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Techniques of Water-Resources Investigations of the U.S. Geological Survey

Book 3, Applications of Hydraulics

Chapter C2

Field Methods for Measurement of Fluvial Sediment

By Thomas K. Edwards and G. Douglas Glysson

This manual is a revision of "Field Methods for Measurement of Fluvial Sediment," by Harold P. Guy and Vernon W. Norman, U.S. Geological Survey Techniques of Water-Resources Investigations, Book 3, Chapter C2, published in 1970.

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TWRI 5-A2.	Determination of minor elements in water by emission spectroscopy, by P.R. Barnett and E.C. Mallory, Jr. 1971. 31 pages.
TWRI 5-A3.[4]	Methods for the determination of organic substances in water and fluvial sediments, edited by R.L. Wershaw, M.J. Fishman, R.R. Grabbe, and L.E. Lowe. 1987. 80 pages.
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TWRI 8-B2.	Calibration and maintenance of vertical-axis type current meters, by G.F. Smoot and C.E. Novak. 1968. 15 pages.

[1]This manual is a revision of "Measurement of Time of Travel and Dispersion in Streams by Dye Tracing," by E.F. Hubbard, F.A. Kilpatrick, L.A. Martens, and J.F. Wilson, Jr., Book 3, Chapter A9, published in 1982.

[2]Spanish translation also available.

[3]This manual is a revision of "Field Methods for Measurement of Fluvial Sediment," by Harold P. Guy and Vernon W. Norman, Book 3, Chapter C2, published in 1970.

[4]This manual is a revision of TWRI 5-A3, "Methods of Analysis of Organic Substances in Water," by Donald F. Goerlitz and Eugene Brown, published in 1972.

[5]This manual supersedes TWRI 5-A4, "Methods for Collection and Analysis of Aquatic Biological and Microbiological Samples," edited by P.E. Greeson and others, published in 1977.

CONTENTS

ILLUSTRATIONS

TABLES

UNIT CONVERSION

Multiply inch-pound unit	*By*	*To obtain SI unit*
	Length	
inch (in.)	25.40	millimeter (mm)
foot (ft)	0.3048	meter (m)
	Area	
square inch ($in.^2$)	6.452	square centimeter (cm^2)
square foot (ft^2)	929.0	square centimeter (cm^2)
	Volume	
U.S. liquid pint (pt)	0.4732	liter (L)
U.S. liquid quart (qt)	0.9464	liter (L)
U.S. liquid gallon (gal)	3.785	liter (L)
U.S. liquid gallon (gal)	3,785	milliliter (mL)
U.S. liquid gallon (gal)	0.003785	cubic meter (m^3)
cubic foot (ft^3)	28,317	cubic centimeter (cm^3)
	Flow rate	
foot per second (ft/s)	0.3048	meter per second (m/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Multiply inch-pound unit	By	To obtain SI unit
	Mass	
ounce, avoirdupois (oz)	28.35	gram (g)
ounce, avoirdupois (oz)	28,350	milligram (mg)
pound, avoirdupois (lb)	453.6	gram (g)
ton, short	0.9072	megagram (Mg)
	Temperature	
degree Fahrenheit (°F)	°C=5/9 (°F–32)	degree Celsius (°C)
	Pressure	
pound per square inch (lb/in.^{2})	6.895	kilopascal (kPa)
	Concentration (Mass/Volume)	
parts per million (ppm)[1]	1.0	milligrams per liter (mg/L)
ounces per quart (oz/qt)	29,955	milligrams per liter (mg/L)
pounds per cubic foot (lb/ft^3)	16,017	grams per cubic meter (g/m^3)

[1]This conversion is true for

$$mg/L = c(ppm) = c$$

when the ratio of weight of sediment to weight of water-sediment mixture is between 0 and 15,900. If this ratio is greater than 15,900, the investigator is referred to Guy (1969, table 1, p. 4) for the correct conversion factor to be used in the formula.

FIELD METHODS FOR MEASUREMENT OF FLUVIAL SEDIMENT

By Thomas K. Edwards and G. Douglas Glysson

Abstract

This chapter describes equipment and procedures for collection and measurement of fluvial sediment. The complexity of the hydrologic and physical environments and man's ever-increasing data needs make it essential for those responsible for the collection of sediment data to be aware of basic concepts involved in processes of erosion, transport, deposition of sediment, and equipment and procedures necessary to representatively collect sediment data.

In addition to an introduction, the chapter has two major sections. The "Sediment-Sampling Equipment" section encompasses discussions of characteristics and limitations of various models of depth- and point-integrating samplers, single-stage samplers, bed-material samplers, bedload samplers, automatic pumping samplers, and support equipment. The "Sediment-Sampling Techniques" section includes discussions of representative sampling criteria, characteristics of sampling sites, equipment selection relative to the sampling conditions and needs, depth- and point-integration techniques, surface and dip sampling, determination of transit rates, sampling programs and related data, cold-weather sampling, bed-material and bedload sampling, measuring total sediment discharge, and measuring reservoir sedimentation rates.

INTRODUCTION

Perspective

Knowledge of the erosion, transport, and deposition of sediment relative to land surface, streams, reservoirs, and other bodies of water is important to those involved directly or indirectly in the development and management of water and land resources. It also is becoming more important that such development and management be carried out in a manner that yields or conforms to a socially acceptable environment. The need for a clear understanding of hydrogeomorphologic processes associated with sediment requires the measurement of suspended and bed sediments for a wide range of hydrologic environments. The complex phenomena of fluvial sedimentation cause the required measurements and related analyses of sediment data to be relatively expensive in comparison with other kinds of hydrologic data. Accordingly, the purpose of this manual is to help standardize and improve efficiency in the techniques used to obtain sediment data, so the quantity and quality of the data can be maximized for a given investment of labor and resource.

Sediment data needs are of practical concern. Some of the general categories include:

1. The evaluation of sediment yield with respect to different natural environmental conditions—geology, soils, climate, runoff, topography, ground cover, and size of drainage area.
2. The evaluation of sediment yield with respect to different kinds of land use.
3. The time distribution of sediment concentration and transport rate in streams.
4. The evaluation of erosion and deposition in channel systems.
5. The amount and size characteristics of sediment delivered to a body of water.
6. The characteristics of sediment deposits as related to particle size and flow conditions.
7. The relations between sediment chemistry, water quality, and biota.

The scope of these requirements indicates that a wide variety of measurements are needed on streams and other bodies of water, ranging from large river basins to very small tributaries that drain areas such as parcels of land under urban development.

The equipment and methods discussed in this report for the collection of a suspended-sediment sample are designed to yield a representative sample of the water sediment mixture. This representative sample may be analyzed for sediment concentration, particle-size distribution, or, if collected with the proper type sampler, any other dissolved, suspended, or total water-quality constituent. Therefore, the equipment and methods described in this report should be used to collect a representative sample for water-quality analysis.

Sediment Characteristics, Source, and Transport

Sediment is fragmental material transported by, suspended in, or deposited by water or air, or accumulated in beds by other natural agents. Sediment particles range in size from large boulders to colloidal-size fragments and vary in shape from rounded to angular. They also vary in mineral composition and specific gravity, the predominant mineral being quartz and the representative specific gravity being 2.65.

Sediment is derived from any parent material subjected to erosional processes by which particles are detached and transported by gravity, wind, water, or a combination of these agents. When the transporting agent is water, the sediment is termed "fluvial sediment." The U.S. Geological Survey (USGS) defines fluvial sediment as fragmentary material that originates mostly from weathering of rocks and is transported by, suspended in, or deposited from water (Federal Inter-Agency Sedimentation Project, 1963b); it includes chemical and biological precipitates and decomposed organic material, such as humus.

Erosion by water is classified as either sheet or channel erosion, with no distinct division between the two. Sheet erosion occurs when sediments are removed from a surface in a sheet of relatively uniform thickness by raindrop splash and sheet flow. Sediment-particle movement and the energy of the raindrops compact and partially seal the soil surface, effectively decreasing the infiltration rate and increasing the amount of flow available to erode and transport the sediment. The amount of material removed by sheet erosion is a function of surface slope, erodibility, and precipitation intensity and drop size.

Land-surface irregularities inhibit continuous sheet flow over large areas. This inhibition serves to concentrate the flow into small rills or channels and streams, which increase in size as they join together downstream. Within these channels, eroded material from the banks or bed of the stream is contributed to the flow until, in theory, the stream is transporting as much sediment as the energy of the stream will allow. Such channel erosion may be general or local along the stream but is primarily local in nature.

Some sediment is carried to streams by wind, but direct contribution to the stream channel by this conveyance usually accounts for only a small part of the total fluvial sediments. Aside from bank caving as a result of stream erosion or processes of mass wasting (Thornbury, 1969), gravitational transfer of sediments occurs toward and into streams. Conveyance by gravitational means ranges from slow creep to rapid landslide. Other significant sources of local sediments are glacial-melt outwash, volcanic activity, mining, earth movement, construction, or additional land-disturbance activities by man.

The stream usually transports sediment by maintaining the finer particles in suspension with turbulent currents and by rolling or skipping the coarser particles along the streambed. Generally, the finer sediments move downstream at about the same velocity as the water, whereas the coarsest sediments may move only occasionally and remain at rest much of the time.

Vertical distributions of suspended-sediment particle sizes may vary among streams and among cross sections within a stream. However, as a general rule, the finer particles are uniformly distributed throughout the vertical, and the coarser particles are concentrated near the streambed. Occasionally, coarse particles may reach the water surface, generally carried by turbulent flow or as a result of dispersive grain stress (Leopold and others, 1964). Thus, with use of the depth- or point-integrating suspended-sediment samplers described here, the sample obtained generally contains a range of particle sizes representative of the suspended-sediment discharge at the sampled vertical. The vertical is divided into two zones, as illustrated by figure 1. This separation is due to the design of the sampler, which limits the effective sampled depth. Sampling the entire depth is not possible because the physical location of the sampler nozzle relative to the bottom of the sampler prevents the nozzle from passing through the zone close to the bed. This portion of the depth is termed the unsampled zone and characteristically carries the higher concentration and coarser particles. The unsampled suspended sediment moving within this zone may or

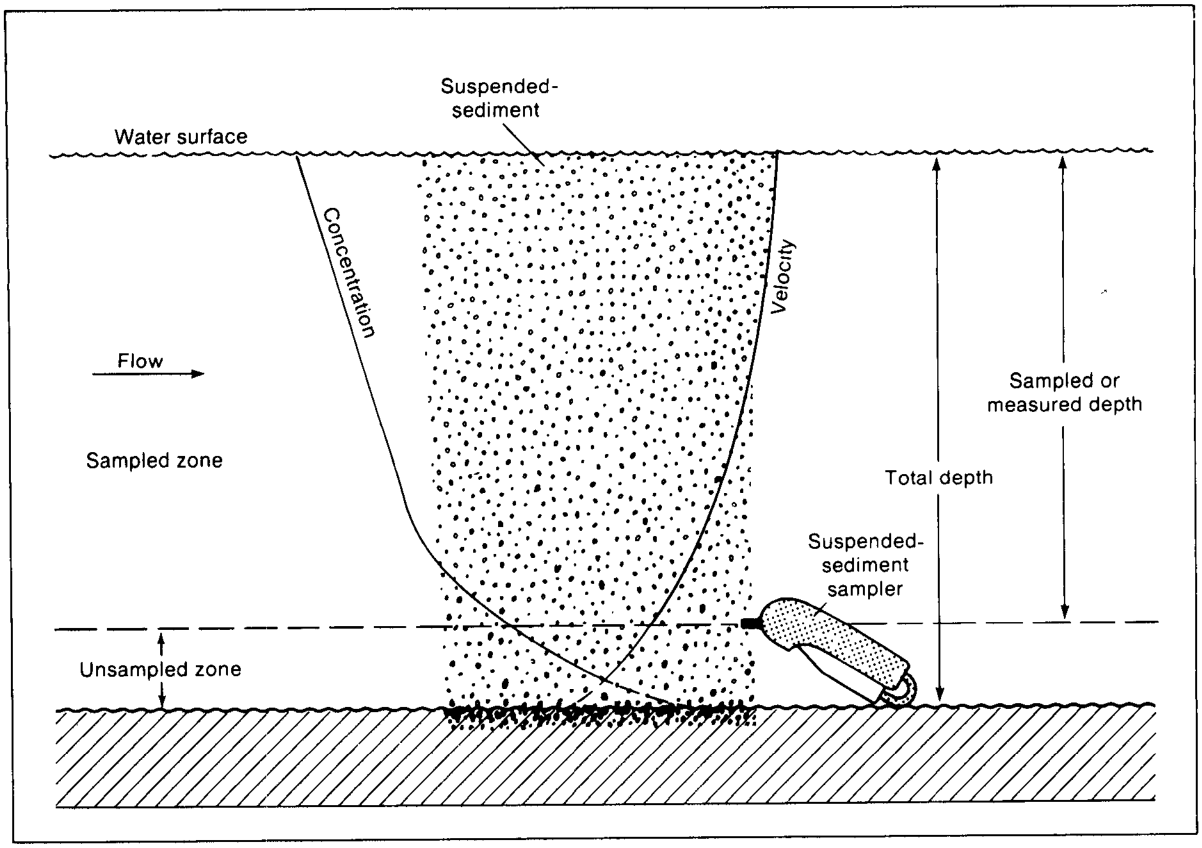

Figure 1. Sampled and unsampled zones in a stream sampling vertical, with respect to velocity of flow and sediment concentration.

may not account for a large part of the total suspended sediment, depending upon the depth, velocity, and turbulence of the flow through the vertical. The measured sediment discharge is nearly equal to the total sediment discharge if the velocity and turbulence conditions within the sampled vertical overcome the tractive force transporting the bedload in the unmeasured zone and effectively disperse all of the sediment being transported into suspension throughout the total depth.

The preceding discussion illustrates the complexity of the study of fluvial sediment transport and some of the many variables involved. The interested reader is directed to more detailed works concerning fluvial-sediment concepts and geomorphic processes, such as the contributions by Colby (1963), Leopold and others (1964), Guy (1970), and Vanoni (1975). The investigator also can obtain pertinent information on the subject by contacting the Federal Inter-Agency Sedimentation Project (F.I.S.P.), Waterways Experiment Station, Vicksburg, Mississippi.

Data Needs

No matter how precise the theoretical prediction of sedimentation processes becomes, it is inevitable that man's activities will continue to cause changes in the many variables affecting sediment erosion, transportation, and deposition; thus, there will be an increasing need for direct and indirect measurement of fluvial-sediment movement and its characteristics. Because of the rapid advances in technology, it seems of little value to list the many specific kinds of sediment problems and the kinds of sediment data required to solve such problems. However, some general areas of concern may be of interest. Sediment data are useful in coping with problems and goals related to water utilization. Many industries require sediment-free water in their processes. A knowledge of the amount and characteristics of sediment in the water resource is needed so that the sediment may be removed as economically as possible before the water is allowed to enter a distribution system. Information on sediment movement and particle-size characteristics is needed in the design of hydraulic structures, such as dams, canals, and irrigation works. Streams and reservoirs that are free of sediment are highly regarded for recreation. Data on sediment movement and particle characteristics are needed to determine and understand how radionuclides, pesticides, and many organic materials are absorbed and concentrated by sediments, thus causing potential health hazards in some streams, estuaries, and water-storage areas. Knowledge concerning the effect of natural and man-made changes in drainage basins on the amount and characteristics of sediment yielded from the drainage basins is useful in helping to predict the stream environment when future basin changes are made. Knowledge about present fluvial-sediment conditions is being used to help establish criteria for water-quality standards and goals.

These data needs require sediment programs that will provide (1) comprehensive information on a national network basis, (2) special information about specific problem areas for water management, and (3) a description and understanding of the relations between water, sediment, and the environment (basic research). The reader is referred to Book 3, Chapter C1 of this series (Guy, 1970, p. 47) for a description of the kinds of sediment records commonly obtained at stream sites. Briefly, the records are of (1) the continuous or daily-record type, where sampling is sufficiently comprehensive to permit computation of daily loads, (2) the partial-record type, where a daily record is obtained for only a part of the year, and (3) the periodic-record type, where samples are taken periodically or intermittently. Usually a series of reconnaissance measurements is made prior to implementing any of these three programs. Even after a specific program is started, it is possible that adjustments may be necessary with respect to equipment, sample timing, or even measurement location. Realignment of efforts in this manner can be avoided in many instances by carefully applying design criteria to adequately meet the objectives of the project.

SEDIMENT-SAMPLING EQUIPMENT

General

In the early days of fluvial-sediment investigations, each investigator, or at least each agency concerned with sediment, developed methods and equipment individually as needed. It soon became apparent that consistent data could not be obtained unless equipment, data collection, and analytical methods were standardized. To overcome this difficulty, representatives of several Federal agencies (the Corps of Engineers of the Department of the Army, the Flood Control Coordinating Committee of the Department of Agriculture, the U.S. Geological Survey, the Bureau of Reclamation, the Office of Indian Affairs of the Department of the Interior, and the Tennessee Valley Authority) met in 1939 to form an interdepartmental committee, with the expressed purpose of standardizing sediment data-collection equipment, methods, and analytical techniques. The test facility for this work was initially located at the Iowa University Hydraulics Laboratory, in Iowa City, Iowa, and remained there for 9 years. In 1946, the committee became known as the Subcommittee on Sedimentation of the Federal Inter-Agency River Basin Committee. In 1948, the subcommittee moved the test facility to the St. Anthony Falls Hydraulic Laboratory, University of Minnesota, in Minneapolis, Minnesota. The subcommittee reorganized the project in 1956 to its present structure as the Federal Inter-Agency Sedimentation Project (F.I.S.P.). In 1992, F.I.S.P. was moved to its present location at the Waterways Experiment Station in Vicksburg, Mississippi. The project is sponsored by a technical committee composed of representatives of the U.S. Army Corps of Engineers, U.S. Geological Survey, Bureau of Reclamation, Agricultural Research Service, U.S. Forest Service, and Bureau of Land Management, working under a formal Guidance Memorandum describing the project's objectives and organization. The F.I.S.P. is overseen by the Technical Committee of the Subcommittee on Sedimentation of the Interagency Advisory Committee on Water Data.

Since its initiation in 1939, approximately 50 reports, dealing with nearly all aspects of measurement and analysis of fluvial sediment movement, have been published by F.I.S.P. The intent of this chapter is not to replace the Inter-Agency Project reports, but to condense and combine their information regarding sediment measurements. The interested reader should contact F.I.S.P. for a listing of individual reports presenting further background material and details on the standard samplers. Sampling equipment is available for purchase by any interested investigator from the F.I.S.P., 3909 Halls Ferry Road, Vicksburg, MS 39180-6199.

The samplers developed by the F.I.S.P. are designated by the following codes: US, United States standard sampler. (In the following discussions this code will appear in the initial reference but will be dropped from succeeding references to the sampler designations.)

D, depth integrating

P, point integrating

H, hand-held by rod or line. (This code is placed after the primary letter designation and is omitted when referring to cable- and reel-suspended samplers.)

BM, bed material

BP, battery pack

BL, bedload sampler

U or SS, single stage

PS or CS, pumping-type sampler

Year, last two digits of the year in which the sampler was developed.

Sediment samplers available from F.I.S.P. or Hydrologic Instrumentation Facility (HIF) include suites of depth-integrating suspended-sediment samplers, point-integrating suspended-sediment samplers, pumping samplers, bed-material samplers, and a bedload sampler. In addition, an array of instruments has been developed to fulfill the need for collecting samples during unpredictable high-flow events. One sampler of particular interest for use in the future is a suspended-sediment sampler that utilizes bags as sample containers to overcome the depth limits of standard samplers due to container size, nozzle diameter, and stream velocity (Federal Inter-Agency Sedimentation Project, 1982b).

Suspended-Sediment Samplers

The purpose of a suspended-sediment sampler is to obtain a representative sample of the water-sediment mixture moving in the stream in the vicinity of the sampler. The F.I.S.P. committee set up several criteria for the design and construction of suspended-sediment samplers:

1. To allow water to enter the nozzle isokinetically. (In isokinetic sampling, water approaching the nozzle undergoes no change in speed or direction as it enters the orifice.)
2. To permit the sampler nozzle to reach a point as close to the streambed as physically possible. (This varies from 3 to 7 inches, depending on the sampler.)
3. To minimize disturbance to the flow pattern of the stream, especially at the nozzle.
4. To be adaptable to support equipment already in use for streamflow measurement.
5. To be as simple and maintenance-free as possible.
6. To accommodate a standard bottle size [that is, 1-pint (473 mL) glass milk bottle, 1-quart (946 mL) glass, 1-liter (1,000 mL) plastic, 2-liter (2,000 mL) plastic, or 3-liter (3,000 mL) plastic, as listed in table 1].

When a suspended-sediment sampler is submerged with the nozzle pointing directly into the flow, a part of the streamflow enters the sampler container through the nozzle as air in the container exhausts under the combined effect of three forces:

1. The positive dynamic head at the nozzle entrance, due to the flow.
2. A negative head at the end of the air-exhaust tube, due to flow separation.
3. A positive pressure due to a difference in elevation between the nozzle entrance and the air-exhaust tube.

When the sample in the container reaches the level of the air exhaust, the flow rate drops, and circulation of the streamflow in through the nozzle and out through the air-exhaust tube occurs. Because the velocity of the water flowing through the bottle is less than the stream velocity, the coarser particles settle out, causing the concentration of coarse particles in the bottle to gradually increase.

Table 1. Sampler designations and characteristics

[Epoxy-coated versions of all samplers are available for collecting trace metal samples; US, United States; in., inches; lbs., pounds; ft/s, feet per second; cd, cadmium, do., ditto; X, type of sampler container size used; --, type of sampler container size not used]

Sampler designation (US)	Construction material	Sampler dimensions Length (in.)	Width (in.)	Weight (lbs.)	Nozzle distance from bottom (in.)	Suspension type	Maximum velocity (ft/s)	Maximum depth (ft)	Sampler container size Pint	Quart	Intake size (in.)	Nozzle color
DH-48	aluminum	13	3.2	4.5	3.5	rod	8.9	8.9	X	--	1/4	yellow
DH-75P[1]	cd-plated	9.25	4.25	1.5	3.27	do.	6.6	15	X	--	3/16	white
DH-75Q[1]	do.	9.25	4.25	1.5	4.49	do.	6.6	15	--	X	3/16	white
DH-75H[1]	do.	9.25	4.25	1.5	--	do.	6.6	15	(2 liter)		3/16	white
DH-59	bronze	15	3.5	22	4.49	handline	5.0	15	X	--	1/8	red
DH-59	do.	15	3.5	22	4.49	do.	5.0	15	X	--	3/16	red
DH-59	do.	15	3.5	22	4.49	do.	5.0	9	X	--	1/4	red
DH-76	do.	17	4.5	22	3.15	do.	6.6	15	--	X	1/8	red
DH-76	do.	17	4.5	22	3.15	do.	6.6	15	--	X	3/16	red
DH-76	do.	17	4.5	22	3.15	do.	6.6	15	--	X	1/4	red
DH-81	plastic	[1]7.5	4.0	.5	([2])	rod	8.9	9	([7])	--	3/16	white
DH-81	do.	[1]7.5	4.0	.5	([2])	do.	8.9	9	([7])	--	1/4	white
DH-81	do.	[1]7.5	4.0	.5	([2])	do.	8.9	9	([7])	--	5/16	white
D-49	bronze	24	5.25	62	4.00	cable reel	6.6	15	X	--	1/8	green
D-49	do.	24	5.25	62	4.00	do.	6.6	15	X	--	3/16	green
D-49	do.	24	5.25	62	4.00	do.	6.6	9	X	--	1/4	green
D-74	do.	24	5.25	62	4.06	do.	6.6	15	X[8]	X	1/8	green
D-74	do.	24	5.25	62	4.06	do.	6.6	15	X[8]	X	3/16	green
D-74	do.	24	5.25	62	4.06	do.	6.6	[3]9, [4]15	X[8]	X	1/4	green
D-74AL	aluminum	24	5.25	42	4.06	do.	5.9	15	X[8]	X	1/8	green
D-74AL	do.	24	5.25	42	4.06	do.	5.9	15	X[8]	X	3/16	green
D-74AL	do.	24	5.25	42	4.06	do.	5.9	[3]9, [4]15	X[8]	X	1/4	green
D-77	bronze	29	9.0	75	7.0	do.	8.0	15	(3 liter)		5/16	white
P-61	do.	28	7.34	105	4.29	do.	6.6	[5]180, [6]120	X[8]	X	3/16	blue
P-63	do.	37	9.0	200	5.91	do.	6.6	[5]180, [6]120	X[8]	X	3/16	blue
P-72	aluminum	28	7.34	41	4.29	do.	5.3	[5]72.2, [6]50.9	X[8]	X	3/16	blue

[1]Without sample bottle attached.
[2]Depends on bottle size used. Calibrated brass nozzles no longer available.
[3]Depth using pint sample container.
[4]Depth using quart sample container.
[5]Depth using pint sample container to transit in 15 to 30 foot increments until entire traverse is completed
[6]Depth using quart sample container to transit in 15 to 30 foot increments until entire traverse is completed.
[7]Any size bottle with standard mason jar treads.
[8]Pint milk bottle can be used with adapter sleeve.

Depth- and Point-Integrating Samplers

A depth-integrating sampler is designed to isokinetically and continuously accumulate a representative sample from a stream vertical while transiting the vertical at a uniform rate (Federal Inter-Agency Sedimentation Project, 1952, p. 22). The simple depth-integrating sampler collects and accumulates a velocity or discharge-weighted sample as it is lowered to the bottom of the stream and raised back to the surface.

The point-integrating sampler, on the other hand, uses an electrically activated valve, enabling the operator to isokinetically sample points or portions of a given vertical. For stream cross sections less than 30 feet deep, the full depth can be traversed in one direction at a time by opening the valve and depth integrating either from surface to bottom or vice versa. Stream cross sections deeper than 30 feet can be integrated in segments of 30 feet or less by collecting integrated-sample pairs consisting of a downward integration and a corresponding upward integration in separate containers.

To eliminate confusion and more adequately differentiate between depth- and point-integrating samplers, a direct reference to Inter-Agency Report 14 (Federal Inter-Agency Sedimentation Project, 1963b, p. 60) is presented here to describe the characteristics of the point-integrating samplers that make them useful in conditions beyond the limits of the simpler depth-integrating samplers.

> Point-integrating samplers are more versatile than the simpler depth-integrating types. They can be used to collect a suspended-sediment sample representing the mean sediment concentration at any point from the surface of a stream to within a few inches of the bed, as well as to integrate over a range in depth. These samplers were designed for depth integration of streams too deep (or too swift) to be sampled in a continuous round-trip integration. When depth integrating, sampling can begin at any depth and proceed either upward or downward from that initial point through a maximum vertical distance of 30 feet.

A point-integrating sampler uses a 3/16-inch nozzle oriented parallel to the streamflow with the cross-sectional area exposed to approaching particles. The air is exhausted from the sample container and directed downstream away from the nozzle area as the sample enters. The intake and exhaust passages are controlled by a valve that can be activated on demand. When the valve is activated (opened to the sampling position), the sampling procedure is identical to that used for depth-integrating samplers. The increased effective depth to which a point-integrating sampler can be used, as compared to the maximum sampling depth to which a depth-integrating sampler is limited, is made possible by a pressure-equalizing chamber (diving-bell principle) enclosed in the sampler body. This chamber equalizes the air pressure in the sample container with the external hydrostatic head near the intake nozzle at all depths to alleviate the inrush of sample water, which would otherwise occur when the intake and air exhaust are opened at depth.

Hand-held samplers—US DH-81, US DH-75, US DH-48, US DH-59, and US DH-76

Where streams are wadable or access can be obtained from a low bridge span or cableway, a choice of five lightweight samplers can be used to obtain suspended-sediment samples via a wading rod or handline.

The DH-81 (fig. 2) consists of a DH-81A adapter and D-77 cap and nozzle. All parts are autoclavable. This construction enables the sampler to be used for collection of depth-integrated samples for bacterial analysis. The DH-81 can be used with 1/8-inch, 3/16-inch, or 1/4-inch nozzles and is suspended from a rod. Any bottle having standard mason jar threads can be used with this sampler. Obviously, the height of the unmeasured zone will vary depending on the size of

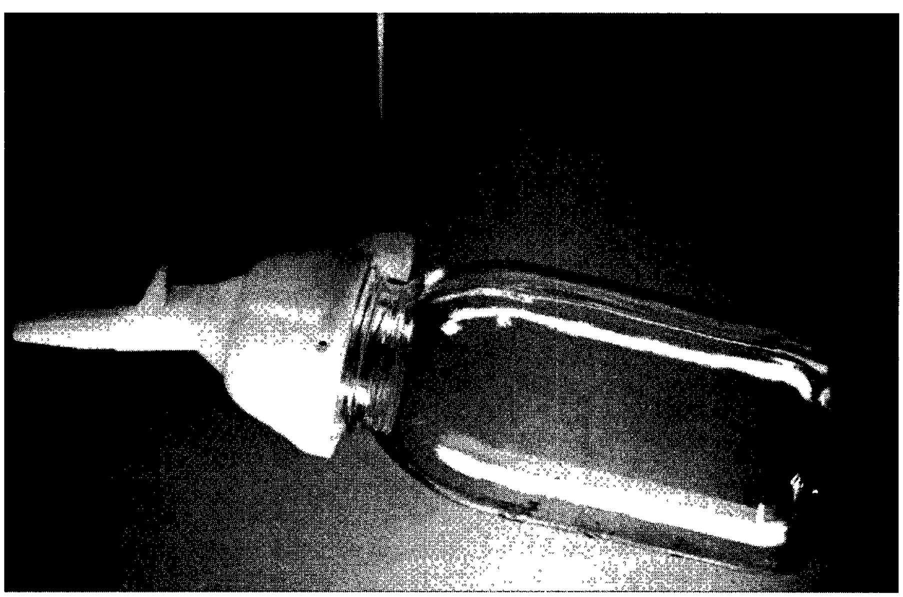

Figure 2. US DH-81 suspended-sediment sampler shown with a US DH-81A adapter, D-77 cap and nozzle, wading rod handle, and quart glass bottle.

bottle used. The DH-81 should be useful for sampling during cold weather because the plastic sampler head and nozzle attach directly to the bottle, eliminating a metal body (which would more rapidly conduct heat away from the nozzle, air exhaust, and bottle and create a more severe sampler-freezeup condition).

The DH-75 (fig. 3) weighs 0.9 pound and is available in two versions, the DH-75P and DH-75Q, which accept plastic containers of pint and quart volumes, respectively. The sampler consists of a cadmium-plated sheet-steel body 9 1/4 inches long, excluding the nozzle and sample container, with a retainer piece and shock cord assembly to hold the sample container against a cast silicone stopper through which the 3/16-inch nozzle and 180-degree air-exhaust tube pass to the mouth of the bottle. The DH-75 was developed as a freeze-resistant sampler. This sampler is not recommended for use as a general purpose depth-integrating suspended-sediment sampler.

The DH-48 sampler (fig. 4) features a streamlined aluminum casting 13 inches long that partly encloses the sample container. The container, usually a round pint glass milk bottle, is sealed against a gasket recessed in the head cavity of the sampler by a hand-operated spring-tensioned pull-rod assembly at the tail of the sampler. A modified version of this sampler is available to accommodate square pint milk bottles also. The sample enters the container through the intake nozzle as the air from the container is displaced and exhausted downstream through the air exhaust. The sampler, including container, weighs 4 1/2 pounds and can sample to within 3 1/2 inches of the streambed. This instrument is calibrated with an intake nozzle 1/4 inch in diameter, but may be used with a 3/16-inch nozzle in high-flow velocity situations (Federal Inter-Agency Sedimentation Project, 1963b, p. 57–60).

Two lightweight (24 and 25 pounds) handline samplers designated "DH-59" and "DH-76" (figs. 5 and 6) are designed for use in shallow unwadable streams with flow velocities up to 5 ft/s (feet per second). These samplers feature streamlined bronze castings 15 and 17 inches in length for the DH-59 and DH-76, respectively. The DH-59 accommodates a round pint sample bottle, while the DH-76, a more recent version of the sampler, is designed to take a quart container. The tail assembly extends below the body of the casting to ensure sampler alignment parallel to the flow direction with the intake nozzle entrance oriented upstream. Intake nozzles of 1/8-inch, 3/16-inch, and 1/4-inch diameters are calibrated for use with these samplers and may be interchanged as necessary when varying flow conditions are encountered from stream to stream. Suspended sediment can be collected to within 4 1/2 inches of the streambed with the DH-59, while the DH-76 can sample to within about 3 inches from the bottom.

These lightweight hand samplers are the most commonly used for sediment sampling during normal flow in small- and, perhaps, intermediate-sized streams. Because they are small, light, durable, and adaptable, they are preferred by hired observers and field people on routine or reconnaissance measurement trips. At many locations, a heavier sampler will be needed only for high-flow periods. It is often desirable, however, to require the observer to use a heavier sampler installed at a fixed location. The small size of the hand samplers also enables the person taking a sample in cold weather to warm the sampler readily if water freezes in the nozzle or air exhaust.

Cable-and-Reel Samplers—US D-74, US D-77, US P-61, US P-63, and US P-72

When streams cannot be waded, but are shallower than about 15 feet, depth-integrating samplers designated "D-74" and "D-77" can be used to obtain suspended-sediment samples. Forerunners of these samplers were the US D-43 and US D-49 samplers, both of which are no longer manufactured. These latter two are only mentioned here because many of these earlier designed instruments are still used at some locations. Sampling techniques for using the older samplers are identical to those presented later in this text relative to operation of the newer D-74 and D-77 samplers.

The D-74 (fig. 7) is a 62-pound sampler (approximately 40 pounds for the aluminum version) designed to be suspended from a bridge crane or cableway by means of a standard hanger bar and cable-and-reel system. This sampler replaces the earlier D-49, which replaced the D-43 for general use. The D-74 has a streamlined cast bronze (or aluminum) body 24 inches long that completely encloses the sample container. This sampler accommodates a round quart bottle, or with addition of an adapter sleeve, a standard pint milk bottle may be used. The sampler head is hinged at the bottom and swings downward to provide access to the sample-container chamber. In this manner, sample containers can be changed during the normal sampling

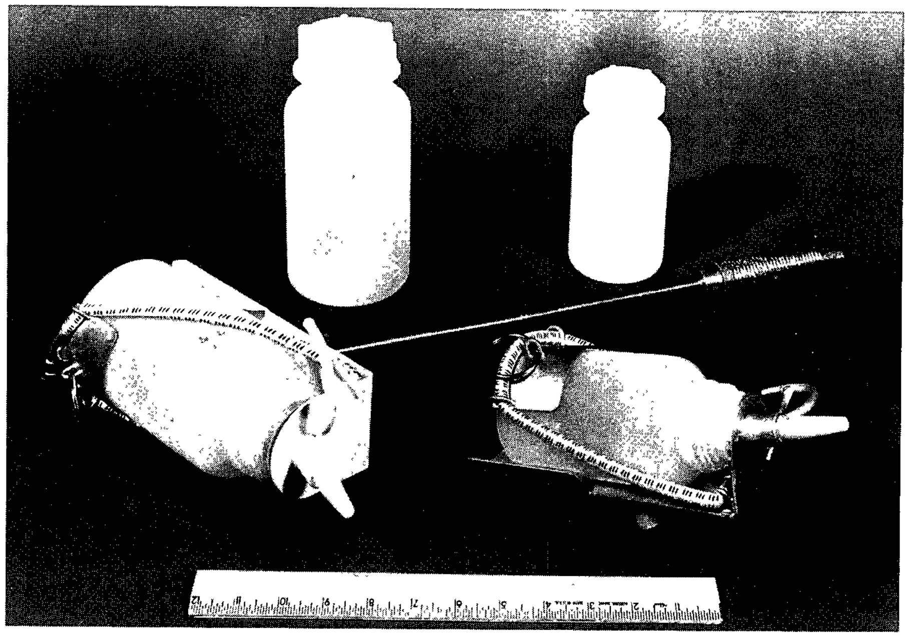

Figure 3. US DH-75 (P and Q) suspended-sediment samplers with sample containers and wading rod.

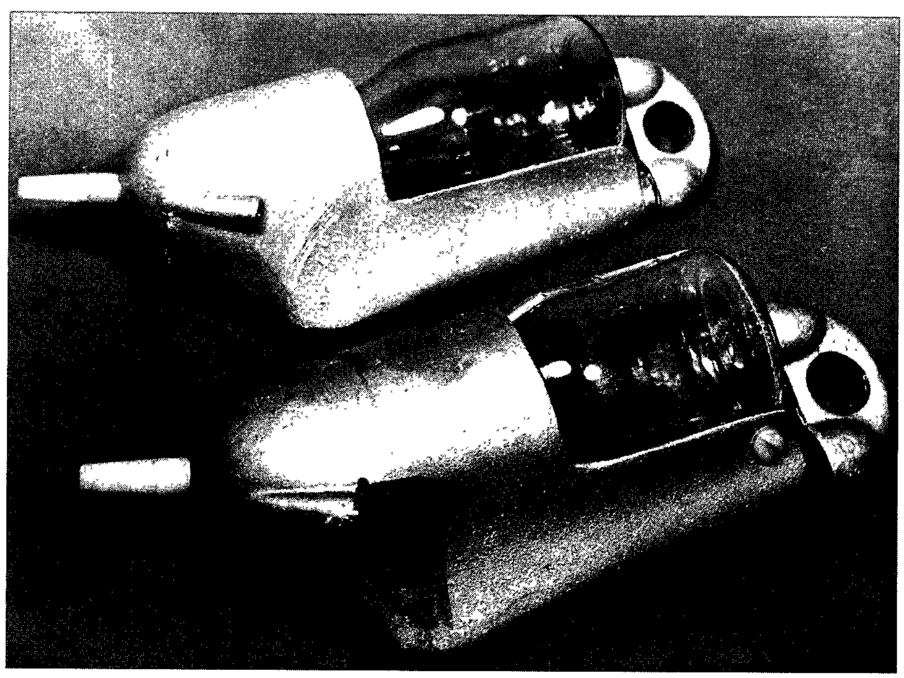

Figure 4. US DH-48 suspended-sediment sampler.

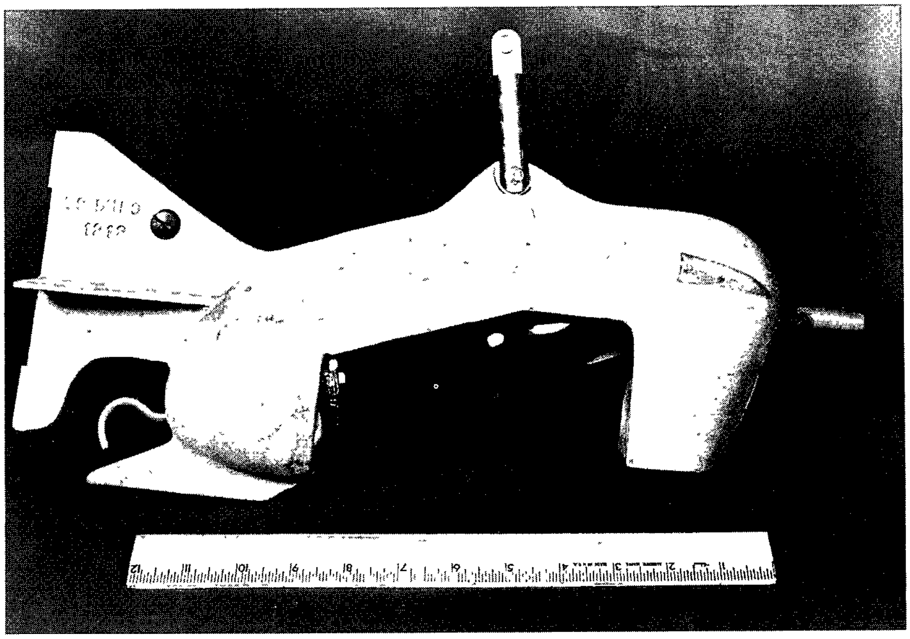

Figure 5. US DH-59 suspended-sediment sampler.

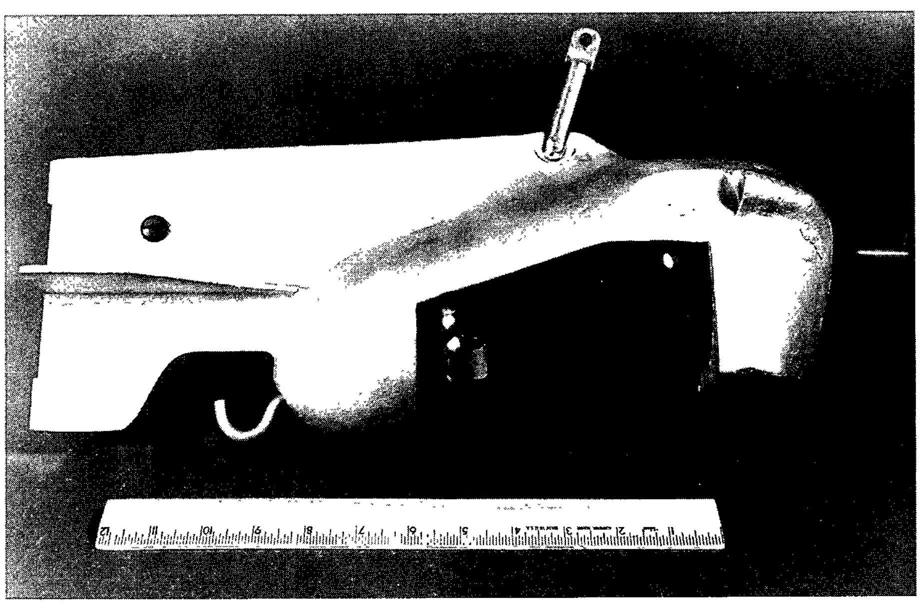

Figure 6. US DH-76 suspended-sediment sampler.

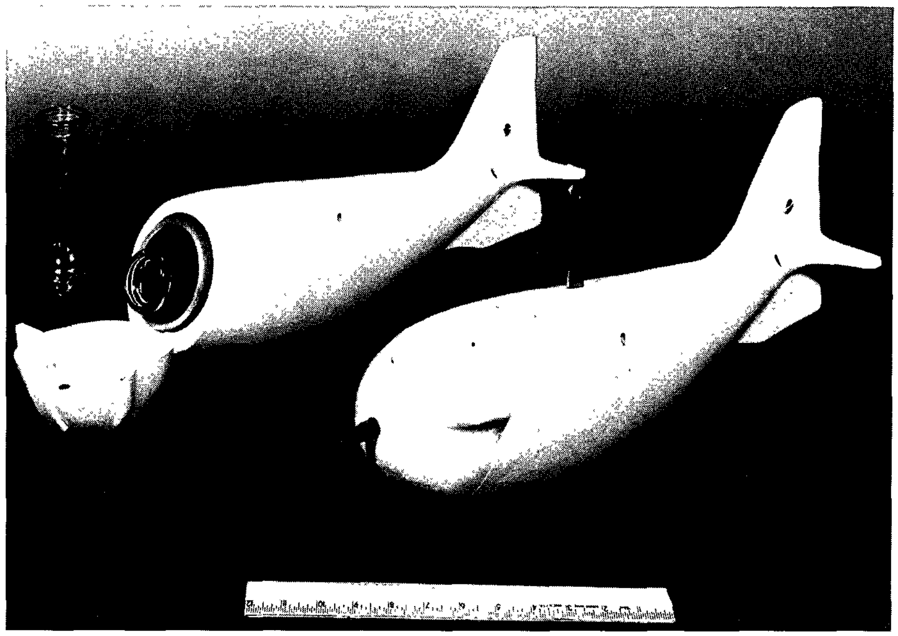

Figure 7. US D-74 suspended-sediment sampler.

routine. The body includes tail vanes that serve to align the sampler and the intake nozzle with the flow. Intake nozzles of 1/8-inch, 3/16-inch, and 1/4-inch diameters are available for use with the sampler and can be interchanged as varying flow conditions dictate. The sample container fills as a filament of water passes through the intake nozzle and displaces air from the container. The air is expelled in the downstream direction through an air-exhaust port in the side of the sampler head. The intake nozzle can be lowered to within about 4 inches of the streambed during sampling (approximately 4 1/3 inches for the aluminum version).

The D-77 is a dramatically different design (fig. 8) as compared to the design configuration of the D-74 and its predecessors. The sampler is 29 inches long and weighs 75 pounds; it has a bronze casting attached to a tail cone with four sheet-metal vanes welded in place to provide a means of orienting the intake nozzle into the flow. The casting is structured to accommodate a 3-liter autoclavable sample container that slides into the sample container chamber and is held in place by means of a spring clip on the bottom of the chamber. This sampler is constructed without a head assembly to cover the mouth of the container and facilitate attachment of the intake nozzle. Instead, a cap, nozzle, and air-exhaust assembly, constructed of autoclavable plastic, is screwed onto the mouth of the sample container, which is entirely exposed at the front of the sampler. This configuration was purposely chosen to allow collection of a large volume (2,700 mL), depth-integrated biological or chemical sample at near- or below-freezing temperatures. Although 1/8-inch, 1/4-inch, 3/16-inch, and 5/16-inch nozzles are available, only 5/16-inch nozzles are recommended for use with this sampler. The distance between the nozzle and sampler bottom is 7 inches.

A version of the D-77 sampler was tested by F.I.S.P. to eliminate the depth-range limit dictated by sample container size, nozzle size, and stream velocity (Federal Inter-Agency Sedimentation Project, 1982b). This version, commonly referred to as a "bag sampler," incorporates a sample bag inside a special rigid container. Information about this sampler and other bag samplers can be obtained from F.I.S.P.

Point-integrating samplers currently manufactured and widely used are the P-61, P-63, and P-72. Forerunners of these samplers were the P-46 and P-50 samplers, which are no longer manufactured but are mentioned here because several of these instruments are still used. The sampling techniques used for obtaining a sample with these older samplers are the same as for the newer samplers. The primary differences between these old and new versions are valve mechanisms and cost. The new versions have a simpler valve and are less expensive.

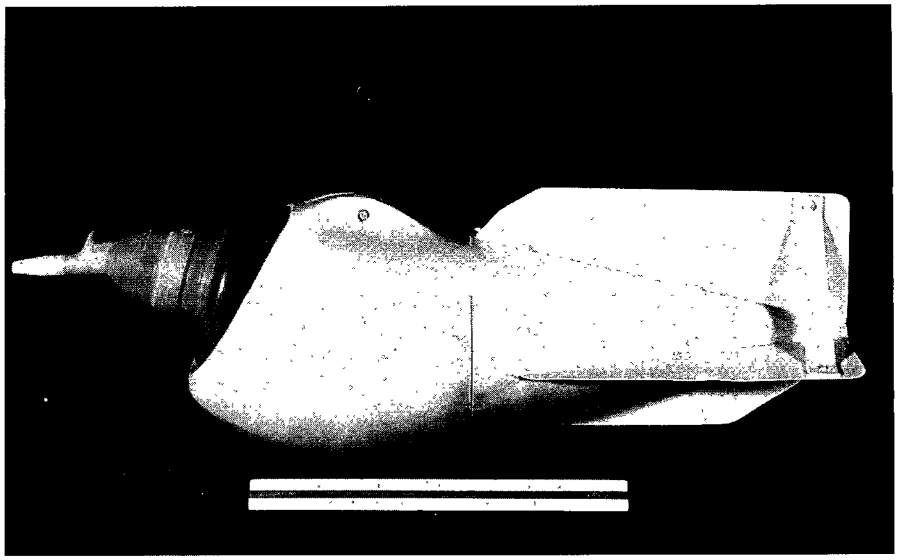

Figure 8. US D-77 suspended-sediment sampler.

The 105-pound P-61 (fig. 9) can be used for depth integration as well as for point integration to a maximum stream depth of 180 feet. The sampler valve for the P-61 has two positions. When the solenoid is not energized, the valve is in the nonsampling position, in which the intake and air-exhaust passages are closed, the air chamber in the body is connected to the cavity in the sampler head, and the head cavity is connected through the valve to the sample container. When the solenoid is energized, the valve is in the sampling position, in which the intake and air exhaust are open, and the connection from the sample container to the head cavity is closed. A P-61 sampler that has been modified to accommodate a quart bottle is illustrated in figure 9. When the ordinary pint bottle is used, the cylindrical adapter must be inserted into the bottle cavity. The maximum sampling depth is about 120 feet when the quart container is used.

The P-63 (fig. 10) is a 200-pound point-integrating suspended-sediment sampler and is better adapted to high velocities. The solenoid head is basically the same as that on the P-61. The P-63 differs from the P-61 mainly in size and weight. The P-63 is cast bronze, is 34 inches long, and has the capacity for a quart-sized round mayonnaise bottle. An adapter is furnished so that a round pint-sized milk bottle can be used. The maximum sampling depth is the same as for the P-61, about 180 feet with a pint sample container and about 120 feet with a quart container.

The 41-pound P-72 is a light-weight version of the P-61. It features a streamlined cast-aluminum shell rather than the bronze used to construct the P-61. The outward appearance of the P-72, the 3/16-inch intake nozzle, the solenoid head, and the accommodation for pint- and quart-sized containers are similar to the P-61. However, the listed maximum stream velocity at which the P-72 is recommended for use is 5.3 ft/s, as opposed to 6.6 ft/s for the P-61, and the depth limit to which this sampler should be used is about 72 feet using the pint container and 51 feet with the quart container. These depths are less than one-half of the maximum usable depths for the P-61 with the same container sizes.

All the point samplers are designed for suspension with a steel cable having an insulated inner conductor core. By pressing a switch located at the operator's station, the operating current may be supplied through the cable to the solenoid in the sampler head by storage batteries connected in series to produce 24 to 48 volts. If the suspension cable is longer than 100 feet, a higher voltage may be desirable. The US BP-76 battery pack has been designed as a portable power source for activating the P-61, P-63, and P-72 samplers and is available from the F.I.S.P. and HIF.

Because of the complex nature of point-integrating samplers, the user may find it necessary to seek additional information given in the Inter-Agency reports (Federal Inter-Agency Sedimentation Project, 1952, 1963b, and 1966).

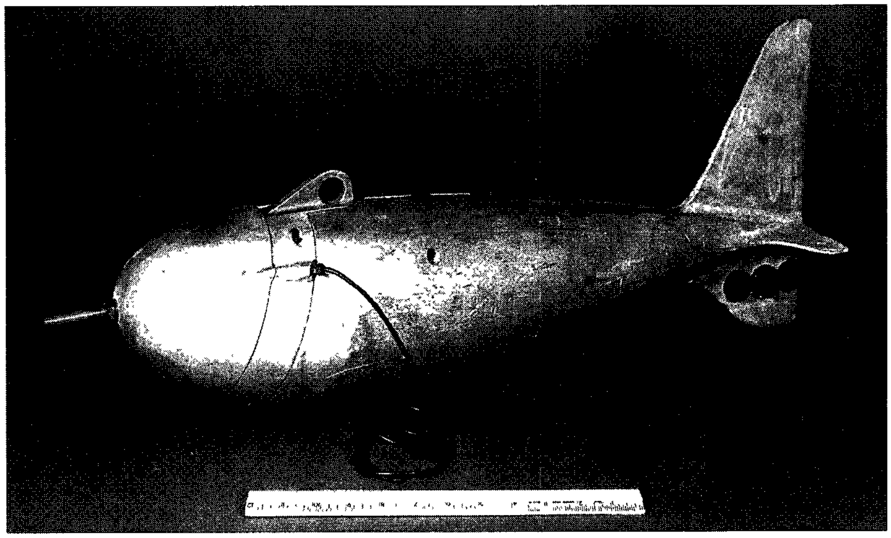

Figure 9. US P-61 point-integrating suspended-sediment sampler.

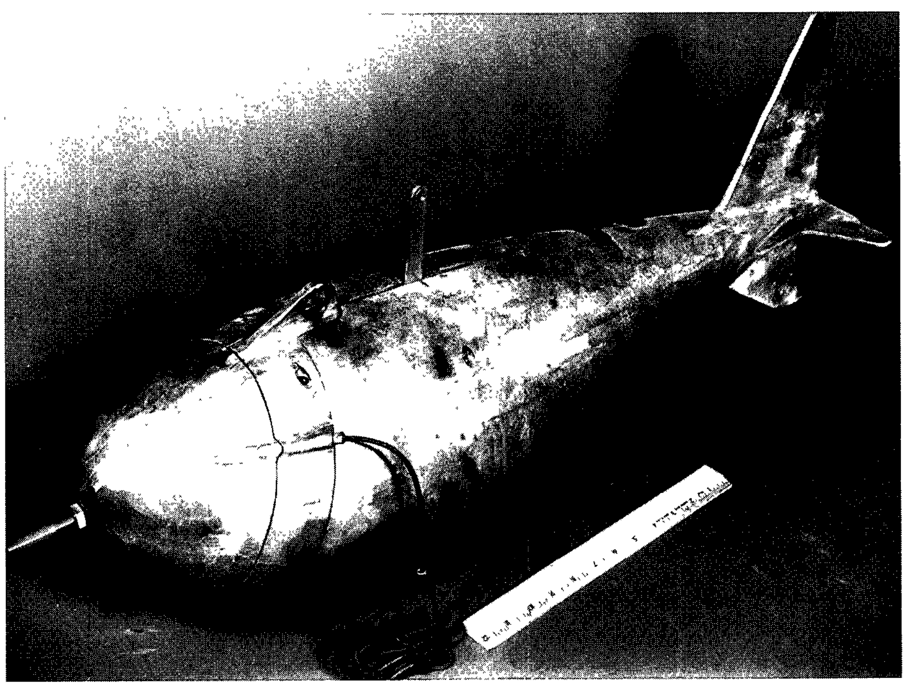

Figure 10. US P-63 point-integrating suspended-sediment sampler.

Sampler Accessories

Nozzles

Each suspended-sediment sampler is equipped with a set of nozzles specifically designed for the particular sampler. These nozzles are cut and shaped externally and internally to ensure that the velocity of water after entering the nozzle is within 8 percent of the ambient stream velocity when the stream velocity is greater than 1 ft/s. It has been found that a deviation in intake velocity from the stream velocity at the sampling point causes an error in the sediment concentration of the sample, especially for sand-sized particles. For example, a plus-10-percent error in sediment concentration is likely for particles of sediment 0.45 mm in diameter, when the intake velocity is 0.75 of the stream velocity (Federal Inter-Agency Sedimentation Project, 1941, p. 38–41). The relation between intake-velocity deviation and errors in concentration resulting from collecting a sample enriched or deficient in sand-size particles (greater than 0.062 mm) is illustrated by figure 11. When sand-size particles are entrained in

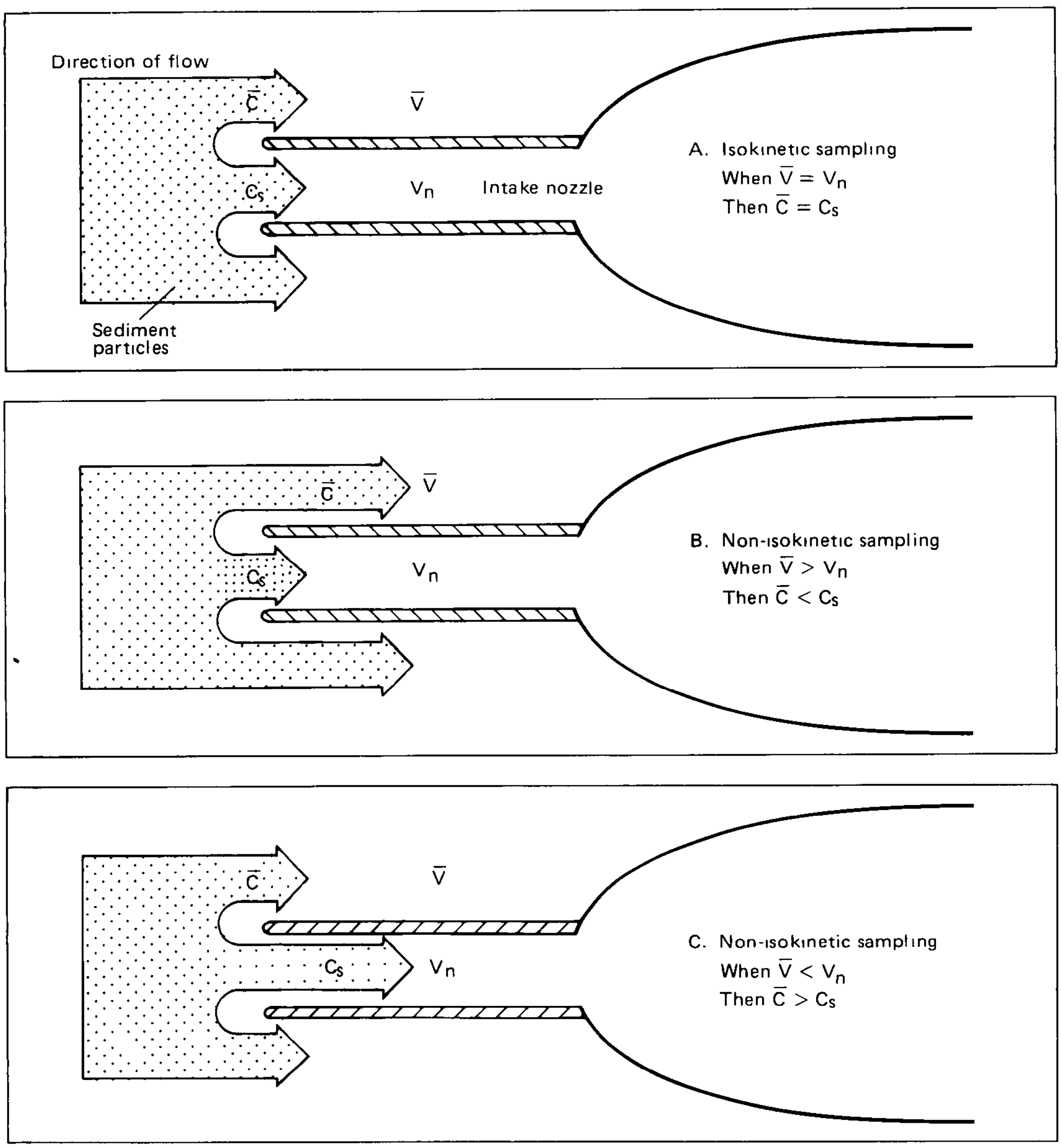

Figure 11. Relation between intake velocity and sample concentration for (*A*) isokinetic and (*B*, *C*) non-isokinetic sample collection of particles greater than 0.062 mm. When $\bar{V}$ = mean stream velocity, V_n = velocity in the sampler nozzle, $\bar{C}$ = mean sediment concentration in the stream, and C_s = sample sediment concentration.

the flow, the intake velocity within the sampler nozzle must be equal to the ambient stream velocity (isokinetic), in order to collect a sample representative of the mean discharge-weighted sediment concentration (fig. 11*A*). The resulting sediment concentration of the sample will be equal to the average discharge-weighted sediment concentration of the approaching flow. However, when the velocity in the nozzle is less than the stream velocity (non-isokinetic, fig. 11*B*), some water that should flow into the nozzle now curves to the side and flows around it. Inertia resists the curving flow and forces the approaching particles (greater than 0.062 mm) to follow straight-line paths into the nozzle. This combination of curved and straight-line movement increases the concentration of coarse particles in the sample. As a result, the sediment concentration in the sample is greater than the concentration in the approaching flow. Likewise, when the velocity in the nozzle is greater than the stream velocity (non-isokinetic, fig. 11*C*), some water that should flow past the nozzle curves to the side and flows into it. Again, inertia resists the curving flow and forces the particles (greater than 0.062 mm) to follow straight-line paths and flow past the nozzle. The result of this combination of curved and straight-line movement is a decrease in the sample concentration relative to the concentration of the approaching flow.

Because, in general, each sampler nozzle is designed for a particular series of samplers, it must be emphasized that a nozzle for one series of samplers should not be used in another series of samplers. However, there are two exceptions to this rule—the same nozzle can be used in the P-61, P-63, and P-72 series, and a nozzle can be interchanged between the D-49 and D-74. To ensure against incorrectly matching samplers and nozzles, all nozzles are color coded to specific sampler designs (table 1).

The reasons for the differences between the nozzles of different series are that (1) the length of flow paths for water and air are different, resulting in differences of flow resistance; and (2) the differential heads between the nozzle entrance and the air exhaust are different. Thus, interchanging nozzles among samplers of various series results generally in an incorrect intake velocity and, thus, incorrect sediment concentration and particle-size distribution in the sample. Therefore, when a nozzle is bent or broken, be certain to use a correct replacement nozzle.

If extra nozzles are needed for a sampler, they can be ordered from the F.I.S.P. at the address in the latest Inter-Agency report. The order must indicate the sampler series. If the exhaust tubes, tail fins, or any other part of a sampler are damaged, the entire sampler should be sent to the F.I.S.P. for repair and recalibration.

Three nozzle diameters—1/4 inch, 3/16 inch, and 1/8 inch—are available for use with all depth-integrating samplers, except for the DH-48, DH-75, D-77, and the point-integrating samplers. The D-77 sampler is the only depth-integrating sampler that uses a 5/16-inch nozzle. Although a nozzle may physically fit a sampler, the match may not be correct. For example, it is possible, but incorrect, to interchange any one of the 1/4-inch, 3/16-inch, and 1/8-inch nozzles listed in table 1 among the depth-integrating or point-integrating samplers. For instance, it is possible, but incorrect, to put DH-48 nozzles in DH-59 samplers. One exception is the D-77, which will not accept any nozzle other than the correct one. To help prevent the incorrect interchange of color-coded nozzles among samplers, new samplers ordered from F.I.S.P. are delivered with a color-coded plastic screw in the tail vane assembly, which indicates the correct color of nozzle to be used with the sampler (for example, DH-59 has a red screw and uses a red nozzle).

The reason for different size nozzles is that stream velocities and depths occur that will cause the sample bottle to overfill for a specific transit rate when using the largest nozzle. More specifically, for depth-integrating samplers with a pint bottle, the maximum theoretical sampling depths for round-trip integration are about 9 feet for the 1/4-inch, and 15 feet with both the 3/16-inch, and 1/8-inch nozzles. Therefore, to reduce the quantity of sample entering the bottle at depths over 9 feet, use a smaller bore nozzle in combination with a pint sample bottle. For a given situation, the largest nozzle should be used to reduce the chance of excluding large sand particles that may be in suspension.

Possible errors caused by using too small a nozzle are usually minor when dealing with fine material (less than 0.062 mm), but tend to increase in importance with increasing particle size. Small nozzles also are more likely than large ones to plug with organic material, sediment, and ice particles. This means that problems with nozzles can exist even when sampling streams transporting mostly fine material.

Point-integrating samplers are supplied only with a 3/16-inch nozzle to match the opening through the valve mechanism.

Gaskets

Of equal importance to using the correct nozzle in the instrument is the necessity for using the proper gasket to seal the bottle mouth sufficiently. Gaskets for this purpose are made of a sponge-like neoprene that deteriorates somewhat with use and time. When samples are being collected for water quality, such as for trace metal analysis, the gasket should be made of silicone rubber to avoid biasing the sample chemistry.

To check the gasket for adequate seal, insert a bottle in the proper position in the sampler; then block the air-exhaust port and force air into the sampler nozzle. **CAUTION**: A field person should never force air into the sampler by placing the mouth directly in contact with the nozzle—due to the possibility of questionable water quality at the site or the likelihood of receiving an electrical shock (if a brass nozzle is in use) upon activating the solenoid of a point-integrating sampler when opening the intake. A safe procedure to perform this check would be to block the air exhaust with a finger and place a short length of clean plastic or rubber tubing snugly over the nozzle and then apply air pressure by blowing into the tubing to force air through the nozzle. If air escapes around the bottle mouth, replace the gasket. If the problem persists, check the spring that pushes the bottle against the gasket. Each sampler series uses a different size or shape of gasket, so it is necessary to have spares for each series in use. Appropriate gaskets may be obtained from the F.I.S.P. (address can be obtained from the latest Inter-Agency report). Gaskets in the "P" series samplers also may be tested by lowering the sampler, with sample bottle in place, into the stream without opening the solenoid. After a minute or so, raise the sampler to the surface and inspect the sample bottle. If the gasket is sealing properly, less than a few milliliters of water should be present in the bottle.

Bottles

Depth- and point-integrating samplers accommodate different bottle sizes and types (fig. 12). Many field people still use pint glass milk bottles, which have been used for many years and can be adapted to every sampler series with the exception of the DH-81 and D-77. Quart-sized glass mayonnaise bottles (Owens-Illinois #6762) are increasing in general use because versions of all samplers, except the DH-48 and D-77, use this size sample container. The D-77

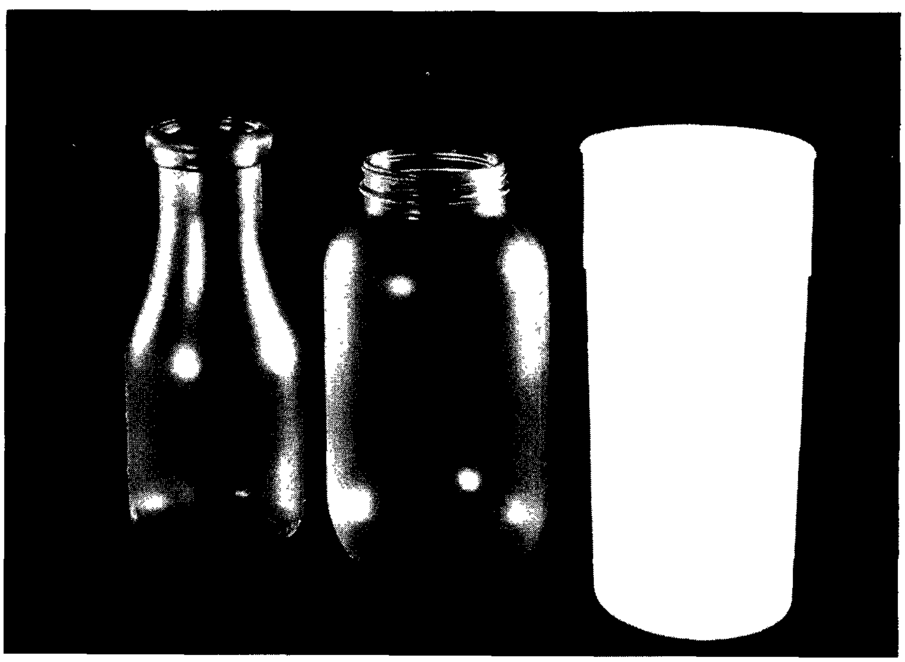

Figure 12. Sample containers to fit PS-69 pumping sampler (left to right): pint glass milk bottle, quart glass mayonnaise bottle, and quart plastic container to fit the PS-69 pumping sampler.

sampler holds a 3-liter plastic autoclavable bottle with standard mason jar threads (Nalge 2115-3000); the DH-81 holds any bottle with standard mason jar threads; and the DH-75 holds a plastic bottle (Bel-Art #F-10906, 1,000 mL) and a variety of other quart/liter bottles. Ideally, each type of glass bottle should have an etched surface to provide a labeling area to accommodate a record of pertinent information concerning each sample. Hydrofluoric acid has been used for this purpose, but care must be exercised when handling and storing this substance. In the past, commercial etching agents have been available for general use. However, the authors do not know of any such agent that is available at this time. This etched labeling surface should easily accept medium-soft blue or black pencil markings of sufficient durability to withstand handling and yet be easily removed during cleaning. Plastic bottles also require an area for labeling. However, this is less of a problem because a grease pencil or other marker that is not readily soluble in water, but that can be removed using a solvent, can be used to write on the side of the bottle.

The practice of using plain bottles with attached tags or marked caps for recording purposes should be avoided whenever possible. These labeling areas are generally small and provide little writing space. Additionally, the use of these labeling devices can result in tags being torn off during transport or in bottles being mislabeled by interchanging caps.

Plastic and teflon bottles are increasing in use throughout the Water Resources Division of the USGS. Several samplers have been designed to use plastic sample containers (the DH-75 series, the DH-81 and D-77 samplers). Compared to glass, these bottles are lightweight, strong, and useful when sampling for certain chemicals.

During depth integration, a collapsible bottle or bag would be the ideal arrangement to eliminate the problem of depth limitation due to the size of the sample container. Depth-integrating samplers incorporating this collapsible sample bag/bottle concept, are currently under development by F.I.S.P.

Bottles are usually stored and transported in wire, wooden, fiberboard, or plastic cases holding 12 to 30 bottles each. In the field, a small bottle carrier, which holds 6, 8, or 10 bottles, is more convenient; eliminates the need to handle the heavier 12- to 30-bottle cases while making a measurement; and provides a neat, convenient, and relatively safe place to set the bottles. When making wading measurements, both hands can be free to operate the sampler if the bottle carrier is suspended from the shoulder with a strap or rope.

Single-Stage Samplers

The single-stage samplers, US U-59 (fig. 13), also designated US SS-59, and US U-73, were designed and tested by the F.I.S.P. to meet the needs for instruments useful in obtaining sediment data on streams where remoteness of site location and rapid changes in stage make it impractical to use a conventional depth-integrating sampler.

The U-59 (SS-59) consists of a pint milk bottle or other sample container, a 3/16-inch inside diameter air exhaust, and 3/16-inch or 1/4-inch inside diameter intake constructed of copper tubing. Each tube is bent to an appropriate shape and inserted through a stopper

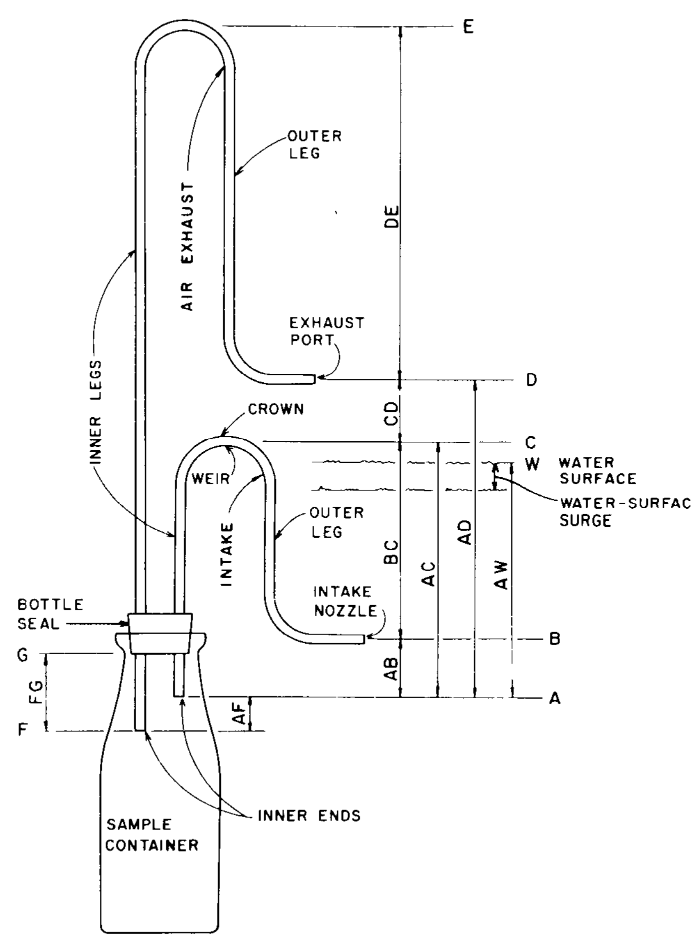

Figure 13. US U-59 single-stage suspended-sediment sampler. Sampling operation using designated letters is described in text (see also Federal Inter-Agency Sedimentation Project, 1961).