Characteristics, Transport, and Yield of Sediment in Juday Creek, St. Joseph County, Indiana, 1993–94

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CONTENTS

FIGURES

CONTENTS

FIGURES—CONTINUED

TABLES

CONVERSION FACTORS AND ABBREVIATIONS

Multiply	By	To Obtain
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
inch (in.)	25.4	millimeter
mile (mi)	1.609	kilometer
pound (lb)	454	grams
pound per cubic foot (lb/ft^3)	16.02	kilogram per cubic meter
pound per day (lb/d)	0.4536	kilogram per day
square foot (ft^2)	0.09290	square meter
square mile (mi^2)	2.590	square kilometer
ton, short	0.9072	megagram
ton per acre per year (ton/acre/yr)	2.242	megagram per hectare per year
ton per day (ton/d)	0.9072	megagram per day
ton per square mile (ton/mi^2)	0.3503	megagram per square kilometer
ton per square mile per day ($ton/mi^2/d$)	0.3503	megagram per square kilometer per day

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 the United States and Canada, formerly called Sea Level Datum of 1929.

The following abbreviations are used in this report:

Abbreviation	Description
g	gram
mg/L	milligram per liter
mm	millimeter
EWI	equal width increment

Characteristics, Transport, and Yield of Sediment in Juday Creek, St. Joseph County, Indiana, 1993–94

By Kathleen K. Fowler *and* John T. Wilson

Abstract

Juday Creek is a tributary of the St. Joseph River in St. Joseph County, north-central Indiana. The creek has been identified as one of the few streams in the State that can support a naturally reproducing brown trout population. A recent study of benthic invertebrates shows a decline in the production rate of insect species and suggests that this decline may be caused by increased sedimentation. This report presents the results of a study of the sediment conditions in Juday Creek from April 1993 through June 1994. Measurements of streamflow, suspended sediment, and bedload were made at six sampling sites during three storms and a period of low flow. A total of 11 samples were collected during storms, and 1 sample was collected during low flow at each site. Bed-material samples were collected at the six sites. Sediment cores were collected from the delta of an instream pond and at a sediment trap near the mouth of the stream. Scour and fill at the six sites were monitored by means of scour chains and surveyed cross sections. The instream pond was surveyed twice, and the volume weight of the sediment was determined to estimate the yield of sediment for the upper reach of Juday Creek.

Particle-size distributions indicate that the bed material is predominantly sand and gravel and that very little of the bed material is silt or finer (less than 0.062 millimeter). Analysis of sediment cores showed that most of the sediment deposited in the sediment trap and instream pond was sand.

Sediment sampling during a period of low flow detected only minimal concentrations of suspended sediment; the maximum concentration was 6 milligrams per liter, equivalent to a daily load of 0.32 ton. Bedload ranged from 5.2 to 76.7 grams per cross-channel sampling, equivalent to 0.11 to 1.70 tons per day.

Sediment sampling during the storms indicates that bedload discharge is the primary mode of sediment transport. Suspended-sediment concentration ranged from 4 to 67 milligrams per liter; the median was 17 milligrams per liter. Bedload ranged from 3.4 to 862 grams per cross-channel sampling; the median was 109 grams. Only 15 percent of the samples were less than 50 grams.

Scour chains and surveyed cross sections documented some scour and fill at most of the sites. Scour and fill tended to balance out; after a 1-year period, the net change in the streambed altitude was minimal. Some infilling was the net result at most of the sites.

Surveys of the instream pond determined that the volume of sediment delivered to the pond from April 1993 to April 1994 was approximately 26,500 cubic feet. The average volume weight of the sediment was determined to be 102 pounds per cubic foot. The sediment yield for the upper reach of Juday Creek from April 1993 to April 1994 was estimated to be 48 tons per square mile.

INTRODUCTION

Many small streams in the upper Midwest are known for cool temperatures, gravel beds, and clear water—conditions favorable for trout. In contrast, streams in the lower Midwest have higher temperatures, greater amounts of sediment, and tend to have fish populations with greater tolerance to these conditions. Juday Creek in northern Indiana is one of the few streams in the State that can support a naturally reproducing brown trout (*Salmo trutta*) population (U.S. Army Corps of Engineers, 1986). Trout depend on the stream substrate not only for food (macroscopic organisms), but also for spawning areas (streambed gravels).

Currently, the extent of the brown trout population in Juday Creek is unknown. According to a recent study of benthic invertebrates, however, the production rates of insect species in the stream have significantly declined since 1981–82 (Kohlhepp, 1991). An increase in sedimentation is a possible cause of this decline, but data on sediment conditions in Juday Creek have not been collected prior to 1992 (Runde, 1994). Suspended-sediment characteristics in other streams in Indiana were compiled by Crawford and Mansue in 1988 and at Trail Creek in northern Indiana (Crawford and Jacques, 1992). Bedload was not measured in either study.

This report documents the sediment conditions in Juday Creek and is the result of a study by the U.S. Geological Survey (USGS) in cooperation with the Indiana Department of Natural Resources (IDNR), Division of Water, and the St. Joseph County Drainage Board.

Purpose and Scope

The purpose of this report is to describe the sediment conditions in Juday Creek during April 1993 through June 1994. Sediment characteristics, transport, and yield were determined by evaluating sediment movement during three runoff events and during low-flow conditions, analyzing streambed material, surveying channel and pond cross-sections, and collecting sediment cores during 1993–94. Information on sediment conditions is beneficial in management decisions by State and local officials concerned with flood control, water-quality management, and fish and wildlife preservation.

Six measurement and sampling sites were selected along Juday Creek (fig. 1). Sediment characteristics were determined from bed-material analyses and sediment cores. Sediment transport was determined from measurements of streamflow, suspended-sediment concentration, and bedload during three periods of runoff and during low-flow conditions. Scour chains and cross-section surveys were used to indicate areas of scour and fill. Channel cross sections at each site were surveyed five times during the course of the study. These cross sections were compared, and changes in channel geometry were evaluated.

Sediment yield was estimated for a reach of Juday Creek just upstream from an area that had been identified as an area of substantial sediment deposition. This area was the delta of an instream pond near site 3 (fig. 1). Cross sections within this area of deposition were surveyed at the beginning and end of the study. Changes in altitude of the pond bottom were used to calculate the volume of sediment deposited. The bulk density, or volume weight, of the accumulated sediment was estimated from sediment samples collected at the pond delta. The change in volume of sediment and average volume weight were used to calculate the load of sediment deposited during a 1-year period.

Physical Setting

Juday Creek is in St. Joseph County in the north-central part of the State. It is tributary to the St. Joseph River and drains approximately 37.7 mi^2 (Hoggatt, 1975). Land use in the area is diverse. Approximately 25 percent of the basin is agricultural, 60 percent residential, and 15 percent commercial (St. Joseph River Basin Commission, 1994). Normal precipitation in the area is about 39 in/yr (National Oceanic and Atmospheric Administration, 1993b).

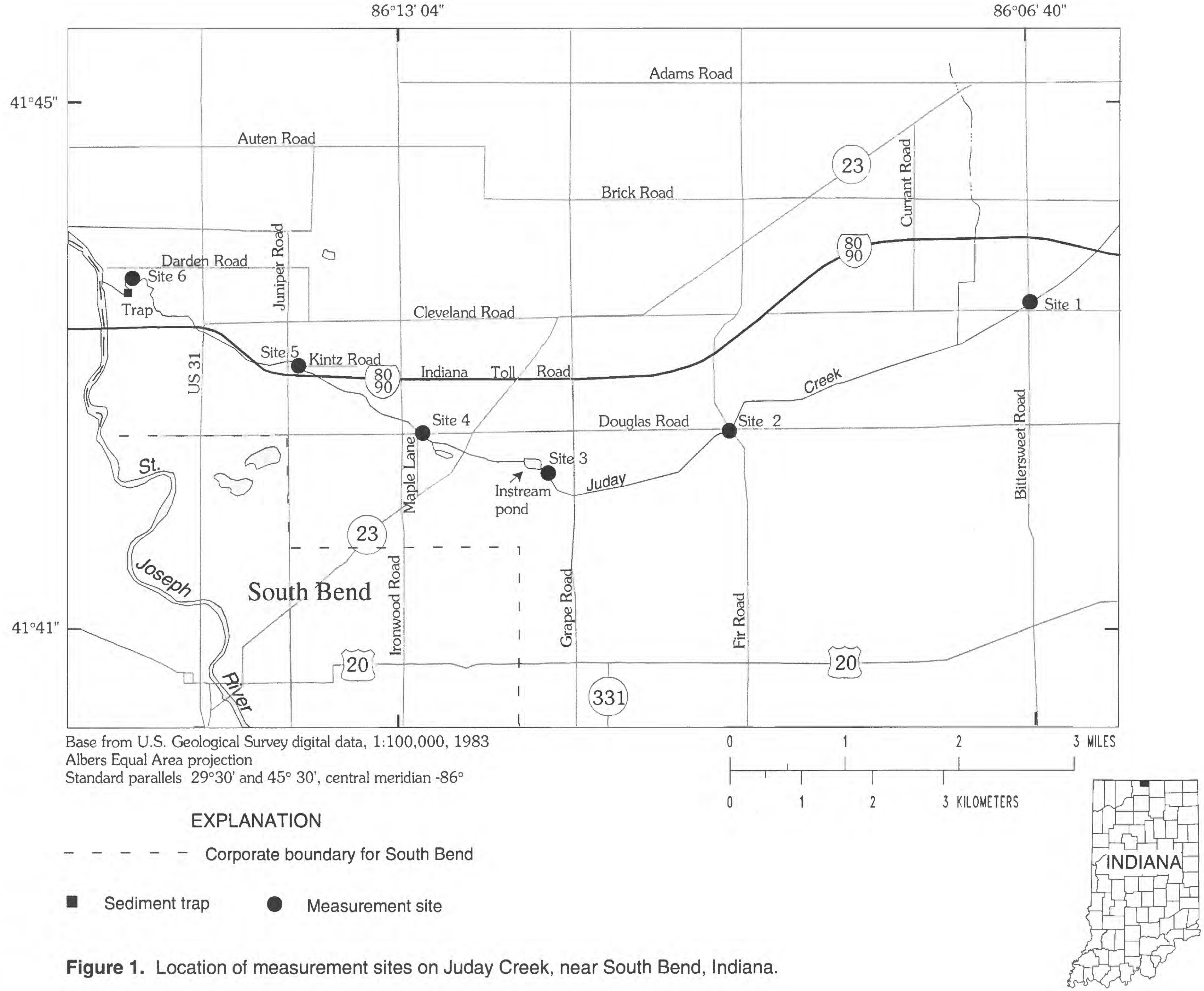


Figure 1. Location of measurement sites on Juday Creek, near South Bend, Indiana.

The Juday Creek Basin is part of the Kankakee Outwash and Lacustrine Plain, which is included in the Northern Moraine and Lake Physiographic Region (Malott, 1922, p. 112). Land-surface altitudes range from 700 ft near the St. Joseph River to 865 ft close to the Michigan border. The Juday Creek Basin is in an area of thick, highly permeable glacial deposits. Much of the area is covered by fine-grained alluvium and underlain by thick outwash sand and gravel. The sand and gravel was deposited by glacial meltwaters at several different times during the late Wisconsin glaciation (Schneider, 1966, p. 42, 52). Sand, transported by the wind and formed into dunes, overlies outwash in some areas. Unconsolidated deposits are typically about 150–200 ft thick (Fowler, 1994, p. 28).

Two general soil types predominate in the basin. Toward the west, the soils are deep, nearly level to sloping, well-drained, coarse- to moderately coarse-textured soils on outwash plains and terraces. In the east, the soils are deep, nearly level, poorly drained, and medium to coarse textured on outwash plains (Benton and others, 1977). Average annual soil loss for these types of soil associations is typically low, ranging from 0 to 4.9 (ton/acre)/yr (Brentlinger and others, 1979, p. 9).

Streamflow in Juday Creek steadily increases from the most upstream site to the instream pond and then declines downstream. This pattern shows that Juday Creek has a gaining reach upstream and a losing reach downstream as noted by Silliman (1994). The upstream reach is affected by the inflow of ground water, whereas the downstream reach loses flow to ground water (Arihood, 1994).

Continuous streamflow records for Juday Creek are available for 1993–94 (Stewart and others, 1994, p. 217; 1995, p. 209). Daily mean flows during this period range from 11.0 to 163 ft^3/s. The instantaneous peak flow for the period of record is 226 ft^3/s on June 9, 1993. The mean annual flow is 23.8 ft^3/s; 80 percent of the time, flow is between 13 and 36 ft^3/s. Figure 2 shows the streamflow at the gaged site (site 6 on figure 1) during the study period and the daily precipitation recorded by the National Weather Service (National Oceanic and Atmospheric Administration, 1993a, 1994).

Methods of Investigations

Site Selection

Selection of the six measurement sites along Juday Creek was based on land-use changes, site accessibility, and basin coverage. Table 1 describes the location, drainage area, altitude, and land use of the sites. The approximate altitudes of the sites are estimates of channel altitudes based on USGS topographic maps with 5-ft contour intervals.

Site 1, the most upstream location, is northwest of the intersection of Bittersweet and Cleveland Roads (fig. 1) and is in an active agricultural area. The stream flows in a ditch approximately 10 ft deep. Channel banks at the measurement site are covered with thick grasses and some overhanging willow trees. Downstream from site 1, Juday Creek passes through more agricultural areas and eventually through a golf course and some residential areas.

Site 2 is near the intersection of Douglas and Fir Roads; the banks are grassy and somewhat undercut. As the stream flows between sites 2 and 3, it passes through residential and agricultural areas and into the Grape Road commercial development area (near the intersection of Grape Road and Douglas Road). Previously an agricultural zone, this area recently has been converted to a commercial and business area.

Site 3 is just upstream from the point where Juday Creek flows through a pond of approximately 6 acres (fig. 1). This pond is referred to hereafter as the "instream pond." The stream widens in this area from approximately 15 ft at site 2 to 25 ft at site 3, and the banks are somewhat more undercut and

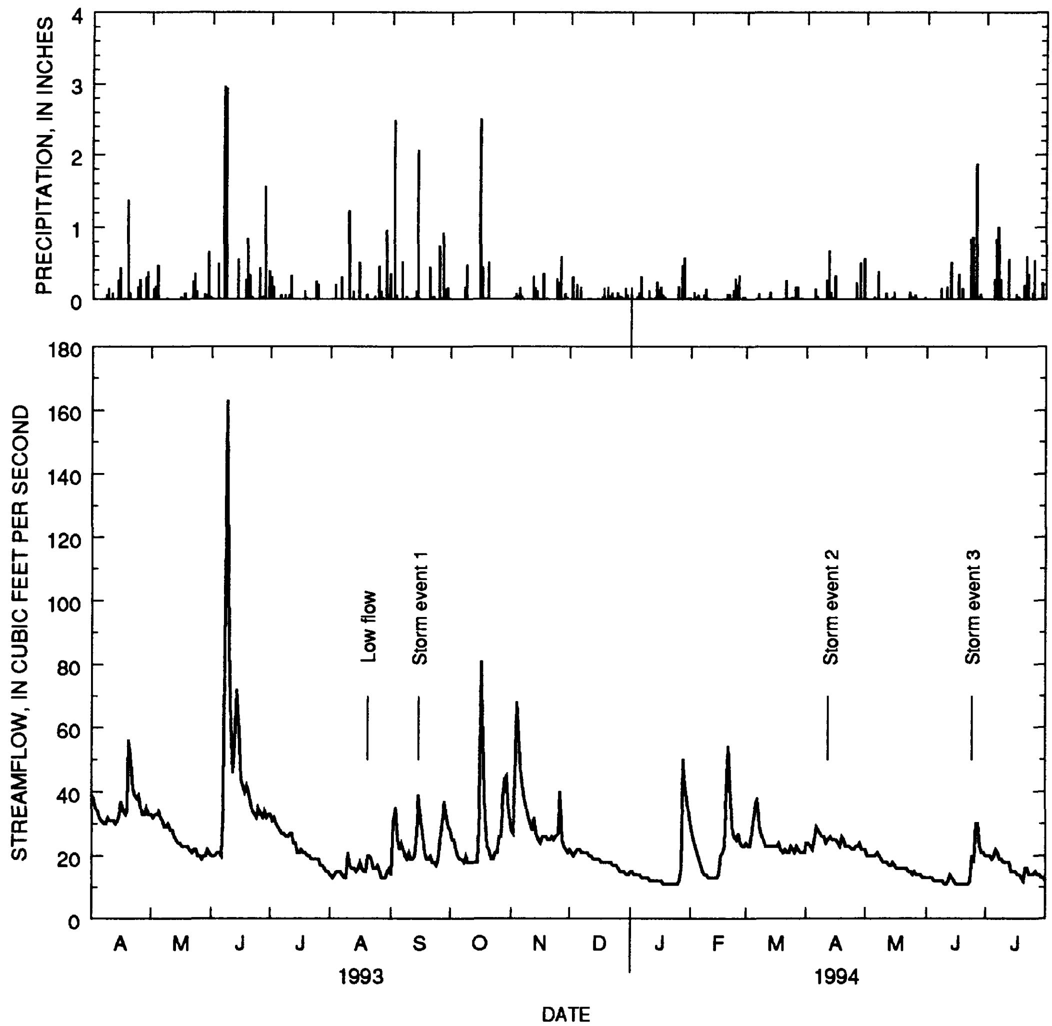


Figure 2. Hydrograph for Juday Creek near South Bend, Indiana (04101370), during the study period with approximate sampling times and the precipitation record for South Bend (National Oceanic and Atmospheric Administration, 1993a-94).

Table 1. Drainage area, altitude, and land use for the six measuring sites on Juday Creek, near South Bend, Indiana
[mi^2, square miles]

Site number	Latitude	Longitude	Drainage area (mi^2)	Approximate altitude in feet above sea level	Land use
Site 1	41°43′31″	86°06′38″	7.00	761[1]	Agricultural
Site 2	41°42′34″	86°09′38″	23.4	742[2]	Agricultural, residential
Site 3	41°42′18″	86°11′36″	27.9	732[2]	Residential, commercial
Site 4	41°42′33″	86°12′48″	29.2	728[2]	Residential, park
Site 5	41°43′04″	86°14′04″	31.1	715[2]	Residential
Site 6	41°43′43″	86°15′47″	37.6	678[3]	Park, residential, commercial

[1]Osceola Quadrangle, 5-ft contour interval, scale 1:24000.
[2]South Bend East Quadrangle, 5-ft contour interval, scale 1:24000.
[3]South Bend West Quadrangle, 5-ft contour interval, scale 1:24000.

slumped. The instream pond through which Juday Creek flows originated as a borrow pit to supply construction material for the Indiana Toll Road during the late 1940's or early 1950's (Rebecca Moffett-Carey, Michiana Area Council of Governments, oral commun., 1994). As the stream enters the pond, velocities generally are reduced and much of the sediment in transport is dropped. Through time, a delta has formed at the inlet.

Between sites 3 and 4, Juday Creek flows through mainly residential areas and wetlands. Site 4 is near the intersection of Douglas Road and Maple Lane. Upstream from the Douglas Road bridge is a wetland area with grassy banks and overhanging willow trees. Downstream from site 4, the stream flows through residential areas to Ironwood Road. From Ironwood Road to site 5, the stream passes near a gravel quarry and open areas (some planned for development) before passing more residential areas.

Site 5 is near Kintz Road and its intersection with Juniper Road. Downstream from the measuring site are low stone dams constructed by homeowners. These dams pool the water locally for aesthetic purposes and small withdrawals. The channel gradient begins to increase as Juday Creek nears site 6 and the St. Joseph River. The approximate channel gradient upstream from site 5 is 6.3 ft/mi; between site 5 and site 6, the gradient increases to 18.2 ft/mi. Between the two most downstream sites, the stream flows through residential, commercial, and forest land.

Site 6 is within the Izaak Walton League property, which is between Darden Road and the Indiana Toll Road and bordered to the west by the St. Joseph River (fig. 1). The USGS operates a continuous-record stream gage and an observer-maintained rain gage at this site. Downstream from the gaging station is a sediment trap constructed to protect the lower reach of the stream from excessive sediment deposition. During 1981–87, 486 ft^3 of sediment were removed from the trap every 1.5–2 years (Kohlhepp, 1991). In 1988, annual dredging was required. In 1990, the trap filled in 4 months. During this study (1993–94), the trap remained full.

Measurements

Streamflow measurements were made at each measurement site during three storms and once during a period of low flow. Either a Price velocity meter, type AA, or a Price pygmy meter was used depending on water depth (the pygmy meter is used for depths up to 1.5 ft and the AA meter for greater depths) (Rantz and others, 1982, p. 84, 145).

Suspended-sediment samples were collected with a depth-integrating, hand-held sampler (US DH–48) which collects sediment and water in 1-pint glass bottles (Guy and Norman, 1970). This depth-integrating sampler collects a velocity-weighted sample as it is lowered to the streambed and raised to the surface (Edwards and Glysson, 1988, p. 7, 10). By use of equal width increments (EWI) and equal transit rates, samples were collected at 10 to 20 cross-channel sampling stations. Samples were composited at the USGS sediment laboratory in Louisville, Ky., to a single discharge-weighted sample for each measurement. Samples were analyzed for total sediment in grams, concentration of suspended sediment in milligrams per liter, and a determination of the sand-fine break. The sand-fine break represents the percentage of sediment greater than 0.062 mm (sand size and larger) and the percentage less than 0.062 mm (silt and clay-size particles).

Bedload was collected with a Helley-Smith hand-held sampler having a 3-in. opening (Emmett, 1980). Bedload is that sediment carried down a stream by rolling and bouncing on or near the streambed. Samples were collected at approximately 7 to 12 equally spaced cross-channel sampling sites, no closer than 1.5 ft apart. The sampling duration was 30 seconds at each collection point. Samples were dried and weighed in the laboratory to determine the mass of bedload (in grams) corresponding to the water discharge at the time of sampling. Bedload discharge was computed from the measured mass of the sample collected during each cross-channel traverse.

Bed material was collected with the US BMH–53 piston-type sampler (Guy and Norman, 1970), designed to sample bed material in wadeable streams. The piston-type sampler is a stainless-steel cylinder 2 in. in diameter and 8 in. in length. Samples were collected at each measurement site, the sediment trap at the Izaak Walton League property, the delta of the instream pond, and the outlet of the pond. The top 3 in. of each sample were analyzed for particle-size distribution because the top 3 in. is the part of the channel bed that would likely be set into motion with increased stream discharge.

Channel cross sections at the six sampling sites, the instream pond and its delta, and the sediment trap were surveyed. Surveying was completed by use of a total station (theodolite with an electronic measuring device) and a data logger. Cross-section locations were selected near the measurement sites in areas having potential for scour or fill. All altitudes were tied to temporary reference marks (steel spike in utility pole or chiseled mark on a bridge) set at each site. These reference marks were assigned arbitrary datums. Where water depths were too great for wading at the instream pond, a boat-mounted fathometer was used to determine depth from the water surface to the pond bottom.

Sediment cores were collected from the delta of the instream pond and the sediment trap by use of a vibracoring technique. Vibracoring is a technology for penetrating and recovering unconsolidated, usually saturated, sediments by use of the principle of liquefaction or the fluidization of fine-grained sediments. The core barrel (aluminum pipe) is attached to a vibrator head and vibrated into the sediment. The resulting core must be measured and adjusted for compaction. Descriptions of the cores indicated the type of sediment deposited. The cores were obtained to determine original bottom depths and possible seasonal or annual variations in deposition.

Table 2. Analysis of replicates collected for quality control of sediment sampling on Juday Creek, near South Bend, Indiana

[g, grams; mg/L, milligrams per liter; mm, millimeters]

Characteristic	Number of replicates	Median	Minimum	Maximum	Percentage difference with matched sample		
					Median	Minimum	Maximum
Bedload (g)	9	332	18	861	48.3	0.1	78.7
Suspended-sediment concentration (mg/L)	8	16.5	8	30	10.2	0	35.3
Percent <0.062 mm	8	42.2	30	93	13.9	3.8	46.6

Quality control (QC) samples (replicates) were collected during each storm sampling to quantify variability in stream sediment and sampling techniques. Simultaneous or sequential replicates were collected for suspended sediment, and sequential replicates were collected for bedload samples. Quality-control replicates were collected for 12.1 percent of the suspended-sediment samples and 13.6 percent of the bedload samples. In all, 66 storm samples were collected for suspended sediment and bedload. Table 2 shows the analysis of the replicates and the percentage differences between matched samples.

Bedload replicates were collected sequentially. The first cross-channel sample was used for calculating tons per day. The second cross-channel sample was the replicate used for QC analysis. The range in bedload replicates is 18 to 861 g. The maximum percentage difference with a matched sample is 78.7 percent. A conservative decision rule was applied to use the maximum percentage difference as the criterion for determining a significant difference when comparing samples. In the interpretation of bedload, only those samples differing by greater than 78.7 percent can be considered significantly different. The cross-channel measurements of bedload tend to account for spatial variability in the samples. The 78.7 percent difference indicates the high temporal variability of bedload at a given time.

Suspended-sediment replicates were collected simultaneously. Two samples were collected at each vertical. The suspended-sediment concentrations of the replicates range from 8 to 30 mg/L. The maximum percentage difference with a matched sample is 35.3 percent. Only those samples differing by greater than 35.3 percent are considered significantly different. The percentage of suspended-sediment finer than 0.062 mm ranges from 30 to 93 percent. The maximum percentage difference with a matched sample is 46.6 percent. As with the other two sediment characteristics, only samples with differences greater than 46.6 percent are considered significantly different.

Acknowledgments

The authors received assistance from many people during data collection and report preparation. The staff at the National Weather Service, South Bend, provided storm forecasts and precipitation information essential for data collection during runoff events. Jeff Runde, a graduate student in the Department of Biology,

and Dr. Steven Silliman, Department of Civil Engineering, Notre Dame University, shared their knowledge and insight of Juday Creek and were willing to provide assistance and answer questions.

CHARACTERISTICS OF SEDIMENT

Streambed Material

Bed material is defined by the Office of Water Data Coordination as "the sediment mixture of which the bed is composed" (U.S. Geological Survey, 1977, Chap. 3, p. 3–5). Bed material was collected at each sampling site by use of a hand-held, piston-type sampler (US BMH–53). The sampler collects bed material to a depth of approximately 8 in., and it will accept bed material containing particles as large as 30 or 40 mm in diameter. Samples from the top 3 in. were retained and analyzed. These were the particles that could be frequently transported as part of the suspended load or bedload but, when at rest, are considered bed material (Edwards and Glysson, 1988). Three cross-channel bed-material samples (left, center, and right) were obtained from each measurement site in August 1993. Samples also were collected from the delta of the instream pond, the outlet of the instream pond, and the sediment trap at the Izaak Walton League property. Table 3 lists the particle-size distributions at each of the sampling locations.

At site 1, the median grain size of each sample is medium sand (0.50–0.25 mm) (see table 4 for grain-size scale.) At this site, the bed material is fairly uniform from one side of the channel to the other. Similarly, the bed material at site 2 consists of medium-grained sand. Medium sand is easily transportable, and streambeds of medium sand often are unstable (W.W. Emmett, U.S. Geological Survey, written commun., 1994). Streams with shifting sand channels do not provide suitable substrate for most fish reproduction. These two most upstream sites are unlikely areas for brown trout spawning. According to Hansen and others (1983, p. 356), "Sand may decrease the food supplies of trout by scouring or burying desirable substrate, destroy cover by aggrading channels and filling pools, and reduce spawning success by covering up or plugging gravel." In addition, a moving sand bed is a poor substrate for habitat and production of invertebrate food organisms.

Site 3 has a gravel channel; median grain sizes range from 3.1 to 8.8 mm. The channel bed at this site, just upstream from the instream pond, is stable in most areas; the slumping banks provide some of the fine-grained sediments. Coarse to very coarse pebbles also were present at this site. Average velocities generally increase in the downstream direction from site 1 to site 3 (table 6) then decrease after the stream passes through the instream pond. The bed material at the lake outlet also is composed of gravels, but the median grain size is smaller (2.0–3.8 mm) than the gravels at the inlet. Bed material collected for the delta is finer grained than the bed material at the inlet and outlet. The median grain size ranges from 0.34 to 0.48 mm and is probably representative of the easily transportable medium sand from the upstream reaches.

The bed material at site 4 varies across the channel; the largest median grain size (1.5 mm) is in the center. Some gravel-size particles are present, but most are medium to coarse sand. In this area, gravels that would be available for invertebrate populations or salmonid spawning would be at risk of being buried by moving sand. Site 5 also has mostly sand-size bed material mixed with some gravel. Data in table 3 indicate that the range of the median particle sizes is from 3.1 mm on the left to 0.37 mm in the center. The bed-material samples from Site 5 were collected in August 1993. Since that time, there has been significant sand deposition (0.7–1.0 ft) at the measurement site, and much of the gravel has been buried.

Site 6 has bed material composed of sand and gravel. Some of the gravel exceeded the sampling capacity of the BMH–53; therefore, the streambed includes particles coarser than table 3 indicates. The average grain size in the center of the channel was 10.8 mm (medium pebbles). The gravel bed material in this area appears to be fairly stable.

Table 3. Particle-size distributions of streambed material in Juday Creek, near South Bend, Indiana
[l, left side of channel; c, center of channel; r, right side of channel; mm, millimeters]

Site number	Median (mm)	Mean (mm)	Percentage of sample weight finer than sieve size (mm)										
			64	32	16	8	4	2	1	0.50	0.25	0.125	0.062
1-l	0.27	0.32			100.0	97.9	96.3	93.5	91.5	85.0	41.5	4.8	3.6
1-c	.33	.49			100.0	96.9	94.2	89.0	84.9	74.8	25.1	1.5	.8
1-r	.32	1.18			100.0	94.1	87.4	81.3	76.8	71.0	34.0	3.1	1.3
2-l	.38	1.04			100.0	97.7	91.4	81.7	76.8	65.1	14.8	.6	.4
2-c	.45	.84			100.0	98.4	92.3	85.0	76.8	58.3	10.5	1.1	1.0
2-r	.27	.29				100.0	99.5	98.7	98.0	93.5	40.8	1.9	.6
3-l	8.80	11.8		100.0	63.9	49.1	37.4	27.9	17.3	10.0	5.0	2.0	1.3
3-c	6.40	12.9	100.0	83.0	67.8	55.0	43.4	35.3	30.5	24.4	8.1	1.3	.7
3-r	3.10	8.80		100.0	80.9	71.9	58.3	36.2	17.8	11.4	7.0	2.3	1.3
Delta-l	.45	.51				100.0	99.9	99.0	91.3	63.0	18.9	1.6	.4
Delta-c	.48	.53					100.0	99.4	93.9	53.4	8.8	.7	.1
Delta-r	.34	.34					100.0	99.9	99.0	86.2	24.9	.9	.2
Outlet-c	3.80	6.25		100.0	87.8	68.8	52.2	39.0	28.6	15.3	3.7	.5	.3
Outlet-r	1.95	3.60		100.0	96.2	83.8	61.7	50.3	43.0	27.9	5.5	.5	.2
4-l	.30	.40			100.0	97.8	94.6	92.4	89.3	79.6	36.0	2.6	.8
4-c	1.50	3.55		100.0	97.0	81.5	68.3	55.4	44.8	30.4	9.5	2.1	1.4
4-r	.27	.45			100.0	99.5	95.2	90.0	85.1	78.5	47.2	8.6	3.3
5-l	3.10	6.50		100.0	84.8	66.1	54.1	45.1	38.6	27.9	13.4	3.7	2.2
5-c	.37	.49				100.0	98.8	95.6	88.9	69.4	12.9	.4	.2
5-r	.40	3.20		100.0	94.0	82.5	72.5	68.2	64.8	56.3	31.5	4.0	1.6
6-l	.37	1.07		100.0	96.5	91.8	87.5	83.1	78.3	67.2	22.8	2.0	.8
6-c	7.20	10.8		100.0	68.0	52.5	41.3	34.4	28.2	15.0	2.4	.3	.1
6-r	.27	.26		100.0	99.1	95.7	95.7	95.7	95.6	93.6	40.0	1.6	.3
Trap-l	.52	1.00			100.0	94.2	89.6	83.5	73.2	48.7	7.5	1.0	.5
Trap-c	.40	.47			100.0	99.8	97.4	94.1	89.7	73.1	16.1	.6	.4
Trap-r	.22	.24				100.0	99.9	99.7	99.0	96.6	68.7	3.6	.8

Table 4. Sediment grain-size scale
[Modified Wentworth scale; from Ingram (1982, Data Sheet 17.1)]

Grade limits (millimeters)	Grade name	
128 - 64	Small cobbles	
64 - 32	Very coarse pebbles	GRAVEL
32 - 16	Coarse pebbles	
16 - 8	Medium pebbles	
8 - 4	Fine pebbles	
4 - 2	Very fine pebbles	
2 - 1	Very coarse sand	
1 - 0.50	Coarse sand	SAND
0.50 - 0.25	Medium sand	
0.25 - 0.125	Fine sand	
0.125- 0.062	Very fine sand	
0.062 - 0.031	Coarse silt	MUD

The sands being transported tend to continue downstream because of a higher stream gradient and higher velocities than those upstream. Table 6 shows that the highest average velocities were found at the most downstream reach, represented by site 6.

The bed material of the sediment trap, downstream from site 6, is fine to coarse sand. The larger particles were to the left and center of the trap. The sediment trap was nearly full, if not completely full, at the time of sampling. Sediment that reached the full trap would have passed over the spillway.

The particle-size distributions of the channel material at each of the sites also was used in the interpretation of the bedload material and scour and fill. These characteristics are affected directly by that part of the channel material likely to be put in motion.

Sediment Cores

Sediment cores were obtained from the delta of the instream pond and the sediment trap at the Izaak Walton League property. The cores from the instream pond delta showed depositional variation across the delta (for core locations, see fig. 25.) Cores collected from the nose of the delta were mostly medium to coarse sand in the upper 1 to 4 ft., underlain by interbedded organic leafy muck and more medium to coarse sands. Below the sand and organic debris layers was a clay or silty clay layer at a depth of 5.3 ft on the left side (core 1), 5.0 ft toward the center (core 2), and 3.6 ft on the right (core 3). An estimate of the original depth was made from core 3. This core, obtained near the right edge of the delta, contained almost a foot of gravel at the bottom. This was the coarsest material found and was similar in size to the gravel at the pond inlet. The total depth cored was 12.3 ft. Adjusting for compaction, the top of the gravel was at approximately 8.3 ft below the top of the delta. This gravel layer was used to estimate that approximately 8.3 ft of sediment deposition had occurred at this point on the delta since the excavated site began to fill (around 1950).

Core 4, collected upstream from the delta edge and closer to the inlet, was coarse grained (sand and gravel) in the upper 2 ft, sand from 2 to 6 ft, then sandy muck and clay below 6 ft. Attempts to core closer to the inlet channel proved unsuccessful because of the abundance of medium to coarse pebbles.

Two core tubes near the downstream end of the sediment trap (Izaak Walton League property) were driven until they reached a very firm, dense layer assumed to be the trap bottom. Adjusted for compaction, the total depth of the core retrieved from the left side was 7.5 ft and the total depth of the one in the center was 7.1 ft. The two cores were similar in composition. Fine to medium sand with some interbedded organic debris was present from the top to 2 to 3.5 ft. Below the sand were gritty, black, organic layers containing leaf and wood debris. Both cores ended in sand that contained lenses of decomposing debris. Total depths of cores collected progressively upstream were 4.7 ft and 2.9 ft, indicative of a thinning of loose material toward the upstream end of the trap. The upstream core tubes were driven to what was apparently the original channel bottom, represented by sand and gravel.

Analysis of the cores did not reveal seasonal variations or annual layering of the sediments. There was no pattern to the sediments to represent more than 40 years of deposition (assuming no previous dredging) at the instream pond. Estimates of the original bottom depths were made at both sites. Information is insufficient, however, to estimate the total volume of sediment deposited at the sediment trap—surveys comparing volume of the trap before and after dredging would be necessary. Analysis of the cores did show that, like the bed material, the deposits at the pond and trap are predominantly sand and some pebbles. This analysis indicates that most of the sediment was transported to the pond and trap as bedload.

TRANSPORT OF SEDIMENT

Sediment transport was analyzed by measurement of streamflow, suspended sediment, and bedload and by monitoring of scour and fill at the six sampling sites. Suspended sediment and bedload were measured during three storms and once during a time of no overland flow. Sediment discharge was calculated for all of the suspended-sediment and bedload measurements. During the study period, only four sets of sediment samples were collected on Juday Creek. The sediment discharges, therefore, are instantaneous; they only apply to the particular time when the measurements were made. The data are too limited to extrapolate an annual load or sediment yield.

Suspended-sediment discharge was calculated by use of the following equation from Guy (1970):

$$Q_s = Q_w C_s k, \qquad (1)$$

where Q_s is instantaneous suspended-sediment discharge, in tons per day;
Q_w is instantaneous streamflow, in cubic feet per second;
C_s is instantaneous suspended-sediment concentration, in milligrams per liter; and
k is a units conversion factor of 0.0027.

Bedload discharge was calculated by use of the following equation from Edwards and Glysson (1988):

$$Q_b = k\,(W_t/T)\,M_t, \qquad (2)$$

where Q_b is bedload discharge, in tons per day;
k is a units conversion factor of 0.381 for a 3-in. nozzle;
W_t is total width of stream from which samples were collected, in feet (equal to the increment width times the total number of vertical samples);
T is total time the sampler was on the streambed, in seconds (computed by multiplying the individual sample time by the total number of vertical samples); and
M_t is total mass of sample collected from all verticals sampled in the cross section, in grams.

The total mass, in grams, of the bedload samples is used in the calculation of bedload discharge and is included in tables 5 and 6 and the text to show how the bedload amounts vary from site to site.

Low-Flow Conditions

Suspended sediment and bedload were measured during a period of low flow to determine how much sediment, if any, is transported during low streamflow, in the absence of overland flow. Suspended-sediment concentration was low at all sites (relative to storm samples), ranging from 1 to 6 mg/L (table 5). The mean suspended-sediment concentration of the storm samples was 20 mg/L. Bedload was more variable than suspended-

Table 5. Sediment transport characteristics for Juday Creek, near South Bend, Indiana, during a period of low flow, August 20, 1993

[ft^3/s, cubic feet per second; ft/s, feet per second; mg/L, milligrams per liter; ton/d, tons per day; g, grams]

Site number	Streamflow (ft^3/s)	Average velocity (ft/s)	Suspended sediment				Bedload (g)	Bedload discharge (ton/d)
			Concentration (mg/L)	Discharge (ton/d)	Percentage by size: <0.062 mm (silt and clay)	Percentage by size: >0.062 mm (sand)		
1	3.99	0.90	4	0.04	47.8	52.2	12.9	0.24
2	17.7	.98	2	.10	20.0	80.0	76.7	1.70
3	18.2	1.30	2	.10	24.7	75.3	21.3	.39
4	20.3	.99	1	.05	40.5	59.5	5.2	.11
5	19.6	.76	3	.16	42.5	57.5	5.5	.11
6	20.0	1.85	6	.32	30.8	69.2	41.1	.84

sediment concentrations, ranging from 5.2 to 76.7 g, or 0.11 to 1.70 ton/d. The mean bedload for the storm samples was 242 g, or 5.37 ton/d. The percentage of suspended sediment less than or greater than the sand-fine break (0.062 mm) is included in table 5; but at such low concentrations, this distinction is not as meaningful as with larger concentrations. The low-flow measurements indicate that some sediment is transported at low flows and that the predominant mode of transport is bedload.

Storm Events

The stream was sampled during three storms for suspended-sediment concentration and bedload. Streamflow also was measured at each sampling. Criteria used to determine response to a storm or rainfall event was the prediction of more than 1 in. accumulating within a 48-hour period. Table 6 is a compilation of the data collected during the three storms, including daily precipitation amounts. Because field crews had to be on site at the onset of the storm, it was essential that the event be forecast by the National Weather Service. Several significant periods of rainfall were not sampled because of the difficulty of predicting rainfall in a small basin. At other times, crews were on site, but the storms missed the Juday Creek Basin.

The first sampled rainfall event was September 14–16, 1993. Five measurements were made at each of the six sites during the rise and fall of the storm hydrograph. Figures 3–8 are graphical representations of the comparisons of the data collected during this event. The first measurements at the sites were made on the steep rising limb of the hydrograph on September 14 (fig. 9). The last measurements were made on the slow decline of the hydrograph on the morning of September 16.

Suspended-sediment concentrations varied from site to site. The lowest concentration, 7 mg/L, was measured at site 1 during the recession (sampling 5, fig. 9). A high of 67 mg/L at site 6 was measured on the rise (sampling 1, fig. 9). The suspended-sediment concentrations obtained from the first sampling event (as well as the two subsequent events) fall below the range where brown trout or other salmonids are affected significantly. According to Lloyd (1987), concentrations below 80 to 100 mg/L constitute a moderate level of protection from suspended sediment. Concentrations greater than 80 mg/L were not measured during the course of this study; however, only a small range of streamflow was sampled. Concentrations as high as 400 mg/L may occasionally occur (Runde, 1994) but are likely to be of short duration.

Table 6. Streamflow, suspended-sediment concentration, bedload, and rainfall data collected during three storms on Juday Creek, near South Bend, Indiana

[Rainfall was measured by the National Weather Service; ft^3/s, cubic feet per second; ft/s, feet per second; mg/L, milligrams per liter; ton/d, tons per day; g, grams; in., inches]

				Suspended sediment						
						Percentage by size				
Site number	Sampling date	Streamflow (ft^3/s)	Average velocity (ft/s)	Concentration (mg/L)	Discharge (ton/d)	<0.062 mm (silt and clay)	>0.062 mm (sand)	Bedload (g)	Bedload discharge (ton/d)	Rainfall (in.)
					Storm event 1					
1	Sept. 14, 1993	8.56	1.03	33	0.76	76.5	23.5	31.6	0.70	
2		20.2	1.01	17	.93	53.4	46.6	109	2.21	
3		28.0	1.51	12	.91	33.6	66.4	191	5.82	
4		24.2	1.10	16	1.04	28.4	71.6	25.9	0.53	
5		25.6	1.04	20	1.38	17.8	82.2	107	2.22	
6		32.4	1.71	67	5.86	32.0	68.0	73.8	1.64	
										2.06
1	Sept. 14, 1993	14.9	1.22	39	1.57	58.8	41.2	68.6	1.52	
2		29.5	1.23	23	1.83	44.9	55.1	109	2.21	
3		35.7	1.74	16	1.54	12.1	87.9	364	10.1	
4		40.8	1.51	12	1.32	19.0	81.0	79.2	1.61	
5		40.3	1.41	34	3.70	30.8	69.2	676	13.9	
6		35.5	1.86	65	6.23	30.0	70.0	414	8.93	
1	Sept. 15, 1993	13.1	1.22	9	.32	48.2	51.8	64.7	1.51	
2		41.1	1.45	13	1.44	59.7	40.3	846	17.2	
3		44.7	1.97	21	2.53	38.6	61.4	406	11.3	
4		46.5	1.61	20	2.51	28.4	71.6	272	5.86	
5		46.4	1.57	30	3.76	19.6	80.4	833	17.4	
6		41.9	1.95	33	3.73	22.6	77.4	475	10.3	
										.01
1	Sept. 15, 1993	11.6	1.23	11	.34	52.1	47.9	78.5	1.74	
2		36.4	1.39	10	.98	45.6	54.4	642	13.0	
3		42.8	1.76	16	1.84	33.8	66.2	612	16.9	
4		42.8	1.35	11	1.27	30.0	70.0	99.4	2.08	
5		45.8	1.50	27	3.34	30.2	69.8	859	18.0	
6		42.2	1.94	24	2.73	28.1	71.9	585	12.6	

Table 6. Streamflow, suspended-sediment concentration, bedload, and rainfall data collected during three storms on Juday Creek, near South Bend, Indiana—Continued

Site number	Sampling date	Streamflow (ft^3/s)	Average velocity (ft/s)	Suspended sediment: Concentration (mg/L)	Suspended sediment: Discharge (ton/d)	Suspended sediment: Percentage by size: <0.062 mm (silt and clay)	Suspended sediment: Percentage by size: >0.062 mm (sand)	Bedload (g)	Bedload discharge (ton/d)	Rainfall (in.)
1	Sept. 16, 1993	9.28	1.17	7	0.18	50.0	50.0	233	5.18	
2		32.6	1.30	24	2.11	21.0	79.0	206	4.20	
3		35.4	1.67	21	2.01	23.1	76.9	636	17.6	
4		36.0	1.34	13	1.26	29.0	71.0	64.4	1.31	
5		37.8	1.35	12	1.22	32.2	67.8	342	7.12	
6		34.0	1.80	21	1.93	38.3	61.7	862	18.1	
										0.00
Storm event 2										
1	April 12, 1994	6.24	.86	19	.32	45.9	54.1	103	2.34	
2		18.6	.82	14	.70	25.1	74.9	9.9	0.21	
3		27.4	1.52	8	.59	42.2	57.8	62.5	1.34	
4		33.7	1.35	45	4.09	15.1	84.9	107	2.41	
5		30.0	1.13	10	.81	45.6	54.4	407	9.26	
6		27.0	1.74	11	.80	26.6	73.4	154	3.20	
										.93[1]
1	April 12, 1994	7.73	.96	12	.25	39.1	60.9	83.6	1.90	
2		25.0	1.07	20	1.35	36.3	63.7	184	3.75	
3		31.3	1.70	8	.68	41.3	58.7	103	2.12	
4		31.3	1.28	11	.93	26.2	73.8	66.3	1.50	
5		29.4	1.12	8	.64	33.7	66.3	320	6.64	
6		26.6	1.89	10	.72	38.0	62.0	242	4.96	

Table 6. Streamflow, suspended-sediment concentration, bedload, and rainfall data collected during three storms on Juday Creek, near South Bend, Indiana—Continued

Site number	Sampling date	Streamflow (ft^3/s)	Average velocity (ft/s)	Suspended sediment: Concentration (mg/L)	Suspended sediment: Discharge (ton/d)	Suspended sediment: Percentage by size: <0.062 mm (silt and clay)	Suspended sediment: Percentage by size: >0.062 mm (sand)	Bedload (g)	Bedload discharge (ton/d)	Rainfall (in.)
Storm event 3										
1	June 23, 1994	3.24	0.71	27	0.24	11.6	88.4	3.4	0.07	
2		12.6	.63	17	.58	28.8	71.2	31.0	0.67	
3		14.7	1.04	11	.44	70.8	29.2	149	3.03	
4		17.9	.90	17	.82	51.6	48.4	94.5	2.00	
5		14.2	.80	25	.96	47.3	52.7	20.1	0.41	
6		11.9	2.03	44	1.41	43.5	56.5	75.8	1.65	
										0.83
1	June 24, 1994	4.45	.78	9	.11	81.2	18.8	16.1	0.41	
2		21.1	.86	19	1.08	59.2	40.8	88.0	1.99	
3		23.5	1.35	25	1.59	61.6	38.4	387	8.20	
4		26.9	1.27	13	.94	63.8	36.2	483	9.81	
5		20.1	.96	20	1.08	67.3	32.7	163	3.63	
6		20.4	1.96	33	1.82	45.5	54.5	409	10.1	
										.85
1	June 24, 1994	4.05	.80	9	.10	42.1	57.9	8.2	0.18	
2		23.1	.89	10	.62	34.8	65.2	88.9	1.86	
3		24.7	1.40	11	.73	85.6	14.4	263	5.56	
4		26.0	1.16	10	.70	67.6	32.4	402	9.06	
5		22.0	1.09	26	1.54	42.4	57.6	98.4	2.17	
6		19.0	1.92	24	1.23	37.5	62.5	412	9.04	
1	June 25, 1994	4.26	.76	4	.05	94.4	5.6	11.0	0.26	
2		19.2	.80	12	.62	43.2	56.8	76.1	1.72	
3		22.1	1.35	17	1.01	46.0	54.0	87.0	1.77	
4		22.3	1.07	12	.72	55.7	44.3	70.4	1.56	
5		19.5	.97	18	.95	35.9	64.1	38.4	0.84	
6		17.0	1.68	24	1.10	30.2	69.8	276	6.23	
										.20

[1]Rainfall is the 48-hour total during April 11–12, 1994, recorded by the National Weather Service, Michiana Regional Airport.

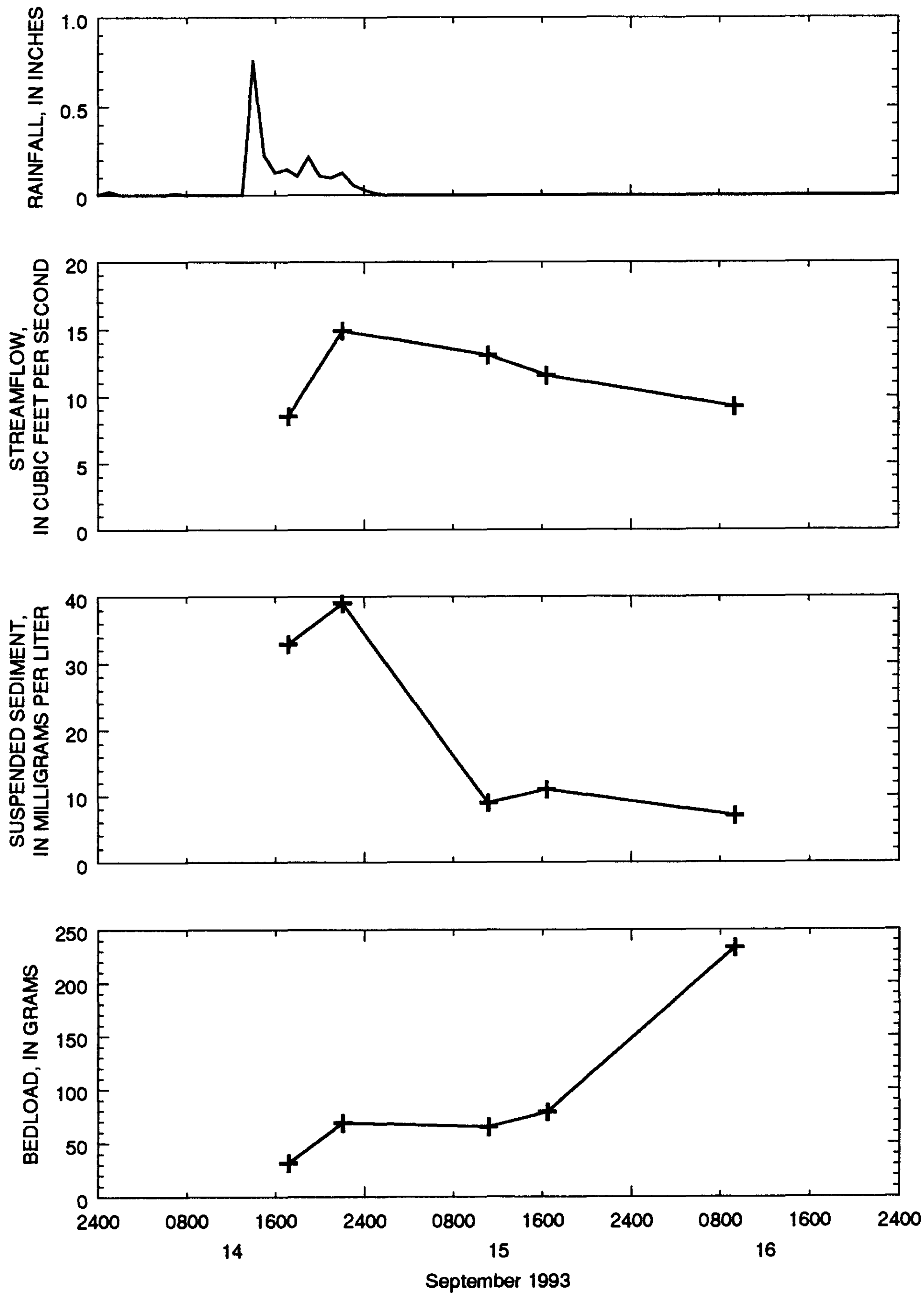


Figure 3. Relation of rainfall, streamflow, suspended-sediment concentration, and bedload at site 1 on Juday Creek, near South Bend, Indiana, for the September 14–16, 1993, sampling.

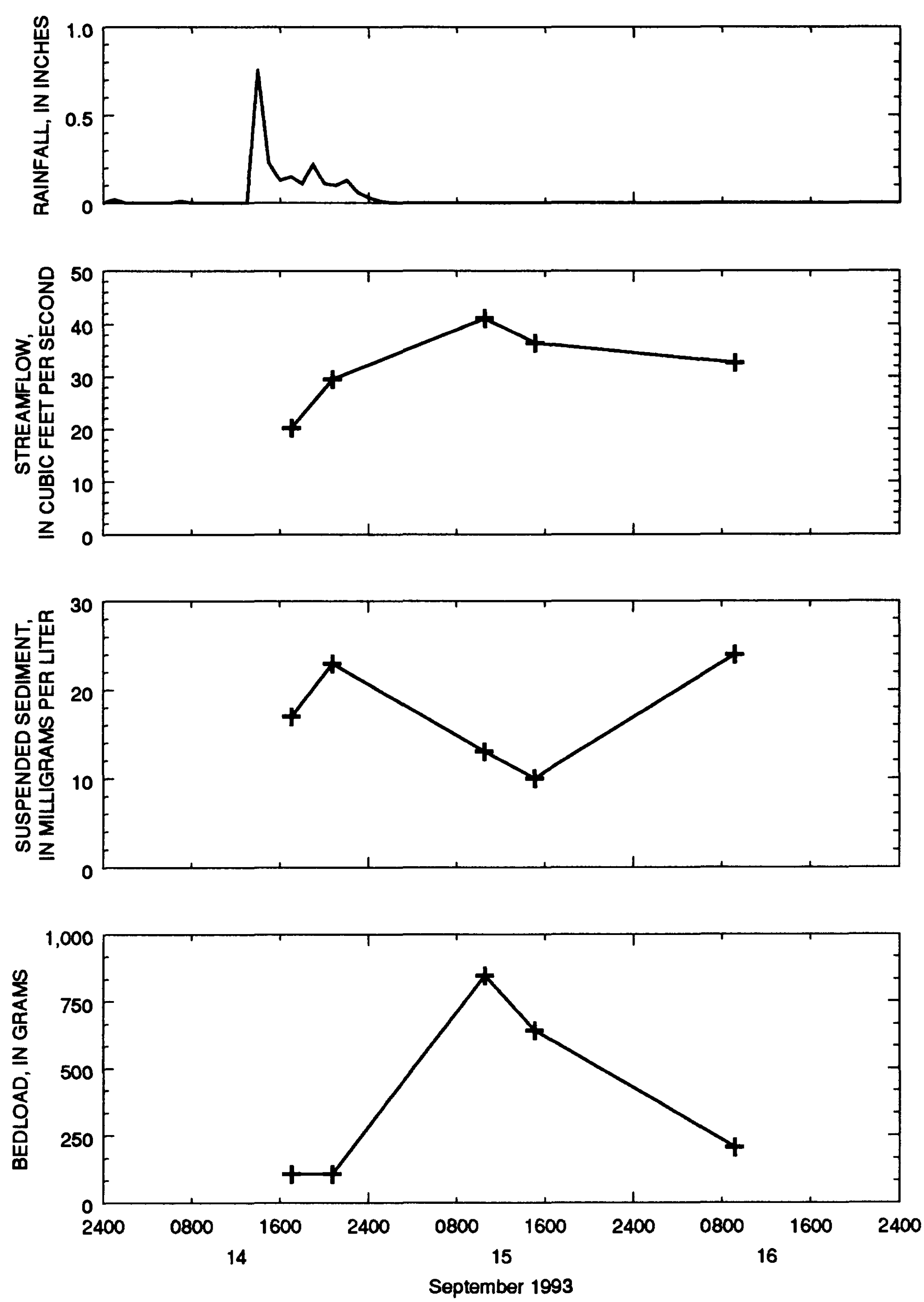


Figure 4. Relation of rainfall, streamflow, suspended-sediment concentration, and bedload at site 2 on Juday Creek, near South Bend, Indiana, for the September 14–16, 1993, sampling.

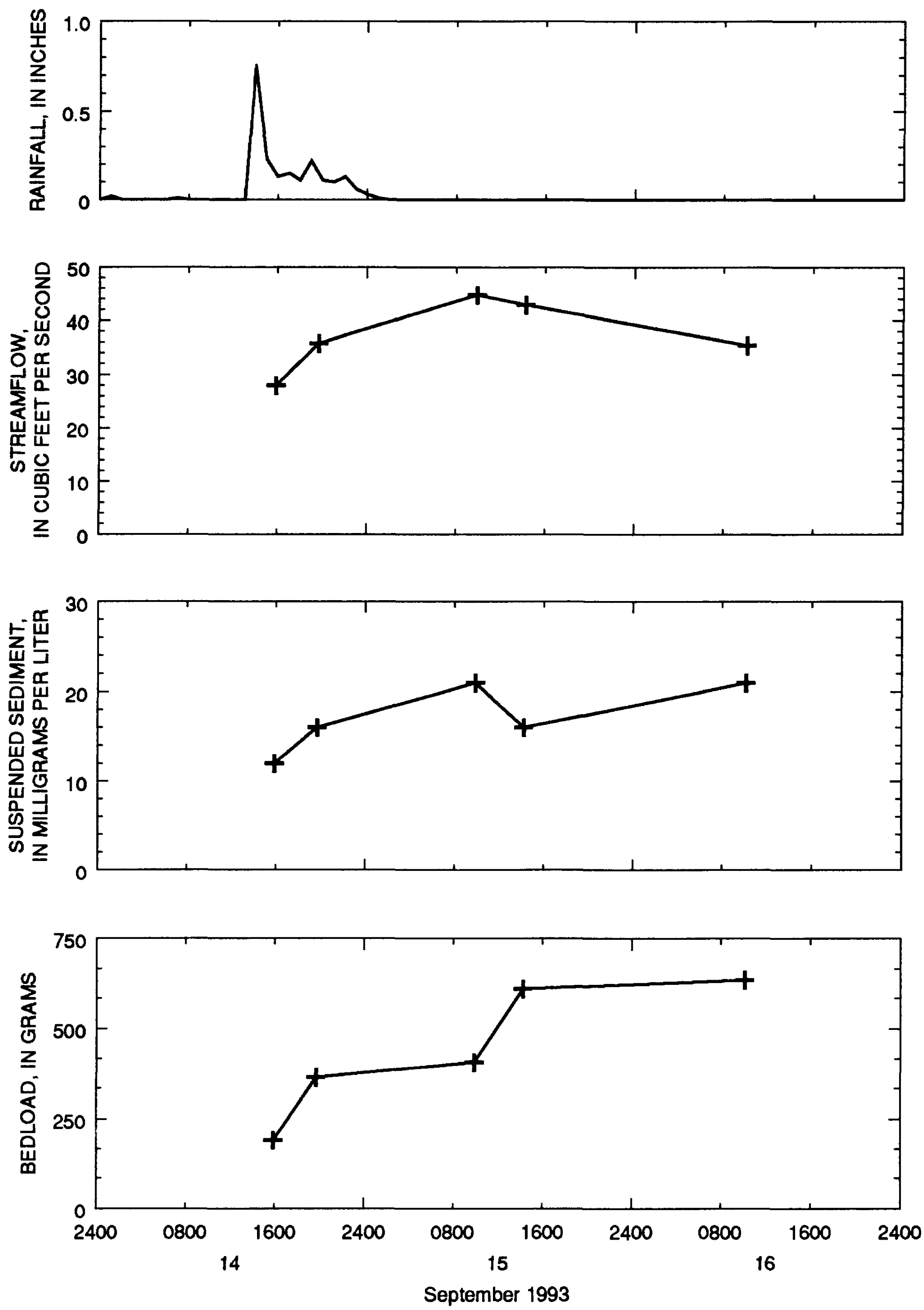


Figure 5. Relation of rainfall, streamflow, suspended-sediment concentration, and bedload at site 3 on Juday Creek, near South Bend, Indiana, for the September 14–16, 1993, sampling.

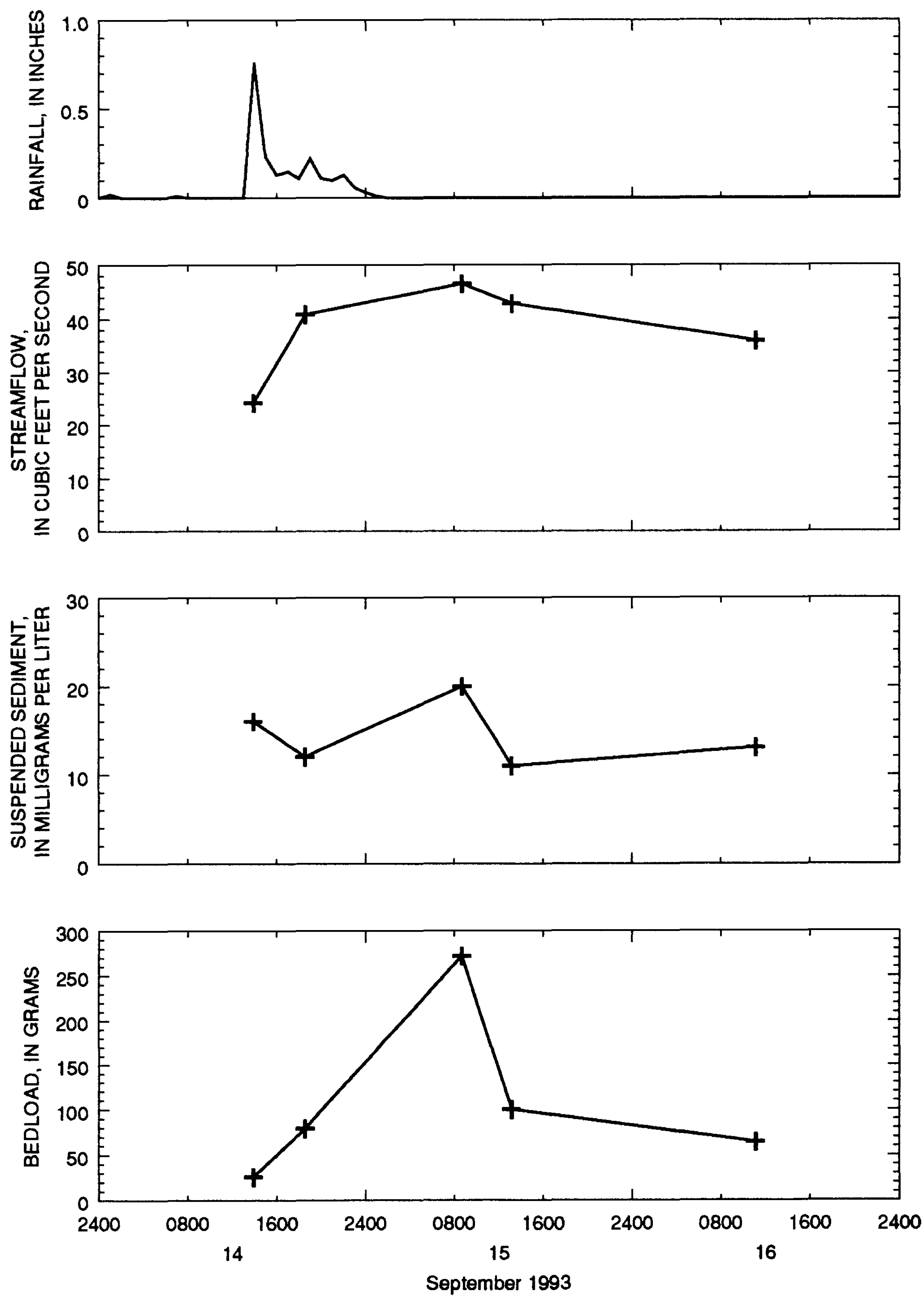


Figure 6. Relation of rainfall, streamflow, suspended-sediment concentration, and bedload at site 4 on Juday Creek, near South Bend, Indiana, for the September 14–16, 1993, sampling.

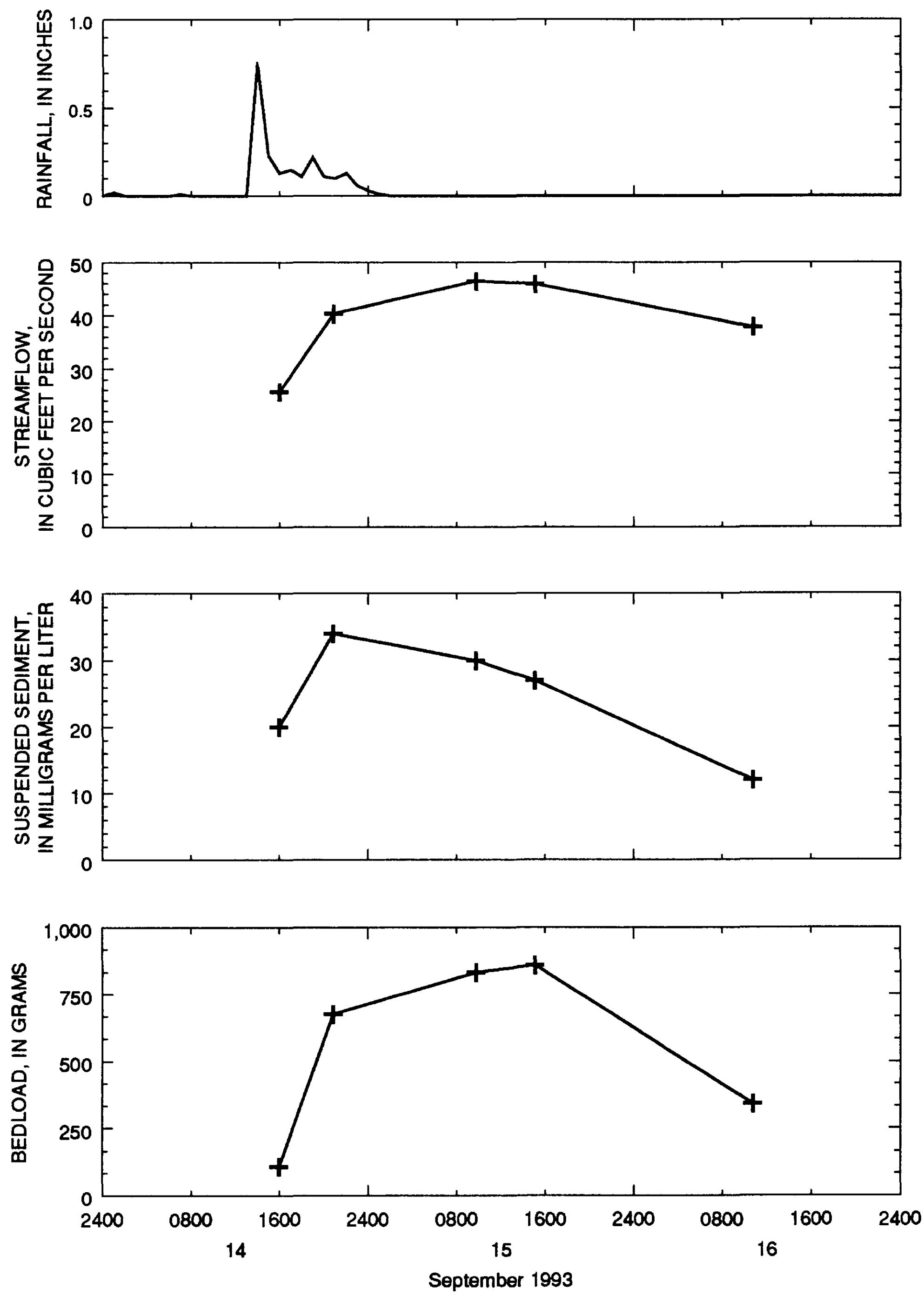


Figure 7. Relation of rainfall, streamflow, suspended-sediment concentration, and bedload at site 5 on Juday Creek, near South Bend, Indiana, for the September 14–16, 1993, sampling.

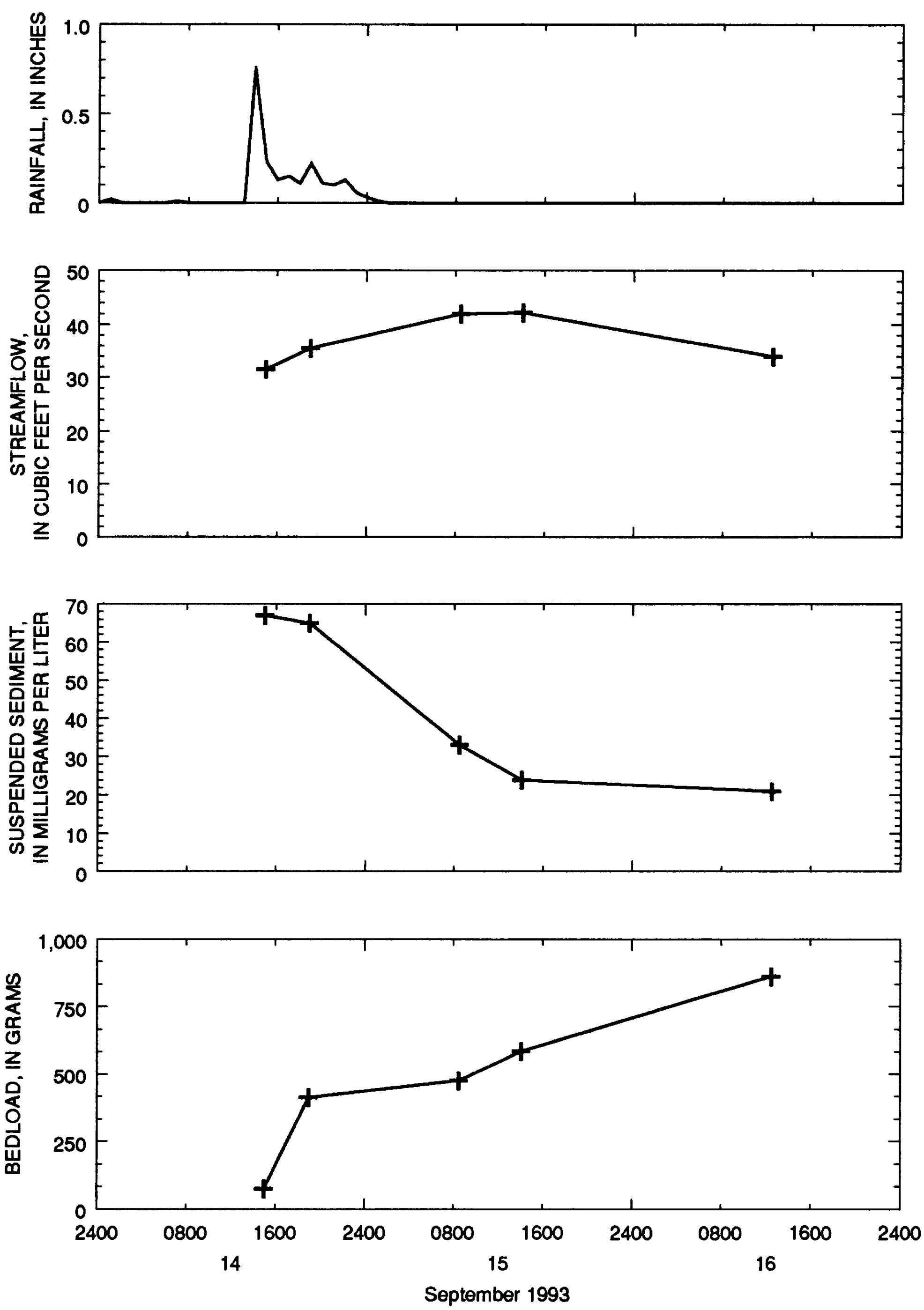


Figure 8. Relation of rainfall, streamflow, suspended-sediment concentration, and bedload at site 6 on Juday Creek, near South Bend, Indiana, for the September 14–16, 1993, sampling.

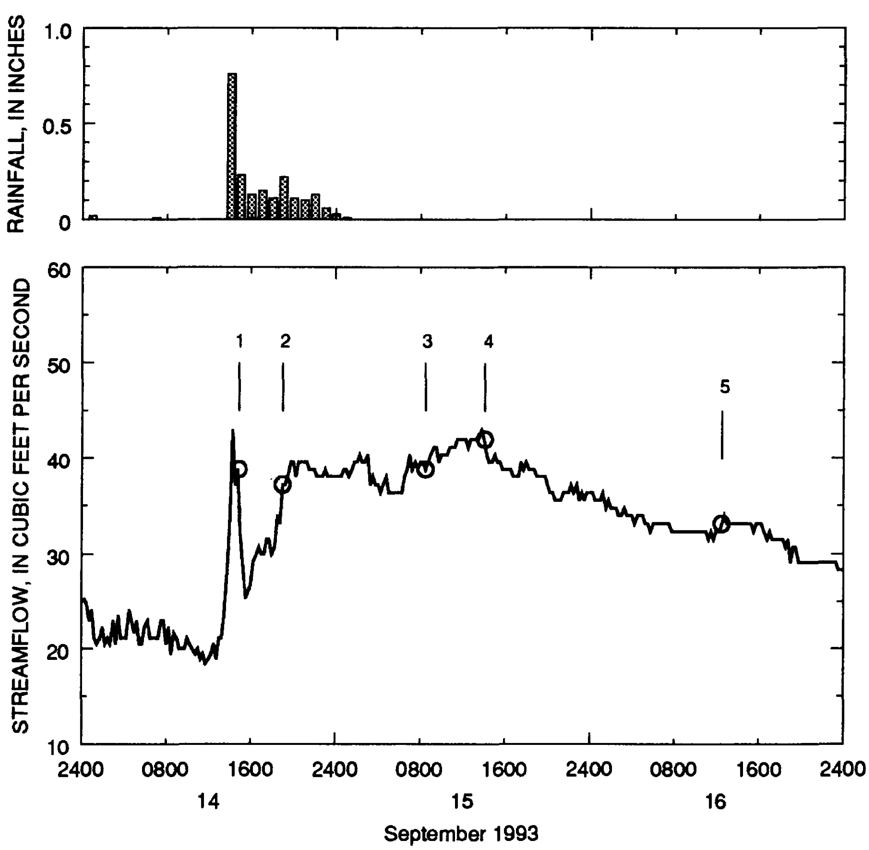


Figure 9. Storm hydrograph for Juday Creek near South Bend, Indiana (04101370), approximate sampling times, and rainfall record for South Bend (National Oceanic and Atmospheric Administration, 1993a).

Peaks in the concentrations of suspended sediment during storm event 1 typically occurred before or were coincident with the streamflow peaks (figs. 3–8). At sites 3 through 6, greater percentages of sand-size particles (>0.062 mm) were consistently in suspension than at sites 1 and 2. At site 1, the stream carried greater amounts of silt- and clay-size particles during the early stages of the storm, then more equal amounts of sand and fines for the duration of the storm. At site 2, the stream carried similar amounts of sand and fines until the third day of sampling, when the percentage of sand-size particles increased.

The bedload collected at each site ranged from 31.6 g at site 1 to 862 g at site 6 (table 6). The stream at site 1 tended to transport the least amount of bedload until the last sampling. This increase could have been caused by sampling a pulse of sediment, by the bank slumping upstream, or possibly by a minor inconsistency in sampling technique. Bedload transport at sites 2 through 5 followed the general shape of the streamflow hydrograph with peaks occurring between measurements 3 and 4 (figs. 4–7). At site 6, as at site 1, bedload increased throughout the rising limb of the hydrograph, and the maximum measured bedload occurred on the recession of the hydrograph (fig. 8). Between sites 3 and 4, a consistent reduction in bedload was noted (table 6). A likely cause of this reduction is the instream pond between the sites. Particles moving along the channel bottom probably would not pass through the pond, which is as deep as 8 ft. After site 4, however, the amount of bedload again increased. Between sites 4 and 5, bedload amounts increased from 99.4 to 859 g during the fourth set of measurements (table 6).

Velocity of bedload particles is generally lower than the mean velocity of water because of the frequent contact of the particles with the streambed. Bedload that passes through one section of Juday Creek may not appear at downstream sections for a few days or even a few storms later. This characteristic of bedload makes the comparison of bedload amounts between sites difficult during any one storm.

Suspended-sediment discharge and bedload discharge in ton/d were compared in figure 10. Only during samplings 1 and 2 was the suspended-sediment discharge ever greater than bedload discharge. The first storm sampling indicates that bedload discharge is the predominant mode of sediment transport along the entire stream.

The second measured storm began on April 11, 1994. By midnight of that day, 0.26 in. of rain had fallen. Two measurements were made at each of the six sites. The first set of measurements was started as the stage began to rise on the morning of April 12 (sampling 1, fig. 11). The second set of measurements was made about 6 hours later. Precipitation on April 12 was 0.67 in. Total precipitation for the storm was 0.93 in. Only two sets of samples were collected because the rainfall was less intense and of shorter duration than was predicted.

Suspended-sediment concentration ranged from a low of 8 mg/L to a high of 45 mg/L. During the first set of measurements, the highest concentration of sediment (45 mg/L) was at site 4, and the lowest concentration was at site 3 (downstream from Grape Road). For the second set of measurements, the highest concentration was at site 2 (20 mg/L), and the lowest concentration was at sites 3 and 5 (8 mg/L). Overall, suspended-sediment concentrations were low throughout the second event because of the smaller amount of rainfall and reduced runoff. Most of the sediment carried in suspension was greater than 0.062 mm at all sites (table 6).

Bedload collected at each site ranged from 9.9 g at site 2 to 407 g at site 5 (table 6). At sites 1, 4, and 5, greater amounts were recorded during the first measurement; whereas at sites 2, 3, and 6, greater amounts were recorded during the second measurement.

Bedload discharge and suspended-sediment discharge are shown in figure 12. Only at sites 2 and 4 during the first set of measurements was suspended-sediment discharge greater than bedload discharge. Again, in storm event 2, bedload discharge was significantly greater than suspended-sediment discharge.

The third sampling was June 23–25, 1994. Early on June 23, the National Weather Service at South Bend forecast as much as 2.0 in. of rainfall during the following 48-hour period. The sampling crew began the first of four sampling sets on the evening of June 23, as the stage began to rise (sampling 1, fig. 13). The last set of measurements was made on the morning of June 25, as the stage began its slow decline.

The suspended-sediment concentrations again were fairly low. The highest concentration measured was 44 mg/L at site 6. The lowest concentration was 4 mg/L at site 1. At most of the sites, concentration peaks were recorded during the early part of the storm, before or nearly coincident with the streamflow peak, which occurred within a few hours of the peak rainfall. The size of the sediment carried in suspension varied throughout the storm and from site to site (table 6). For example, at site 1, the first measurement showed that 88 percent of the particles were greater than 0.062 mm or sand size. By the last measurement, 94 percent of the particles in transport were silt and clay size. Measurements at the other sites showed less extreme variation. At low concentrations, a few particles of one size or another can affect the percentage breakdown.

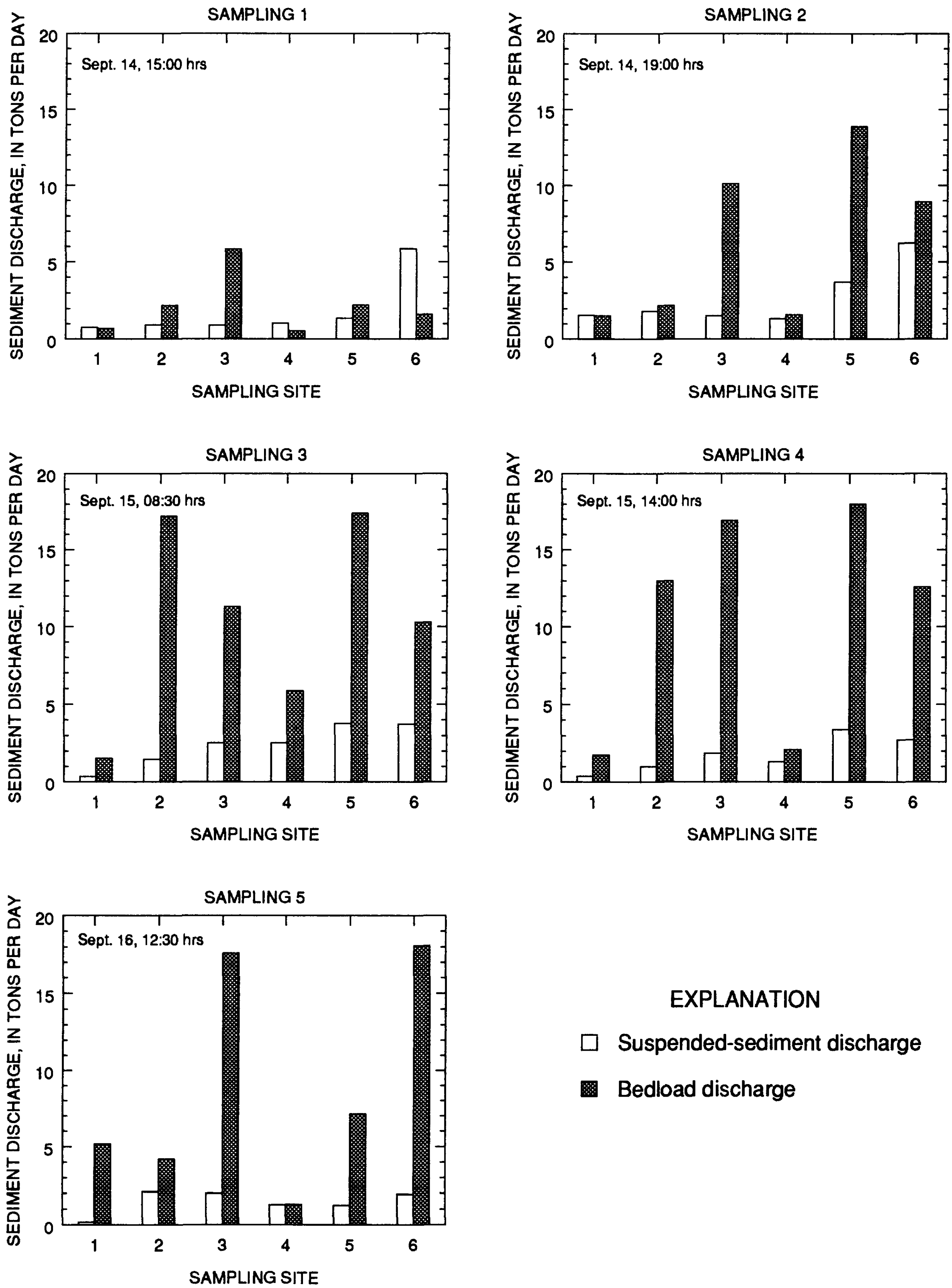


Figure 10. Suspended-sediment discharge and bedload discharge at the six sites for the September 14–16, 1993, sampling on Juday Creek, near South Bend, Indiana.

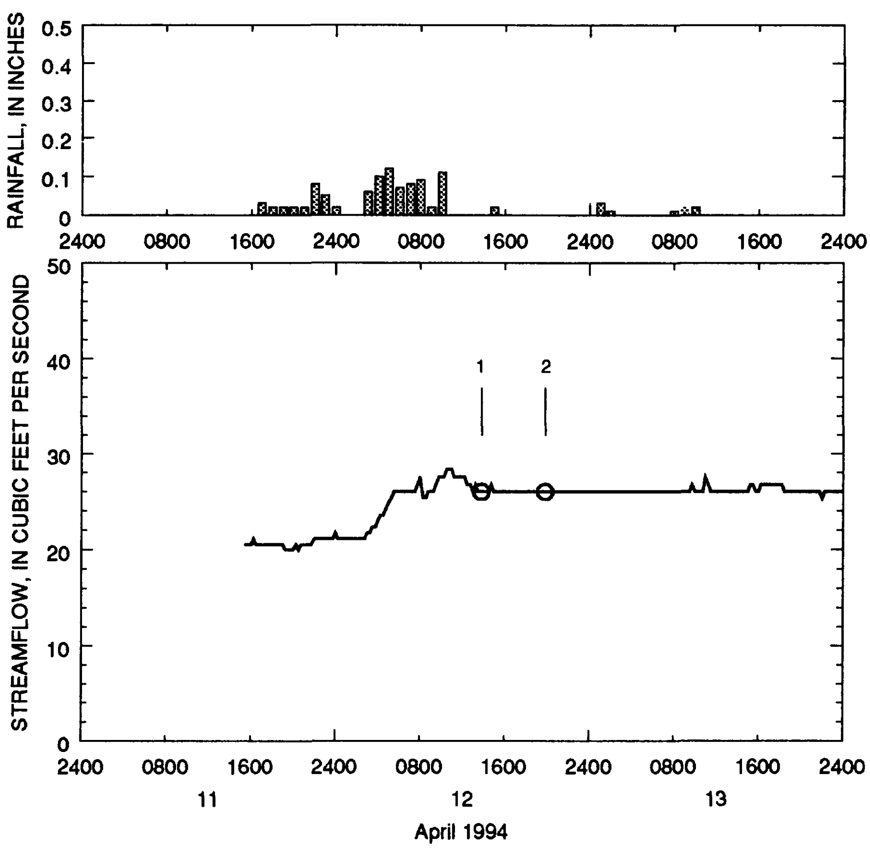


Figure 11. Storm hydrograph for Juday Creek near South Bend, Indiana (04101370), approximate sampling times, and rainfall record for South Bend (National Oceanic and Atmospheric Administration, 1994).

Bedload amounts for this rainfall event generally were less than those of the previous storms. The greatest amount, 483 g, was measured at site 4 during the second set of measurements. The least amount was 3.4 g, measured at site 1 during the first measurement; this measurement also corresponded to the smallest streamflow (3.24 ft^3/s). The bedload peaks generally occurred during the periods of highest streamflow on June 24 (figs. 13 and 14). This sampling did not show the reduction in bedload downstream from the instream pond, as did the previous events. This finding indicates that the supply of bedload to site 4 is controlled by the streambed and bank conditions of the upstream reach, even though the instream pond traps sediment.

Comparison of suspended-sediment discharge and bedload discharge in figure 14 shows the predominance of bedload in total sediment discharge. The graph shows some marked increases in bedload discharge from site 3 to site 4 (relative to the previous sampling events), whereas the graph of bedload discharge at site 5 shows a corresponding reduction.

The three sampled storms differed in many respects. The first event took place in early autumn. This event was characterized by intense rainfall on the first day and the highest suspended-sediment concentrations and bedloads. The second event

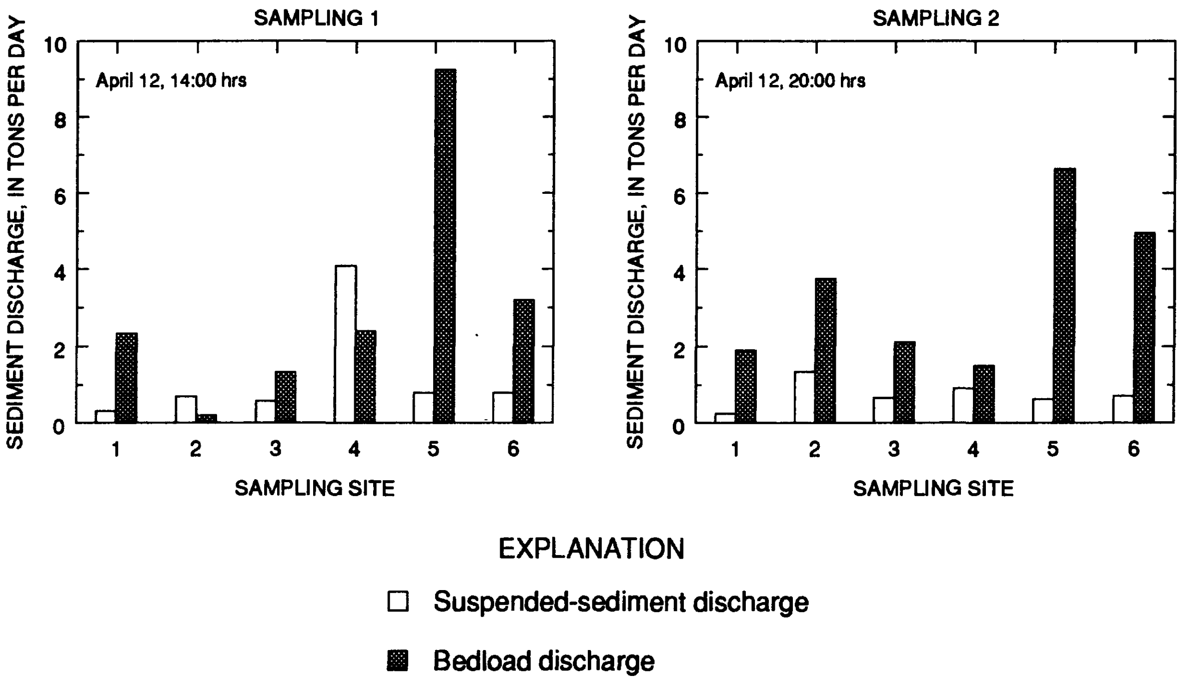


Figure 12. Suspended-sediment discharge and bedload discharge at the six sites for the April 12, 1994, sampling on Juday Creek, near South Bend, Indiana.

was a short-duration spring storm, with less runoff and smaller amounts of suspended sediment and bedload than the first event. The third event was sampled over 3 days in early summer. At the onset of the third storm, streamflow was about half of what it was at the beginning of the other two storms (figs. 9, 11, and 13). This condition could account for the much smaller bedloads at sites 1, 2, and 5.

Suspended-sediment concentrations for the storms ranged from 4 to 67 mg/L; in 85 percent of the samples, concentration was less than 30 mg/L. The median suspended-sediment concentration was 17 mg/L. This median concentration is within the range of medians (17 to 79 mg/L), reported by Crawford and Mansue (1988) for 15 streams in northern Indiana. The range in concentrations, however, is much narrower than for most streams. The narrow range of observed concentrations is likely due to the small drainage area and the narrow range of sampled flows on Juday Creek. As mentioned previously, Juday Creek maintains a narrow range of streamflow. Eighty percent of the time, the flow is 13 to 36 ft^3/s.

Suspended-sediment concentrations for Juday Creek do not correlate strongly with streamflow. Figure 15 shows the variations in suspended-sediment concentration and streamflow for all of the samples (66 storm samples and 6 low-flow samples). One reason for the variations may be that concentrations tend to peak before the streamflow peak and then gradually diminish. According to Crawford and Mansue (1988), most suspended-sediment loads in Indiana are transported in a short

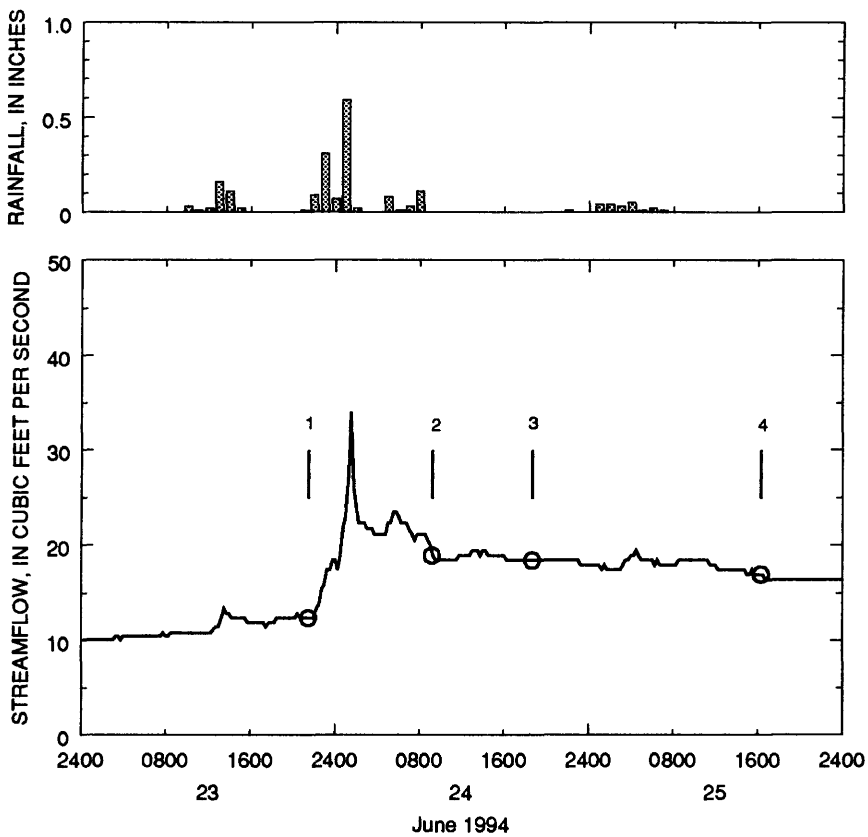


Figure 13. Storm hydrograph for Juday Creek near South Bend, Indiana (04101370), approximate sampling times, and rainfall record for South Bend (National Oceanic and Atmospheric Administration, 1994).

period of time during high flows (a few days a year). It is possible that much larger concentrations could occur but were not measured because of the sampling intervals. The sampling of the three storms did not include large streamflows; however, figure 2 shows that large streamflows did occur during the study period.

Little data on bedload are available for comparison with this study. Available literature suggests that bedload is highly variable in time and space (Gomez and others, 1991). Bedloads for the storms ranged from 3.4 to 862 g; the median bedload was 109 g and the mean was 242 g. Although it is variable, bedload does correlate somewhat with streamflow. Figure 16 shows the variations in bedload and streamflow for all the samples. Many of the smaller bedloads are at or below 20 ft^3/s. The samples collected at site 1, especially those collected at less than 10 ft^3/s, show a separate and more distinct pattern and correlate more strongly with streamflow. Bedload discharge exceeds suspended-sediment discharge in almost all comparisons (figs. 10, 12, and 14). The particle-size distributions of the bed material (table 3) indicate that most of the material available for transport is sand size, which will be transported mostly as bedload. These particles in transport could be a threat to the spawning of salmonids and to their food sources. The small amount of silt and clay in the bed-material samples may explain why the suspended-sediment concentrations are low and why 75 percent of the samples had mostly sand-size particles in suspension (more than 50 percent of sample >0.062mm).

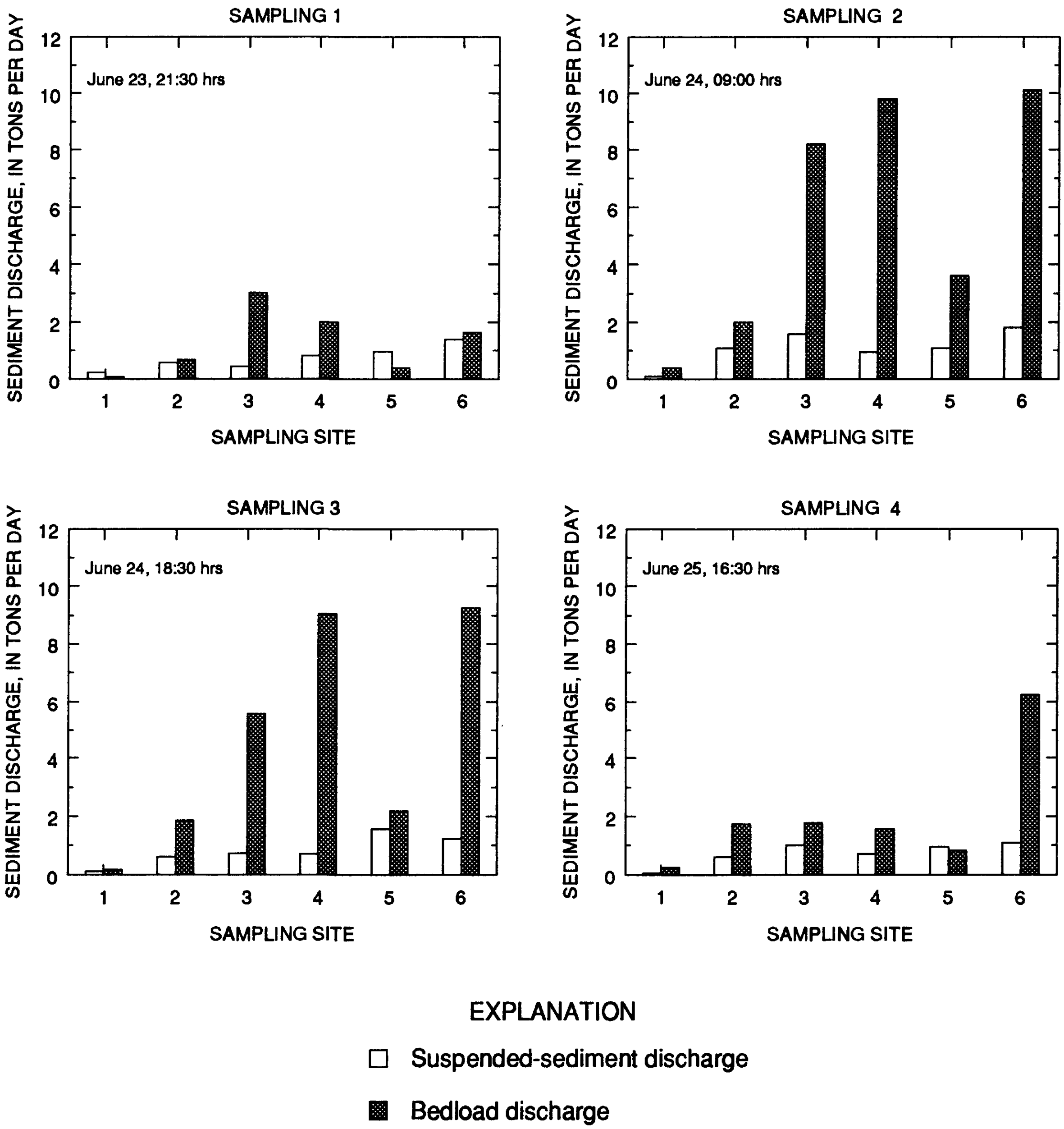


Figure 14. Suspended-sediment discharge and bedload discharge at the six sites for the June 23–25, 1994, sampling on Juday Creek, near South Bend, Indiana.

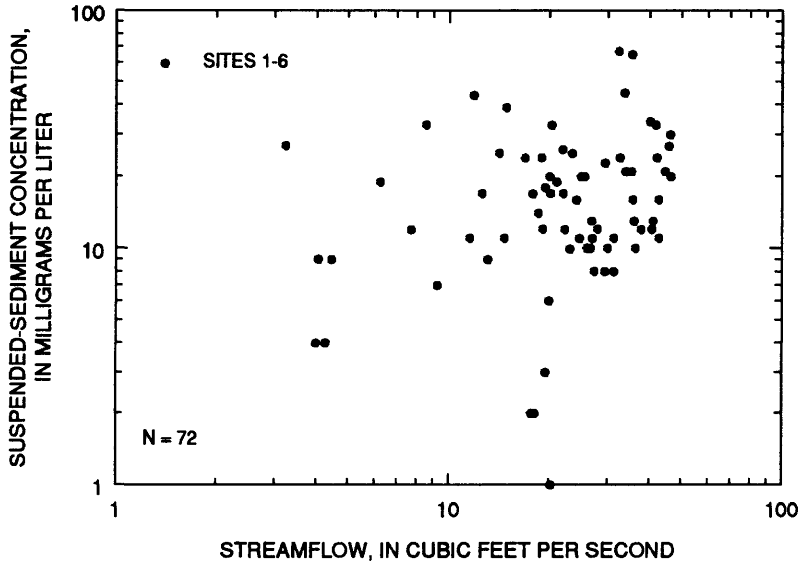


Figure 15. Variations in suspended-sediment concentration and streamflow in Juday Creek, near South Bend, Indiana.

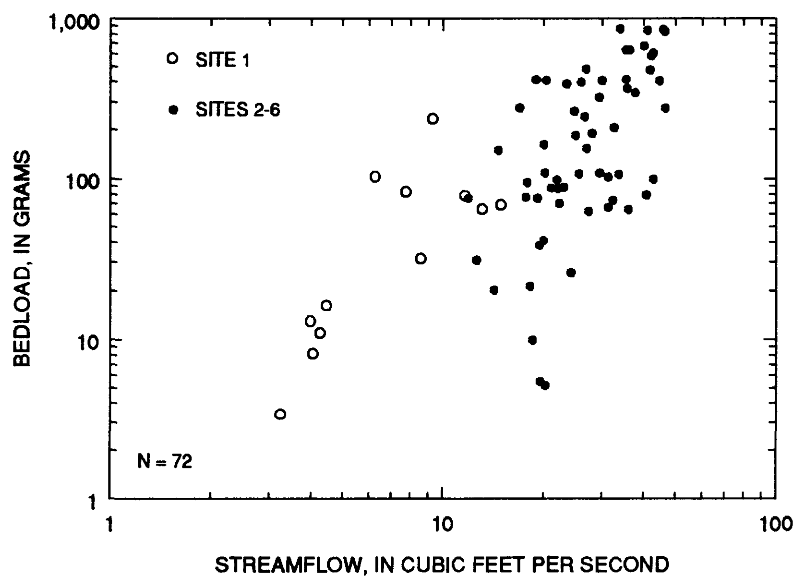


Figure 16. Variations in bedload and streamflow in Juday Creek, near South Bend, Indiana.

The relations of streamflow, suspended sediment, and bedload along the study reach of Juday Creek are summarized in figure 17. The medians for the 11 samples at each site are plotted. Suspended-sediment concentration increases from site 1 to site 2, remains fairly uniform through site 4, and then increases again through site 6. Bedload increases from site 1 to site 3, drops off sharply at site 4, and then increases through site 6. Streamflow increases steadily from site 1 to site 4 and then declines through site 6. This pattern, which also can be seen in most of the sampling events in table 6, shows that Juday Creek has a gaining reach and a losing reach. This trend also was noted by Silliman (1994). The upstream reach is affected by the inflow of ground water, whereas the downstream reach is losing flow to ground water (Arihood, 1994).

Variations in sediment discharge between sampling sites are shown in figure 18. Median suspended-sediment discharge, bedload discharge, and combined sediment discharge for the 11 storm samples are shown. Suspended-sediment discharge increases gradually along the entire reach. Bedload discharge increases from site 1 to site 3, then declines sharply downstream from the instream pond. Bedload discharge then increases from site 4 downstream to site 6. Figure 18, as well as figure 17, shows that bedload transport accounts for most of the sediment discharge.

Streamflow, suspended sediment, and bedload affect the overall sediment conditions in Juday Creek. Suspended sediment appears to have less effect on stream quality than does bedload. Bedload could alter the stream most significantly with respect to aquatic life.

Scour and Fill

Scour and fill, or changes in the streambed altitude, were measured by use of scour chains and with reference to surveyed channel cross sections. Scour chains are primarily a means for measuring streambed scour, but infilling over the chains also can be measured. Surveyed cross sections not only document areas of scour or fill, but also show (with time) changes in channel morphology.

Scour Chains

A scour chain is a short section of chain driven vertically into the streambed to record scour. As the streambed scours, the chain falls. The length of chain lying on the streambed equals the depth of scour at that point. The chain is buried with sediment if infilling occurs. Cycles of scour and fill can be recorded only with frequent measurement of scour chains. The use of scour chains, however, enables documentation of maximum scour at a site during a specific time period. During high flow, the streambed may scour to below pre-flood levels and then quickly refill. If the site were surveyed even a short time after the high flow, the maximum scour and subsequent fill may not be observed.

Scour chains were placed at each of the six sites along cross sections perpendicular to flow in straight reaches of channel. The chains were driven vertically into the streambed with a steel bar. The lower ends of the chains were driven below the level of anticipated scour, and the tops of the chains were level with the streambed. Flagging was attached to the top link to aid in locating the chains for recovery. The locations of the cross sections were marked and, by use of a tag line, the stationing of the chains (distance from the stream bank) was recorded. The tag-line stationing and a metal detector were used to pinpoint the locations of the scour chains for recovery when the measurements of scour and fill were made.

Thirty-one chains were placed in the stream channel, at least three chains at each site. Twenty-two of the chains were recovered at the end of the study. Table 7 lists the scour chains, by site, and the measured scour and fill. The scour chains are numbered from left to right looking downstream, so number 1 is always the closest to the left bank. At site 2, the scour chains were laid out in two cross sections about 30 ft apart.

The scour chain measurements indicate that the net change in streambed altitude for the study period (about 15 months) averaged about 0.1 ft at

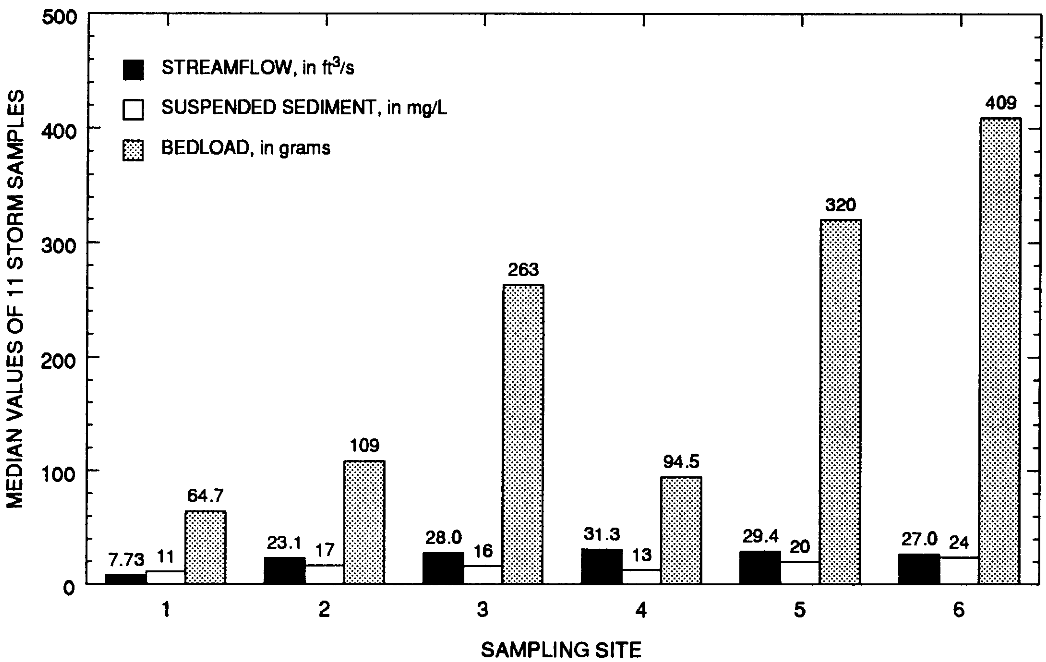


Figure 17. Relations of streamflow, suspended-sediment concentration, and bedload between sampling sites along Juday Creek, near South Bend, Indiana.

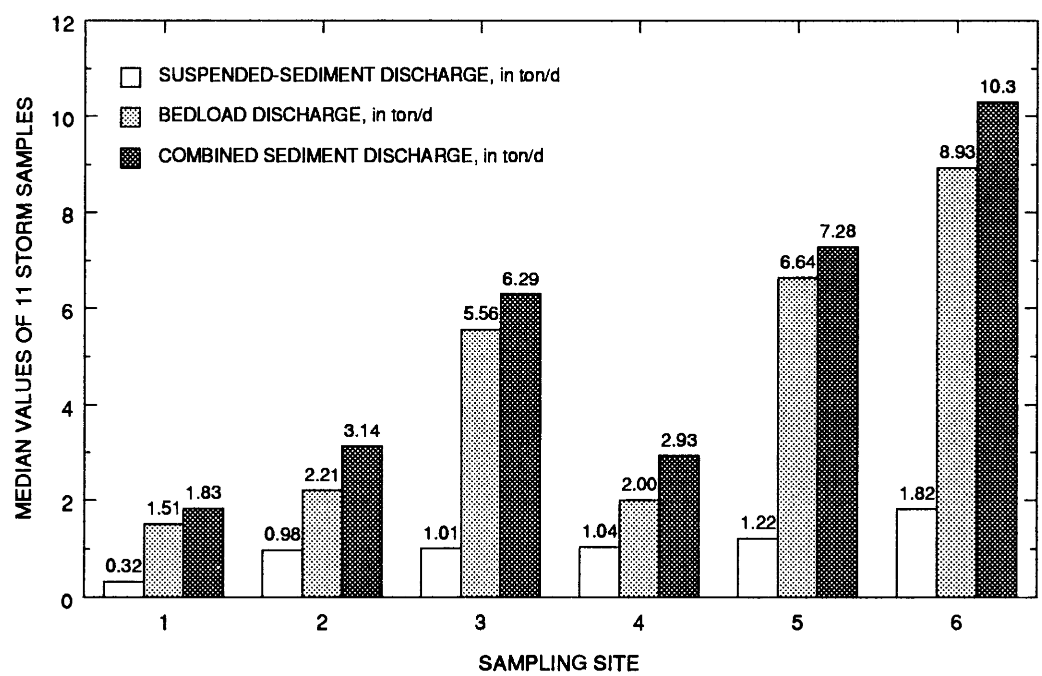


Figure 18. Variations in sediment discharge between sampling sites along Juday Creek, near South Bend, Indiana.

Table 7. Measurements of scour and fill by use of scour chains in Juday Creek, near South Bend, Indiana

[Chains were installed in April 1993 and remeasured in July 1994]

Chain number	Scour (feet)	Fill (feet)	Net change in streambed altitude (feet)	Streambed sediment type
1-1	0	0.07	0.07	
1-2	0	.28	.28	Sand
1-3	0	.43	.43	
2-1	.34	.46	.12	
2-2	.23	.40	.17	
2-3	*	*	*	Sand
2-4[1]	0	.08	.08	
2-5[1]	0	.17	.17	
2-6[1]	0	.14	.14	
3-1	.12	.10	-.02	
3-2	0	.08	.08	
3-3	.12	0	-.12	
3-4	0	.10	.10	Gravel
3-5	0	.08	.08	
3-6	0	.07	.07	
4-1	.12	0	-.12	
4-2	*	*	*	
4-3	*	*	*	Sand, gravel
4-4	.67	.69	.02	
4-5	.45	.11	-.34	
4-6	.12	.09	-.03	
5-1	0	.62	.62	
5-2	*	*	*	
5-3	*	*	*	Sand, gravel
5-4	*	*	*	
5-5	*	*	*	
5-6	*	*	*	
6-1	*	*	*	
6-2	0	0	0	Sand, gravel
6-3	0	.10	.10	
6-4	0	.17	.17	

*Chain was not recovered.

[1]Chain was located along a second cross section at site 2.

most of the study sites (table 7). Most of the scour chains indicated that the net change is infilling. At some sites, however, chains recorded a small amount of scour as the net change. Most of the chains that showed scour also showed subsequent infilling, a pattern that is consistent with the natural scour and fill cycles of a sandy streambed. The maximum observed scour was at site 4, near the center of the channel. Sites 1 and 5 show the most consistent pattern of infilling; no scour was observed. At site 5, only one of the scour chains was recovered. The infilling at site 5 also is documented in the surveyed cross sections (fig. 23).

Scour chains provide only point measurements of the changes in streambed altitude, and they may not represent streambed conditions for long reaches of channel.

Surveyed Cross Sections

Scour and fill at each site were also documented with reference to surveyed channel cross sections, which also record changes in channel morphology. Three separate cross sections were surveyed at each site. Their spacing ranged from about 25 to 165 ft. The cross sections were positioned so that they would not interfere with the scour chains. The locations of these cross sections were marked in the field so they could be resurveyed four times between April 1993 and April 1994. The surveying was done with a total station and a data logger that recorded the coordinates of the surveyed points and the land-surface altitude. Approximately 20 to 30 points were surveyed along each section to define the shape of the channel. With this number of points, the spacing was close enough to identify changes in the channel without having to resurvey the same points. An arbitrary datum was assumed at each site, and two reference marks were established so that horizontal and vertical control could be reproduced for all five surveys. Because the purpose of the surveyed cross sections was to document the relative changes in the streambed, the reference marks were not referenced to sea level.

A representative cross section from each site is included to show the relative changes in the channel throughout the study period (figs. 19–24). All the cross sections represent the view downstream. The survey of April 1993 represents the initial conditions. The survey of June 22–25, 1993, followed thunderstorms during which the South Bend area had almost 6 in. of rainfall (National Oceanic and Atmospheric Administration, 1993a). As a result of this heavy rainfall, Juday Creek reached an instantaneous peak flow of 226 ft^3/s at the USGS streamflow-gaging station on June 9 (Stewart and others, 1994, p. 217). The relative magnitude of this peak flow compared to the rest of the study period can be seen in the hydrograph for the study period (fig. 2). The November 1993 survey was an interim survey to monitor the streambed, and the April 1994 survey was the 1-year follow up to the initial survey. The channel cross sections also were surveyed in March 1994; however, they were not included in the figures because they were virtually the same as those for April 1994.

Site 1 is in an agricultural area where the channel has been dredged. The cross sections from site 1 show the trapezoidal shape of a dredged channel (fig. 19). Minimal bank loss and only minor fluctuations in the streambed altitude were noted at this site. The April 1994 cross section is close to the initial survey, showing some fill. The streambed is fairly stable, considering the sandy bed material (tables 3 and 4) and the straight reach. The stability probably can be attributed to the small drainage area, about 7.0 mi^2. Sufficient streamflows and velocities did not occur during the study period to induce significant sediment transport.

Site 2 also has a trapezoidal channel but not as symmetrical as the channel at site 1 (fig. 20). The high flows of June 1993 scoured the base of the left bank, which remained scoured through the final survey. The June 1993 survey also shows almost 1 ft of scour along some of the streambed; however, by November 1993, much of this area had refilled.

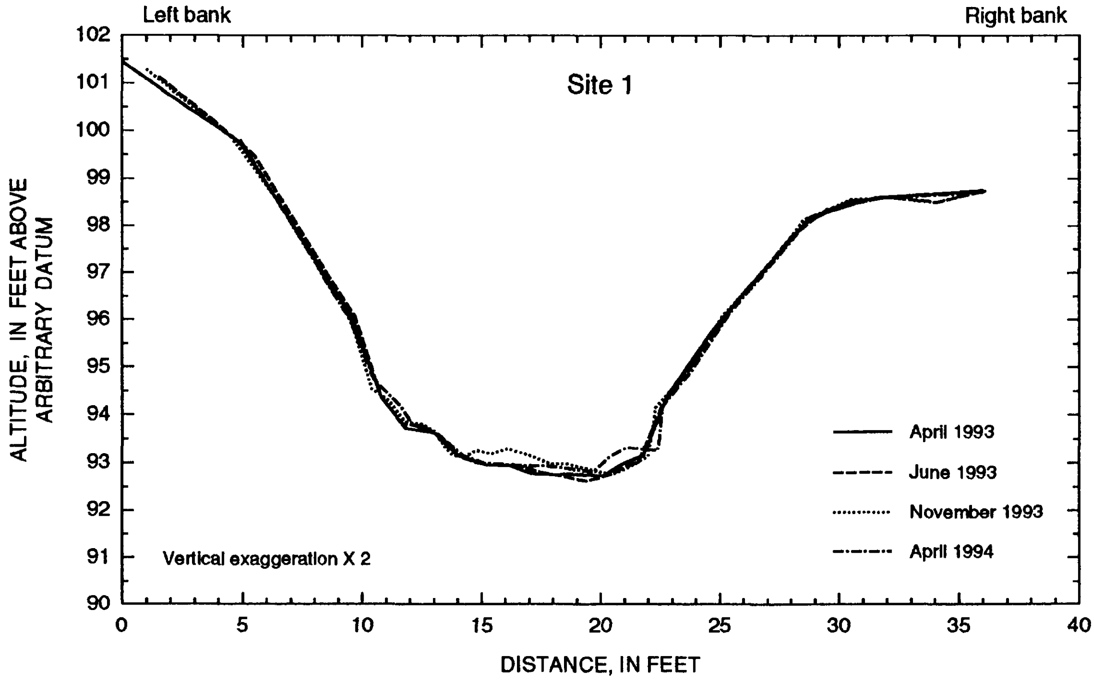


Figure 19. Channel cross sections from four surveys showing scour and fill at site 1 on Juday Creek, near South Bend, Indiana.

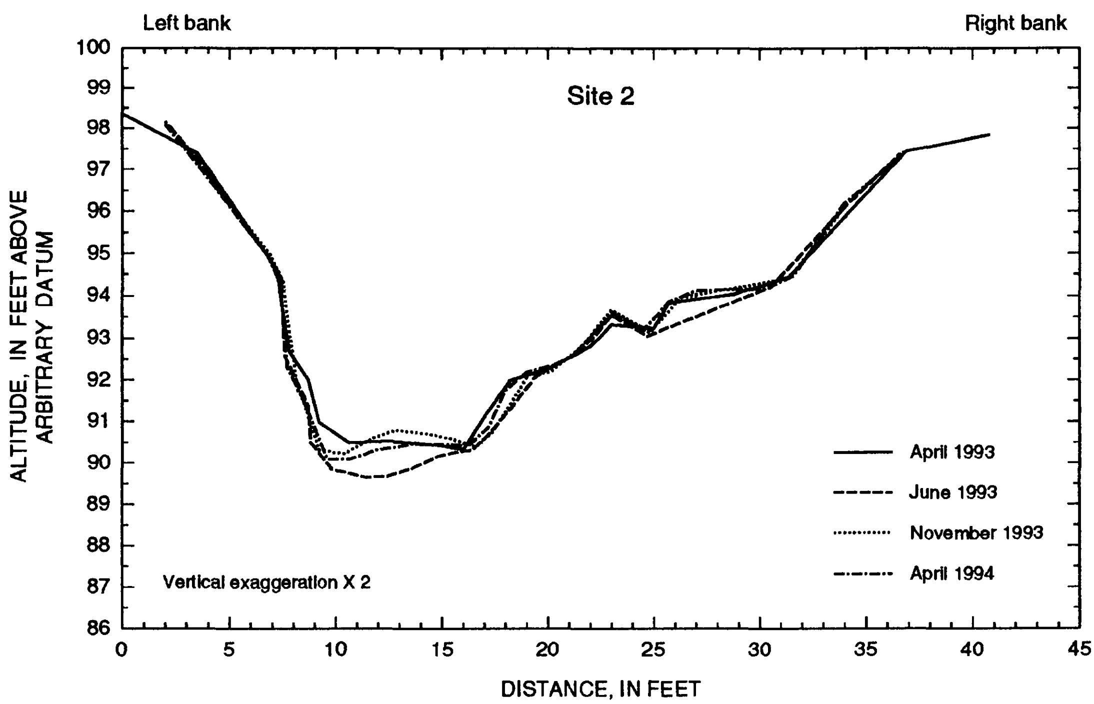


Figure 20. Channel cross sections from four surveys showing scour and fill at site 2 on Juday Creek, near South Bend, Indiana.

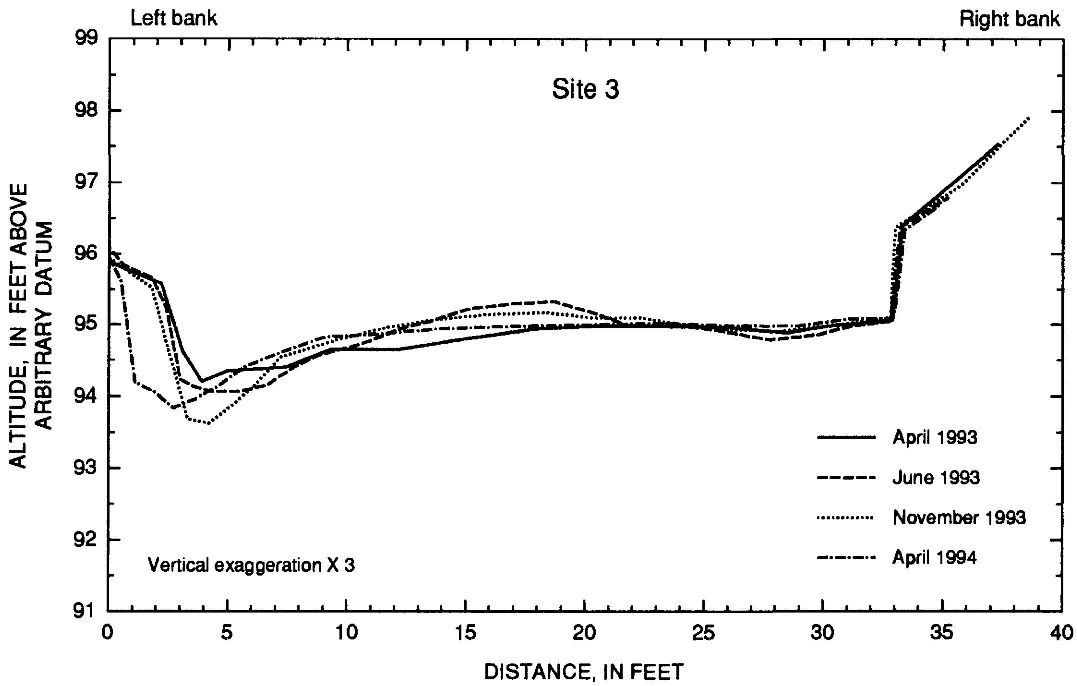


Figure 21. Channel cross sections from four surveys showing scour and fill at site 3 on Juday Creek, near South Bend, Indiana.

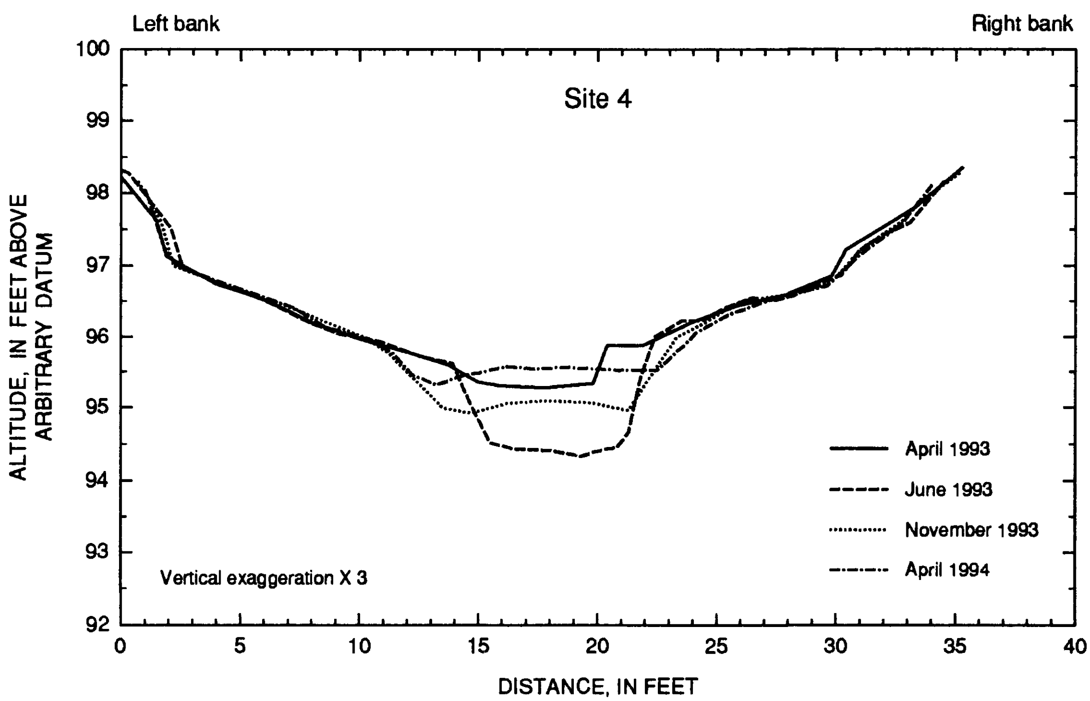


Figure 22. Channel cross sections from four surveys showing scour and fill at site 4 on Juday Creek, near South Bend, Indiana.

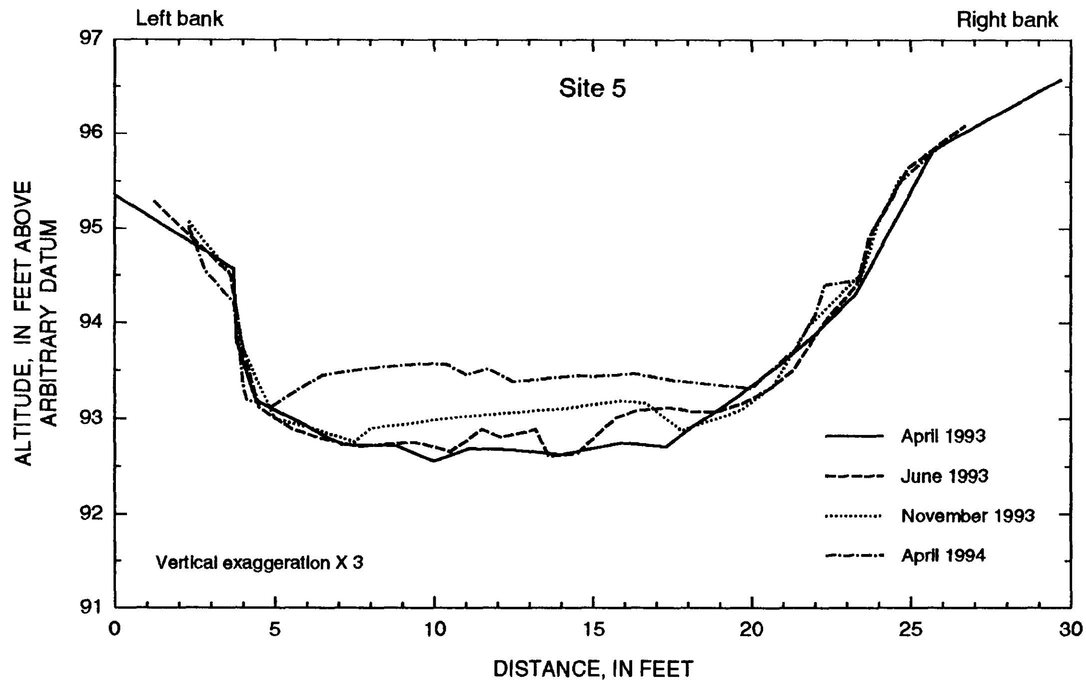


Figure 23. Channel cross sections from four surveys showing scour and fill at site 5 on Juday Creek, near South Bend, Indiana.

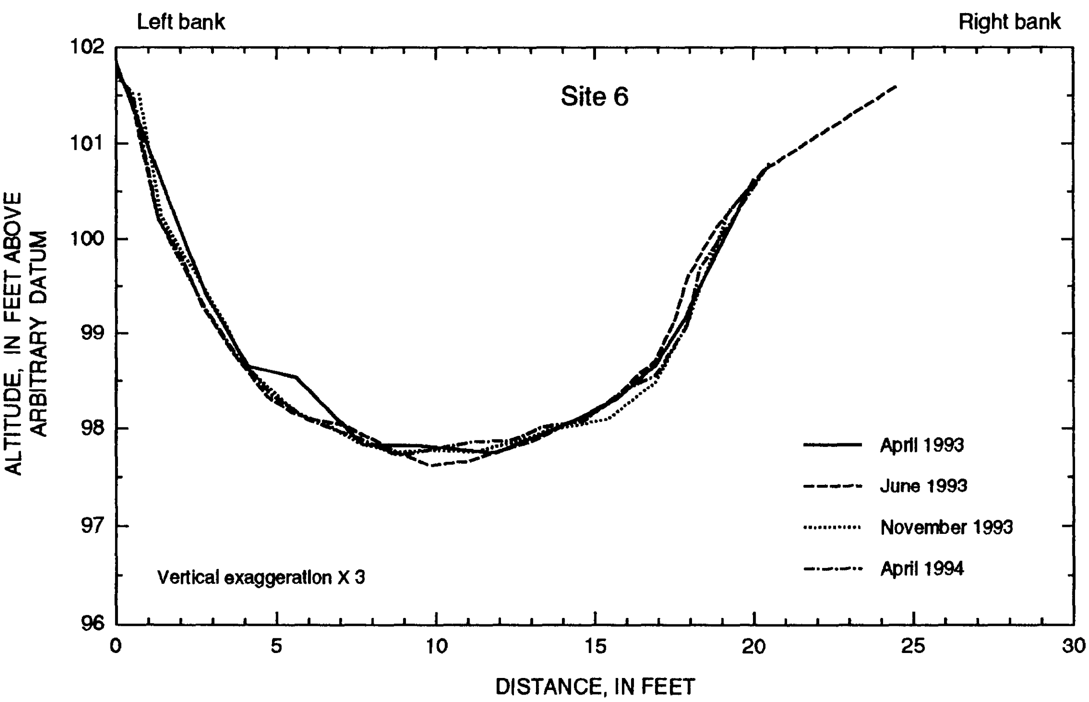


Figure 24. Channel cross sections from four surveys showing scour and fill at site 6 on Juday Creek, near South Bend, Indiana.

By April 1994, the streambed returned to virtually the same conditions as during the initial survey 1 year before, except for the left side of the channel which remained about one-half foot lower. This fluctuation of the streambed with changing streamflow can be expected where the streambed material is sand or finer particles.

Site 3 is at the inlet to the instream pond, where the channel is wider and the banks are lower (fig. 21). The streambed along this reach is mostly firm gravel. As Juday Creek flows into the instream pond, it meanders to the right; this meander explains the relatively stable right side of the channel and the scoured left bank. The fill near the middle of the channel is in response to the redistribution of flow to the left where the channel area is increasing. The scour and fill at this cross section is limited to only about one-half foot, but the base of the left bank has shifted about 3 ft to the left.

The maximum observed scour occurred at site 4 as a result of the heavy rains of June 1993 (fig. 22). The maximum scour below the April 1993 streambed level was about 1.4 ft. This cross section is just upstream from the scour chains, which recorded a maximum scour of 0.67 ft (table 7). The November 1993 and April 1994 surveys indicate that the streambed had been refilling since June 1993. Most of the scour and fill at site 4 has occurred near the middle of the channel, where the velocity is highest and the water is deepest. The particle-size analysis of the streambed material indicates that the streambed in the middle of the channel is mostly very fine pebbles; closer to the banks, the streambed is medium sand.

Site 5 is the only site where most of the channel has continuously infilled (fig. 23). The maximum fill is about 1 ft; at most places, the channel has filled about 0.7 ft to 0.8 ft. This accumulation of sand made recovery of the scour chains difficult. The sediment accumulation along this reach probably is caused by a stone dam just downstream from the study site. The stone dam pools the water and functions as a sediment trap for the bedload, which would otherwise probably continue to travel downstream. Parts of the reach between sites 4 and 5 were not accessible. Conditions along this reach could contribute to the increased sedimentation at site 5. The particle-size analysis of the streambed material shows that most of the streambed is gravel (tables 3 and 4). The bed-material samples, however, were collected in August 1993. The streambed was very firm when the scour chains were driven into the channel (April 1993). The bed-material samples and the firm conditions noted at that time indicate that the "normal" streambed is coarser and firmer than the loose sand that was found during the April 1994 survey.

This trapping of the sandy bedload also was observed at a rock riffle about 300 ft upstream from site 3. Sediment trapping observed at these sites indicates some bedload storage in the channel. Increased streamflow or changes in the riffles could facilitate a pulse of bedload transport.

The streambed at site 6 is a firm sand and gravel channel that has undergone little change during the study period (fig. 24). Site 6 is on the Izaak Walton League property just upstream from the confluence of Juday Creek and the St. Joseph River. The stream gradient along this reach is steeper than that of the upstream reaches. The particle-size analysis indicates that the streambed is sand and gravel, but there is coarser material along this reach that was too large for the sampler. Some of the irregularities in the cross sections at site 6 may be a result of the surveying rod resting on large cobbles for one survey but not for others.

YIELD OF SEDIMENT

Sediment yield was determined for the upper reach of Juday Creek, which includes the area upstream from the instream pond. The lower reach is from the Izaak Walton League sediment trap near the mouth, upstream to the instream pond. Sediment yield could not be calculated for the lower reach. The sediment trap was near full capacity at the original survey, and it was not dredged during the course of the study; therefore, a change in volume could not be calculated.

The bottom of the 6-acre instream pond was surveyed in April 1993 and April 1994 to determine the volume of sediment delivered to the pond during 1 year. Nineteen cross sections were surveyed, most of them traversing the delta where Juday Creek flows into the pond. The vertical and horizontal datum for the pond surveys were the same as those established for site 3. A total station was used to survey in the shallow water around the delta, and a fathometer was used to record continuous profiles where the water was deep. The total station recorded northing and easting coordinates as well as altitude. Coordinates and altitudes also were determined for the data points used from the fathometer records.

The surveyed data for the surface of the pond bottom was contoured by use of ARC/INFO[1], a geographic information system. The time periods represented by the contour maps are April 1993 and April 1994 (figs. 25 and 26). Juday Creek enters the pond in the southeast corner, where a delta has formed. A change in the shape of the delta can be seen between the two contour maps. The general shape of the delta is outlined by the 90- to 95-ft contour lines. The April 1994 map shows that the delta is broader and that it has prograded to the northwest. Away from the delta, in the deeper water, little change was detected, an indication that most of the sedimentation was at the delta. To identify the areas of sediment accumulation more closely, ARC/INFO was used to compute the difference between the April 1993 surface and the April 1994 surface (fig. 27). Figure 27 shows that most sediment accumulated around the delta where it drops off to deeper water. Some of the area in the southeast corner of the pond where sediment has not accumulated is above the water surface. The sediment accumulation along the north and south shorelines probably is from bank erosion.

[1]Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Areas of sedimentation and the changing shape of the delta also can be seen in cross sections (fig. 28). The locations of these cross sections are shown on the contour maps. Section E-E′ is closest to the inlet and shows the least amount of sedimentation. The water is shallow and swift as it flows through this area, and this condition is not conducive to deposition. The large trough at the left end of the section is in an area of backwater and does not receive much direct flow. Section E-G shows that sedimentation has occurred along most of the section, especially in the trough at the northeast edge of the delta. As much as 5 ft of sediment has accumulated here in a 1-year period. Section E-K also shows sedimentation along most of the section. The thickest accumulation of sediment is about 160 ft from endpoint E. Figure 27 shows a thick accumulation of sediment in this area just to the northwest of section E-K.

ARC/INFO was used to estimate the volume of sediment deposited between April 1993 and April 1994. A water-surface altitude of 96 ft was assumed, and pond volumes were computed for both surveys. The difference between the two was assumed to be the volume of sediment. The sediment accumulation along the north and south shorelines probably is from bank erosion and cannot be attributed to stream sediment transport (fig. 27). An analysis of the trend of sediment thickness showed that this sediment accumulation was not associated with the fluvial sedimentation near the delta. Therefore, this area of the pond was not included in the estimate of the volume of sediment. Only the area east of section E-N was used to estimate the volume of sediment. This assumption may underestimate the sediment yield, especially the suspended-sediment contribution, but it prevents the inclusion of sediment believed not to be derived from Juday Creek.

The volume of sediment deposited in the instream pond between April 1993 and April 1994 was estimated to be 26,500 ft^3, or about 0.6 acre-ft. The drainage area at the pond is approximately 27.9 mi^2. The sediment yield, in terms of volume, for the upper reach of Juday Creek from April 1993 to April 1994 was estimated to be about 950 ft^3/mi^2.

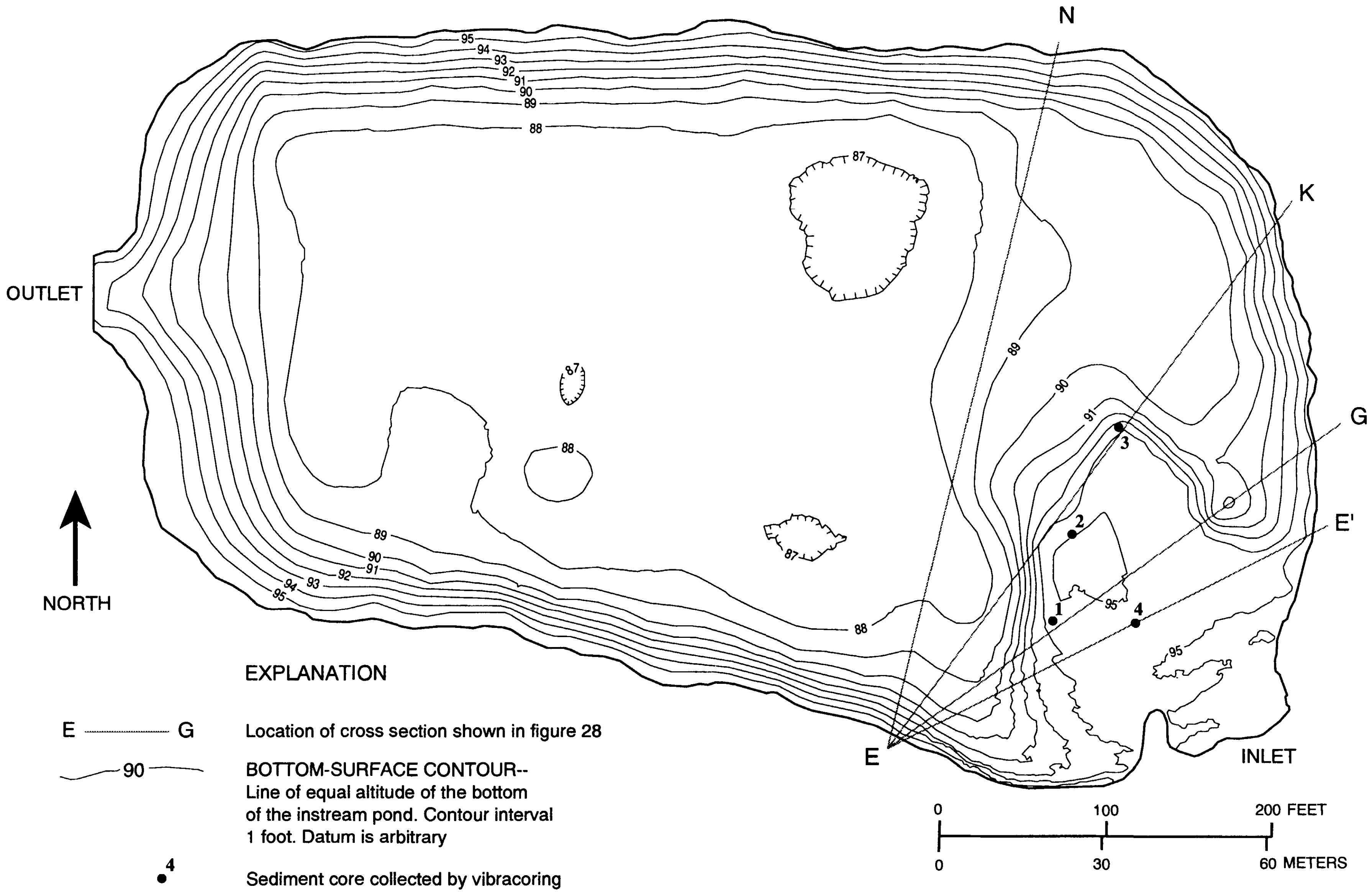
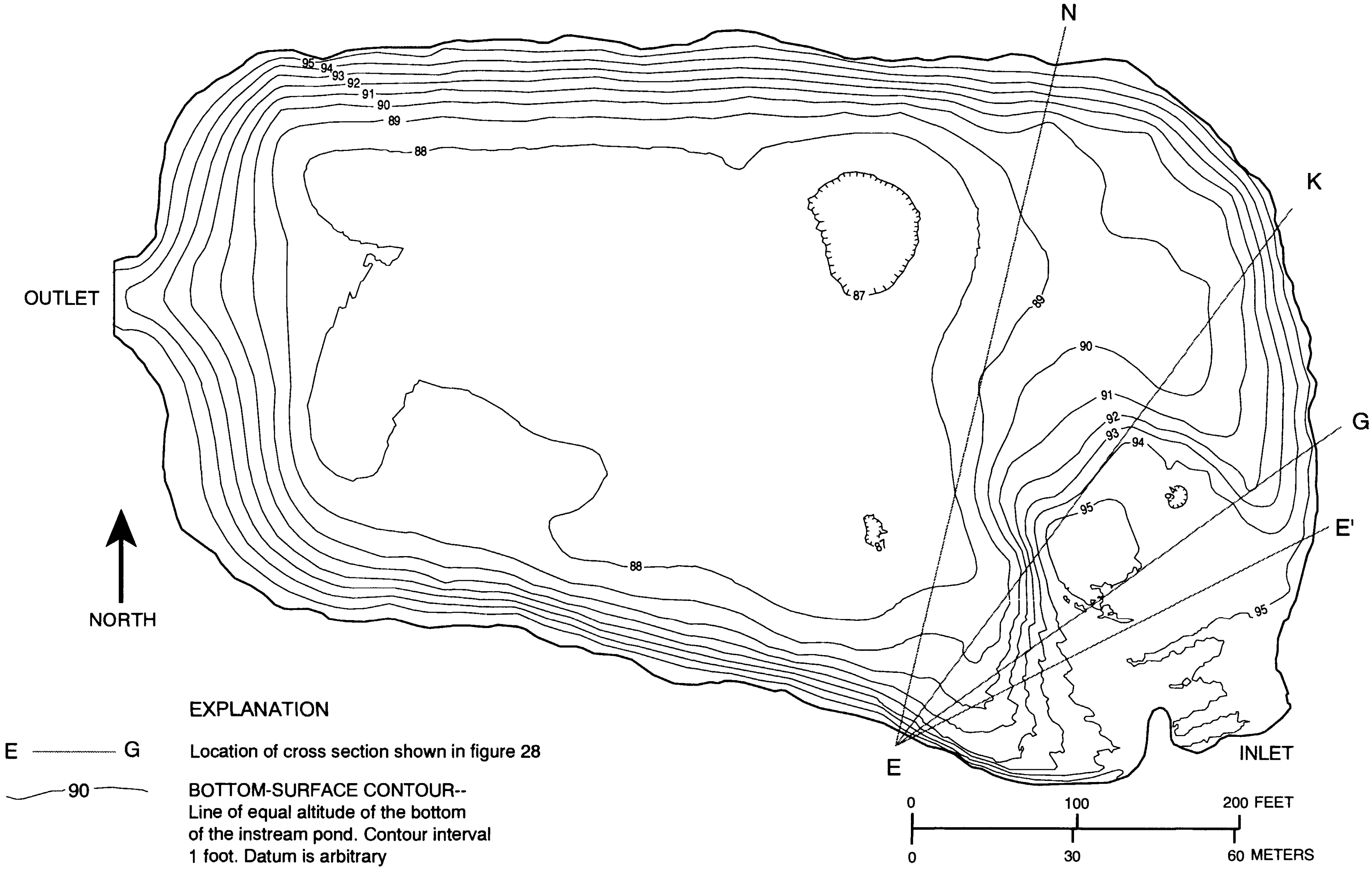


Figure 25. Configuration of the bottom of the instream pond on Juday Creek, near South Bend, Indiana, April 1993.

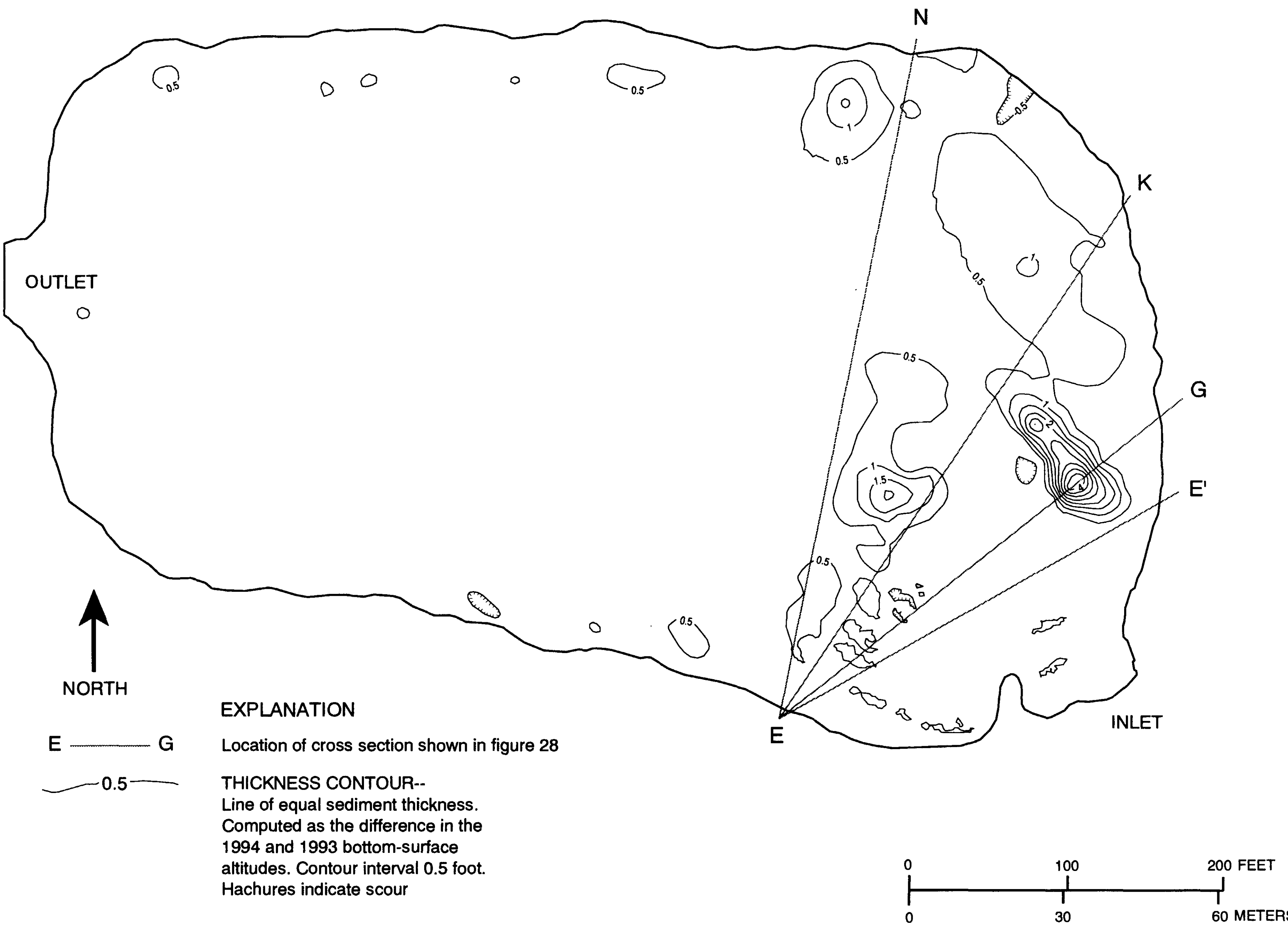


EXPLANATION

E ——— G Location of cross section shown in figure 28

—90— BOTTOM-SURFACE CONTOUR--Line of equal altitude of the bottom of the instream pond. Contour interval 1 foot. Datum is arbitrary

Figure 26. Configuration of the bottom of the instream pond on Juday Creek, near South Bend, Indiana, April 1994.



EXPLANATION

E ——— G Location of cross section shown in figure 28

—0.5— THICKNESS CONTOUR--
Line of equal sediment thickness. Computed as the difference in the 1994 and 1993 bottom-surface altitudes. Contour interval 0.5 foot. Hachures indicate scour

Figure 27. Sediment accumulation at the instream pond on Juday Creek, near South Bend, Indiana, April 1993 through April 1994.

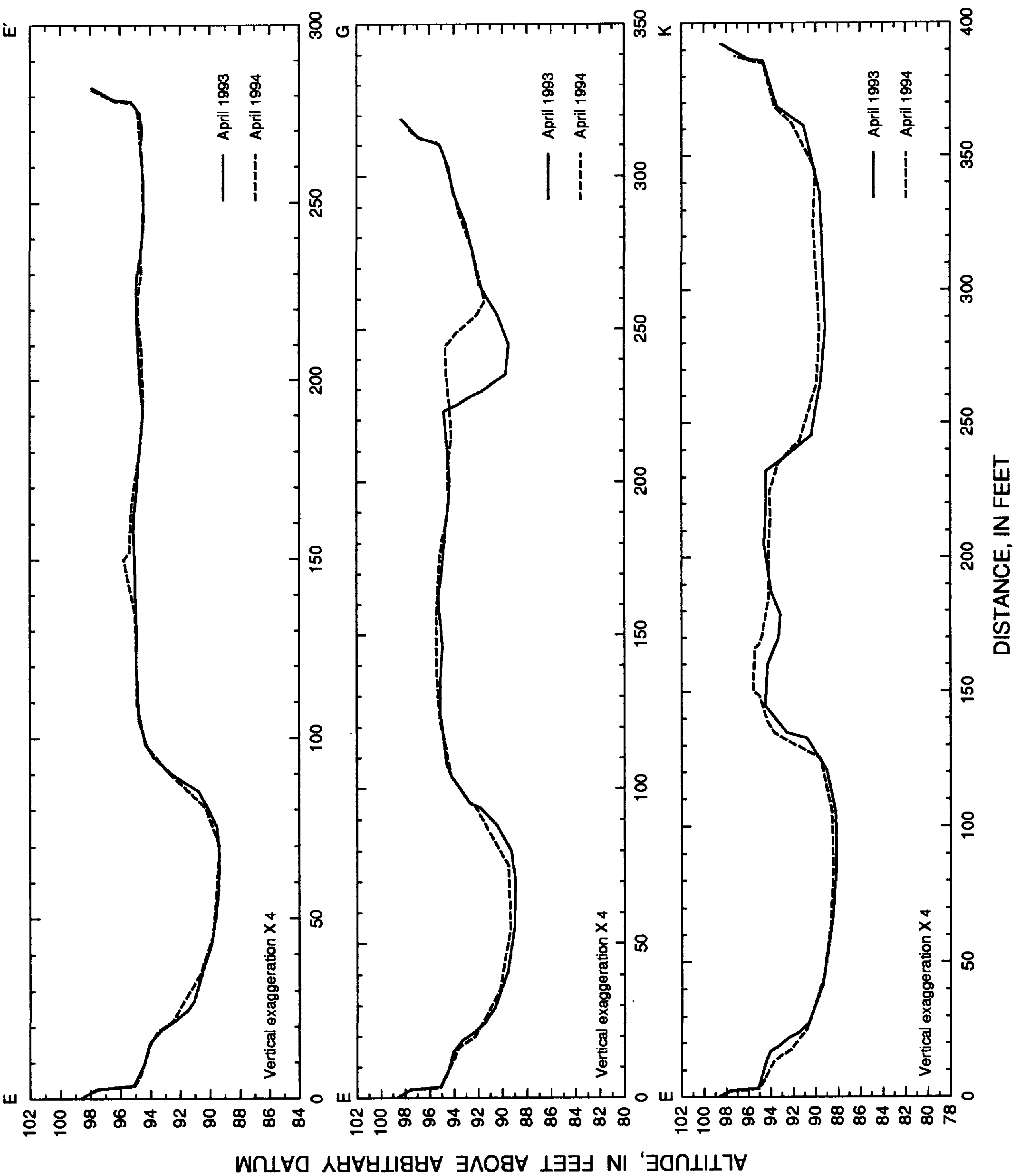


Figure 28. Cross sections of the instream pond on Juday Creek, near South Bend, Indiana, April 1993 and April 1994. Locations of the cross sections are shown in figures 25–27.

Sediment samples were collected along the delta edge for particle-size distribution analyses. The results show that the sediment being deposited on the delta is predominantly medium to coarse sand, with only a trace finer than 0.062 mm (table 3). Any finer grained material not deposited with the sand would have been deposited in deeper water. No significant accumulations of sediment are in the areas of deeper water (fig. 27). The graphs of sediment discharge show that bedload discharge usually is much higher than suspended-sediment discharge at site 3 (figs. 11, 13, and 15). Given the grain-size distributions and the data from site 3, it is assumed most of the sediment is transported onto the delta as bedload.

Estimation of the sediment yield in terms of weight required an estimate of the bulk density. The bulk density or volume weight of the sediments was estimated by collection of core samples with known volumes along the delta edge where sedimentation occurred. Three samples were collected in 1-foot long cylinders, and the volume weight ranged from 99 to 104 lb/ft^3. The average volume weight was estimated to be 102 lb/ft^3; therefore, the sediment load for the year was 1,350 tons. The sediment yield in terms of weight for the upper reach of Juday Creek from April 1993 to April 1994 was about 48 ton/mi^2. The daily average sediment load into the pond for the 1-year period was 3.7 ton, and the daily average sediment yield was 0.13 ton/mi^2.

The sediment yield cannot be compared directly to yields published for other streams in Indiana. No known sediment-yield data are available that include the contribution of bedload. Crawford and Jacques (1992) studied the suspended-sediment in Trail Creek at Michigan City, Ind. They estimated that the annual suspended-sediment yield for the 1981–90 water years ranged from 68 to 153 ton/mi^2 and averaged 114 ton/mi^2. A study of the suspended-sediment characteristics of streams in Indiana included 15 streams in the Northern Moraine and Lake Region (Crawford and Mansue, 1988, p. 67). Estimated average annual suspended-sediment yields of these streams ranged from 11 to 152 ton/mi^2; the median yield was 59 ton/mi^2. The estimated sediment yield for Juday Creek is in reasonable agreement with results from these studies; however, because the other studies do not account for bedload discharge, direct comparisons cannot be made.

SUMMARY AND CONCLUSIONS

Juday Creek is a small tributary to the St. Joseph River that drains 37.7 mi^2 of north-central Indiana. The sediment conditions of the stream were examined during 1993 and 1994 to determine the characteristics, transport, and yield of sediment in Juday Creek. This report includes analyses of bed material, suspended-sediment concentration, and bedload at six sampling sites. Sediment cores were collected from the pond delta and sediment trap. Cross sections were surveyed and scour chains were used to evaluate scour and fill at the six sites. An instream pond was surveyed in April 1993 and again in April 1994 to estimate the sediment yield for the upper reach of Juday Creek.

The particle-size distribution of the bed material and the sediment core descriptions document the sediment characteristics of the streambed of Juday Creek. The streambed along most of the channel is composed of medium sand. In the upper reaches of the stream, the streambed is primarily fine to medium sand. Near the instream pond, bed material becomes a mixture of sand and gravel. Bed-material and sediment cores collected from the pond delta indicate that medium to coarse sand is the predominant particle size being deposited at that location. The bed material in the lower reach of the stream is sand and gravel. The most downstream reach has a stable streambed of gravel and sand; this reach has the coarsest particles in the entire length. The particle-size distributions of all samples indicate that most of the bed material is coarser than 0.062 mm—that is, sand size and larger.

Measurements made during low flows and storms and additional measurements of scour and fill were analyzed to determine sediment transport in Juday Creek. Streamflow, suspended sediment, and bedload were measured during three storms and during a low-flow period. Scour and fill were measured by means of scour chains and surveyed cross sections. Changes in channel size and shape during the study period were determined from surveyed cross sections.

Sediment samples collected during the low flows provided data for comparison to those collected during storms. The median suspended-sediment concentration was 2.5 mg/L, and the median bedload was 17.1 g. These values, although low, indicate that some sediment transport occurred even during periods of low flow.

Measurements of streamflow during the storm sampling ranged from 3.24 to 46.5 ft^3/s. Streamflow measurements along Juday Creek indicate gaining and losing reaches. In the upper reach, the stream receives inflow of ground water; the downstream reach loses flow to ground water.

Suspended-sediment concentrations did not correlate strongly with streamflow. The concentrations tended to peak before the streamflow peak and then gradually diminish. Concentrations in storm samples analyzed were less than 70 mg/L, and in most samples were 30 mg/L or less. The median suspended-sediment concentration was 17 mg/L. These concentrations are below levels reported to have significant adverse effects on brown trout and other salmonids.

Bedload along Juday Creek was variable. During low flows loads ranged from 5.2 to 76.7 g. For the three storms, loads ranged from about 3.4 to 862 g; the median was 109 g. Although highly variable, bedload correlates with streamflow. Median values of bedload generally increased downstream. As streamflow increased, so did amounts of bedload. During almost all sampling events, bedload discharge exceeded suspended-sediment discharge. Bedload discharge is the predominant mode of sediment transport along the entire stream.

Measurements from the scour chains indicate that the net change in streambed altitude for the study period was minimal (–0.34 to 0.62 ft) but that some infilling occurred at most of the study sites. Surveyed cross sections documented that scour and fill has occurred at most of the sites, and that bank erosion occurred at two sites. Scour and fill tended to balance out; after a 1-year period, the average net change in the streambed altitude was about 0.1 ft. At one of the sites, the channel progressively filled throughout the study period. The infilling was likely caused by a low stone dam that functions as a bedload trap. The trapping of bedload at a rock riffle also was observed just upstream from the instream pond. This trapping indicates not only storage, but also movement of sediment along the stream.

Sediment yield for the upper reach of Juday Creek was estimated by determining the volume of sediment delivered to the instream pond during a 1-year period. The bottom of the pond was surveyed in April 1993 and in April 1994. A geographic information system was used to contour the bottom surface of the pond for both surveys and to compute the decrease in volume of the pond between the surveys. The difference in the volumes was assumed to be the volume of sediment delivered to the pond. The volume of sediment deposited in the pond was estimated to be 26,500 ft^3. Most of the sediment was sand deposited on a delta at the upstream end of the pond. The average volume weight of the sediment was estimated to be 102 lb/ft^3; therefore, the total weight of sediment deposited was 1,350 tons. The sediment yield from April 1993 to April 1994 was estimated to be about 48 ton/mi^2.

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