SEDIMENT TRANSPORT, PARTICLE SIZE, AND LOADS IN NORTH FISH CREEK IN BAYFIELD COUNTY, WISCONSIN, WATER YEARS 1990–91

By William J. Rose and David J. Graczyk

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 95-4222

Prepared in cooperation with the
WISCONSIN DEPARTMENT OF NATURAL RESOURCES

Madison, Wisconsin
1996

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
Gordon P. Eaton, Director

For additional information write to:

District Chief
U.S. Geological Survey
6417 Normandy Lane
Madison, WI 53719

Copies of this report can be purchased from:

U.S. Geological Survey
Earth Science Information Center
Open-File Reports Section
Box 25286, MS 517
Denver Federal Center
Denver, CO 80225

CONTENTS

FIGURES

TABLES

CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS

Multiply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
foot per mile (ft/mi)	0.1894	meter per kilometer
square mile (mi^2)	2.590	square kilometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
ton (short)	0.9072	megagram
inch per hour (in/h)	25.4	millimeter per hour

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.

Miscellaneous abbreviations: Sediment particle sizes are given in millimeters (mm) and centimeters (cm).

Sediment Transport, Particle Size, and Loads in North Fish Creek in Bayfield County, Wisconsin, Water Years 1990–91

By William J. Rose *and* David J. Graczyk

Abstract

North Fish Creek is underused as a trout and salmon hatchery despite its excellent water quality. The shifting-sand streambed in the lower 9 miles of the stream inhibits successful spawning and is a poor habitat for macroinvertebrates, the primary food for juvenile trout and salmon. To provide data necessary for evaluation of potential sand-loading-control practices, the U.S. Geological Survey determined total-sediment transport, particle size, and loads for three sites, designated A, B, and C, on North Fish Creek during water years 1990–91.

At site C, the most upstream site, all sediment was transported as suspended sediment. The average annual total-sediment load during 1990–91 was 479 tons. About 88 percent of the load was transported during periods of snowmelt or storm runoff. About 75 percent of the sediment load was silt- and clay-size particles; the remainder was sand.

Total-sediment discharge was calculated by the modified-Einstein procedure to determine total sediment transport-rate relations for site A, the most downstream site, and for site B. Annual total-sediment load was 11,960 tons in water year 1990 and 18,430 tons in water year 1991 at site B. About 97 percent of the total load was transported during periods of snowmelt and storm runoff. About 60 percent of the total-sediment load was sand-size particles.

Annual total-sediment loads were 20,690 tons and 33,100 tons in water years 1990 and 1991, respectively, at site A. About 67 percent of the total-sediment load was sand-size particles.

Annual average streamflow, as indicated by flow in the Bois Brule River, was about 16 percent below average in water year 1990, and about 4 percent above average in water year 1991.

There was little relation between watershed area and sediment loads for the three sites. The watershed of site C is about 41 percent of that of site A, but the sand load at site C was only 1 percent of that at site A. The watershed area between sites B and C is 40 percent of that above site A, but this area yielded 49 percent of the sand load at site A. Nineteen percent of the watershed above site A is between sites A and B, yet this area yielded about 50 percent of the sand load at site A.

INTRODUCTION

Maintenance of anadromous trout and salmon has been identified as a top priority in the "Lake Superior Management Plan" of the Wisconsin Department of Natural Resources (WDNR) (Bruce Swanson, Wisconsin Department of Natural Resources, written commun., 1989). North Fish Creek, a tributary to Chequamegon Bay on Lake Superior, has excellent water quality and is capable of sustaining anadromous runs of trout and salmon.

North Fish Creek is underused as a trout and salmon hatchery stream in comparison to other nearby streams. An analysis of reproduction in nearby streams shows that reproduction in North Fish Creek is only 40 to 50 percent of its potential (Wisconsin Department of Natural Resources, written commun., 1988). Fisheries managers believe that the shifting-sand streambed in the lower 9 mi of the stream inhibits successful spawning and is a poor habitat for macroinvertebrates, a primary food for juvenile trout and salmon.

The streambed of the lower 9 mi of North Fish Creek is underlain by 2 to 3 ft of sand; however, notes from a land survey in the 1850's indicated that the streambed was a gravel-cobble substrate at one location (Wisconsin Department of Natural Resources, written commun., 1988). The source of the sand may be the typically steep banks of the main channel that are being eroded during high flows and gully erosion from small intermittent streams tributary to North Fish Creek.

If the sand input to North Fish Creek could be halted or controlled, the habitat for spawning trout and salmon may improve. Another benefit of sand control would be the reestablishment of pools, which might improve the winter survival of pre-smolt trout and salmon.

Input of sand to the stream could be reduced by implementing bank stabilization and/(or) control of upland soil erosion or by the removal of sand by constructing in-channel sand traps. Sand traps have been used successfully in similar streams in Michigan (Hansen and others, 1983). Evaluation of whether sand-loading control is feasible and which control practices would be most applicable to North Fish Creek depends on determination of the annual sand load at selected stream sites. In October 1989, the U.S. Geological Survey (USGS), in cooperation with the WDNR, began a study of stream-sediment characteristics at three sites on North Fish Creek.

Purpose and Scope

The purposes of this report are to summarize and interpret sediment data that will aid in evaluation of potential sand-control practices along North Fish Creek. Data were collected during water years[1] 1990–91 at sites on North Fish Creek near Benoit, near Moquah, and near Ashland. The report includes (1) a description of the relation of total-sediment discharge to water discharge, (2) a description of particle size of suspended sediment, bedload, and bed material, (3) estimates of annual coarse- (>0.0625 mm) and fine- (<0.0625 mm) sediment loads, and (4) comparisons of total-sediment loads from one site to another.

[1]A water year is the 12-month period, October 1 through September 30. The water year is designated by the calendar year in which it ends. Thus, the year ended September 30, 1990, is called the "1990 water year."

Acknowledgments

We thank the WDNR personnel who read the staff gages at the data-collection sites. Without their assistance, we would not have been able to obtain the necessary data to complete the study.

PHYSICAL SETTING

North Fish Creek flows northeastward into Fish Creek at the confluence with South Fish Creek about 1 mi upstream from Chequamegon Bay of Lake Superior. North Fish Creek is 27.7 mi from the mouth to the basin divide, and its average channel slope is 21.6 ft/mi. The area of the North Fish Creek watershed is about 47 mi^2. About 60 percent of the watershed is forested, 20 percent is agricultural lands (mostly hay and pasture), and the remaining 20 percent is other land uses.

The surficial geology of the North Fish Creek watershed is mostly clay overlying till and stratified sand and gravel (Young and Skinner, 1974). The surface of the area northwest of the watershed, locally called the "sand barrens," is pitted outwash of stratified sand and gravel. The high permeability (5-10 in/hr) sand and gravel contributes to the high base flow in the North Fish Creek (Young and Skinner, 1974). The bedrock of the basin is wholly Precambrian and consists of sandstone, shale and conglomerates (Young and Skinner, 1974). The soils of the watersheds are silty clay loam and loamy sand (Hole, 1976).

DATA-COLLECTION NETWORK

Streamflow- and sediment-monitoring stations were established at three sites on North Fish Creek in October 1989. From downstream to upstream, the sites were (1) North Fish Creek near Ashland (site A) at U.S. Highway 2, (2) North Fish Creek near Moquah (site B) at Old U.S. Highway 2, and (3) North Fish Creek near Benoit (site C) at U.S. Highway 2 (fig. 1). For simplicity, the sites are hereafter referred to as "sites A, B, and C." Site B was a streamflow-gaging station equipped to continuously monitor streamflow. Sites A and C were partial-record gaging stations equipped with staff and crest-stage gages. Frequency of and the type of data collected at each site are given in table 1.

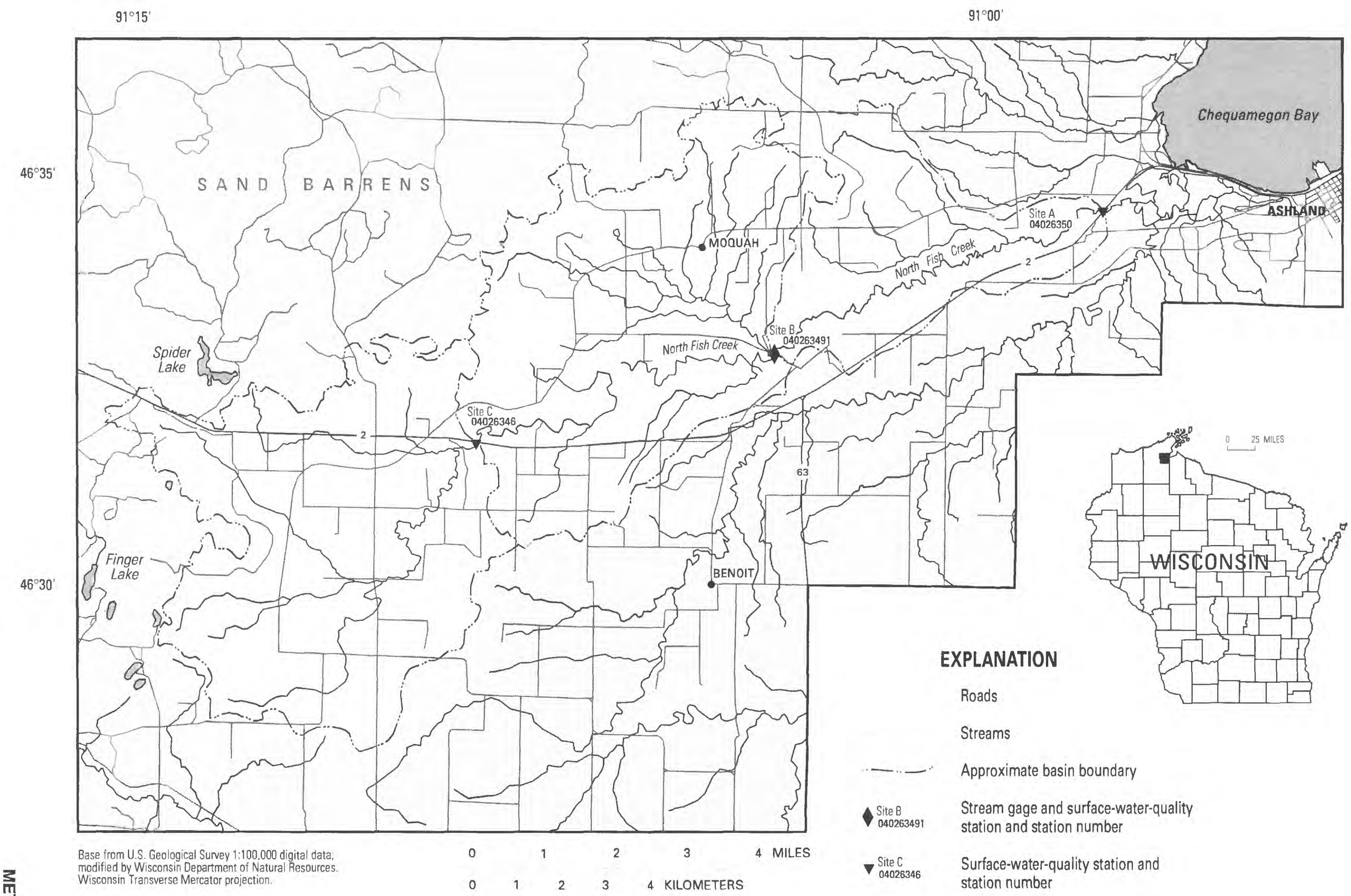

Figure 1. Locations of data-collection stations on North Fish Creek.

Table 1. Description of hydraulic measurements and sediment analyses for North Fish Creek monitoring sites, water years 1990–91

[X, instrumented or samples collected; --, not instrumented or samples not collected]

	Hydraulic measurements			Types of sediment samples		
Site	Continuous streamflow	Intermittent stream stage	Intermittent streamflow	Suspended-sediment concentration and particle size	Bed-material particle size	Helley-Smith bedload
A	--	X	X	X	X	X
B	X	--	--	X	X	X
C	--	X	X	X	--	--

METHODS

Data Collection

Standard stream-gaging methods (Rantz and others, 1982) were used to measure streamflow at all sites. Streamflow was measured at about 6-week intervals during low flow and more often during high flow to define stage-discharge relations for the sites. The gaging station at site B was equipped to record water levels at 15-minute intervals.

Staff gages at sites A and C were read weekly by a local WDNR observer. During periods of storm or snowmelt runoff, staff gages were read daily or more frequently by WDNR and USGS personnel. The crest-stage gages, which were maintained by USGS personnel, recorded peak stages.

Daily average discharges at sites A and C were estimated from an analysis of gage-height readings and discharge measurements at the sites and daily average discharge from the continuous gaging station at site B. Weekly stage readings and periodic discharge measurements were used to estimate the daily discharge for low flow. Storm hydrographs for high flows when discharged changed rapidly were defined by plotting gage-height readings. Hourly discharges were determined and summed to compute the daily discharge.

Suspended-sediment samples were collected by use of depth-integrating samplers, most commonly the US D-49. Velocity-weighted samples were collected by the equal-width-increment (EWI) method (Edwards and Glysson, 1988).

Bedload was measured with a Helley-Smith bedload sampler (Helley and Smith, 1971) at sites A and B. The Helley-Smith bedload sampler was equipped with a 3-in. by 3-in. square nozzle with a 3.22 flare ratio and a 0.25-mm-mesh collection bag. The single equal-width increment (SEWI) bedload-sampling method was used (Edwards and Glysson, 1988). Two traverses were made across the stream, and about 20 sampling locations were in each traverse. The sampler was allowed to rest on the bottom for 30 seconds at each sampling location. Subsamples were composited, air dried, and weighed. Selected bedload samples were analyzed for particle size. The sampling cross section at site C was over a concrete apron at the entrance of a box culvert. Because of supercritical water velocities at this section, all sediment transport was assumed to be in the suspended phase; thus, total sediment discharge was considered to be equal to suspended-sediment discharge.

Surface bed material was sampled at sites A and B by use of US BMH-60, US BM-54, or US BMH-80 rotary-bucket bed-material samplers (Edwards and Glysson, 1988). Particle-size distribution of a given sediment sample is a breakdown of the sample into size classes with the weight of each size class expressed as percentage of the whole sample. Streambed sediments were sampled at 10 to 14 equally spaced locations. Surface bed-material samples were not collected at site C because the bottom of the sampled cross section was concrete. The laboratory methods used to analyze water, bed material, and bedload samples at a USGS laboratory in Iowa City, Iowa, were outlined by Guy (1969). Concentrations of suspended-sediment samples were determined by the filtration method, and particle-size distributions were determined by the visual-accumulation-tube method. Particle-size distributions of bed material and bedload were determined by the sieve method.

Sediment Discharge and Load Computation

Instantaneous total-sediment discharges were determined by two methods. One method consisted of summing concurrently measured Helley-Smith bedload discharge and suspended-sediment discharge. The second method was the modified Einstein procedure (Colby and Hembree, 1955). The procedure is applicable to alluvial channels where bed material is finer than 16 mm and where a significant part of the measured suspended sediment is composed of particles of the same size as particles in the bed material (Stevens, 1985). Input data required to use the modified Einstein procedure are streamflow, average water depth, effective width of the channel, suspended-sediment and bed-sediment particle size, suspended-sediment concentration, average depth of suspended-sediment sampling verticals, and depth of the unsampled zone. Hydraulic and channel geometry were determined by direct measurement during streamflow measurements, and sediment data were determined from sample analyses. A computer program by Stevens (1985) was used to do calculations for the modified Einstein procedure.

Total sediment transport curves were constructed according to procedures outlined by Glysson (1987). The equations defining the curves were determined by regression (least squares) analysis of streamflow and total-sediment discharge.

Estimates of daily total-sediment load were determined by applying average streamflow to the sediment-transport equation. Monthly and annual loads were calculated by summing the daily loads.

HYDROLOGIC CONDITIONS DURING THE STUDY

Precipitation during the study (water years 1990–91) was less than normal in the first year and greater than normal in the second year (fig. 2A). Normal precipitation, which is defined as the 1961–90 average annual precipitation, was 30.1 in. at the U.S. Weather Bureau station at the University of Wisconsin Experimental Farm at Ashland, Wis., about half a mile southwest of site A (Pamela Naber-Knox, University of Wisconsin Extension, Geological and Natural History Survey, written commun., 1994). Precipitation was 25.8 in., or about 4 in. below normal, during water year 1990 and 36.2 in., or about 6 in. above normal, in water year 1991 (fig. 2A). Maximum monthly precipitation during the study was 8.45 in. in July 1991, or 4.5 in. above the 1961–90 normal precipitation for July for northwest Wisconsin (Pamela Naber-Knox, University of Wisconsin Extension, Geological and Natural History Survey, written commun., 1994)(fig. 3A). The minimum monthly precipitation as rainfall was 0.62 in. in May 1990 (fig. 3A). This was 2.8 in. below the 1961–90 normal precipitation for May for northwest Wisconsin (Pamela Naber-Knox, University of Wisconsin Extension, Geological and Natural History Survey, written commun., 1994).

Streamflow, as indicated by flow in the Bois Brule River, about 30 mi west of the North Fish Creek Watershed, was less than the long-term average in water year 1990 and greater than the long-term average in water year 1991 (table 2 and fig. 2B). The Bois Brule River Watershed is about 37 percent larger than the North Fish Creek Watershed, but the two streams and watersheds are hydrologically similar. Streamflow characteristics for the Bois Brule River and North Fish Creek sites are summarized in table 2. The annual average streamflow in water year 1990 at the Bois Brule River was about 16 percent below the average annual streamflow for the 1943–91 period; in water year 1991 the annual average streamflow was 4 percent greater than the average annual streamflow for the 1914–91 period. Peak instantaneous flow for the Bois Brule River during water years 1990–91 was less than the 2-year-recurrence-interval flow (Krug and others, 1992, p. 25).

Streamflow at site C was more responsive than streamflow at sites A and B to the approximately 11 in. greater precipitation in water year 1991 than in water year 1990 (fig. 3A and 3B). The annual average streamflow was 16, 13, and 72 percent greater in water year 1991 than in the water year 1990 at sites A, B, and C, respectively (table 2). The large increase in the annual average discharge for site C was because a larger proportion of runoff from the

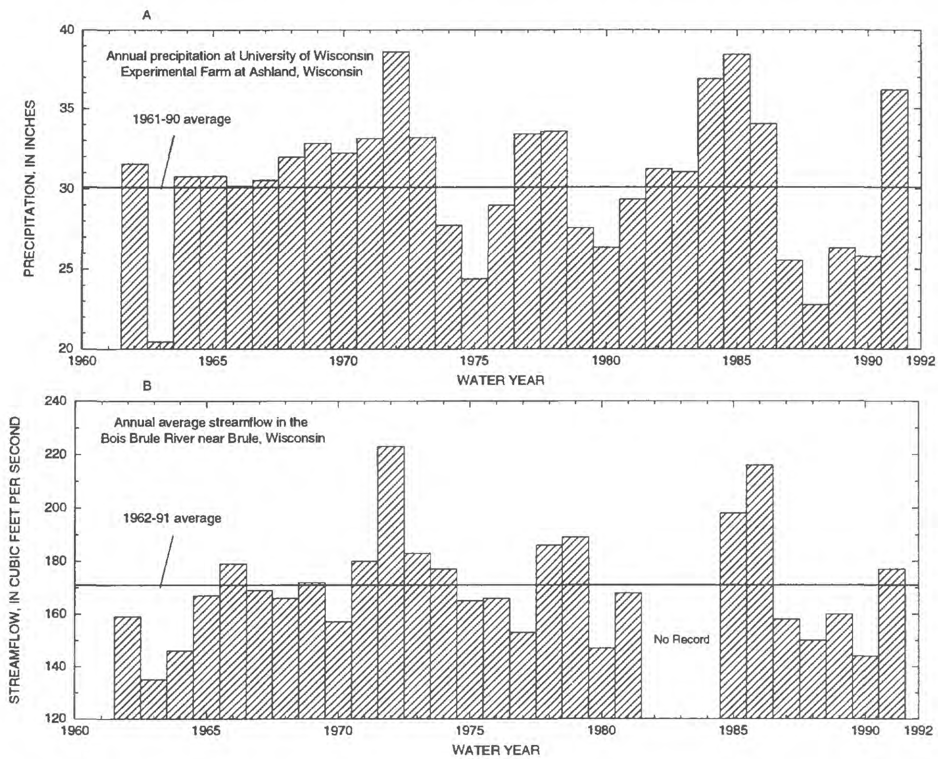

Figure 2. Annual and long-term averages of (A) precipitation and (B) streamflow before and during the study period.

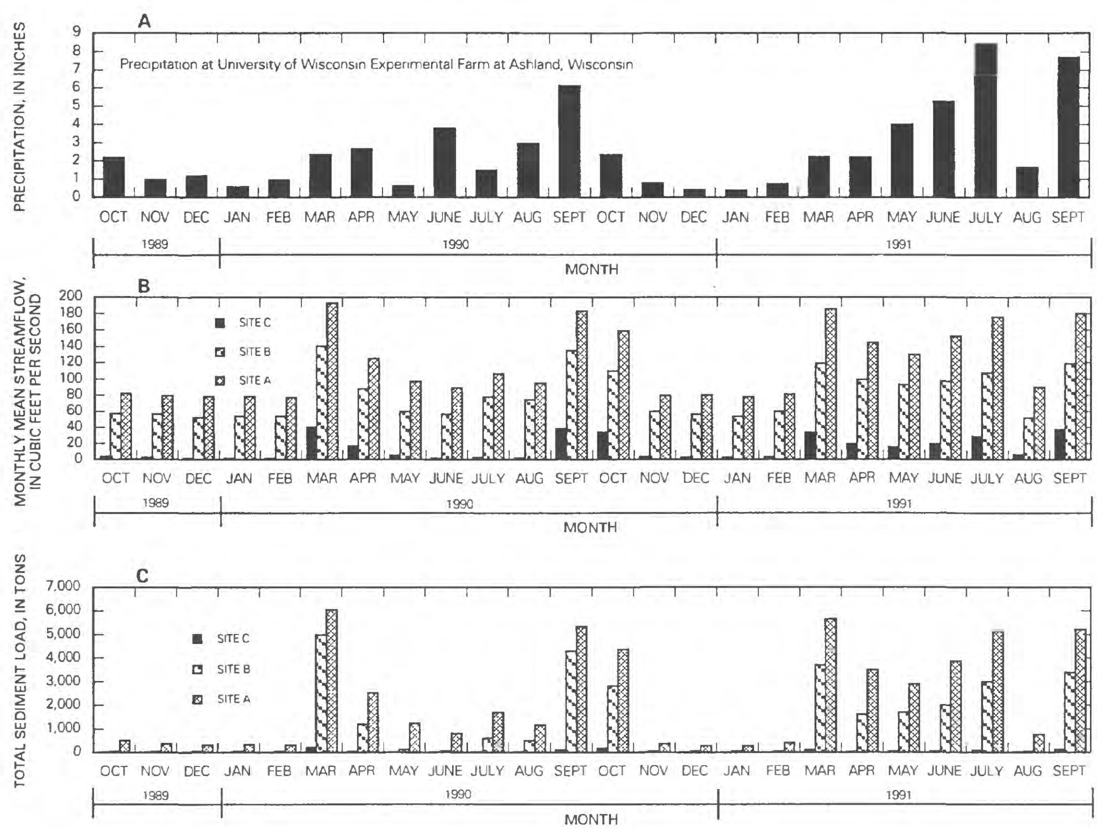

Figure 3. Monthly (A) precipitation, (B) streamflow, and (C) total-sediment load at North Fish Creek, sites A, B, and C, water years 1990–91

Table 2. Summary of streamflow characteristics for sites A, B, and C on North Fish Creek and for the Bois Brule River at Brule, Wis.

[Number in parentheses is U.S. Geological Survey station number; DA, drainage area in square miles; WY, water year; --, data not available; N/A, not applicable]

	North Fish Creek						Bois Brule River at Brule, Wis.			
	site A (04026350) DA = 47.4		site B (040263491) DA = 38.4		site C (04026346) DA = 19.3		(04025500) DA =118		Period of record[1]	
Streamflow characteristic	WY1990	WY1991	WY1990	WY1991	WY1990	WY1991	WY1990	WY1991	Average	Peak
Annual average streamflow, in cubic feet per second	106	123	75.7	85.7	10.1	17.4	144	177	171	N/A
Annual average streamflow, in cubic feet per second per square mile	1.42	1.65	1.16	1.31	.28	.48	1.20	1.50	1.45	N/A
Runoff, in inches	19.3	22.4	15.7	17.8	3.80	6.57	16.2	20.4	19.7	N/A
Overland-flow runoff, in inches	3.8	6.5	3.3	5.0	1.66	3.60	.60	2.1	1.6	N/A
Base-flow runoff, in inches	15.5	15.9	12.4	12.8	2.14	2.97	15.6	18.3	18.1	N/A
Percentage of total flow from base flow	80	71	79	72	56	45	94	90	92	N/A
Minimum 7-day average low flow in cubic feet per second	75	77	50	50	1.5	2.7	110	89	N/A	N/A
Peak instantaneous streamflow, in cubic feet per second	--	--	1,170	1,690	--	--	404	521	--	1,520

[1] 1943–81, 1985–91

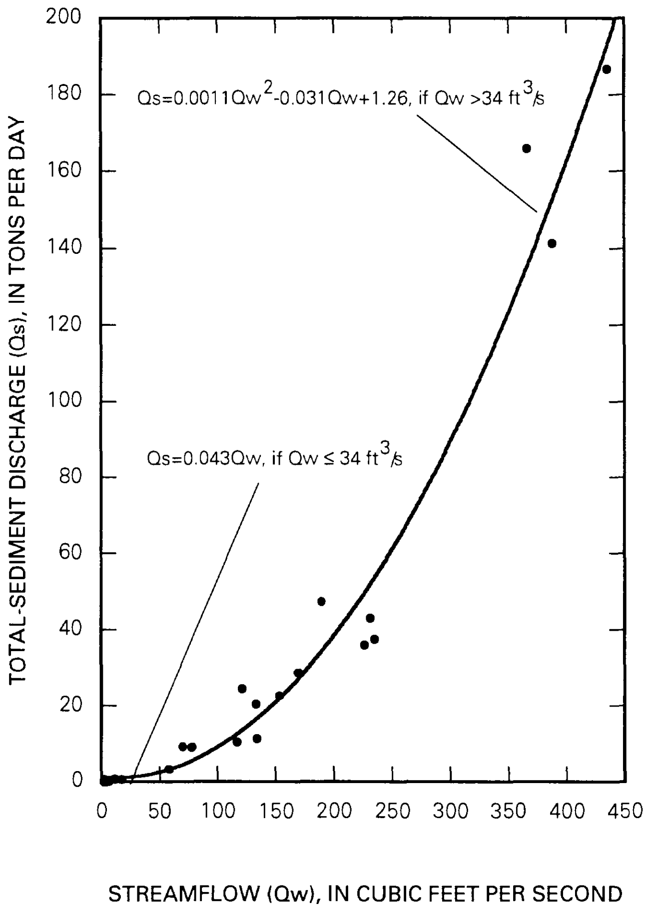

Figure 4. Relation of total-sediment discharge to streamflow at North Fish Creek, site C.

watershed above site C was from overland flow than from the watersheds above the other two sites. A hydrograph-analysis program by White and Sloto (1990) was used to do the separation of overland flow and baseflow from total flow. Overland flow at site C makes up 50 to 60 percent of total streamflow (table 2), whereas overland flow at sites A and B makes up only 20 to 30 percent of the total streamflow (table 2).

NORTH FISH CREEK NEAR BENOIT (SITE C)

North Fish Creek near Benoit (site C) is the most upstream of the three sampling sites. The altitude of the channel at this site is about 900 ft above sea level. The watershed upstream from the site is predominantly forest, hay, and pasture lands although a small part (less than 10 percent) is row-crop farmland. The low-water sampling and measuring cross section was about 70 ft upstream from a concrete culvert under U.S. Highway 2. Most of the streambed at this cross section is coarse gravel, but some sand, silt, and clay can be found at the edges of the water. The high-flow sampling and measuring cross section was at the culvert entrance. Near-channel vegetation upstream and downstream from the cross section is mostly trees and low brush. The streambed at this cross section was the concrete apron of the culvert entrance. The steep apron and culvert slope (greater than critical slope), caused supercritical and turbulent flow at the sampling cross section. Hence, all sediment was assumed to be transported in suspension.

Sediment Transport

The total-sediment transport at North Fish Creek at site C is represented by two equations in which streamflow is the explanatory variable (fig. 4). A linear equation describes the relation between streamflow and total-sediment discharge if streamflow is less than or equal to 34 ft^3/s. For streamflows greater than 34 ft^3/s, a second-degree polynomial equation describes the relation. Both equations were used to calculate total sediment discharge.

Suspended-sediment concentrations ranged from 3 to 168 mg/L (table 3). Streamflow ranged from 1.5 to 435 ft^3/s (table 3). The daily average streamflow during the study, for which the transport equations were used, ranged from 1.5 to 320 ft^3/s.

Sediment Particle Size

Suspended sediment was predominately silt and clay (particle sizes less than 0.0625 mm). The average composition of silt and clay in 24 samples from site C was 77 percent (table 3). The percentage of particles greater than sand size (0.0625 mm) generally increased with increasing streamflow (table 3). The greatest percentage of sand observed in any suspended-sediment sample was 53 percent on March 14, 1990, at a streamflow of 366 ft^3/s (table 3). Particle-size information on bedload and bed

Table 3. Streamflow and suspended-sediment concentration and particle size at North Fish Creek, site C
[mo-d-yr, month, day, year; ft^3/s, cubic feet per second; mg/L, milligrams per liter; mm, millimeter]

Date (mo-d-yr)	Streamflow (ft^3/s)	Suspended-sediment concentration (mg/L)	Percentage of sediment particles greater than 0.0625 mm diameter	Percentage of sediment particles less than 0.0625 mm diameter
05-25-89	70	49	3	97
09-20-89	2.2	3	11	89
11-08-89	3.5	7	0	100
01-16-90	1.5	7	5	95
03-13-90	133	57	23	77
03-14-90	366	168	53	47
03-14-90	388	135	52	48
03-15-90	235	59	36	64
06-25-90	1.6	5	18	82
09-19-90	11	22	21	79
10-17-90	435	159	34	66
10-18-90	231	69	41	59
10-18-90	153	55	44	56
12-06-90	2.6	12	22	78
03-21-91	121	75	27	73
05-09-91	15	13	34	66
06-19-91	78	43	17	83
06-21-91	189	93	13	87
07-29-91	169	63	35	65
09-03-91	226	59	16	84
09-09-91	134	31	18	82
09-09-91	117	33	23	77
09-10-91	58	21	12	88
10-09-91	5.6	10	0	100

material was not available for site C because they were not sampled.

Sediment Load

Average annual total-sediment load during water years 1990–91 was 479 tons. Annual total-sediment load was 368 tons in water year 1990 and 590 tons in water year 1991 (table 4). The maximum monthly total load was 214 tons in March 1990, and the minimum monthly total load was 2.2 tons in January and February 1990 (table 4, fig. 3C).

Most of the sediment load (about 88 percent) was transported during periods of snowmelt or storm runoff. Consequently, sediment transport was greatest during months of greatest streamflow (table 4 and fig. 3B and 3C). In water year 1990, 85 percent of the annual total-sediment load was transported during March and September (table 4). In water year 1991, 65 percent of the annual total-sediment load occurred during the months of October, March, and September (table 4).

In water year 1990, 272 tons (74 percent) of the annual total-sediment load was silt and clay, or particles finer than 0.0625 mm in diameter; 95.9 tons (26 percent) was sand, or particles coarser than 0.0625 mm in diameter (table 4). In water year 1991, 444 tons (75 percent) of the annual total-sediment

Table 4. Monthly sediment load finer and coarser than 0.0625 millimeter and total-sediment load at North Fish Creek at Benoit, Wis. (site C), water years 1990 and 1991
[mm, millimeter]

Month	Total-sediment load finer than 0.0625 mm (tons)	Total-sediment load coarser than 0.0625 mm (tons)	Total-sediment load (tons)
		Water year 1990	
October 1989	4.2	0.6	4.8
November 1989	3.4	.5	3.9
December 1989	2.0	.3	2.3
January 1990	1.9	.3	2.2
February 1990	1.9	.3	2.2
March 1990	146	67.8	214
April 1990	19.3	3.3	22.6
May 1990	6.5	1.0	7.5
June 1990	2.2	.3	2.5
July 1990	3.4	.5	3.9
August 1990	2.7	.4	3.1
September 1990	78.9	20.6	99.5
Total	272	95.9	368
		Water year 1991	
October 1990	118	59.8	178
November 1990	4.6	.6	5.2
December 1990	3.4	.5	3.9
January 1991	3.4	.5	3.9
February 1991	3.4	.5	3.9
March 1991	76.9	20.9	97.8
April 1991	21.6	3.5	25.1
May 1991	25.7	5.8	31.5
June 1991	37.9	9.7	47.6
July 1991	58.9	16.6	75.5
August 1991	7.5	1.1	8.6
September 1991	82.9	26.1	109
Total	444	146	590

load was silt and clay, and 146 tons (25 percent) was sand (table 4). Therefore, the percentage of sand load was constant even though the total load in water year 1991 was almost twice that in water year 1990.

NORTH FISH CREEK NEAR MOQUAH (SITE B)

North Fish Creek near Moquah (site B) is the middle sampling site (fig. 1). The altitude of the channel at this site is about 670 ft above sea level. The cross section for low- and high-water sampling and measuring is at the upstream side of the bridge at Old Highway 2 and approximately 75 ft downstream from the confluence of North Fish Creek with Pine Creek. Most of the streambed at the cross section is composed of fine to medium sand and small gravel. About 10 ft of the streambed along the left side of the base-flow channel is predominately boulders. The

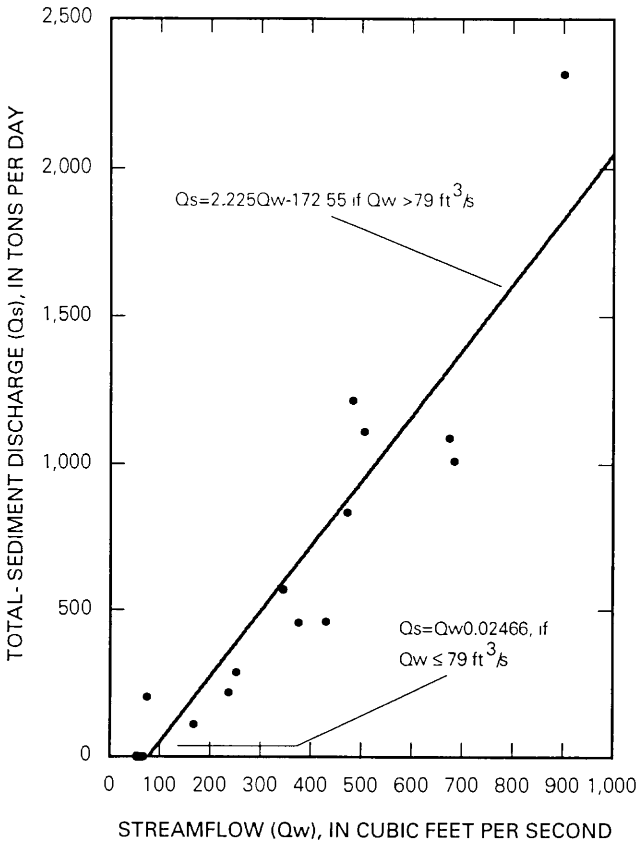

Figure 5. Relation of total-sediment discharge to streamflow at North Fish Creek, site B.

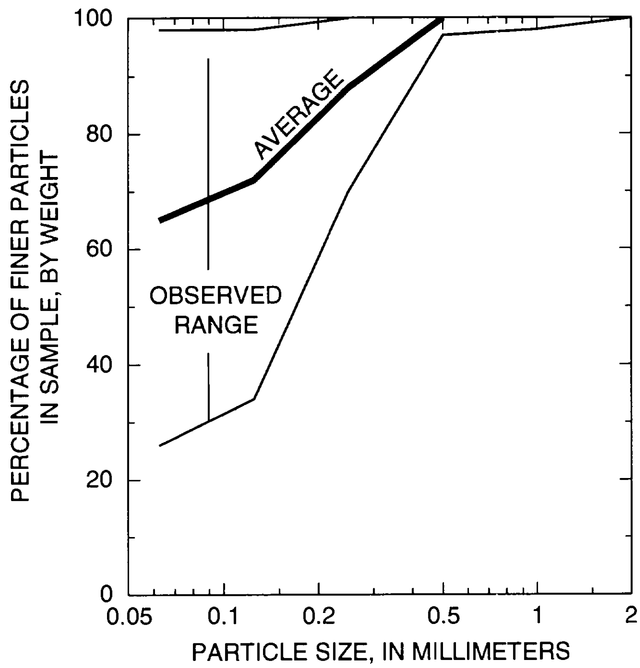

Figure 6. Cumulative frequency distribution of average particle size and range of particle size in 20 suspended-sediment samples from North Fish Creek near Moquah, site B, September 1989 through October 1991.

channel was about 35 ft wide at low flow and about 40 ft wide during the highest flow observed during water years 1990–91. Most of the near-channel vegetation upstream and downstream from the cross section is trees and low brush.

Sediment Transport

The total-sediment transport in North Fish Creek at site B is represented by two equations in which streamflow is the explanatory variable (fig. 5). Both of the equations describe linear relations; the first equation applies to streamflow less than or equal to 79 ft^3/s, whereas the second equation applies to streamflows greater than 79 ft^3/s. The equations are based on total-sediment discharges that were calculated by use of the modified Einstein procedure from data collected at streamflows ranging from 53 to 901 ft^3/s (table 5). Suspended-sediment concentrations ranged from 4 to 840 mg/L (table 5). The daily average streamflow for which the transport equations were used ranged from 48 to 696 ft^3/s.

Sediment Particle Size

On the average, most suspended sediment at site B was silt and clay (particles smaller than 0.0625 mm). The silt and clay fractions of 20 suspended-sediment samples ranged from 26 to 98 percent and averaged 65 percent, as shown in figure 6. The percentage silt and clay did not show a general trend with discharge as was the case from site C. The diameter of the largest particles was 0.5 mm in all but two of the samples.

The particle sizes of surface bed material from 20 samples ranged from 0.0625 to 32 mm (fig. 7). The material in the left 10 ft of the channel bed was composed of particles greater than 32 mm in diameter, including boulders estimated at 10 to 30 cm in diameter that did not fit in the sampler. Hence, these large particles are not represented in the curves in figure 7.

The particle sizes of materials collected with the Helley-Smith bedload samplers were fairly uni-

Table 5. Streamflow and suspended-sediment concentration and particle size at North Fish Creek, site B
[mo-d-yr, month, day, year; ft^3/s, cubic feet per second; mg/L, milligrams per liter; mm, millimeter]

Date (mo-d-yr)	Streamflow (ft^3/s)	Suspended-sediment concentration (mg/L)	Percentage of sediment particles greater than 0.0625 mm diameter	Percentage of sediment particles less than 0.0625 mm diameter
05-25-89	192	252	50	50
09-20-89	56	11	2	98
11-08-89	6.0	7	14	86
01-09-90	53	16	30	70
03-13-90	236	220	37	63
03-13-90	472	422	40	60
03-14-90	674	539	39	61
03-14-90	684	488	44	56
03-15-90	901	788	46	54
06-26-90	55	9	6	94
09-18-90	67	8	14	86
10-18-90	375	350	59	41
12-06-90	54	4	20	80
03-21-91	345	403	34	66
06-19-91	167	183	48	52
06-21-91	506	468	36	64
07-29-91	430	299	53	47
09-03-91	482	840	53	47
09-09-91	252	237	74	26
10-09-91	63	8	12	88

form. About 90 percent of bedload particles ranged from 0.125 to 1 mm in diameter, as is shown in figure 8.

Sediment Load

Total annual sediment load at site B was 11,960 tons in water year 1990 and 18,430 tons in water year 1991 (table 6). About 97 percent of the total-sediment load during water years 1990 and 1991 was transported during periods of snowmelt and storm runoff. The maximum monthly total load was 5,000 tons in March 1990, and the minimum monthly total load was 40 tons in November and December 1989; January, February, and June 1990; and January and August 1991 (table 6 and fig. 3C).

About 60 percent of the annual total-sediment load was sand or particles coarser than 0.0625 mm in both water years. In water year 1990, 7,200 tons of the annual total load was sand; in water year 1991, 11,030 tons was sand (table 6). As at site C, percentage of sand load was constant even though the total load in 1991 was 1.5 times greater than in water year 1990.

NORTH FISH CREEK NEAR ASHLAND (SITE A)

North Fish Creek near Ashland (site A) is the most downstream of the three sampling sites (fig. 1). The altitude of the channel at this site is about 615 ft above sea level. The cross section where low- and high-water sampling and measuring was done was at the downstream side of the U.S. Highway 2 bridge. The channel width ranged from 52 ft at the smallest streamflow to 107 ft at the largest streamflow

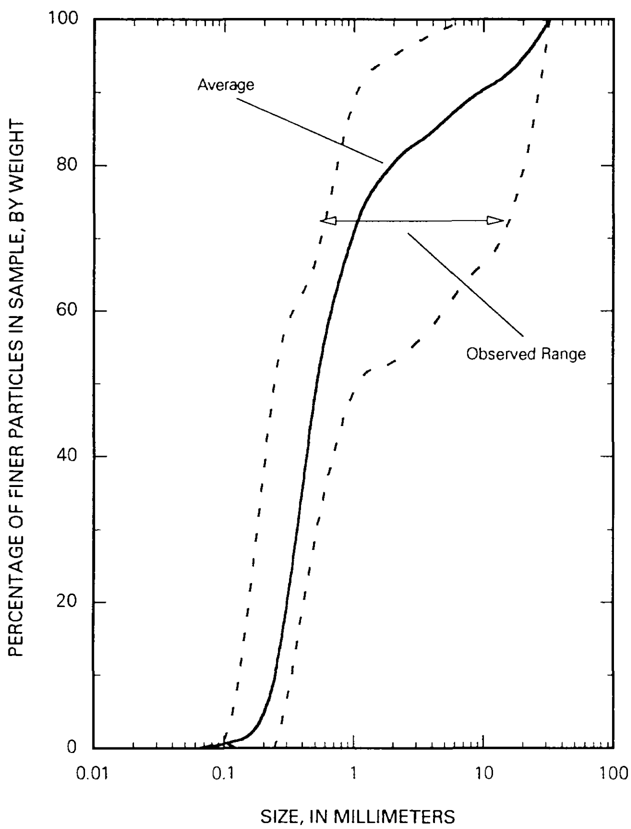

Figure 7. Cumulative frequency distribution of average particle size and range of particle sizes in surface bed-material samples from North Fish Creek, site B.

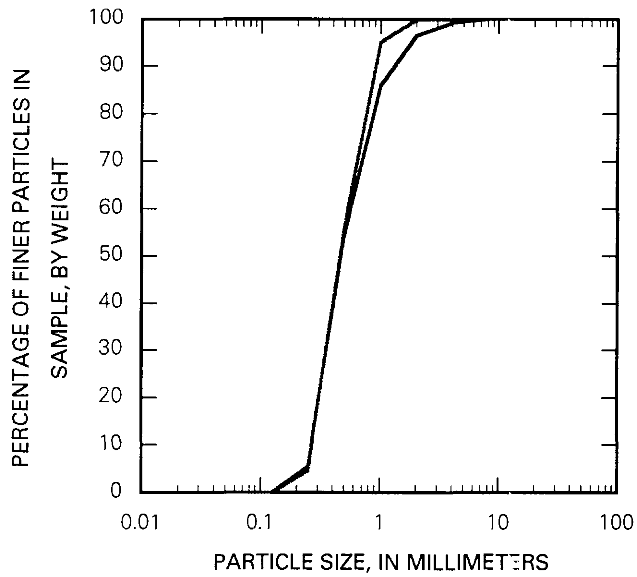

Figure 8. Cumulative frequency distribution of particle sizes of two Helley-Smith bedload samples from North Fish Creek, site B.

observed. Most of the streambed consisted of sand, but the right edge of the channel bed was silty.

The near-channel vegetation upstream and downstream from the sampling section consists of large trees and low brush. The channel banks, which are only about 2 ft higher than the water surface at base flow, are overtopped during high flows.

Sediment Transport

The total-sediment transport in North Fish Creek at site A is represented by two equations in which streamflow is the explanatory variable (fig. 9). Both of the equations describe linear relations; one equation applies to streamflow less than or equal to 80 ft^3/s; the other applies to streamflow greater then 80 ft^3/s. The equations are based on total-sediment discharges that were calculated by use of the modified Einstein procedure from data that were collected at streamflows ranging from 76 to 1,090 ft^3/s (table 7). Suspended-sediment concentrations ranged from 6 to 733 mg/L (table 7). The daily average flows for which the equations were used ranged from 75 to 880 ft^3/s (fig. 9).

Sediment Particle Size

On the average, suspended sediment at site A was about evenly split between silt and clay (particles smaller than 0.0625 mm) and sand-size particles. The silt and clay fractions of 20 samples ranged from 16 to 95 percent and averaged 53 percent as shown in figure 10. The percentage silt and clay did not show a trend related to streamflow (table 7). The largest particles were 0.5 mm in all but four of the samples and no particles were greater than 1 mm.

The surface bed material was fairly uniform in size. The particle sizes of 20 samples ranged from 0.0625 to 4 mm (fig. 11). About 70 percent of the material ranged between 0.3 and 1.0 mm.

The Helley-Smith bedload samples were of fairly uniform particle size. About 90 percent of bedload particles ranged from 0.125 to 1 mm, as shown in figure 12.

Table 6. Monthly sediment load finer and coarser than 0.0625 millimeter and total-sediment load at North Fish Creek near Moquah, Wis. (site B), water years 1990 and 1991
[mm, millimeter]

Month	Total-sediment load finer than 0.0625 mm (tons)	Total-sediment load coarser than 0.0625 mm (tons)	Total-sediment load (tons)
	Water year 1990		
October 1989	20	30	50
November 1989	20	20	40
December 1989	20	20	40
January 1990	20	20	40
February 1990	20	20	40
March 1990	2,000	3,000	5,000
April 1990	500	700	1,200
May 1990	40	70	110
June 1990	20	20	40
July 1990	200	400	600
August 1990	200	300	500
September 1990	1,700	2,600	4,300
Total	4,760	7,200	11,960
	Water year 1991		
October 1990	1,100	1,700	2,800
November 1990	20	30	50
December 1990	20	30	50
January 1991	20	20	40
February 1991	20	30	50
March 1991	1,500	2,200	3,700
April 1991	600	1,000	1,600
May 1991	700	1,000	1,700
June 1991	800	1,200	2,000
July 1991	1,200	1,800	3,000
August 1991	20	20	40
September 1991	1,400	2,000	3,400
Total	7,400	11,030	18,430

Sediment Load

Total annual sediment load at site A was 20,690 tons in water year 1990 and 33,100 tons in water year 1991 (table 8). About 86 percent of the total-sediment load during water years 1990–91 was transported during periods of snowmelt and storm runoff. The maximum monthly total load was 6,050 tons in March 1990, and the minimum monthly total load was 310 tons in February 1990 (table 8, fig. 3C).

About 67 percent of the annual total-sediment load was sand or particles coarser than 0.0625 mm. In water year 1990, 13,910 tons of the annual total load was sand; in water year 1991, 22,240 tons was sand (table 8).

Table 7. Streamflow and suspended-sediment concentration and particle size at North Fish Creek, site A

[mo-d-yr, month, day, year; ft^3/s, cubic feet per second; mg/L, milligrams per liter; mm, millimeter]

Date (mo-d-yr)	Streamflow (ft^3/s)	Suspended-sediment concentration (mg/L)	Percentage of sediment particles greater than 0.0625 mm diameter	Percentage of sediment particles less than 0.0625 mm diameter
05-25-89	312	474	34	66
09-20-89	78	13	34	66
11-08-89	87	14	36	64
01-16-90	76	124	82	18
03-13-90	349	199	56	44
03-13-90	349	274	66	34
03-14-90	703	465	73	27
03-15-90	699	306	74	26
06-26-90	89	38	64	36
09-19-90	96	50	6	94
10-18-90	1,090	271	58	42
10-18-90	725	244	53	47
12-06-90	79	6	17	83
03-21-91	323	436	39	61
05-09-91	120	24	20	80
06-19-91	521	336	40	60
06-21-91	381	331	31	69
07-29-91	598	233	41	59
09-03-91	708	733	24	76
09-09-91	341	110	40	60
10-09-91	96	63	84	16

COMPARISON OF LOADS AT SITES A, B, AND C

There was little relation between watershed area and average annual loads at the three sites for water years 1990 and 1991. Almost half (41 percent) of the watershed above site A is above site C, but total load at site C was only 2 percent of the total load at site A. Silt and clay, and sand loads at site C were 4 percent and 1 percent of the loads at site A.

Forty percent of the watershed above site A is between sites B and C. However, 54 percent of the total load, 64 percent of the silt and clay load, and 49 percent of the sand load were derived from this part of the watershed at site A. About 3 percent of the total sediment load transported passed site B is from the watershed above site C.

The watershed between sites A and B, which is only 19 percent of the watershed above site A, yielded 44 percent of the average annual total load at site A. The watershed between sites A and B yielded 32 percent of the silt and clay load and 50 percent of the sand load at site A.

SUMMARY

North Fish Creek is underused as a trout and salmon hatchery despite its excellent water quality. The shifting-sand streambed in the lower 9 mi of the stream inhibits successful spawning and is a poor habitat for macroinvertebrates, the primary food for juvenile trout and salmon. To provide data necessary for evaluation of potential sand-loading-control practices, the USGS determined total-sediment

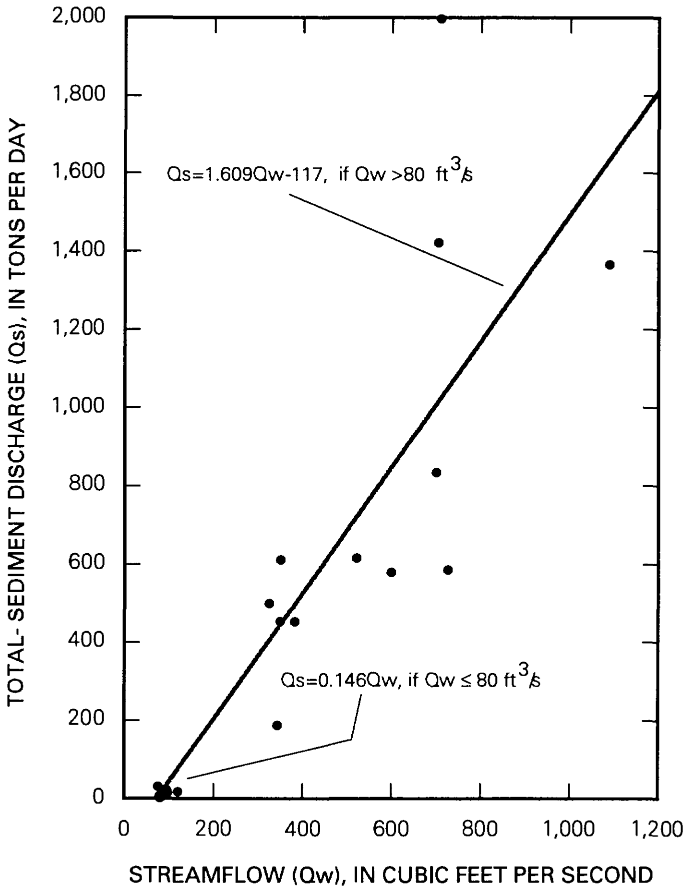

Figure 9. Relation of total-sediment discharge to streamflow at North Fish Creek, site A.

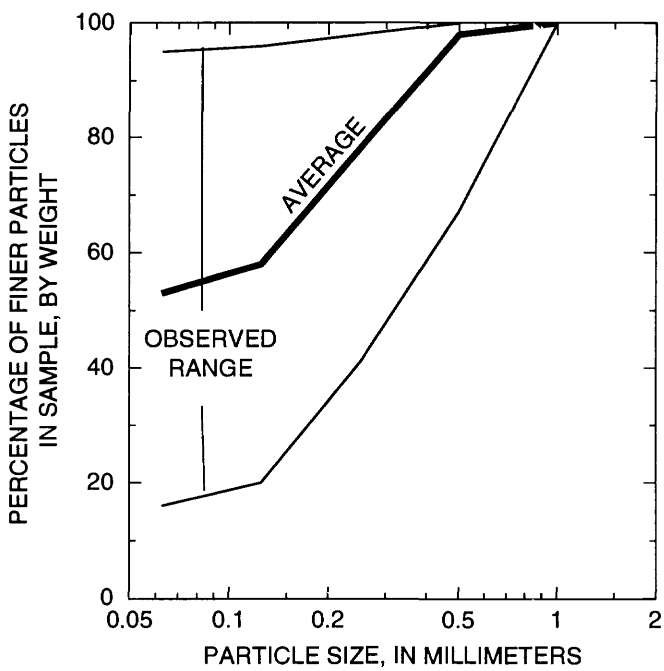

Figure 10. Cumulative frequency distribution of average particle size and range of particle size in 20 suspended-sediment samples from North Fish Creek near Ashland, site A, September 1989 through October 1991.

transport, particle sizes, and loads for three sites on North Fish Creek during water years 1990–91.

Annual average streamflow, as indicated by flow in the Bois Brule River, was about 16 percent below average in water year 1990 and about 4 percent above average in water year 1991. Annual peak flow was less than the 2-year-recurrence-interval flow during both years.

Owing to the high flow velocity at the sampling section at site C, all sediment was transported as suspended sediment. Suspended-sediment concentrations ranged from 3 to 168 mg/L. The average composition of silt and clay in 24 suspended-sediment samples was 77 percent. The average annual sediment load for water years 1990 and 1991 was 479 tons. About 88 percent of the load was transported during periods of snowmelt or storm runoff. About 75 percent of the sediment load was silt- and clay-size particles; the remainder was sand.

Total-sediment discharge was calculated by use of the modified Einstein procedure to determine the relation of total-sediment transport and streamflow for site B. Data collected at streamflows ranging from 53 to 901 ft^3/s and suspended-sediment concentrations ranging from 4 to 840 mg/L were used in the calculations. On the average, silt and clay composition of 20 suspended-sediment samples was 65 percent. Bed-material particle size ranged from 0.0625 to 32 mm. Annual total-sediment load was 11,960 tons in water year 1990 and 18,430 tons in water year 1991. About 97 percent of the total load was transported during periods of snowmelt and storm runoff. About 60 percent of the total-sediment load was sand-size particles.

Relation of total-sediment transport and streamflow for site A were determined from total-sediment discharges calculated by use of the modified Einstein procedure. Data collected at streamflows ranging from 76 to 1,090 ft^3/s and suspended-sediment concentrations ranging from 6 to 733 mg/L were used in the calculations. The average silt and clay composition of 20 suspended-sediment samples

Table 8. Monthly sediment load finer and coarser than 0.0625 millimeter and total-sediment load at North Fish Creek near Ashland, Wis. (site A), water years 1990 and 1991
[mm, millimeter]

Month	Total-sediment load finer than 0.0625 mm (tons)	Total-sediment load coarser than 0.0625 mm (tons)	Total-sediment load (tons)
	Water year 1990		
October 1989	170	340	510
November 1989	120	250	370
December 1989	110	240	350
January 1990	120	240	360
February 1990	100	210	310
March 1990	1,980	4,070	6,050
April 1990	830	1,690	2,520
May 1990	400	820	1,220
June 1990	260	540	800
July 1990	560	1,140	1,700
August 1990	380	780	1,160
September 1990	1,750	3,590	5,340
Total	6,780	13,910	20,690
	Water year 1991		
October 1990	1,430	2,940	4,370
November 1990	120	260	380
December 1990	130	260	390
January 1991	110	230	340
February 1991	140	290	430
March 1991	1,870	3,820	5,690
April 1991	1,150	2,530	3,500
May 1991	950	1,950	2,900
June 1991	1,270	2,600	3,870
July 1991	1,690	3,470	5,160
August 1991	290	580	870
September 1991	1,710	3,490	5,200
Total	10,860	22,240	33,100

was 54 percent. Particle size of most (70 percent) of bed material ranged from 0.3 to 1.0 mm. Annual total-sediment loads were 20,690 tons and 33,100 tons in water years 1990 and 1991, respectively. About 67 percent of the total-sediment load was sand-size particles.

There was little relation between watershed area and sediment loads for the three sites. The watershed of site C is about 41 percent of that above site A, but the sand load at site C was only 1 percent of that at site A. The watershed area between sites B and C is 40 percent of that above site A, but this area yielded 49 percent of the sand load at site A. Twelve percent of the watershed above site A is between sites A and B, yet this area yielded about 50 percent of the sand load at site A.

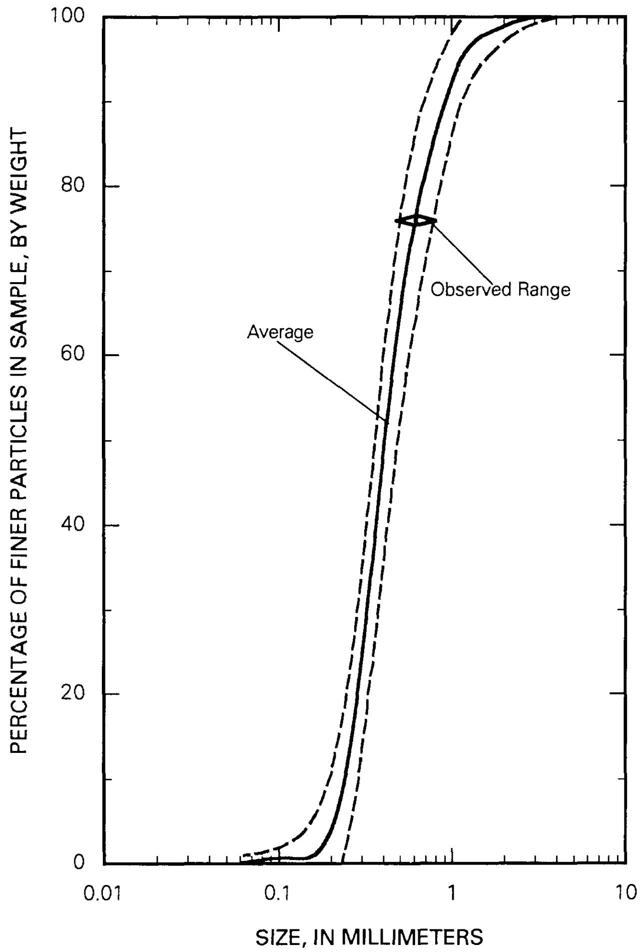

Figure 11. Cumulative frequency distribution of average particle size and range of particle sizes in surface bed-material samples from North Fish Creek, site A.

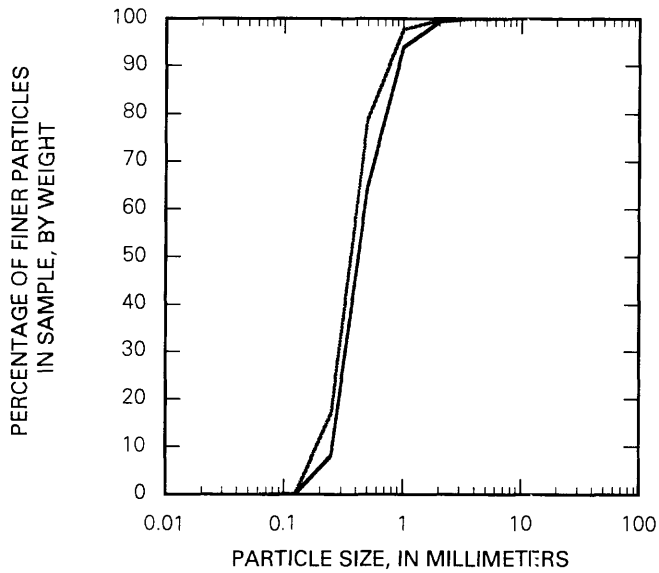

Figure 12. Cumulative frequency distribution of particle sizes of two Helley-Smith bedload samples from North Fish Creek, site A.

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.

Edwards, T.K., and Glysson, G.D., 1988, Field methods for measurement of fluvial sediment: U.S. Geological Survey Open-File Report 86-531, 118 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, chap. C1, 58 p.

Hansen, E.A., Alexander, G.R., and Dunn, W.H., 1983, Sand sediment in a Michigan trout stream—part I, a technique for removing sand bedload from streams: North American Journal of Fisheries Management, v. 3, p. 355-364.

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.

Hole, F.D., 1976, Soils of Wisconsin: Madison, University of Wisconsin Press, 223 p.

Krug, W.R., Conger, D.H., and Gebert, W. A., 1992, Flood-frequency characteristics of Wisconsin streams: U.S. Geological Survey Water-Resources Investigations Report 91-4128, 185 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 85-4027, 14 p.

White, K.E., and Sloto, R.A., 1990, Baseflow-flow-frequency characteristics of selected Pennsylvania streams: U.S. Geological Survey Water-Resources Investigations Report 90-4160, 67 p., 1 pl.

Young, H.L., and Skinner, E.L., 1974, Water resources of Wisconsin Lake Superior basin: U.S. Geological Survey Hydrologic Investigation Atlas HA-524, 3 sheets, scale 1:1,000,000.