SEDIMENT TRANSPORT, PARTICLE SIZES, AND LOADS IN LOWER REACHES OF THE CHIPPEWA, BLACK, AND WISCONSIN RIVERS IN WESTERN WISCONSIN

By

W.J. ROSE

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MANUEL LUJAN, JR., *Secretary*

U.S. GEOLOGICAL SURVEY

Dallas L. Peck, *Director*

For additional information write to:

District Chief
U.S. Geological Survey
Water Resources Division
6417 Normandy Lane
Madison, Wisconsin 53719

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CONVERSION FACTORS AND ABBREVIATIONS

For the use of readers who prefer metric (International System) units, rather than the inch-pound terms used in this report, the following conversion factors may be used:

Multiply inch-pound unit	By	To obtain metric unit
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
miles (mi^2)	2.590	square kilometer (km^2)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
ton, short	0.9072	megagram (Mg)
feet per mile (ft/mi)	0.1893	meters per kilometer (m/km)

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Sea Level Datum of 1929."

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ABSTRACT

Hydraulic and sediment data were collected at three sites on the Chippewa River (near Caryville, at Durand, and near Pepin); at one site near Galesville on the Black River; and at one site at Muscoda on the Wisconsin River during water years 1976–83. This report summarizes an interpretation of those data by providing (1) a description of the relation of suspended sediment, bedload, and total-sediment discharge to water discharge; (2) a description of particle-size characteristics of bed material, bedload, and suspended sediment; and (3) estimates of annual and average annual suspended load, bedload, and total-sediment load for water years 1974–83. Direct measurement with a Helley-Smith bedload sampler and calculations by the modified-Einstein procedure were used to estimate bedload.

Single equations describe the suspended- and total-sediment transport-rate relations for Chippewa River at Durand and main channel at Pepin, and the Black River near Galesville. Two equations were needed to define the transport-rate relations for the Chippewa River near Caryville and Wisconsin River at Muscoda.

Bed material at all sites except Chippewa River near Caryville were of similar particle size and exhibited little variation with time or location in the river cross sections. Median diameter at these sites ranged from 0.35 to 0.84 mm (millimeter). At Chippewa River near Caryville, median diameter ranged from 0.42 to 15 mm. Helley-Smith bedload at Chippewa River at Durand and near Pepin, Black River near Galesville, and Wisconsin River at Muscoda were of similar particle size. About 57 to 65 percent of bedload at all sites except Chippewa River near Caryville was in the 0.4- to 0.6-mm size range. About 50 percent of bedload at Chippewa River near Caryville was in the 0.5- to 1.0-mm size range. Suspended sediment at all sites except Chippewa River near Caryville was in the sand-size range; the average median diameters were between 0.17 and 0.22 mm. At Chippewa River near Caryville, 60 percent (on the average) of suspended sediment was finer than 0.062 mm.

Average annual total-sediment load and the percentage transported as bedload were determined for a 10-year period (water years 1974–83)(October 1,1973–September 30, 1982). These loads and percentages were, respectively, 123,000 tons and 35 percent at Chippewa River near Caryville; 1,073,000 tons and 61 percent at Chippewa River at Durand; 940,000 tons and 44 percent at Chippewa River near Pepin; 277,000 tons and 43 percent at Black River near Galesville; and 558,000 tons and 49 percent at Wisconsin River at Muscoda.

INTRODUCTION

Transport of sediment to the Mississippi River by tributary streams necessitates expensive dredging to maintain navigation channels, fills backwater areas, and degrades or eliminates fish and wildlife habitat. These and other concerns caused Congress to authorize the Great River Study in the Water Resources Development Act of 1976 (PL 94–587). As part of the Great River Study, the U.S. Army Corps of Engineers provided funding for collecting sediment-transport data at five sites on Wisconsin's three largest tributaries to the Mississippi River (fig. 1). Considerable hydraulic and sediment data were collected at these sites from 1976 through 1983. Most of these data were published in the U.S. Geological Survey's annual data reports (U.S. Geological Survey, 1977–82; Holmstrom and others, 1983–84). The U.S. Army Corps of Engineers (St. Paul, Minn.) funded this study to interpret and synthesize those data.

PURPOSE AND SCOPE

The purposes of this report are to summarize and interpret sediment data that were collected during water years 1976–83[1] at sites on the Chippewa River near Caryville, at Durand, and near Pepin; the Black River near Galesville; and the Wisconsin River at Muscoda. Specifically, the report includes: (1) a description of transport characteristics or the relation of suspended-sediment, bedload, and total-sediment discharge to water discharge; (2) a description of particle-size characteristics of suspended sediment, bedload, and bed material; and (3) estimates of annual and average suspended-, bedload-, and total-sediment loads for the 10-year period during water years 1974–83.

[1]A "water year" begins October 1 and ends September 30 of the following year.

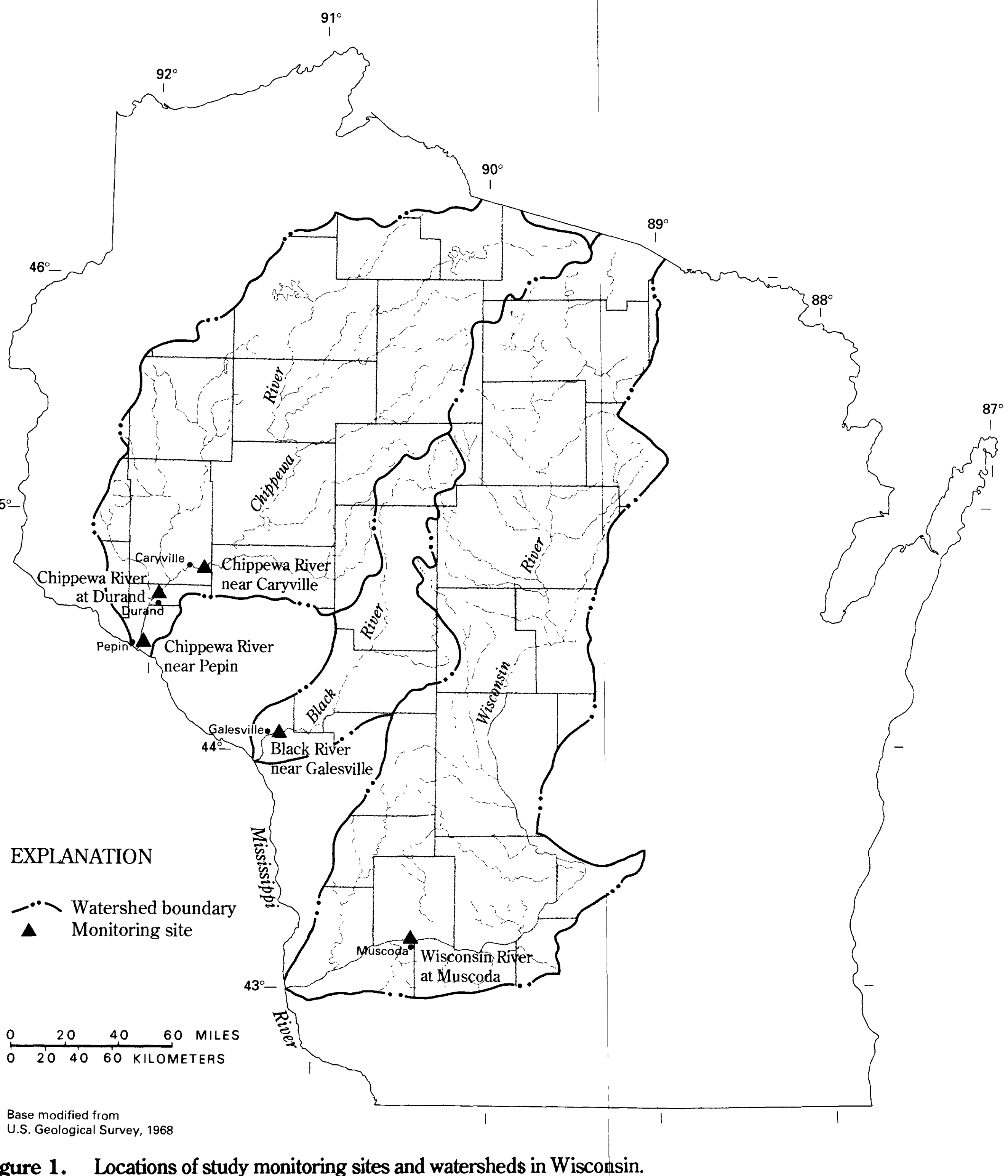


Figure 1. Locations of study monitoring sites and watersheds in Wisconsin.

DATA COLLECTION AND ANALYSIS

Streamflow data were collected and processed following procedures outlined by Rantz and others (1982). These data consisted of daily discharges from gaging stations and hydraulic data from "instantaneous" discharge measurements.

Suspended-sediment samples were collected using velocity-weighted depth-integrating samplers, most commonly the US D–49. Samples were collected by the equal-width-increment (EWI) method (previously referred to as the equal-transit-rate (ETR) method)(Guy and Norman, 1970).

Bedload was sampled using a Helley-Smith bedload sampler (Helley and Smith, 1971), which has a 3-in. by 3-in. (inch) square nozzle and a 0.25-mm mesh collection bag. Standardized sampling techniques were not yet published when the sampler was used in this study; however, the techniques recommended by Emmett (1980, p. 8) were followed as much as possible. Each sample was obtained by making two sampling traverses across the river; each traverse consisted of about 20 sampling locations. The sampling period for each sampling location was 30 seconds. The material from each 20-subsample traverse was composited, air dried, weighed, and analyzed for particle size.

Surface bed material was sampled with either a US BMH–60 or a US BM–54 rotary-bucket bed-material sampler (Guy and Norman, 1970). River beds were sampled at 10 to 14 equally spaced locations in river cross sections.

The laboratory methods used to analyze water samples for suspended-sediment concentration, particle size, bed material, and bedload material for particle size are outlined by Guy (1969). Suspended-sediment samples were analyzed for concentration by the filtration method and for particle size by the sieve-pipet method. Bed material and bedload were analyzed for particle size by the sieve method.

Frequency of sampling varied from site to site and also from one year to another at each site. Sampling covered the range flow experienced at a site during a given year. Specific comments on data availability are given in the discussions of the study sites.

SEDIMENT-DISCHARGE AND LOAD-COMPUTATION METHODS

Instantaneous total-sediment discharges were obtained by two methods. One method consisted of summing measured Helley-Smith bedload discharge and suspended-sediment discharge, as determined from concurrently collected bedload and suspended-sediment samples.

The second of the two methods was the modified-Einstein procedure (Colby and Hembree, 1955). The procedure is applicable to alluvial channels that have bed material finer than 16 mm and if a significant part of the measured suspended sediment is composed of particles of the same size as particles in the bed material (Stevens, 1985, p. 1). Data required to use the procedure are water discharge, average water depth, effective width of the channel, water temperature, suspended-sediment particle size, bed-material particle size, suspended-sediment concentration, average depth of suspended-sediment sampling verticals, and depth of unsampled zone. Hydraulic and channel geometry data were obtained by direct measurement during water-discharge measurements, and sediment data were obtained from sediment-sample analyses. A computer program by Stevens (1985) was used to do the modified-Einstein procedure calculations.

For simplicity in this report, unmeasured-sediment discharge is arbitrarily defined as the approximate equivalent of Helley-Smith bedload discharge. Unmeasured-sediment discharge is total-sediment discharge (determined by the modified Einstein procedure) minus measured suspended-sediment discharge. Emmett (1980, p. 1) explains how bedload discharge, as determined by sampling with a Helley-Smith sampler, differs from actual bedload discharge.

Total- and suspended-sediment transport curves were constructed following procedures outlined by Glysson (1987). In most cases the equations defining the curves were determined by linear regression (least squares) of logarithmic transformed values of water discharge and sediment discharge.

Annual suspended- and total-sediment load estimates were obtained by applying daily mean water discharges to the sediment transport equations to get daily sediment loads. When there was not a functional relation between suspended-sediment concentration and water discharge, daily loads were determined by multiplying average of all sampled concentrations times daily mean water discharge. Likewise, in one case where total-sediment discharge was not functionally related to water discharge, daily total-sediment load was determined by multiplying average total-sediment discharge per unit water discharge times daily mean water discharge. Annual loads were calculated by summing daily loads.

The 10-year period (water years 1974–83) for which annual loads were calculated is the 10-year period preceding the end of data collection at most of the sites. This period, though somewhat arbitrarily selected, provides a more representative estimate of average annual load than if just the years during which data were collected were used. It is assumed that the transport equations are applicable for the 10-year period.

CHIPPEWA RIVER

Sediment-transport monitoring was done at the downstream ends of three subreaches, all in the lower Chippewa River. The three monitoring sites were near Caryville, at Durand, and near Pepin (fig. 2). Sediment transport in the lower Chippewa River is likely influenced by several dams and reservoirs on the river and on its largest tributaries. The lower Chippewa River is the reach from the most downstream dam at Eau Claire to the confluence with the Mississippi River near Pepin. The total drainage area of the Chippewa River basin is 9,410 mi^2 (square miles) (Henrich and Daniel, 1983). Of this total, about 8,500 mi^2 (or about 90 percent) is upstream from dams. Hence, it is likely that most of the sediment from the upstream 90 percent of the basin is trapped by reservoirs and does not enter the lower Chippewa River.

The Eau Claire River and Elk Creek are the largest and second largest tributaries to the Chippewa River between

Caryville and the dam at Eau Claire. A dam and reservoir (Altoona Lake) are near the mouth of the Eau Claire River, and they probably trap most of the sediment from the Eau Claire River that would otherwise enter the Chippewa River. Likewise, a dam and reservoir are on Elk Creek about 3 mi (miles) upstream from its confluence with the Chippewa River. The Eau Claire River and Elk Creek basins upstream from dams comprise about 79 percent of the drainage area between Caryville and Eau Claire.

The Red Cedar River is the main tributary between Durand and Caryville. The most downstream dam on the Red Cedar River is in Menomonie, about 14 mi upstream from the confluence with the Chippewa River. About 81 percent of the drainage area between Durand and Caryville is upstream of dams and reservoirs.

The drainage area between Pepin and Durand is small (about 400 mi^2). The largest tributary between Pepin and Durand is the Eau Galle River, with a drainage area of 250 mi^2. About 64 mi^2 of the Eau Galle basin is upstream from the Spring Valley dam and reservoir.

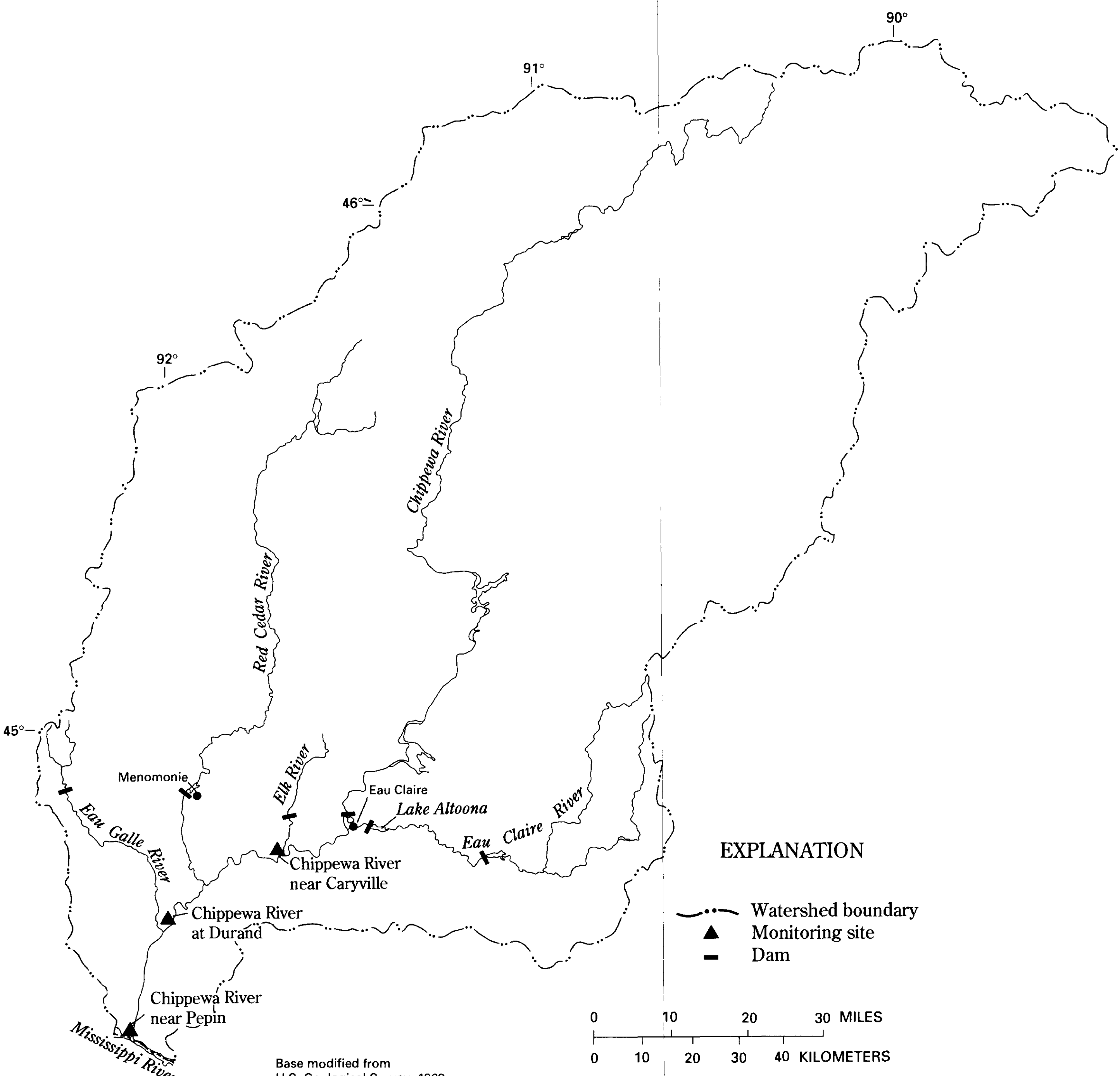


Figure 2. Locations of monitoring sites and selected tributaries in the Chippewa River watershed.

CHIPPEWA RIVER NEAR CARYVILLE

Site Description

Water discharge measuring and sediment sampling was done from the upstream side of the County Highway H bridge about 0.5 mi north of Caryville. The flood plain in the Caryville area is 1.5- to 2-mi wide. The County Highway H road embankment confined all flow within the bridge-opening channel during the study period. The channel is about 400-ft wide at low flow and about 800-ft wide at high flow. The channel reach near the bridge is relatively straight, but the bridge is skewed about 12 degrees from being perpendicular to the channel. The river cross section at the bridge is fairly representative of the river reach within 0.5 mi upstream and downstream from the bridge.

Data Availability

Intermittent sediment sampling and water discharge measuring began in August 1976 and ended in September 1981. From August 1976 through September 1979, water discharge, suspended sediment, Helley-Smith bedload, and surface bed material were measured or sampled about eight times per year. The suspended sediment was analyzed for concentration, and seven bedload and all bed-material samples were analyzed for particle size.

From March 1980 through September 1981, the sampling program was changed to collect the data needed to use the modified-Einstein procedure. Bedload sampling was ended, and the volume of water collected for suspended-sediment analyses was increased to insure there would be enough sediment to analyze for particle size. Fourteen data sets were collected to use the modified-Einstein procedure.

Continuous streamflow data were available for the Chippewa River at Chippewa Falls, Chippewa River at Durand, and Red Cedar River at Menomonie. These data were used with drainage areas to estimate daily mean discharges for the Chippewa River at Caryville.

Sediment Transport

Both suspended- and total-sediment transport in the Chippewa River near Caryville are represented by two functional relationships with water discharge. The change from one relation to the other occurs for suspended-sediment discharge when water discharge is about 5,700 ft^3/s (cubic feet per second) and, for total-sediment discharge, it occurs when water discharge is about 4,200 ft^3/s.

Suspended-sediment concentration and water discharge are not functionally related when water discharge is less than 8,000 ft^3/s (fig. 3). Observed concentrations during discharges less than 8,000 ft^3/s ranged from 3 to 11 mg/L

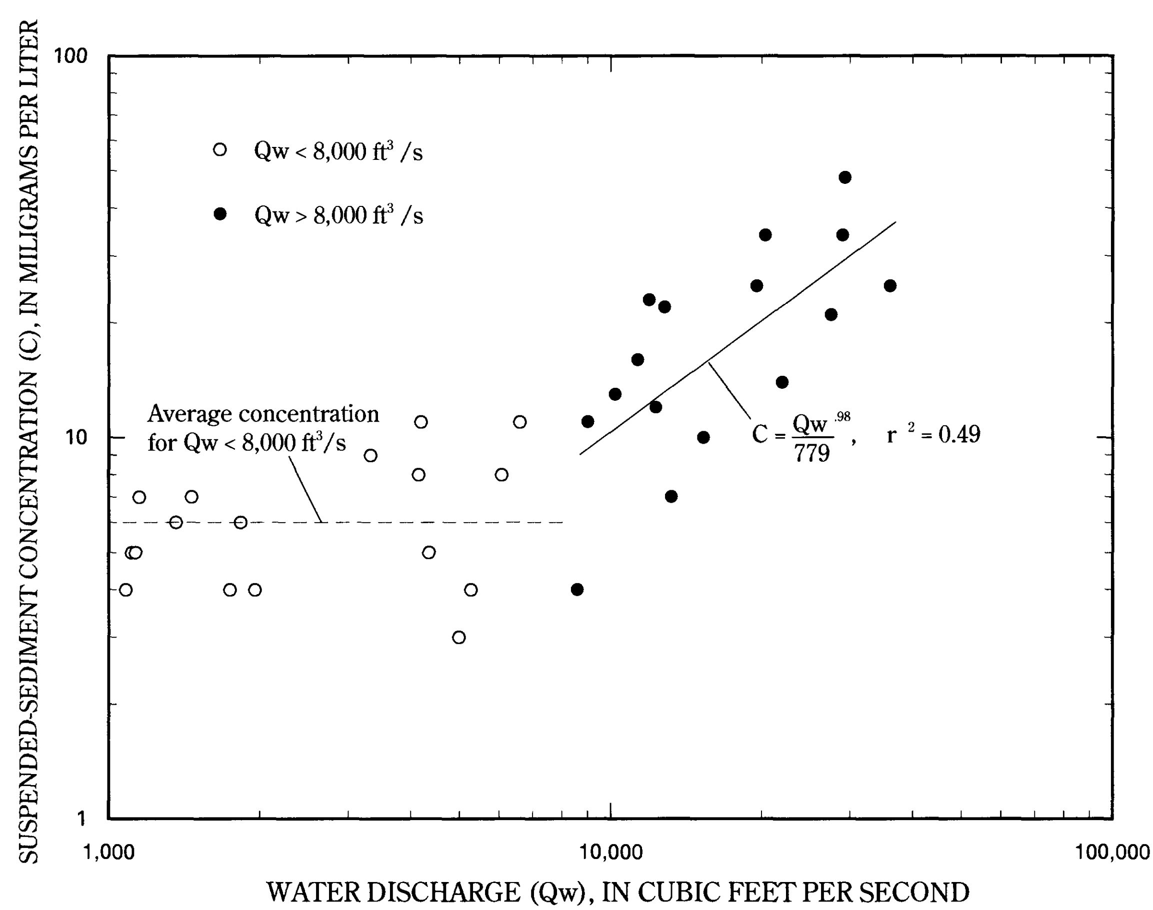


Figure 3. Relation of suspended-sediment concentration to water discharge at Chippewa River near Caryville.

(milligrams per liter) and averaged about 6 mg/L. Suspended-sediment concentration and water discharge do exhibit a functional relation when discharges are greater than 8,000 ft^3/s (fig. 3). Observed concentrations for discharges greater than 8,000 ft^3/s ranged from 4 to 48 mg/L. The two suspended-sediment transport rate relations are shown in figure 4. The relation for discharges greater than 5,700 ft^3/s is the regression line for water discharge versus suspended-sediment discharge. For discharge less than 5,700 ft^3/s, the relation line is the average observed suspended-sediment concentration (6 mg/L) times the units conversion factor (0.0027) times water discharge.

The bedload data indicate a marginal sediment supply from upstream sources, especially when water discharge is less than about 8,000 ft^3/s. Bedload discharge was absent in all but 3 of 17 observations during water discharges less than 8,000 ft^3/s (fig. 5). Bedload and water discharge are related at discharges greater than 8,000 ft^3/s. Zero bedload was measured or calculated in only 4 of 19 observations at discharges greater than 8,000 ft^3/s.

Two total-sediment transport rate relations were developed and are shown in figure 4. The equations for suspended-sediment discharge and total-sediment discharge for the low water discharge range are very similar. Suspended-sediment discharge was equal to total-sediment discharge for all but 3 of the 17 data points defining the relations. The crossing of the lines defining the suspended- and total-sediment transport relations results from the methods used to define the relations. In reality, of course, suspended-sediment discharge is always less than total-sediment discharge for a given water discharge.

Sediment Particle Size

The particle size of bed material varied considerably both with time and location in the sampling cross section. The median particle diameter[2] size of 35 observations ranged from 0.42 to 15 mm (fig. 6). The variation in median particle size was not related to water discharge. The cross-channel variation in particle size is illustrated in figure 7. The median particle diameter of the 10 subsamples ranged from about 0.3 to 32 mm.

The particle size of Helley-Smith bedload was less variable than the bed material. On the average, about 50 percent of the material was in the 0.5- to 1.0-mm size range (fig. 8). The median particle diameter of seven bedload samples ranged from about 0.5 to 1.2 mm.

Suspended sediment was less than 1 mm in diameter. On the average, about 60 percent of the suspended sediment was

[2] "Median particle diameter" is the diameter such that half the mass of material is composed of particles larger than the median particle diameter and the other half is composed of particles smaller than the median diameter.

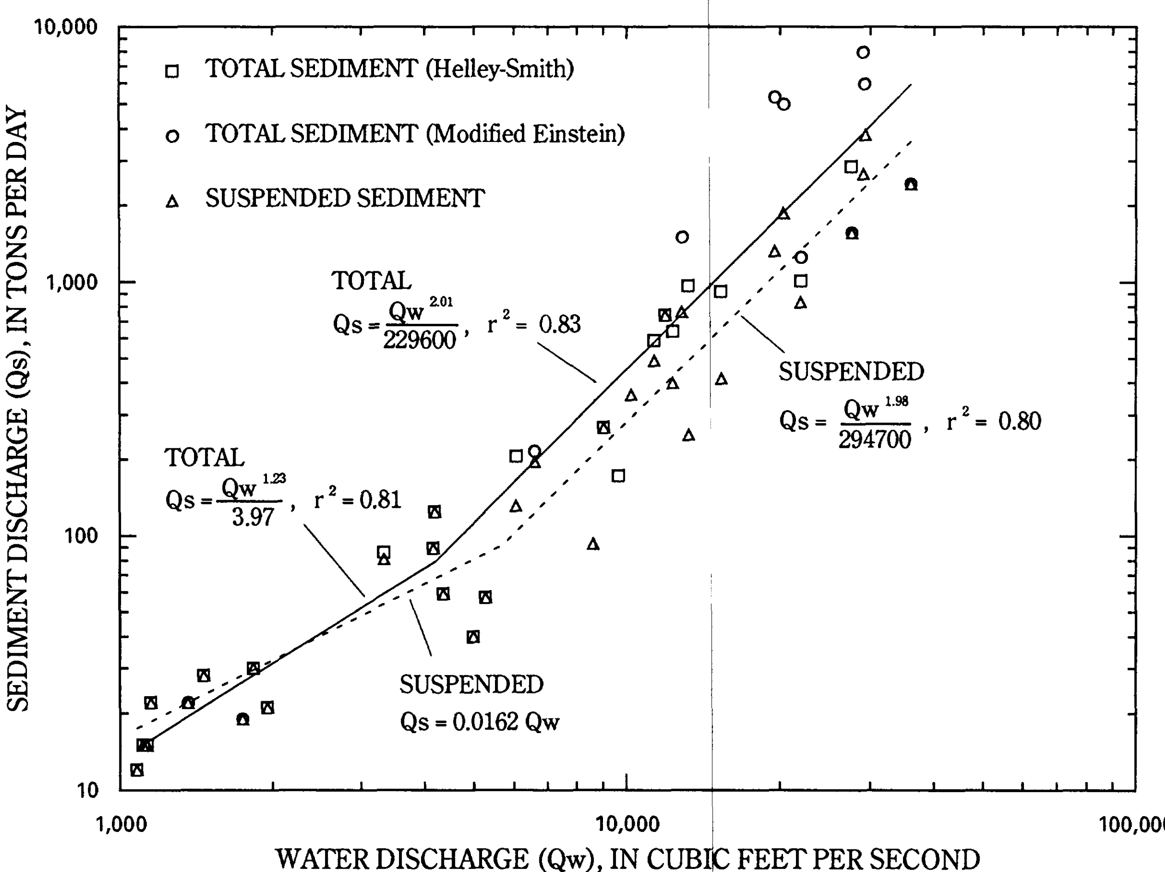


Figure 4. Relations of suspended- and total-sediment discharge to water discharge at Chippewa River near Caryville.

in the silt and clay size range or less than 0.062 mm. The average and range of particle sizes from 14 samples are shown in figure 9.

Sediment Load

Total annual sediment load ranged from 44,000 to 194,000 tons and averaged 123,000 tons during 1974–83. Sediment loads and average annual water discharge are shown below.

About 65 percent of the total load was transported as suspended sediment and 35 percent was transported as bedload or unmeasured-sediment discharge. The relative proportions of suspended- and unmeasured-sediment loads for the 10-year period are shown in figure 10.

Water year	Average water discharge (ft^3/s)	Suspended-sediment load (tons)	Unmeasured-sediment load (tons)	Total sediment load (tons)
1974	6,210	64,000	32,000	96,000
1975	6,040	75,000	40,000	115,000
1976	6,200	85,000	49,000	134,000
1977	3,600	31,000	13,000	44,000
1978	7,110	74,000	40,000	114,000
1979	7,170	91,000	51,000	142,000
1980	5,900	65,000	33,000	98,000
1981	6,150	71,000	38,000	109,000
1982	6,940	115,000	66,000	181,000
1983	8,730	121,000	73,000	194,000

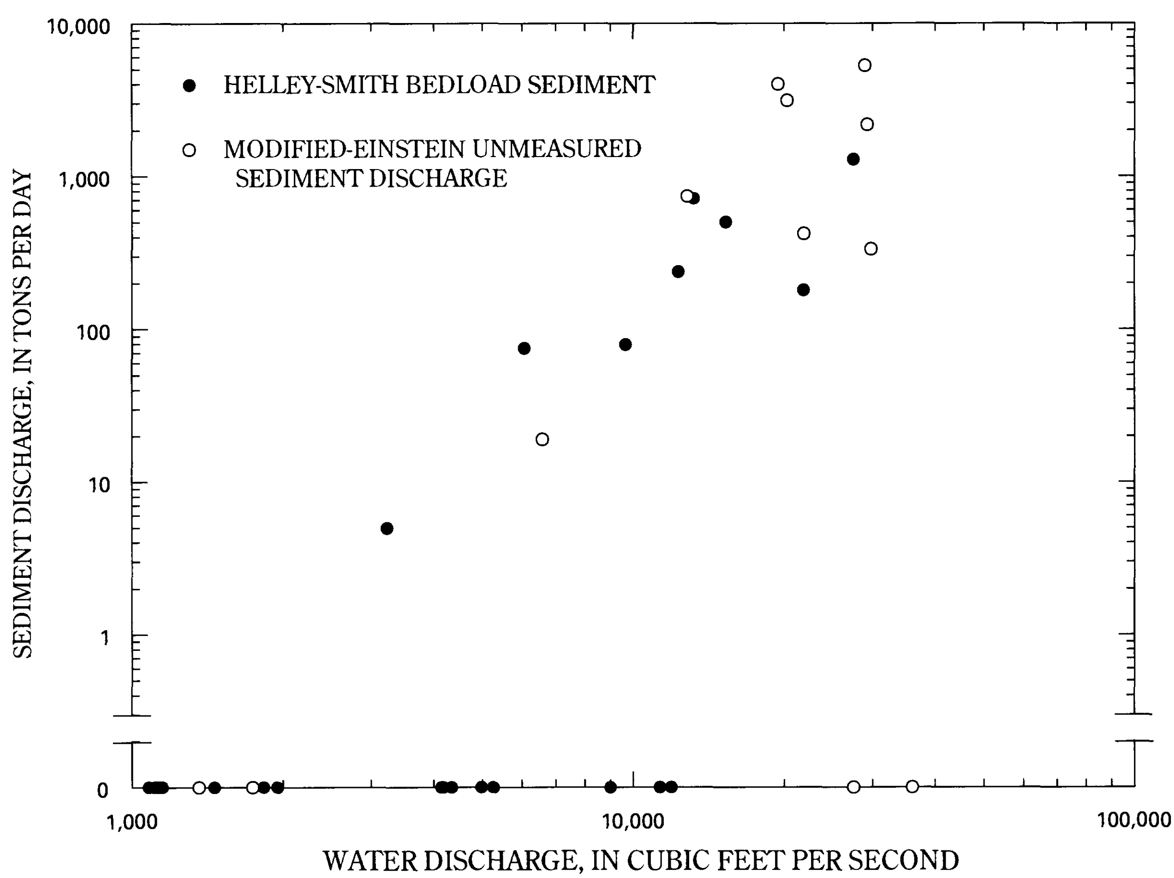


Figure 5. Relation of Helley-Smith bedload discharge and modified-Einstein unmeasured-sediment discharge to water discharge at Chippewa River near Caryville.

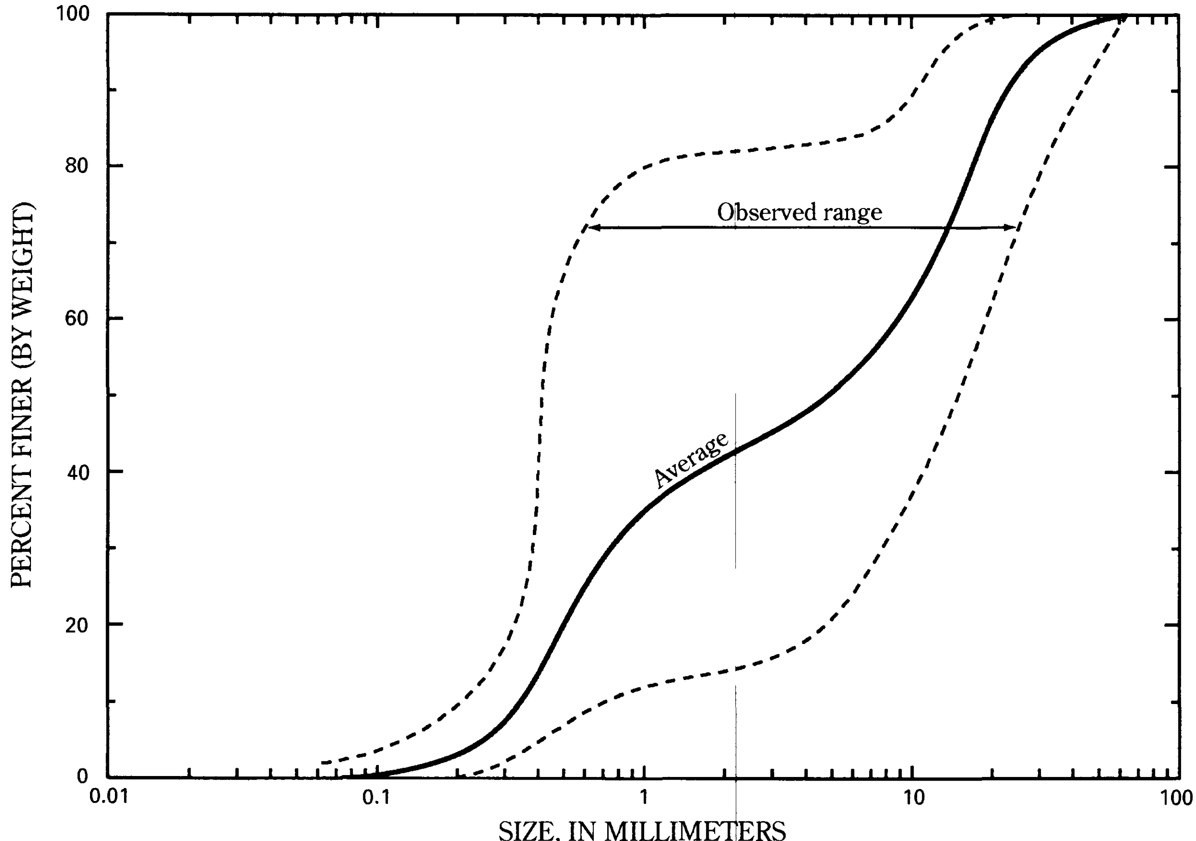


Figure 6. Cumulative-frequency distribution of average and range of particle sizes in 35 surface bed material samples from Chippewa River near Caryville from August 1976 through September 1981.

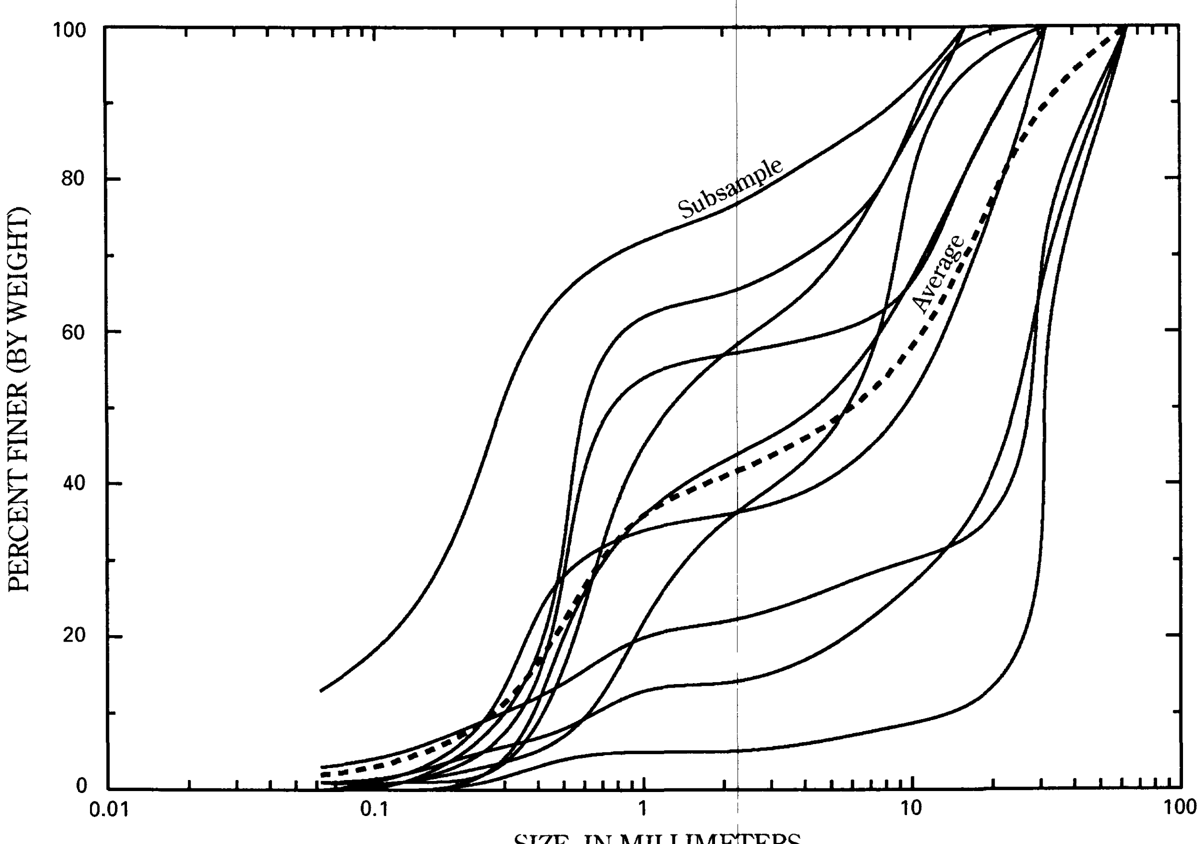


Figure 7. Cumulative-frequency distribution of particle sizes in surface bed material from 10 equally spaced locations in the channel cross section on March 15, 1977, at Chippewa River near Caryville.

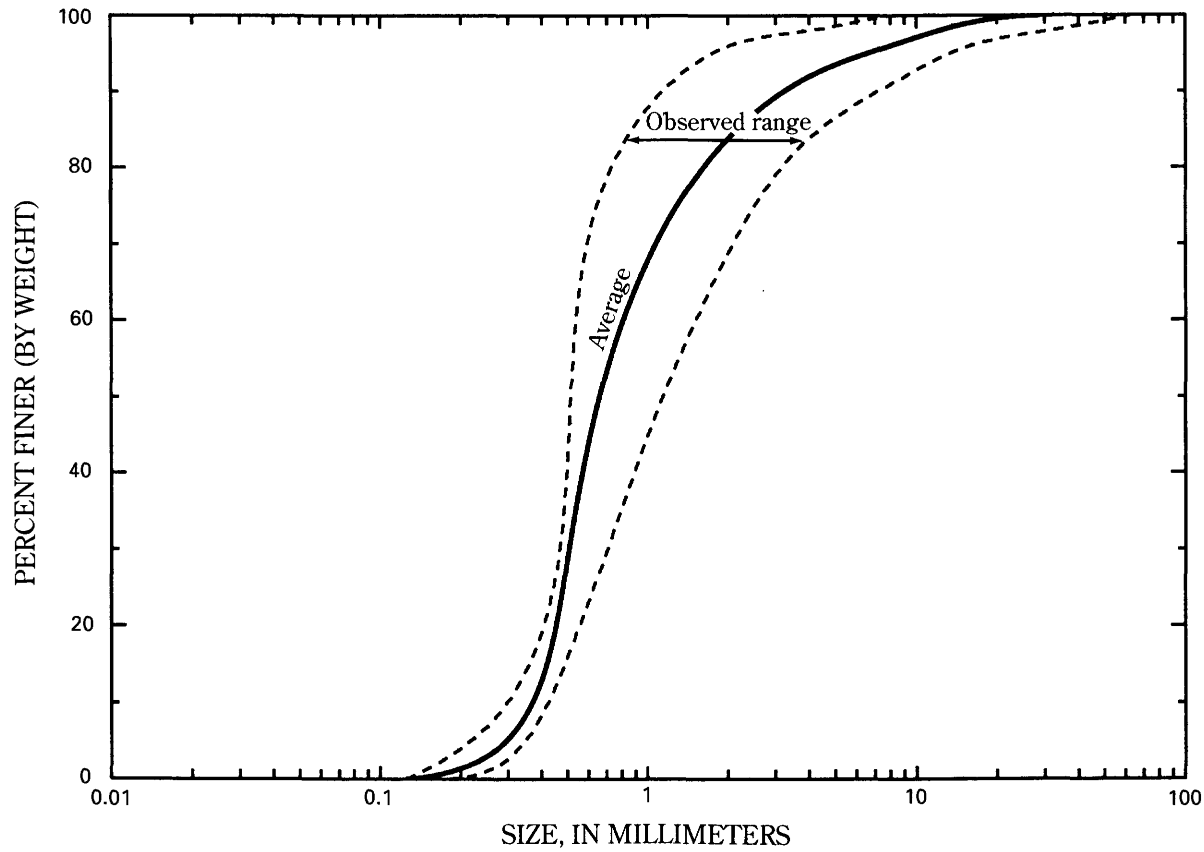


Figure 8. Cumulative-frequency distribution of average and range of particle sizes in seven Helley-Smith bedload samples from Chippewa River near Caryville from August 1976 through September 1979.

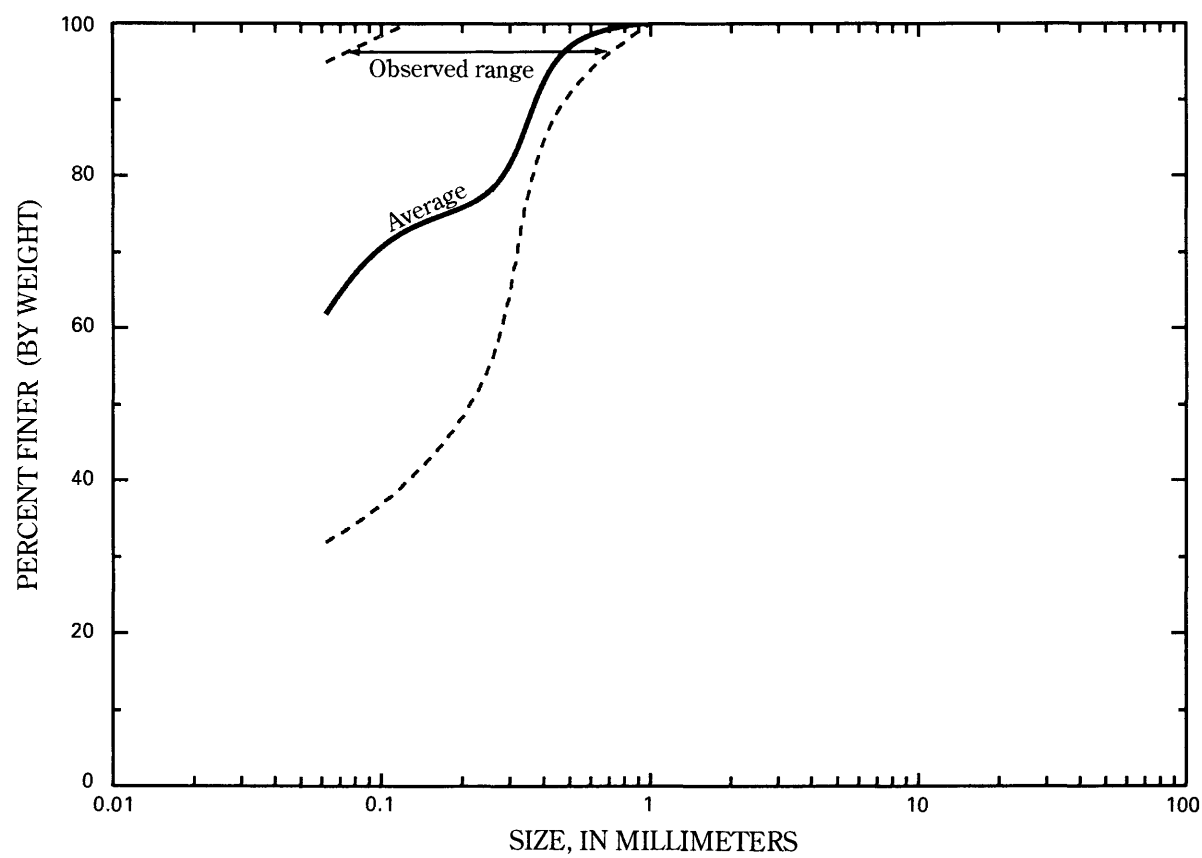


Figure 9. Cumulative-frequency distribution of average and range of particle sizes in 14 suspended-sediment samples from Chippewa River near Caryville from August 1976 through September 1981.

Most of the coarse-grained (>0.062 mm) part of the average annual load (123,000 tons) probably is derived from the river reach and watershed between Caryville and Eau Claire. Dams and reservoirs on the Chippewa and Eau Claire Rivers at Eau Claire probably trap virtually all coarse-grained sediment from upstream sources. About 60 percent (on the average) of suspended sediment at Caryville is fine grained (<0.062 mm) and about 65 percent of the total load is suspended sediment. Thus, at least 60 percent of the sediment load at Caryville is coarse grained (>0.062 mm) and probably is derived from the river reach between Caryville and Eau Claire.

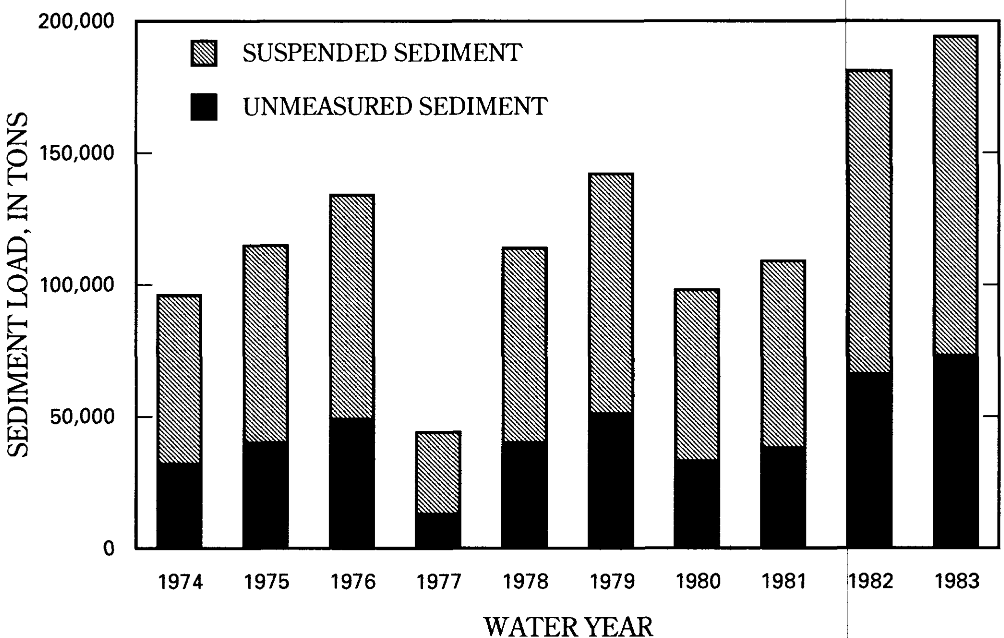


Figure 10. Annual suspended- and unmeasured-sediment loads at Chippewa River near Caryville, water years 1974–83.

CHIPPEWA RIVER AT DURAND

Site Description

The Chippewa River at Durand flows in a northeast to southwest direction in about a 1- to 2-mi-wide flood plain. The main channel flows along the southeast side of the flood plain. Stream discharge measuring and sediment sampling were done from U.S. Highway 10 bridges. In addition to the main channel bridge, a bridge near the middle and another near the northwest side of the flood plain convey water at high flow (above 49,000 ft^3/s). The water surface width in the main channel ranges from about 500 ft at low flow to about 1,100 ft at high flow.

Data Availability

Intermittent sediment sampling began in April 1974 and ended in September 1983. From April 1974 to October 1975 only suspended-sediment concentration measurements were made. From November 1975 through September 1979 water discharge, suspended sediment, Helley-Smith bedload, and bed material were measured or sampled about seven times per year. Suspended sediment was analyzed for concentration and bedload and bed material were analyzed for particle size.

From March 1980 through September 1983, the sampling program was changed to collect the data needed to employ the modified-Einstein procedure. Helley-Smith bedload sampling was ended and the volume of water collected for suspended-sediment analyses was increased to insure there would be enough sediment for particle-size analyses. Twenty-six data sets were available to employ the modified-Einstein procedure.

A streamflow-gaging station at Durand has provided continuous record of stream discharge since July 1928.

Sediment Transport

Sediment transport in the Chippewa River at Durand exhibits a functional relationship with water discharge throughout the sampled range. Figure 11 shows the relationship between suspended-sediment concentration and water discharge. Observed concentrations ranged from 4 to 413 mg/L. The suspended-sediment transport-rate relation is shown in figure 12.

The total-sediment transport rate relation in figure 13 is based only on modified Einstein procedure calculations. The total and suspended-sediment transport-rate relations converge with increasing water discharge, indicating that total-sediment discharge is composed of a higher percentage of bedload discharge at low than at high river discharge.

Unmeasured sediment discharge computed for a given water discharge was greater than measured bedload discharge as shown by the curves in figure 13. Any discussion to try to explain why the curves are different would require consideration of many complicated factors and is beyond the scope of this report.

Sediment Particle Size

There was little temporal variation in bed material particle size and little variation in particle size at different locations in the river cross section. The range and average of bed material particle size from 50 observations is shown in figure 14. The median diameter ranged from 0.47 to 0.84 mm and exhibited little variation with water discharge. The cross channel variation is shown in figure 15. The particle sizes of seven of the nine subsamples are very similar (median particle diameter ranged from 0.5 to 0.61 mm). The two remaining subsamples were finer and coarser than the other seven, and had median diameters of 0.24 and 11 mm.

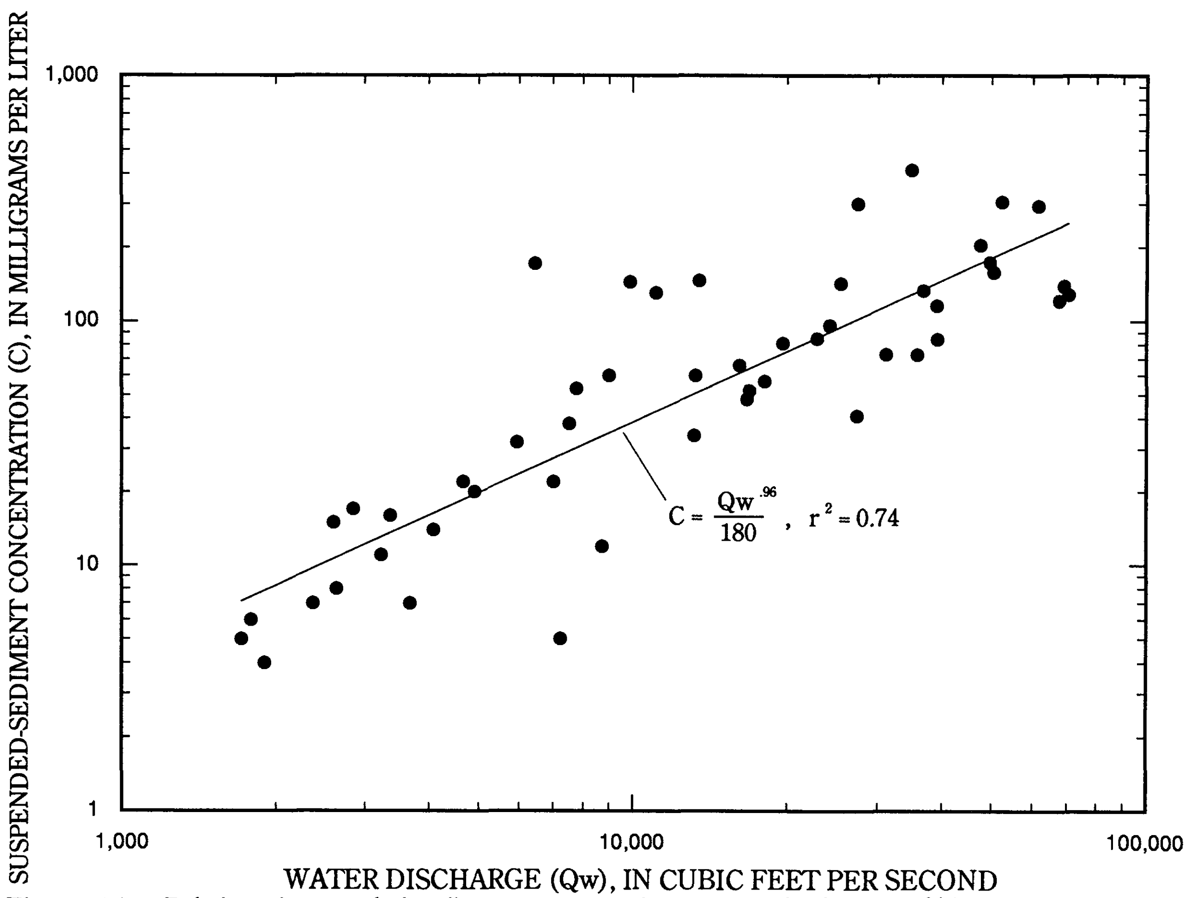


Figure 11. Relation of suspended-sediment concentration to water discharge at Chippewa River at Durand.

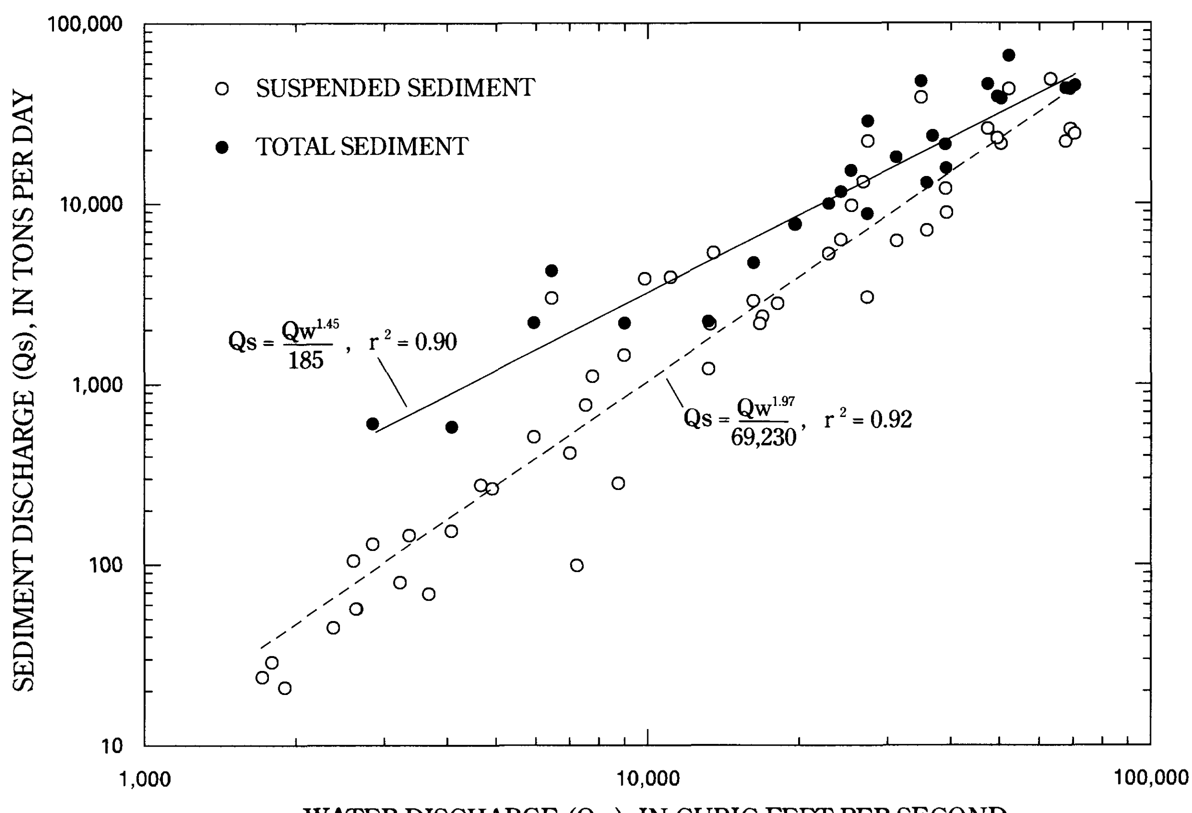


Figure 12. Relations of suspended- and total-sediment discharge to water discharge at Chippewa River at Durand.

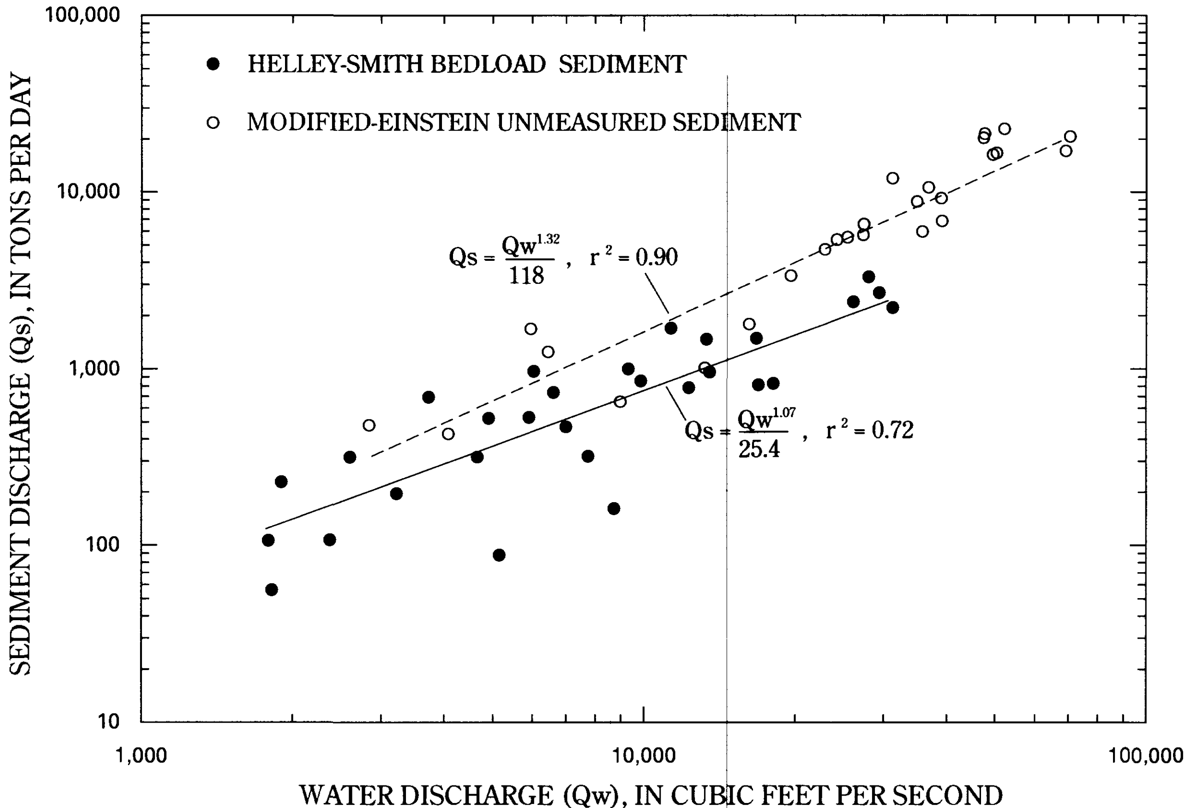


Figure 13. Relations of Helley-Smith bedload discharge and modified-Einstein unmeasured-sediment discharge to water discharge at Chippewa River at Durand.

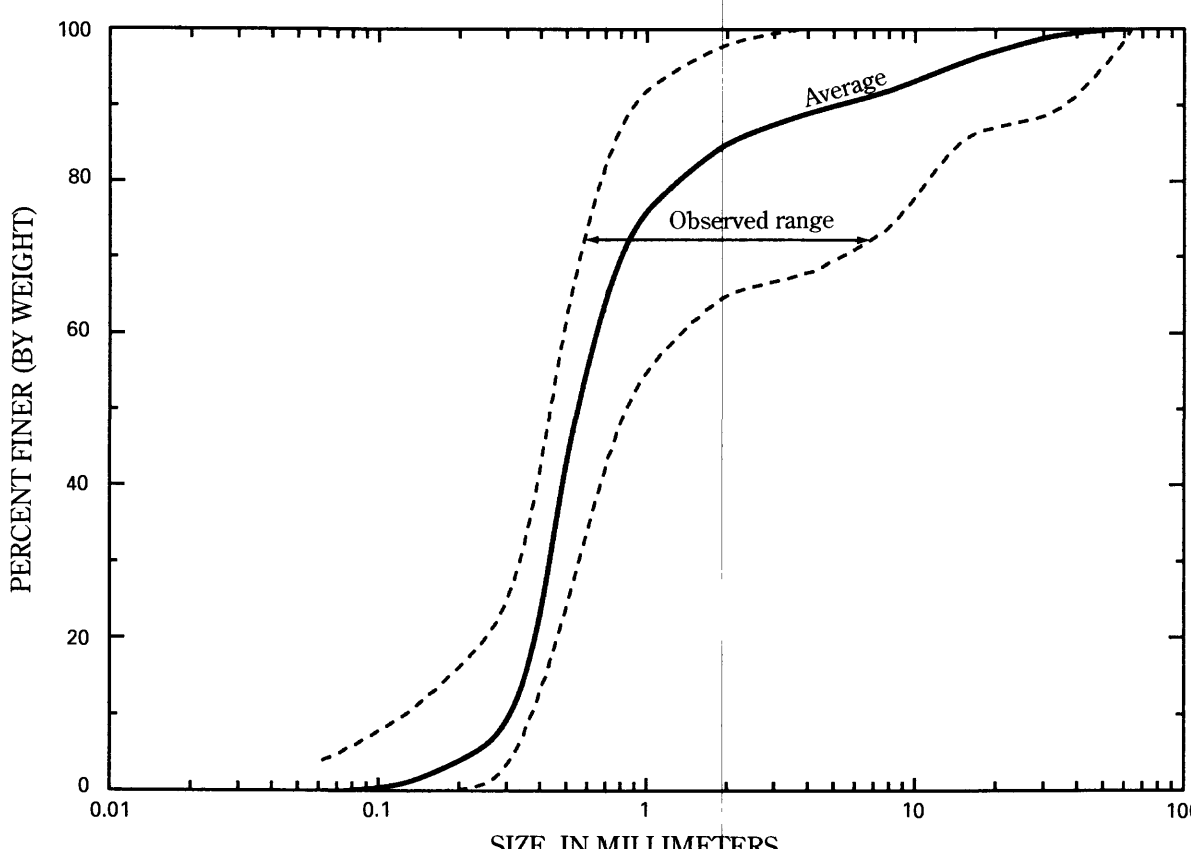


Figure 14. Cumulative-frequency distribution of average and range of particle sizes in 50 surface bed material samples from Chippewa River at Durand from November 1975 through September 1983.

The particle size of the measured bedload was even less variable than the bed material. About 57 percent of the material was in the 0.4- to 0.6-mm size range (fig. 16). The median particle diameter of 29 bedload samples ranged from 0.5 to 0.73 mm.

Suspended sediment was less than 2 mm in diameter. The average and range of particle size from 26 samples is shown in figure 17. The average median particle diameter was 0.22 mm, and about 26 percent of the suspended sediment was in the silt- and clay-size range.

Sediment Load

Total annual sediment load ranged from 503,000 to 1,574,000 tons and averaged 1,073,000 tons during 1974-83. Sediment loads and average annual water discharge are shown below.

Water year	Average water discharge (ft^3/s)	Suspended-sediment load (tons)	Unmeasured sediment load (tons)	Total sediment load (tons)
1974	8,010	346,000	638,000	984,000
1975	7,850	406,000	608,000	1,014,000
1976	7,980	445,000	628,000	1,073,000
1977	4,860	151,000	352,000	503,000
1978	8,960	393,000	734,000	1,127,000
1979	9,160	485,000	751,000	1,236,000
1980	7,840	364,000	625,000	989,000
1981	7,820	354,000	620,000	974,000
1982	8,770	585,000	675,000	1,260,000
1983	11,000	669,000	905,000	1,574,000

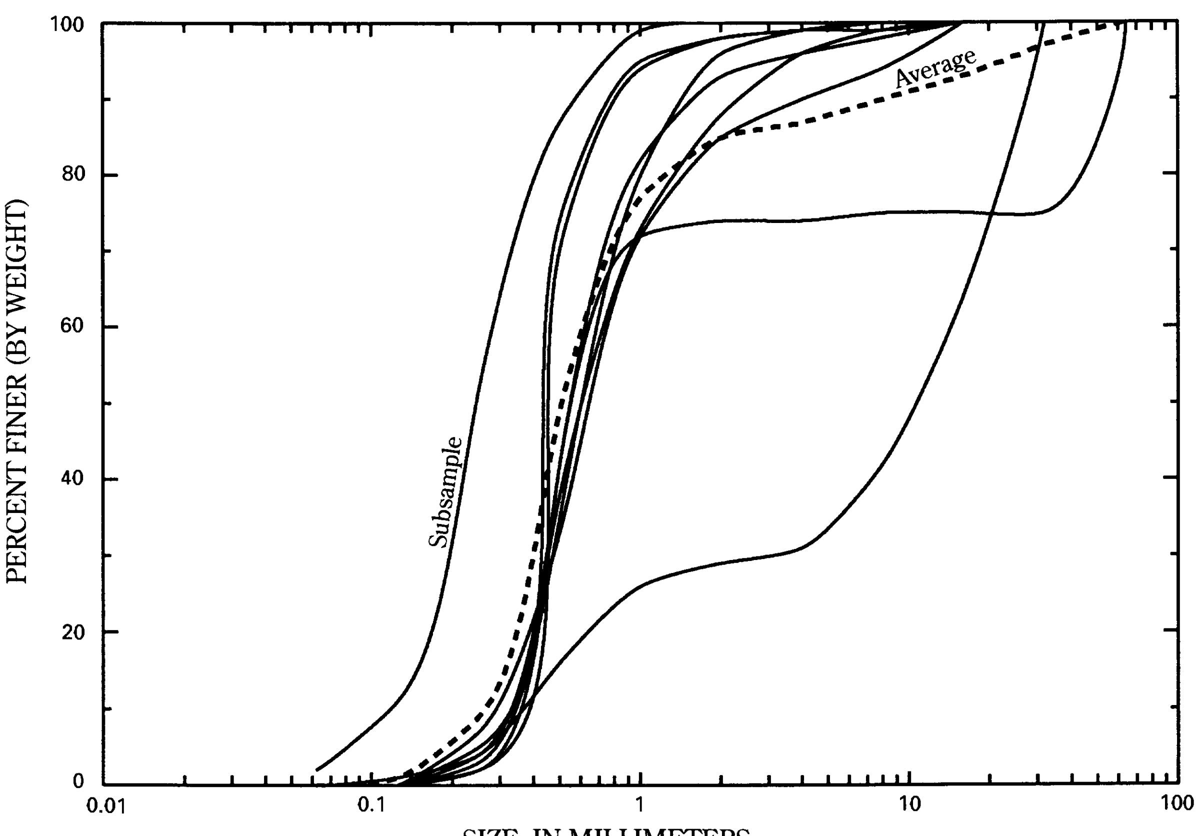


Figure 15. Cumulative-frequency distribution of particle sizes in surface bed material from nine equally spaced locations in the channel cross section on April 4, 1981, at Chippewa River at Durand.

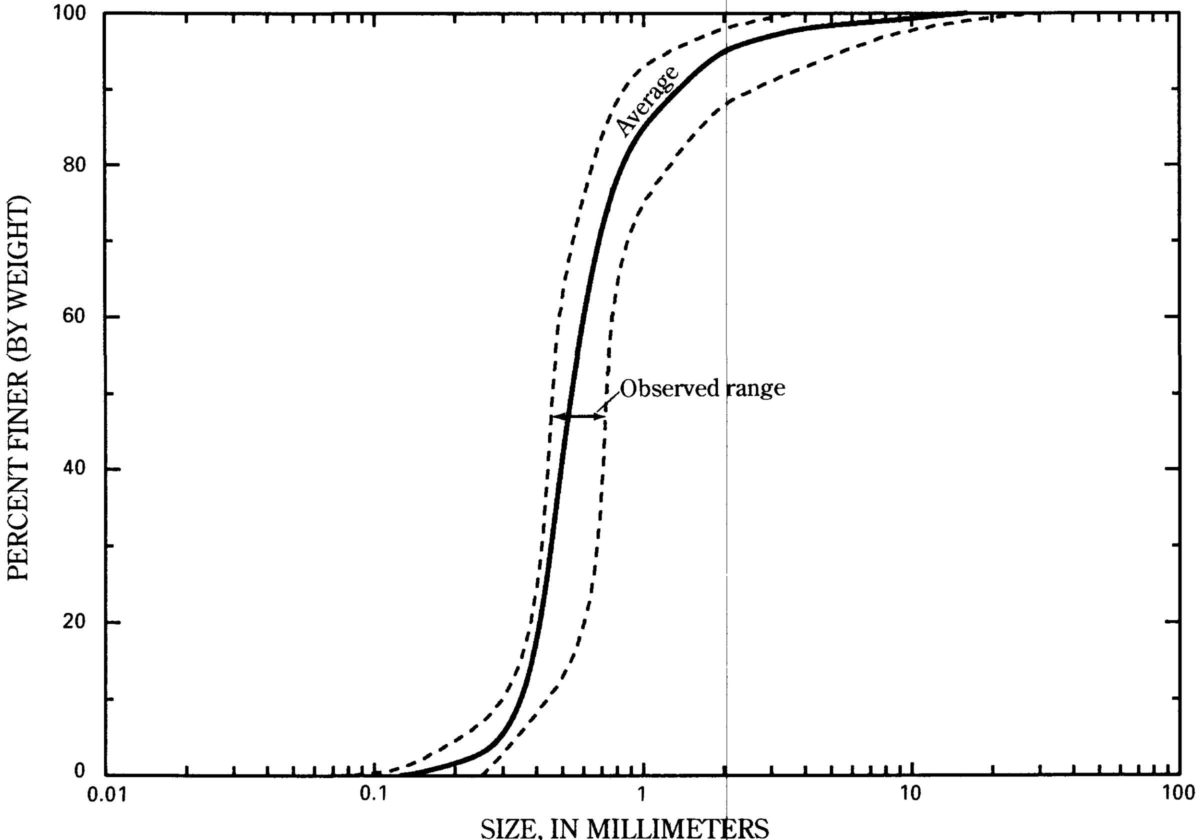


Figure 16. Cumulative-frequency distribution of average and range of particle sizes in 29 Helley-Smith bedload samples from Chippewa River at Durand from November 1975 through September 1979.

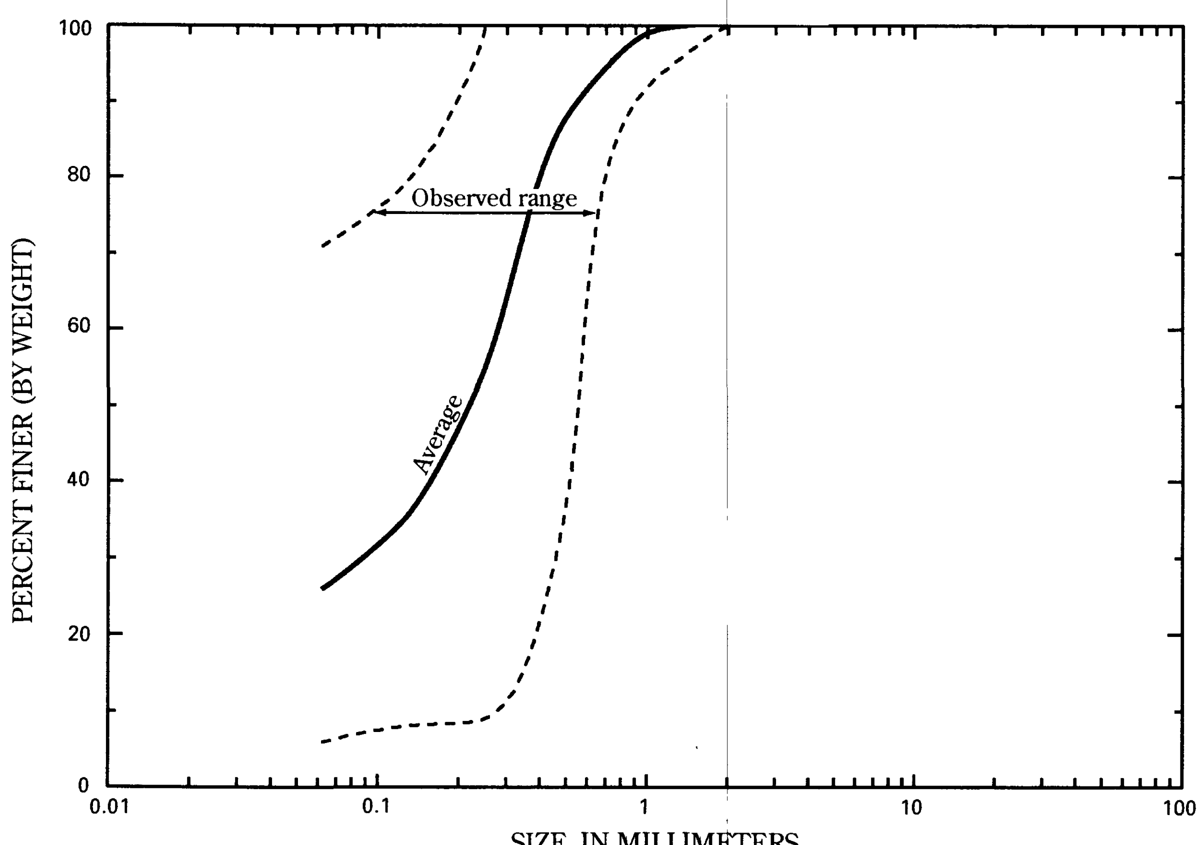


Figure 17. Cumulative-frequency distribution of average and range of particle sizes in 26 suspended-sediment samples from Chippewa River at Durand from November 1975 through September 1983.

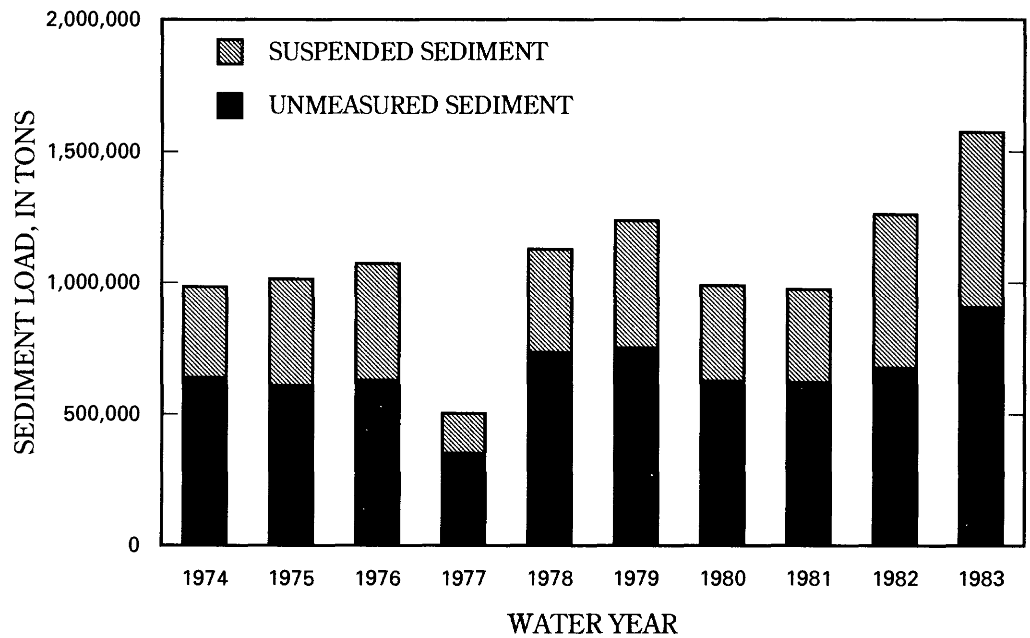


Figure 18. Annual suspended- and unmeasured-sediment loads at Chippewa River at Durand, water years 1974–83.

About 39 percent of the total load was transported as suspended sediment and 61 percent was transported as bedload or unmeasured-sediment discharge. The relative proportions of suspended- and unmeasured-sediment loads for the 10-year period are illustrated in figure 18.

Most or about 89 percent of the average annual load at Durand was derived from the river reach and watershed between Durand and Caryville. This reach yielded 950,000 tons of sediment or about 7.7 times more than was yielded from the river upstream of Caryville.

CHIPPEWA RIVER NEAR PEPIN

Site Description

The Chippewa River crossing at State Highway 35 flows through eight bridge openings about 2 mi upstream from the confluence with the Mississippi River. The bridges are numbered 1–8 on figure 19. Bridge 7, through which flow is perennial, is referred to as the "main channel." Flow in the remaining channels is intermittent and dependent on total river discharge. Channels spanned by bridges 1-6 are referred to as "east channels"; the channel spanned by bridge 8 is referred to as the "west channel."

Most flow in the west channel is derived from the main channel just upstream of the highway. The water flows westward, parallel to the highway, and crosses the highway through bridge opening number 8 (fig. 19). The east channels derive their water from the main channel at several "spillover" points along a 10-mi long reach of the river north of State Highway 35. The water flows south through tortuous channels and sloughs to the six east channel bridge openings.

Data Availability

Hydraulic data were available from discharge measurements made during the period September 1976 through September 1983. Forty-two measurements of flow, ranging from 2,490 to 33,900 ft^3/s, were made in the main channel. Eleven to 16 measurements were made in the various east channels. The range of flow (combined flow of all six east channels) measured was 1,500 to 38,800 ft^3/s. Twenty measurements ranging from 479 to 4,460 ft^3/s were made in the west channel.

Continuous streamflow data were available for the Chippewa River at Durand. These data and drainage-area information were used to estimate daily mean discharges for the Chippewa River near Pepin.

Intermittent sediment sampling began in September 1976 and ended in September 1984. From September 1976 through September 1979, 22 sets of suspended-sediment concentration, Helley-Smith bedload discharge and particle size, and bed-material particle-size data were collected from the main channel. During this period, only suspended-sediment samples were collected from the east and west channels.

Beginning in March 1980 and through September 1983, the sampling program for the main and west channels was changed to collect data needed to use the modified-Einstein procedure. Twenty-four modified-Einstein procedure data sets were collected for the main channel and 10 were collected for the west channel. During this period, only suspended sediment was sampled regularly from the east channels Selected east channels were sampled once for bed-material particle-size analysis.

Sediment Transport

MAIN CHANNEL

Sediment transport in the main channel exhibits a functional relation with water discharge. The relation between suspended-sediment concentration and water discharge is shown in figure 20. Observed concentrations ranged from 10 to 330 mg/L. Figure 21 shows the suspended-sediment transport rate relation.

The total-sediment discharge transport rate relation shown in figure 21 is based only on modified-Einstein procedure calculations. There is a slight, but probably insignificant, convergence of the total- and suspended-sediment transport-rate relations with increasing water discharge.

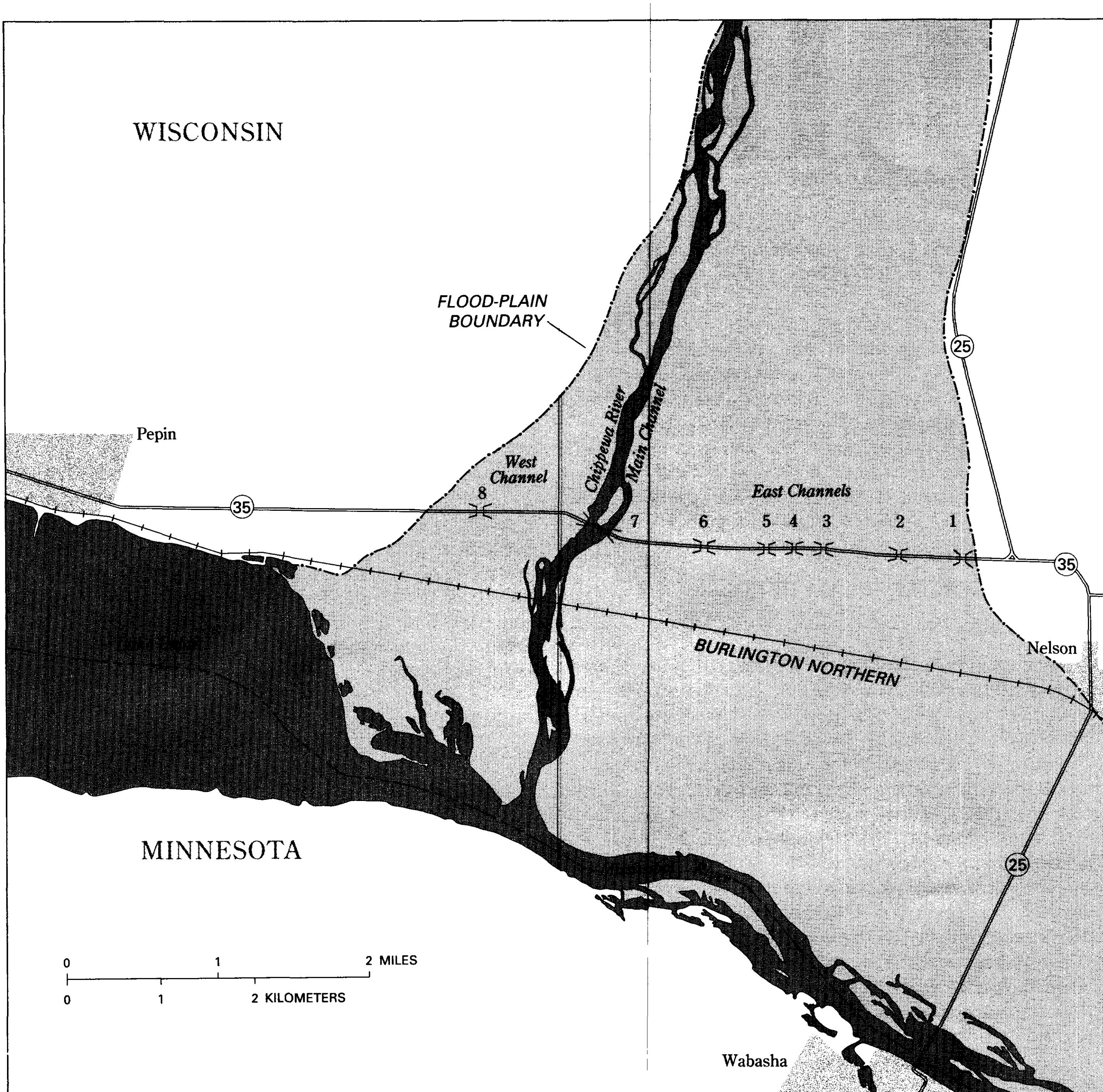
Measured bedload discharge generally was greater than computed unmeasured-sediment discharge when water discharge was less than about 6,000 ft^3/s. At water discharges greater than 6,000 ft^3/s, measured bedload generally was less than unmeasured-sediment discharge (fig. 22). As was described for the Chippewa River at Durand, differences between the bedload and unmeasured discharge curves are caused by a variety of complicated factors. Discussion of these factors is beyond the scope of the report.

WEST CHANNEL

Neither suspended-sediment discharge nor total-sediment discharge had a functional relationship with water discharge. Figures 23 and 24 show the relation of suspended-sediment concentration to water discharge and total sediment discharge to water discharge. Measured suspended-sediment concentrations ranged from 24 to 241 mg/L and averaged 72 mg/L.

EAST CHANNELS

Suspended-sediment concentrations in the east channels were always less than those in either the main or west channels, and were poorly related to water discharge. The



Base modified from U. S. Geological Survey
Wabasha 1:62,500, 1951

Figure 19. Location of main channel and bridges at Chippewa River near Pepin.

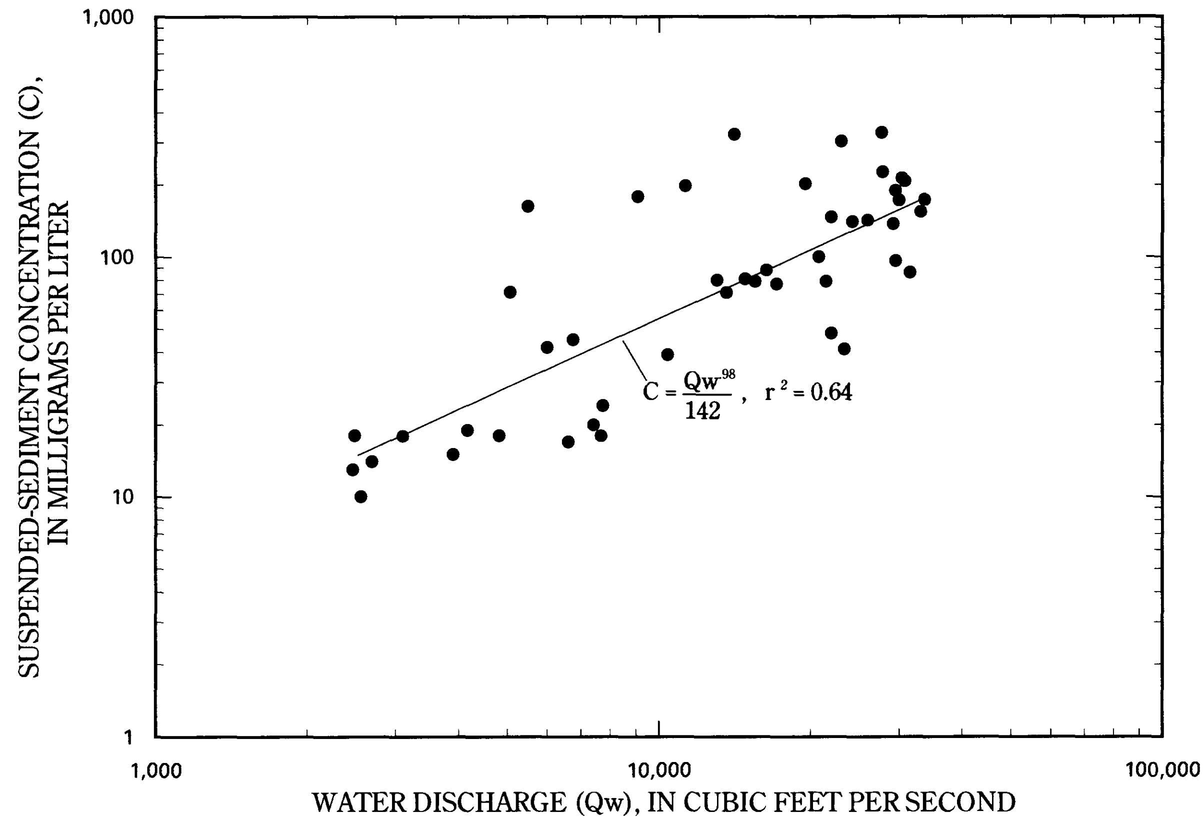


Figure 20. Relation of suspended-sediment concentration to water discharge at main channel of Chippewa River near Pepin.

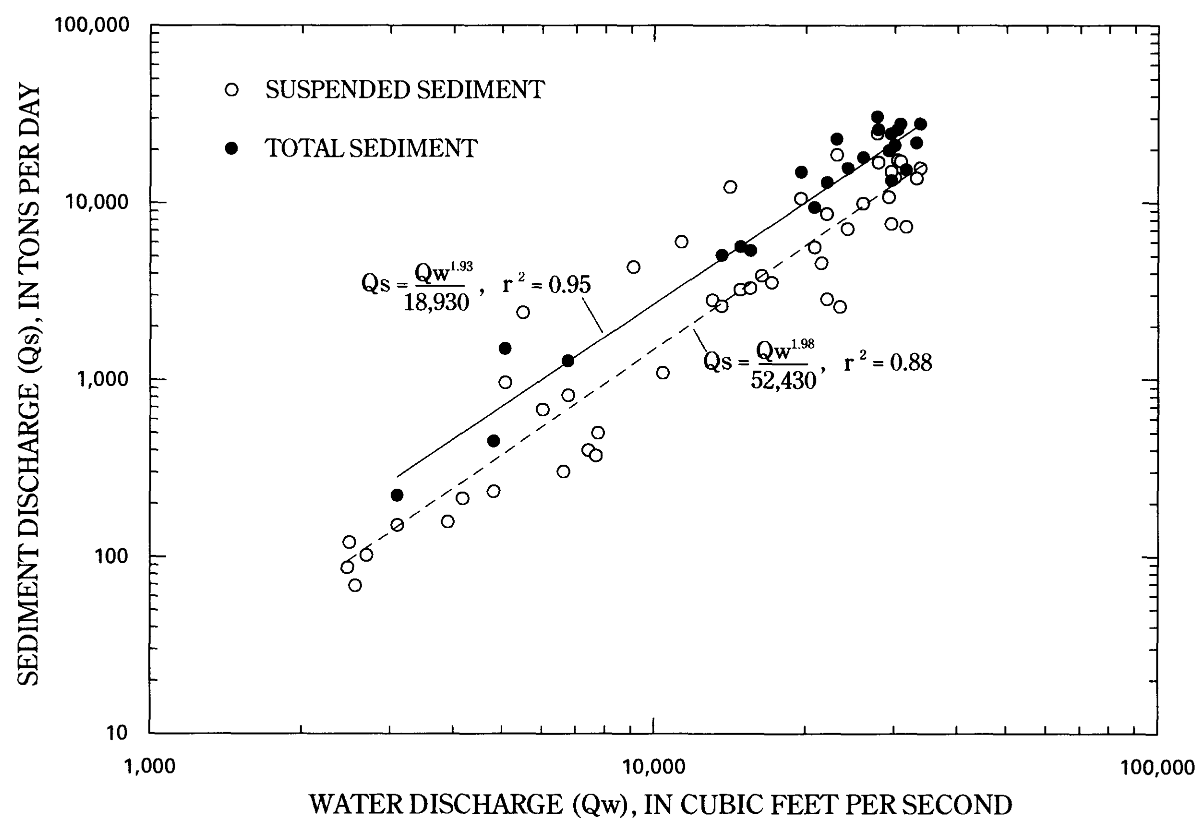


Figure 21. Relations of suspended- and total-sediment discharge to water discharge at main channel of Chippewa River near Pepin.

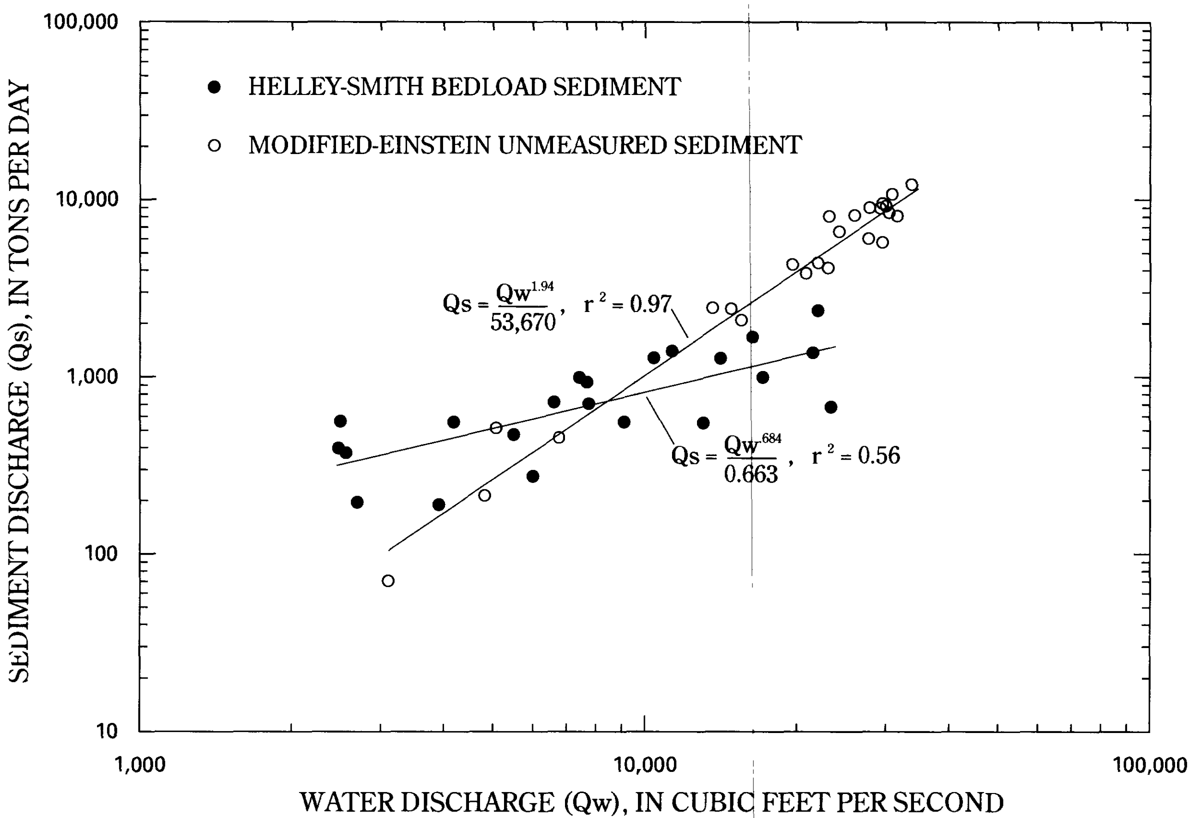


Figure 22. Relations of Helley-Smith bedload discharge and modified-Einstein unmeasured-sediment discharge to water discharge at main channel of Chippewa River near Pepin.

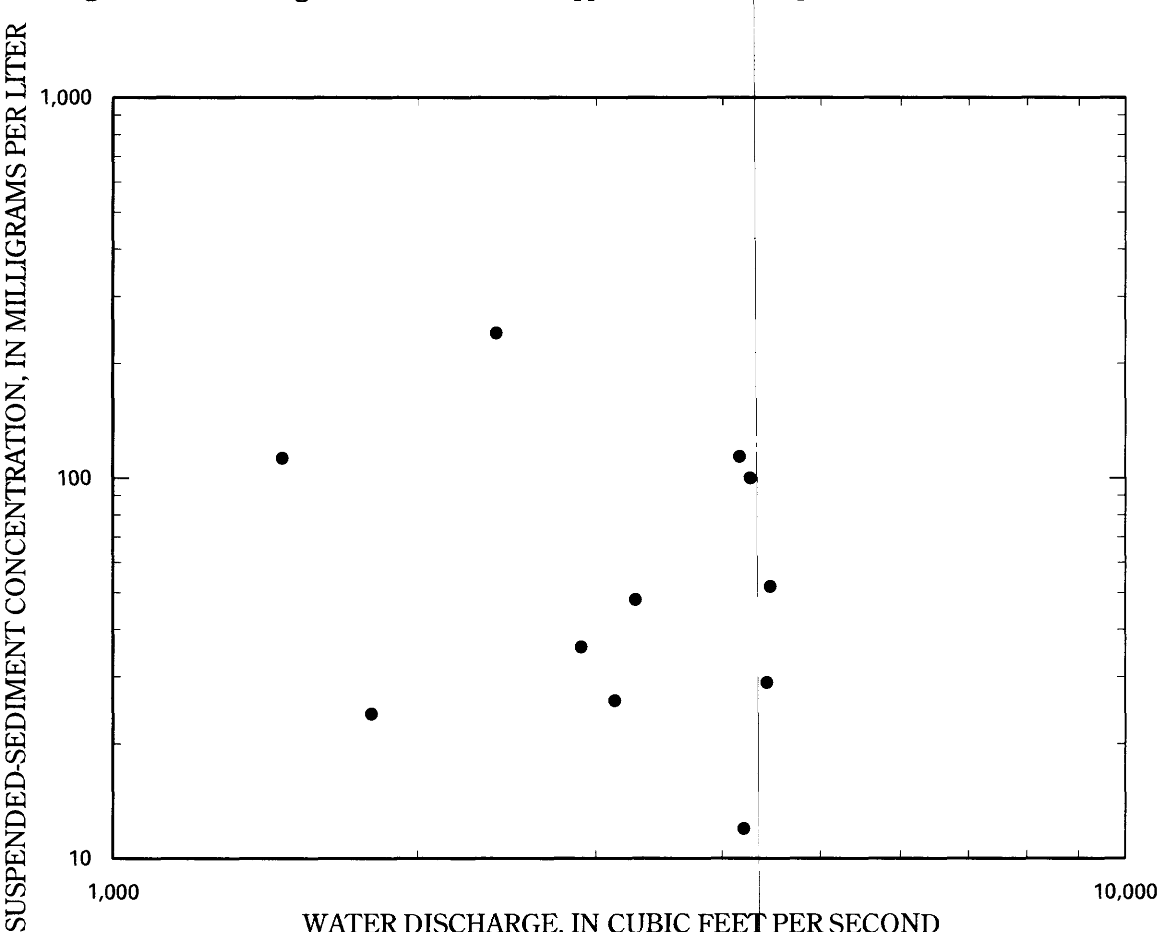


Figure 23. Relation of suspended-sediment concentration to water discharge at west channel of Chippewa River near Pepin.

nine observed suspended-sediment concentrations ranged between 6 and 101 mg/L and averaged 28 mg/L. The relation of suspended-sediment concentration to water discharge is shown in figure 25.

Little evidence of bedload transport was seen in the east channels. Flow in these channels occurs only when total river discharge is greater than about 13,000 ft^3/s. The suspended-sediment concentration in the channels was, on the average at the time of sampling, about one-fifth the concentration in the main channel. The suspended-sediment particle size was predominantly (73 percent) finer than 0.062 mm. The heavily vegetated flood plain and channels through which the water

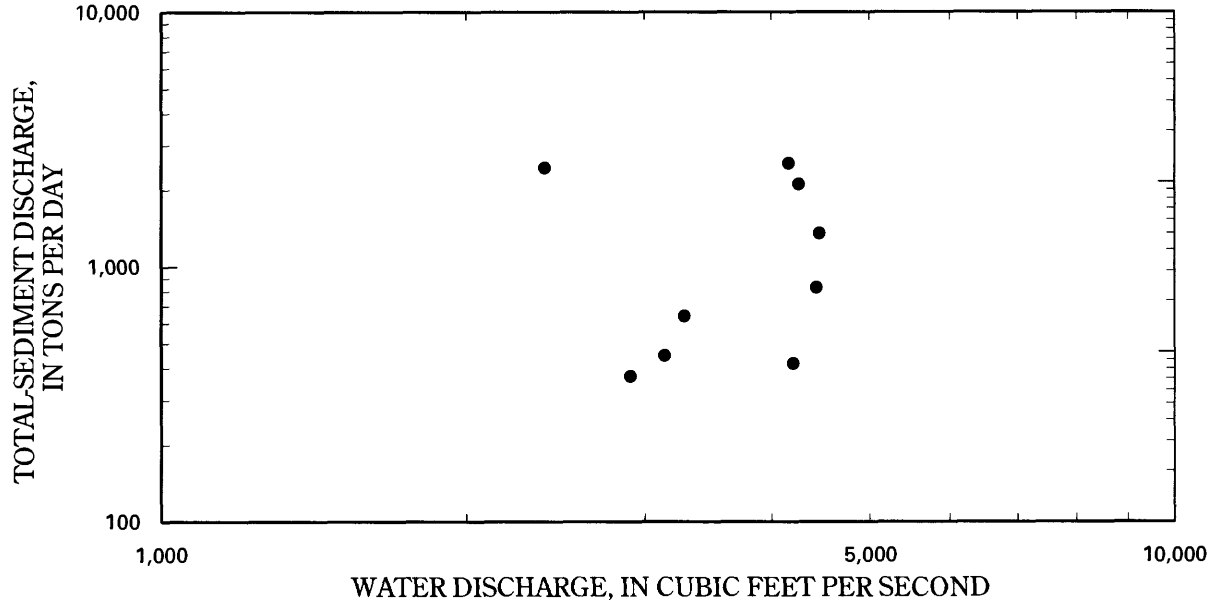


Figure 24. Relation of total-sediment discharge to water discharge at west channel of Chippewa River near Pepin.

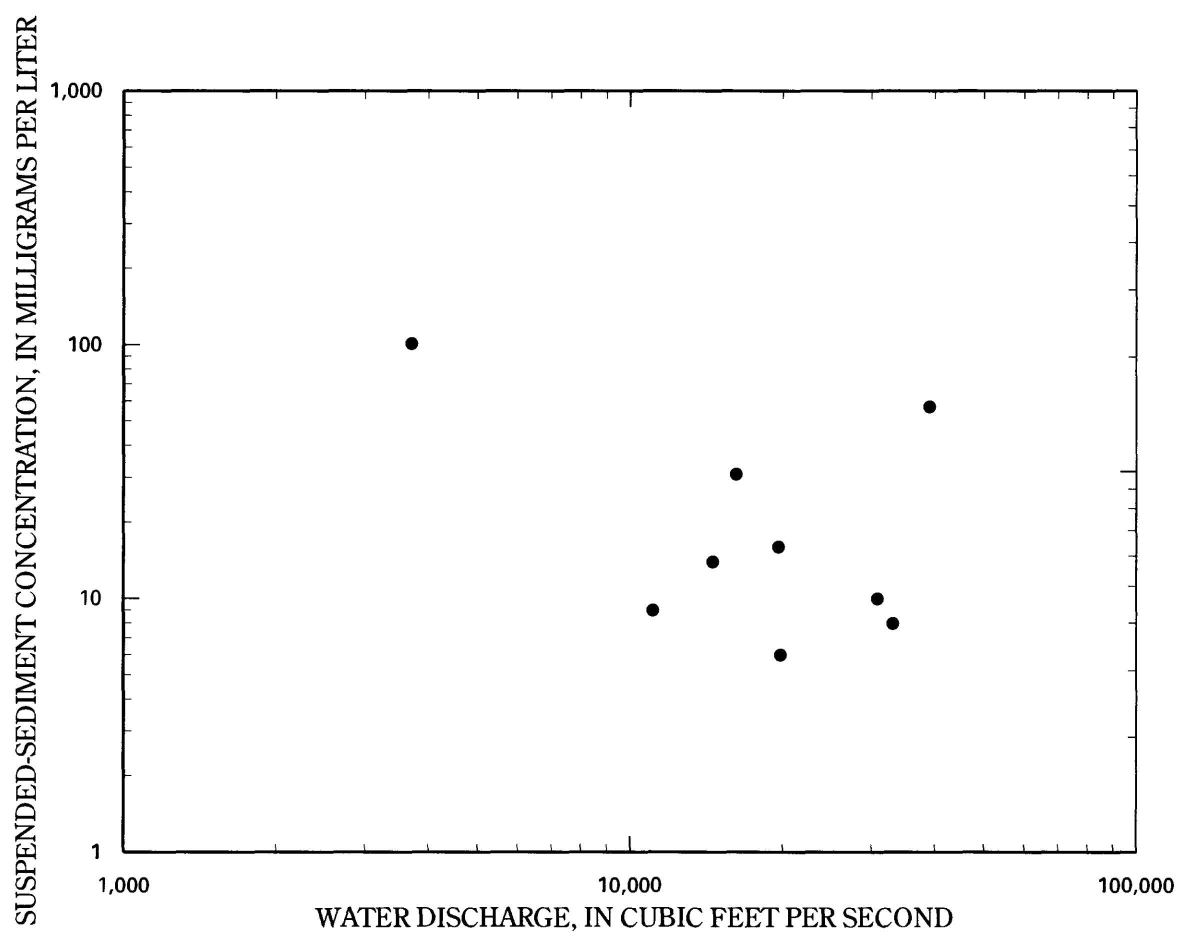


Figure 25. Relation of suspended-sediment concentration to water discharge at east channels of Chippewa River near Pepin.

passes after leaving main channel spillover areas apparently traps most of the coarse (>0.062-mm) sediment before it reaches the sampling cross sections. Thus, total-sediment discharge is assumed to be approximately equal to suspended-sediment discharge.

SEDIMENT-DISCHARGE DISTRIBUTION IN CHANNELS

The sediment discharge distribution among the main, west, and east channels does not reflect the water-discharge distribution among the channels.

The distribution of water discharge among channels as a function of total water discharge is shown in figure 26. When the total river discharge is less than about 13,000 ft^3/s, the entire discharge is in the main channel. In the 30- to 70,000-ft^3/s discharge range, the dominant proportion of total discharge increasingly shifts from the main channel to the east channels. When total discharge is greater than about 70,000 ft^3/s, most of the flow is in the east channels.

Most total sediment transport occurs in the main channel at all water discharges. Figure 27 shows the relationship between total-sediment discharge and water discharge for the various channels. All sediment is transported in the main channel at water discharges less than about 13,000 ft^3/s because all flow is in the main channel. When the total river discharge is 80,000 ft^3/s, only about 40 percent of the flow is in the main channel, but about 85 percent of the sediment transport is in the main channel.

Sediment Particle Size

MAIN CHANNEL

There was little temporal or spatial variation in bed-material particle size in the main channel. The range and average of bed-material particle size from 47 observations is shown in figure 28. The median diameter ranged from 0.37 to 0.59 mm, and averaged 0.49 mm. The cross-channel variation on April 8, 1981 is shown in figure 29. The particle sizes of 8 of the 10 subsamples were very similar (median diameter ranged from 0.5 to 0.61 mm). The two remaining subsamples were finer and had median particle diameters of 0.24 and 0.3 mm.

Helley-Smith bedload was very uniform in particle size (fig. 30). About 62 percent of the material was in the 0.4- to 0.6-mm size range; the median particle diameter of 23 bedload samples ranged from 0.49 to 0.53 mm.

Suspended sediment was less than 2 mm in diameter. The average and range of particle size from 24 samples is shown in figure 31. The median particle diameter was 0.17 mm and about 30 percent was in the silt- and clay-size range (<0.062 mm).

WEST CHANNEL

The west channel's bed material was somewhat coarser than that of the main channel. The range and average of particle-size from nine observations is shown in figure 32.

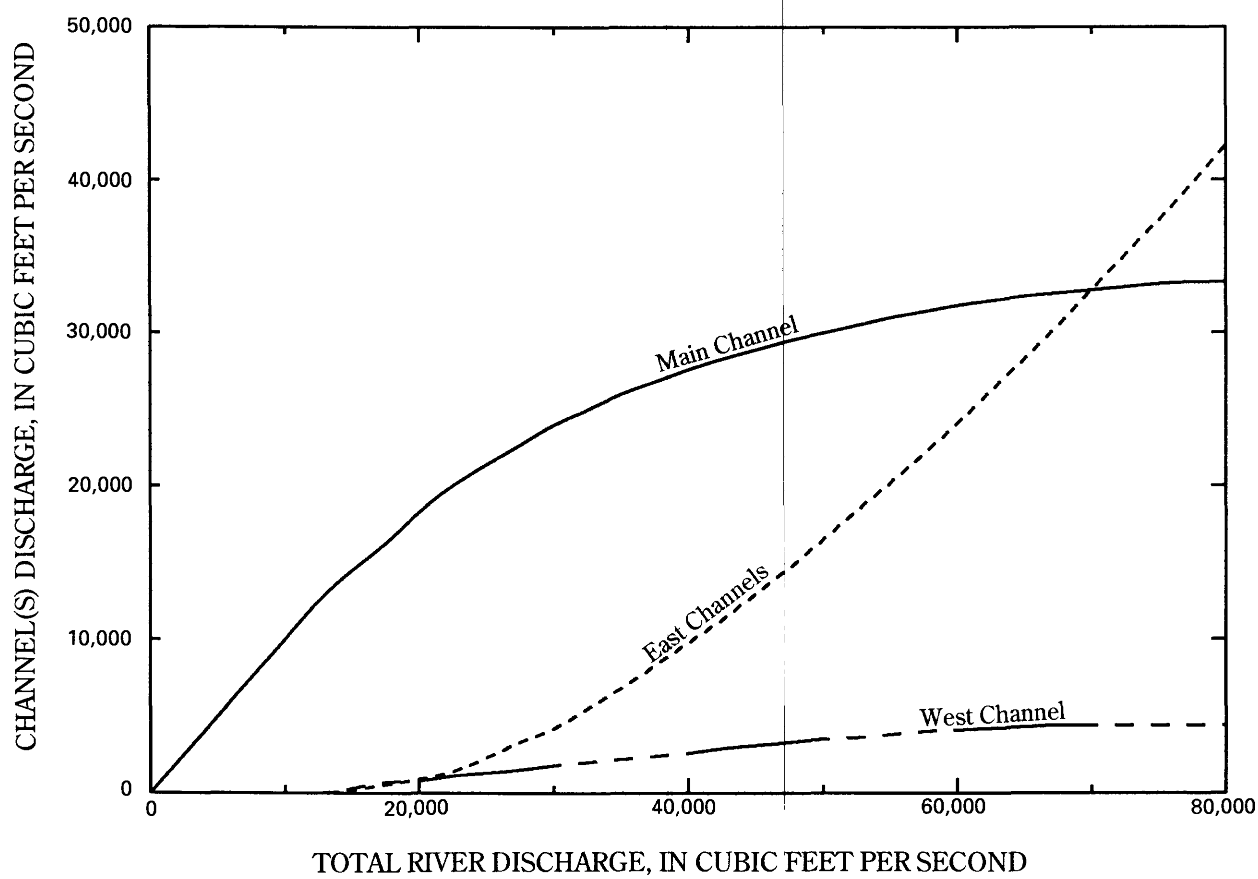


Figure 26. Distribution of water discharge among channels in relation to total river discharge at Chippewa River near Pepin.

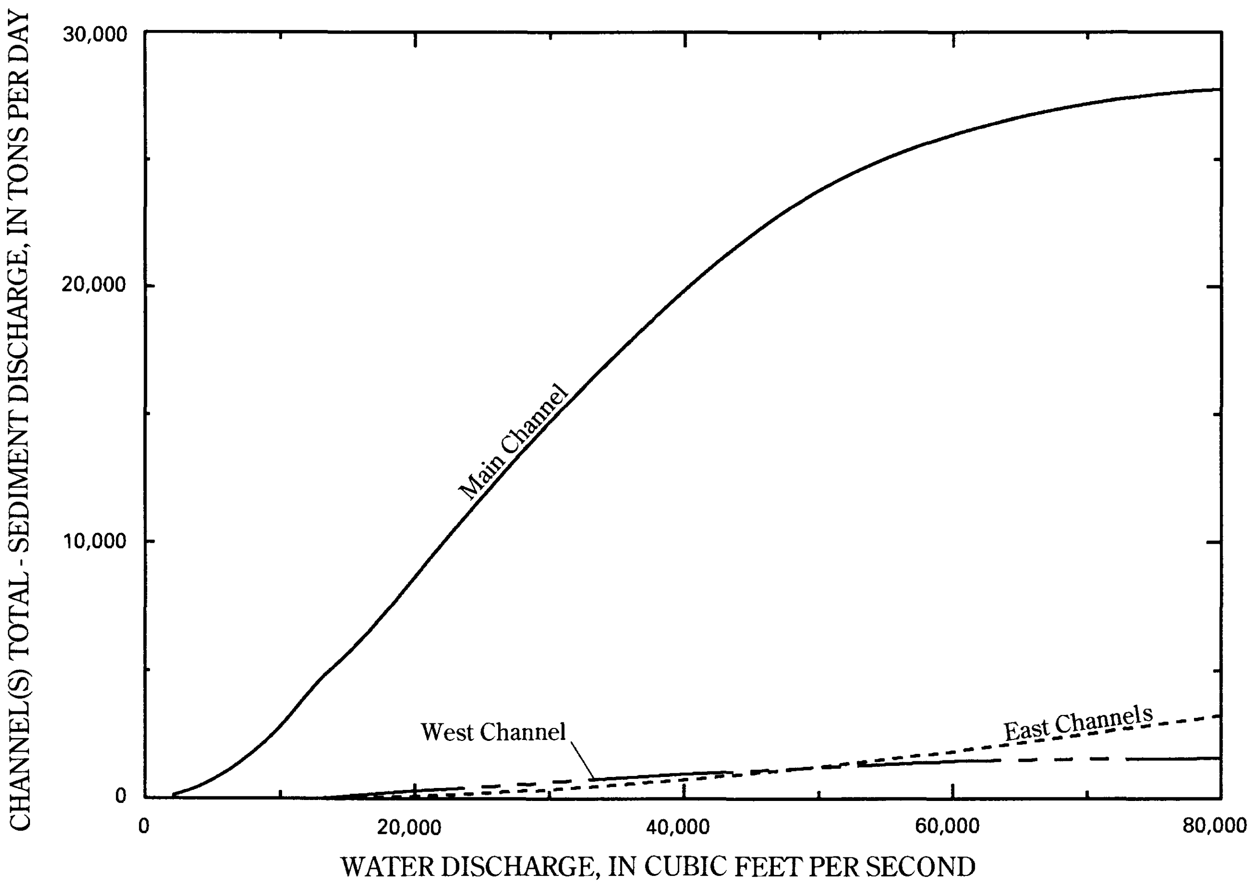


Figure 27. Distribution of total-sediment discharge among channels in relation to water discharge at Chippewa River near Pepin.

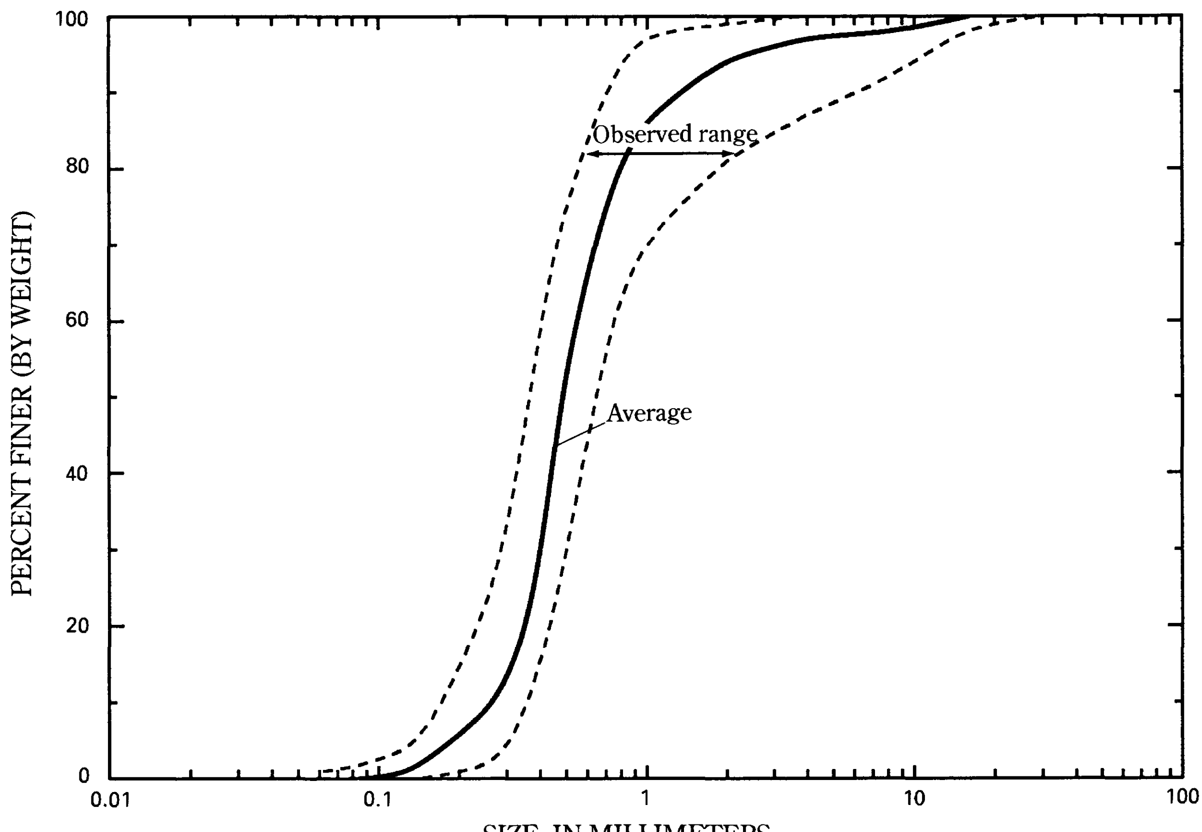


Figure 28. Cumulative-frequency distribution of average and range of particle sizes in 47 surface bed material samples from main channel of Chippewa River near Pepin from September 1976 through September 1983.

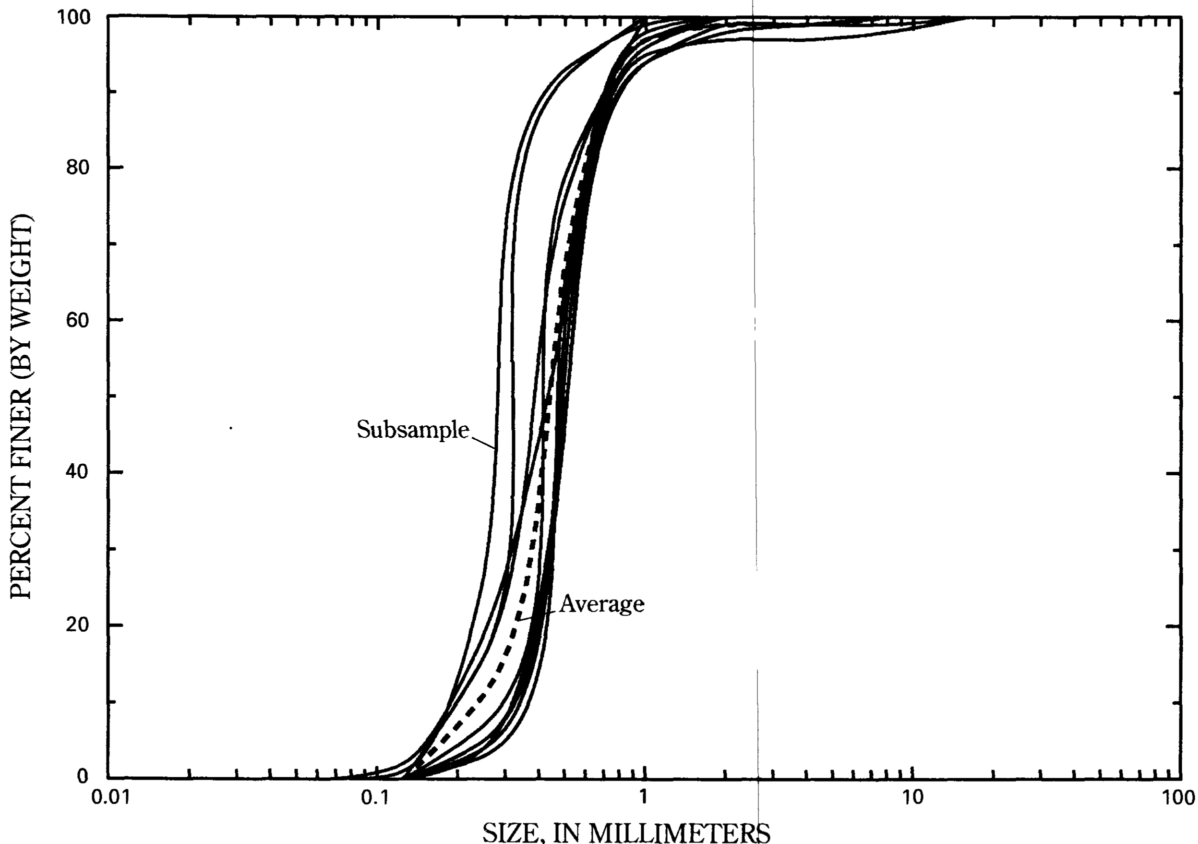


Figure 29. Cumulative-frequency distribution of particle sizes in surface bed material from 10 equally spaced locations in the main channel cross section on April 8, 1981, at Chippewa River near Pepin.

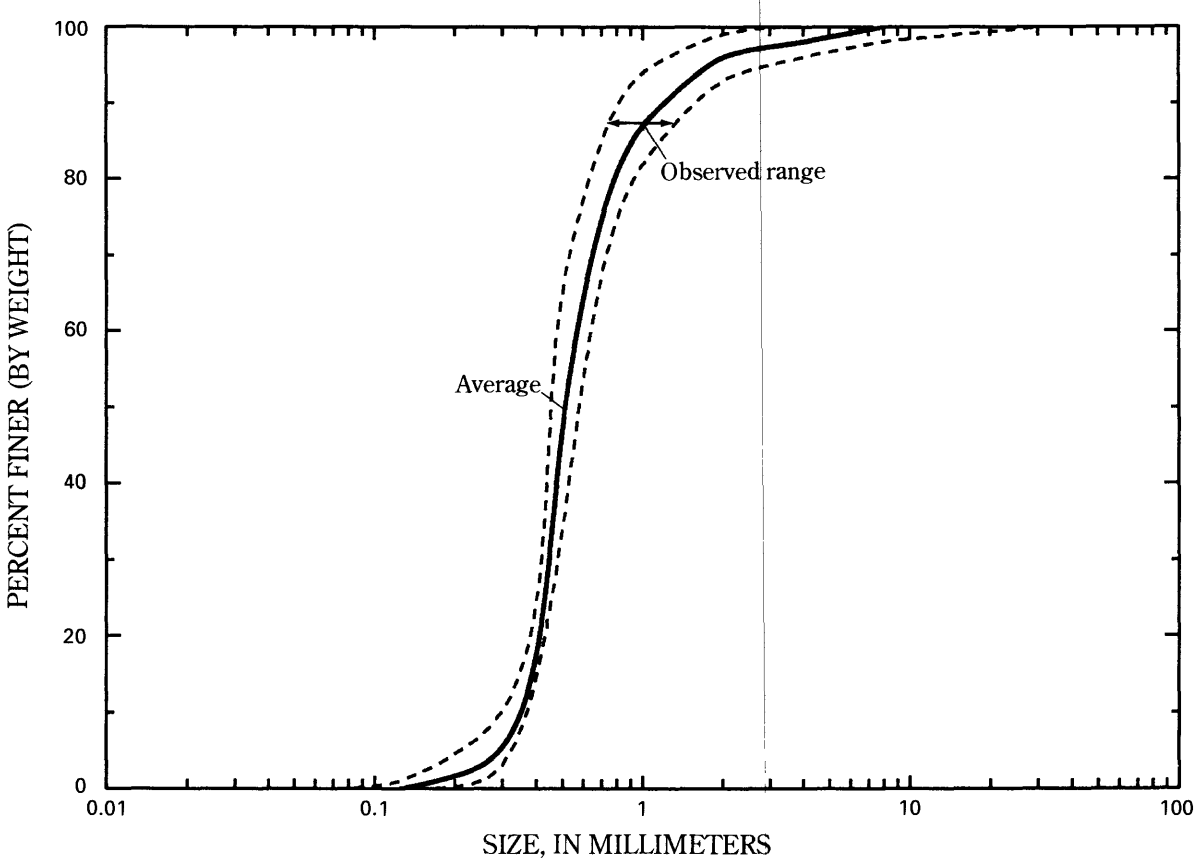


Figure 30. Cumulative-frequency distribution of average and range of particle sizes in 23 Helley-Smith bedload samples from main channel at Chippewa River near Pepin from September 1976 through September 1979.

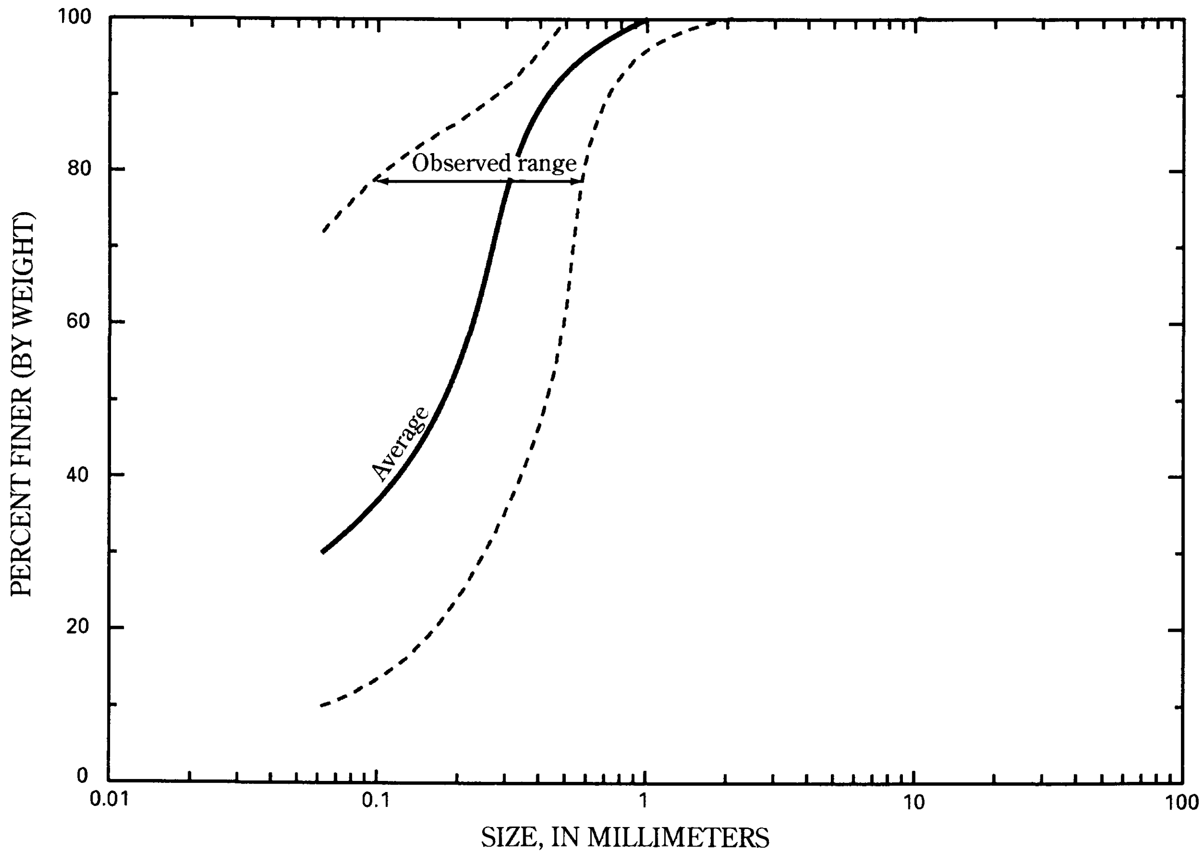


Figure 31. Cumulative-frequency distribution of average and range of particle sizes in 24 suspended-sediment samples from main channel of Chippewa River near Pepin from September 1976 through September 1983.

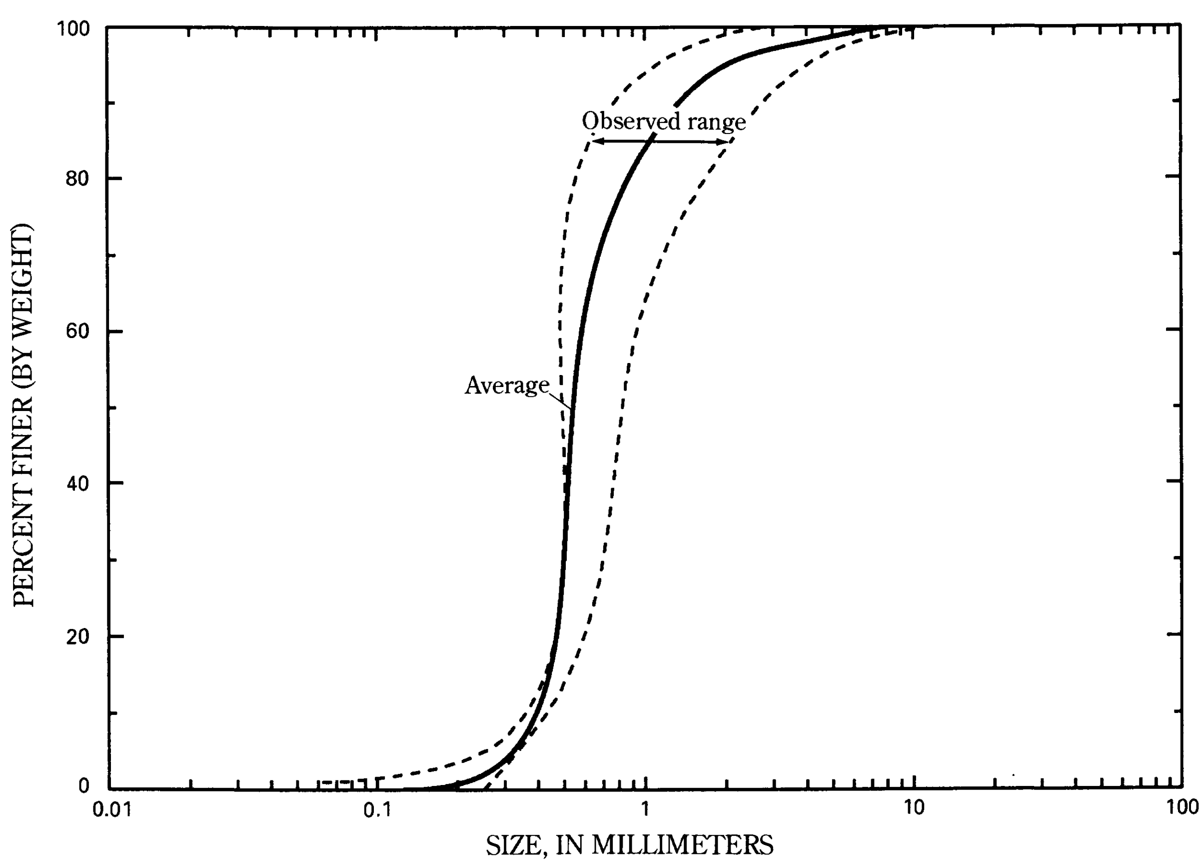


Figure 32. Cumulative-frequency distribution of average and range of particle sizes in nine surface bed material samples from west channel of Chippewa River near Pepin from October 1979 through September 1983.

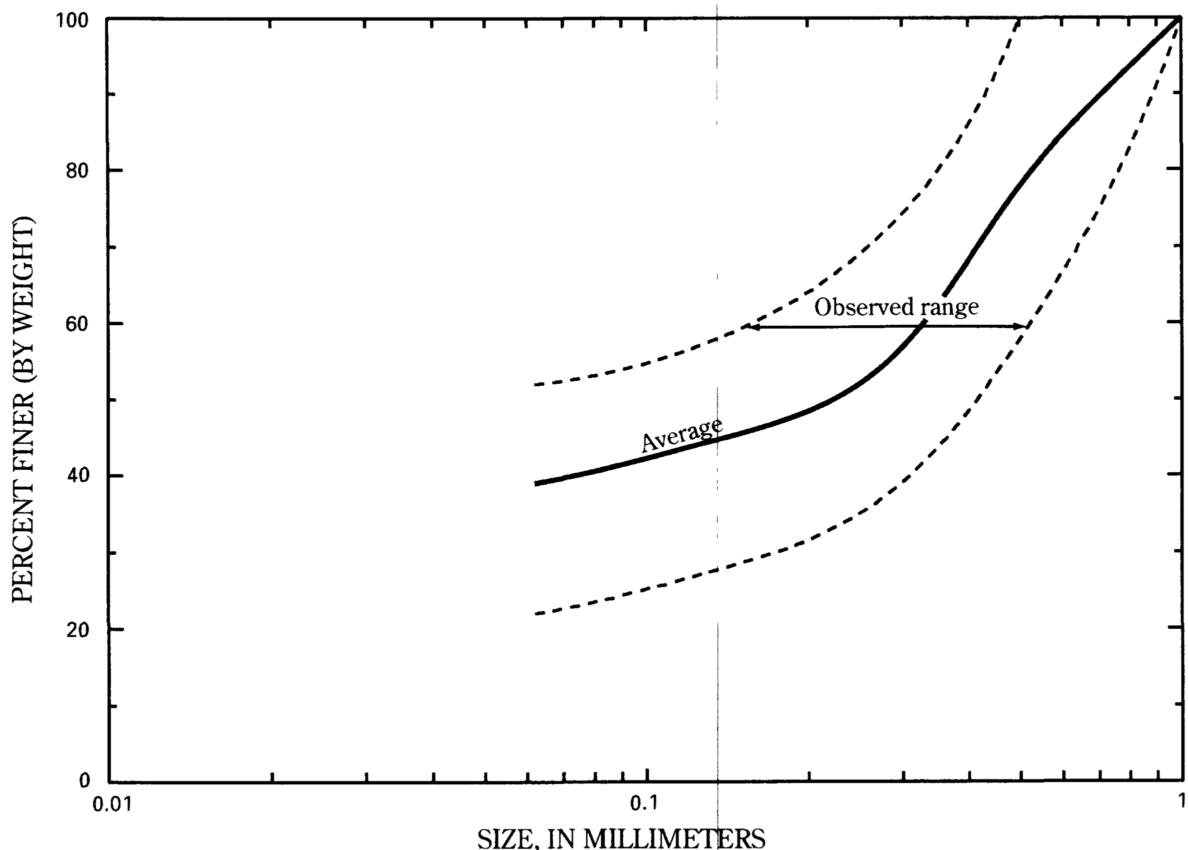


Figure 33. Cumulative-frequency distribution of average and range of particle sizes in nine suspended-sediment samples from west channel of Chippewa River near Pepin from October 1979 through September 1983.

The median diameter ranged from 0.49 to 0.82 mm and averaged 0.53 mm.

Particle size of bedload is not available for the west channel because bedload samples were not collected.

Suspended sediment in the west channel was coarser than in the main channel. The average and range of particle sizes are shown in figure 33. The average median diameter was 0.22 mm and about 39 percent was in the silt- and clay-size range (<0.062 mm).

EAST CHANNELS

Few particle-size data are available for the east channels. Neither bed material nor bedload were sampled. The average of eight analyses indicated that 73 percent of the suspended sediment was in the silt- and clay-size range (<0.062 mm).

Sediment Load

Total sediment load ranged from 321,000 tons in 1977 to 1,380,000 tons in 1983, and averaged 940,000 tons during the 1974–83 period. Most or about 97 percent of the load was transported in the main channel, about 2 percent in the west channel, and about 1 percent in the east channels. Annual sediment loads and average annual water discharge are shown below.

About 56 percent of main channel load and about 55 percent of west channel load was transported as suspended sediment. All the load in the east channels was transported as suspended sediment. The relative proportions of suspended- and unmeasured-sediment loads and distribution of the load among channels is shown in figure 34.

About 12 percent of the average annual load at Durand or 133,000 tons is deposited in the river and flood plain

Water year	Annual average water discharge (ft^3/s)	Total-sediment load: Main channel (tons)	West channel (tons)	East channels (tons)	All channels combined (tons)
1974	8,335	853,000	13,500	5,300	871,800
1975	8,160	820,000	16,600	10,800	847,400
1976	8,294	915,000	20,200	11,400	946,600
1977	5,052	318,000	2,200	450	320,650
1978	9,319	1,055,000	17,400	5,200	1,077,600
1979	9,524	1,143,000	26,100	9,700	1,178,800
1980	8,150	748,000	12,700	4,500	765,200
1981	8,137	942,000	17,800	8,300	968,100
1982	9,125	994,000	27,700	19,400	1,041,100
1983	11,484	1,340,000	25,200	14,800	1,380,000

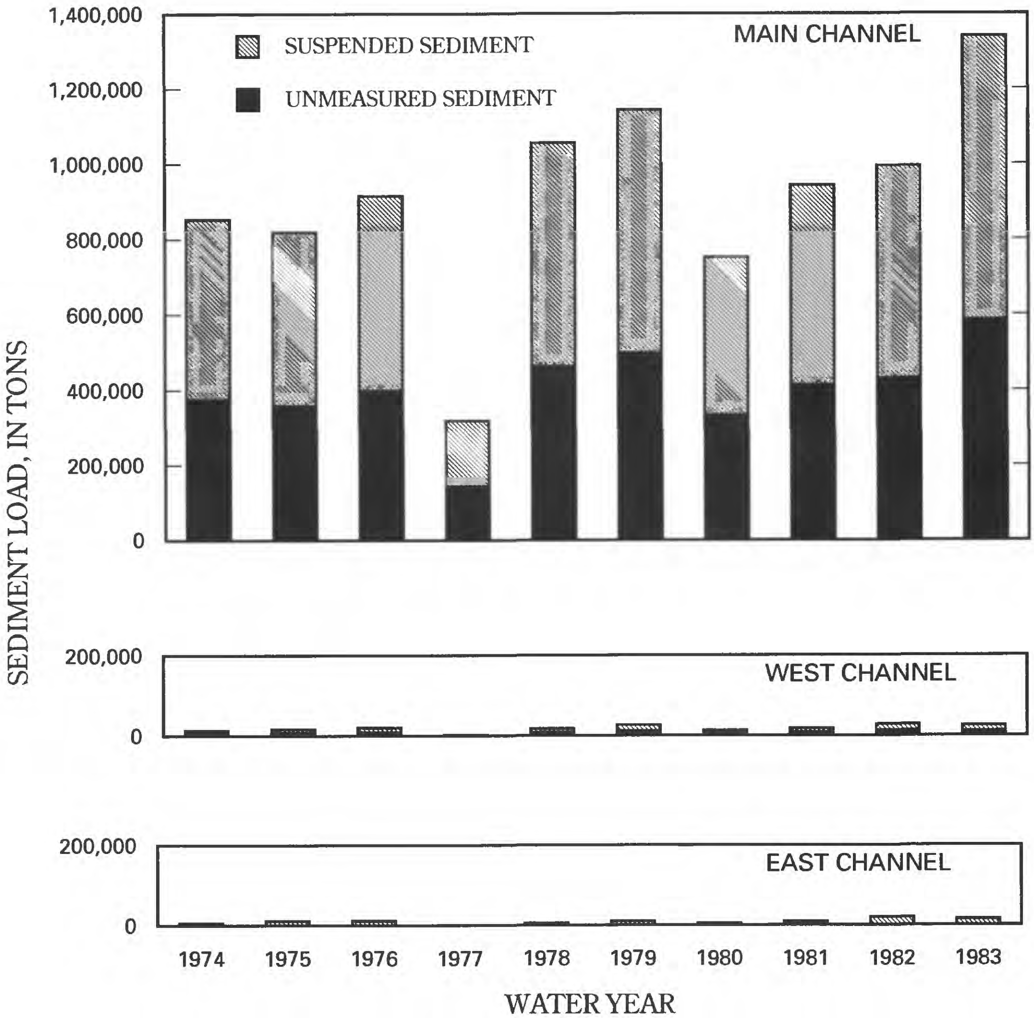


Figure 34. **Annual suspended- and unmeasured-sediment loads in main, west, and east channels at Chippewa River near Pepin, water years 1974–83.**

between Pepin and Durand and about 940,000 tons of sediment is discharged into the Mississippi River annually. The actual deposition in the reach between Durand and Pepin could be more or less than 12 percent owing to inherent measurement errors. However, the deposition shown by this study supports the interpretation by Martin (1932, p. 169) that the Chippewa River delta near Pepin is covered by modern flood-plain deposits.

BLACK RIVER NEAR GALESVILLE

The Black River at the monitoring site at the U.S. Highway 53 crossing near Galesville is about 13 river miles upstream (north) of where the river enters Lake Onalaska. The watershed area upstream from the monitoring site is 2,080 mi^2 and comprises about 92 percent of the watershed upstream from Lake Onalaska. About 60 percent of the watershed, or roughly that portion upstream of the Lake Arbutus dam near Hatfield, Wis. (fig. 35), is in glaciated area; the lower 40 percent of the watershed is in the unglaciated or "driftless" area. Although the lower Black River passes through an unglaciated area, the 1- to 2-mi-wide flood plain was formed by glacial outwash deposits (Young and Borman, 1973).

SITE DESCRIPTION

The river at the monitoring site flows from east to west through a narrows in the generally 1- to 2-mi-wide flood plain. Water-discharge measuring and sediment sampling were done from a cableway about 300 ft downstream from the U.S. Highway 53 bridge and about 1,200 ft downstream from the U.S. Geological Survey gaging station. The water-surface width ranges from about 300 ft at low flow to about 600 ft at high flow.

DATA AVAILABILITY

Intermittent sediment sampling began in May 1976 and ended in September 1981. From May 1976 through September 1979, water discharge, suspended-sediment, Helley-Smith bedload discharge, and bed-material were measured or sampled about 30 times. Suspended sediment was analyzed for concentration, and bedload and bed material were analyzed for particle size.

From March 1980 through September 1981, the sampling program was modified to collect the data needed to employ the modified-Einstein procedure. Bedload sampling was ended and the volume of water collected for suspended-sediment analyses was increased to ensure there would be enough sediment collected for particle-size analyses. Nineteen data sets, 18 of which were collected during high flow, were available to use the modified-Einstein procedure. Three suspended-sediment concentration analyses and one bedload measurement that were not parts of complete sets also were available.

A streamflow-gaging station has provided continuous discharge record since December 1931.

SEDIMENT TRANSPORT

Sediment transport in the Black River near Galesville is functionally related to water discharge. The relationship between suspended-sediment concentration and water discharge is shown in figure 36. Observed concentrations ranged from 2 to 1,130 mg/L. Figure 37 shows the suspended-sediment transport-rate relation.

The total-sediment transport-rate relation (fig. 37) is based on both modified-Einstein and Helley-Smith data. The decision to do this was arbitrary because it was not known which of the two transport-rate relations (Helley-Smith or modified-Einstein) best represented the true transport-rate relation. The total- and suspended-sediment transport-rate relations converge with increasing water discharge, possibly indicating that bedload discharge is a higher percentage of total-sediment discharge at low than at high river discharge.

Measured bedload and modified-Einstein unmeasured-sediment discharge rate relations do not compare well (fig. 38). Unfortunately, the data do not cover comparable discharge ranges. All but one of the measured bedload values are for water discharge less than 10,400 ft^3/s, and all but one of the modified-Einstein unmeasured sediment-discharge values are for water discharge greater than 3,900 ft^3/s.

SEDIMENT PARTICLE SIZE

Bed-material particle size varied little temporally and varied only slightly more spatially in the river cross section. The range and average of bed-material size distributions from 40 observations (each observation is an average of 8 to 10 subsamples) is shown in figure 39. Median particle diameter ranged from 0.35 to 0.52 mm and averaged 0.47 mm. Cross-channel variability is shown in figure 40, in which particle-size curves of subsamples of one of the 40 observations are plotted. The median particle diameter of the subsamples ranged from about 0.25 to 0.52 mm and averaged about 0.47 mm.

Measured bedload was of very uniform size and is indicated by the steepness of the particle-size curves in figure 41. About 65 percent of the material was in the 0.4- to 0.6-mm size range. The median particle diameter of 31 samples ranged from 0.31 to 0.52 mm.

Silt and clay (particles <0.062 mm) comprised 8 to 85 percent of suspended sediment. The average and range of particle size from 19 samples is shown in figure 42. On the average, median particle diameter was 0.2 mm and about 34 percent was in the silt- and clay-size range.

SEDIMENT LOAD

Total annual sediment load ranged from 42,300 to 471,000 tons and averaged 277,000 tons during water years 1974–83. Annual sediment loads and average annual water discharges are shown at right.

About 57 percent of the total load was transported as suspended sediment and 43 percent was transported as bedload or unmeasured-sediment discharge. The rela-

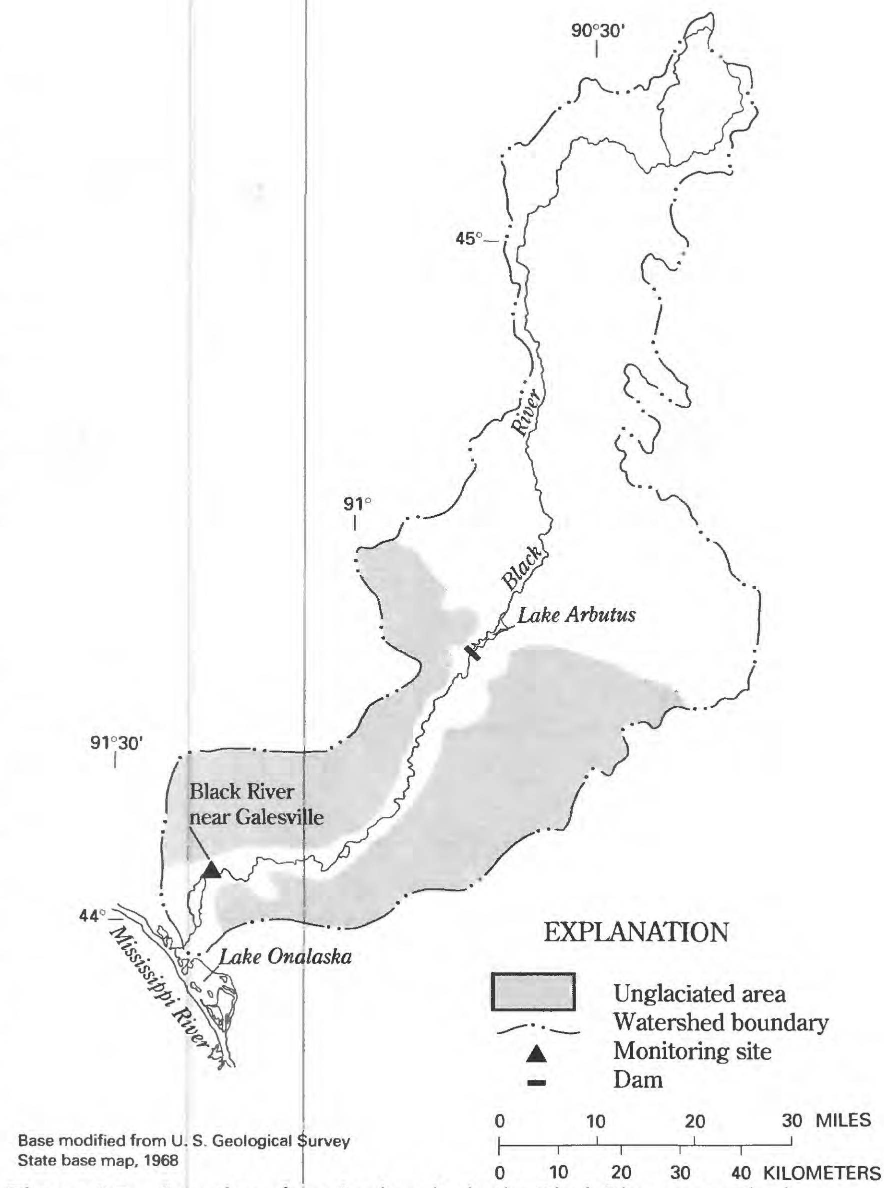


Figure 35. Location of monitoring site in the Black River watershed.

Water year	Average water discharge (ft^3/s)	Suspended-sediment load (tons)	Unmeasured-sediment load (tons)	Total sediment load (tons)
1974	1,424	80,000	79,000	159,000
1975	1,632	122,000	98,000	220,000
1976	1,885	160,000	122,000	282,000
1977	669	16,300	26,000	42,300
1978	1,972	151,000	123,000	274,000
1979	2,228	208,000	146,000	354,000
1980	2,600	291,000	180,000	471,000
1981	1,915	115,000	111,000	226,000
1982	2,082	171,000	131,000	302,000
1983	2,677	261,000	179,000	440,000

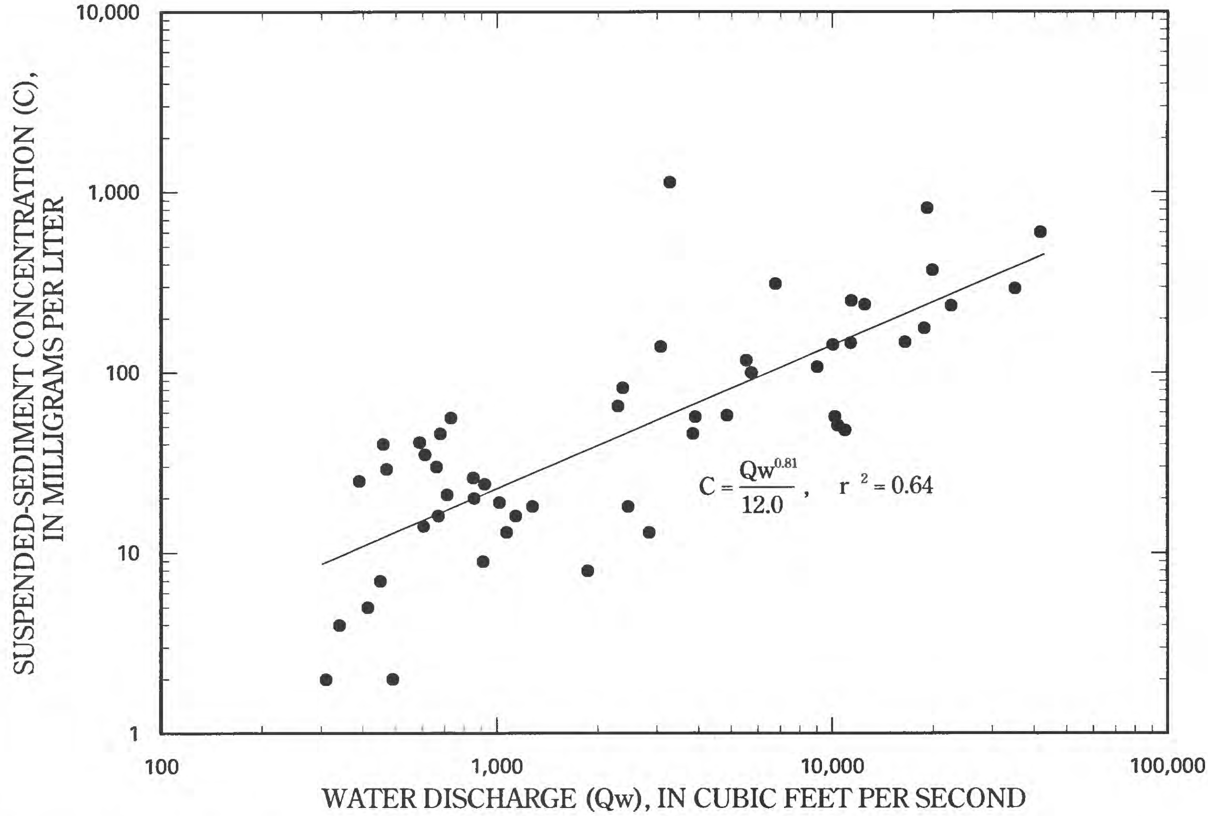


Figure 36. Relation of suspended-sediment concentration to water discharge at Black River near Galesville.

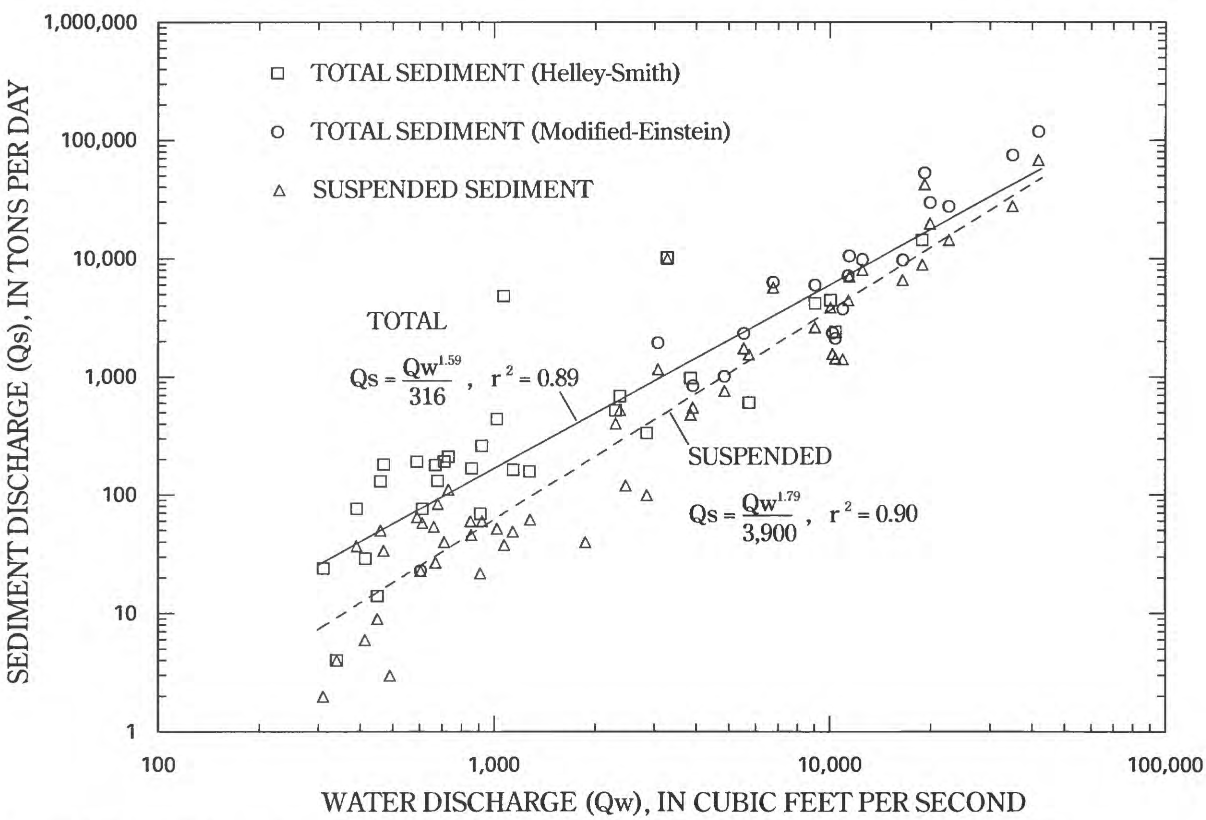


Figure 37. Relations of suspended- and total-sediment discharge to water discharge at Black River near Galesville.

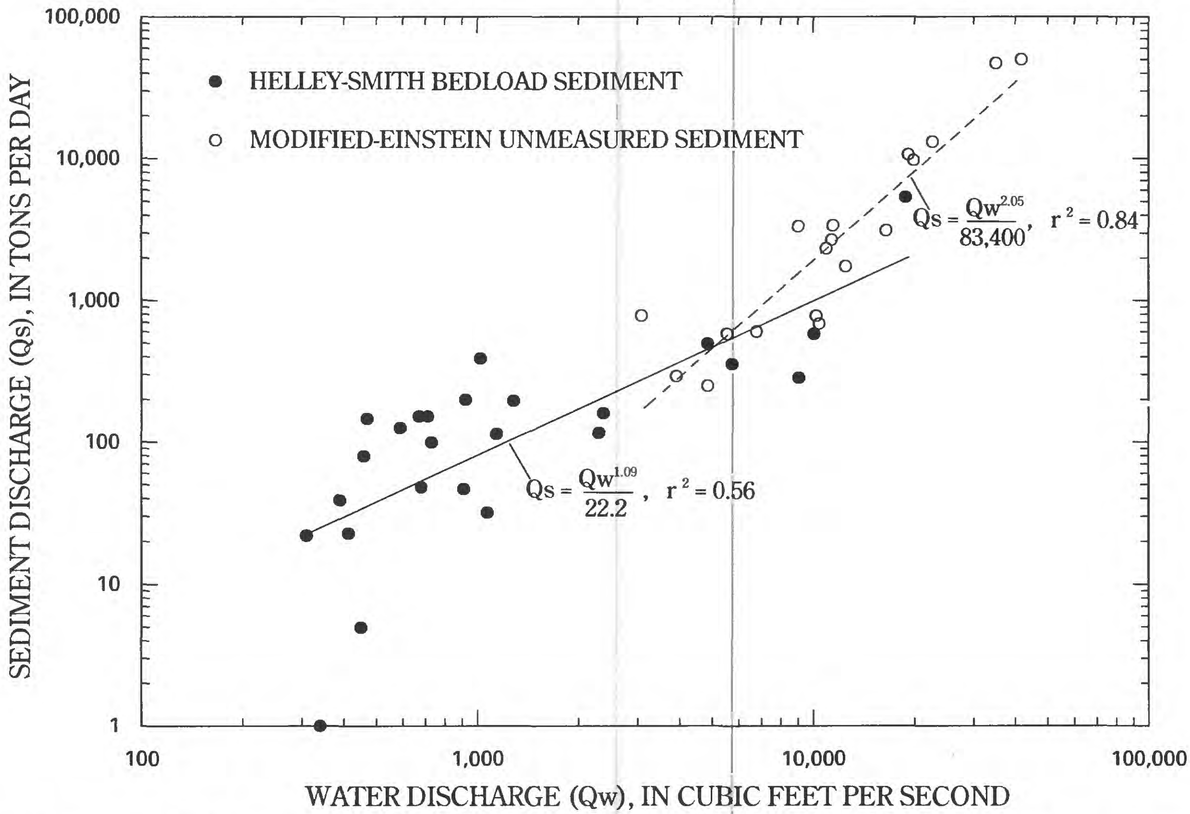


Figure 38. Relations of Helley-Smith bedload and modified-Einstein unmeasured-sediment discharge to water discharge at Black River near Galesville.

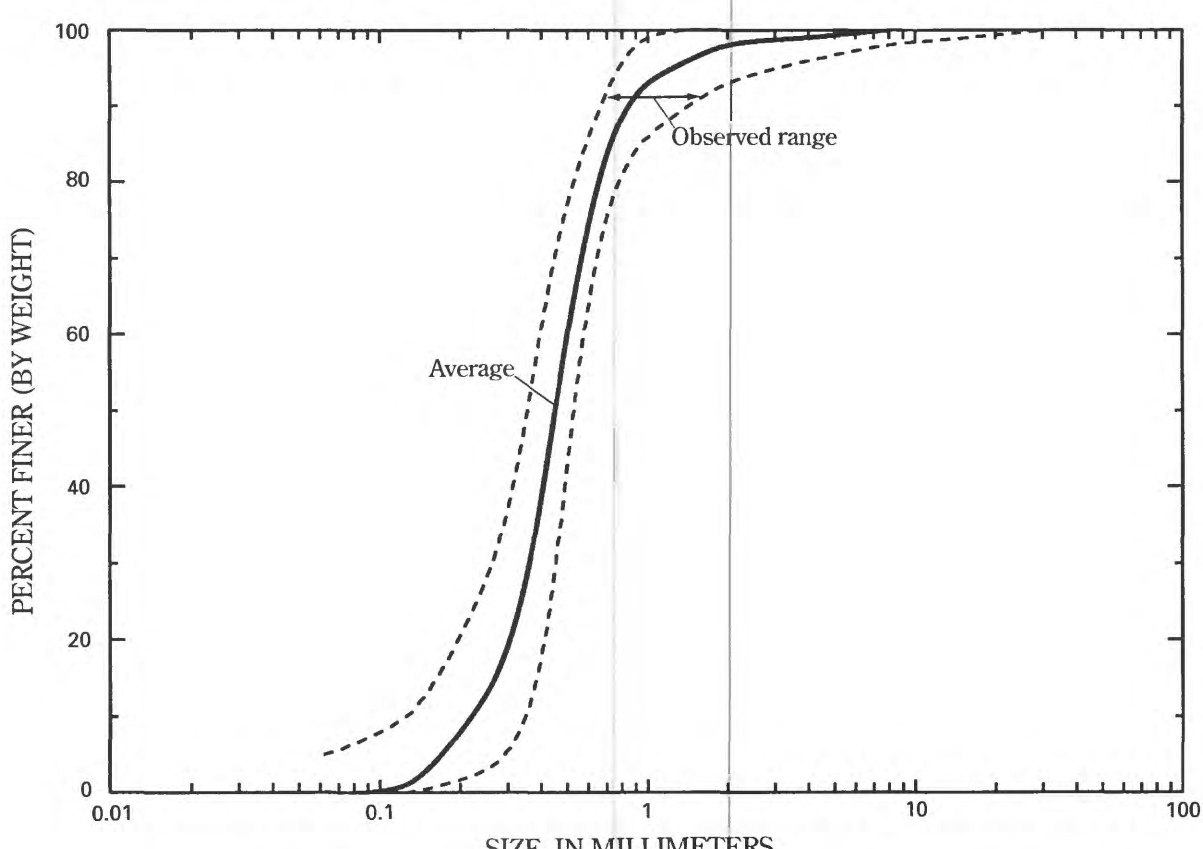


Figure 39. Cumulative-frequency distribution of average and range of particle sizes in 40 surface bed material samples from Black River near Galesville from May 1976 through September 1981.

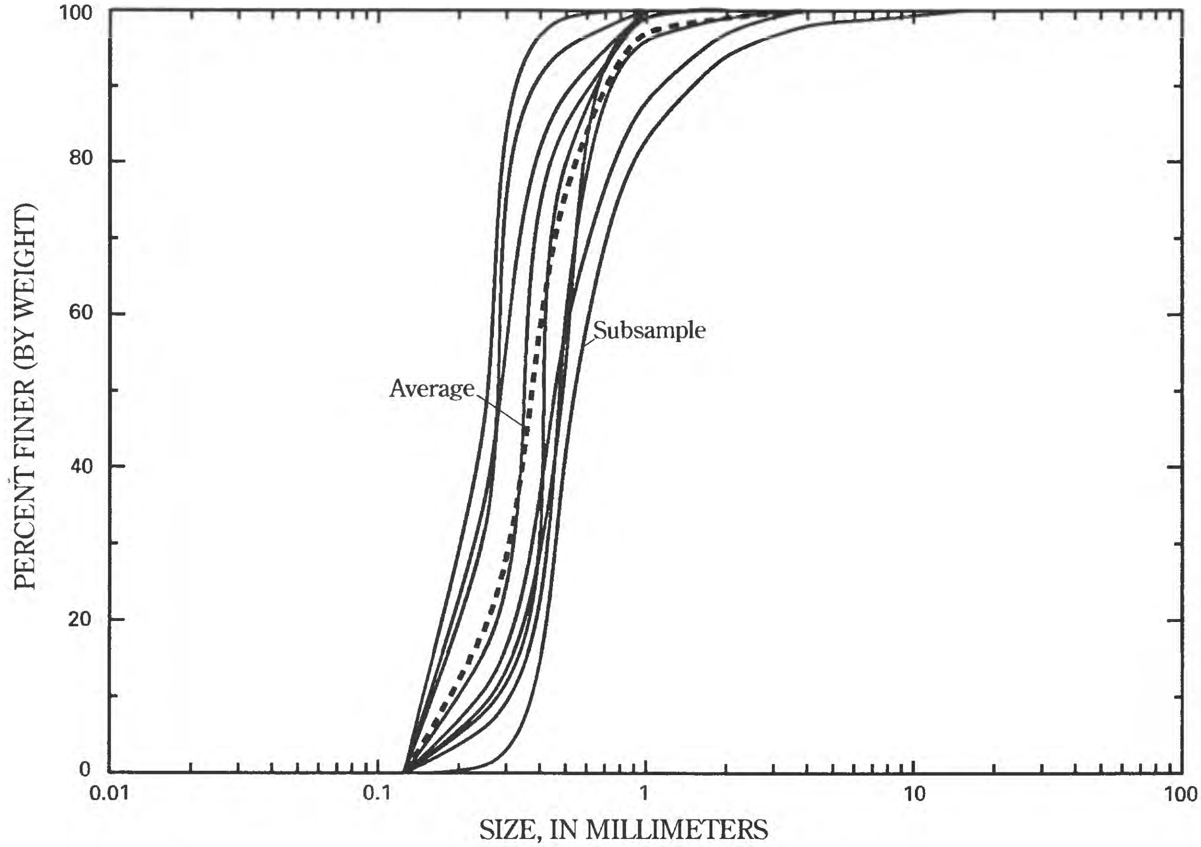


Figure 40. Cumulative-frequency distribution of particle sizes in surface bed material from nine equally spaced locations in the channel cross section on April 12, 1980, at Black River near Galesville.

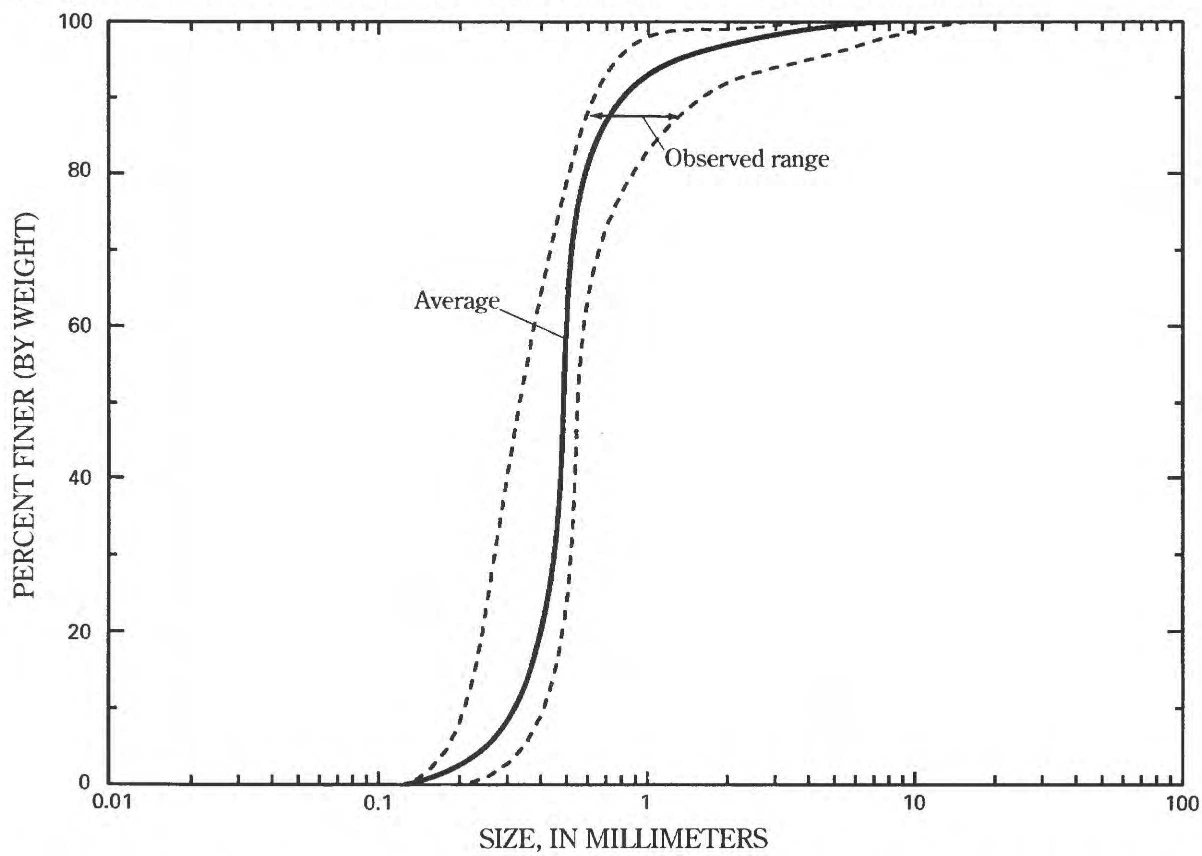


Figure 41. Cumulative-frequency distribution of average and range of particle sizes in 31 Helley-Smith bedload samples from Black River near Galesville from May 1976 through September 1979.

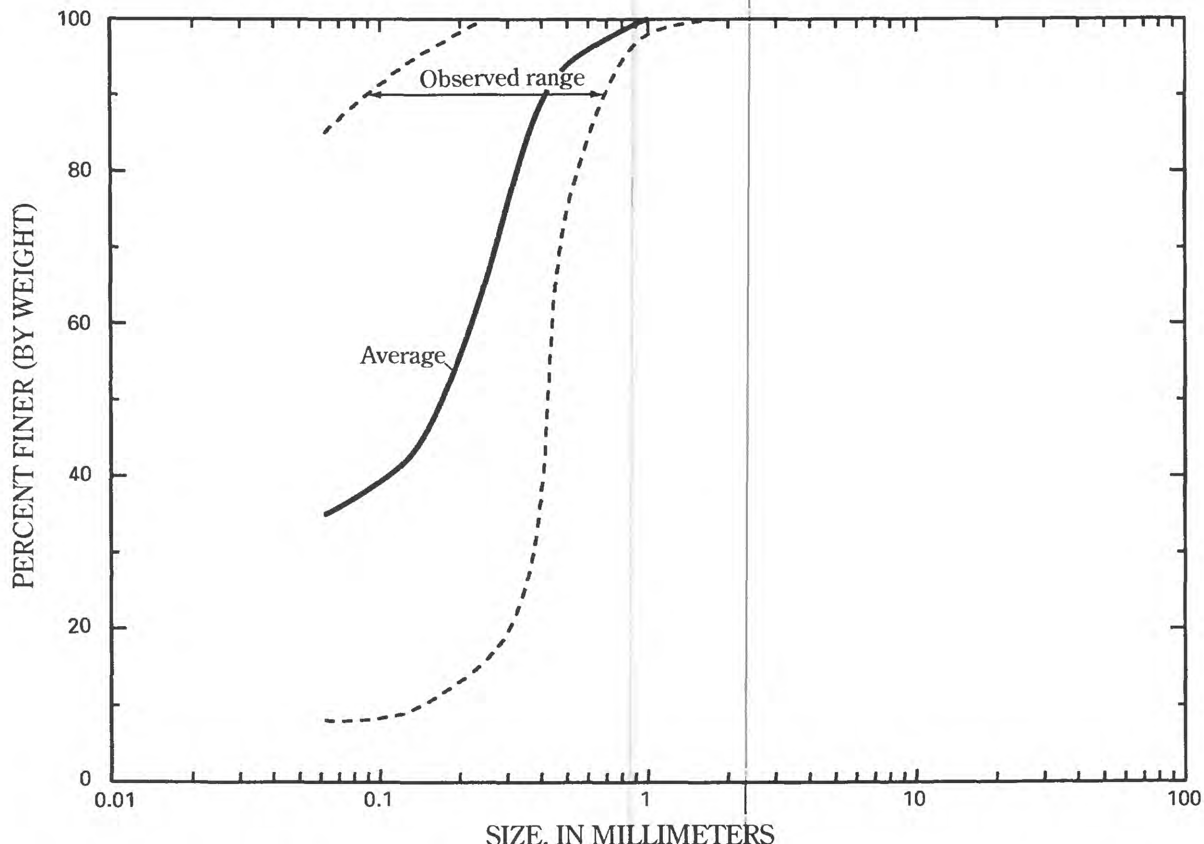


Figure 42. Cumulative-frequency distribution of average and range of particle sizes in 19 suspended-sediment samples from Black River near Galesville from October 1979 through September 1981.

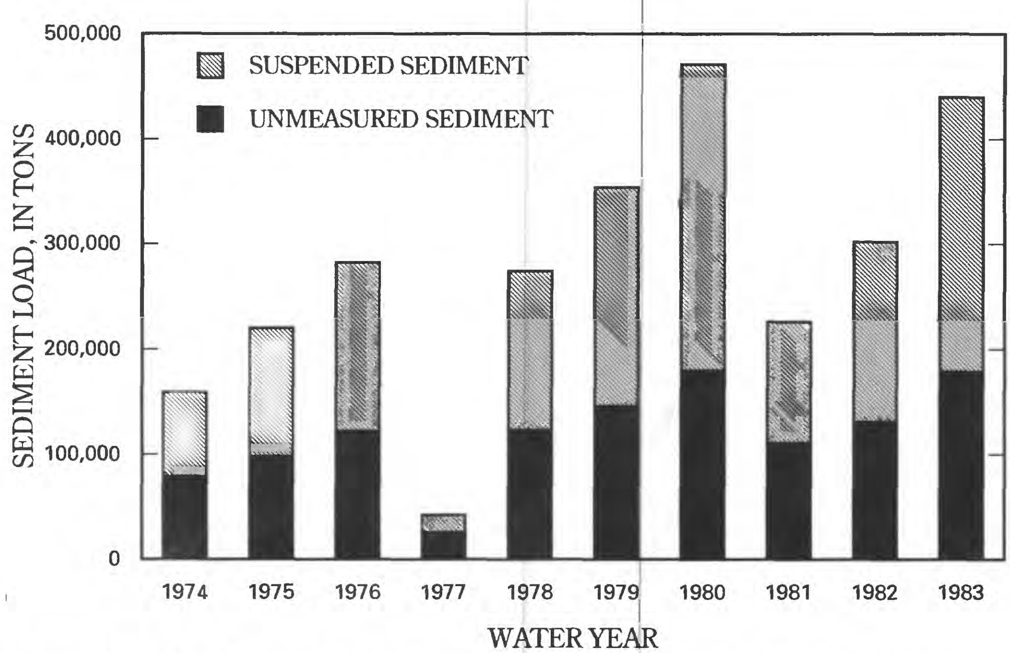


Figure 43. Annual suspended- and unmeasured-sediment loads at Black River near Galesville, water years 1974–83.

tive proportions of suspended- and unmeasured-sediment loads for the 10-year period are shown in figure 43.

WISCONSIN RIVER AT MUSCODA

The Wisconsin River at Muscoda at State Highway 80 at Muscoda is about 40 mi upstream from the confluence with the Mississippi River near Prairie du Chien, Wis. (fig. 44). The area of the watershed upstream from the Muscoda monitoring site is 10,400 mi^2 or about 87 percent of the entire Wisconsin River watershed.

The most downstream of the many dams and reservoirs on the Wisconsin River is at Prairie du Sac and forms Lake Wisconsin about 43 mi upstream from Muscoda. About 76 percent or 9,180 mi^2 of the entire Wisconsin River watershed is upstream from the Prairie du Sac dam.

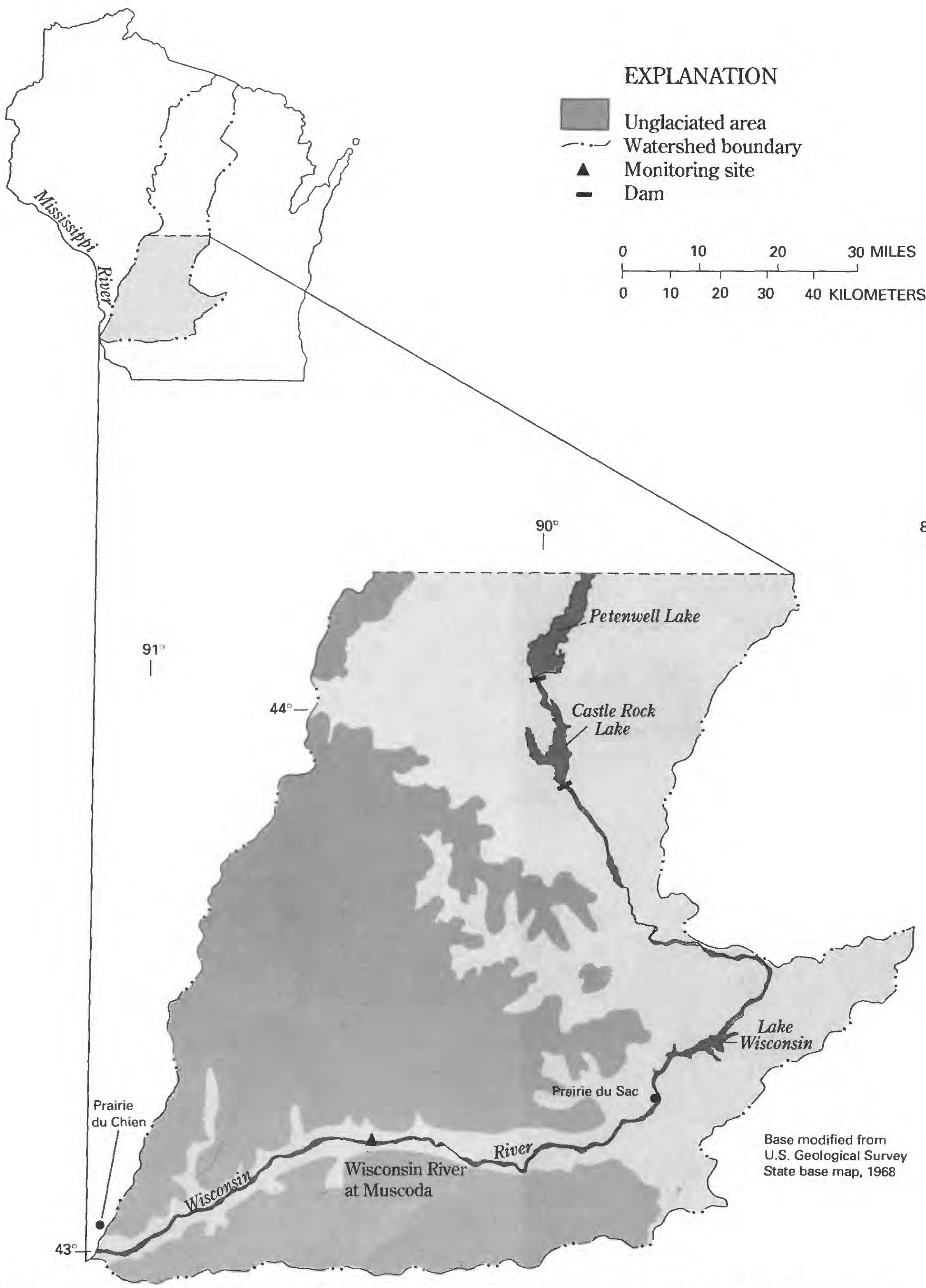


Figure 44. Location of Wisconsin River at Muscoda monitoring site in watershed and Wisconsin.

The margin between the glaciated and unglaciated or "driftless" areas of the watershed also passes near Prairie du Sac. Although the river downstream from Prairie du Sac is in unglaciated area, the 2- to 5-mi-wide flood plain was formed by glacial outwash deposits (Hindall and Borman, 1974). The average slope of the river between Prairie du Sac and the mouth is about 1.5 ft/mi.

SITE DESCRIPTION

The river at the monitoring site flows from east to west. Water discharge measuring and sediment sampling was done from the downstream side of the State Highway 80 bridge at the U.S. Geological Survey gaging station. The water-surface width at the bridge cross section ranges from about 800-ft wide at low flow to about 1,090-ft wide at high flow. There are 13 4-ft-wide bridge-support piers in the cross section.

DATA AVAILABILITY

Intermittent sampling began in January 1976 at about monthly intervals (except during ice-cover periods) to get suspended-sediment concentration, Helley-Smith bedload discharge, and particle-size data. In March 1977, sampling of bed material for particle-size analysis was added to the monthly sampling effort.

Beginning in March 1980, the sampling program was changed to collect data needed to employ the modified-Einstein procedure. Bedload measuring was ended and the volume of water collected for suspended-sediment analyses was increased to insure there was enough sediment for particle-size analysis. In all, 28 data sets were available to use the modified-Einstein procedure.

A streamflow-gaging station has provided continuous discharge record since October 1913.

SEDIMENT TRANSPORT

Suspended- and total-sediment transport are governed by two functional relationships with water discharge. For suspended-sediment discharge one relationship applies to discharges less than 12,800 ft^3/s; the other for discharges greater than 12,800 ft^3/s. For total-sediment discharge, the first relation applies to discharges less than 13,200 ft^3/s; the second for discharges greater than 13,200 ft^3/s.

At water discharges less than about 15,000 ft^3/s, suspended-sediment concentration is not functionally related to water discharge (fig. 45). Observed concentrations averaged 21 mg/L and ranged from 3 to 59 mg/L at discharges less than 15,000 ft^3/s. There is a relationship between water discharge and suspended-sediment concentration at discharges greater than about 15,000 ft^3/s (fig. 45).

At discharges greater than 15,000 ft^3/s, concentrations ranged from 10 to 220 mg/L. The two suspended-sediment transport-rate relations are shown in figure 46. The coefficient in the relation for discharges less than 12,800 ft^3/s is the average observed concentration (21 mg/L) times a units conversion factor (0.0027).

The total-sediment transport-rate relations shown in figure 46 are based on both modified-Einstein and Helley-Smith data. This arbitrary decision was made because it is unknown which of the two methods (Helley-Smith or modified-Einstein) yielded values closest to true values.

Measured bedload and modified-Einstein unmeasured discharge-rate relations do not compare well. Measured

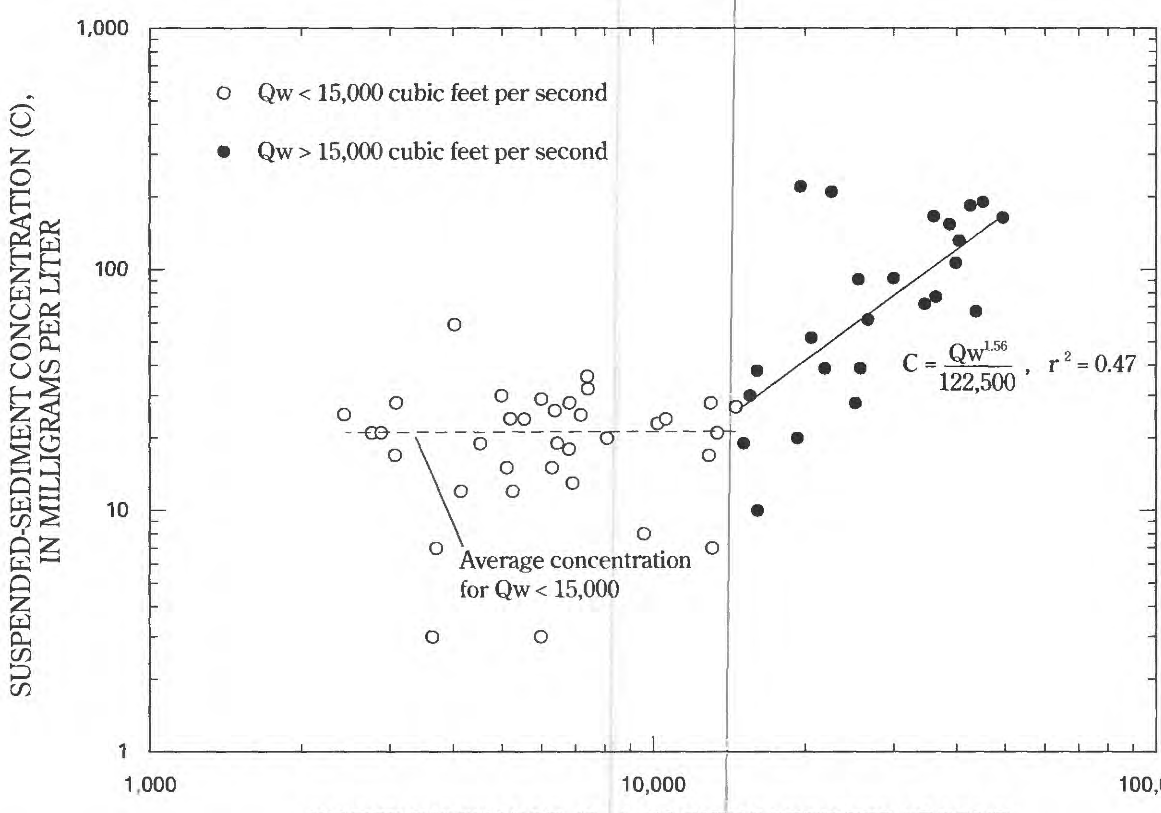


Figure 45. Relation of suspended-sediment concentration to water discharge at Wisconsin River at Muscoda.

bedload is greater than modified-Einstein unmeasured sediment discharge at discharges less than 10,000 ft³/s; at discharges greater than about 15,000 ft³/s the reverse is true (fig. 47).

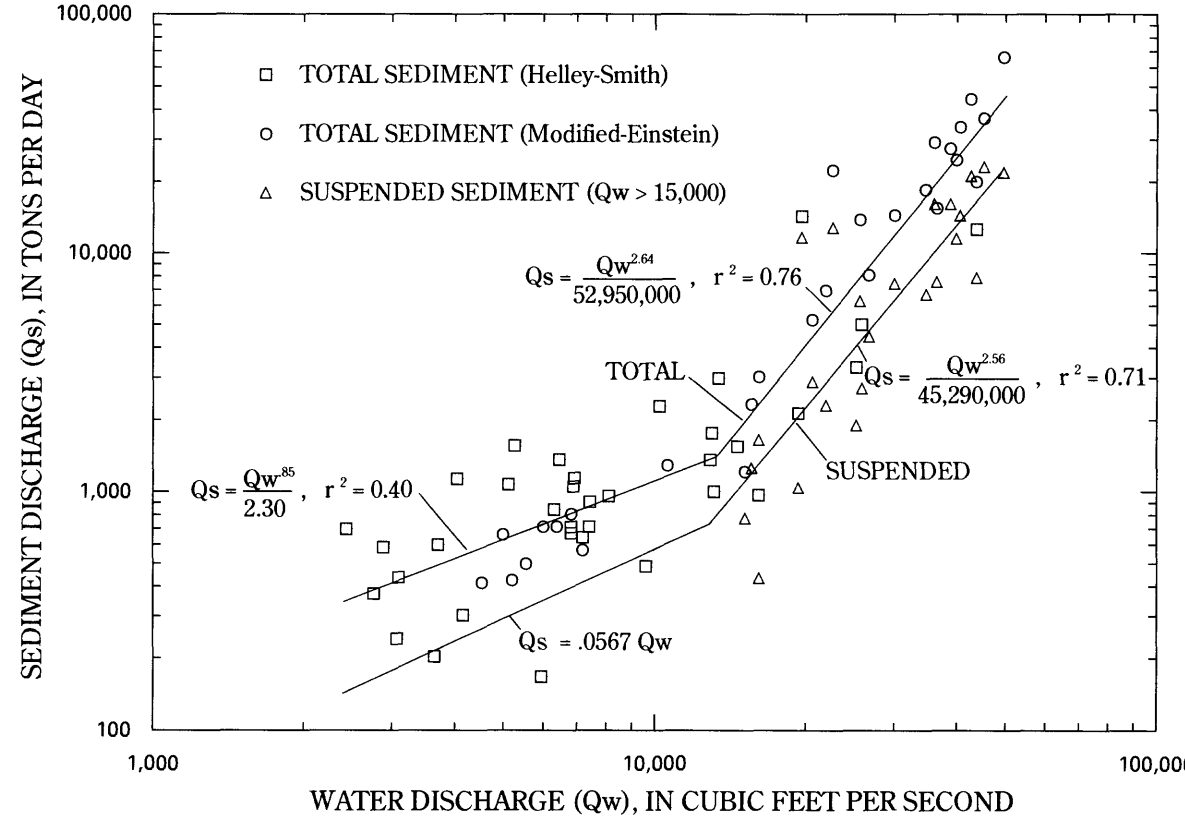


Figure 46. Relations of suspended- and total-sediment discharge to water discharge at Wisconsin River at Muscoda.

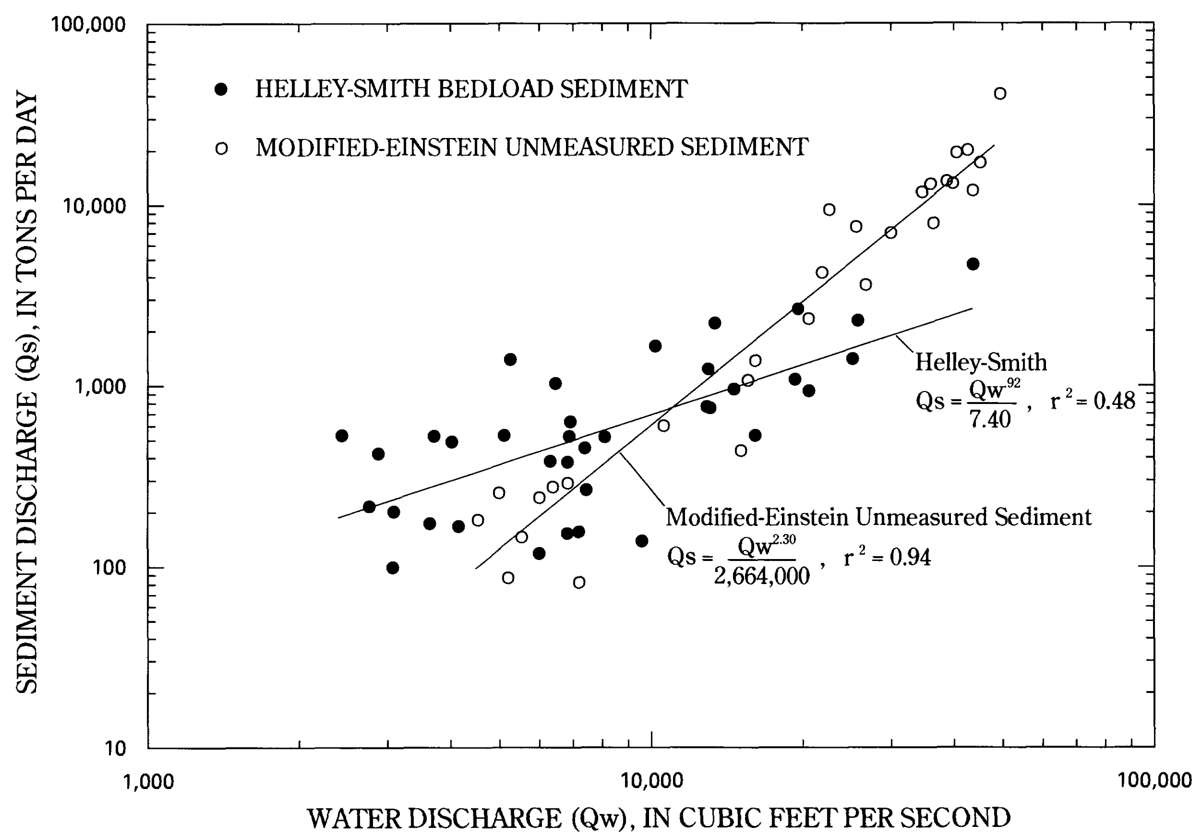


Figure 47. Relations of Helley-Smith bedload discharge and modified-Einstein unmeasured-sediment discharge to water discharge at Wisconsin River at Muscoda.

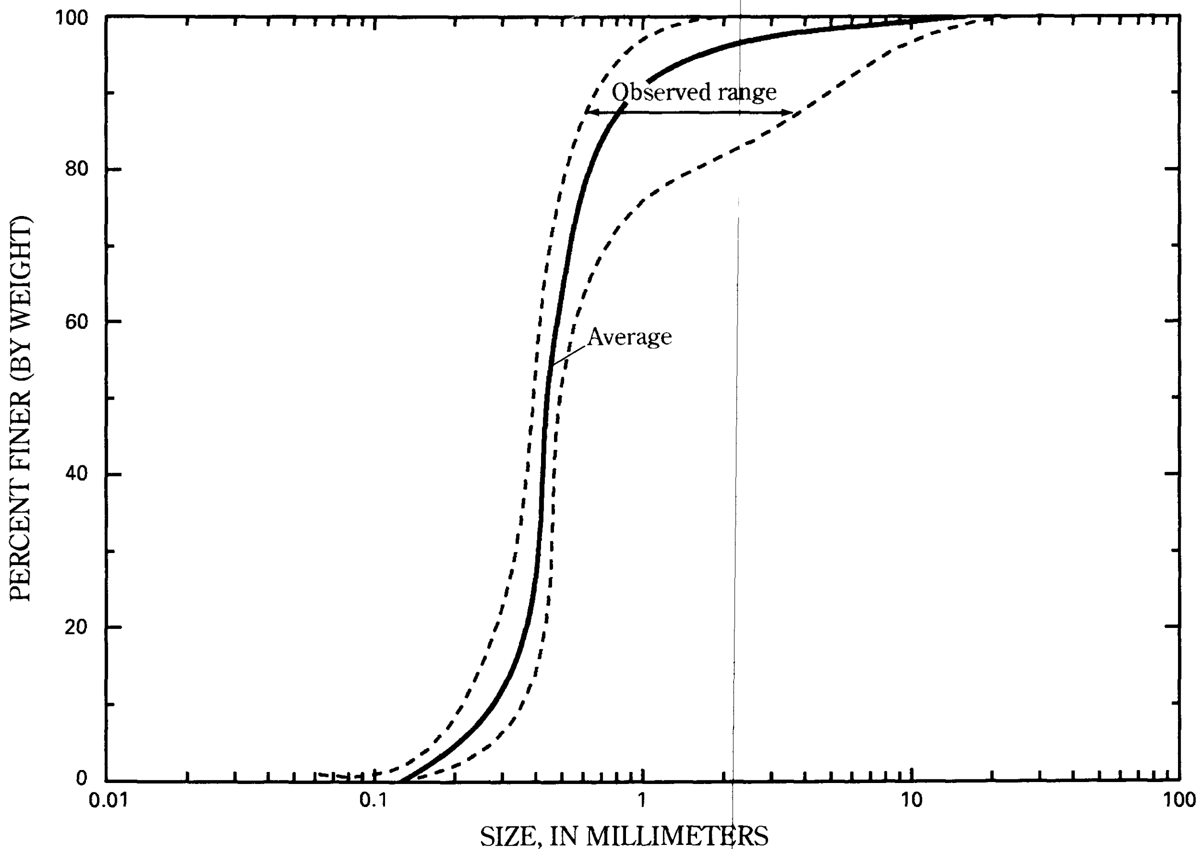


Figure 48. Cumulative-frequency distribution of average and range of particle sizes in 51 surface bed material samples from Wisconsin River at Muscoda from January 1976 through September 1983.

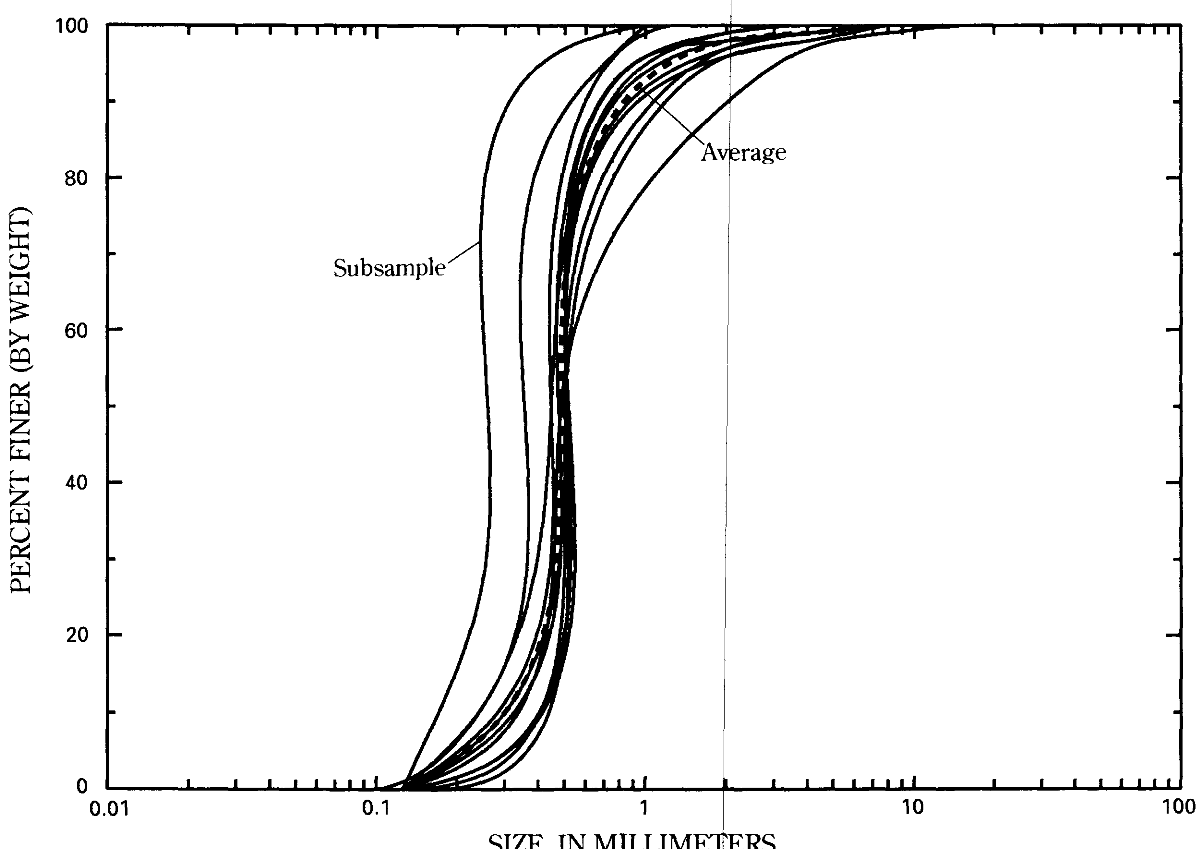


Figure 49. Cumulative-frequency distribution of particle sizes in surface bed material from 12 equally spaced locations in the channel cross section on April 9, 1982, at Wisconsin River at Muscoda.

SEDIMENT PARTICLE SIZE

Bed-material particle size varies little with time, across the river cross section, or with river discharge. The range and average of 51 observations (each observation is an average of about 12 subsamples) of particle size is shown in figure 48. Median particle diameter averaged 0.44 mm and ranged from 0.39 to 0.48 mm. Cross-channel variability for one sampling date is shown in figure 49; median particle diameter of particles in the subsamples ranged from 0.26 to 0.54 mm.

Measured bedload was of fairly uniform size (fig. 50) and varied little with time. On the average, about 62 percent of the material was in the 0.4- to 0.6-mm size range. The median particle diameter of material from 33 Helley-Smith bedload measurements ranged from 0.28 to 0.54 mm.

On the average, 60 percent of suspended sediment was in the 0.062- to 1.0-mm size range and median particle diameter was 0.2 mm. Suspended sediment in the silt- and clay-size (<0.062 mm) range ranged from 4 to 94 percent and averaged 40 percent for 31 samples. Particle-size curves are shown in figure 51.

SEDIMENT LOAD

Total annual sediment loads ranged from 191,000 tons in water year 1977 to 840,000 tons in water year 1979. Total annual sediment load averaged 558,000 tons during water years 1974-83. Annual sediment loads and annual average water discharges are shown below.

On the average, about 51 percent of the total load was transported as suspended sediment and 49 percent was transported as bedload or unmeasured-sediment discharge. The relative proportions of suspended- and unmeasured-sediment loads are shown in figure 52.

Water year	Average water discharge (ft^3/s)	Suspended-sediment load (tons)	Unmeasured-sediment load (tons)	Total sediment load (tons)
1974	8,411	203,000	198,000	401,000
1975	8,588	278,000	271,000	549,000
1976	9,219	383,000	370,000	753,000
1977	4,145	86,000	105,000	191,000
1978	9,717	253,000	239,000	492,000
1979	10,520	430,000	410,000	840,000
1980	9,613	330,000	317,000	647,000
1981	9,030	218,000	210,000	428,000
1982	8,828	282,000	274,000	556,000
1983	11,180	375,000	350,000	725,000

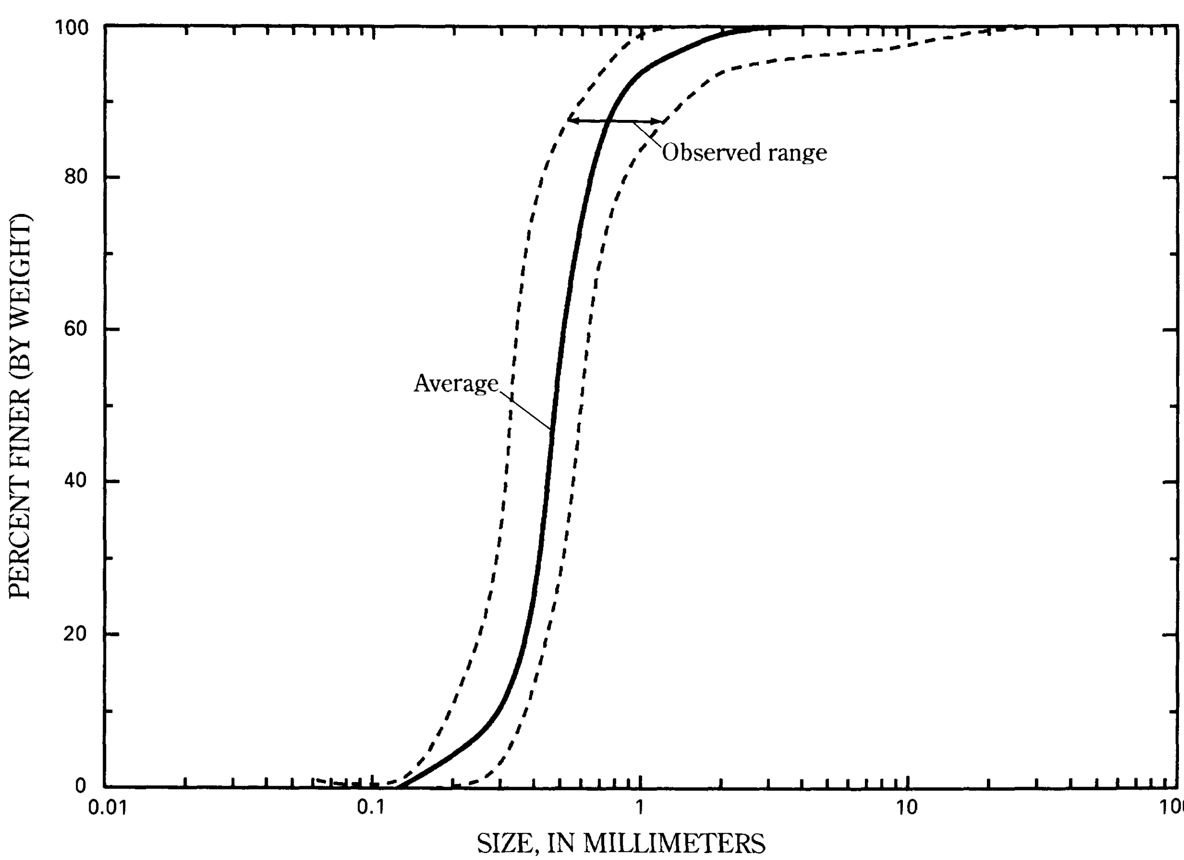


Figure 50. Cumulative-frequency distribution of average and range of particle sizes in 33 Helley-Smith bedoad samples from Wisconsin River at Muscoda from January 1976 through September 1979.

SUMMARY

Sediment data were collected during water years 1976–83 at sites on the Chippewa River near Caryville, at Durand, and near Pepin; the Black River near Galesville; and the Wisconsin River at Muscoda. Suspended sediment, surface bed material, and bedload (using the Helley-Smith samples) were sampled. These data were interpreted to describe the relation of suspended sediment, bedload, and total-sediment discharge to water discharge; to describe sediment particle-size characteristics; and to provide average and annual sediment load estimates that are based on flow records for water years 1974–83.

Suspended-sediment concentrations at all five monitoring sites were generally low (<100 mg/L), reflecting the effects of deposition in upstream reservoirs. Suspended-sediment concentration was related to water discharge for the full range of discharge at Chippewa River at Durand, the main channel of Chippewa River near Pepin, and Black River near Galesville; and for discharge greater than 8,000 ft^3/s at Chippewa River near Caryville, and 15,000 ft^3/s at Wisconsin River at Muscoda. Suspended-sediment concentration was not related to water discharge at Chippewa River near Caryville when discharge was less than 8,000 ft^3/s, at the west and east channels of Chippewa River near Pepin, and when discharge was less than 15,000 ft^3/s at Wisconsin River at Muscoda. Ranges of observed suspended-sediment concentrations are listed at right.

Modified-Einstein unmeasured-sediment discharge was greater than measured (Helley-Smith) bedload discharge at water discharges greater than 6,000, 6,000, and 10,000 ft^3/s at the main channel of Chippewa River near Pepin, Black River near Galesville, and Wisconsin River near Muscoda, respectively; below these water discharges measured bedload discharge was less than unmeasured-sediment discharge. Bedload transport was insignificant at Chippewa River near Caryville when water discharge was less than 8,000 ft^3/s; above 8,000 ft^3/s measured bedload discharge and unmeasured-sediment discharge were of similar magnitude for a given water discharge. Unmeasured-sediment discharge was greater than measured bedload for the full range of water discharge at Chippewa River at Durand.

Site	Range of observed concentration (mg/L)
Chippewa River near Caryville	3– 48
Chippewa River at Durand	4– 413
Chippewa River near Pepin	
Main channel	10– 330
West channel	24– 241
East channels	6– 100
Black River near Galesville	2–1,130
Wisconsin River near Muscoda	3– 220

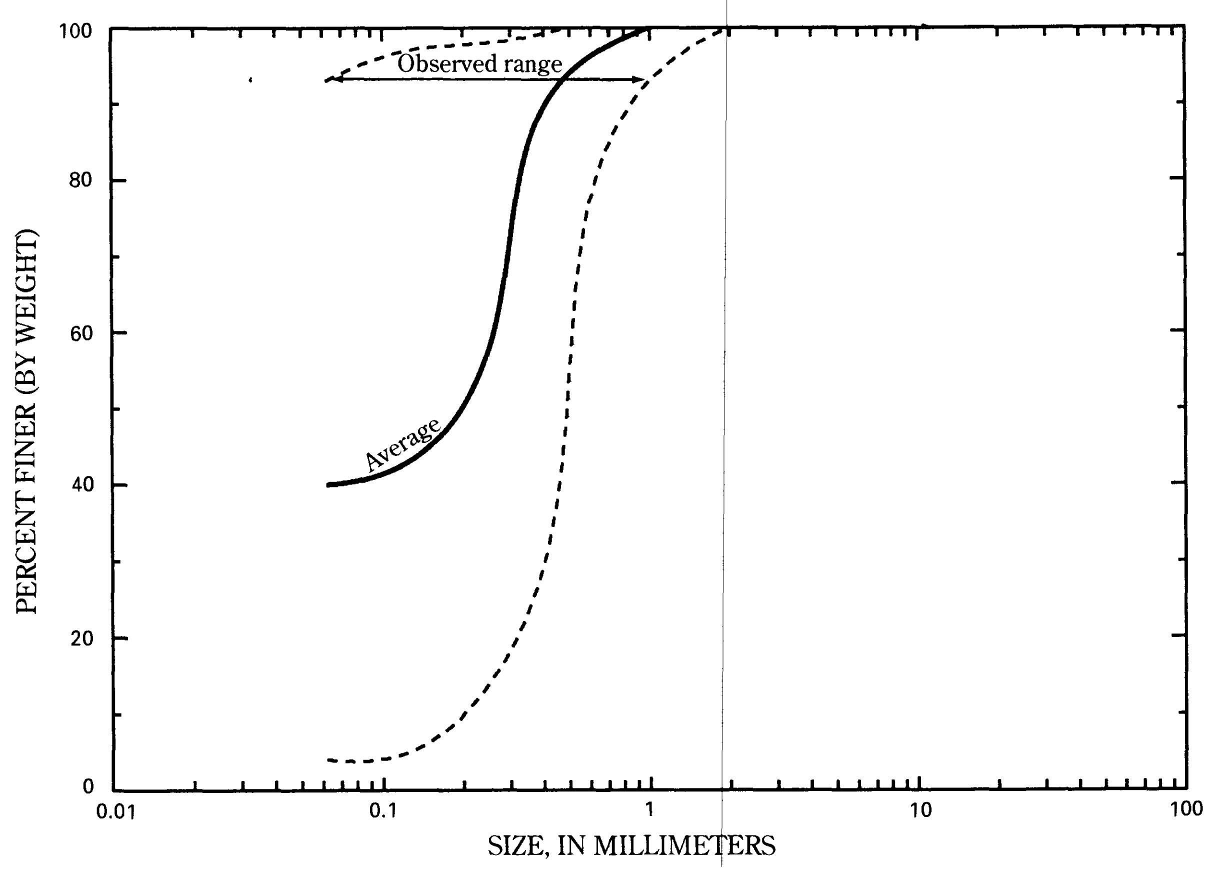


Figure 51. Cumulative-frequency distribution of average and range of particle sizes in 31 suspended-sediment samples from Wisconsin River at Muscoda from October 1979 through September 1983.

Particle-size characteristics of bed material, measured bedload, and suspended sediment for all the sites except Chippewa River near Caryville were similar. At Chippewa River near Caryville, however, bed material and measured bedload were coarser and suspended sediment was finer than at the other four sites. These data are summarized in table 1.

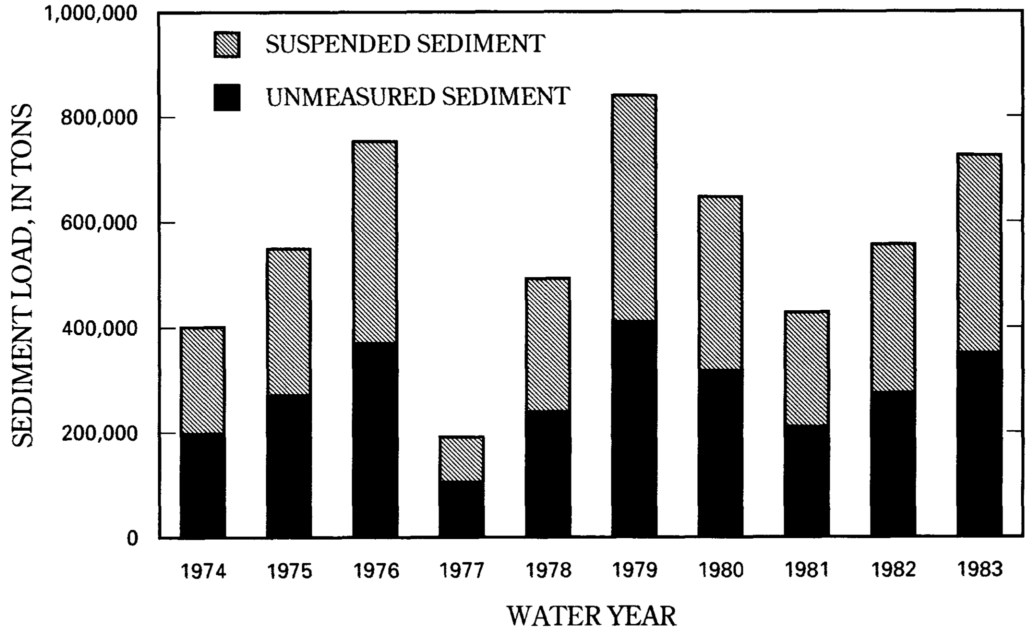


Figure 52. Annual suspended- and unmeasured-sediment loads at Wisconsin River at Muscoda, water years 1974–83.

Table 1.—*Summary of sediment particle size and annual total-sediment loads at monitoring sites*
[mm = millimeters]

	Chippewa River near Caryville	Chippewa River at Durand	Chippewa River near Pepin[1]	Black River near Galesville	Wisconsin River at Muscoda
			Particle size		
Bed material: Range of median diameter of average bed material (mm)	0.42–15	0.47–0.84	0.37–0.59	0.35–0.52	0.39–0.48
Range of median diameter of subsamples in a typical cross section (mm)	.30–32	24–11	24-.61	.25– .52	.26–.54
Bedload: Range of median diameter (mm)	.50–1.2	.50–73	.49–.53	.31–.52	.28–.54
Suspended sediment: Percent finer than 0.062 mm	60	26	30	34	40
Median diameter (mm)	<.0625	.22	.17	.20	.20
			Annual total sediment loads, 1974–83		
Maximum (tons)	44,000	503,000	321,000	42,300	191,000
Minimum (tons)	194,000	1,574,000	1,380,000	471,000	840,000
Average (tons)	123,000	1,073,000	940,000	277,000	558,000
Percentage transported as suspended sediment	35	39	56	57	51

[1]Particle-size data are for the main channel only and sediment-load data are for the main, west, and east channels combined.

Total annual sediment loads for the five monitoring sites for 1974-83 are summarized in table 1. The percentage of total load transported as suspended sediment ranged from 35 at Chippewa River near Caryville to 57 at Black River near Galesville.

Sediment-discharge and load distribution do not reflect the water-discharge distribution among the main, west, and east channels. In the 30- to 70,000-ft^3/s discharge range, the dominant proportion of total discharge increasingly shifts from the main channel to the east channels. When total discharge exceeds 70,000 ft^3/s, most flow is in the east channels. Most sediment transport is in the main channel at all water discharges. For example, when total river discharge is 80,000 ft^3/s, only 40 percent of flow is in the main channel, but 85 percent of sediment is transported in the main channel. On the average about 97 percent of total annual sediment load was transported in the main channel, 2 percent in the west channel, and 1 percent in the east channels.

Most sediment being transported in the lower Chippewa River is derived from the river and watershed downstream of Eau Claire. The reach of river between Durand and Caryville yielded the most sediment, and there is net deposition of sediment in the reach between Durand and Pepin.

REFERENCES CITED

Colby, B.R., and Hembree, C.H., 1955, Computations of total sediment discharge, Niobrara River near Cody, Nebraska: U.S. Geological Survey Water-Supply Paper 1357, 187 p.

Emmett, W.W., 1980, A field calibration of the sediment-trapping characteristics of the Helley-Smith bedload sampler: U.S. Geological Survey Professional Paper 1139, 44 p.

Glysson, G.D., 1987, Sediment transport curves: U.S. Geological Survey Open File Report 87–218, 47 p.

Guy, H.P., 1969, Laboratory theory and methods for sediment analysis: U.S. Geological Survey Techniques of Water Resources Investigations, Book 5, Chapter C1, 58 p.

Guy, H.P., and Norman, V.W., 1970, Field methods for measurement of fluvial sediment: U.S. Geological Survey Techniques of Water Resources Investigations, Book 3, Chapter C2, 59 p.

Helley, E.J., and Smith, Winchell, 1971, Development and calibration of a pressure-difference bedload sampler: U.S. Geological Survey Open-File Report, 18 p.

Henrich, E.W., and Daniel, D.N., 1983, Drainage area data for Wisconsin streams: U.S. Geological Survey Open-File Report 83–933, 322 p.

Hindall, S.M., and Borman, R.G., 1974, Water resources of Wisconsin—lower Wisconsin River basin: U.S. Geological Survey Hydrologic Investigations Atlas HA–479, 3 sheets, scale 1:1,000,000.

Holmstrom, B.K., Harr, C.A., and Erickson, R.M., 1983, Water resources data—Wisconsin, water year 1982: U.S. Geological Survey Water-Data Report WI–82–1, 426 p.

___1984, Water resources data—Wisconsin, water year 1983: U.S. Geological Survey Water-Data Report WI–83–1, 352 p.

Martin, Lawrence, 1932, The physical geography of Wisconsin: Wisconsin Geological and Natural History Survey Bulletin 36, 608 p.

Rantz, S.E., and others, 1982, Measurement and computation of streamflow: U.S. Geological Survey Water-Supply Paper 2175, 631 p.

Stevens, H.H., 1985, Computer program for the computation of total sediment discharge by the modified Einstein procedure: U.S. Geological Survey Water-Resources Investigations Report 85–4047, 14 p.

U.S. Geological Survey, 1977, Water resources data for Wisconsin, 1976: U.S Geological Survey Water-Data Report WI–76–1, 596 p.

___1978, Water resources data for Wisconsin, 1977: U.S. Geological Survey Water-Data Report WI–77–1, 639 p.

___1979, Water resources data for Wisconsin, 1978: U.S. Geological Survey Water-Data Report WI–78–1, 500 p.

___1980, Water resources data for Wisconsin, 1979: U.S. Geological Survey Water-Data Report WI–79–1, 514 p.

___1981, Water resources data for Wisconsin, 1980: U.S. Geological Survey Water-Data Report WI–80–1, 505 p.

___1982, Water resources data for Wisconsin, 1981: U.S. Geological Survey Water-Data Report WI–81–1, 413 p.

Young, H.L., and Borman, R.G., 1973, Water resources of Wisconsin—Trempealeau–Black River basin: U.S. Geological Survey Hydrologic Investigations Atlas HA–474, 4 sheets, scale 1:1,000,000.