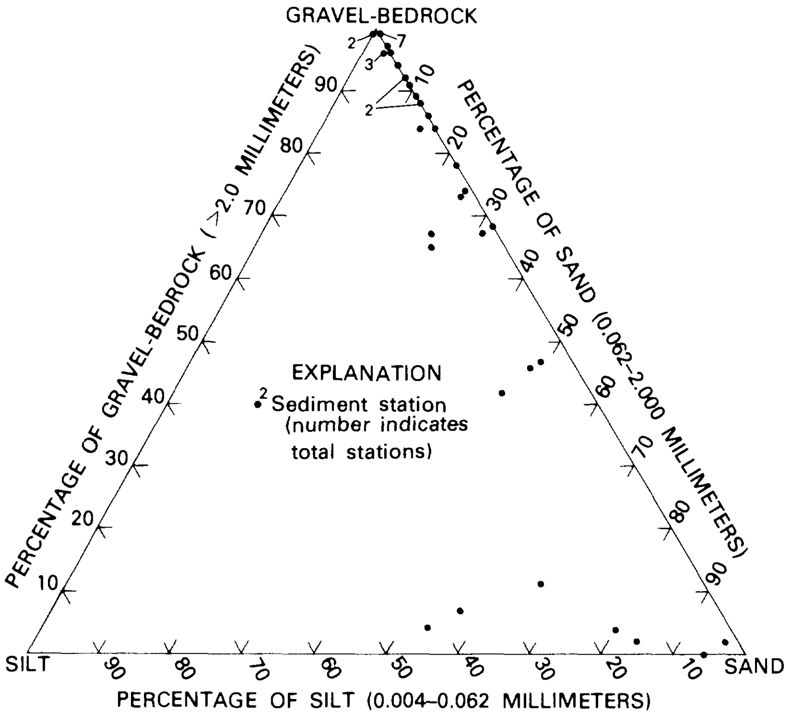


FIGURE 17.—Percentage of textural composition of the stream channel bed at inventory network and selected daily sediment stations, water years 1970–74.

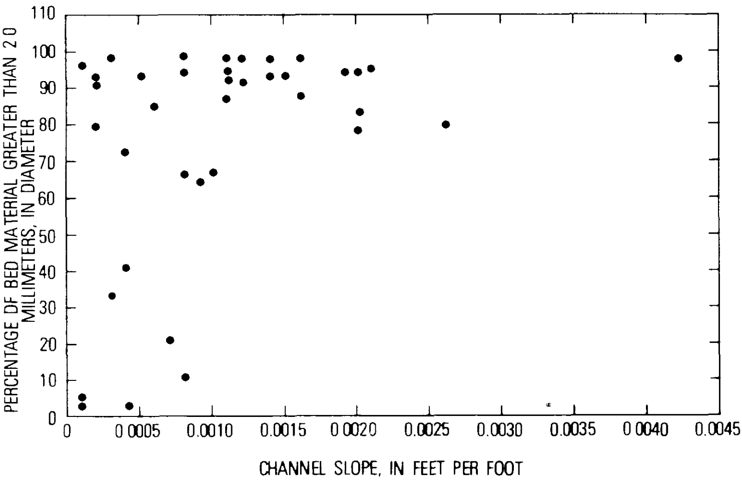


FIGURE 18.—Average percent of bed material greater than 2.0 mm in diameter versus mean station channel slope for the inventory network stations.

some of the stations with slopes less than 0.0010 suggests that the available supply of fine sediments exceeds the transporting capacity of the stream at those stations.

SEDIMENT YIELD

Sediment yield is defined as the quantity of soil material transported by a stream and originating from the land surface or from the channel. In this report sediment yield is expressed in tons per square mile (tonnes per square kilometer) per year. Sediment yields in Ohio were determined by extrapolating estimates of total sediment discharge for the daily sediment and inventory network stations. Previous discussion has implied that the principal mode of transport by Ohio streams is suspension. Sediment discharges listed in tables 9 and 11 could provide reasonable estimates for determining yield. Yield computed by dividing mean annual suspended-sediment discharge at a station by its drainage area is given for the Ohio sediment stations in table 15. Mean annual runoff, in cubic feet per second per square mile [$(ft^3/s)/mi^2$], and mean concentration are also included in table 15. The mean concentration is the concentration computed from the discharge equation for Q_s and Q_w values equal to the total suspended-sediment discharge and the total water discharge, respectively, for the base period.

TABLE 15.—*Mean annual runoff and sediment yield for the period, water years 1946–70*

Station No.	Runoff [(ft³/s)/mi²]	Discharge-weighted mean concentration (mg/L)	Percent of annual bedload discharge in terms of annual suspended-sediment discharge	Suspended-sediment yield [(tons/mi²)/yr]
03109500	0.99	141	<1	137
03110000	1.05	171	5–10	177
03111500	.95	260	5–10	244
03114000	1.28	180	<5	227
03115400	1.27	128	<5	160
03116200	.89	150	<5	132
03117500	1.01	95	5–10	95
03123000	.84	162	<5	134
03137000	1.07	163	5–10	172
03139000	.87	195	5–10	168
03144000	1.05	150	<1	155
03146000	1.03	140	<5	143
03159500	.99	209	<1	204
03159540	1.07	324	<5	340
03202000	1.06	65	25–50	68
03223000	.93	168	<5	154
03230500	.86	266	5–10	224
03230800	.84	240	<5	198
03232000	.91	242	<5	216
03234000	.98	365	5–10	365
03234500	.88	272	5–10	235
03237500	1.16	481	<5	552
03238500	1.12	419	<1	262
03240000	.84	147	5–10	128
03241500	.95	191	5–10	193
03244000	1.03	541	<1	627
03246200	1.08	245	<5	262
03261500	.86	169	<5	143
03262700	.88	168	<5	146
03264000	.95	193	<5	180
03265000	.87	211	<5	182
03267000	.88	159	5–10	138
03271800	1.08	348	5–10	368
03272800	1.04	399	5–10	409
04185000	.75	75	<1	56
04186500	.84	236	<1	196
04189000	.72	209	5–10	149
04191500	.84	216	<5	180
04193500	.78	244	<1	187
04195500	.73	256	5–10	184
04196000	.92	219	<5	199
04196800	.72	289	<1	206
04197000	.76	243	5–10	181
04198000	.76	250	<5	188
04199000	.78	468	5–10	362
04199500	.89	410	5–10	359
04200500	.78	276	<1	213
04208000	1.12	266	<5	293
04212000	1.19	102	<5	120
04212500	1.31	78	<5	100
04213000	1.57	157	<1	244

Mean annual total-sediment discharge was estimated by adding an estimate of mean annual bedload discharge to the mean annual suspended-sediment discharge. The bedload estimates are subjectively determined from particle-size distributions of suspended sediment and bed material and from table 16, which is "Maddock's

TABLE 16.—*Maddock's classification for determining bedload*
[From Lane and Borland, 1951]

Concentration of suspended load (ppm)	Type of material forming the channel of the stream	Texture of the suspended material	Percent bedload in terms of measured suspended load (percent)
Less than 1,000	Sand	Similar to bed material	25–150
Less than 1,000	Gravel, rock, or consolidated clay.	Small amount of sand	5– 12
1,000–7,500	Sand	Similar to bed material	10– 35
1,000–7,500	Gravel, rock, or consolidated clay.	25 percent sand or less	5– 12
Over 7,500	Sand	Similar to bed material	5– 15
Over 7,500	Gravel, rock, or consolidated clay.	25 percent sand or less	2– 8

classification for determining bedload." A review of Lane and Borland's (1951) discussion on estimating bedload will help to understand the determination of bedload in Ohio and Maddock's classification.

The three major variables that affect the amount of bedload a stream can transport are: (1) size of bed material; (2) average stream velocity; and (3) the channel characteristics: depth, size, shape, and roughness. The effect of these variables on bedload can be generalized by the following: (1) percentage of bedload discharge will increase with a decrease in concentration of suspended material; (2) the smaller difference between the particle distributions of suspended sediment and bed material will yield higher percentages of bedload discharge; (3) the ratio of bedload discharge to suspended-sediment discharge is usually larger for low or medium water discharge than it is for high water discharges; (4) bedload discharge is usually greater in wide, shallow channels than in deep narrow channels; (5) bedload discharge is small at high turbulent cross sections.

The above discussion and Maddock's classification pertain more to conditions at a given time. When evaluating the average bedload discharge for a period of time, flow variability must be considered (Lane and Borland, 1951, p. 122). During a long period of time most of the total sediment discharge occurs with the higher or more turbulent flows, which tend to have lower percentages of bedload discharge. Lower flows will have a greater percentage of bedload discharge, but do not contribute substantially to the total annual sediment discharge. The percentage of annual bedload discharge, therefore, will be smaller than the percentages given in Maddock's classification.

To illustrate the method used to estimate percentage bedload discharge, consider, again, the station on the Kokosing River at

Millwood. The information from table 13 shows that the particle-size distribution of suspended-sediment samples contains small percentages of sand. The composition of the bed channel (table 14) is primarily (91 percent) bedrock or coarse-size particles (gravel, cobbles and boulders) with a small amount of sand (9 percent). The size distributions applied to Maddock's classification indicate a range of 5 to 12 percent bedload discharge. To account for the variability of flow, the percentage range was prorated from 5 percent at the highest sediment discharges to 12 at the lowest discharges. Considering the duration values in table 10, an annual percentage of bedload discharge, in terms of suspended sediment, would probably range between 5 and 10 percent.

Several of the stations in Ohio have deposits of fine material in the measured sections. This type of bed material is not included in Maddock's classification. As discussed previously, deposits of fine material indicate that the supply of fine material exceeds the capability of the stream to transport sediment at the section of deposition. It is probable, however, that some sediment is discharged as bedload at these stations. The bedload discharge in this case would be seasonal, during the nongrowing season, when sheet erosion is usually at a minimum. Runoff, with light sheet erosion, would tend to suspend the fine sediment deposits as flow increased. Bedload discharge would occur after the fine material had been removed by medium to high flow. The seasonal nature of this bedload discharge and its dependency on higher flows limit its duration. Average annual bedload discharge, in percentage of mean annual suspended sediment at these stations, is expected to be small and is estimated at less than 5 percent.

The estimated annual percentage ranges of bedload discharge are included in table 15. On the basis of these percentages and the mean annual suspended-sediment yields, a total yield map of Ohio (fig. 19) was developed. Approximate areas in percentage of the total land surface area of Ohio (41,249 mi^2, Ohio Division of Water, 1973) are included in figure 19 for each range of yield. Highest sediment yields are in the southwestern part of the State. Yields exceeding 500 (tons/mi^2)/yr [(175 t/km^2)/yr] occur in the lower Paint Creek basin, Todd Fork basin, and in the Kentucky Bluegrass area (MLRA 121). Lowest sediment yields, less than 100 (tons/mi^2)/yr [(35 t/km^2)/yr] are in Indiana and Ohio Till Plains (MLRA 111) in the northwest corner of the State. This area was defined by a yield of 56 (tons/mi^2)/yr [(20 t/km^2)/yr] in the Tiffin River basin (station 04185000). Yields within a given major land-resource area show a tendency to vary with topog-

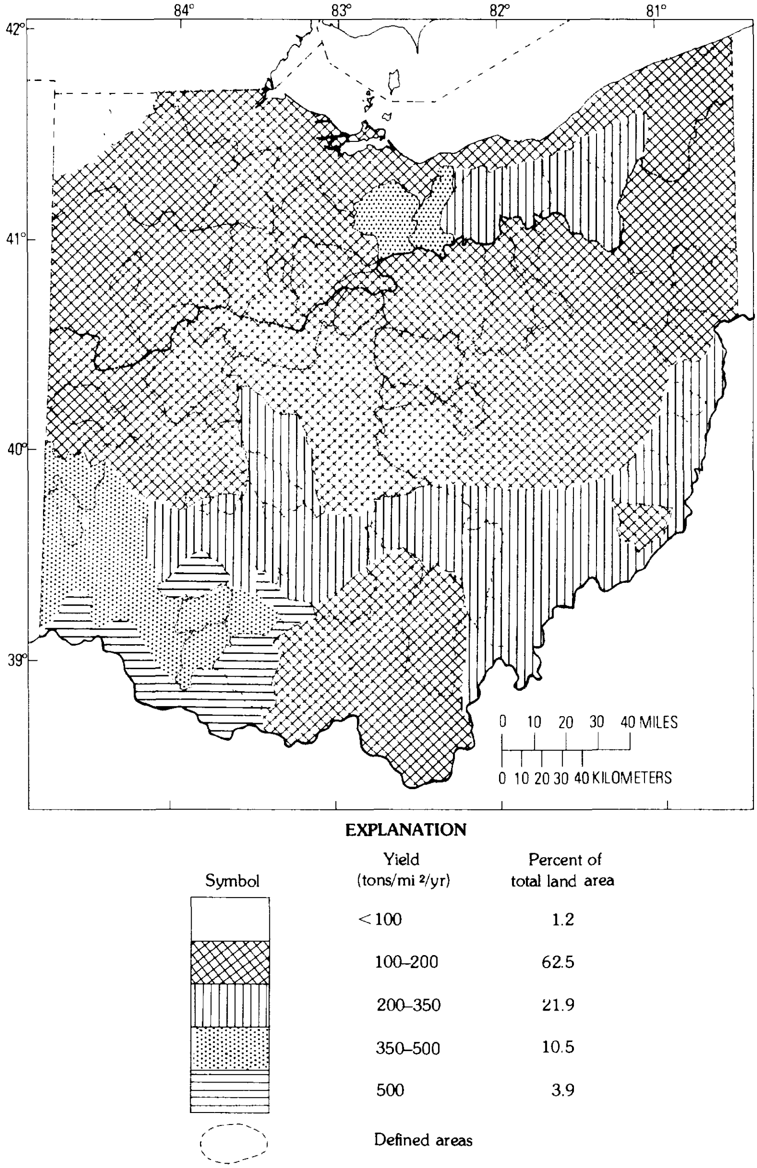


FIGURE 19.—Sediment yield map of Ohio (for drainage areas greater than 50 square miles).

raphy. This is especially true in Indiana and Ohio Till Plains (MLRA 111) in the western half of the State. In the Scioto River, Little Miami River, and Great Miami River basins, yields increase substantially southward, as topography changes from level in the upper part of the basins to fairly rugged in the lower parts.

The methods used to determine mean sediment discharges and yields are based on the assumption that the basin characteristics during the period of data collection represent the average characteristics during the base period. In general, the values are probably representative because of the relatively large drainage areas of the sediment stations. Land-use changes, are generally not extensive enough to affect the annual fluvial sediment characteristics of a large basin significantly. Yields above stations where local changes in land use influenced the measured fluvial sediment were not used in regionalizing yield. Sediment yield from station, 03229000, Alum Creek at Columbus was not computed because of highway construction immediately upstream from the station during part of the period of collection.

The reported yields are further limited to drainage area size. It is not advisable to use figure 19 for areas less than 50 mi^2 (130 km^2). The minimum drainage area used to define yield was 63.2 mi^2 (164 km^2). A knowledge of sediment yield from an area should require a more comprehensive comparison of the basin characteristics of the area with the characteristics of the nearest sediment stations. In addition, the basin characteristics during the base period at the nearby sediment stations should be compared with the characteristics during the data collection period.

It is emphasized that the reported mean annual sediment yields are averages for the 25 year base period. Mean annual values for different periods of time can easily be determined by the methods described in this section and use of the following:

a. Water discharge data for the period;
b. The least squares relation between annual sediment discharge and Kn to determine mean annual sediment discharge at the daily stations in table 8;
c. The flow duration (for the period) and the sediment transport curves to determine mean annual suspended-sediment discharge at the inventory network stations.

A map (fig. 20) showing isopleths of discharge-weighted mean concentration was constructed to provide an alternate method in estimating sediment yields and mean suspended-sediment dis-

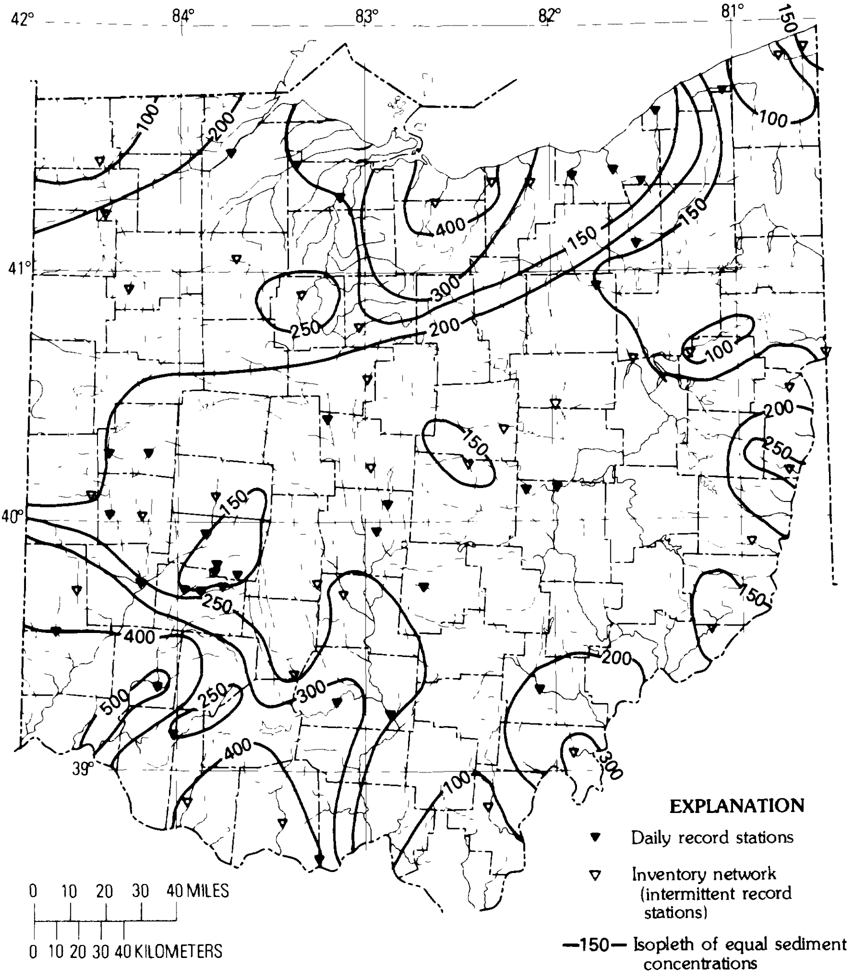


FIGURE 20.—Generalized map showing discharge-weighted mean suspended-sediment concentrations in milligrams per liter, 1946–70.

charge for shorter time periods. The method is not considered accurate enough for final design, planning purposes, or evaluations. It is included in this report because of its simplicity and the frequent need for preliminary estimates. Yield and the discharge are estimated by: (1) obtaining a mean concentration from the isopleth map; (2) obtaining an estimate of the mean annual runoff, in cubic feet per second per square mile, for the period from nearby water-discharge recording stations; (3) multiplying the product of the concentration and the runoff by the factor 0.986

TABLE 17.—*Standard deviation of annual discharge-weighted mean concentration and suspended-sediment yield for selected daily record stations*

Station		Years of record	Standard deviation of annual discharge-weighted mean concentration		Standard deviation of annual suspended-sediment yield	
No.	Name		(mg/L)	In percent of mean annual concentration	[(tons/mi²)/yr]	In percent of mean annual concentration
03139000	Killbuck Creek at Killbuck	7	134	74	237	133
03159500	Hocking River at Athens	9	36	18	68	20
03234000	Paint Creek near Bourneville	6	60	17	109	29
03234500	Scioto River at Higby	20	68	28	76	33
03240000	Little Miami River near Oldtown	6	174	93	98	49
03241500	Massies Creek at Wilberforce	6	75	46	162	108
03244000	Todd Fork near Roachester	6	127	21	239	42
03261500	Great Miami River at Sidney	6	33	21	86	54
03265000	Stillwater River at Pleasant Hill	10	53	26	80	48
04193500	Maumee River at Waterville	23	63	25	87	46
04195500	Portage River at Woodville	6	54	22	128	62
04198000	Sandusky River near Fremont	6	60	23	95	52
04208000	Cuyahoga River at Independence	23	77	29	120	40

(0.0027×365.25) to obtain yield, in tons per square mile per year. Mean suspended-sediment discharge is obtained by multiplying the yield by the drainage area.

Estimating average yields for shorter time periods directly from the yield map (fig. 19) is not practical. Sediment yield for a given stream station will vary substantially from year to year. An indication of the variability in annual yields is given in table 17 by the standard deviation of suspended-sediment yield for selected daily stations. The standard deviations of annual discharge-weighted mean concentration at the daily stations are also included in table 17. Comparison of these standard deviations substantiates the authors' preference for using the discharge-weighted mean concentration method for obtaining preliminary estimates of yields for shorter periods.

Again it is emphasized that the methods presented, herein, to estimate yields are applicable for stream stations with drainage areas greater than 50 mi^2.

DEPOSITION

Deposition of sediment can become a major economic and environmental problem. In Ohio, fluvial sediment deposition occurs in the harbors and bays of Lake Erie and in the inland reservoirs and lakes. Based on studies of 85 reservoirs, Hahn (1955, p. 1) concluded that "Sedimentation has caused tremendous damage to reservoirs in Ohio." Except for the flood-detention reservoirs in the Great Miami River basin, reservoirs in Ohio trap most of the sediment that enters them. The percentage of inflowing sediment that is deposited is known as the trap efficiency of the reservoir. Using the capacity-inflow ratio method given by Brune (1953, p. 414), the average trap efficiency of Ohio's reservoirs is 94 percent (based on data from 21 reservoirs, ranging in capacity from 6,900 to 285,000 acre-ft (8.51 to 352 hm^3)). The detention reservoirs in the Great Miami River basin probably have trap efficiencies between 10 and 40 percent (Brune, 1953, p. 407).

If the specific dry weight of the sediment deposits are known, the yield map and the sediment yields and bedload factors given in table 15 for nearby sediment stations can be used to estimate the annual deposition rate for a reservoir. For example, consider Beach City Lake, 71,700 acre-ft (88.4 hm^3) total capacity, in the Upper Muskingum River basin. The average annual volume rate of sediment deposition is estimated to be 26.2 acre-ft/yr (0.030 hm^3/yr) based on the following assumptions:

a. Ninety-five percent trap efficiency from Brune's curve using mean annual runoff at station, 03123000, Sugar Creek above Beach City to compute inflow.
b. Sediment yield of 140 (tons/mi^2)/yr [(49.0 t/km^2)/yr] from figure 19 and table 15 for the 300 mi^2 (777 km^2) of drainage area.
c. Specific dry weight of deposits equal to 70 lb/ft^3 (1,200 kg/m^3).

Deposition in stream channels is not considered to be significant in Ohio because most transported sediment is composed of fine particle sizes (see particle-size section) that are not subject to permanent deposition in streams. Some significant deposition, however, has been observed in several small streams owing to accelerated erosion in the watershed. Urban development is currently a major cause of accelerated erosion in Ohio. Guy (1970b) has described many of the sediment problems in urban areas.

SUMMARY AND CONCLUSIONS

This report has presented characteristics of fluvial sediment in Ohio streams and regional estimates of sediment yield. Relevant concepts and methodology of data analysis are also presented. Analyses were based on fluvial sediment data from 38 inventory network stations and several daily record stations. Daily duration tables of water discharge, discharge-weighted mean suspended-sediment concentration, and suspended-sediment discharge are given for most of the stations. Sediment yields in Ohio, based on the water year period, 1946–70, range from less than 100 (tons/mi^2)/yr [(35.0 t/km^2)/yr] in the extreme northwest corner of the State to more than 500 (tons/mi^2)/yr [(175 t/km^2)/yr] in the southern part of the Indiana and Ohio Till Plains (MLRA 111) and the Kentucky Bluegrass area (MLRA 121). Yields from drainage areas greater than 50 mi^2 (130 km^2) range between 100 and 200 (tons/mi^2)/yr [(35.0 to 70.0 t/km^2)/yr] for 63 percent of Ohio. Yields within a given land-resource area show a tendency to vary with topography; that is, areas with more rugged topography produce the higher yields.

Based on an average of the inventory network stations, 92 percent of the total suspended-sediment discharge and 58 percent of the water discharge for the base period occurred during 10 percent of the time. Daily record stations showed that 89 percent of the suspended-sediment discharge and 54 percent of the water discharge occurred in 10 percent of the time. Instantaneous sediment transport curves could be defined at the inventory network stations by least squares relations for water discharges not exceeded 0.1 percent of the time. Computation of mean annual suspended-sediment discharge (base period 1946–70) at those stations were made by the flow duration and sediment transport curve method using an estimated discharge-weighted mean concentration for water discharges greater than 0.1 percent duration value.

Estimated ranges of mean annual bedload discharge, in percentage of mean annual suspended-sediment discharge, were made at most of the sediment stations. Estimates were based on particle-size distributions of bed material and suspended sediment and Maddock's classification for determining bedload. Highest bedload discharge was estimated between 25 and 50 percent at Raccoon Creek at Adamsville. Bedload discharge at all other stations was estimated below 10 percent of the suspended-sediment discharge.

Concentration of suspended sediment in Ohio streams usually precedes or coincides with peak water discharge during significant runoff. Duration data from daily stations indicate that the daily discharge-weighted mean concentration of sediment is less than 100 mg/L 75 percent of the time and less than 50 mg/L 50 percent of the time. Discharge-weighted mean concentration for the base period was shown regionally to range from less than 100 mg/L in the Sandy Creek, Raccoon Creek, and Tiffin River basins to greater than 500 mg/L in the Todd Fork basin. Most areas are shown with a discharge-weighted mean concentration between 150 and 200 mg/L.

Generally, the suspended sediment in Ohio streams contains only a small amount of sand. Percentage of sand in suspended sediment ranged from 1 to 2 percent in northwestern Ohio to 15 percent in the east and southeastern highlands. Silt sizes were highest (50–51 percent) in northeastern Ohio.

From the 38 inventory network stations, only 8 stations indicated an appreciable amount of sand as bed material. Gravel or larger-size sediments and bedrock constituted 65 percent or more of the textural composition of the streambed at the other stations.

REFERENCES

Austin, M. E., 1965, Land resource, regions and major land resource areas: U.S. Dept. Agriculture Handbook 296, 82 p.

Brune, G. M., 1953, Trap efficiency of reservoirs: Am. Geophys. Union Trans., v. 34, no. 3, p. 407–418.

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

——— 1963, Fluvial sediments—a summary of source, transportation, deposition, and measurement of sediment discharge: U.S. Geol. Survey Bull. 1181–A, 47 p.

Cross, W. P., and Hedges, R. E., 1959, Flow duration of Ohio streams: Ohio Dept. Nat. Resources, Div. Water Bull. 31, 152 p.

Dawdy, D. R., and Matalas, N. C., 1964, Statistical and probability analysis of hydrologic data, Chapter 8 in Handbook of Applied Hydrology: New York, McGraw Hill, p. 8–90.

Federal Inter-Agency Sedimentation Project of the Inter-Agency Committee on Water Resources, 1943, Density of sediments deposited in reservoirs—Inter Agency Report 9: Minneapolis, Minn., St. Anthony Falls Hydraulics Lab., 60 p.

——— 1952, The design of improved types of suspended-sediment samplers—Inter-Agency Report 6: Minneapolis, Minn., St. Anthony Falls Hydraulic Lab., 103 p.

——— 1974, Instruments and reports for fluvial sediment investigations—Inter-Agency Report Catalog: Minneapolis, Minn., St. Anthony Falls Hydraulic Lab., 61 p.

Guy, H. P., 1969, Laboratory theory and methods for sediment analysis: U.S. Geol. Survey Techniques Water-Resources Inv., book 5, chap. C1, 58 p.

——— 1970a, Fluvial sediment concepts: U.S. Geol. Survey Techniques Water-Resources Inv., book 3, chap. C1, 55 p.

——— 1970b, Sediment problems in urban areas: U.S. Geol. Survey Circ. 601–E, 8 p.

Guy, H. P., and Norman, V. W., 1970, Field methods for measurement of fluvial sediment: U.S. Geol. Survey Techniques Water-Resources Inv., book 3, chap. C2, 59 p.

Hahn, C. L., 1955, Reservoir sedimentation in Ohio: Ohio Dept. Nat. Resources, Div. Water Bull. 24, 87 p.

Lane, E. W., and Borland, W. M., 1951, Estimating bedload, Letters to the editor: Am. Geophys. Union Trans. v. 32, no. 1, p. 121–123.

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

McKee, J. E., and Wolf, H. W., 1971, Water quality criteria [2d ed.]: The Resources Agency of California, State Water Quality Control Board, Pub. no. 3–A, 548 p.

Maddock, Thomas, Jr., 1969a, The behavior of straight open channels with moveable beds: U.S. Geol. Survey Prof. Paper 622–A, 70 p.

——— 1969b, Economic aspects of sedimentation: Am. Soc. Civil Engineers Sedimentation Manual, HY 1, p. 191–207.

Nelson, L. M., 1970, A method of estimating annual suspended-sediment discharge, *in* Geological Survey Research 1970: U.S. Geol. Survey Prof. Paper 700–C, p. C233–C236.

Ohio Division of Lands and Soil, 1973, Know Ohio's soil regions: Ohio Dept. Nat. Resources, Div. Lands and Soil, map and associated text.

Ohio Division of Water, 1962, Hydrologic atlas of average annual precipitation, temperature, streamflow, and water loss in Ohio: Ohio Dept. Nat. Resources, Div. Water, Ohio Water Plan Inventory Report 13.

——— 1973, Principal streams and their drainage areas: Ohio Dept. Nat. Resources, Div. Water map.

Pierce, L. T., 1959, Climate of the States, Ohio: U.S. Weather Bur., Climatography of the United States, no. 60–33, 19 p.

Sayre, W. W., Guy, H. P., and Chamberlain, A. R., 1963, Uptake and transport of radionuclides by stream sediments: U.S. Geol. Survey Prof. Paper 433–A, 35 p.

U.S. Department of Agriculture, 1971, Ohio soil and water conservation needs inventory: The Ohio Soil and Water Conservation Needs Committee, Columbus, Ohio, 131 p.

U.S. Weather Bureau, 1961, Rainfall frequency atlas of the United States: U.S. Weather Bur. Tech. Paper no. 40, 61 p.

——— 1964, Two-to ten-day precipitation for return periods of 2 to 100 years in the contiguous United States: U.S. Weather Bur. Tech. Paper no. 49, 29 p.