U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

FIELD COMPARISONS OF SIX PRESSURE-DIFFERENCE BEDLOAD SAMPLERS IN HIGH-ENERGY FLOW

by

Dallas Childers

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Manuscript preparation and graphic design by Christine G. Janda. Selected graphics by Lisa Faust.

Conversion Factors

The International System (SI) units used in this report can be converted to inch-pound units by using the following conversion factors:

MULTIPLY	BY	TO OBTAIN
kilogram (kg)	2.205	[1]pound (lb)
kilogram per second-meter (kg/s-m)	0.6705	pound per second-foot (lb/s-ft)
kilometer (km)	0.6214	mile (mi)
square kilometer (km^2)	0.3861	square mile (mi^2)
meter (m)	3.281	foot (ft)
square meter (m^2)	10.76	square foot (ft^2)
meter per second (m/s)	3.281	foot per second (ft/s)
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)
millimeter (mm)	0.903937	inch (in.)

Temperature in degrees Celsius can be converted to degrees Fahrenheit by using the following formula:

$$°F = 1.8 x °C + 32.0$$

[1] This dquivalence, from mass to weight, is based on a gravitational acceleration of 32.17 foot per second per second.

Explanation of Terms

active bedload zone – a part of a cross section of a stream having measurable bedload transport.

bedload – sediment moving on or near the streambed, by rolling, sliding, and skipping.

bedload discharge – the quantity of bedload passing a cross section of a stream in a unit of time.

bedload sampler – a device for sampling bedload.

bedload sampling efficiency – bedload transport rate sampled by a bedload sampler divided by the true bedload transport rate that would have existed if the ampler were not present on the streambed, expressed as a decimal.

bedload transport rate – a quantity of bedload passing through a cross section or portion of a cross section of a stream in a unit of time.

bed material – the sediment mixture of which the bed is composed.

cross-section density – the mass of the bedload sampler divided by the area of its cross-section perpendicular to the flow, in grams per square centimeter.

hydraulic effieiency – mean velocity of flow that enters the sampler nozzle (spatially-integrated across the nozzle entrance area) divided by the ambient velocity that would have existed if the sampler were not present on the streambed, expressed as a decimal.

intake nozzle – a

nozzle area-expansion ratio – the ratio of the cross-section area of the sampler nozzle where flow exits its downstream end divided by the cross-section area of the sampler nozzle where flow enters its upstream end.

pressure-difference bedload sampler – a

representative bedload sample – a bedload sample equal to the true bedload transport and having the true bedload particle-size distribution, within defined limits of error.

sampled bedload – a sediment sample collected by a bedload sampler. The sample includes a part of the true bedload (determined by the bedload sampling efficiency of the sampler) and a part of the suspended-sediment load (determined primarily by the hydraulic efficiency of the bedload sampler) moving in the zone defined by the height of the bedload sampler near the streambed.

sampled bedload transport rate or sampled bedload rate – the instantaneous rate of bedload transport sampled at a point on the streambed (sampled in a zone the width of the sampler nozzle) in kilograms per second.

sampling interval – the time interval from the start of one bedload sampling time at a point on the streambed to the start of the next sampling time at the same point on the bed; for example, a sample taken every five minutes denotes a 5-minute sampling interval.

sampling period – the duration of the sampling activity; for example, when samples are collected from 10:30 to 11:16 a.m. at a single point on the streambed once every five minutes (5-minute sampling interval), using a sampling time of 60 seconds, the sampling period would be 46 minutes.

EXPLANATION OF TERMS—*continued*

sampling time – the time that the bedload sampler is resting on the streambed and collecting bedload, in seconds.

sampling point or sampling station – a point on the streambed within a cross section where a bedload sample is collected.

sediment discharge – the mass or volume of sediment (usually mass) passing a stream transect in a unit of time. The term may be qualified, for example, as suspended-sediment discharge, bedload discharge, or total-sediment discharge.

sediment particle-size classification – the classification used in this report agrees with recommendations made by the American Geophysical Union Subcommittee on Sediment Terminology. The classification used follows:

sand	.062 to 2.00 millimeters
gravel	2.00 to 64.0 millimeters
cobble	64.0 to 256 millimeters
boulders	>256 millimeters

suspended sediment – sediment that is suspended by the upward components of turbulent currents.

true bedload transport rate – the bedload transport rate at a point representative of unit width of the bed, as kilogram per second per meter width of the streambed.

unit bedload transport rate – the bedload transport rate at a point representative of unit width of the bed, as kilogram per second per meter width of the streambed.

unsampled zone – the zone in a sampling vertical between the suspended-sediment sampler nozzle and the bottom of the sampler that is normally unsampled by a sampler.

Field Comparisons of Six Pressure-Difference Bedload Samplers in High-Energy Flow

By Dallas Childers

ABSTRACT

Field comparisons of sampling characteristics of six pressure-difference bedload samplers, modeled after the Helley-Smith bedload sampler, were made in a natural stream having turbulent, high-velocity flow and high bedload transport rates. The samplers have intake nozzles with entrance dimensions (width and height) ranging from 76 x 76 millimeters to 305 x 152 millimeters and include nozzle area expansion ratios of 1.40 and 3.22. Hydraulic efficiencies of the bedload samplers range from 1.35 to 1.54. Two of the sampler nozzles were also tested with modified sampler frame and tail configurations.

Data from thirteen field tests were used to compare bedload samplers. During each field test, 23 to 63 individual samples were collected. During most tests, the same number of samples was collected for each bedload sampler tested. Most field tests were conducted by sampling alternately with differently designed samplers at one common point on the bed. Sampling times ranged from 4 to 60 seconds, sampling intervals ranged from about 3 to 5 minutes, and sampling periods ranged from about 2.5 to 4 hours.

Flow velocities and depth were measured at the sampling vertical once during each field test. During different tests, measured velocities ranged from 2.12 to 3.16 meters per second, depths ranged from 0.55 to 1.46 meters, and computed Froude numbers ranged from 0.61 to 0.97. Individual sampled bedload rates ranged from 0.004 to 15.9 kilograms per second-meter and were variable through a range of at least two orders of magnitude during a sampling period. During different tests, calculated mean sampled bedload rates ranged from 0.076 to 9.09 kilograms per second-meter. Bedload sediment collected during different field tests had mean intermediate particle diameters that ranged from 0.93 to 36.2 millimeters.

Evaluation of field performance for each of the 6 bedload samplers tested showed that only the Toutle River-1 and Toutle River-2 bedload samplers were stable in high-energy flow without the use of a stayline. However, use of a stayline improved the stability of all bedload samplers tested.

The sampling ratio of each pair of samplers tested was computed by dividing the mean bedload transport rate sampled by one sampler by the mean rate sampled by a

second sampler. Ratios of sampled bedload rates between all sampler pairs ranged from 0.40 to 5.73. These ratios provide insight into relative sampling characteristics of bedload samplers during high-energy flow. The Toutle River-2 bedload sampler was developed in this study for sampling bedload under conditions of high velocity and turbulence and high sediment transport rates. This sampler has a mass of 100 kilograms, overall length of 1.52 meters, nozzle entrance that is 305 millimeters wide and 152 millimeters high, and hydraulic efficiency estimated at 1.40. The Toutle River-1 bedload sampler appears to provide representative bedload samples of bedload consisting of a mixture of sediment in the size range between 1.0 and 128.0 millimeters.

INTRODUCTION

Field measurement of bedload transport has been restricted by the lack of a selection of samplers to use under different bedload transport conditions. Large variations in ***bedload transport rate***, particle-size distribution, and bed topography (Carey, 1985, Hubbell and others, 1986; Pitlick, 1988; Dinehart, 1989) occur at different stream sites and even at different times at the same stream site. Because of this variability, several bedload samplers of different designs may be needed to sample ***bedload*** under a wide range of sediment transport and hydraulic conditions.

The 1980 eruptions of Mount St. Helens, Washington, created hydrologic conditions that contributed to high energy flow in streams near the volcano. The flows were characterized by high velocity and turbulence and unusually high transport rates of both ***suspended sediment*** and bedload (Childers and others, 1987). The lateral blast and subsequent ashfall on May 18, 1980, deposited erodible sediment on steep mountainous terrain near the volcano. A debris avalanche that traveled about 22 km (kilometer) down the valley of the North Fork Toutle River deposited a large mass of sediment readily available for transport. Mudflows in the basin drastically altered the original pool-and-riffle channel geometries leaving steep-sloped, sand-dominated channels. As a result, streamflow in these channels was endowed with the potential for higher velocities and greater ***sediment discharges***. Under these conditions, bedload transport rates commonly exceed the calibration transport rate defined for available ***bedload samplers***. Also, ***intake nozzles*** on most bedload samplers are not large enough to sample the large bedload sediment sizes often transported. A bedload sampler is needed to sample high rates of bedload transport. A rare opportunity existed in the Toutle River after the events of May 18, 1980, to evaluate relative bedload sampling rates and other performance characteristics of several bedload samplers under extreme conditions.

Errors that may arise during the sampling of bedload need to be clearly defined. Potential sources of error that need to be examined include: (1) sampler design and calibration of hydraulic and sediment-trapping efficiencies to maximize bedload sampler performance under different types of bedload and sampling conditions, (2) the techniques of sampling bedload to minimize errors in the collection of individual samples, and (3) the design of bedload sampling programs to obtain samples representative of variations in bedload transport rates and particle size distributions in space and time.

Purpose and Scope

The purpose of this study was to assess different bedload samplers for use in high-energy flow having high velocity and turbulence and high bedload transport rates. A second purpose was to reduce sources of error in sampling bedload.

This report presents the results of field tests of six ***pressure-difference bedload samplers***. Comparisons were made of field performance characteristics and sampling rates of bedload samplers having intake nozzles previously calibrated in flumes under laboratory conditions. Comparisons were made under field conditions that included high-energy flow, high bedload transport rate, and transport of a wide range of bedload particle sizes.

Potential sources of error during bedload sampling were examined, including effects of sampler design and fabrication details, equipment and techniques used during sampling, and design of the sampling program. Effects of variations in fabrication details of bedload samplers were tested to assess their effect on stability of the samplers and enhance their sampling characteristics. Sampling techniques and equipment that minimize inaccuracies in bedload sampling also were evaluated. The effects of sampling program design were assessed.

Previous Investigations

The original Helley-Smith bedload sampler has been calibrated in both field and flume studies at relatively low flow velocities and bedload transport rates (Helley and Smith, 1971; Druffel and others, 1976; Emmett, 1980; 1981). Calibration curves of sediment-trapping efficiency as determined in a flume also have been made available for the four bedload sampler nozzles tested in the six bedload samplers evaluated in this study (Hubbell and others, 1985; 1987; Hubbell and Stevens, 1986; Hubbell, written commun., 1987).

Table 1.—*Characteristics of bedload samplers used in the field comparison program*
[mm, millimeters; kg, kilograms]

Sampler number	Hubbell[1] nozzle number	Sampler name	Entrance dimensions Width (mm)	Entrance dimensions Height (mm)	Nozzle area expansion ratio	Hydraulic[2] efficiency	Mass (kg)
1	1	Helley-Smith[3]	76	76	3.22	1.54	52
2	3	FIASP[4]	76	76	1.40	1.35	63
3	6	Helley-Smith[5]	152	152	3.22	1.54	70
4	6	TR-1[6]	152	152	3.22	1.54	75
5	5	Hubbell No.5[7]	305	152	1.40	1.40	57
6	5	TR-2[8]	305	152	1.40	1.40	100

[1] Hubbell and others, 1985

[2] Druffel and others, 1976; Hubbell and others, 1985.

[3] Helley-Smith sampler, nozzle, and large frame fabricated by GBC Fabricators, Denver, Colorado, 1985.

[4] FIASP (Federal Inter-Agency Sedimentation Project) bedload sampler nozzle, large frame fabricated by GBC, 1985; nozzle fabricated at CVO, 1986.

[5] Double-scale version of the Helley-smith sampler fabricated by GBC Fabricators, Denver, Colorado, 1985.

[6] TR-1 (Toutle River bedload sampler #1), nozzle fabricated by GBC Fabricators, Denver, Colorado, 1985; frame and tail fabricated at CVO, 1986.

[7] Hubbell No. 5 sampler, fabricated by Product Manufacturing, Inc., St. Paul, Minnesota, 1979.

[8] TR-2 (Toutle River sampler #2), fabricated at CVO, 1986.

BEDLOAD SAMPLERS AND EQUIPMENT

Bedload Samplers

Bedload samplers used in this study are the pressure-difference type and are the same as, or similar in design to, the original Helley-Smith sampler (Helley and Smith, 1971). Each has an intake nozzle with a nylon mesh catchment bag, a tail section with fins for stabilization, and a frame assembly of curved rods or tubes, which connects the nozzle to the tail section. The tubular frame assembly of some samplers is partly or completely filled with lead to increase stability in the flow by increasing sampler mass and shifting centroid of mass forward.

To sample bedload, the sampler is placed on the streambed for a measured length of time with the nozzle entrance oriented into the flow, allowing sediment to enter and pass through the nozzle. Fine sediment passes through the mesh bag attached to the rear of the nozzle, while particles larger than the mesh openings are trapped in the bag.

A spatial overlap of sampling zones exists between some of the bedload samplers described in this study and some of the suspended-sediment samplers currently in use. Some bedload samplers can collect bedload and suspended-sediment near the streambed to a point 152 mm (millimeter) above the bed. All bedload samplers compared in this study traverse the full depth of the flow with an open nozzle and are capable of trapping suspended sediment and organic matter while in transit between the water surface and the streambed.

Characteristics of the samplers tested in these comparisons are listed in table 1. Sampler nozzles tested are identical to four nozzles previously calibrated in a flume at the St. Anthony Falls, Minnesota, Hydraulic Laboratory (Hubbell and others, 1985). Test bedload sampler #1 (fig. 1) is identical to the original Helley-Smith bedload sampler (Helley and Smith, 1971) field-calibrated by Emmett (1980), except it has a larger frame to accommodate a larger nylon mesh catchment bag that allows sampling higher bedload transport rates. Sampler #2 (fig. 2) has a large frame identical to sampler #1 but is equipped with a nozzle identical to nozzle 2 as flume-tested by Hubbell and others (1985). Sampler #3 (fig. 3) is a double-scale version of sampler #1.

Sampler #4 (fig. 4), designated the TR-1 (Toutle River-1) bedload sampler, has nozzle dimensions identical to that of sampler #3 and has a longer frame, larger nylon mesh catchment bag, redesigned tail section, and greater mass than sampler #3. St. Anthony Falls Hydraulics Laboratory loaned the bedload sampler with Hubbell nozzle 5; for this study, it was also identified as sampler #5 (fig. 5). Sampler #6 (figs. 6 and 7), designated the TR-2 (Toutle River-2) sampler, has the same nozzle as sampler #5, with a longer frame, larger nylon mesh catchment bag, newly designed tail section, and greater mass.

The design of sampler #6 (the TR-2) incorporates knowledge gained during the testing of modifications incorporated into the design of sampler #4 (TR-1): (1) the tail section is extended bilaterally to place the vertical tail fins outside the turbulent zone that exists directly behind the sampler nozzle and nylon mesh bag, (2) the tubular frames of both sampler #4 and #6 lie close to the sides of the intake nozzles to reduce friction in the flow, (3) samplers #4 and #6 have high ***cross-section density*** and the mass of sampler #6 can be increased through a range from 55 to 100 kg (kilogram) by adding lead in the tubular frame, and (4) the open design of the frame of sampler #6 allows the mesh bag dimensions to be greatly increased to permit sampling of high transport rates, and provision can be made for removing the sample from the rear of the bag.

Nylon Mesh Bag

The bedload samplers used in this study trap and retain bedload in a nylon bag with a specified mesh size. Nylon bags of three mesh sizes were tested. Bags having a mesh size of 0.25 mm frequently became clogged with fine sand-sized sediment when sand flux was high. Bags having a mesh size of 0.50 mm never became clogged during this study; however, some clogging did occur using bags of this mesh size at other sites during a different bedload data collection program.

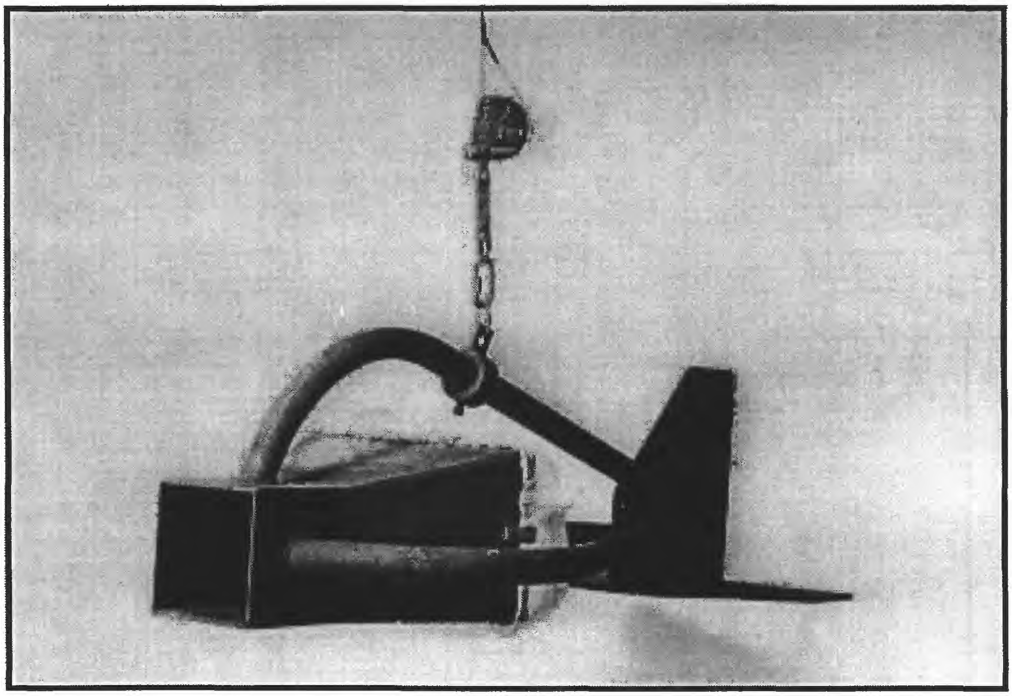

FIGURE 1.—Test sampler #1 is a Helley-Smith bedload sampler having a 76 x 76 millimeter nozzle entrance and a 3.22 nozzle area expansion ratio.

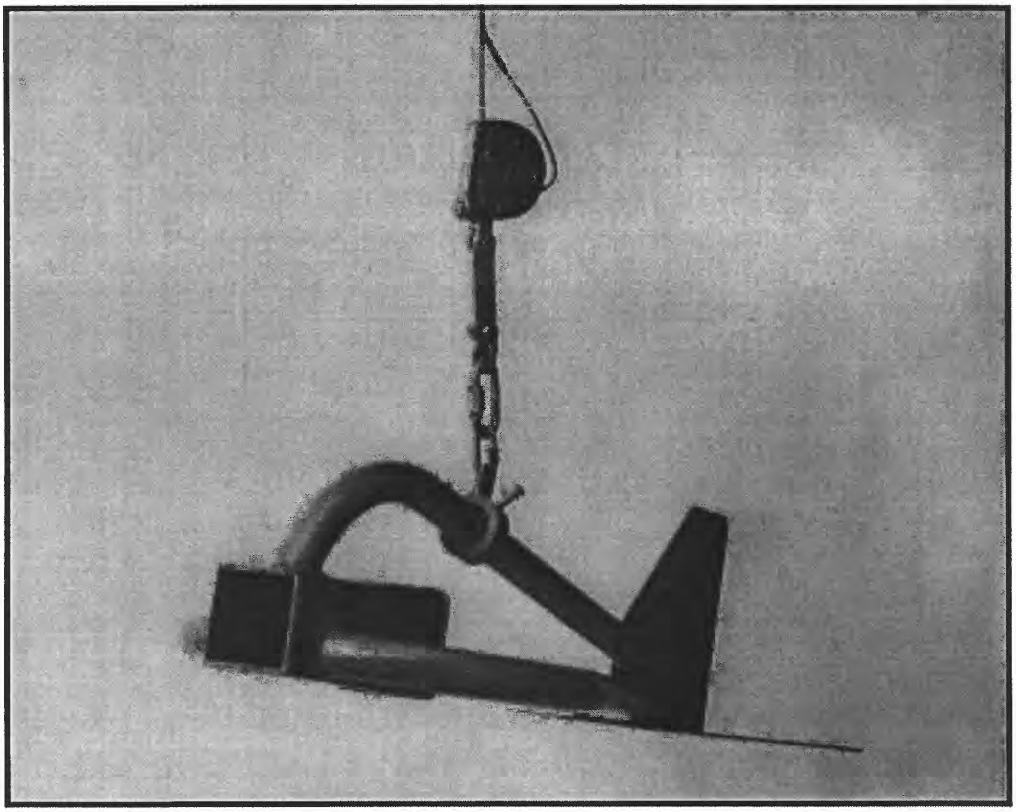

FIGURE 2.—Test sampler #2 is a Federal Inter-Agency Sedimentation Project bedload sampler having a 76 x 76 millimeter nozzle entrance and a 1.40 nozzle area expansion ratio.

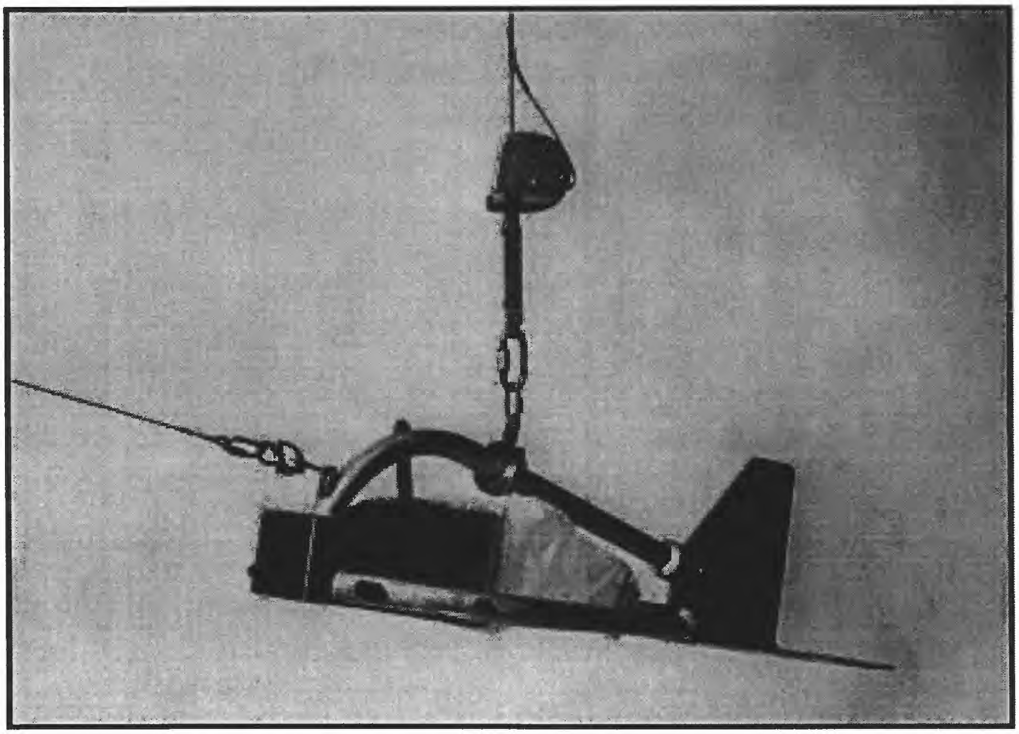

FIGURE 3.—Test sampler #3 is a Helley-Smith bedload sampler having a 152 x 152 millimeter nozzle entrance and a 3.22 nozzle area expansion ratio.

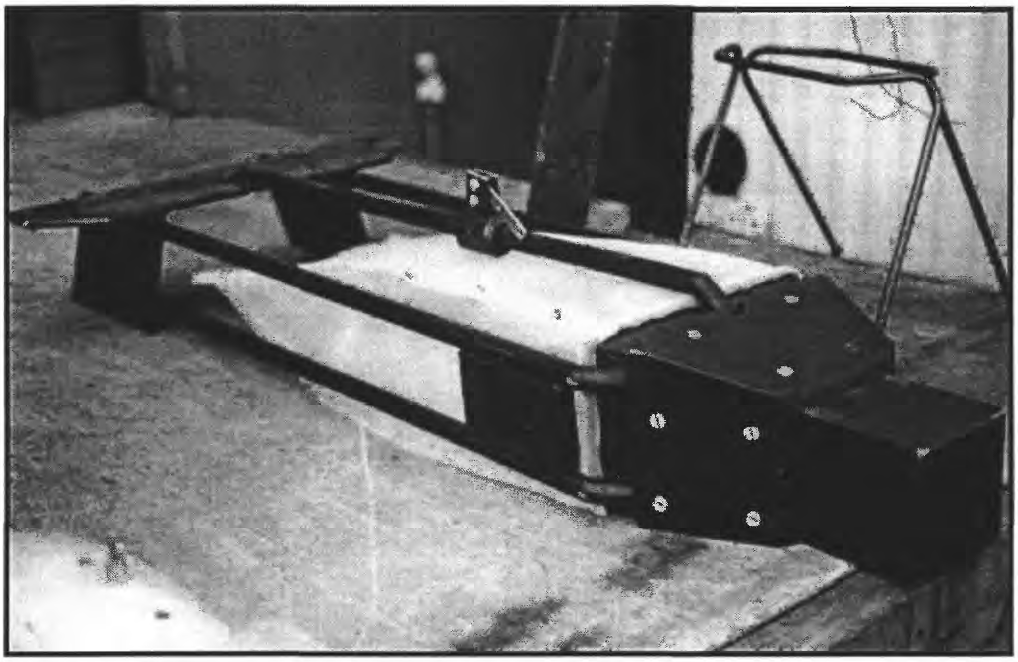

FIGURE 4.—Test sampler #4 is a Toutle River-1 bedload sampler having a 152 x 152 millimeter nozzle entrance and a 3.22 nozzle area expansion ratio.

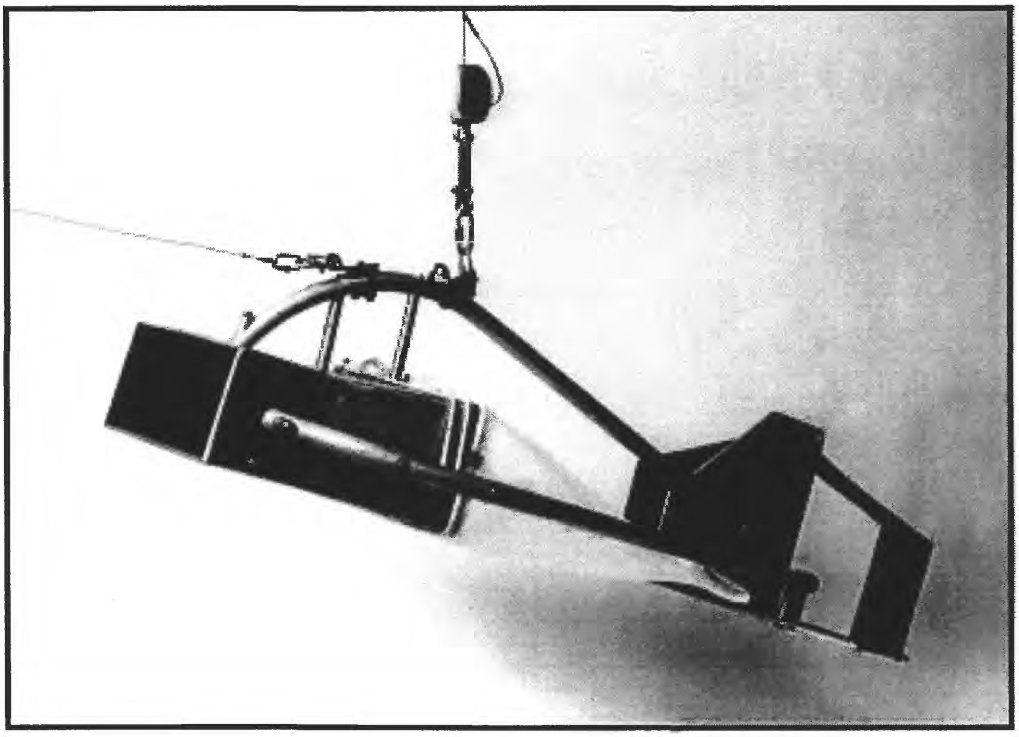

FIGURE 5.—Test sampler #5 is a Hubbell-5 bedload sampler having a 305 x 305 millimeter nozzle entrance and a 1.40 nozzle area expansion ratio.

To alleviate potential problems from sampling with different mesh sizes, a bag with 1.0 mm mesh size was adopted as the standard for both studies. Samples were collected during this study using bags having 0.50 mm mesh size prior to April 1, 1986, and using bags having 1.00 mm mesh size after that date.

Bedload transport rates are computed from whole samples and include all sediment particle-size classes present. Because nylon bag mesh size was increased from 0.50 mm to 1.00 mm after the beginning of the study, separate comparisons are presented for subsets of the portion of sampled bedload greater than 1.00 mm diameter.

To accommodate the high bedload transport rates encountered in the field, the largest volume mesh bags that could fit within the frame of each sampler were custom-fabricated. The mesh bags were designed to permit removal of the sample from an opening at the rear of the bag. The rear opening of the mesh bag was kept closed during sampling by a pair of modified locking pliers that were secured to the tail section of the bedload sampler by a flexible steel cable (fig. 8). A schematic drawing of the mesh bag used in the TR-2 bedload sampler is shown in figure 9.

Support Equipment

A truck-mounted, hydraulic-powered crane was used to suspend the samplers during data collection. A stayline was used at all times to stabilize samplers in the flow. Observations made during sample collection verified earlier observations that the force of the flow, associated with higher velocities near the surface, drags the sampler downstream from the suspension point (fig. 10). As the sampler is lowered through the water, the lesser force, associated with lower velocities occurring naturally near the bed allows the sampler to move upstream and to move

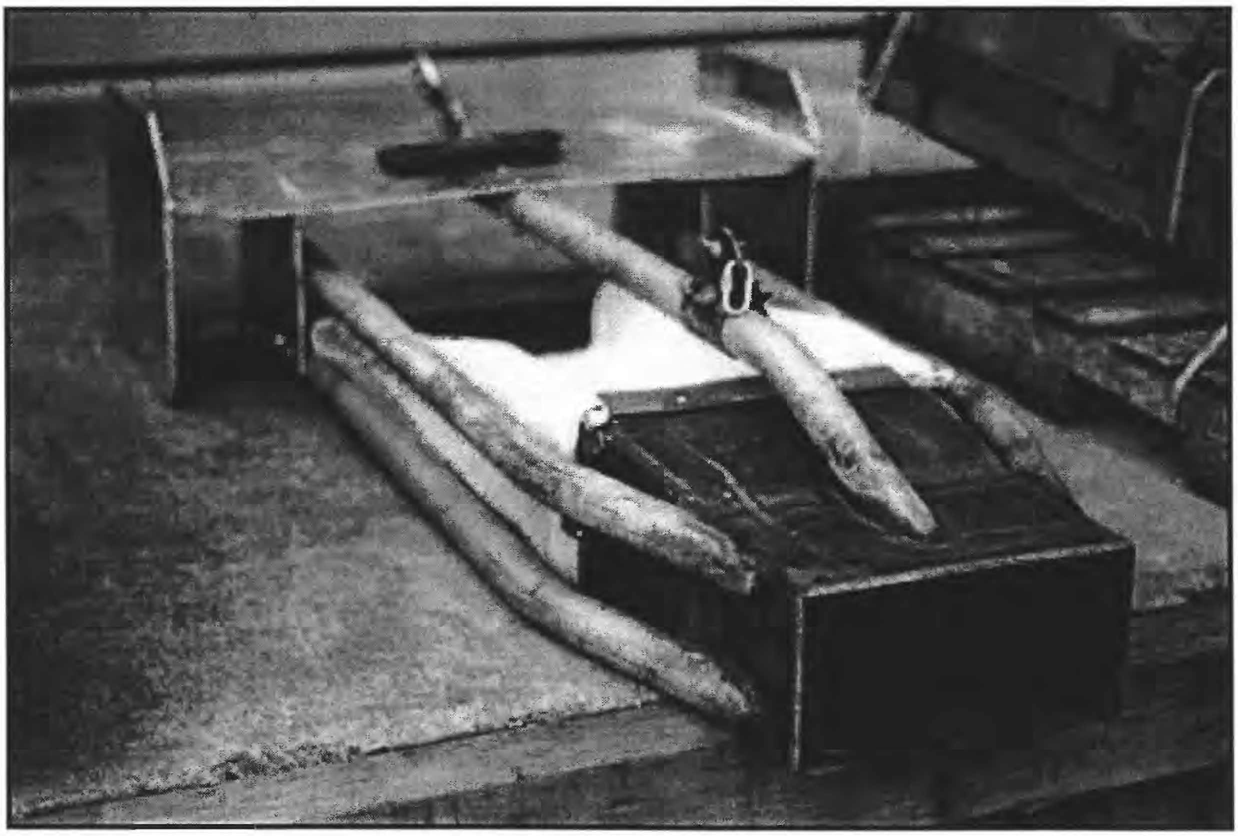

FIGURE 6.—Test sampler #6 is a Toutle River-2 bedload sampler having a 305 x 152 millimeter nozzle entrance and a 1.40 nozzle area expansion ratio.

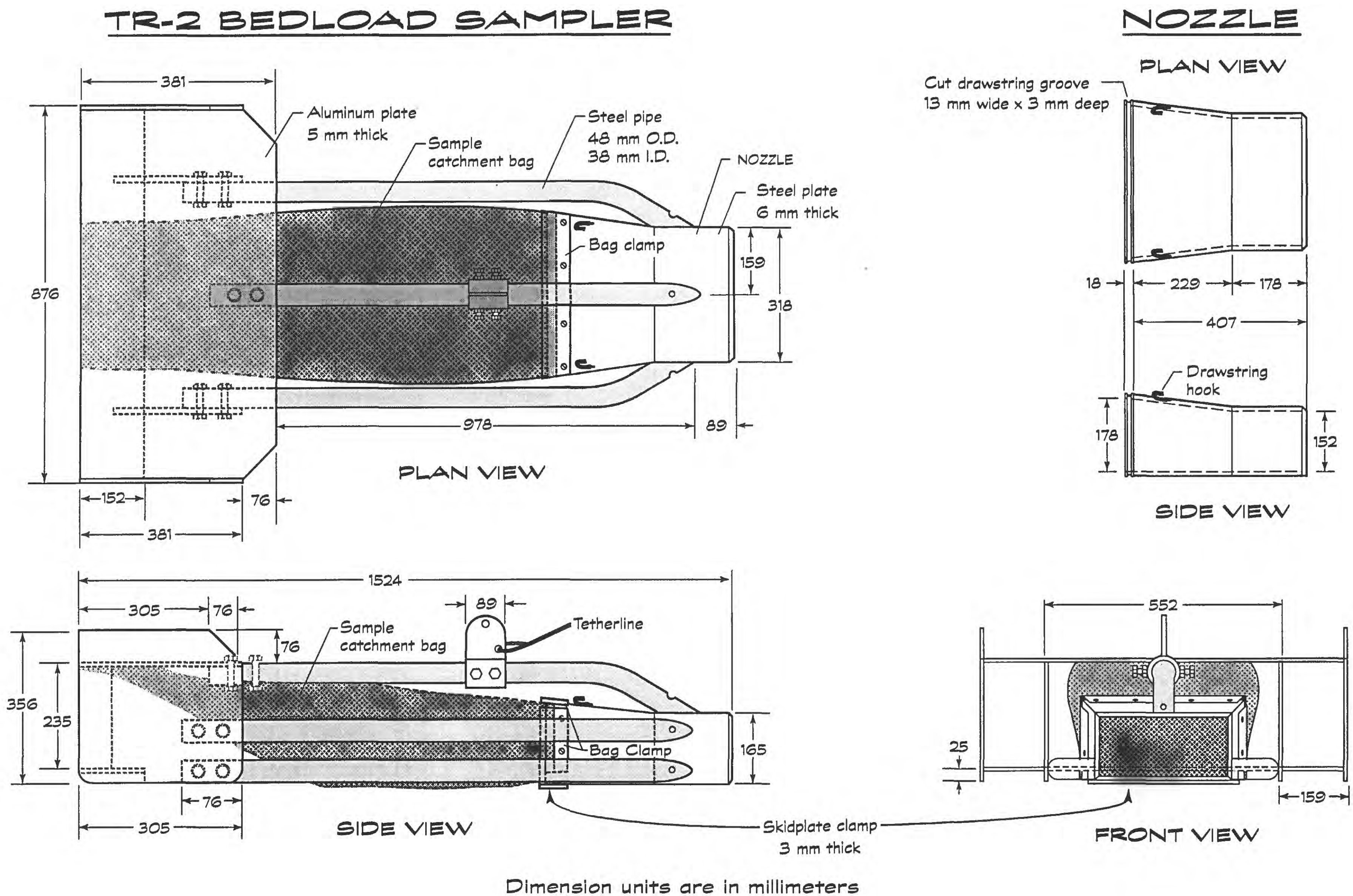

FIGURE 7.—Diagram of test bedload sampler #6 (Toutle River-2) with the 305 x 152 millimeter nozzle and 1.40 nozzle area expansion ratio.

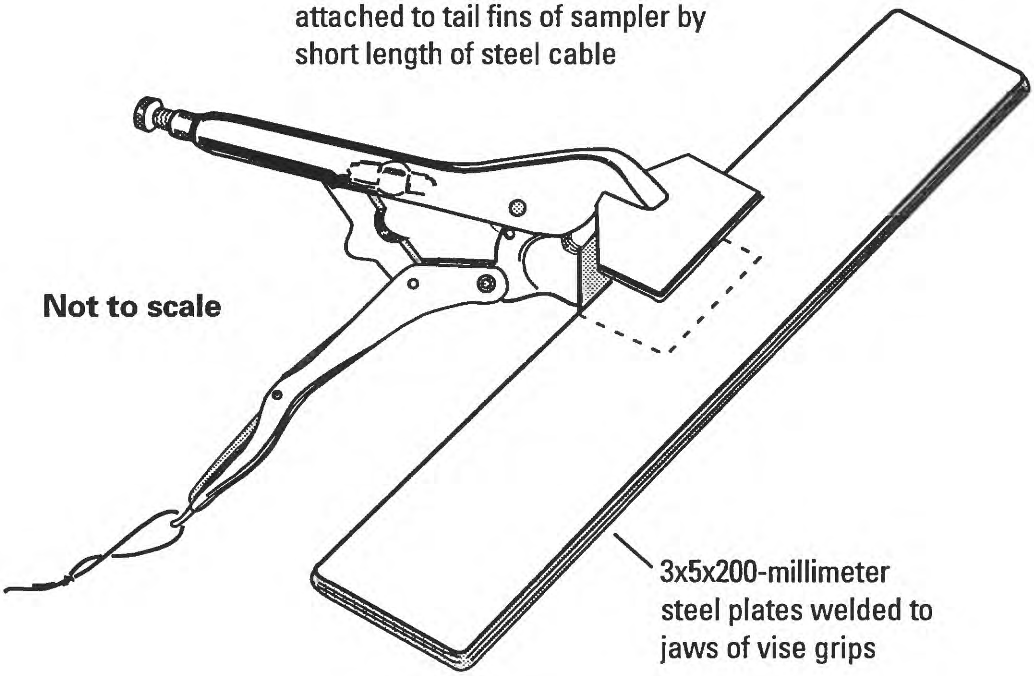

FIGURE 8.—Modified clamping pliers used to close the rear of the nylon mesh bedload sampling bag.

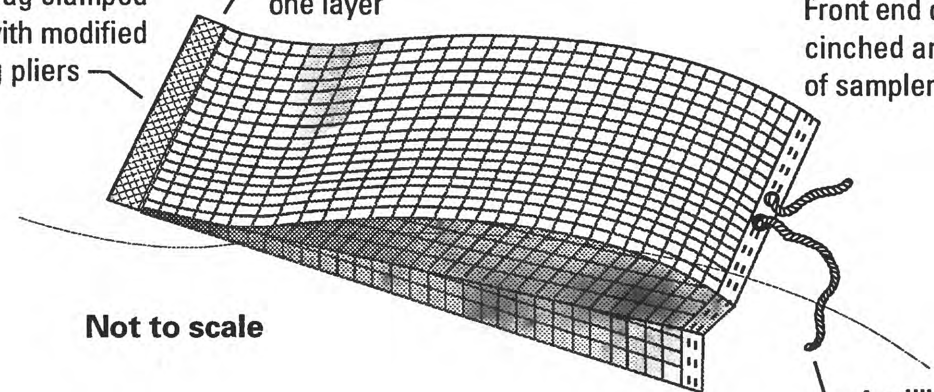

FIGURE 9.—Nylon mesh bedload sampling bag used with the Toutle River-2 (TR-2) bedload sampler.

downward toward the bed along the arc subtended by the suspension line. This action can cause the sampler to scoop sediment from the bed.

Use of a stayline and tetherline minimizes or eliminates sampling errors that occur from scooping. It also minimizes lateral movement and allows the sampler to be placed repeatedly at or near the same location on the streambed (fig. 10).

The sampler is connected to the stayline by a tetherline. The tetherline was attached to the forward part of the top frame rod or tube of samplers #1, #2, #3, and #5. On these samplers, the tetherline had two functions, to prevent the sampler from being pulled downstream by the force of the flow and to improve sampler stability in high velocity and turbulence. The alignment of the vector formed by the tetherline was directed toward the approximate centroid of mass of each sampler. This was necessary to prevent the pull of the tetherline from lifting the sampler nozzle from the bed or from digging into the bed. For samplers #4 and #6, a tetherline was attached to the top of the sampler at the suspension line attachment point. Although the tetherline was needed to prevent samplers #4 or #6 from being pulled downstream by the force of the flow, each of these samplers was stable in high velocity and turbulence without the tetherline.

DATA PROGRAM

Factors Affecting Sampling of Bedload Transport

Design of a bedload sampling program must consider spatial and temporal variations in bedload transport rates (Hubbell, 1964; Emmett, 1980; Pitlick, 1988). Spatial variations have been observed at different points upstream and downstream along the streambed and laterally across the channel; temporal variations have been observed at a single point on the streambed. To minimize the effects of spatial variations on bedload, one fixed ***sampling point*** is consistently used in this study when collecting bedload samples during comparisons of sampler performance.

Temporal bedload-rate variations during short time periods (normally seconds to hours in length) are associated with several phenomena. One association is with bedform migration during subcritical flow (Hamamori, 1962; Emmett, 1981; Hubbell, 1986). Studies have shown that when dunes are present at a point on the bed, bedload transport rates vary temporally through a range from zero to more than four times the mean transport rate (Schoklitsch, 1934; Hamamori, 1962; Carey, 1985; Hubbell, 1986). As the dune migrates downstream past a point on the bed, bedload transport rate tends to decrease temporally from a maximum near the crest to a minimum in the trough.

Small bedforms called ripples may be superimposed on top of primary bedforms such as dunes. Bedforms can change shape as they move downstream, and bedload rate distributions occurring over one bedform might differ greatly from those occurring over the next bedform. When this occurs, a program designed to sample the full range of rates and define the mean rate requires that a large number of samples be taken as several primary bedforms pass the sampling point.

Short term temporal bedload rate variations also may be rated to velocity fluctuations near the bed (Ehrenberger, 1931; Karolyi, 1947). For example, the initiation of motion of bedload particles larger in size than sand has been shown to be related to velocity (Helley, 1969). Bedload also has been observed to move as groups of clusters of rocks sometimes called bedload sheets (Whiting and others, 1988). When bedload transport rate varies in association with velocity fluctuations as movement of particle groups or clusters, the number of samples required to define the mean bedload rate is a function of both the sampling interval and the frequency of the transport rate variations. A program designed to sample the full range of transport rates and define the mean rate may require that a large number of samples be taken. That number can best be determined by field experiment.

Variations in bedload particle-size distribution commonly are associated with bedload transport rate variations and may be related to both velocity fluctuations and supply of sediment sizes available. The continually changing velocity field near the bed may cause selective entrainment or selective deposition of bedload according to particle size. Selective deposition may result in a variation in the supply of sizes available for subsequent transport. Size variation may be most noticeable as the intermittent shift of particle-size distribution in repetitive bedload samples that is a function of the size of the largest particle in the sample.

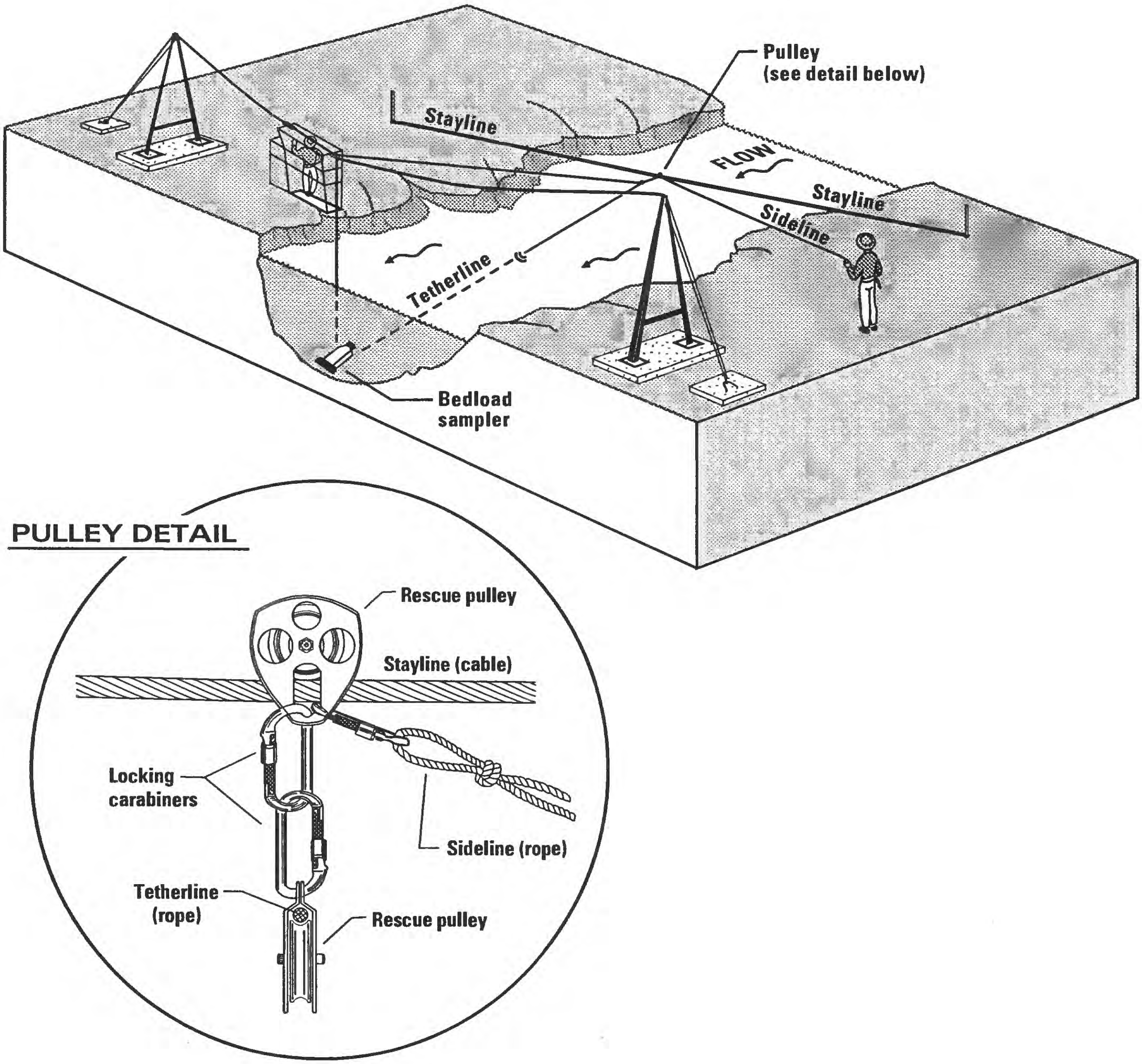

FIGURE 10.—Placement of bedload sampler in the proper position on streambed using stayline and tetherline.

The preceding discussion shows that temporal variation in bedload transport rate can be large; therefore a large number of samples is required to compare performance of bedload samplers. The number of samples needed to adequately compare samplers must be large enough to represent the full range of bedload transport rates, to determine the mean rate, to represent the variations in particle-size distribution, and to determine the mean particle-size distribution. That number might vary with hydraulic and transport conditions and can best be determined by (1) analysis of large data sets gathered under a variety of conditions and (2) knowledge of the presence, type, and scale of bedforms. This discussion relates primarily to the bedload observed during field tests when most or all particle sizes available for transport also were found moving as bedload.

Methods of Comparison and Sources of Error

As described earlier, bedload sampling accuracy may be improved by reducing three main sources of error. These include: (1) sampler calibration, (2) sampling technique, and (3) sampling program design.

Comparison of bedload samplers can best be accomplished by comparing sampled bedload transport rates with ***"true" bedload transport rates***. However, true rates could not be determined in this study. A bedload trap could not be used to determine true bedload transport rates because the large scale of the river and high bedload transport rates would require construction of a prohibitively large and expensive facility. Calibration curves developed in other studies could not be applied to data to determine true bedload transport rates because sampled transport rates in this study commonly exceed maximum transport rates shown on calibration curves (Hubbell, written commun., 1987).

Ratios between mean sampled bedload rates of different samplers provide insight into the relative calibration of each sampler compared under these test conditions. If sampler A collects more bedload than sampler B during a test, the sampling ratio (sampled bedload rate of A divided by sampled bedload rate of B) is greater than 1.0 and sampler A has a higher sampling efficiency than sampler B. The bedload sampling ratio also can be computed for each particle size class.

The technique used to obtain individual samples can have a potentially greater effect on sample error than either sampler calibrations or program design, but sampling technique errors are more difficult to quantify. Errors caused by inappropriate sampling technique are minimized by using staylines during sampling and by using a consistent technique.

Errors derived from design of the sampling program were minimized by taking all samples in a data set at a single point on the streambed. During most field tests, samples were obtained by alternating the samplers being tested. By maintaining the same technique and sampling program design, errors from those sources should have been uniform during each test.

Field Tests

The data-collection program was tailored to provide three types of information while sampling bedload at a single point on the bed: (1) sampled bedload transport rates and particle-size distributions during field tests of two or three samplers at a time, (2) relative stability and other performance characteristics of samplers tested, and (3) transport rates and bedload particle-size distributions obtained with a single sampler relative to the length of ***sampling time***.

Except for field test A2, two or three samplers were used during each test to compare bedload transport rates, particle-size distributions and performance characteristics (table 2). During most field tests, sampling time was held constant during each individual field test. During different tests, sampling times between about 4 and 60 seconds were used.

Field test A2 was conducted to determine the effect of different sampling times on sampled bedload transport rate and particle-size distributions. A single sampler, the TR-2 sampler, was used during the field test and sampling times were varied at 4, 8, and 12 seconds.

During the first two field tests (C1 and D1, table 2), bedload samples were obtained by collecting sequential samples with a single sampler to define the temporal variations in sampled bedload rate and the mean rate for that sampler. This was followed by collecting sequential samples with additional samplers in the same manner. After studying the results of this sampling program, the

Table 2.—*Summary of field test data*

[m^3/s, cubic meters per second; m, meters; m/s meters per second; —, no data]

Field test number	Date	Number of samples	Sampling time (seconds)	Samplers[1] tested	Water discharge[2] (m^3/s)	Water temperature[3] (Celsius)	Sampling vertical Depth (m)	Sampling vertical Mean velocity (m/s)
C1	1/15/86	33	30	1, 4, 5	49.5	7.0	0.67	2.12
D1	1/16/86	23	30	1, 4, 5	61.0	7.0	1.47	2.30
E1	1/29/86	48	10	1, 3, 5	62.5	7.5	1.43	3.16
F1	2/19/86	40	10	1, 5	69.5	5.0	1.10	2.18
G1	2/27/86	40	10	5, 6	133.0	10.0	—	—
K1	3/12/86	40	30	5, 6	96.5	10.5	—	—
M1	3/20/86	50	10	5, 6	56.5	10.5	1.28	2.85
O1	3/28/86	50	10	5, 6	61.0	11.0	1.01	2.66
P1	4/17/86	48	15	1, 2	49.5	12.0	—	—
Q1	4/30/86	48	20	1, 2	56.5	7.5	1.46	2.59
A2	4/13/87	63	4, 8, 12	6	56.5	12.0	1.04	2.66
B2	4/22/87	50	20	5, 6	48.0	11.5[4]	0.55	2.26
C2	4/23/87	50	20	5, 6	47.0	8.5[4]	0.61	2.17

[1] Sampler 1 = Helley-Smith bedload sampler, 76 mm x 76 mm nozzle, 3.22 area-expansion ratio.
Sampler 2 = FIASP bedload sampler, 76 mm x 76 mm nozzle, 1.40 area-expansion ratio.
Sampler 3 = Helley-Smith bedload sampler, 152 mm x 152 mm nozzle, 3.22 area-expansion ratio.
Sampler 4 = TR-1 bedload sampler, 152 mm x 152 mm nozzle, 3.22 area-expansion ratio.
Sampler 5 = Hubbell No. 5 bedload sampler, 305 mm x 152 mm nozzle, 1.40 area-expansion ratio.
Sampler 6 = TR-2 bedload sampler, 305 mm x 152 mm nozzle, 1.40 area-expansion ratio.

[2] Water discharge at beginning of the field test.

[3] Water temperatures were estimated from nearby sites.

[4] Water temperatures were measured at the site.

procedure was redesigned to obtain samples by alternating between the samplers were compared. This procedure reduced potential bias caused by changes in the mean bedload transport rate during the sampling period while sampling temporal variations.

Sampling Conditions

Data for sampler comparisons were collected in the Toutle River at Coal Bank bridge near Silver Lake, Washington (fig. 11). Sampling conditions were variable because of the naturally changing flow conditions at the site where velocity, turbulence, and bedload transport rate varied both spatially and temporally. A representative water-surface slope of the Toutle River at the site was 0.010.

Variations in bedload rates may have been caused by both bedform migration and velocity fluctuations. Although bedforms were not discernible from depth soundings, low amplitude bedforms may have been present at times during sampling.

During each field comparison, the sampling vertical was selected by testing for the location of highest bedload transport rate in the cross section exclusive of any zone of standing waves. Most bedload sampler comparisons were made in subcritical flow a few meters from the edge of a supercritical flow zone characterized by antidunes.

At the sampling vertical, mean velocity ranged from 2.12 to 3.16 m/s (meter per second) and depths ranged from 0.55 to 1.47 m (meter) (table 2). Bedload samples were collected when

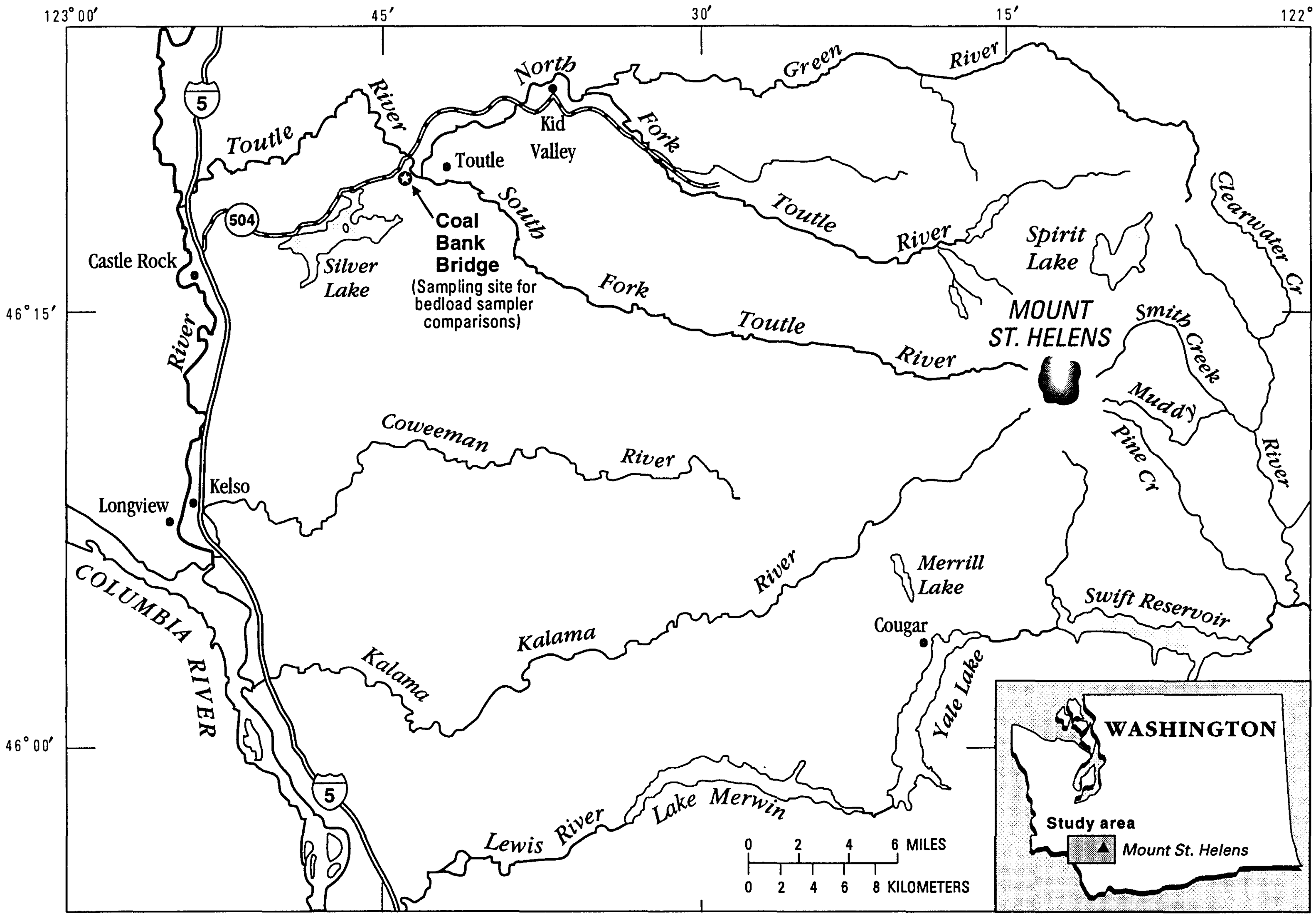

FIGURE 11.—Location of sampling site for bedload sampler comparisons at Coal Bank bridge on the Toutle River, Washington.

computed Froude numbers were between about 0.61 and 0.97 using the formula:

$$F^2 = \frac{V^2}{gd}$$

where:

V = depth-averaged velocity of the flow, in meters per second,

g = acceleration of gravity, in meters per second per second, and

d = depth of low, in meters

Formulas for Computation of Unit Bedload Transport Rate

Bedload samples were analyzed to determine dry mass and distribution of particle-sizes. Calculations of sampled bedload transport rate for one-meter width of the streambed were made by the formula:

$$qb_i = \frac{kM}{T}$$

where:

qb_i = sampled bedload transport rate, in dry mass kg/sec-m of width;

k = coefficient to adjust for sampler width and convert units;

k = 0.013123 for sampler with nozzle 76.2 mm wide;

k = 0.006562 for sampler with nozzle 152.4 mm wide;

k = 0.03281 for sampler with nozzle 304.8 mm wide;

M = dry mass of bedload, in grams; and

T = sampling time, in seconds

Relative (dimensionless) bedload transport rate was calculated by dividing each individual transport rate by the mean rate from that data set, using the formula:

$$qb = \frac{qb_i}{Qb}$$

where:

qb = dimensionless transport rate; and

Qb = mean sampled bedload transport rate for a data set kg/s-m.

DATA ANALYSIS

Sampled Bedload

Data from thirteen field tests (table 3) show that median sampled bedload particle diameters ranged from 0.93 to 36.2 mm. Sampling times for field test A2 are provided in tables 2 and 4. Mean sampled ***unit bedload transport rates*** for totals of all particle-size classes ranged from 0.076 to 9.09 kg/sec-m (kilogram per second-meter) (table 5). Bedload transport rates are summarized in tables 6 to 9 to allow easier comparison between pairs of samplers. Mean sampled rates for totals of all particle-size classes, excluding sediment finer than 1.00 mm in diameter, ranged from 0.075 to 6.01 kg/sec-m (table 6). Bedload transport rates are summarized by particle-size class in table 7 for samplers #1, #3, #4, and #5, and in table 8 for samplers #1 and #2. Mean bedload transport rates are shown more than once in some tables for easier comparison. Bedload rates are summarized by particle-size class in table 9*A* for samplers #5 and #6 when bedload consisted primarily of gravel, and in table 9*B* when bedload consisted primarily of sand.

Sampling time was changed systematically during field test A2 to determine its effect on bedload characteristics. Results of this test are summarized in table 10 and illustrated in figure 12. The data shown in figure 12 indicate that the mean sampled bedload transport rate decreases slightly with increased sampling time. Relative transport rates were classed by each of the three sampling times and ordered according to magnitude. This allowed comparison of bedload rates for the three sampling times at levels of common probability of occurrence (fig. 13). As shown in figure 13, the variation in sampled bedload transport rate, as defined by relative slopes of probability curves defined by the data, decreased as the sampling time was increased, whereas particle-size distribution remained relatively unchanged (fig. 14).

Individual sampled bedload transport rates ranged from 0.004 to 15.9 kg/sec-m (Appendix). Samples generally consisted of sediment ranging in particle size from less than 1 mm to greater than 64 mm.

All data sets illustrate temporal variation in sampled bedload transport rate (figs. 16-25). At any point on the streambed, these variations can

Table 3.—*Median particle diameter, millimeters, of bedload sediment sampled during field tests*
[Numbers in parentheses represent number of samples taken; additional data provided in appendix]

Field test	Sampler number[1] 1	2	3	4	5	6
C1	2.00 (10)			5.50 (11)	3.90 (12)	
D1	6.70 (07)			1.86 (08)	0.96 (08)	
E1	3.22 (16)		24.5 (16)		3.28 (16)	
F1	5.78 (20)				2.30 (20)	
G1					26.5 (20)	34.0 (20)
K1					11.9 (20)	36.2 (20)
M1					0.93 (25)	1.11 (25)
O1					2.91 (25)	2.79 (25)
P1	9.60 (24)	9.80 (24)				
Q1	9.00 (24)	9.20 (24)				
A2						3.49 (63)
B2					16.2 (25)	9.70 (25)
C2					10.2 (25)	8.80 (25)

[1]Sampler 1 = Helley-Smith bedload sampler, 76 mm x 76 mm nozzle, 3.22 area-expansion ratio.
Sampler 2 = FIASP bedload sampler, 76 mm x 76 mm nozzle, 1.40 area-expansion ratio.
Sampler 3 = Helley-Smith bedload sampler, 152 mm x 152 mm nozzle, 3.22 area-expansion ratio.
Sampler 4 = TR-1 bedload sampler, 152 mm x 152 mm nozzle, 3.22 area-expansion ratio.
Sampler 5 = Hubbell No. 5 bedload sampler, 305 mm x 152 mm nozzle, 1.40 area-expansion ratio.
Sampler 6 = TR-2 bedload sampler, 305 mm x 152 mm nozzle, 1.40 area-expansion ratio.

Table 4.—*Mean sampled unit bedload transport rate, kilograms per second-meter, and median particle diameters, millimeters, for different sampling times, field test A2*
[kg/s-m = kilogram per second-meter]

Sampling times (seconds)	Median bedload particle diameter (millimeters)	Total unit bedload transport rate (kg/s-m)	Bedload > 1.00 mm unit bedload transport rate (kg/s-m)
4	3.65	9.29	6.17
8	2.87	9.07	5.75
12	3.94	8.89	6.10

Table 5.—*Mean sampled unit bedload transport rate, kilograms per second-meter, for each field test*

[Numbers in parentheses represent number of samples taken; additional data provided in appendix]

	Sampler number[1]					
Field test	1	2	3	4	5	6
C1	2.26 (10)			4.71 (11)	0.819 (12)	
D1	2.01 (07)			6.04 (08)	1.10 (08)	
E1	8.04 (16)		5.25 (16)		2.42 (16)	
F1	6.79 (20)				2.29 (20)	
G1					3.21 (20)	2.46 (20)
K1					0.092 (20)	0.076(20)
M1					2.03 (25)	3.45 (25)
O1					2.27 (25)	3.90 (25)
P1	2.97 (24)	2.64 (24)				
Q1	3.31 (24)	2.00 (24)				
A2						9.09 (63)
B2					0.823 (25)	1.49 (25)
C2					2.05 (25)	2.15 (25)

[1] Sampler 1 = Helley-Smith bedload sampler, 76 mm x 76 mm nozzle, 3.22 area-expansion ratio.
Sampler 2 = FIASP bedload sampler, 76 mm x 76 mm nozzle, 1.40 area-expansion ratio.
Sampler 3 = Helley-Smith bedload sampler, 152 mm x 152 mm nozzle, 3.22 area-expansion ratio.
Sampler 4 = TR-1 bedload sampler, 152 mm x 152 mm nozzle, 3.22 area-expansion ratio.
Sampler 5 = Hubbell No. 5 bedload sampler, 305 mm x 152 mm nozzle, 1.40 area-expansion ratio.
Sampler 6 = TR-2 bedload sampler, 305 mm x 152 mm nozzle, 1.40 area-expansion ratio.

result from both the natural diversity in true bedload transport rates and those variations caused by sampling technique and sampler design.

The data graphed in figures 15 to 18 are summarized in tables 6, 7, and 8. The graphs in figures 15 and 16 show that sampler #4 collected more unit bedload than sampler #1, and sampler #1 collected more than sampler #5. Figures 17 and 18 also show that sampler #1 collected more unit bedload than sampler #5. However, the graph in figure 17 shows that sampler #1 collected more unit bedload than sampler #3. Samplers #3 and #4 have identical sampler nozzle dimensions but different frames and tails. The difference in the unit bedload rates may have been caused by the lighter mass of sampler #3 and a poor fit with the streambed. The graph in figure 19 shows sampler #1 collected more unit bedload than sampler #2; however, the graph in figure 20 shows about the same sampling rate for both samplers.

The data graphed in figures 21 to 26 are summarized in tables 6, 9*A* and 9*B*. The graphs in figures 21 and 22 show that sampler #5 collected more bedload than sampler #6 when the sediment consisted mostly of gravel (table 9*A*). The graphs in figures 23 to 25 show that sampler #6 collected more unit bedload than sampler #5 when the sediment consisted of mostly sand (table 9*B*). The graph in figure 26 shows that samplers #5 and #6 collected bedload at about the same rates when the sediment consisted of mostly fine gravel.

Sampling Ratios

As sampling ratio was computed for each test by dividing the bedload transport rate sampled by

Table 6.—*Mean sampled unit bedload transport rate, kilograms per second-meter, for bedload sediment larger than 1.00 millimeter in particle diameter for each field test*

[mm = millimeters; numbers in parentheses represent number of samples taken; additional data provided in appendix]

	Sampler number[1]					
Field test	**1**	**2**	**3**	**4**	**5**	**6**
Particle-size class 1 mm to 64 mm						
C1	2.01 (10)			4.24 (11)	0.68 (12)	
D1	1.62 (07)			3.17 (08)	0.52 (08)	
E1	5.10 (16)		4.06 (16)		1.52 (16)	
F1	5.91 (20)				1.58 (20)	
P1	2.94 (24)	2.62 (24)				
Q1	3.22 (24)	1.89 (24)				
Particle-size class 1 mm to 128 mm						
G1					3.20 (20)	2.46 (20)
K1					0.090 (20)	0.075 (20)
M1					0.97 (25)	1.79 (25)
O1					1.74 (25)	3.05 (25)
A2						6.01 (63)
B2					0.78 (25)	1.41 (25)
C2					1.85 (25)	1.96 (25)

[1] Sampler 1 = Helley-Smith bedload sampler, 76 mm x 76 mm nozzle, 3.22 area-expansion ratio.
Sampler 2 = FIASP bedload sampler, 76 mm x 76 mm nozzle, 1.40 area-expansion ratio.
Sampler 3 = Helley-Smith bedload sampler, 152 mm x 152 mm nozzle, 3.22 area-expansion ratio.
Sampler 4 = TR-1 bedload sampler, 152 mm x 152 mm nozzle, 3.22 area-expansion ratio.
Sampler 5 = Hubbell No. 5 bedload sampler, 305 mm x 152 mm nozzle, 1.40 area-expansion ratio.
Sampler 6 = TR-2 bedload sampler, 305 mm x 152 mm nozzle, 1.40 area-expansion ratio.

one bedload sampler by the rate sampled by a second sampler. Ratios between mean sampled bedload rates of different samplers allow systematic comparison of sampling characteristics of sampler pairs under test conditions.

Sampling ratios were derived from data in tables 6, 7, 8, 9*A* and 9*B* and are shown in table 11*A* and 11*B* and in figures 27 to 32. Mean ratios by particle-size class were calculated by dividing the mean sampled rate collected for each particle-size class with one sampler by that of a second sampler in the same field test. Two techniques were used to calculate the total sampling ratios shown in tables 11*A* and 11*B* for each pair of samplers. In the first technique, the bulk sample ratio was determined as the mean of the individual sampling ratios by size class for bedload sediment > 1 mm in size. This technique gives equal weight to the ratio of each size class, regardless of the amount of bedload sampled in each class. In the second technique, the mean sample class ratio was determined by dividing the mean of the total bedload rate of one sampler by that of the second sampler for bedload sediment > 1 mm in size. This technique derives a mass-weighted mean based on mass of bedload in each size class.

Table 7.—*Comparison of bedload samplers #1, #3, #4, and #5 using mean sampled unit bedload transport rate, kilograms per second-meter, by particle-size class*

[Total unit bedload 1 <X <64 = sum of sediment between 1.0 mm and 64.0 mm in size]

Field[1] test	Particle-size class, in millimeters								Total unit bedload transport rate	Unit bedload transport rate 1<X<64
	<1.0	1 to 2	2 to 4	4 to 8	8 to 16	16 to 32	32 to 64	64 to 128		
Sampler #1, 76 x 76 millimeter nozzle										
C1	0.244	0.453	0.245	0.300	0.451	0.412	0.153	0.000	2.258	2.014
D1	0.396	0.155	0.182	0.365	0.579	0.301	0.033	0.000	2.011	1.615
Mean	**0.320**	**0.304**	**0.214**	**0.332**	**0.515**	**0.356**	**0.093**	**0.000**	**2.134**	**1.814**
E1	2.769	2.077	0.752	0.605	0.588	0.612	0.462	0.171	8.036	5.096
F1	0.871	1.473	0.752	0.988	1.119	0.993	0.563	0.027	6.786	5.915
Mean	**1.070**	**1.040**	**0.483**	**0.564**	**0.684**	**0.580**	**0.303**	**0.050**	**4.473**	**3.653**
Sampler #3, 152 x 152 millimeter nozzle										
E1	0.570	0.638	0.406	0.453	0.767	0.933	0.865	0.616	5.248	4.062
Sampler #4, 152 x 152 millimeter nozzle										
C1	0.405	0.684	0.520	0.600	0.852	1.064	0.521	0.065	4.711	4.241
D1	2.862	0.377	0.380	0.665	0.991	0.612	0.148	0.000	6.035	3.173
Mean	**1.634**	**0.530**	**0.450**	**0.632**	**0.922**	**0.838**	**0.334**	**0.032**	**5.373**	**3.707**
Sampler #5, 305 x 152 millimeter nozzle										
C1	0.117	0.128	0.066	0.079	0.130	0.157	0.119	0.023	0.819	0.679
D1	0.573	0.056	0.068	0.106	0.177	0.095	0.021	0.000	1.096	0.523
Mean	**0.345**	**0.092**	**0.067**	**0.092**	**0.154**	**0.126**	**0.140**	**0.012**	**0.958**	**0.671**
E1	0.828	0.402	0.189	0.161	0.197	0.293	0.276	0.070	2.416	1.588
F1	0.718	0.350	0.188	0.201	0.296	0.274	0.202	0.065	2.294	1.576
Mean	**0.559**	**0.234**	**0.128**	**0.137**	**0.200**	**0.205**	**0.155**	**0.040**	**1.656**	**1.097**

[1]Field test C1 tested samplers #1, #4, and #5;
Field test D1 tested samplers #1, #4, and #5;
Field test E1 tested samplers #1, #3, and #5;
Field test F1 tested samplers #1 and #5.

Table 8.—*Comparison of bedload samplers #1 and #2 using mean sampled unit bedload transport rate, kilograms per second-meter, by particle-size class.*

[Total unit bedload 1<X<64 = sum of sediment between 1.0 mm and 64.0 mm in size]

Field[1] test	Particle-size class, in millimeters								Total unit bedload transport rate	Unit bedload transport rate 1<X<64
	<1.0	1 to 2	2 to 4	4 to 8	8 to 16	16 to 32	32 to 64	64 to 128		
Sampler #1, 76 x 76 millimeter nozzle										
P1	0.024	0.279	0.419	0.568	0.875	0.568	0.233	0.000	2.966	2.942
Q1	0.065	0.342	0.308	0.436	0.748	0.772	0.611	0.024	3.306	3.217
Mean	**0.044**	**0.310**	**0.364**	**0.502**	**0.812**	**0.670**	**0.422**	**0.012**	**3.136**	**3.080**
Sampler #2, 76 x 76 millimeter nozzle										
P1	0.028	0.279	0.352	0.340	0.794	0.593	0.257	0.000	2.643	2.615
Q1	0.094	0.358	0.279	0.307	0.330	0.370	0.248	0.019	2.005	1.892
Mean	**0.061**	**0.318**	**0.316**	**0.324**	**0.562**	**0.482**	**0.252**	**0.009**	**2.324**	**2.254**

[1] Field test P1 tested samplers #1 and #2; field test Q1 tested samplers #1 and #2.

UNIT BEDLOAD SAMPLING RATIO COMPARISONS

Two techniques were used to compute the mean sampling ratio between two bedload samplers as shown in tables 11*A* and 11*B*. The first technique, the bulk sample ratio, is computed from the total sample. This technique uses all bedload particle sizes collected in the nylon mesh sampling bag. Different mixtures of bedload particle sizes can produce different bulk sample ratios.

The second technique, the mean sample class ratio, is computed from the average of the mean ratios for all particle-size classes greater than 1.0 mm and less than 64 mm, for samplers #1 through #4 and from 1.0 mm to 128 mm for samplers #5 and #6. The mean sample class ratio computed from the second technique is more representative of the relative sampling rates of the two samplers compared. This technique excludes bedload sediment having smaller diameters than can be retained by the nylon mesh sampling bag and larger diameters than can be sampled by the sampler because of its physical dimensions.

The mean sample class ratio shows that sampler #1 collected bedload at a mean rate about 1.36 times that of sampler #2 (table 11*A*). That mean ratio is 1.35 when the bulk sample ratio is used. As shown in tables 11*A* and 11*B*, the ratios vary from one particle-size class to the next. The sampling ratio increases from 0.98 for bedload sediment in the 1 mm to 2 mm size class to 1.68 for bedload sediment in the 32 mm to 64 mm size class (fig. 27 and table 11). Under these high-energy flow conditions, the bedload sampling rate of sampler #1 increased with respect to sampler #2 as sediment size increased. Either computational technique derives a sampling ratio greater than 1.00. As shown in table 1, sampler #1 has a higher ***hydraulic efficiency*** but is the same nozzle entrance dimensions as sampler #2.

The mean sample class ratio shows that sampler #1 collected bedload at a mean rate about 1.25 times that of sampler #3 (table 11*A* and fig. 28). That mean ratio was 1.53 when the bulk sample ratio was used. As shown in figure 28, the ratio decreases from 3.26 for bedload sediment in the 1 mm to 2 mm size class to only 0.53 for bedload sediment in the 32 mm to 64 mm class. Sampler #1 had a higher bedload sampling rate than sampler #3 for bedload sediment less than 8.0 mm and a lower bedload sampling rate than sampler #3 for all sizes of bedload sediment larger

Table 9*A*. *Comparison of bedload samplers 5# and #6 when bedload had a relatively low percentage of sand-sized sediment using mean sampled unit bedload transport rate, kilograms per second-meter, by particle-size class.*

[Total unit bedload 1<X<64 = sum of sediment between 1.0 mm and 64.0 mm in size]

Field[1] test	Particle-size class, in millimeters								Total unit bedload transport rate	Unit bedload transport rate 1<X<64
	<1.0	1 to 2	2 to 4	4 to 8	8 to 16	16 to 32	32 to 64	64 to 128		
Sampler #5, 305 x 152 millimeter nozzle										
G1	0.008	0.040	0.096	0.251	0.523	0.849	0.976	0.470	3.213	3.205
K1	0.002	0.006	0.002	0.002	0.005	0.009	0.025	0.041	0.092	0.090
B2	0.048	0.034	0.052	0.091	0.198	0.297	0.103	0.000	0.823	0.775
C2	0.208	0.127	0.210	0.397	0.523	0.432	0.157	0.000	2.054	1.846
Mean	**0.066**	**0.052**	**0.090**	**0.185**	**0.312**	**0.397**	**0.315**	**0.128**	**1.546**	**1.479**
Sampler #6, 305 x 152 millimeter nozzle										
G1	0.004	0.016	0.034	0.098	0.314	0.628	0.878	0.490	2.462	2.458
K1	0.001	0.004	0.001	0.001	0.004	0.008	0.026	0.031	0.076	0.075
B2	0.074	0.048	0.105	0.249	0.420	0.429	0.141	0.022	1.488	1.414
C2	0.196	0.143	0.264	0.506	0.554	0.353	0.135	0.000	2.151	1.955
Mean	**0.069**	**0.053**	**0.101**	**0.214**	**0.323**	**0.354**	**0.295**	**0.136**	**1.544**	**1.476**

[1] Field test G1 tested samplers #5 and #6; field test K1 tested samplers #5 and #6; field test B2 tested samplers #5 and #6; field test C2 tested samplers #5 and #6.

Table 9*B*. *Comparison of bedload samplers #5 and #6 when bedload had a relatively low percentage of sand-sized sediment using mean sampled unit bedload transport rate, kilograms per second-meter, by particle-size class.*

[Total unit bedload 1<X<64 = sum of sediment between 1.0 mm and 64.0 mm in size]

Field[1] test	Particle-size class, in millimeters								Total unit bedload transport rate	Unit bedload transport rate 1<X<64
	<1.0	1 to 2	2 to 4	4 to 8	8 to 16	16 to 32	32 to 64	64 to 128		
Sampler #5, 305 x 152 millimeter nozzle										
M1	1.059	0.261	0.133	0.120	0.161	0.154	0.118	0.024	2.030	0.971
O1	0.531	0.430	0.213	0.255	0.338	0.269	0.185	0.045	2.266	1.735
Mean	**0.795**	**0.346**	**0.173**	**0.188**	**0.250**	**0.211**	**0.152**	**0.034**	**2.148**	**1.353**
Sampler #6, 305 x 152 millimeter nozzle										
M1	1.659	0.432	0.187	0.194	0.407	0.280	0.184	0.108	3.451	1.792
O1	0.851	0.896	0.425	0.385	0.514	0.400	0.280	0.146	3.897	3.046
Mean	**1.255**	**0.664**	**0.306**	**0.290**	**0.460**	**0.340**	**0.232**	**0.127**	**3.674**	**2.419**

[1] Field test M1 tested samplers #5 and #6; field test O1 tested samplers #5 and #6.

Table 10.—*Comparison of the effect of different sampling times on mean sampled unit bedload transport rate, kilograms per second-meter, by particle-size class for field test using sampler #6.*

[Numbers in parentheses represent number of samples; additional data are provided in the appendix. Total unit bedload 1<X<64 = sum of sediment between 1.0 mm and 64.0 mm in size]

Field[1] test	Particle-size class, in millimeters								Total unit bedload transport rate	Unit bedload transport rate 1<X<64
	<1.0	1 to 2	2 to 4	4 to 8	8 to 16	16 to 32	32 to 64	64 to 128		
Sampler #6, 305 x 152 millimeter nozzle										
4 seconds sampling time (21)										
A2a	3.120	0.927	0.987	1.126	1.312	1.202	0.619	0.000	9.293	6.173
8 seconds sampling time (21)										
A2b	3.326	0.895	0.881	1.047	1.268	1.193	0.462	0.000	9.072	5.746
12 seconds sampling time (21)										
A2c	2.795	0.895	0.843	1.170	1.434	1.228	0.530	0.000	8.894	6.099
Mean	**3.080**	**0.906**	**0.937**	**1.114**	**1.709**	**1.208**	**0.537**	**0.000**	**9.087**	**6.006**

[1]Field test A2 tested sampler #6 only;

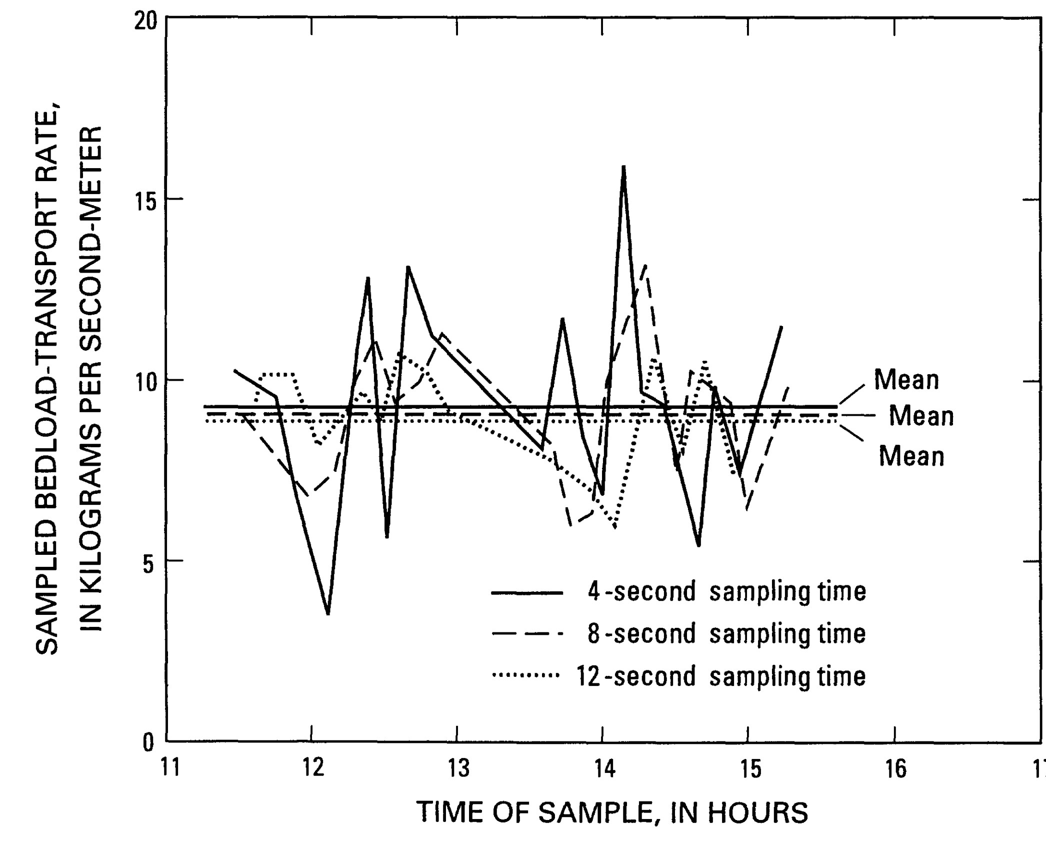

FIGURE 12.—Sampled unit bedload transport rate ane clock time for different sampling times for sampler #6, the 305-mm Toutle River-2 bedload sampler, A@ field test.

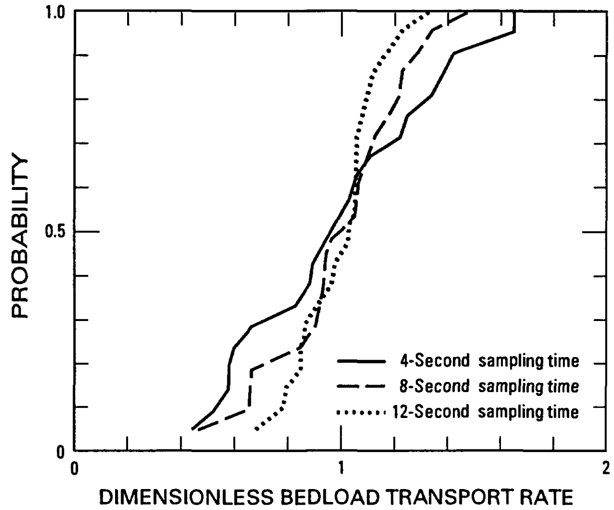

FIGURE 13.—Probability that dimensionless sampled bedload transport rate is equal to or less than the indicated dimensionless rate for different sampling times using sampler #6 (the 305-mm Toutle River-2 bedload sampler), A2 field test.

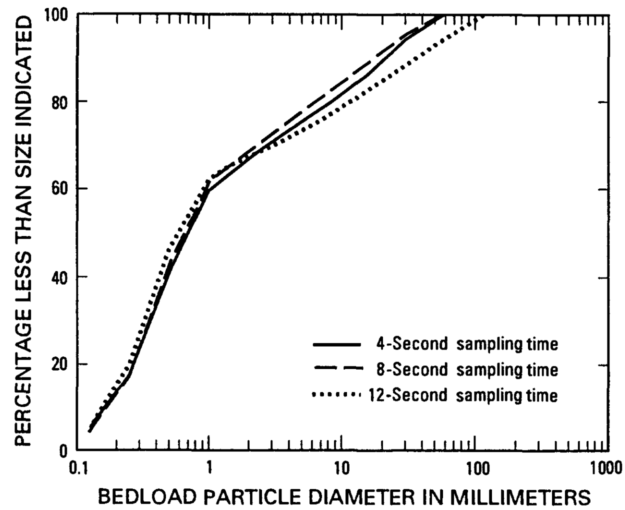

FIGURE 14.—Particle-size distributions of bedload sediment for different sampling times using sampler #6 (the 305-mm Toutle River-2 bedload sampler), A2 field test.

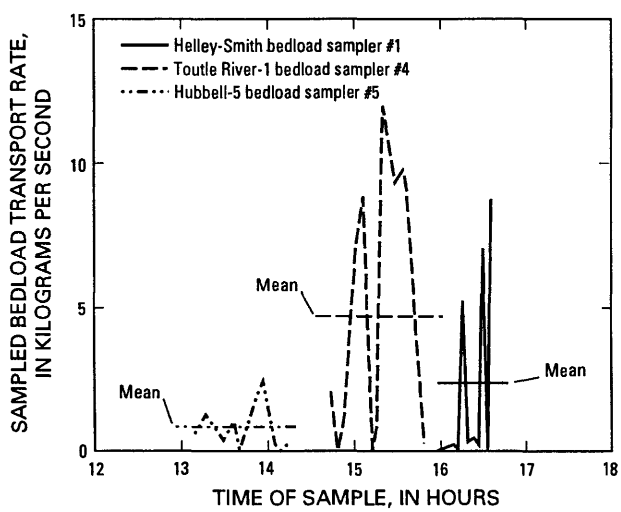

FIGURE 15.—Sampled unit bedload transport rate and clock time using using bedload samplers #1 (the 76-mm Helley-Smith), #4 (the 152-mm Toutle River-1), and #5 (the 305-mm Hubbell-5), C1 field test.

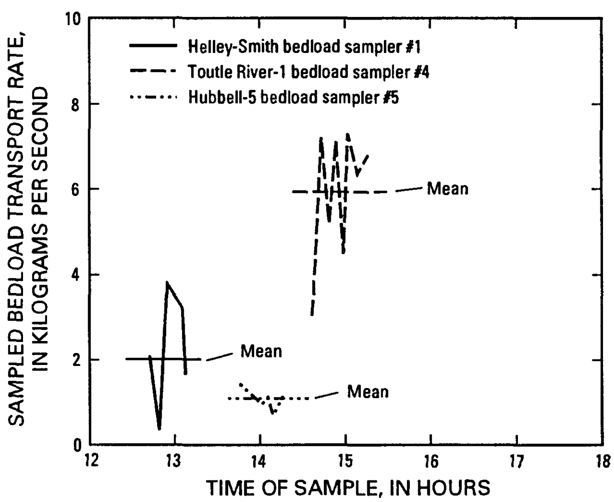

FIGURE 16.—Sampled unit bedload transport rate and clock time using using bedload samplers #1 (the 76-mm Helley-Smith), #4 (the 152-mm Toutle River-1), and #5 (the 305-mm Hubbell-5), D1 field test.

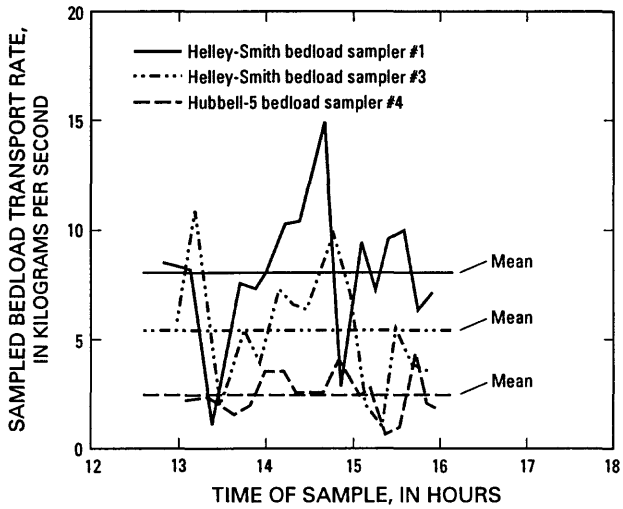

FIGURE 17.—Sampled unit bedload transport rate and clock time using using bedload samplers #1 (the 76-mm Helley-Smith), #3 (the 152-mm Helley-Smith), and #5 (the 305-mm Hubbell-5), E1 field test.

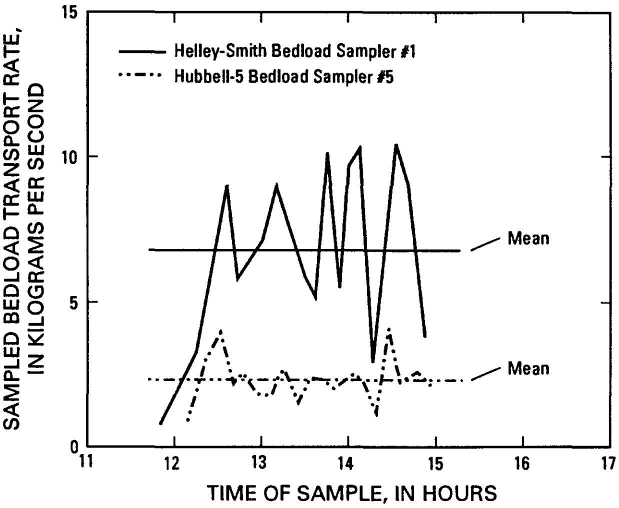

FIGURE 18.—Sampled unit bedload transport rate and clock time using using bedload samplers #1 (the 76-mm Helley-Smith) and #5 (the 305-mm Hubbell-5), F1 field test.

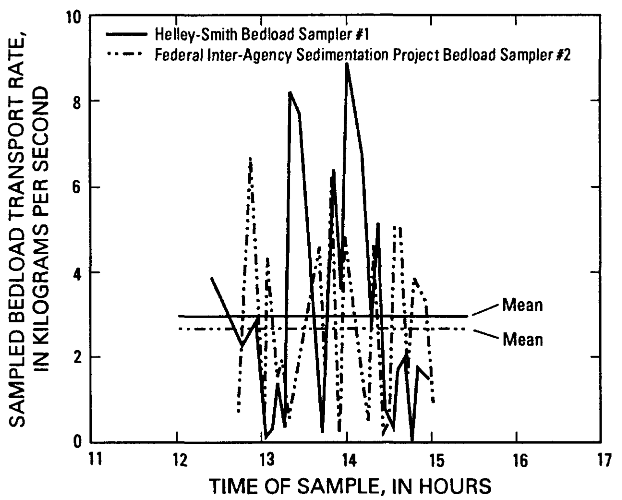

FIGURE 19.—Sampled unit bedload transport rate and clock time using using bedload samplers #1 (the 76-mm Helley-Smith) and #2 (the 76-mm Federal Inter-Agency Sedimentation Project), P1 field test.

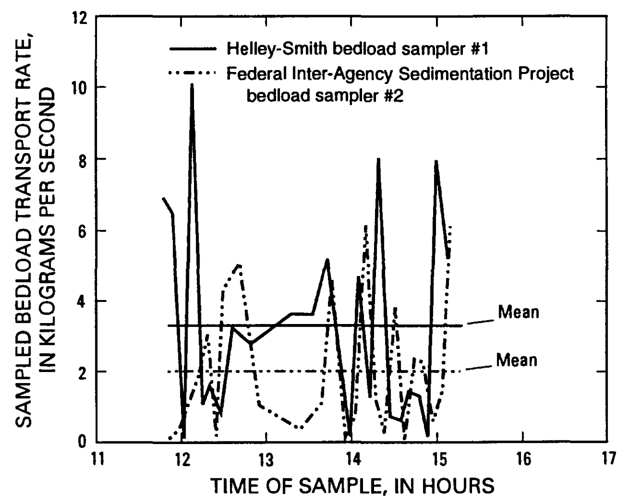

FIGURE 20.—Sampled unit bedload transport rate and clock time using using bedload samplers #1 (the 76-mm Helley-Smith) and #2 (the 76-mm Federal Inter-Agency Sedimentation Project), Q1 field test.

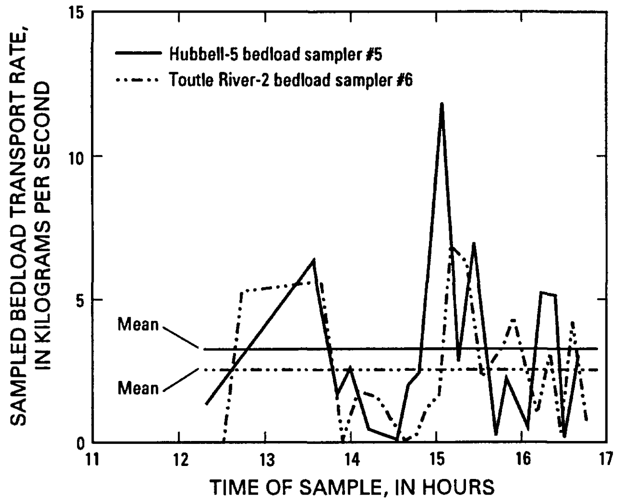

FIGURE 21.—Sampled unit bedload transport rate and clock time using using bedload samplers #5 (the 305-mm Hubbell-5) and #6 (the 305-mm Toutle River-2), G1 field test.

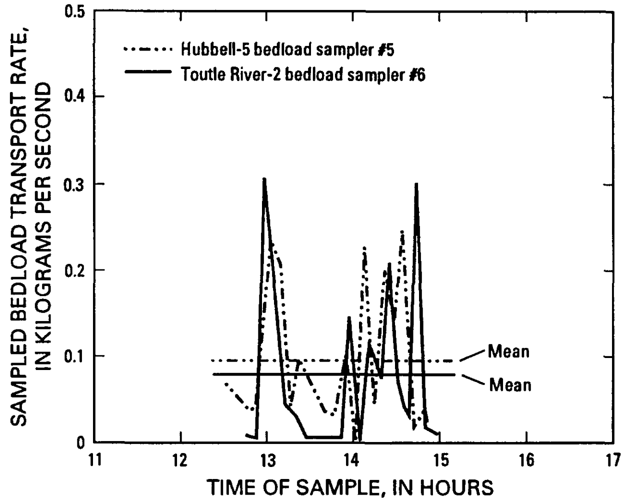

FIGURE 22.—Sampled unit bedload transport rate and clock time using using bedload samplers #5 (the 305-mm Hubbell-5) and #6 (the 305-mm Toutle River-2), K1 field test.

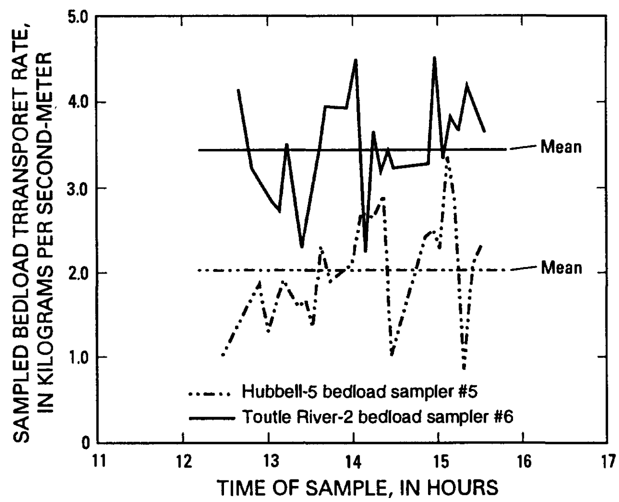

FIGURE 23.—Sampled unit bedload transport rate and clock time using using bedload samplers #5 (the 305-mm Hubbell-5) and #6 (the 305-mm Toutle River-2), M1 field test.

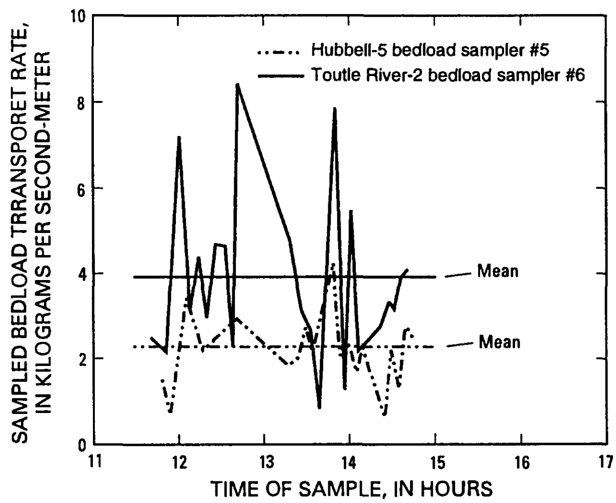

FIGURE 24.—Sampled unit bedload transport rate and clock time using using bedload samplers #5 (the 305-mm Hubbell-5) and #6 (the 305-mm Toutle River-2), O1 field test.

than 8.0 mm. As shown in table 1, sampler #1 has the same hydraulic efficiency but half the nozzle entrance dimensions as sampler #3.

The mean sample class ratio shows that sampler #1 collected bedload at a mean rate of 0.49 times that of sampler #4 (table 11*A* and fig. 29). That mean ratio was 0.40 when the bulk sample ratio was used. As shown in figure 29, the ratio decreases from 0.57 for bedload in the 1 mm to 2 mm size class to only 0.28 for bedload in the 32 mm to 64 mm class. Sampler #1 had a lower bedload sampling rate than sampler #3 for all sizes of sediment greater than 1.0 mm. As shown in table 1, sampler #1 has the same hydraulic efficiency but half the nozzle entrance dimensions as sampler #4.

The mean sample class ratio shows that sampler #1 collected bedload at a mean rate about 3.42 times that of sampler #5 (table 11*A* and fig. 30). That mean ratio was 2.70 when the bulk sample ratio was used. As shown in figure 30, the bedload sampling ratio decreased from 4.44 for sediment in the 1 mm to 2 mm size class to 1.95 for sediment in the 32 mm to 64 mm particle-size class. The bedload sampling rate of sampler #1 decreased with respect to sampler #5 as sediment size increased. As shown in table 1, sampler #1 has a higher hydraulic efficiency than sampler #5.

The mean sample class ratio shows that sampler #3 collected bedload at a mean rate 3.70 times that of sampler #5 (table 11*A* and fig. 31). That mean ratio was 3.65 when the bulk sample ratio was used. As shown in figure 31, the bedload sampling ratio was greatest for the particle-size classes between about 4 mm and 32 mm.

The mean sample class ratio shows that sampler #4, which has the same nozzle dimensions as sampler #3, collected bedload at a rate 5.73 times that of sampler #5 (table 11*A* and fig. 32). That mean ratio was 5.61 when the bulk sample ratio was used. As shown in table 1, samplers #3 and #4 have higher hydraulic efficiency than sampler #5. Sampler #4 has a higher mass than sampler #3 and may have a closer fit with a streambed.

The mean sample class ratio shows that sampler #6 collected bedload at a mean rate 1.70 times that of sampler #5 (table 11*B* and fig. 33) for bedload that had a relatively high percentage of sand-sized sediment. Median bedload particle diameters ranged from 0.93 mm to 2.91 mm (table 3). The bulk sample ratio was 1.71. The mean sample class ratio shows that sampler #6 collected bedload at about the same rate as sampler #5 (table 11*B* and fig. 34) when the bedload had a relatively low percentage of sand-sized bedload. Median bedload particle diameters ranged from

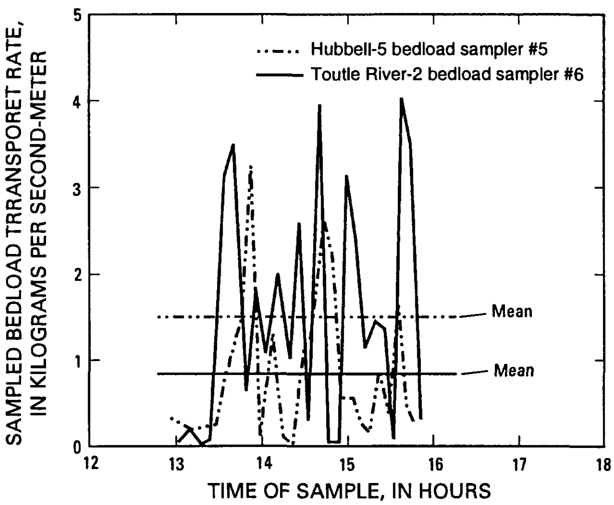

FIGURE 25.—Sampled unit bedload transport rate and clock time using using bedload samplers #5 (the 305-mm Hubbell-5) and #6 (the 305-mm Toutle River-2), B2 field test.

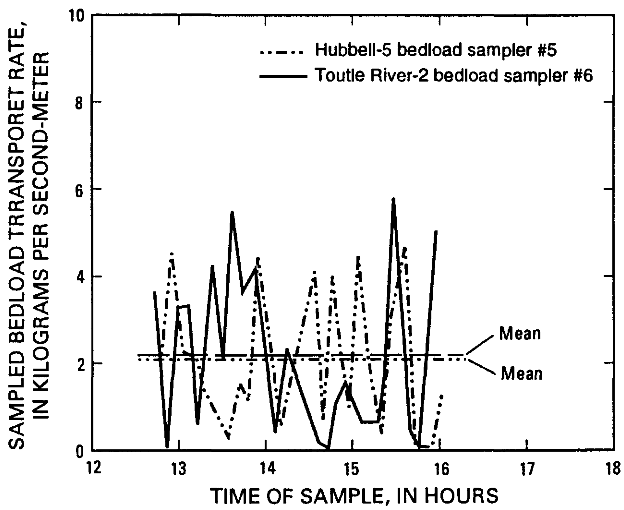

FIGURE 26.—Sampled unit bedload transport rate and clock time using using bedload samplers #5 (the 305-mm Hubbell-5) and #6 (the 305-mm Toutle River-2), C2 field test.

Table 11*A*.—*Mean unit bedload sampling ratios, by particle-size class, between pairs of bedload samplers.*

[Sampling ratio computed by dividing bedload rate of the first sampler by the bedload rate of second sampler tested.]

Samplers tested[1]	Bedload sampling ratios by size class, in millimeters							Bulk sample ratio from means of total bedload samples (all size classes)	Mean sample class ratio from mean of bedload size classes >1 millimeter
	1 to 2	2 to 4	4 to 8	8 to 16	16 to 32	32 to 64	64 to 128		
#1, #2	0.98	1.15	1.55	1.44	1.39	1.68	—	1.35	1.36
#1, #3	3.26	1.85	1.34	0.77	0.66	0.53	—	1.53	1.25
#1, #4	0.57	0.48	0.52	0.56	0.42	0.28	—	0.40	0.49
#1, #5	4.44	3.77	4.12	3.42	2.83	1.95	—	2.70	3.42
#3, #5	2.42	3.40	4.18	4.35	4.24	3.32	—	3.65	3.70
#4, #5	5.76	6.72	6.87	5.99	6.65	2.39	2.67	5.61	5.73

[1]Sampler #1 = Helley-Smith bedload sampler, 76 mm x 76 mm nozzle, 3.22 area-expansion ratio.
Sampler #2 = FIASP bedload sampler, 76 mm x 76 mm nozzle, 1.40 area-expansion ratio.
Sampler #3 = Helley-Smith bedload sampler, 152 mm x 152 mm nozzle, 3.22 area-expansion ratio.
Sampler #4 = FR-1 bedload sampler, 152 mm x 152 mm nozzle, 3.22 area-expansion ratio.

Table 11*B*.—*Mean unit bedload sampling ratios, by particle-size class, between pairs of bedload samplers when bedload has different percentages of sand-sized sediment.*

[Sampling ratio computed by dividing bedload rate of the first sampler by the bedload rate of second sampler tested.]

Samplers tested[1]	Bedload sampling ratios by size class, in millimeters							Bulk sample ratio from means of total bedload samples (all size classes)	Mean sample class ratio from mean of bedload size classes >1 millimeter
	1 to 2	2 to 4	4 to 8	8 to 16	16 to 32	32 to 64	64 to 128		
Bedload with a high percentage of sand[2]									
#6, #5	1.92	1.77	1.54	1.84	1.61	1.53	3.73	1.71	1.70
Bedload with a low percentage of sand[3]									
#6, #5	1.02	1.12	1.16	1.04	0.89	0.94	1.06	1.03	1.00

[1] Sampler #5 = Hubbell No. 5 bedload sampler, 305 mm x 152 mm nozzle, 1.40 area-expansion ratio.
Sampler #6 = Toutle River-2 (TR-2) bedload sampler, 305 mm x 152 mm nozzle, 1.40 area-expansion ratio.
[2] Median bedload sediment particle diameters ranged from 0.93 mm to 2.91 mm.
[3] Median bedload sediment particle diameters ranged from 8.80 mm to 34.0 mm.

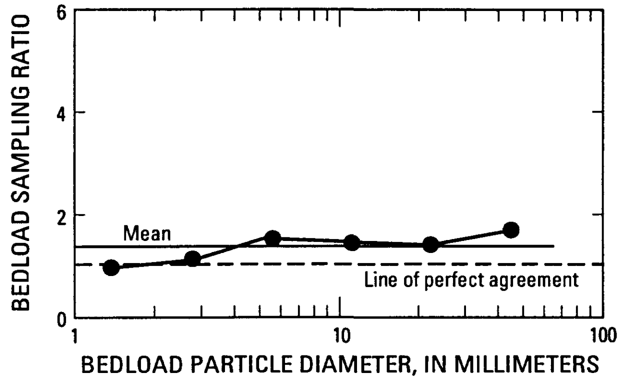

FIGURE 27.—Bedload sampling ratio between samplers #1 ((the 76-mm Helley-Smith) and #2 (the 76-mm Federal Inter-Agency Sedimentation Project) by bedload particle size class.

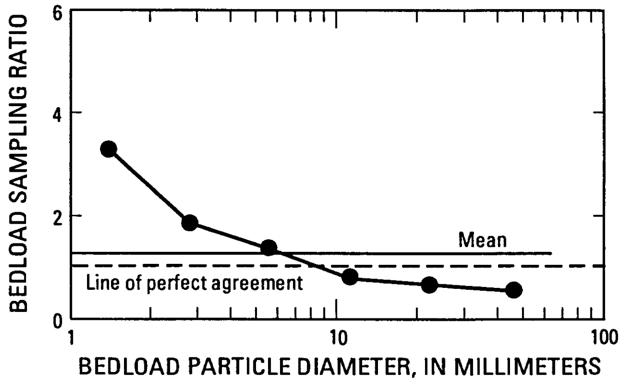

FIGURE 28.—Bedload sampling ratio between samplers #1 (the 76-mm Helley-Smith) and #3 (the 152-mm Helley-Smith) by bedload particle size class.

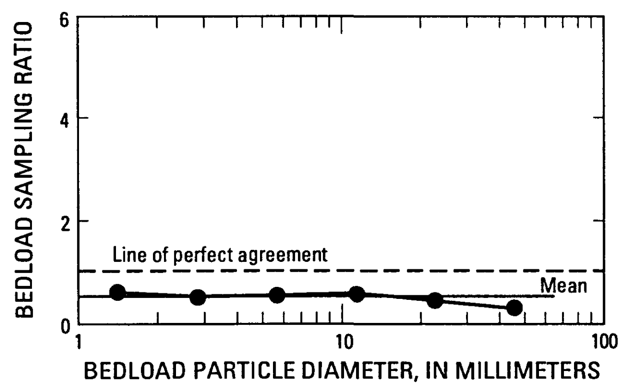

FIGURE 29.—Bedload sampling ratio between samplers #1 (the 76-mm Helley-Smith) and #4 (the 152-mm Toutle River-1) by bedload particle size class.

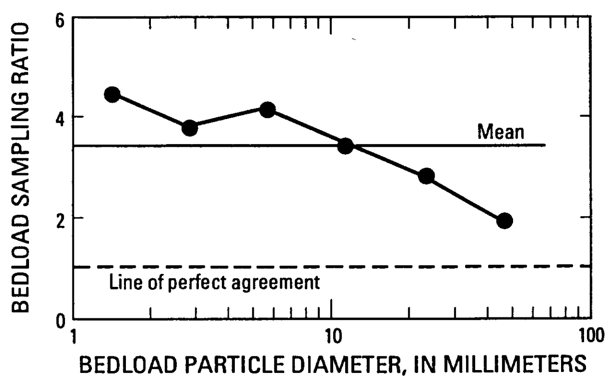

FIGURE 30.—Bedload sampling ratio between samplers #1 (the 76-mm Helley-Smith) and #5 (the 305-mm Hubbell-5) by bedload particle size class.

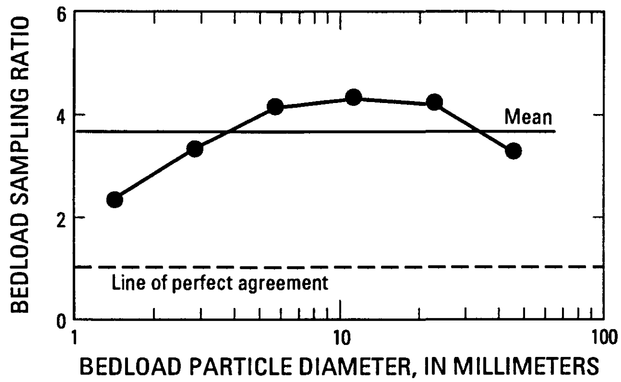

FIGURE 31.—Bedload sampling ratio between samplers #3 (the 152-mm Helley-Smith) and #5 (the 305-mm Hubbell-5) by bedload particle size class.

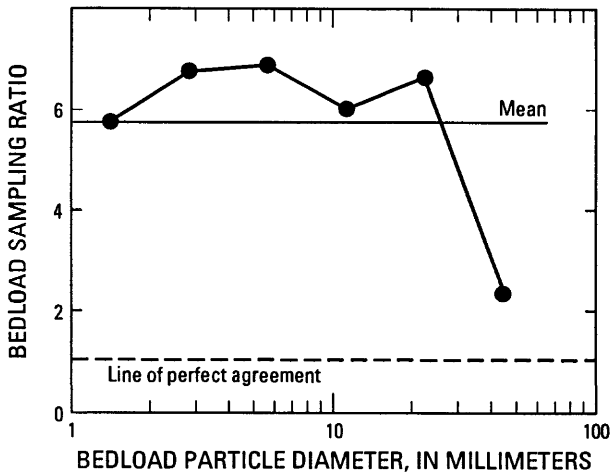

FIGURE 32.—Bedload sampling ratio between samplers #4 (the 152-mm Toutle River-1) and #5 (the 305-mm Hubbell-5) by bedload particle size class.

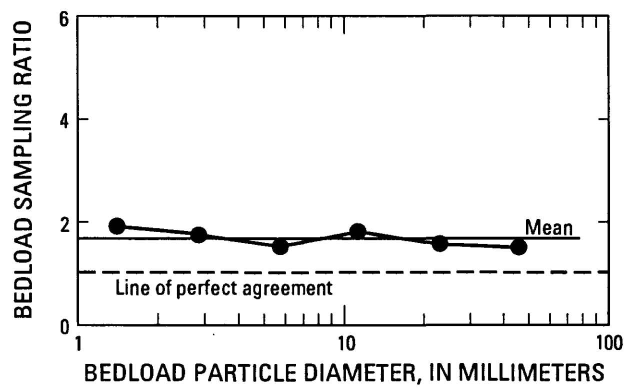

FIGURE 33.—Bedload sampling ratio between samplers #6 (the 305-mm Toutle River-2) and #5 (the 305-mm Hubbell-5) when the bedload had a relatively high percentage of sand-sized sediment, by bedload particle size class.

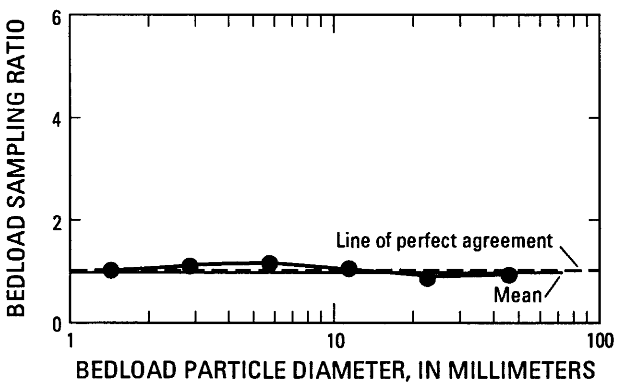

FIGURE 34.—Bedload sampling ratio between samplers #6 (the 305-mm Toutle River-2) and #5 (the 305-mm Hubbell-5) when the bedload had a relatively low percentage of sand-sized sediment, by bedload particle size class.

8.80 mm to 34.0 mm (table 3). The bulk ratio was 1.03. As shown in table 1, both samplers have the same nozzle dimensions and hydraulic efficiency but sampler #6 has greater mass than sampler #5 and may have a closer fit with the streambed.

The differences in sampling ratios by bedload particle size may be caused by three main factors. These include: (1) the relation between bedload particle size and dimension of the sampler nozzle, (2) differences in mass of the samplers and the closeness of fit with the streambed, and (3) differences in hydraulic efficiencies in pairs of sampler compared.

The largest bedload particle than can be sampled with a particular sampler is restricted by its nozzle width. Both samplers #1 and #2 should be used to sample bedload having particle diameters to about 16 mm. Particles larger than 16 mm in intermediate diameter may interfere with one another as they enter a nozzle only 76 mm wide. The double-scale size of samplers #3 and #4 allow them to sample bedload particle diameters to about 32 mm. The wider nozzle width of samplers #5 and #6 allows them to sample bedload sediment to about 64 mm in size.

Because of the small capacity of the nylon mesh bag, restricted by the design of the sampler frame, samplers #1, #2, #3, and #5 cannot accurately sample bedload transport rates as high as can samplers #4 and #6. Samplers #4 and #6 can collect bedload when transport rates are nearly double those that can be collected by sampler #3 and #5 because of larger nylon mesh catchment bag.

As shown in table 1, all bedload samplers tested have hydraulic efficiencies that are greater than 1.0. Use of any of these samplers when the bedload contains a high percentage of sand may result in oversampling by mining sediment from the streambed. Also, nylon mesh sample catchment bags on all six samplers can easily become clogged when the bedload contains sand in the same size class as the bag mesh.

FACTORS AFFECTING SAMPLING RESULTS

Bedload Sampler Stability

Test samplers #1, #2, #3, and #5 are not stable in high-energy flow because of high width/length ratios and tail surfaces located in the turbulent zone immediately behind the nozzle and mesh bag. Instability appeared as a oscillation of the sampler to either side of the vertical line below the suspension point. Sampler #5 was more stable with the installation of a "shroud" around the tail section (fig. 5), and all samplers were more stable with the use of a stayline. Test samplers #4 and #6 were much more stable than all other samplers, even when tested without a stayline.

All samplers tested in the program performed better submerged when they had been suspended in the air at a slope of about 1 to 10 with the nozzle slightly higher than the tail. This attitude allowed the sampler to enter the flow more easily, have a nearly horizontal attitude when submerged, and remain properly oriented in the flow when lowered to the streambed. Testing indicated that when the sampler tail was much lower than the nozzle, samplers #3 and #5 sometimes hydroplaned on the water surface and because submerged only with difficulty.

Test samplers #1 and #2 were unstable in the flow when balanced at the end of the suspension line in a nearly horizontal attitude because the centroid of mass of each sampler is near the center of its length. A solution to the instability was to always use the sampler with a tether line attached to the sampler frame at a point forward of the suspension point (fig. 2). Test sampler #3 was the least stable in high velocity and turbulence of all the samplers tested because of its high width/length ratio and the central location of its balance point. It became only marginally stable when used with a tether line.

Test sampler #4 was always stable in turbulent flow, even when used without a tether line because of its low width-to-length ratio and high cross-sectional density. Test sampler #5 was only marginally stable without the tether line. Because of the shroud around the tail section, the sampler was very stable when used with a tether line; however, it generally hydroplaned on the water surface and was not easily submerged because of its relatively light weight. Once submerged, sampler #5 was more stable in the flow than either sampler #1, #2 or #3. Test sampler #6 had about the same stability as sampler #4 and was stable with or without a tether line because of its low width-to-length ratio and high cross-sectional density.

Bedload Sampler Trap Efficiency and Design

Sediment-trapping efficiency and hydraulic efficiency are important characteristics inherent in the design of any bedload sampler. If a bedload sampler has a sampling efficiency greater than 1.0 it may be that its hydraulic efficiency also will be greater than 1 and flow will be accelerated into the nozzle entrance. This can cause streambed erosion immediately upstream from the sampler nozzle. "Oversampling" caused by "mining" sediment from the bed cannot be accurately accounted for in the calibration of sampling efficiency. Conversely, a hydraulic efficiency less than 1 can cause decelerated flow approaching the nozzle entrance. This condition may result in the accumulation of sediment on the streambed immediately upstream from the nozzle. As a mound develops, an unpredictable amount of subsequent bedload may be diverted to either side of the sampler nozzle. These conditions cannot be accounted for in the calibration of nozzle sampling efficiency. Regardless of the hydraulic efficiency, the acceleration of the flow around the nozzle sidewall can erode the streambed under the corners of the sampler nozzle entrance (Hubbell and others, 1986). This narrows the bed surface in front of the nozzle and reduces the effective nozzle width available for entrance of bedload into the sampler.

The manner in which the bedload sampler sits on the streambed is determined by characteristics of the design, including: (1) mass of the sampler, (2) length and width of the sampler with respect to the sizes of the ***bed material*** sediment particles or dimensions of bedforms, (3) parts of the sampler actually touching the bed, and (4) design of the bedload sampler nozzle entrance.

To collect a more accurate bedload sample, the ideal sampler would possess the following characteristics:

1. The sampler entrance would be several times larger than the largest bedload particle to allow entrance with minimum interference from other bedload particles.
2. The construction of the bedload sampler would enable a good "fit" between the sampler bottom and the streambed to minimize loss of bedload particles under the sampler due to the presence of bedforms or large bed material particles.
3. The sampler would accommodate a large sample volume to allow sampling high bedload transport rates and accurately sample particle-size distribution. This would allow sufficient sampling time to minimize error associated with measurement of time. A ten-second minimum sampling time is desirable.
4. The hydraulic efficiency and sampling efficiency of a bedload sampler would be determined for the full range of field conditions under which is will be used. The hydraulic efficiency would be known because it affects the sampling efficiency. Ideally, the sampling efficiency would be as near 1.00 as can be accomplished by design of the sampler and would be as nearly constant as possible through a wide range of bedload transport rate, particle-size distribution, and flow velocity.
5. Sampler performance, while traveling between the surface and the streambed, would be stable under a wide range of velocity, turbulence, and water depth.

Bedload Sampling Technique

Field tests show that care needs to be exercised in the placement and retrieval of a bedload sampler at the streambed. The following are errors which can be avoided by using proper sampling technique:

1. If the tail of the sampler touches the streambed before the nozzle, the force of the flow may rotate the sampler nozzle to the side, with the part of the tail touching the bed functioning as a pivot point. This pivoting action can cause the nozzle to rest on the bed at an angle to the direction of flow and bedload, decreasing the ***bedload sampling efficiency***. This can be avoided by balancing the sampler in the air so that it has a slope of about 1 to 10 with the tail lower than the nozzle. This allows the sampler to have a nearly horizontal attitude when submerged.
2. If the bedload sampler nozzle contacts the bed before other sampler points touch, the nozzle may scoop a bed material sample and

add it to the bedload sample. This can occur when the sampler is balanced so that the nozzle is lower than the tail or if the sampler is lowered through the flow at a high rate so that the large area of the tail surface causes the sampler to dive nose first. This can be avoided by balancing the sampler as described above and by lowering the sampler slowly enough that all parts of the sampler contact the bed at the same time.

3. If the bedload sampler nozzle entrance does not have good contact with the bed, bedload particles may pass under the sampler. This condition can occur when the suspension line to the sampler is kept too taut and the bottom of the sampler does not make firm contact with the bed. The loss of bedload sediment under this condition can be avoided by allowing the suspension line to be slightly slack when sampling bedload. This procedure allows consistency in technique and lessens the likelihood of a gap between the sampler nozzle entrance and the streambed and resultant loss of bedload under the sampler.

4. If the bedload sampler moves upstream along the streambed, it may scoop a bed material sample and add it to the bedload sample. This can occur under three conditions.

   (a) Normally the stream velocity near the water surface causes the sampler to be pulled downstream along an arc defined by the length of the suspension line. As the sampler is lowered toward the streambed through the column of flowing water, it experiences less drag from the flow as it nears the streambed due to the decrease in velocity. This allows the sampler to swing upstream and downward along the arc. When this movement occurs near the bed, the bedload sampler may strike the bed and scoop a bed material sample. This characteristic is most pronounced with a long suspension line.

   (b) If the sampler is dragged along the streambed as it is being retrieved after sampling bedload, it can dredge bed material. This can occur when the sampler has been placed on the bed downstream of the suspension point. The addition of the bedload sample increases the total weight of the sampler, allowing it to sometimes be dragged a short distance before it can be lifted from the bed by its suspension line.

   (c) Natural turbulence near the bed can allow the sampler to drift upstream along the arc subtended by the suspension line in response to fluctuating velocity and flow direction and scoop bed material as the sampler is hoisted from the bed.

   These errors can be avoided by lowering the sampler slowly when it is near the bed to prevent nose diving, by retrieving the sampler quickly when sampling is complete, and by use of a tether line. If the length of the tether line is adjusted to place the bedload sampler below a vertical suspension line, any upstream movement of the sampler near the bed will be upward along the arc subtended by the suspension line.

5. The equipment with which the sampler will be used such as suspension mechanisms (cable or rod), power available for hoisting and lowering the sampler (electric, hydraulic, or manpower), and means of access to the stream (boat, cable, bridge, or by wading), must be appropriate for the scale of sampler (physical dimensions and mass) required for the water depths and velocities and the particle sizes of the bedload sediment (sand, gravel, or cobble bedload).

SUMMARY

Field comparisons of sampling characteristics of six pressure-difference bedload samplers, modeled after the Helley-Smith bedload sampler, were made in a natural stream having turbulent, high-velocity flow, and high bedload transport rates. The samplers have intake nozzles with entrance dimensions (width and height) ranging from 76 x 76 mm to 305 x 152 mm and include nozzle area expansion ratios of 1.40 and 3.22.

The sampling ratio of each pair of samplers tested was computed by dividing the mean bedload transport rate sampled by one sampler by the mean rate sampled by a second sampler. These ratios provide insight into relative sampling characteristics

of bedload samplers during high-energy flow. Under those conditions and when the bedload consists of mixtures of sand- and gravel-sized sediment, sampler #1 (76-mm Helley-Smith bedload sampler) sampled unit bedload at a rate averaging 17 times that of sampler #2 (76-mm Federal Inter-Agency Sedimentation Project bedload sampler). Sampler #1 sampled unit bedload at a rate averaging 1.25 times that of sampler #3 (152-mm Helley-Smith bedload sampler) and 0.49 times that of sampler #4 (152-mm Toutle River-1 bedload sampler). Samplers #3 and #4 have nozzles in the same relative proportions as sampler #1 but double in size. Sampler #1 sampled unit bedload at a rate averaging 3.42 times that of sampler #5 (305-mm Hubbell-5 bedload sampler). Sampler #3 sampled unit bedload at a rate averaging 3.70 times that of sampler #5. Sampler #4 sampled unit bedload at a rate averaging 5.73 times that of sampler #5. Sampler #6 (305-mm Toutle River-2 bedload sampler) sampled unit bedload at a rate averaging 1.70 times that of sampler #5 when the bedload had a relatively high percentage of sand-sized sediment (46 to 63 percent). Sampler #6 sampled unit bedload at the same rate as sampler #5 when the bedload had a relatively small percentage of sand-sized sediment (6 to 20 percent).

Sampler stability was greatly improved by using staylines during field tests. Stability of sampler #5 was improved by including in its original design a shroud around the tail section. Bedload samplers #4 and #6 are derived from the designs of samplers #3 and #5 and include design modifications to improve stability and sampling characteristics. Samplers #4 and #6 were designed to have low width/length ratios which increased their stability as compared with samplers #3 and #5. The large size of the tail section of sampler #6 increased its stability in turbulent flow. Stability of both samplers #4 and #6 was improved by increasing cross-sectional density. Evaluation of field performance for each of the 6 bedload samplers tested showed that only the Toutle River-1 and Toutle River-2 bedload samplers were stable in high-energy flow without the use of a stayline. However, use of a stayline improved the stability of all bedload samplers tested.

Accuracy of bedload samples collected at a single vertical was improved by: (1) increasing sampler stability, (2) using a sampler with a nozzle larger than bedload particle sizes in transport, (3) developing appropriate field technique and always using the same technique, and (4) increasing the dimensions of the nylon mesh catchment bag to accommodate high bedload transport rates.

The Toutle River-2 bedload sampler was developed in this study for sampling bedload under conditions of high velocity and turbulence and high sediment transport rates. This sampler has a mass of 100 kg, overall length of 1.52 m, nozzle entrance that is 305 mm wide and 152 mm high, and hydraulic efficiency estimated at 1.40. It appears to provide representative bedload samples of bedload consisting of a mixture of sediment in the size range between 1.0 mm and 128.0 mm.

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APPENDIX

Appendix I-*A*.—*Particle-size distribution of sampled bedload sediment from field test C1, Toutle River at Coal Bank bridge on January 15, 1986*

Sample number	Sampler number	Time	Mass of sample (grams)	Sampling time (seconds)	Percent by mass finer than sieve size indicated									
					0.25	0.50	1.00	2.00	4.00	8.00	16.00	32.00	64.00	128.00
C101	5	1307	4057.3	30	0.1	1.5	7.9	20.5	29.8	43.0	62.1	85.4	99.0	100.0
C102	5	1316	11,642.8	30	0.8	4.5	12.9	25.1	36.0	50.6	68.2	86.6	95.2	100.0
C103	5	1322	7,778.4	30	0.7	5.7	27.8	47.3	52.0	57.5	68.2	83.2	100.0	100.0
C104	5	1328	3,254.9	30	1.5	6.5	18.3	43.3	50.9	57.0	64.7	72.8	100.0	100.0
C105	5	1335	9,424.6	30	1.0	4.7	15.0	33.5	43.9	53.0	65.9	83.5	100.0	100.0
C106	5	1339	254.1	30	0.3	1.8	14.1	91.0	98.2	99.5	99.8	100.0	100.0	100.0
C107	5	1346	8,773.8	30	1.4	5.6	16.8	36.0	46.8	58.3	76.4	91.2	100.0	100.0
C108	5	1351	17,522.8	30	0.6	3.1	12.2	24.3	31.7	42.6	61.5	79.1	94.8	100.0
C109	5	1356	21,977.7	30	0.4	2.4	10.5	22.4	28.0	35.9	53.4	80.0	95.5	100.0
C110	5	1404	2,168.3	30	0.2	1.0	5.0	24.7	27.9	30.1	35.6	63.8	100.0	100.0
C111	5	1408	191.4	30	0.4	2.0	13.2	76.4	82.6	84.1	84.3	100.0	100.0	100.0
C112	5	1413	2,722.9	30	3.3	12.0	27.5	59.8	73.8	82.7	93.7	100.0	100.0	100.0
C113	4	1443	9,406.6	30	0.2	1.7	8.0	23.0	30.1	36.9	53.0	74.7	95.2	100.0
C114	4	1448	66.6	30	1.5	7.9	38.4	93.0	98.5	100.0	100.0	100.0	100.0	100.0
C115	4	1452	5,378.1	30	0.1	0.5	3.9	10.0	14.9	25.3	55.0	89.2	100.0	100.0
C116	4	1500	31,124.4	30	0.1	0.5	2.2	8.0	16.2	27.3	46.4	73.0	94.7	100.0
C117	4	1506	40,499.3	30	0.2	1.5	5.6	14.5	21.8	33.1	53.3	85.3	100.0	100.0
C118	4	1512	26.2	30	1.1	6.1	25.6	83.6	97.3	100.0	100.0	100.0	100.0	100.0
C119	4	1516	7,330.1	30	0.2	1.6	8.6	26.9	38.7	51.0	66.3	91.8	100.0	100.0
C120	4	1520	55,112.5	30	0.3	2.4	11.2	26.9	40.0	54.8	73.5	92.2	97.9	100.0
C121	4	1529	42,536.9	30	0.1	1.4	8.9	28.9	42.2	56.1	72.5	92.5	100.0	100.0
C122	4	1535	44,899.1	30	0.2	2.3	12.8	31.8	45.0	58.2	74.1	91.1	100.0	100.0
C123	4	1548	564.9	30	0.2	2.0	19.0	50.0	60.5	66.5	75.4	86.7	100.0	100.0
C124	1	1557	102.3	30	0.5	5.4	29.8	88.3	95.2	97.1	97.8	100.0	100.0	100.0
C125	1	1609	277.0	15	0.1	0.5	7.4	37.8	47.2	55.3	69.6	100.0	100.0	100.0
C126	1	1612	20.4	15	0.5	3.4	14.0	88.4	97.6	100.0	100.0	100.0	100.0	100.0
C127	1	1616	6,007.7	15	0.1	1.6	12.9	35.4	47.5	61.1	82.5	98.4	100.0	100.0
C128	1	1619	374.7	15	0.0	0.4	8.0	42.2	53.5	59.4	71.9	84.0	100.0	100.0
C129	1	1623	547.8	15	0.1	0.6	9.3	46.1	55.9	65.1	76.7	100.0	100.0	100.0
C130	1	1626	317.9	15	0.1	0.6	11.0	54.9	62.3	66.6	75.4	100.0	100.0	100.0
C131	1	1630	8,081.4	15	0.2	1.9	12.0	29.0	37.8	50.5	71.4	90.2	100.0	100.0
C132	1	1633	133.5	15	0.2	1.4	14.2	48.8	56.6	60.9	80.7	100.0	100.0	100.0
C133	1	1636	10,002.0	15	0.1	1.0	8.7	26.8	38.8	53.5	73.3	92.0	100.0	100.0
Sampler number 5 average =					**0.9**	**4.2**	**15.1**	**42.0**	**50.1**	**57.9**	**69.5**	**85.5**	**98.7**	**100.0**
Sampler number 4 average =					**0.4**	**2.5**	**13.1**	**36.1**	**45.9**	**55.4**	**70.0**	**88.8**	**98.9**	**100.0**
Sampler number 1 average =					**0.2**	**1.7**	**12.7**	**49.8**	**59.2**	**67.0**	**79.9**	**96.5**	**100.0**	

Appendix I-*B*.—*Particle-size distribution of sampled bedload sediment from field test D1, Toutle River at Coal Bank bridge on January 16, 1986*

Sample number	Sampler number	Time	Mass of sample (grams)	Sampling time (seconds)	Percent by mass finer than sieve size indicated									
					0.25	0.50	1.00	2.00	4.00	8.00	16.00	32.00	64.00	128.00
D101	1	1242	2,373.4	15	0.1	1.6	4.0	12.7	28.1	52.6	82.1	97.8	100.0	
D102	1	1248	612.4	21	0.2	2.6	4.9	19.2	37.5	66.3	91.8	100.0	100.0	
D103	1	1250	1,286.9	21	0.3	3.6	5.9	12.8	23.5	48.3	83.8	100.0	100.0	
D104	1	1252	3,325.2	21	0.5	7.9	13.7	18.5	23.7	39.2	77.8	96.5	100.0	
D105	1	1255	5,786.8	20	1.3	22.9	40.5	43.9	46.6	56.8	81.0	99.0	100.0	
D106	1	1305	2,466.2	10	0.3	5.8	13.9	24.2	35.4	56.4	87.1	97.7	100.0	
D107	1	1307	1,288.3	10	0.6	9.8	20.3	34.0	47.3	67.9	88.1	100.0	100.0	
D108	5	1346	3,296.0	30	3.4	45.1	66.6	68.3	69.1	71.3	83.1	95.5	100.0	
D109	5	1352	11,207.7	30	4.8	45.6	66.1	70.2	75.2	86.4	95.2	99.5	100.0	
D110	5	1357	10,569.7	30	3.6	34.0	50.7	55.3	60.8	70.7	90.6	98.5	100.0	
D111	5	1401	8,793.8	30	4.6	44.1	63.0	67.4	73.3	81.3	91.7	100.0	100.0	
D112	5	1405	9,926.6	30	3.6	25.9	36.2	41.4	48.6	56.7	84.5	98.0	100.0	
D113	5	1409	6,143.7	30	3.7	36.9	51.2	55.3	58.8	66.7	84.7	95.6	100.0	
D114	5	1412	9,911.8	30	2.5	23.4	32.6	43.9	58.3	75.8	93.9	98.5	100.0	
D115	5	1416	10,377.6	30	4.3	34.1	46.3	52.9	61.1	75.0	91.7	99.0	100.0	
D116	4	1437	13,852.7	30	0.7	8.7	16.3	20.9	27.8	47.6	87.3	99.7	100.0	
D117	4	1444	33,110.5	30	1.7	26.2	54.9	60.8	66.8	76.9	91.4	99.1	100.0	
D118	4	1449	23,553.5	30	1.9	20.7	32.3	38.5	48.0	65.9	86.5	99.4	100.0	
D119	4	1454	32,815.0	30	2.3	24.5	36.9	43.8	55.7	76.7	95.2	99.8	100.0	
D120	4	1459	20,397.2	30	2.4	37.5	61.2	63.5	64.6	67.1	77.7	96.8	100.0	
D121	4	1503	33,636.7	30	1.8	29.1	63.2	69.5	73.8	80.9	92.1	99.4	100.0	
D122	4	1510	28,642.1	30	9.9	21.7	32.2	45.3	53.1	61.3	72.0	88.0	100.0	
D123	4	1516	31,056.1	30	2.2	33.4	57.6	61.2	64.1	70.2	89.6	98.1	100.0	
Sampler number 1 average =					**0.5**	**7.7**	**14.7**	**23.6**	**34.6**	**55.4**	**84.5**	**98.7**	**100.0**	
Sampler number 4 average =					**2.9**	**25.2**	**44.3**	**50.4**	**56.7**	**68.3**	**86.5**	**97.5**	**100.0**	
Sampler number 5 average =					**3.8**	**36.1**	**51.6**	**56.8**	**63.2**	**73.0**	**89.4**	**98.1**	**100.0**	

Appendix I-C.—*Particle-size distribution of sampled bedload sediment from field test E1, Toutle River at Coal Bank bridge on January 29, 1986*

Sample number	Sampler number	Time	Mass of sample (grams)	Sampling time (seconds)	Percent by mass finer than sieve size indicated 0.25	0.50	1.00	2.00	4.00	8.00	16.00	32.00	64.00	128.00
E101	1	1247	6,465.3	10	1.4	11.7	41.5	56.8	60.4	64.9	74.5	81.9	86.6	100.0
E102	3	1257	8,723.3	10	1.4	3.9	10.3	29.1	38.0	49.9	65.6	85.6	100.0	100.0
E103	5	1302	6,618.0	10	1.7	11.2	30.2	49.7	61.5	72.4	84.5	93.1	100.0	100.0
E104	1	1307	6,220.2	10	0.4	2.2	12.4	37.4	49.7	58.5	67.1	78.5	100.0	100.0
E105	3	1312	16,723.0	10	0.0	0.0	0.0	0.3	0.6	3.5	27.2	64.7	88.4	100.0
E106	5	1317	7,111.1	10	2.6	13.4	37.2	56.4	64.9	72.3	81.8	95.5	100.0	100.0
E107	1	1321	759.3	10	0.0	0.1	2.5	23.8	29.6	33.1	38.1	40.8	100.0	100.0
E108	3	1326	2,985.7	10	0.0	0.1	1.0	12.4	19.5	26.5	35.2	51.7	68.4	100.0
E109	5	1336	4,589.3	10	9.2	42.6	71.3	87.8	94.0	97.4	99.4	100.0	100.0	100.0
E110	1	1341	5,720.5	10	1.7	11.4	42.5	63.6	69.6	75.0	81.2	86.1	100.0	100.0
E111	3	1344	8,186.1	10	0.0	0.0	0.2	1.6	2.1	3.6	16.3	41.6	81.9	100.0
E112	5	1347	5,740.8	10	4.5	29.5	62.0	77.8	83.6	88.8	95.2	100.0	100.0	100.0
E113	1	1351	5,525.8	10	0.1	0.6	5.8	28.6	51.5	72.4	87.5	96.8	100.0	100.0
E114	3	1354	5,675.8	10	0.1	0.2	2.1	21.1	29.4	34.4	38.7	48.3	71.4	100.0
E115	5	1358	10,777.0	10	2.6	10.5	24.1	35.5	42.8	50.5	62.6	76.8	87.5	100.0
E116	1	1402	6,318.8	10	0.5	3.9	21.9	54.1	73.8	85.8	92.6	95.6	100.0	100.0
E117	3	1407	11,067.1	10	0.0	0.2	2.7	18.2	28.3	41.2	62.8	74.9	80.2	100.0
E118	5	1410	10,463.8	10	1.1	5.4	22.9	48.9	60.8	69.9	80.6	90.9	100.0	100.0
E119	1	1412	7,831.7	10	0.5	5.4	38.1	74.1	79.8	86.7	92.4	97.0	100.0	100.0
E120	3	1416	10,048.7	10	0.0	0.1	1.4	17.6	33.5	55.8	76.7	91.2	100.0	100.0
E121	5	1419	7,650.0	10	2.7	9.3	26.0	45.1	54.8	68.0	79.9	89.5	100.0	100.0
E122	1	1422	7,906.3	10	1.2	9.9	44.0	77.4	85.0	87.5	91.3	98.9	100.0	100.0
E123	3	1426	9,606.2	10	0.0	0.1	1.1	13.5	18.6	23.6	32.3	46.2	61.9	100.0
E124	5	1437	7,796.0	10	2.6	11.5	29.5	42.6	48.4	55.2	67.7	86.3	100.0	100.0
E125	1	1440	5,653.8	5	0.3	2.0	13.8	42.8	53.7	61.1	70.9	88.0	89.2	100.0
E126	3	1445	14,965.9	10	0.0	0.2	2.2	14.7	27.6	38.0	53.0	77.6	100.0	100.0
E127	5	1448	12,102.3	10	1.3	4.4	15.7	43.1	56.7	64.5	69.2	80.7	100.0	100.0
E128	1	1450	1,062.1	5	0.1	1.8	13.6	55.5	68.8	75.1	80.2	100.0	100.0	100.0
E129	3	1456	10,852.4	10	0.4	1.5	5.9	23.2	35.6	47.2	62.1	76.0	89.0	100.0
E130	5	1502	7,568.1	10	7.2	44.4	77.1	87.9	92.1	94.3	96.5	100.0	100.0	100.0
E131	1	1505	3,605.7	5	2.1	19.5	50.9	69.7	76.2	82.6	88.0	93.6	100.0	100.0
E132	3	1508	2,902.2	10	0.0	0.0	1.2	15.8	21.9	27.2	33.1	44.9	86.2	100.0
E133	5	1511	8,454.4	10	3.2	15.9	41.9	56.4	62.1	66.4	71.8	80.3	86.4	100.0
E134	1	1514	2,738.0	5	2.5	21.9	65.6	88.0	92.3	94.6	97.9	100.0	100.0	100.0
E135	3	1518	1,468.2	10	0.0	0.0	0.4	8.4	14.6	20.0	30.1	56.7	100.0	100.0
E136	5	1520	1,837.4	10	0.5	3.2	16.1	54.6	65.7	71.7	81.3	100.0	100.0	100.0
E137	1	1523	3,639.7	5	1.9	13.8	53.6	78.3	83.8	87.7	92.6	98.4	100.0	100.0
E138	3	1528	8,271.0	10	0.1	0.3	2.6	19.5	31.0	42.2	59.7	70.5	80.9	100.0
E139	5	1531	2,765.7	10	0.1	0.3	2.6	23.5	38.1	52.2	67.2	76.8	100.0	100.0
E140	1	1534	3,808.6	5	0.9	7.5	34.4	55.8	69.0	84.0	94.7	98.0	100.0	100.0

Appendix I-C.—*Particle-size distribution of sampled bedload sediment from field test E1, Toutle River at Coal Bank bridge on January 29, 1986*— continued

Sample number	Sampler number	Time	Mass of sample (grams)	Sampling time (seconds)	Percent by mass finer than sieve size indicated									
					0.25	0.50	1.00	2.00	4.00	8.00	16.00	32.00	64.00	128.00
E141	3	1539	5,850.7	10	6.1	36.3	74.6	90.2	93.1	95.1	97.3	98.9	100.0	100.0
E142	5	1542	13,178.8	10	0.0	0.1	1.3	8.2	11.8	14.8	23.2	54.5	93.2	100.0
E143	1	1544	3,346.2	7	5.2	33.6	68.0	82.1	84.4	86.9	91.6	98.1	100.0	100.0
E144	3	1548	5,434.1	10	8.3	48.0	79.3	89.4	93.1	95.7	98.5	100.0	100.0	100.0
E145	5	1550	6,105.2	10	4.6	29.9	63.1	75.3	79.7	84.8	90.7	98.2	100.0	100.0
E146	1	1553	2,709.4	5	0.1	1.0	14.8	48.0	57.0	65.2	73.0	81.4	100.0	100.0
E147	3	1556	5,171.8	10	6.4	22.0	46.0	58.4	63.9	74.0	85.5	95.0	100.0	100.0
E148	5	1559	4,994.9	10	5.9	38.4	78.3	89.8	94.0	96.8	98.8	100.0	100.0	100.0
Sampler number 1 average =					**1.2**	**9.1**	**32.7**	**58.5**	**67.8**	**75.1**	**82.1**	**89.6**	**98.5**	**100.0**
Sampler number 3 average =					**1.4**	**9.1**	**14.4**	**27.1**	**34.4**	**42.4**	**54.6**	**70.2**	**88.0**	**100.0**
Sampler number 5 average					**3.1**	**16.9**	**37.5**	**55.2**	**63.2**	**70.0**	**78.2**	**88.9**	**97.9**	**100.0**

Appendix I-*D.—Particle-size distribution of sampled bedload sediment from field test F1, Toutle River at Coal Bank bridge on February 19, 1986*

Sample number	Sampler number	Time	Mass of sample (grams)	Sampling time (seconds)	Percent by mass finer than sieve size indicated 0.25	0.50	1.00	2.00	4.00	8.00	16.00	32.00	64.00	128.00
F101	1	1150	577.7	10	0.1	0.4	4.1	25.1	33.5	41.3	54.3	85.6	100.0	100.0
F102	5	1208	2,549.1	10	1.9	9.4	20.0	33.8	38.6	42.4	48.9	58.4	82.3	100.0
F103	1	1214	2,444.8	10	0.1	0.2	1.7	9.4	16.1	24.4	37.8	76.7	100.0	100.0
F104	5	1220	8,579.9	10	1.5	8.2	18.5	34.0	45.8	56.7	71.8	86.7	100.0	100.0
F105	1	1226	4,763.9	10	0.6	7.4	31.7	57.8	67.9	81.0	91.6	97.9	100.0	100.0
F106	5	1231	12,019.5	10	1.8	8.4	20.3	37.8	47.2	55.4	69.5	86.7	95.4	100.0
F107	1	1236	6,907.0	10	0.6	4.1	15.3	33.5	43.8	54.5	75.5	89.9	100.0	100.0
F108	5	1240	6,536.9	10	2.4	12.9	37.0	65.8	76.5	83.9	91.7	97.9	100.0	100.0
F109	1	1243	4,429.9	10	0.1	1.5	7.5	25.8	34.9	53.8	74.8	89.5	100.0	100.0
F110	5	1246	7,786.3	10	2.1	13.1	30.4	50.1	57.4	63.1	72.7	83.6	92.6	100.0
F111	1	1251	4,938.9	10	0.2	3.9	14.8	38.9	50.6	67.3	85.3	100.0	100.0	100.0
F112	5	1256	5,592.9	10	4.7	19.6	37.3	56.0	65.8	75.9	87.7	95.5	100.0	100.0
F113	1	1301	5,485.8	10	0.7	5.5	21.1	40.7	47.2	57.9	72.3	90.3	100.0	100.0
F114	5	1305	5,409.0	10	2.8	14.6	29.4	41.6	47.0	54.1	65.1	79.5	100.0	100.0
F115	1	1310	6,880.9	10	0.1	2.3	13.4	31.5	37.6	50.7	64.9	82.7	100.0	100.0
F116	5	1314	8,334.0	10	2.4	12.4	30.3	47.7	56.3	66.5	94.3	96.3	100.0	100.0
F117	1	1320	5,519.8	10	0.0	0.2	2.7	17.0	27.3	41.2	59.1	83.2	100.0	100.0
F118	5	1325	4,661.2	10	3.9	16.1	28.2	39.0	42.8	47.4	56.1	74.2	100.0	100.0
F119	1	1329	4,487.6	10	0.1	1.8	9.9	36.0	49.2	69.1	87.0	96.6	100.0	100.0
F120	5	1333	7,196.0	10	3.9	18.6	33.7	43.7	50.6	59.8	74.2	82.6	92.8	100.0
F121	1	1337	3,955.8	10	0.1	2.2	12.3	38.0	49.0	64.2	79.1	91.6	100.0	100.0
F122	5	1340	7,079.3	10	5.1	24.5	49.4	65.6	74.0	82.1	90.9	100.0	100.0	100.0
F123	1	1345	7,752.3	10	0.6	5.4	24.3	66.4	82.5	88.2	91.4	95.4	100.0	100.0
F124	5	1349	6,246.0	10	3.3	20.4	43.2	60.3	67.4	75.7	84.6	94.5	100.0	100.0
F125	1	1353	3,391.6	8	0.0	0.4	4.1	26.1	38.6	55.1	75.7	95.0	100.0	100.0
F126	5	1356	6,871.0	10	4.1	24.6	47.1	58.4	63.0	69.5	78.1	87.6	92.8	100.0
F127	1	1400	6,645.8	9	0.0	0.9	7.8	30.6	41.3	55.3	74.4	90.6	100.0	100.0
F128	5	1403	7,673.8	10	4.3	21.4	44.6	60.6	68.4	73.9	78.4	83.9	86.5	100.0
F129	1	1407	6,276.4	8	0.1	1.2	9.8	31.7	42.1	57.5	71.5	85.7	94.7	100.0
F130	5	1411	6,475.9	10	4.7	22.0	44.6	60.6	68.6	76.5	85.1	93.9	100.0	100.0
F131	1	1416	1,794.8	8	0.0	0.1	2.2	15.7	30.2	48.1	71.5	84.4	100.0	100.0
F132	5	1419	3,592.4	10	3.9	22.7	47.4	62.4	67.5	73.5	83.1	91.7	100.0	100.0
F133	1	1424	4,637.8	8	0.2	4.7	22.6	44.7	52.7	70.6	86.2	97.3	100.0	100.0
F134	5	1427	12,685.5	10	0.4	2.3	6.0	13.9	22.8	37.0	67.4	88.2	100.0	100.0
F135	1	1432	6,412.0	8	0.4	3.4	12.3	31.3	46.6	66.4	85.4	94.5	100.0	100.0
F136	5	1435	6,833.4	10	3.8	19.1	35.4	49.9	60.9	73.7	88.5	96.8	100.0	100.0
F137	1	1441	5,471.8	8	0.2	2.1	8.4	27.4	43.5	61.9	83.0	97.2	100.0	100.0
F138	5	1447	7,921.8	10	2.6	14.1	29.7	44.1	53.6	63.6	75.2	87.9	100.0	100.0
F139	1	1452	2,597.6	9	0.0	0.3	2.8	14.2	21.0	33.7	58.0	85.6	100.0	100.0
F140	5	1457	6,330.4	10	2.9	16.0	33.3	46.3	52.4	59.6	69.6	81.7	94.6	100.0
Sampler number 1 average =					**0.2**	**2.4**	**11.4**	**32.1**	**42.8**	**57.1**	**73.9**	**90.5**	**99.7**	**100.0**
Sampler number 5 average =					**3.1**	**16.0**	*333*	**48.6**	*56.3*	**64.5**	**76.1**	**87.4**	**96.9**	**100.0**

Appendix I-*E.—Particle-size distribution of sampled bedload sediment from field test G1, Toutle River at Coal Bank bridge on February 27, 1986*

Sample number	Sampler nnmber	Time	Mass of sample (grams)	Sampling time (seconds)	Percent by mass finer than sieve size indicated 0.25	0.50	1.00	2.00	4.00	8.00	16.00	32.00	64.00	128.00
G101	5	1215	7,552.1	20	0.1	0.2	0.5	3.3	8.2	14.0	23.4	42.2	71.2	100.0
G102	6	1230	1,355.3	20	0.3	0.7	1.5	4.6	7.8	11.8	17.2	29.8	100.0	100.0
G103	5	1238	15,283.5	20	0.1	0.1	0.3	1.5	5.0	12.2	24.4	41.1	72.1	100.0
G104	6	1244	24,031.1	15	0.0	0.1	0.2	0.7	2.1	7.1	20.0	43.1	77.2	100.0
G105	5	1332	29,021.5	15	0.0	0.0	0.1	0.2	0.3	0.9	6.5	24.4	67.5	100.0
G106	6	1339	16,853.6	10	0.1	0.1	0.2	1.2	3.2	6.4	15.7	44.6	85.5	100.0
G107	5	1349	4,532.0	10	0.1	0.2	0.4	1.6	3.8	8.2	20.1	40.0	73.8	100.0
G108	6	1354	145.9	10	1.6	3.3	8.4	33.5	59.6	75.3	82.5	100.0	100.0	100.0
G109	5	1400	8,041.0	10	0.1	0.3	0.5	1.6	3.4	7.7	13.4	34.7	74.0	100.0
G110	6	1405	5,201.2	10	0.1	0.1	0.2	1.0	2.7	7.2	15.3	37.4	68.3	100.0
G111	5	1410	1,315.9	10	0.1	0.3	0.7	3.1	7.0	13.4	25.0	42.6	100.0	100.0
G112	6	1417	4,585.0	10	0.1	0.3	0.6	2.9	6.7	12.6	20.9	38.6	62.0	100.0
G113	5	1432	228.6	10	0.4	0.7	3.1	19.9	37.3	51.0	64.9	74.1	100.0	100.0
G114	6	1437	72.5	10	1.1	3.1	12.5	56.4	73.8	82.6	94.6	100.0	100.0	100.0
G115	5	1440	5,520.1	10	0.1	0.2	0.2	0.4	0.6	2.2	10.8	31.6	67.7	100.0
G116	6	1445	467.3	10	0.3	0.6	1.3	5.7	12.0	19.0	28.3	56.5	100.0	100.0
G117	5	1448	7,435.7	10	0.1	0.1	0.3	1.7	4.3	7.8	15.7	35.4	79.0	100.0
G118	6	1453	3,217.8	10	0.1	0.1	0.4	1.4	2.5	2.5	8.3	12.2	23.1	100.0
G119	5	1458	23,033.4	10	0.0	0.1	0.1	0.8	2.6	10.0	37.1	78.2	96.4	100.0
G120	6	1502	4,961.0	10	0.1	0.1	0.3	2.3	8.5	25.9	52.6	84.7	100.0	100.0
G121	5	1505	36,018.7	10	0.1	0.1	0.3	1.3	5.1	21.3	49.2	76.0	93.9	100.0
G122	6	1510	21,043.1	10	0.0	0.0	0.0	0.0	0.2	2.1	14.9	51.5	88.3	100.0
G123	5	1516	8,330.8	10	0.0	0.0	0.0	0.5	2.4	7.9	20.8	45.2	95.6	100.0
G124	6	1521	19,189.0	10	0.0	0.0	0.0	0.0	0.2	3.9	29.7	68.7	97.7	100.0
G125	5	1527	21,531.5	10	0.0	0.0	0.1	0.6	1.9	4.9	12.7	45.9	90.7	100.0
G126	6	1532	6,367.6	10	0.0	0.1	0.1	0.3	0.4	0.5	5.3	27.6	94.9	100.0
G127	5	1542	54.8	10	0.9	1.6	7.7	55.8	75.5	92.0	100.0	100.0	100.0	100.0
G128	6	1547	10,313.9	10	0.0	0.0	0.0	0.3	1.4	6.9	21.9	36.2	63.6	100.0
G129	5	1550	6,721.8	10	0.0	0.1	0.3	2.5	6.9	14.4	27.4	50.4	83.7	100.0
G130	6	1555	13,229.0	10	0.0	0.0	0.0	0.0	0.6	5.2	21.9	50.0	76.5	100.0
G131	5	1604	1,148.1	10	0.1	0.2	0.5	2.1	4.3	13.6	44.0	88.3	100.0	100.0
G132	6	1610	2,765.7	10	0.1	0.2	0.3	1.4	2.2	2.8	4.6	13.4	49.0	100.0
G133	5	1614	15,880.9	10	0.0	0.1	0.2	2.1	6.1	13.2	27.3	57.9	82.0	100.0
G134	6	1620	9,891.7	10	0.1	0.1	0.2	0.5	0.7	0.8	1.2	11.9	62.1	100.0
G135	5	1624	15,478.9	10	0.1	0.2	0.5	2.7	9.0	22.5	38.4	57.8	83.8	100.0
G136	6	1628	795.3	10	0.1	0.3	0.9	4.4	7.2	10.0	12.9	24.1	100.0	100.0
G137	5	1631	499.1	10	0.1	0.2	1.1	9.7	18.7	33.7	63.3	89.3	100.0	100.0
G138	6	1636	12,648.2	10	0.0	0.1	0.3	1.5	4.6	10.5	19.0	34.0	78.9	100.0
G139	5	1640	9,343.3	10	0.1	0.2	0.6	4.6	11.2	20.5	43.2	69.7	93.0	100.0
G140	6	1645	1,702.1	10	0.1	0.2	0.7	3.1	6.1	12.7	25.0	67.3	100.0	100.0
Sampler number 5 average =					**0.1**	**0.2**	**0.9**	**5.8**	**10.7**	**18.6**	**33.4**	**56.2**	**86.2**	**100.0**
Sampler number 6 average =					**0.2**	**0.5**	**1.4**	**6.1**	**10.1**	**15.3**	**25.6**	**46.6**	**81.4**	**100.0**

Appendix I-*F.—Particle-size distribution of sampled bedload sediment from field test K1, Toutle River at Coal Bank bridge on March 12, 1986*

Sample number	Sampler number	Time	Mass of sample (grams)	Sampling time (seconds)	Percent by mass finer than sieve size indicated									
					0.25	0.50	1.00	2.00	4.00	8.00	16.00	32.00	64.00	128.00
K101	5	1229	418.3	20	0.3	0.7	4.7	15.5	16.9	17.5	18.9	21.0	100.0	100.0
K102	6	1244	60.6	20	1.2	3.3	20.0	78.0	92.1	97.5	100.0	100.0	100.0	100.0
K103	5	1248	322.3	30	0.7	1.7	7.1	21.3	25.8	29.1	36.3	36.3	100.0	100.0
K104	6	1252	61.6	30	3.4	9.6	37.4	78.9	84.1	88.0	90.6	100.0	100.0	100.0
K105	5	1255	519.2	30	0.6	1.8	8.4	26.1	31.4	36.4	45.4	71.1	100.0	100.0
K106	6	1258	2,735.2	30	0.1	0.2	0.4	1.2	1.4	2.2	10.3	25.5	64.4	100.0
K107	5	1302	2,049.3	30	0.1	0.2	0.8	2.7	3.4	4.2	7.4	17.5	46.8	100.0
K108	6	1305	1,642.3	30	0.1	0.2	0.9	3.1	3.4	3.8	7.4	30.2	69.6	100.0
K109	5	1309	1,839.4	30	0.1	0.3	1.4	4.9	5.8	6.7	10.1	19.5	41.7	100.0
K110	6	1313	404.5	30	1.0	1.9	5.5	20.0	24.4	28.8	45.2	72.3	100.0	100.0
K111	5	1316	354.2	30	0.5	1.1	5.3	15.0	16.7	17.6	19.8	31.0	100.0	100.0
K112	6	1319	303.9	30	0.6	1.2	4.5	12.1	13.2	14.0	16.0	34.4	100.0	100.0
K113	5	1322	882.9	30	0.2	0.5	2.5	7.9	9.3	11.0	17.0	30.5	56.5	100.0
K114	6	1326	63.6	30	3.6	8.5	30.7	83.0	93.7	97.5	100.0	100.0	100.0	100.0
K115	5	1329	630.5	30	0.2	0.5	2.4	6.6	7.6	8.2	8.4	8.4	8.4	100.0
K116	6	1334	52.1	30	5.4	11.4	34.6	89.4	96.5	100.0	100.0	100.0	100.0	100.0
K117	5	1339	325.6	30	0.8	1.7	9.0	30.0	38.7	49.8	67.6	80.1	100.0	100.0
K118	6	1343	62.7	30	2.7	8.5	33.1	86.9	93.8	100.0	100.0	100.0	100.0	100.0
K119	5	1347	283.9	30	0.8	1.7	6.0	17.4	21.5	26.7	31.3	31.3	100.0	100.0
K120	6	1350	97.3	39	2.2	4.9	21.0	61.4	72.9	82.4	100.0	100.0	100.0	100.0
K121	5	1353	844.0	30	0.3	0.7	2.5	6.4	7.6	9.2	11.4	31.1	54.7	100.0
K122	6	1356	1,310.4	30	0.2	0.4	1.2	3.2	3.6	4.0	4.3	5.1	30.9	100.0
K123	5	1400	48.4	30	3.1	8.1	41.2	92.1	96.3	97.7	100.0	100.0	100.0	100.0
K124	6	1404	40.6	30	2.7	7.4	29.2	82.0	91.1	96.1	100.0	100.0	100.0	100.0
K125	5	1407	2,010.0	30	0.1	0.3	1.4	3.7	4.7	5.8	6.9	8.0	37.2	100.0
K126	6	1411	1,059.7	30	0.3	0.7	2.5	7.3	8.7	10.1	12.8	17.3	27.0	100.0
K127	5	1414	396.4	30	0.3	0.7	3.7	11.0	12.4	12.8	14.2	16.0	16.0	100.0
K128	6	1419	663.2	30	0.5	1.0	3.3	9.4	11.0	12.9	21.5	36.5	100.0	100.0
K129	5	1422	1,792.0	30	0.3	0.7	2.8	10.9	16.0	23.5	39.3	62.5	100.0	100.0
K130	6	1425	1,873.0	30	0.1	0.3	1.0	3.0	3.6	4.2	6.0	10.9	73.3	100.0
K131	5	1429	1,192.0	30	0.1	0.1	0.3	5.5	7.0	9.1	16.3	29.2	65.8	100.0
K132	6	1432	545.7	30	0.6	1.3	3.4	10.4	12.7	16.9	26.0	36.4	100.0	100.0
K133	5	1435	2,205.6	30	0.2	0.3	1.0	2.9	4.0	5.2	7.5	8.8	11.1	100.0
K134	6	1439	233.4	30	1.2	3.0	6.1	22.3	36.6	44.7	69.8	100.0	100.0	100.0
K135	5	1442	142.6	30	1.9	4.1	17.3	47.6	56.1	60.4	74.2	100.0	100.0	100.0
K136	6	1445	2,683.6	30	0.2	0.3	1.1	3.2	4.1	5.0	7.2	9.3	24.7	100.0
K137	5	1448	318.0	30	0.9	2.3	8.8	28.3	39.0	54.8	92.4	100.0	100.0	100.0
K138	6	1451	147.0	30	1.7	4.1	16.9	55.7	69.9	80.8	98.4	100.0	100.0	100.0
K139	5	1455	128.7	30	1.9	4.3	19.6	52.7	63.2	73.1	100.0	100.0	100.0	100.0
K140	6	1458	98.2	30	2.4	5.0	12.1	30.2	34.5	39.8	49.5	100.0	100.0	100.0

	0.25	0.50	1.00	2.00	4.00	8.00	16.00	32.00	64.00	128.00
Sampler number 5 average =	**0.7**	**1.6**	**7.3**	**20.4**	**24.2**	**27.9**	**36.2**	**45.1**	**71.9**	**100.0**
Sampler number 6 average =	**1.5**	**3.7**	**13.2**	**37.0**	**42.6**	**46.4**	**53.3**	**63.9**	**84.5**	**100.0**

Appendix I-G.—*Particle-size distribution of sampled bedload sediment from field test M1, Toutle River at Coal Bank bridge on March 20, 1986*

Sample number	Sampler number	Time	Mass of sample (grams)	Sampling time (seconds)	Percent by mass finer than sieve size indicated									
					0.25	0.50	1.00	2.00	4.00	8.00	16.00	32.00	64.00	128.00
M101	5	1228	6,177.3	20	11.2	42.7	63.6	73.9	78.8	82.4	87.3	94.8	100.0	100.0
M102	6	1240	25,298.5	20	5.8	30.9	54.5	65.6	71.2	77.1	82.1	92.6	96.5	100.0
M103	5	1245	6,977.8	15	8.6	34.5	59.4	75.6	82.4	86.2	89.4	94.4	100.0	100.0
M104	6	1249	14,663.1	15	6.4	27.5	47.1	58.4	64.1	70.5	87.3	96.5	100.0	100.0
M105	5	1254	8,606.3	15	10.6	41.2	61.1	69.1	71.7	73.8	76.5	80.4	84.5	100.0
M106	6	1256	13,683.6	15	10.3	40.0	59.2	65.2	68.3	71.9	85.4	90.8	96.2	100.0
M107	5	1300	5,837.0	15	16.3	54.0	72.1	78.0	80.1	82.1	87.0	94.8	100.0	100.0
M108	6	1302	13,001.2	15	8.6	36.7	58.4	72.7	79.1	83.4	88.0	92.9	94.9	100.0
M109	5	1305	7,432.7	15	7.8	28.6	50.4	61.4	65.5	69.8	79.6	86.1	93.7	100.0
M110	6	1308	12,534.2	15	8.7	37.0	58.6	65.7	68.3	71.9	94.6	91.2	100.0	100.0
M111	5	1311	8,702.5	15	5.6	20.6	35.2	49.0	60.9	71.2	86.8	96.4	100.0	100.0
M112	6	1314	16,101.1	15	5.9	25.7	41.1	53.7	61.8	71.8	85.2	95.6	100.0	100.0
M113	5	1321	7,262.5	15	7.9	31.6	52.0	63.4	69.0	76.2	85.9	93.0	95.1	100.0
M114	6	1324	10,518.8	15	9.2	35.5	55.3	66.1	70.5	76.0	89.2	96.0	100.0	100.0
M115	5	1327	7,608.2	15	8.9	31.1	49.3	62.0	71.8	81.4	89.2	96.8	100.0	100.0
M116	6	1330	13,124.9	15	10.1	42.8	65.3	75.1	79.3	82.9	85.2	89.4	92.6	100.0
M117	5	1332	6,064.0	15	9.5	30.0	56.0	75.2	82.8	87.4	93.1	98.0	100.0	100.0
M118	6	1335	9,900.4	10	3.5	19.2	40.4	58.6	68.0	75.8	90.0	97.1	100.0	100.0
M119	5	1338	7,077.9	10	11.3	36.2	60.7	72.6	77.1	81.7	87.5	93.0	100.0	100.0
M120	6	1341	12,047.7	10	4.4	19.5	32.0	41.7	47.8	54.8	76.2	85.7	92.4	100.0
M121	5	1344	5,792.2	10	8.7	32.6	50.9	61.5	66.4	72.9	85.1	96.0	100.0	100.0
M122	6	1356	11,975.4	10	6.8	33.1	54.7	64.9	68.8	72.3	83.4	92.5	97.2	100.0
M123	5	1400	6,439.8	10	1.6	5.4	16.3	39.4	54.4	65.9	74.3	86.1	100.0	100.0
M124	6	1403	13,702.6	10	5.6	26.4	48.8	63.4	69.9	75.4	83.5	89.0	100.0	100.0
M125	5	1406	8,338.8	10	5.1	20.0	43.1	61.6	67.6	72.0	85.9	92.1	95.5	100.0
M126	6	1409	6,833.9	10	5.2	22.9	48.2	66.9	76.9	83.5	91.4	98.5	100.0	100.0
M127	5	1412	8,135.2	10	9.1	44.3	76.1	87.3	90.6	93.7	96.4	98.7	100.0	100.0
M128	6	1415	11,107.8	10	0.3	1.3	25.7	66.4	71.1	74.5	87.0	97.9	100.0	100.0
M129	5	1417	8,045.1	10	10.5	43.1	65.2	74.2	79.6	83.4	89.0	93.7	100.0	100.0
M130	6	1420	9,730.8	10	9.3	41.6	69.4	81.3	84.9	88.8	96.0	98.8	100.0	100.0
M131	5	1422	8,859.4	10	7.9	32.5	54.1	68.0	74.5	81.7	90.0	96.8	100.0	100.0
M132	6	1425	10,449.6	10	5.9	31.6	51.1	59.6	63.6	68.5	80.8	90.9	100.0	100.0
M133	5	1427	3,043.6	10	15.2	56.9	79.9	89.6	92.2	93.8	96.1	97.0	100.0	100.0
M134	6	1429	9,838.4	10	5.4	23.5	42.4	52.5	57.5	63.1	81.1	92.9	100.0	100.0
M135	5	1452	7,456.4	10	8.2	27.6	44.9	56.3	64.7	75.2	85.5	97.8	100.0	100.0
M136	6	1454	9,975.3	10	5.4	25.0	43.8	55.1	59.8	66.9	81.2	93.6	100.0	100.0
M137	5	1457	7,704.1	10	7.2	28.9	45.2	54.1	59.3	65.6	79.4	89.2	100.0	100.0
M138	6	1459	13,780.9	10	5.6	25.7	41.4	52.6	58.8	64.4	76.2	85.5	97.3	100.0
M139	5	1502	6,960.4	10	7.1	26.6	50.8	68.0	75.4	81.1	86.5	96.3	100.0	100.0
M140	6	1505	10,149.6	10	5.2	22.7	38.6	49.6	55.5	62.2	74.7	91.0	100.0	100.0

Appendix I-*G.—Particle-size distribution of sampled bedload sediment from field test M1, Toutle River at Coal Bank bridge on March 20, 1986*— continued

Sample number	Sampler number	Time	Mass of sample (grams)	Sampling time (seconds)	Percent by mass finer than sieve size indicated									
					0.25	0.50	1.00	2.00	4.00	8.00	16.00	32.00	64.00	128.00
M141	5	1508	10,213.1	10	9.1	35.3	54.0	64.7	70.3	75.5	80.7	90.3	100.0	100.0
M142	6	1510	11,635.5	10	4.8	22.6	39.9	51.0	56.9	63.9	78.2	84.9	90.0	100.0
M143	5	1513	8,444.4	10	7.7	32.7	55.7	66.8	72.0	76.5	82.2	88.7	100.0	100.0
M144	6	1516	11,147.8	10	4.6	19.2	33.3	43.0	47.9	53.1	65.4	71.2	77.5	100.0
M145	5	1519	2,551.8	10	8.0	25.4	49.6	70.5	78.0	83.3	89.4	97.0	100.0	100.0
M146	6	1522	12,686.3	10	7.2	30.4	52.6	63.6	69.0	75.3	89.0	98.3	100.0	100.0
M147	5	1525	6,355.8	10	6.4	23.3	39.1	51.8	64.8	74.3	84.5	93.7	100.0	100.0
M148	6	1528	11,871.3	10	8.6	32.4	52.5	63.7	68.4	73.6	81.3	87.7	91.0	100.0
M149	5	1532	7,196.2	10	5.7	23.0	42.2	56.1	63.0	69.0	80.8	91.7	100.0	100.0
M150	6	1534	11,103.9	10	7.3	35.8	61.0	71.5	76.0	81.7	93.9	96.1	100.0	100.0
Sampler number 5 average =					**8.6**	**32.3**	**53.1**	**66.0**	**72.5**	**78.2**	**85.9**	**93.3**	**98.8**	**100.0**
Sampler number 6 average =					**6.4**	**28.4**	**48.6**	**61.1**	**66.5**	**72.1**	**83.9**	**91.9**	**97.0**	**100.0**

Appendix I-*H.—Particle-size distribution of sampled bedload sediment from field test O1, Toutle River at Coal Bank bridge on March 26, 1986*

Sample number	Sampler number	Time	Mass of sample (grams)	Sampling time (seconds)	Percent by mass finer than sieve size indicated 0.25	0.50	1.00	2.00	4.00	8.00	16.00	32.00	64.00	128.00
O101	6	1140	15,024.1	20	0.3	2.7	18.2	39.5	49.4	59.1	69.5	81.2	89.2	100.0
O102	5	1148	7,072.7	15	2.5	8.2	26.3	47.5	54.9	66.4	78.1	93.8	100.0	100.0
O103	6	1151	9,816.0	15	0.5	3.3	16.1	37.9	53.7	65.5	84.1	91.8	95.7	100.0
O104	5	1154	2,008.6	10	9.3	23.3	60.6	85.9	90.0	93.0	95.8	97.9	100.0	100.0
O105	6	1201	21,884.9	10	1.5	7.0	40.0	82.4	91.6	93.9	94.7	97.2	100.0	100.0
O106	5	1203	10,473.9	10	2.7	9.3	32.8	48.5	54.7	68.8	86.2	99.3	100.0	100.0
O107	6	1208	9,560.3	10	2.9	9.4	41.9	67.6	75.9	82.0	88.2	96.1	100.0	100.0
O108	5	1211	8,319.4	10	1.4	4.3	16.6	31.5	40.1	51.3	71.5	84.7	100.0	100.0
O109	6	1214	13,354.2	10	1.9	6.4	28.9	50.7	56.4	61.2	69.0	82.5	93.8	100.0
O110	5	1217	6,697.7	10	1.6	5.2	20.4	35.1	40.9	48.6	60.9	76.0	100.0	100.0
O111	6	1220	9,055.4	10	1.6	5.8	30.2	67.5	79.5	86.3	91.3	94.4	100.0	100.0
O112	5	1223	6,832.0	10	2.0	7.6	37.0	70.9	82.1	88.0	94.2	100.0	100.0	100.0
O113	6	1226	14,276.7	10	0.3	2.1	12.1	30.5	44.7	60.2	72.1	87.4	96.1	100.0
O114	5	1229	7,793.6	10	0.9	4.5	23.4	48.0	59.0	72.4	84.3	92.6	100.0	100.0
O115	6	1232	14,151.7	10	0.8	3.6	14.8	29.9	39.7	52.1	70.1	85.4	92.5	100.0
O116	5	1234	8,224.5	10	1.7	5.3	19.9	36.4	46.1	59.9	78.4	90.4	100.0	100.0
O117	6	1238	6,895.7	10	0.3	2.0	14.2	37.4	48.5	56.7	64.4	75.3	100.0	100.0
O118	5	1240	9,039.0	10	1.3	4.2	17.1	41.4	52.6	59.3	72.0	87.3	95.4	100.0
O119	6	1242	25,664.9	10	0.4	1.7	11.8	31.0	40.7	49.4	66.6	77.1	87.2	100.0
O120	5	1305	6,667.8	10	2.5	8.0	30.7	58.5	68.3	73.6	82.1	87.2	87.2	100.0
O121	6	1308	17,523.6	10	0.4	2.6	15.1	38.7	51.7	66.4	83.6	91.2	93.7	100.0
O122	5	1317	5,570.9	10	2.6	7.9	26.8	47.3	54.5	65.5	83.0	93.3	100.0	100.0
O123	6	1319	14,619.1	10	1.2	5.2	21.6	37.4	44.6	53.6	69.0	80.8	92.3	100.0
O124	5	1324	6,108.7	10	2.4	9.3	32.5	54.2	62.4	71.7	81.0	89.9	100.0	100.0
O125	6	1327	9,547.7	10	2.5	9.0	34.2	62.1	69.3	74.0	82.2	93.0	100.0	100.0
O126	5	1330	8,284.1	10	1.9	5.6	19.6	36.9	46.0	56.0	80.4	94.6	100.0	100.0
O127	6	1333	8,030.1	10	2.5	9.1	37.2	62.5	69.3	72.6	76.8	88.1	100.0	100.0
O128	5	1335	6,373.1	10	0.8	4.0	18.2	39.4	53.7	71.3	89.4	96.8	100.0	100.0
O129	6	1339	2,485.5	10	0.2	1.3	8.5	30.4	35.6	39.4	44.1	53.6	70.2	100.0
O130	5	1343	8,737.6	10	1.3	4.2	17.2	34.5	42.8	52.7	63.9	78.6	88.0	100.0
O131	6	1345	12,293.7	10	1.3	4.9	18.9	38.4	48.7	59.5	75.3	86.8	100.0	100.0
O132	5	1349	12,904.1	10	0.3	1.8	7.5	20.3	34.4	50.6	70.6	88.1	100.0	100.0
O133	6	1351	23,840.5	10	0.6	3.4	19.5	45.8	65.3	80.9	92.2	96.0	97.8	100.0
O134	5	1354	6,151.4	10	4.1	14.4	46.0	72.5	82.3	89.1	94.3	98.7	100.0	100.0
O135	6	1357	3,836.9	10	1.0	7.4	37.5	70.3	79.3	85.4	92.3	98.8	100.0	100.0
O136	5	1400	7,331.8	10	1.4	5.0	13.7	23.3	30.1	38.3	49.9	68.0	91.8	100.0
O137	6	1402	16,689.6	10	0.5	3.0	14.0	30.5	41.0	50.7	70.5	90.7	100.0	100.0
O138	5	1405	4,994.1	10	3.0	10.2	28.5	39.0	43.0	47.3	57.7	75.3	100.0	100.0
O139	6	1407	6,622.5	10	1.8	6.7	27.8	51.9	59.4	66.1	82.9	97.1	100.0	100.0
O140	5	1410	7,073.1	10	2.8	11.5	37.1	58.4	67.8	77.0	84.7	93.8	100.0	100.0

Appendix I-*H.—Particle-size distribution of sampled bedload sediment from field test O1, Toutle River at Coal Bank bridge on March 26, 1986*— continued

Sample number	Sampler number	Time	Mass of sample (grams)	Sampling time (seconds)	Percent by mass finer than sieve size indicated 0.25	0.50	1.00	2.00	4.00	8.00	16.00	32.00	64.00	128.00
O141	6	1422	8,359.3	10	1.8	8.5	32.8	59.9	75.5	83.5	91.4	98.5	100.0	100.0
O142	5	1425	1,890.1	10	1.1	5.5	26.3	52.5	62.0	69.3	78.3	96.2	100.0	100.0
O143	6	1428	10,112.2	10	2.5	8.2	29.1	52.2	59.4	66.0	77.2	93.1	100.0	100.0
O144	5	1430	6,581.0	10	0.9	5.3	24.9	47.3	61.8	82.1	97.4	100.0	100.0	100.0
O145	6	1432	9,598.7	10	1.6	6.2	28.1	52.5	63.0	73.7	83.2	87.4	92.0	100.0
O146	5	1435	3,872.8	10	3.0	10.5	35.2	58.6	66.9	78.6	88.9	93.5	100.0	100.0
O147	6	1437	11,893.4	10	2.9	4.5	11.7	26.2	37.8	51.9	79.5	93.5	100.0	100.0
O148	5	1440	8,385.1	10	0.5	2.4	9.7	19.3	24.7	35.8	71.1	92.1	100.0	100.0
O149	6	1442	12,474.1	10	0.1	0.7	4.8	15.2	28.4	49.5	80.8	92.8	100.0	100.0
O150	5	1445	7,570.1	10	1.6	5.4	17.4	33.9	46.4	67.0	82.5	90.7	93.7	100.0
Sampler number 5 average =					**2.1**	**7.3**	**25.8**	**45.6**	**54.7**	**65.3**	**79.1**	**90.4**	**98.2**	**100.0**
Sampler number 6 average =					**1.3**	**5.0**	**22.8**	**45.9**	**56.3**	**65.6**	**78.0**	**88.4**	**96.0**	**100.0**

Appendix I-*1.—Particle-size distribution of sampled bedload sediment from field test P1, Toutle River at Coal Bank bridge on April 17, 1986*

Sample number	Sampler number	Time	Mass of sample (grams)	Sampling time (seconds)	Percent by mass finer than sieve size indicated									
					0.25	0.50	1.00	2.00	4.00	8.00	16.00	32.00	64.00	128.00
P101	1	1225	4,477.6	15	0.0	0.0	0.3	6.1	18.3	41.0	71.1	86.6	100.0	
P102	2	1243	776.4	15	0.0	0.1	0.8	4.9	9.8	24.4	63.1	100.0	100.0	
P103	1	1246	2,559.9	15	0.0	0.0	0.6	7.8	17.2	35.5	66.5	92.2	100.0	
P104	2	1252	7,671.5	15	0.0	0.0	0.1	4.5	22.5	22.5	67.0	89.2	100.0	
P107	1	1257	3,252.8	15	0.0	0.0	0.5	8.0	22.4	44.6	79.6	100.0	100.0	
P108	2	1300	1,202.9	15	0.0	0.0	3.3	29.8	52.3	66.5	77.5	93.6	100.0	
P109	1	1303	96.8	15	0.1	0.2	1.9	24.6	44.3	73.6	100.0	100.0	100.0	
P110	2	1305	4,967.5	15	0.0	0.0	0.5	9.6	25.2	49.3	80.7	96.9	100.0	
P111	1	1308	355.5	15	0.1	0.1	2.9	19.3	26.1	30.6	41.2	47.5	100.0	
P112	2	1311	1,729.3	15	0.0	0.0	0.7	8.0	15.2	25.3	43.8	71.6	100.0	
P113	1	1312	1,558.7	15	0.0	0.0	0.9	11.2	23.9	39.9	66.5	93.8	100.0	
P114	2	1315	2,165.0	15	0.0	0.0	1.0	17.4	42.5	67.3	88.4	100.0	100.0	
P115	1	1317	384.4	15	0.0	0.0	2.1	16.0	25.6	35.5	66.8	88.4	100.0	
P116	2	1319	616.5	15	0.0	0.0	0.5	7.1	12.6	29.4	59.4	83.3	100.0	
P117	1	1322	9,357.3	15	0.1	0.1	1.3	13.4	28.4	43.6	72.3	96.0	100.0	
P118	2	1325	1,956.7	15	0.0	0.0	0.5	7.4	14.9	27.0	52.1	79.6	100.0	
P119	1	1327	8,782.6	15	0.0	0.0	0.2	4.2	16.4	41.1	75.6	94.5	100.0	
P120	2	1341	5,308.4	15	0.0	0.1	3.0	20.4	31.2	45.5	66.4	95.1	100.0	
P121	1	1343	248.7	15	0.1	0.2	3.3	51.5	80.2	94.4	100.0	100.0	100.0	
P122	2	1345	1,081.9	15	0.0	0.1	1.4	19.7	33.4	43.1	61.6	82.0	100.0	
P123	1	1347	2,687.8	15	0.0	0.0	0.8	12.3	31.3	58.5	89.9	100.0	100.0	
P124	2	1350	7,126.6	15	0.0	0.0	1.9	15.1	30.7	48.9	80.8	97.6	100.0	
P125	1	1352	7,341.5	15	0.1	0.2	2.1	17.5	32.7	49.2	73.9	91.2	100.0	
P126	2	1355	221.5	15	0.1	0.2	3.8	33.1	55.1	74.0	89.7	100.0	100.0	
P127	1	1357	3,883.2	15	0.0	0.0	1.0	14.4	32.7	60.5	84.7	98.2	100.0	
P128	2	1359	5,656.2	15	0.0	0.0	2.2	19.0	30.0	40.7	58.4	88.1	100.0	
P129	1	1401	10,157.7	15	0.0	0.0	0.2	4.7	15.2	35.0	72.3	91.4	100.0	
P130	2	1409	2,848.2	15	0.0	0.0	0.9	9.3	15.2	20.7	31.0	56.1	100.0	
P131	1	1412	7,696.2	15	0.0	0.0	1.1	14.3	34.4	61.4	86.0	98.3	100.0	
P132	2	1416	525.6	15	0.0	0.0	1.1	17.4	36.3	61.2	86.5	100.0	100.0	
P133	1	1418	3,522.1	15	0.0	0.0	0.8	12.6	26.2	26.2	78.5	91.4	100.0	
P134	2	1420	5,324.6	15	0.0	0.0	0.5	7.5	19.9	37.7	69.1	91.5	100.0	
P135	1	1423	5,924.8	15	0.0	0.0	0.8	12.1	32.8	56.3	81.8	98.0	100.0	
P136	2	1426	218.2	15	0.1	0.1	1.9	24.7	43.8	65.4	89.6	100.0	100.0	
P137	1	1428	838.5	15	0.0	0.0	0.2	1.8	3.0	5.3	15.4	71.3	100.0	
P138	2	1430	492.6	15	0.0	0.0	0.5	7.1	15.6	34.1	65.3	81.4	100.0	
P139	1	1433	395.9	15	0.0	0.0	0.6	12.7	39.4	52.0	66.6	87.2	100.0	
P140	2	1435	5,805.4	15	0.0	0.0	0.6	9.0	22.7	39.4	71.4	96.0	100.0	

Appendix I-*I*.—*Particle-size distribution of sampled bedload sediment from field test P1, Toutle River at Coal Bank bridge on April 17, 1986*— continued

Sample number	Sampler number	Time	Mass of sample (grams)	Sampling time (seconds)	Percent by mass finer than sieve size indicated									
					0.25	0.50	1.00	2.00	4.00	8.00	16.00	32.00	64.00	128.00
P141	1	1437	1,916.1	15	0.0	0.0	0.2	3.5	8.3	16.0	33.7	62.6	100.0	
P142	2	1439	5,793.7	15	0.0	0.0	0.4	6.5	14.0	26.2	62.3	88.9	100.0	
P143	1	1442	2,250.6	15	0.0	0.0	0.2	5.6	14.1	25.3	47.6	77.3	100.0	
P144	2	1444	1,882.5	15	0.0	0.1	1.2	11.7	20.4	31.4	51.7	79.7	100.0	
P145	1	1447	32.2	15	0.3	0.6	4.3	40.3	50.9	57.1	60.9	100.0	100.0	
P146	2	1449	4,413.0	15	0.0	0.0	0.6	14.2	35.3	35.5	83.0	98.5	100.0	
P147	1	1451	3,960.8	30	0.0	0.0	0.9	9.9	24.5	41.3	67.2	88.4	100.0	
P148	2	1457	3,768.3	15	0.0	0.0	0.4	6.0	15.8	30.4	66.2	84.4	100.0	
P149	1	1459	1,654.4	15	0.0	0.0	0.8	7.6	11.8	17.8	34.3	69.4	100.0	
P150	2	1502	941.9	15	0.0	0.1	1.3	16.4	30.1	48.4	71.2	100.0	100.0	
Sampler number 1 average =					**0.0**	**0.1**	**1.2**	**13.8**	**27.5**	**43.4**	**68.0**	**88.5**	**100.0**	
Sampler number 2 average =					**0.0**	**0.1**	**1.2**	**13.6**	**26.9**	**41.4**	**68.2**	**89.7**	**100.0**	

Appendix I-*J*.—*Particle-size distribution of sampled bedload sediment from field test Q1, Toutle River at Coal Bank bridge on April 30, 1986*

Sample number	Sampler number	Time	Mass of sample (grams)	Sampling time (seconds)	Percent by mass finer than sieve size indicated									
					0.25	0.50	1.00	2.00	4.00	8.00	16.00	32.00	64.00	128.00
Q101	1	1146	5,261.5	10	0.0	0.0	1.1	13.7	23.8	37.1	56.4	82.9	100.0	100.0
Q102	2	1150	53.0	15	0.2	0.2	6.9	52.7	69.1	74.5	100.0	100.0	100.0	100.0
Q103	1	1153	7,447.8	15	0.0	0.0	0.5	7.0	15.6	29.1	52.2	73.4	100.0	100.0
Q104	2	1156	286.2	15	0.2	0.6	4.0	19.1	22.7	27.1	35.2	47.8	100.0	100.0
Q105	1	1202	84.4	15	0.0	0.4	10.4	70.7	88.9	94.9	100.0	100.0	100.0	100.0
Q106	2	1205	1,239.5	15	0.0	0.0	0.5	8.7	23.6	58.8	83.4	100.0	100.0	100.0
Q107	1	1208	15,380.9	20	0.0	0.0	0.4	4.1	12.3	28.0	63.4	89.3	100.0	100.0
Q108	2	1212	2,953.9	20	0.0	0.5	8.4	38.4	57.3	72.3	83.8	93.0	100.0	100.0
Q109	1	1215	1,569.6	20	0.0	0.1	2.2	14.7	23.3	30.6	42.9	69.0	100.0	100.0
Q110	2	1218	4,954.8	20	0.0	0.1	4.0	26.3	41.3	58.1	67.3	81.9	92.7	100.0
Q111	1	1220	2,420.0	20	0.0	0.0	1.3	11.5	19.8	34.5	63.1	92.7	100.0	100.0
Q112	2	1224	205.0	20	0.0	0.1	4.2	31.0	43.8	57.4	81.5	100.0	100.0	100.0
Q113	1	1227	1,223.9	20	0.0	0.0	0.7	8.6	15.7	23.9	61.1	100.0	100.0	100.0
Q114	2	1230	6,856.7	20	0.0	0.2	1.4	7.6	13.6	23.6	43.3	77.2	95.1	100.0
Q115	1	1236	4,876.2	20	0.0	0.1	0.8	5.4	9.0	14.3	24.3	45.7	100.0	100.0
Q116	2	1241	7,803.9	20	0.1	1.9	13.9	35.7	45.6	57.4	68.7	82.5	100.0	100.0
Q117	1	1249	4,243.9	20	0.0	0.1	4.6	25.1	36.9	49.7	64.7	80.8	100.0	100.0
Q118	2	1255	1,552.3	20	0.0	0.3	5.5	23.6	36.5	47.7	64.7	85.3	100.0	100.0
Q121	1	1318	5,971.9	20	0.0	0.0	1.6	11.2	17.0	27.8	46.4	65.5	92.8	100.0
Q122	2	1324	522.6	20	0.0	0.0	0.3	2.1	3.3	4.7	6.7	13.0	100.0	100.0
Q123	1	1332	5,897.2	20	0.0	0.1	2.6	14.4	22.2	29.0	42.6	71.9	92.5	100.0
Q124	2	1338	1,631.7	20	0.0	0.1	1.4	9.3	14.2	19.8	34.4	72.3	100.0	100.0
Q125	1	1343	7,922.7	20	0.0	0.3	5.8	23.2	31.2	47.4	70.8	87.4	100.0	100.0
Q126	2	1346	7,067.5	20	0.0	0.2	1.9	12.0	23.6	41.1	64.6	84.8	100.0	100.0
Q127	1	1351	3,024.0	20	0.0	0.1	1.5	7.5	10.1	18.4	46.0	78.8	100.0	100.0
Q128	2	1356	224.0	20	0.0	0.2	6.4	37.0	55.0	72.7	88.6	100.0	100.0	100.0
Q129	1	1359	61.2	20	0.2	0.5	3.0	28.6	57.2	77.0	100.0	100.0	100.0	100.0
Q130	2	1402	1,042.0	20	0.0	0.0	0.8	13.5	29.8	45.1	56.6	74.1	100.0	100.0
Q131	1	1406	7,200.1	20	0.0	0.0	0.6	5.9	11.4	22.2	41.3	70.0	100.0	100.0
Q132	2	1410	9,379.7	20	0.1	0.6	4.3	25.7	46.8	64.5	80.0	92.5	100.0	100.0
Q133	1	1413	1,901.8	20	0.0	0.0	2.4	25.4	49.7	67.1	82.1	100.0	100.0	100.0
Q134	2	1417	1,884.1	20	0.0	0.1	1.8	11.2	20.0	37.6	71.2	100.0	100.0	100.0
Q135	1	1419	12,519.0	20	0.0	0.0	0.5	3.4	8.7	25.4	59.5	89.4	100.0	100.0
Q136	2	1423	323.2	20	0.1	0.3	6.9	52.9	78.4	91.2	100.0	100.0	100.0	100.0
Q137	1	1427	1,047.2	20	0.3	1.7	9.3	34.8	45.3	51.8	62.4	81.3	100.0	100.0
Q138	2	1431	5,814.4	20	0.0	0.3	9.8	42.7	61.3	83.2	96.6	100.0	100.0	100.0
Q139	1	1434	844.1	20	0.2	0.5	3.7	20.0	27.8	37.5	55.7	74.0	100.0	100.0
Q140	2	1437	29.2	20	0.3	0.3	8.4	55.9	73.6	87.7	100.0	100.0	100.0	100.0

Appendix I-*J.—Particle-size distribution of sampled bedload sediment from field test Q1, Toutle River at Coal Bank bridge on April 30, 1986*— continued

Sample number	Sampler number	Time	Mass of sample (grams)	Sampling time (seconds)	Percent by mass finer than sieve size indicated									
					0.25	0.50	1.00	2.00	4.00	8.00	16.00	32.00	64.00	128.00
Q141	1	1440	2,129.9	20	0.0	0.0	1.6	16.5	28.2	37.6	49.9	71.0	100.0	100.0
Q142	2	1444	3,559.1	20	0.0	0.0	0.7	10.9	23.5	37.7	57.2	88.6	100.0	100.0
Q143	1	1447	1,961.7	20	0.0	0.4	3.4	15.9	23.3	29.7	39.8	54.6	100.0	100.0
Q144	2	1450	3,444.3	20	0.0	0.0	2.2	17.2	28.8	37.7	52.6	84.8	100.0	100.0
Q145	1	1453	216.7	20	0.0	0.2	4.7	39.7	56.0	63.6	82.8	100.0	100.0	100.0
Q146	2	1457	807.4	20	0.0	0.4	5.9	39.7	52.7	58.9	69.1	87.3	100.0	100.0
Q147	1	1500	12,086.4	20	0.0	0.1	1.3	12.1	26.9	42.5	68.2	89.3	100.0	100.0
Q148	2	1503	2,049.2	20	0.0	0.1	2.4	11.4	15.0	19.0	29.3	58.8	100.0	100.0
Q149	1	1507	7,823.0	20	0.3	0.9	6.5	30.5	49.8	65.5	74.6	87.8	100.0	100.0
Q150	2	1509	9,263.7	20	0.0	0.2	3.3	22.8	42.1	61.2	80.9	94.9	100.0	100.0
Sampler number 1 average =					**0.0**	**0.2**	**2.9**	**18.7**	**29.6**	**41.0**	**60.4**	**81.5**	**99.4**	**100.0**
Sampler number 2 average =					**0.0**	**0.3**	**4.4**	**25.3**	**38.4**	**51.6**	**67.3**	**84.1**	**99.5**	**100.0**

Appendix I-*K*.—*Particle-size distribution of sampled bedload sediment from field test A2, Toutle River at Coal Bank bridge on April 13, 1987*

Sample number	Sampler number	Time	Mass of sample (grams)	Sampling time (seconds)	Percent by mass finer than sieve size indicated									
					0.25	0.50	1.00	2.00	4.00	8.00	16.00	32.00	64.00	128.00
A201	6	1127	15,671.7	5	3.4	8.7	19.5	27.4	39.9	54.8	75.6	96.9	100.0	
A202	6	1131	27,412.3	10	2.1	10.4	31.9	45.5	56.5	69.5	86.8	100.0	100.0	
A203	6	1135	40,743.0	15	1.8	8.8	27.8	39.0	47.1	58.1	76.6	91.5	100.0	
A204	6	1139	37,211.5	12	2.3	11.6	29.6	41.6	52.3	65.2	81.8	98.1	100.0	
A205	6	1144	11,736.6	4	3.1	10.8	29.3	37.5	48.2	59.0	73.2	78.5	100.0	
A206	6	1148	18,339.1	8	2.8	8.4	20.7	29.0	43.6	58.1	68.6	82.0	100.0	
A207	6	1151	37,238.8	12	2.6	15.2	36.6	45.1	53.2	64.7	78.6	93.7	100.0	
A208	6	1156	9,045.5	5	1.0	7.4	31.0	40.6	49.8	60.2	73.8	92.2	100.0	
A209	6	1158	16,654.5	8	4.4	18.9	44.1	52.8	64.2	73.9	84.7	97.1	100.0	
A210	6	1202	32,556.1	13	3.7	17.9	41.2	47.5	51.5	57.6	69.1	85.3	100.0	
A211	6	1206	4,230.6	4	0.4	1.6	6.3	9.1	18.6	41.0	67.1	100.0	100.0	
A212	6	1209	20,395.7	9	2.2	10.7	29.6	38.8	45.9	53.8	67.8	80.2	100.0	
A213	6	1212	32,994.7	12	0.9	3.0	9.2	15.5	29.6	53.0	75.9	95.9	100.0	
A214	6	1215	11,342.3	4	6.6	19.9	37.8	45.8	53.6	61.8	72.2	81.8	100.0	
A215	6	1218	24,568.7	8	2.6	19.4	46.7	55.3	61.9	71.7	84.9	95.6	100.0	
A216	6	1221	35,983.7	12	2.5	20.1	43.0	56.3	63.9	73.0	82.1	94.3	100.0	
A217	6	1223	15,705.3	4	3.8	12.6	33.7	45.1	58.8	70.9	83.7	96.5	100.0	
A218	6	1226	27,368.4	8	3.4	16.8	43.7	53.5	60.8	69.4	78.9	90.2	100.0	
A219	6	1229	32,616.0	12	2.3	8.5	28.4	40.8	50.4	63.8	82.0	97.1	100.0	
A220	6	1231	6,871.4	4	7.6	25.8	51.4	58.2	58.3	67.3	83.8	100.0	100.0	
A221	6	1234	23,045.5	8	4.5	14.9	47.7	60.3	65.6	71.1	80.5	96.5	100.0	
A222	6	1237	39,135.8	12	3.7	21.2	51.9	59.1	63.1	69.3	82.2	97.9	100.0	
A223	6	1240	16,043.3	4	4.9	17.9	41.5	49.6	55.7	62.7	72.0	82.4	100.0	
A224	6	1243	23,995.0	8	1.1	12.5	34.4	43.7	51.9	64.6	81.6	100.0	100.0	
A225	6	1247	37,592.9	12	3.0	14.1	37.7	47.5	57.4	69.4	84.5	98.5	100.0	
A226	6	1250	13,749.1	4	0.6	2.1	9.5	27.2	43.6	60.0	81.1	97.2	100.0	
A227	6	1253	27,614.0	8	4.7	21.1	46.5	54.7	62.5	71.9	84.3	95.1	100.0	
A228	6	1256	33,807.8	12	2.5	13.4	36.8	47.6	56.9	72.1	89.2	100.0	100.0	
A229	6	1335	9,888.8	4	3.2	12.5	32.9	43.4	53.2	65.5	79.1	93.3	100.0	
A230	6	1339	20,121.2	8	2.4	7.7	18.1	24.7	35.6	52.9	75.8	95.2	100.0	
A231	6	1343	28,028.1	12	1.9	7.8	18.6	24.0	33.5	54.5	76.1	89.5	100.0	
A232	6	1344	17,830.3	5	2.4	15.2	52.9	65.8	73.0	82.7	93.2	100.0	100.0	
A233	6	1346	14,346.8	8	4.0	11.5	36.1	46.1	59.9	72.1	82.5	93.3	100.0	
A234	6	1349	26,259.7	12	0.5	2.1	8.7	18.2	35.5	58.8	81.6	93.0	100.0	
A235	6	1352	10,078.8	4	4.9	23.3	56.8	64.2	71.5	79.8	90.7	100.0	100.0	
A236	6	1355	17,382.9	9	0.2	2.1	13.8	21.9	27.5	37.0	55.4	81.1	100.0	
A237	6	1357	33,454.3	16	1.7	7.4	24.9	38.5	52.3	67.9	83.1	95.4	100.0	
A238	6	1400	8,320.1	4	4.9	20.0	47.8	56.4	63.4	71.6	81.1	100.0	100.0	
A239	6	1402	24,854.2	8	2.3	10.8	27.5	38.3	52.3	69.2	89.3	99.0	100.0	
A240	6	1405	21,992.8	12	0.5	2.2	8.6	16.8	30.5	54.1	74.2	88.1	100.0	

Appendix I-*K*.—*Particle-size distribution of sampled bedload sediment from field test A2, Toutle River at Coal Bank bridge on April 13, 1987*— continued

Sample number	Sampler number	Time	Mass of sample (grams)	Sampling time (seconds)	Percent by mass finer than sieve size indicated 0.25	0.50	1.00	2.00	4.00	8.00	16.00	32.00	64.00	128.00
A241	6	1409	19,407.9	4	2.8	11.3	36.0	51.4	72.0	86.6	95.0	100.0	100.0	
A242	6	1411	29,275.6	8	3.2	16.5	41.8	54.7	66.0	76.8	90.3	97.8	100.0	
A243	6	1414	31,854.3	12	2.2	9.1	23.2	31.4	40.3	54.1	72.0	88.2	100.0	
A244	6	1417	11,831.9	4	3.4	15.1	37.5	51.4	59.3	68.4	80.3	91.7	100.0	
A245	6	1419	32,758.7	8	3.3	19.0	47.5	59.2	67.0	77.0	90.3	98.9	100.0	
A246	6	1422	39,012.0	12	2.8	17.2	40.9	49.4	55.8	65.6	81.0	92.1	100.0	
A247	6	1425	11,466.7	4	3.1	11.1	31.1	43.0	54.6	67.9	80.6	95.1	100.0	
A248	6	1430	20,203.5	9	5.1	23.4	48.8	55.8	65.1	77.3	89.2	100.0	100.0	
A249	6	1434	29,761.4	12	3.3	18.1	49.0	63.7	72.7	82.5	90.1	94.6	100.0	
A250	6	1437	28,199.9	9	0.7	3.7	16.5	33.5	52.5	66.5	80.9	97.4	100.0	
A251	6	1440	6,540.5	4	0.0	0.5	4.8	7.9	12.5	26.2	54.4	87.4	100.0	
A252	6	1443	8,514.2	12	2.3	11.7	29.1	37.1	46.5	59.4	78.6	92.9	100.0	
A253	6	1447	15,031.3	5	2.4	11.0	35.8	45.4	53.6	64.8	78.7	92.3	100.0	
A254	6	1452	23,328.9	8	6.8	23.7	44.0	50.0	56.9	67.0	81.4	100.0	100.0	
A255	6	1455	27,249.7	12	2.7	15.1	36.1	47.2	55.9	66.1	79.8	95.4	100.0	
A256	6	1457	9,234.2	4	7.9	27.7	51.1	55.0	60.1	71.0	89.2	95.3	100.0	
A257	6	1500	15,744.2	8	6.0	28.5	58.4	65.4	70.8	77.7	85.5	93.2	100.0	
A258	6	1503	32,221.4	12	1.5	6.7	22.3	38.2	53.3	69.1	87.9	100.0	100.0	
A259	6	1505	11,358.4	4	0.7	2.4	6.0	8.0	27.3	54.6	76.2	90.2	100.0	
A260	6	1507	19,973.8	8	5.1	18.2	40.0	46.7	56.9	70.9	84.0	94.1	100.0	
A261	6	1510	33,933.4	12	2.3	13.6	35.7	46.7	53.7	62.0	75.5	88.9	100.0	
A262	6	1514	14,072.5	4	2.1	11.0	34.7	47.4	58.6	67.6	79.3	92.5	100.0	
A263	6	1516	23,977.3	8	1.2	6.4	22.3	32.1	42.7	59.9	77.2	94.3	100.0	

	0.25	0.50	1.00	2.00	4.00	8.00	16.00	32.00	64.00
Sampler number 6 average =	**2.9**	**13.0**	**33.1**	**42.7**	**52.5**	**65.0**	**80.0**	**93.9**	**100.0**
4-second samples =	**3.3**	**12.8**	**32.7**	**41.9**	**51.7**	**64.0**	**79.1**	**93.5**	**100.0**
8-second samples =	**3.2**	**14.5**	**36.2**	**45.8**	**55.5**	**67.1**	**80.9**	**94.3**	**100.0**
12-second samples =	**2.2**	**11.7**	**30.4**	**40.5**	**50.3**	**63.8**	**80.1**	**93.8**	**100.0**

Appendix I-*L*.—*Particle-size distribution of sampled bedload sediment from field test B2, Toutle River at Coal Bank bridge on April 22, 1987*

Sample number	Sampler number	Time	Mass of sample (grams)	Sampling time (seconds)	Percent by mass finer than sieve size indicated									
					0.25	0.50	1.00	2.00	4.00	8.00	16.00	32.00	64.00	128.00
B201	5	1256	931.2	10	0.1	0.8	3.6	4.7	6.0	9.7	28.9	56.7	100.0	100.0
B202	6	1302	103.7	10	0.4	13.1	76.8	87.3	91.8	92.0	100.0	100.0	100.0	100.0
B203	5	1306	748.2	10	0.4	3.5	20.4	29.6	39.8	56.6	59.4	100.0	100.0	100.0
B204	6	1310	1,122.5	20	2.3	8.2	35.7	51.9	63.4	73.1	89.5	100.0	100.0	100.0
B205	5	1313	1,127.9	20	0.2	1.6	10.5	16.7	24.2	37.7	83.4	100.0	100.0	100.0
B206	6	1317	100.0	20	1.6	15.9	63.8	78.1	86.4	87.1	100.0	100.0	100.0	100.0
B207	5	1320	1,297.2	20	0.6	1.8	3.4	8.2	16.7	34.6	49.0	100.0	100.0	100.0
B208	6	1324	351.8	20	0.4	4.6	22.1	28.9	34.4	38.1	82.3	100.0	100.0	100.0
B209	5	1327	1,328.2	20	0.2	1.8	7.7	8.8	9.5	13.2	33.9	33.9	100.0	100.0
B210	6	1333	18,777.4	20	0.4	1.2	5.0	9.8	17.0	30.0	56.9	89.9	100.0	100.0
B211	5	1337	6,033.6	20	0.3	2.1	10.9	18.8	31.1	48.7	70.7	91.0	100.0	100.0
B212	6	1341	21,147.5	20	0.1	0.2	0.4	0.4	0.7	8.0	41.8	88.8	100.0	100.0
B213	5	1345	8,583.6	20	0.1	0.6	2.8	3.5	4.6	10.3	34.9	95.1	100.0	100.0
B214	6	1349	3,816.1	20	0.7	3.0	10.4	12.4	14.3	17.5	32.0	72.0	100.0	100.0
B215	5	1352	19,740.2	20	0.3	1.4	7.1	16.0	31.4	51.7	78.8	100.0	100.0	100.0
B216	6	1355	10,789.5	20	1.0	3.3	9.5	18.2	33.5	54.8	74.6	100.0	100.0	100.0
B217	5	1359	503.0	20	0.5	2.5	14.3	18.1	20.2	22.1	23.3	100.0	100.0	100.0
B218	6	1402	6,738.3	20	0.4	1.6	4.9	8.4	19.4	45.7	77.9	100.0	100.0	100.0
B219	5	1407	7,970.3	20	0.4	1.9	8.5	12.4	17.2	27.3	61.0	94.0	100.0	100.0
B220	6	1411	12,150.9	20	2.6	8.0	19.6	29.0	39.1	53.8	69.3	86.4	100.0	100.0
B221	5	1415	574.2	20	1.2	3.7	10.0	13.2	16.4	21.4	37.5	100.0	100.0	100.0
B222	6	1419	6,084.5	20	0.1	0.3	1.2	1.4	1.5	3.5	27.0	84.3	100.0	100.0
B223	5	1422	71.1	20	3.0	17.6	74.5	86.6	91.2	92.0	100.0	100.0	100.0	100.0
B224	6	1426	15,746.5	20	0.6	1.8	5.1	9.2	19.2	39.2	68.8	90.2	100.0	100.0
B225	5	1429	7,118.8	20	0.3	0.9	3.2	3.9	4.3	5.9	17.7	58.2	100.0	100.0
B226	6	1432	1,739.4	20	1.0	4.9	28.3	45.1	57.6	70.2	83.5	100.0	100.0	100.0
B227	5	1436	7,922.9	20	0.1	0.4	2.3	7.8	20.7	42.7	64.4	100.0	100.0	100.0
B228	6	1440	24,047.1	20	0.3	1.1	3.4	6.1	15.4	40.5	74.1	100.0	100.0	100.0
B229	5	1443	15,861.5	20	0.2	1.1	4.8	8.9	16.1	29.5	55.7	85.8	100.0	100.0
B230	6	1446	271.8	20	1.5	12.5	54.5	70.5	80.0	89.0	100.0	100.0	100.0	100.0
B231	5	1449	13,098.0	20	0.1	0.4	1.8	3.1	5.7	14.2	46.4	90.5	100.0	100.0
B232	6	1453	221.3	20	1.0	10.6	45.7	62.9	75.6	84.8	100.0	100.0	100.0	100.0
B233	5	1456	3,337.4	20	0.2	1.3	6.9	9.3	10.8	12.6	14.7	33.1	100.0	100.0
B234	6	1459	19,006.8	20	0.1	0.2	0.9	1.9	9.5	32.4	69.4	88.4	100.0	100.0
B235	5	1503	3,378.7	20	0.2	1.6	12.8	19.1	23.1	34.3	53.0	84.7	100.0	100.0
B236	6	1506	13,581.1	20	0.2	0.8	3.1	4.6	9.4	24.8	57.3	86.4	100.0	100.0
B237	5	1509	1,526.1	20	0.7	4.9	29.2	40.4	46.2	52.9	61.9	100.0	100.0	100.0
B238	6	1512	6,877.1	20	0.1	0.3	1.4	1.8	2.2	7.2	31.4	80.1	100.0	100.0
B239	5	1516	903.6	20	0.3	2.5	11.9	17.7	25.5	35.1	42.8	100.0	100.0	100.0
B240	6	1519	8,738.1	20	0.1	0.2	0.9	1.4	5.6	17.3	49.3	73.6	100.0	100.0

Appendix I-*L.—Particle-size distribution of sampled bedload sediment from field test B2, Toutle River at Coal Bank bridge on April 22, 1987*— continued

Sample number	Sampler number	Time	Mass of sample (grams)	Sampling time (seconds)	Percent by mass finer than sieve size indicated									
					0.25	0.50	1.00	2.00	4.00	8.00	16.00	32.00	64.00	128.00
B241	5	1522	5,325.2	20	0.1	0.2	0.7	0.9	1.2	3.8	25.8	100.0	100.0	100.0
B242	6	1525	8,198.8	20	0.1	0.3	1.1	1.4	2.3	10.4	45.9	93.0	100.0	100.0
B243	5	1528	2,176.0	20	0.3	2.1	13.1	22.9	32.7	44.2	63.0	100.0	100.0	100.0
B244	6	1532	441.5	20	0.5	3.8	17.3	23.4	29.1	34.3	50.6	100.0	100.0	100.0
B245	5	1535	10,108.2	20	0.1	0.2	0.4	0.5	0.7	4.6	38.0	92.3	100.0	100.0
B246	6	1538	24,457.6	20	0.3	1.4	5.2	10.0	19.5	37.2	59.5	77.6	86.2	100.0
B247	5	1541	2,636.3	20	0.3	1.5	6.5	8.5	9.7	10.2	10.4	33.9	100.0	100.0
B248	6	1544	20,332.1	20	0.1	0.3	1.1	2.0	9.6	35.4	63.6	92.0	100.0	100.0
B249	5	1547	1,439.9	20	0.7	3.6	20.6	29.0	40.2	49.3	78.8	100.0	100.0	100.0
B250	6	1551	1,777.4	20	0.5	3.0	19.1	31.5	41.9	56.8	67.4	100.0	100.0	100.0

	0.25	0.50	1.00	2.00	4.00	8.00	16.00	32.00	64.00	128.00
Sampler number 5 average =	**0.4**	**2.4**	**11.5**	**163.**	**21.8**	**30.6**	**49.3**	**85.6**	**100.0**	**100.0**
Sampler number 6 average =	**0.7**	**4.0**	**17.5**	**23.9**	**31.1**	**43.3**	**66.9**	**92.1**	**99.4**	**100.0**

Appendix I-*M.—Particle-size distribution of sampled bedload sediment from field test C2, Toutle River at Coal Bank bridge on April 23, 1987*

Sample number	Sampler number	Time	Mass of sample (grams)	Sampling time (seconds)	Percent by mass finer than sieve size indicated 0.25	0.50	1.00	2.00	4.00	8.00	16.00	32.00	64.00	128.00
C201	6	1244	22,346.2	20	1.2	4.0	12.5	23.7	38.1	60.1	84.9	98.2	100.0	100.0
C202	5	1249	13,943.8	20	0.1	0.4	1.3	2.3	6.3	23.9	64.6	100.0	100.0	100.0
C203	6	1253	193.5	20	3.6	24.0	83.2	93.2	94.9	100.0	100.0	100.0	100.0	100.0
C204	5	1256	27,522.6	20	0.1	0.2	0.9	2.0	10.3	38.8	73.7	94.0	100.0	100.0
C205	6	1300	19,769.0	20	0.8	2.3	6.8	12.1	20.8	44.2	79.4	95.7	100.0	100.0
C206	5	1303	13,843.4	20	2.6	10.9	28.0	40.1	53.0	69.4	90.3	100.0	100.0	100.0
C207	6	1307	20,058.1	20	0.3	0.8	2.7	5.8	21.5	60.2	89.1	100.0	100.0	100.0
C208	5	1311	14,334.7	21	0.1	0.4	0.9	1.2	3.1	23.5	70.9	100.0	100.0	100.0
C209	6	1314	3,360.9	20	0.7	2.4	9.0	12.0	15.1	21.4	37.5	100.0	100.0	100.0
C210	5	1319	7,919.7	20	0.2	1.5	8.5	14.6	22.6	35.3	59.7	94.3	100.0	100.0
C211	6	1324	25,803.1	20	0.8	2.5	8.6	18.7	33.2	55.3	80.0	95.0	100.0	100.0
C212	5	1328	4,626.1	20	0.6	3.4	14.8	22.4	30.2	40.3	56.7	100.0	100.0	100.0
C213	6	1331	12,570.3	20	2.2	5.7	13.8	20.2	29.8	46.9	68.9	92.5	100.0	100.0
C214	5	1335	1,826.0	20	0.6	2.5	13.4	19.2	25.0	30.7	44.8	100.0	100.0	100.0
C215	6	1338	33,327.9	20	1.7	6.4	15.7	24.3	39.1	63.0	86.5	98.4	100.0	100.0
C216	5	1343	9,423.6	20	0.2	0.6	1.9	2.5	4.5	14.6	36.9	71.7	100.0	100.0
C217	6	1345	22,079.8	20	1.2	3.3	9.3	19.1	35.4	58.3	84.6	100.0	100.0	100.0
C218	5	1349	6,821.7	20	0.4	2.3	12.8	19.5	25.3	33.9	45.2	58.1	100.0	100.0
C219	6	1353	25,239.2	20	1.9	6.3	16.3	27.0	42.5	65.9	87.4	98.0	100.0	100.0
C220	5	1356	26,923.2	20	1.0	3.4	10.2	19.3	35.6	57.0	76.3	92.1	100.0	100.0
C221	6	1400	16,481.7	20	0.2	0.6	1.8	2.6	4.8	22.3	62.5	89.5	100.0	100.0
C222	5	1404	14,578.0	20	0.1	0.3	1.0	1.5	6.0	35.0	69.7	90.7	100.0	100.0
C223	6	1407	2,411.3	20	0.9	4.6	18.3	26.3	35.1	48.2	77.2	100.0	100.0	100.0
C224	5	1411	3,262.8	20	0.2	0.8	3.6	4.9	6.4	8.7	12.0	25.3	100.0	100.0
C225	6	1415	14,085.5	20	0.4	1.4	4.7	7.7	13.5	26.5	45.2	59.8	100.0	100.0
C226	5	1434	24,867.2	20	2.2	7.4	20.9	34.7	49.6	64.6	81.6	100.0	100.0	100.0
C227	6	1437	997.5	20	1.7	6.6	27.0	36.0	41.3	45.6	59.4	100.0	100.0	100.0
C228	5	1440	3,854.5	20	0.3	1.3	6.5	8.7	10.7	12.8	16.2	33.7	100.0	100.0
C229	6	1443	240.2	20	1.9	8.3	24.8	28.2	29.7	30.9	31.9	100.0	100.0	100.0
C230	5	1446	24,278.7	20	0.9	3.5	9.3	13.6	22.4	46.1	80.2	100.0	100.0	100.0
C231	6	1449	5,953.3	20	0.1	0.5	2.5	4.6	9.7	27.3	64.1	100.0	100.0	100.0
C232	5	1452	13,214.8	20	0.9	4.2	12.9	21.1	33.9	58.8	81.7	97.7	100.0	100.0
C233	6	1455	9,317.0	20	0.2	0.8	3.4	5.8	17.2	45.4	68.5	93.1	100.0	100.0
C234	5	1458	5,663.5	20	0.8	3.2	11.2	16.4	25.5	43.8	69.5	89.3	100.0	100.0
C235	6	1501	6,825.4	20	0.2	0.8	4.1	7.1	14.5	36.4	70.3	88.3	100.0	100.0
C236	5	1505	27,368.1	20	1.8	7.6	22.3	34.5	51.3	69.9	85.3	92.2	100.0	100.0
C237	6	1508	3,599.0	20	0.7	2.6	9.5	12.6	16.2	26.0	56.5	75.2	100.0	100.0
C238	5	1511	13,162.9	20	0.1	0.3	0.9	1.4	3.1	18.8	58.7	86.4	100.0	100.0
C239	6	1517	3,645.9	20	0.4	1.5	5.8	7.9	10.5	17.1	47.7	100.0	100.0	100.0
C240	5	1520	2,073.6	20	0.4	1.5	6.7	8.0	9.1	11.2	17.3	47.1	100.0	100.0

Appendix I-*M.—Particle-size distribution of sampled bedload sediment from field test C2, Toutle River at Coal Bank bridge on April 23, 1987*— continued

Sample number	Sampler number	Time	Mass of sample (grams)	Sampling time (seconds)	Percent by mass finer than sieve size indicated 0.25	0.50	1.00	2.00	4.00	8.00	16.00	32.00	64.00	128.00
C241	6	1523	10,891.6	20	1.5	4.4	13.2	21.4	32.2	50.6	69.7	90.4	100.0	100.0
C242	5	1526	18,019.8	20.5	0.5	2.0	7.0	15.7	30.7	46.9	71.4	100.0	100.0	100.0
C243	6	1529	35,261.2	20	0.9	3.1	7.3	12.7	29.4	64.6	87.9	96.6	100.0	100.0
C244	5	1536	28,402.1	20	0.8	3.2	8.8	15.5	31.1	57.9	81.6	100.0	100.0	100.0
C245	6	1540	2,512.5	20	0.7	2.6	6.4	7.4	7.8	8.2	10.2	19.6	100.0	100.0
C246	5	1543	324.5	20	4.1	20.5	75.9	84.4	87.4	90.9	100.0	100.0	100.0	100.0
C247	6	1546	270.6	20	6.6	29.1	82.6	90.8	94.3	97.4	100.0	100.0	100.0	100.0
C248	5	1554	341.2	20.5	1.8	10.9	57.0	74.8	84.4	94.7	100.0	100.0	100.0	100.0
C249	6	1558	30,532.2	20	0.8	2.2	6.4	12.7	25.7	50.5	76.8	93.4	100.0	100.0
C250	5	1601	7,280.5	20	0.6	3.0	12.6	16.4	19.4	24.8	38.9	75.0	100.0	100.0

	0.25	0.50	1.00	2.00	4.00	8.00	16.00	32.00	64.00
Sampler number 5 average =	**0.9**	**3.8**	**14.0**	**19.8**	**27.5**	**42.1**	**63.3**	**85.9**	**100.0**
Sampler number 6 average =	**1.3**	**5.1**	**15.8**	**21.6**	**30.1**	**46.9**	**69.0**	**91.3**	**100.0**