U. S. DEPARTMENT OF THE INTERIOR
March 3, 1849

Techniques of Water-Resources Investigations of the United States Geological Survey

FIELD METHODS FOR MEASUREMENT OF FLUVIAL SEDIMENT

BOOK 3

CHAPTER C2

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FIELD METHODS FOR MEASUREMENT OF FLUVIAL SEDIMENT

By Harold P. Guy and Vernon W. Norman

Book 3

APPLICATIONS OF HYDRAULICS

UNITED STATES DEPARTMENT OF THE INTERIOR

WALTER J. HICKEL, Secretary

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PREFACE

The series of manuals on techniques describes procedures for planning and executing specialized work in water-resources investigations. The material is grouped under major subject headings called books and further subdivided into sections and chapters; Section C of Book 3 is on sediment and erosion techniques.

The unit of publication, the chapter, is limited to a narrow field of subject matter. This format permits flexibility in revision and publication as the need arises.

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FIELD METHODS FOR MEASUREMENT OF FLUVIAL SEDIMENT

By Harold P. Guy and Vernon W. Norman

Abstract

This report describes field methods for the measurement of fluvial sediment. The diversity of the hydrologic and physical environments and data requirements therefrom make it desirable that the persons involved in sediment measurements be familiar with the basic sediment concepts and the equipment and techniques to be used for making timely and efficient sediment measurements.

In addition to an introduction, the report consists of two main sections. The section on "Sediment sampling equipment" includes a discussion of the characteristics and limitations of commonly used samplers and some of the modifications of this equipment for special measurements. The other section on "Sediment sampling techniques" includes a discussion of the characteristics of measurement sites, the selection of sampling verticals and transit rates, the methods of making sediment-discharge measurements, sampling quality control and timing, and some of the requirements for sediment-related data.

Introduction

Perspective

Knowledge of the erosion, movement, 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 is also becoming more and more apparent that such development and management be carried out in a manner that yields or conforms to a socially acceptable environment. The required knowledge of sediment makes necessary the measurement of suspended and bed sediments for a wide range of hydrologic environments. The complex phenomena of fluvial sedimentation make the required measurements and related analyses of sediment data relatviely expensive in comparison with other kinds of hydrologic data. Accordingly, the purpose of this manual is to help standardize and improve the efficiency of the techniques used to obtain sediment data, so that more knowledge can be obtained for a given investment of labor and resource.

It is of academic interest to note that Holeman (1968), on the basis of sediment data for several streams, has estimated that the annual worldwide yield of sediment to the oceans is about 20 billion tons (18 billion metric tons). If an assumed specific weight of 60 lb per cu ft (pounds per cubic foot) is used, this converts to about 15.3 million acre-feet (1.9 million hectare-meters).

Most sediment data needs are of more 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 the 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 relationships between sediment, water quality, and biota.

The scope of these requirements indicates that a large variety of measurements is needed on streams and other bodies of water ranging down to very small areas as for a parcel of land under urban development.

The authors have drawn heavily not only on the ideas from many experienced coworkers in the field, but on voluminous literature in an attempt to assemble the required methodology, and where desirable, some of the background theory, for performing fluvial sediment measurements in the field without having to refer to many sources in the literature. Because of this extensive condensation of the literature, it is expected that the reader may have to rely on additional sources given in the references and elsewhere to cope with the complicated problems of some measurements requiring special equipment and techniques.

The collection of reliable sediment data in an efficient manner requires a high degree of coordination of all activities. These activities vary from the collection of the sample in the field to the analysis in the laboratory and to the tabulation and publication of the data in suitable form.

Sediment characteristics, source, and transport

Sediment is fragmental material derived primarily from the physical and chemical disintegration of rocks from the earth's crust. Such particles range in size from large boulders to colloidal size fragments and vary in shape from rounded to angular. They also vary in specific gravity and mineral composition, the predominant mineral being quartz.

Once the sediment particles are detached, they may either be transported by gravity, wind, or water, or else by a combination of these agents. When the transporting agent is water, the sediments is termed "fluvial sediment", and the act of moving or removing the particles from their resting places is called erosion.

Erosion by water may be divided into sheet and channel erosion, but no distinct division separates the two. Sheet erosion occurs when fine-grained silts and clays are removed from a surface in a sheet of relatively uniform thickness by raindrop, splash, and sheet flow. The movement of sediment particles and the energy of the raindrops compacts and partially seals the soil surface which decreases the infiltration rate and increases the amount of sheet flow available to erode and transport the sediment. Thus, the amount of material removed by sheet erosion varies with such factors as surface slope, precipitation intensity and drop size, soil type, and vegetative cover.

Because of irregularities in the land surface, sheet flow does not occur continuously over large areas but quickly concentrates into small rills or channels and streams which grow in size as each joins another. Within these channels, the water erodes the available material in the banks or bed of the stream until the stream is "loaded" with as much sediment as the energy of the stream will allow it to carry. Such channel erosion may be general or local along the stream but is primarily local in nature.

Thus, most of the sediment transported by a given stream comes from sheet erosion and from upstream rill or channel erosion. Sometimes sediment may be transported to the stream by wind, but this is generally a minute part of the total of the fluvial sediments. Aside from bank caving from stream erosion, many kinds of mass wasting or gravitational transfer of sediments toward and into streams take place. These may range from slow creep to the very rapid landslide. Other sediments, which may be found locally in sizeable quantities, may be derived from glacial melt, mining, gravel plant operations, and many types of construction activities by man.

Depending on the size of each sediment particle, the stream transports the sediment by maintaining the particle in suspension with turbulent currents or by rolling or skipping the particle along the streambed. 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.

The distribution of the suspended-sediment sizes in the vertical direction may vary from stream to stream and from cross section to cross section within the same stream. Generally, the finer sediments are distributed uniformly throughout the vertical, and the coarser particles are concentrated near the streambed but with some coarse particles reaching the water surface at times. Thus, when sampling with the samplers described in this chapter, the sample obtained will contain a range of particle sizes which are in suspension in the increment of flow that enters the sampler. Inasmuch as the sampler nozzle cannot reach the lower 0.3 to 0.4 foot of a vertical, it is not possible to sample or measure the entire flow, and therefore, the sediment obtained by the sampler in the sampling zone is defined as measured sediment discharge. The higher concentration and coarser sizes of sediment passing beneath the sampler nozzle, in suspension and on the bed, is defined as unmeasured sediment discharge. This unmeasured part may or may not be a sizeable part of the total sediment (measured plus unmeasured) and is sometimes computed empirically. Figure 1 illustrates these concepts. At some stream cross sections, all the sediment sizes being transported may be thrown into a fairly uniform suspension throughout the entire vertical by natural or artificial turbulence. The measured part at these sites is representative of the entire vertical and represents total sediment discharge.

From this brief discussion it should be evident that the study of fluvial sediment transport is complex because of the many variables involved. For the interested reader a more detailed summary of fluvial sediment concepts can be found in Colby (1963) and in Guy (1970).

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.

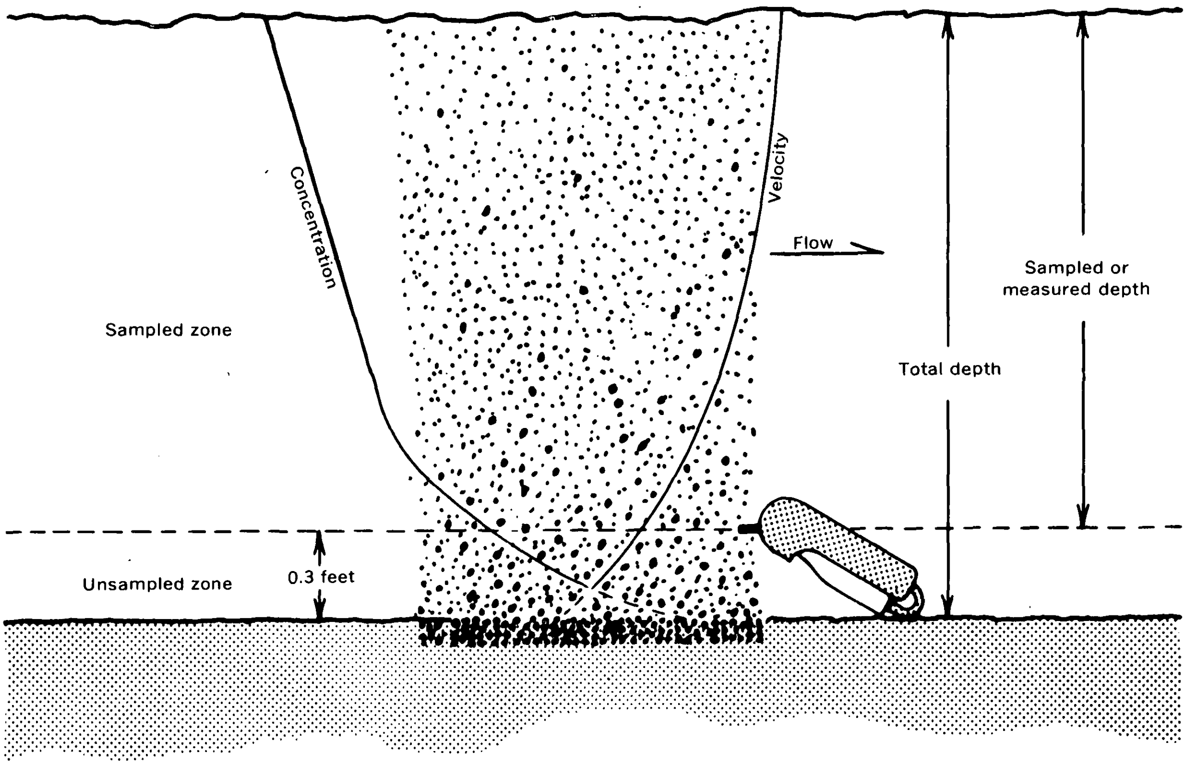


Figure 1.—Measured and unmeasured sampling zones in a stream sampling vertical with respect to velocity of flow and sediment concentration. J. K. Culbertson (Written commun., May 1968).

Sediment data is useful in coping with water utilization problems and goals. 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 the distribution system. Many industries require sediment-free water in their processes. Information on sediment movement and particle size characteristics are 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, herbicides, 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 drainage basins is useful in helping to predict the stream environment when future basin changes are made. Knowledge of 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 yield (1) comprehensive information on a national network basis, (2) special information at specific problem areas for water management, and (3) a description and understanding of the relationships 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 are made prior to implementing any of these three programs. Even after a specific program is started, it is expected that adjustments will be necessary with respect to equipment, sample timing, or even measurement location.

Sediment Sampling Equipment

General

In the early days of fluvial sediment investigations, each investigator and at least each agency developed methods and equipment according to need. It soon became apparent that comparable results would not be obtained if the equipment, data collection, and analysis methods varied. To overcome this difficulty, an array of standard samplers and methods was developed by the Federal Inter-Agency Sedimentation Project (F.I.A.S.P.) of the Inter-Agency Committee on Water Resources, located first at Iowa City, Iowa, and since 1948 at the St. Anthony Falls Hydraulic Laboratory in Minneapolis, Minnesota. The number of reports published by F.I.A.S.P. since 1939 totals 36, as of October 1966. They cover almost all aspects of measurement and analysis of sediment movement in streams. (See Inter-Agency Report "Catalog" (F.I.A.S.P., 1966) for a complete listing of reports.) The intent of this chapter is not to replace the Inter-Agency Project reports, but to condense and combine their information on making sediment measurements. Therefore, the reader should refer to the F.I.A.S.P. reports for further background material and details on the standard samplers.

It is well to note that the samplers carry the following coded designation:

US, United States standard sampler (After first use in designating a sampler in this chapter, it will usually no longer be included as part of the designation).
D, depth integrating.
P, point integrating.
H, hand held by rod or rope. For cable-and-reel suspension the H is omitted.
BM, bed material.
U, single stage.
YEAR, year (last two digits) in which the sampler was developed.

As indicated by the F.I.A.S.P. (1963a, p. 3), sediment samplers currently recommended for field use include three depth-integrating suspended-sediment samplers, two point-integrating suspended-sediment samplers, and three bed-material samplers. In addition an array of instruments have been developed such as the single-stage sampler and the pumping samplers used to obtain sediment information from flashy streams and where the services of an observer cannot be obtained.

Suspended-sediment samplers

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

1. To allow water to enter the sample bottle through the nozzle at the same velocity as the surrounding stream velocity.
2. To permit the sampler nozzle to reach a point as close to the stream bed as physically possible. (This varies from 3½ to 6 inches (9 to 15 cm) according to 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 one pint (473 ml) glass milk bottle. (Exceptions are the US P–63 and US P–50 which hold both pint- and quart-sized bottles.)

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

1. The dynamic positive head of the flow at the nozzle entrance.
2. A negative head at the end of the air-outlet tube.
3. A hydrostatic pressure because of the difference in elevation between the nozzle entrance and the air-outlet tube.

When the sample in the container reaches the level at the end of the nozzle, especially the air-outlet tube, the desired flow rates will not be attained and the sample will become contaminated by deposition from flow circulating in through the nozzle and out through the air-outlet tube.

Depth-integrating samplers

"A depth-integrating sampler is designed to accumulate a water-sediment sample from a stream vertical at such a rate that the velocity in the nozzle at point of intake is always as nearly as possible identical with the immediate stream velocity, while running the vertical at a uniform speed." (F.I.A.S.P., 1952, p. 22). The simple depth-integrating sampler collects and accumulates the sample as it is lowered to the bottom of the stream and raised back to the surface. The sampler must be moved at a uniform rate in a given direction but not necessarily at equal rates in both directions.

The point-integrating sampler, on the other hand, can be operated to obtain a depth-integrating sample from deep or swift streams by holding the valve open while integrating the stream depth in parts. For streams less than 30 feet deep, either the full depth can be sampled by integrating from the surface to the bottom only, or vice versa; or if the stream is deeper than about 30 feet (9 m), the limiting distance through which the sampler can adequately integrate in one direction, then the vertical can be integrated in parts.

Hand-held samplers—US DH–48 and US DH–59

Where streams can be waded, or where a low bridge is accessible, a choice of two lightweight hand samplers can be used to obtain suspended-sediment samples.

The smallest of the two is designated "DH-48" (fig. 2). It consists of a streamlined aluminum casting, 13 inches (33 cm) long, which partly encloses the sample container. The container, usually a round pint glass milk bottle, is sealed against a gasket in the head cavity of the sampler by a hand-operated spring-tensioned pull-rod assembly at the tail of the sampler. The sampler is collected through the intake nozzle and is discharged into the bottle. The displaced air from the bottle is ejected downstream through the air exhaust alongside the head of the sampler. The sampler, including the container, weights 4½ pounds (2 kg). A standard stream-gaging wading rod, or other suitable handle, is threaded into the top of the sampler body for suspending the sampler. The instrument can sample to within 3½ inches (9 cm) of the streambed. The sampler is calibrated with a nozzle that has an inside diameter of ¼ inch (6.3 mm). However, a $\frac{3}{16}$-inch (4.8-mm) nozzle may also be used (F.I.A.S.P., 1963b, p. 57–60).

The other lightweight sampler, designated "DH–59," (fig. 3) was designed to be suspended by a hand-held rope in streams too deep to be waded. It too, only partly encloses the sample container. The sampler body is 15 inches (38 cm) long, is made of bronze in the form of a streamlined casting, and weighs about 24 pounds (11 kg). Because of its light weight, it is limited in use to streams with velocities less than about 5 fps (feet per second) (1.5 meters per second). The rope is usually cotton or nylon and is not included in the purchase of the sampler. Note in figure 3 that the tail vane extends below the body of the sampler and the bottle. This extension forces the sampler nozzle to orient itself into the flow before submergence. The sampler will not traverse closer than about 4 inches (10 cm) of the streambed. The instrument is calibrated and supplied with ¼-inch, ³⁄₁₆-inch, and ⅛-inch nozzles.

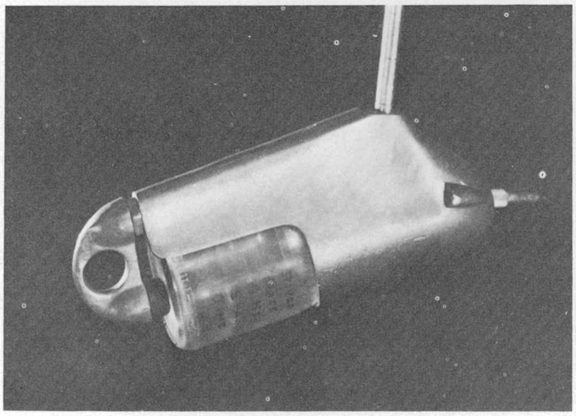


Figure 2.—Depth-integrating suspended-sediment wading-type hand sampler, US DH–48. F. S. Witzigman (written commun., December 1968).

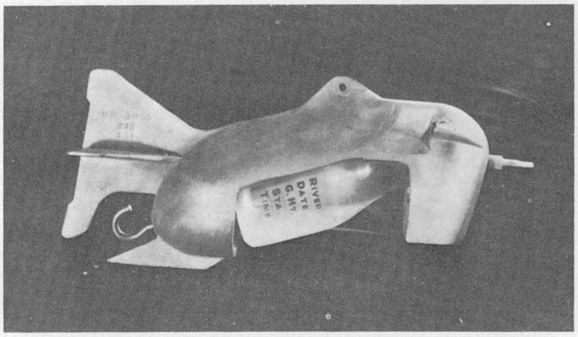


Figure 3.—Depth-integrating suspended-sediment hand-type sampler, US DH–59. F. S. Witzigman (written commun., December 1968).

These two 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 fieldmen on routine or on reconnaissance measurement trips. At most 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 a problem exists with ice in the nozzle or air exhaust. (See p. 50 for details on cold-weather sampling.)

Cable-and-reel samplers—US D–43 and US D–49

When streams cannot be waded, but are less than 15 to 18 feet deep, depth-integrating samplers designated "D–43" and "D–49" can be used to obtain suspended-sediment samples. See page 34 for more detail on sampling depth limits.

The D–43 is a 50-pound sampler designed for sampling with a cable-and-reel suspension. It is the forerunner to the D–49 and is no longer being manufactured, but because of its lighter weight many are still being used by the Water Resources Division at locations where stability problems are slight. Its body is a bronze streamlined casting with a hinged head which is opened to receive the normal pint sampling bottle. A double hinge is located at the top of the head so that the head is raised to expose the opening. Extreme care should be taken to see that the head does not fall and pinch a hand or finger when placing or removing a sample bottle. The sampler is attached to the cable through a standard or shortened hanger bar as used in making current meter measurements with the C-type sounding weights. Similar to the DH-59, the tailfin of the D–43 extends below the body profile to force the sampler into proper alignment with the stream current before the nozzle enters the water. The overall length of the sampler is 20½ inches (51 cm). It can take a sample within approximately 4¾ inches (12 cm) above the streambed. Three nozzle sizes can be used: the ¼-inch (6.4 mm), $^3/_{16}$-inch (4.8 mm), or ⅛-inch (3.2 mm) bore.

Through considerable use after development, the following undesirable characteristics were noted in the D–43:

1. With an increase in depth, velocity, or turbulence, the stability of the instrument decreased.
2. The tail-vane extension acted as a pivot point when it touched the streambed and the suspension cable became slack. The head of the sampler would swing sideways before the cable tightened for the return trip to the surface.
3. A safety hazard existed because the head is hinged at the top.

With the intention of avoiding and correcting these characteristics, the D–49 sampler (fig. 4) was designed and constructed. The major changes from the D–43 include:

1. Greater stability was achieved by making the instrument 3½ inches longer or a total of 24 inches (61 cm), by improving the body streamlines, by adding about 12 pounds (5.5 kg) to the weight (approximately 62 pounds (28 kg) total), and by moving the center of buoyancy backward, thereby eliminating the need for extension of the tail vane below the body profile.
2. The hinge and latch positions were reversed for improved safety. Minor changes included simplifying the bottle gasket, using a preshaped stainless steel exhaust tube to eliminate expensive boring, and casting lugs in the bottom of the cavity to hold the bottle spring. These major and minor changes allowed sampling within 4 inches (10 cm) of the streambed rather than 4¾ inches (12 cm) for the D–43.

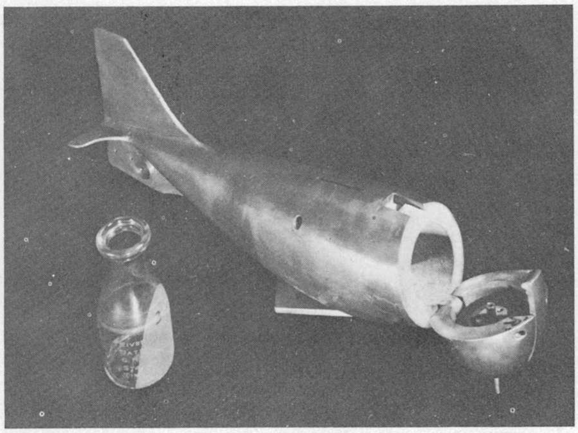


Figure 4.—Depth-integrating suspended-sediment cable-and-reel sampler, US D–49. F. S. Witzigman (written commun., December 1968).

Point-integrating samplers—US P-46, US P–61, US P–63 and US P–50

Some general characteristics of the rather complicated point-integrating samplers can best be described by direct quotation from Inter-Agency Report 14 (F.I.A.S.P., 1963b, p. 60):

> Point-integrating samplers are more versatile than the simpler depth-integrating types. They can be used to collect a sample that represents the mean sediment concentration at any selected point beneath the surface of a stream except within a few inches of the bed, and also to sample continuously over a range in depth. They are used for depth-integration in streams too deep (or two swift) to sample in a round-trip integration. In depth integration, sampling can start at any depth and continue in either an upward or downward direction for a maximum vertical distance of about 30 feet.
>
> A point-integrating sampler has a $^3/_{16}$ inch (4.8 mm) nozzle that points directly into the streamflow, and an air exhaust that permits air to leave the sample container as the sample enters. The intake and exhaust passages are controlled by a valve. When the valve is in the sampling position, the sampling action is the same as in a depth-integrating sampler. A pressure-equalizing chamber (diving-bell principle) is enclosed in the sampler body to equalize the air pressure in the container with the external hydrostatic head at the intake nozzle at all depths. The inrush, which would

otherwise occur when the intake and air exhaust are opened below the surface of the stream, is thereby eliminated.

The US P–46 consists of a 100-pound (46-kg) streamlined cast bronze shell, an inner recess to hold a round pint milk bottle, a pressure-equalizing chamber, and a tapered three-position rotary valve operated by solenoid which controls the sample-intake and air-exhaust passages. The three positions for the valve are: (1) intake and air exhaust closed, pressure-equalizing passage open, (2) intake and air exhaust open, equalizing passage closed, and (3) all passages closed. As the sampler is submerged, water enters the pressure-equalization chamber through a permanent opening in the bottom of the shell, and this compresses the air in the chamber and sample container.

The 105-pound (48-kg) US P–61 (fig. 5) is similar to the P–46, but is simpler and somewhat less expensive. It can be used for depth integration as well as for point integration to stream depths of at least 180 feet (55 m), whereas, the P–46 is limited to 75 or 100 feet depending on the arrangement of the air exhaust in the sampler head. The sampler valve for the P–61 has two positions instead of three as in the P–46. When the solenoid is not energized, the valve is in the nonsampling position whereby 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, whereby the intake and air exhaust are open and the connection from the sample container to the head cavity is closed. Figure 5 illustrates a P–61 that has been modified to accommodate a quart-sized mayonnaise bottle. When the ordinary pint bottle is used, the cylindrical adapter must be inserted into the bottle cavity. The maximum sampling depth should be limited to about 120 feet when the quart-sized container is used.

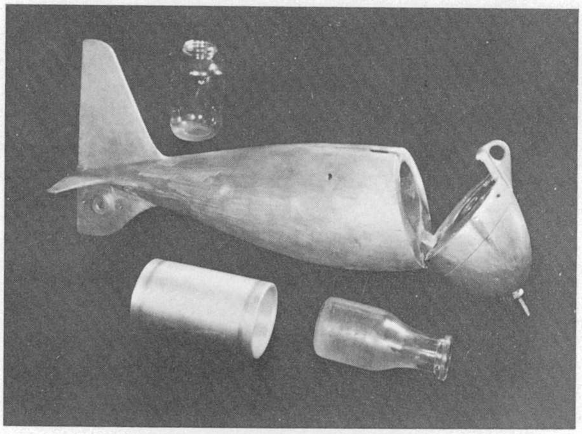


Figure 5.—Point-integrating suspended-sediment cable-and-reel sampler, US P–61. F. S. Witzigman (written commun., December 1968).

The US P–63, a 200-pound (91-kg) electrically-operated suspended-sediment sampler, is better adapted to very great depths and high velocities. The P–63 differs from the P–61 mainly in size, weight, and in the capacity of the sample container that can be used. The P–63 is cast bronze, 34 inches (86 cm) long, and has the capacity for a quart-sized round milk bottle. An adapter is furnished so that a round pint-sized milk bottle can be used. The maximum sampling depth is about 180 feet (55 m) with a pint sample container and 120 feet (37 m) with a quart container.

The 300-pound (136-kg) US P–50 is designed for use in extremely deep streams and high velocities. Because of obvious handling difficulties, and the fact that its operating characteristics are similar to the P–63, further discussion seems unnecessary.

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 (30 m), a higher voltage may be desirable.

Because of the complex nature of point integrating samples, the reader may find it necessary to seek additional information given in the inter-agency reports (F.I.A.S.P. (1952, 1963b, and 1966)).

Sampler nozzles, gaskets, and bottles

Nozzles.—Each suspended-sediment sampler is equipped with a set of nozzles that may have been calibrated specifically for the particular sampler, but more than likely, the given calibration was for a particular series of samplers having similar physical characteristics. For the individually calibrated units, almost one-third of the purchase price of the sampler represents calibration costs. These nozzles are cut and shaped externally and internally to insure that the velocity of water after entering the nozzle is within 3 to 5 percent of the immediate stream velocity. It has been found that a deviation in intake velocity from the stream velocity at the sampling point causes error in the concentration of the sample, especially for the 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 25 percent less than stream velocity (F.I.A.S.P., 1941, p. 38–41). The relation of sediment size to errors in concentration with respect to deviation of intake velocity is given in figure 6.

Because each of the sampler nozzles is calibrated for its particular sampler or series of samplers, it must be emphasized that a nozzle from one series of samplers cannot be properly used in another series of samplers. The only exceptions are the recent P–61 and P–63 series which use the same nozzles. For the D–43 and P–46 series, the nozzles are calibrated for each individual sampler and should not be interchanged among even their own series.

The reasons for the differences between the nozzles of different series are : (1) the length of flow paths for water and air are different, and it results in differences of flow resistance, and (2) the differential heads between the nozzle entrance and the air exhaust are different. Thus, interchanging nozzles between sampler 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 damaged, be certain to use a correct replacement nozzle.

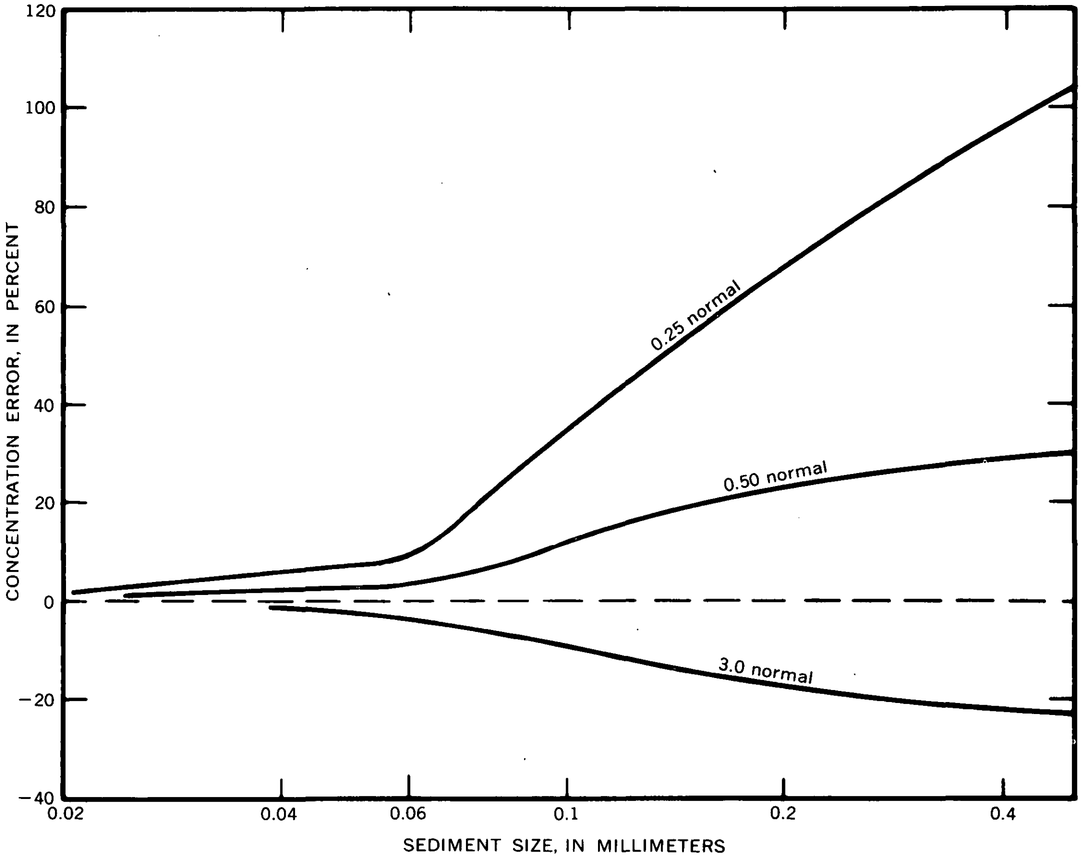


Figure 6.—Error in sediment concentration for given sediment size when intake velocity is 0.25, 0.50, and 3.0 times the stream velocity. Adapted from F.I.A.S.P. (1941, p. 40).

If extra nozzles are needed for a specific sampler or series, they can be obtained by writing to the F.I.A.S.P. (address can be obtained from the latest inter-agency report) and including the sampler number. If exhaust tubes on the samplers become damaged or deformed, the entire sampler should be sent to the F.I.A.S.P. for repair and recalibration.

Except for the DH–48, three different size nozzles, ¼-inch, 3/16-inch, and ⅛-inch, may be used to take samples with the depth-integrating samplers. The DH–48 was designed for use in slow wadable streams, and therefore, a ⅛-inch nozzle has never been calibrated for this instrument. Table 1 may help determine to which instrument a specific nozzle belongs. Note that just because a nozzle may physically fit a sampler, it is not necessarily the correct one. For example, it is possible, but incorrect, to use the same nozzle in a D–43, a DH–48, a DH–59, or a D–49.

As will be explained again later (p. 34), the reason for different size nozzles is that stream velocities and depths occur which will cause the sample bottle to overfill for a specific transit rate when using the largest nozzle. More specifically, the maximum theoretical sampling depths for round trip integration are about 8, 14, and 15 feet for the ¼-, 3/16-, and ⅛-inch nozzles, respectively, and twice these depths for one way integration when the ordinary pint sample bottle is used. Therefore, in order to reduce the quantity of sample entering the bottle, the next smaller nozzle is used with the view that the best sample is obtained with the largest nozzle which can be used in a given situation. The larger the nozzle, the smaller the chance of excluding large sand particles which may be in suspension. It should be pointed out that possible errors caused by using too small a nozzle are usually minor when dealing with fine material (<0.062 mm) but tend to increase in importance with increasing particle size. See figure 6. Also it has been found through experience that the small nozzles plug with organic material, sediment, and ice particles easier than the large ones. This means that problems with nozzles can even exist with streams transporting mostly fine material.

Point-integrating samplers are supplied only with a 3/16-inch nozzle because the opening through the valve mechanism is only three-sixteenths of an inch.

Gaskets.—Of equal importance to the correct nozzle in the instrument is the necessity to use the proper gasket to seal the bottle mouth sufficiently. The gasket for this purpose is usually made of a spongelike neoprene material which deteriorates somewhat with use and time. Thus, to avoid leakage around the mouth of the sample bottle which will yield bad samples, it is best to check the gaskets occasionally. It is possible that gaskets can be misaligned or even lost during transportation, or while changing bottles when taking samples.

To check the gasket for adequate seal, insert a bottle in the proper position in the sampler, then while the air-exhaust port is closed with a finger, blow through the sampler nozzle. If air escapes around the bottle mouth, the gasket needs replacing, or perhaps the spring loaded foot holding the bottle in place is not working properly. Each sampler series uses a different size or shaped gasket, so it is necessary to have spares of each series on hand. Appropriate gaskets may be obtained from the F.I.A.S.P.

Table 1.—Guide for comparing suspended-sediment sampler nozzles

Sampler US—	Pertinent nozzle characteristics			
	Length (in.)	Exhaust end tapered ¼ inch per foot; approx 1 inch deep	Flat part of knurled collar stamped with sampler No.	Other
DH–48	4⅛	No	No	No flat part.
DH–59	4⅛	Yes	No	No flat part.
D–43	3⅞	Yes	Yes	
D–49	3⅞	Yes	No	Flat part has no number.
P–46	3¾	No	No	Tailor-made for each individual sampler.
P–61	4	No	No	Interchangeable between both sampler series.
P–63	4	No	No	

(Address can be obtained from the latest interagency report.)

Bottles.—At present, most districts use the standard pint-sized glass milk bottles for which the instruments were designed. Each bottle is partially etched to provide a writing surface on which to record pertinent information concerning each sample. (See fig. 20.) The writing surface should accommodate marking with a medium soft blue or black pencil of sufficient durability to withstand handling and yet be easily removed when the bottles are cleaned. The Ohio District (P. W. Anttila, written commun., August 1968) uses a compound commercially called "Activated Jack Frost" to provide the writing surface on glass bottles. It can be purchased from McKay Chemical Company, 880 Pacific Street, Brooklyn, N.Y. 11238. Hydrofluoric acid has been used for this purpose, but is less desirable because it must be handled carefully and stored in a polyethylene container. "Activated Jack Frost" can be stored in a metal container.

Some districts use plain bottles and attach tags for recording purposes. The required information can also be recorded on the bottle cap if there are no alternatives, but this should be avoided because of the small writing space and because of the possibility of putting the cap on the wrong bottle.

A trial use of plastic bottles is underway (1968) in Alaska. These should eliminate such problems as etching, breakage from handling and freezing, and most important reduce weight and transport costs. The ideal plastic bottle should be disposable to avoid cleaning costs. The ideal arrangement would also involve the use of a collapsible bottle so that the problem of air compressibility (p. 34) during depth integration could be avoided.

Bottles are usually stored and transported in wire, wooden, or fiberboard cases holding 20 to 30 bottles each. However, in the field, it is desirable to use a small bottle carrier which holds six, eight, or 10 bottles. This eliminates the need to handle the heavier 20- or 30-bottle cases while making a measurement and provides a neat, convenient, and relatively safe place to set the bottles. In making wading measurements both hands can be freed to operate the sampler if the bottle carrier is suspended from the shoulder with a strap or rope.

Single-stage samplers

The single-stage sampler, US U–59, was tested by the F.I.AS.P. to meet the needs for an instrument that would obtain some sediment data on small fast-rising streams where it is impractical to use a conventional depth-integrating sampler. As noted in the U.S. Inter-Agency Report "Catalog" (F.I.A.S.P., 1966, p. 30):

> The US U–59 sampler consists of a pint milk bottle or other sampler container, a 3/16-inch inside diameter copper tube intake. Each tube is bent to an appropriate shape and inserted through a stopper which fits tightly into the top of the container. There are two general types of this sampler, one with a vertical intake and the other with a horizontal intake. Under some conditions either type could be used but the two are not always interchangeable.

Ordinarily, the vertical-intake sampler would be used to sample streams carrying mostly sediments finer than 0.062 mm. The vertical-intake sampler has the advantage of somewhat less fouling by debris and deposits of sediment in the intake nozzle than the horizontal type of intake. Conversely, the horizontal-intake sampler should be used to sample streams carrying a considerable amount of sediment coarser than 0.062 mm.

The basic sampling operation of the instrument when velocities and turbulences are small as indicated by F.I.A.S.P. (1961, p. 17) follows (see fig. 7.):

> When the stream surface rises to the elevation of the intake nozzle, the water-sediment mixture enters; and as the water surface continues to rise in the stream, it also rises in the intake. (The general elevations and dimensions are expressed without regard to the inside diameter of the tube or without distinction between the weir and the crown of the siphon.) When the water-surface elevation *W* reaches *C*, flow starts over the weir of the siphon, primes the siphon, and begins to fill the sample bottle under the head *AC*. Filling continues until the sample rises to *F* in the bottle, and water is forced up the air exhaust to the elevation *W*. Actually, the momentum of flow in the tubes causes a momentary rise above *W* in the air exhaust. Water drains out of the inner leg of the intake. When the stream rises to *D*, air is trapped in the air exhaust. As long as sufficient air remains in the tubes, no flow can pass through to alter the original

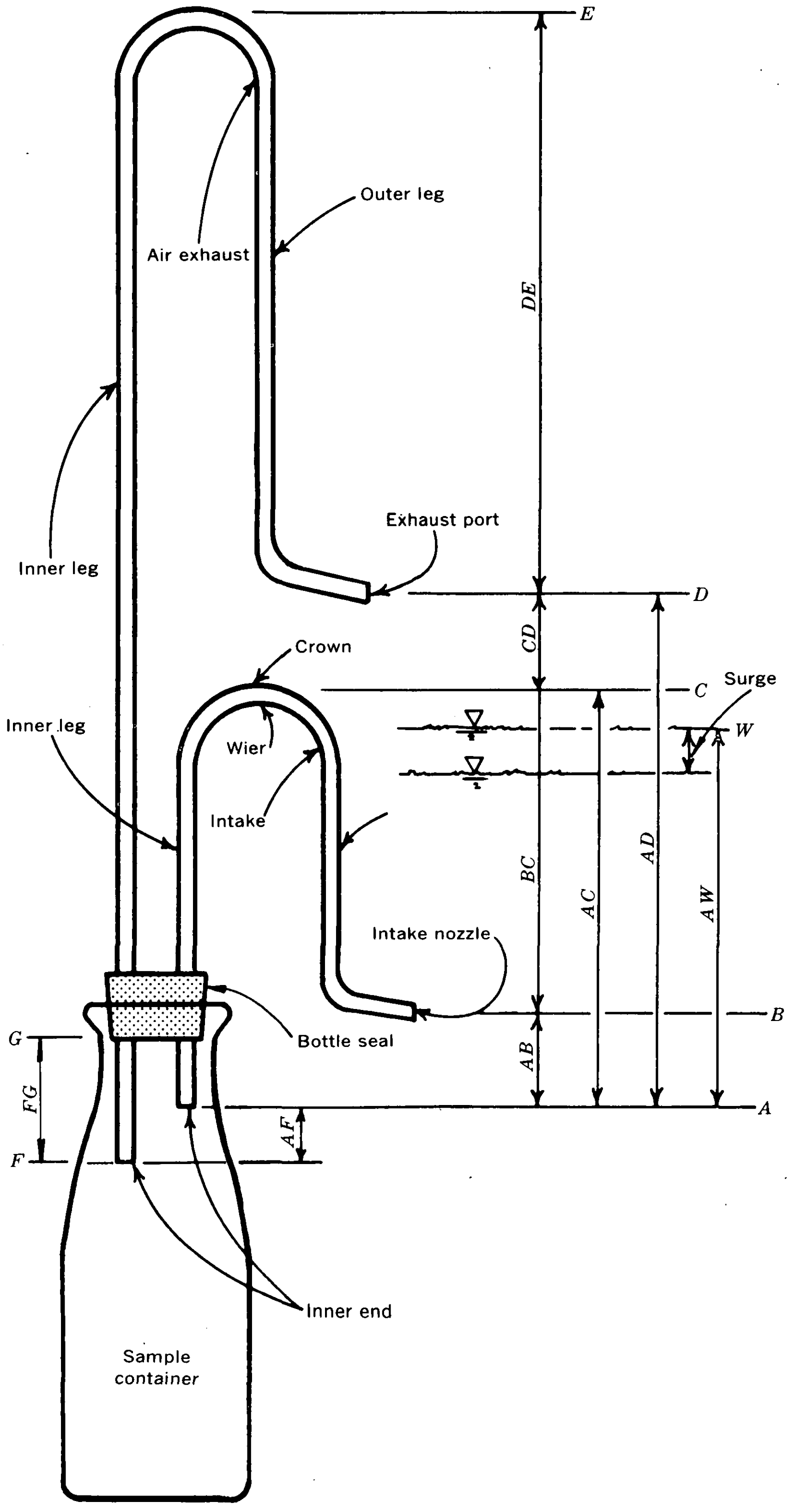


Figure 7.—Components and dimensions of the basic single-stage suspended-sediment sampler, US U–59. Adapted from F.I.A.S.P. (1961, p. 16).

sample unless a differential head that exceeds the height of invert is built up. (If the legs of an invert are not symmetrical, the inverts have different effective air-trap heights resisting flow into and out of the bottle.) For conditions without significant surge and velocity effects at the intake nozzle or exhaust port, the heights BC and DE may be small.

If, after the normal time of sampling, the depth of submergence over the sample bottle increases, the air in the bottle is compressed and a small additional sample enters the bottle. This additional sample will enter through the tube having the smallest height of invert. Under variable submergence the entrance of water will compress the air in the bottle on rising stages, and some expanding air will escape on falling stages; thus the quantity of air in the bottle becomes less and less, and the water rises in the bottle.

The sampling operation just described is somewhat idealistic because in reality the operation is affected by the flow velocity and turbulence which alters the effective pressure at the nozzle entrance.

The U–59 has many limitations with respect to good sampling objectives. It must be considered a type of point sampler because it samples a single point in the stream at whatever stage the intake nozzle is positioned before a flow event occurs. Its primary purpose is to collect a sample automatically, and it is used at stations on flashy streams or other locations where extreme difficulty is encountered in trying to reach a station to collect samples at appropriate times by the normal procedure with standard equipment. Besides being automatic it has the advantage of being inexpensive so that a "battery" of them can be used to obtain a sample at several elevations or times during the rising hydrograph. However, despite these seemingly important advantages, it should not be used indiscriminately to obtain samples, because of its many limitations. Other specific limitations, which usually affect the sampling of the sands more than the fines, are given below essentially as listed in the Inter-Agency reports.

1. Samples are collected at or near the stream surface, and therefore, in the analysis of the data, theoretical adjustments for vertical distribution of sediment concentration or size are necessary.
2. Samples are usually obtained near the edge of the stream or near a pier or abutment, and therefore, theoretical adjustments for lateral variations in sediment distribution are required.
3. Even though several combinations of size, shape, and orientation of intake and air-exhaust tubes are available, the installed system may not result in intake ratios sufficiently close to unity to sample sands accurately for a specific runoff event.
4. Covers or other protection from trash, drift, and vandalism often create unnatural flow lines at the point of sampling.
5. Water from condensation may accumulate in the sample container prior to sampling.
6. Sometimes the sediment content of the sample changes during subsequent submergence.
7. The device is not adapted to sampling on falling stages or on secondary rises.
8. No specific sampler design is best for all stream conditions.
9. The time and gage height at which a sample was taken may be uncertain.

In an attempt to cover a wide range of operating conditions for the U–59 samplers, four "standard" models were designed. The many specific details of these are further described in F.I.A.S.P. (1961).

Before a bank of the U–59 samples can be designed and installed, it is necessary to have some knowledge of the seasonal stage characteristics of the stream, in order that a desirable number of samples be obtained for a given storm event and throughout the season. The stream stage and flow velocity characteristics not only affects the design with respect to the vertical spacing of the samplers, but also the support necessary for the bank of samplers.

The user of the U–59 may find it necessary to use an insect repellant in the bottles or tubes to prevent bugs from building nests or otherwise plugging the intake and exhaust. In freezing climates, precaution must be taken to prevent broken bottles by physical protection, by immediate removal of the bottles, or by use of antifreeze.

Bed-material samplers

Limitations

The samplers described in this section are physically limited to those capable of collecting bed-material samples consisting of particles finer than about 30 or 40 mm in diameter. As noted in the description of individual samplers, there may also be limitations with respect to some very fine sediments for some of the samplers. The collection and analysis of material larger than coarse gravel logically becomes more difficult and costly because other techniques are required to avoid handling heavy samples with larger and more expensive equipment. Because of the difficulty in measuring large sizes, little information regarding size distribution is available on streams having gravel, cobble, and boulder beds. Therefore, much of the equipment for measurement of large bed material is of an experimental nature, and standard equipment is not available for routine use. Several references are available, however, on direct and indirect methods of sampling and analysis of coarse bed materials. (Lane and Carlson, 1953; Kellerhals, 1967; and Wolman, 1954).

Hand-held samplers—US BMH–53 and US BMH–60

The Federal Inter-Agency Project has developed three types of instruments for sampling the bed material of streams where most of the material is finer than medium gravel. The smallest of the three, designated as the "US BMH–53" (see fig. 8) is designed to sample the bed of wadable streams. The instrument is 46 inches in total length and usually is made of corrosion resistant materials. The collecting end of the sampler is a stainless steel thin-walled cylinder 2 inches in diameter and 8 inches long with a tight-fitting brass piston. The piston is held in position by a rod which passes through the handle to the opposite end. The piston creates a partial vacuum above the material being sampled and thereby compensates in a reverse direction for some of the frictional resistance required to push the sampler into the bed. This partial vacuum also retains the sample in the cylinder while the sampler is being removed from the bed. The piston also serves to force the sample from the cylinder in a manner that results in a sample column with a minimum of distortion from which material at different depths from the surface may be visualized and subsamples obtained. (See F.I.A.S.P. (1963b, 1966) for more detiled information.)

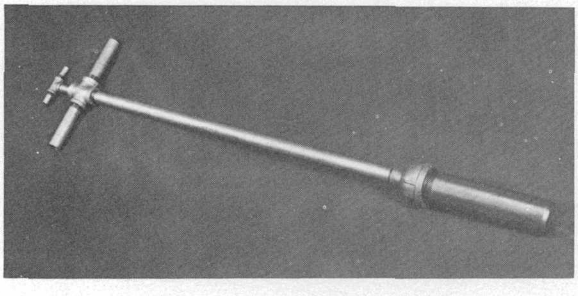


Figure 8.—Hand-held piston-type bed-material sampler, US BMH–53.

The bed material of deeper streams or lakes can be sampled with the US BMH–60. (See fig. 9.) This is a hand-line sampler about 22 inches (56 cm) long, made of cast aluminum, has tail vanes, and is available in weights of 30, 35, or 40 pounds (13.6, 15.9, or 18.2 kg). Because of its light weight, its use should be restricted to streams of moderate depths and velocities and whose bed material is also moderately firm and yet does not contain much gravel.

The sampler mechanism of the US BMH–60 consists of a scoop or bucket driven by a cross-curved constant-torque motor-type spring that rotates the bucket from front to back. The scoop, when activated by release of tension on the hanger rod, can penetrate into the bed about 1.7 inches (4.3 cm) and can hold approximately 175 cc of material. The scoop is aided in penetration of the bed by extra weight in the sampler nose. To cock the bucket into an open position for sampling (that is, retracted into the body, the sampler must first be supported by the hand line; then the bucket can be rotated (back to front) with an allen wrench to an open position.

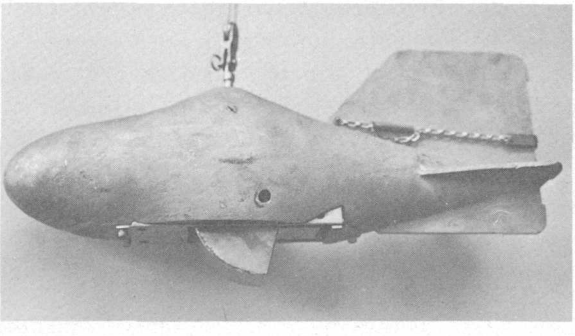


Figure 9.—Hand-line spring-driven rotary-bucket 30-pound bed-material sampler, US BMH–60. Adapted from F.I.A.S.P. (1963, p 103).

The hanger rod to which the hand line is attracted is grooved so that a safety yoke can be placed in position to maintain tension on the hanger rod assembly. **Caution: At no time should the hand or fingers be placed in the bucket opening, as the bucket may accidentally close with sufficient force to cause permanent injury!** A piece of wood or a brush can be used to remove any material adhering inside the sample bucket. (See F.I.A.S.P. (1963b, 1966) for more detailed information.)

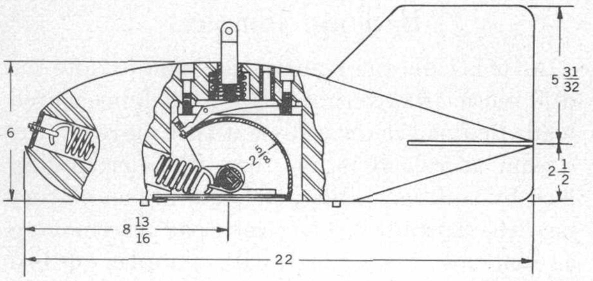
The bucket closes when the safety yoke is removed and tension on the hand line is released as will occur when the sampler comes to rest on the streambed. A gasket on the closure plate prevents trapped material from contamination or being washed from the bucket.

Cable-and-reel sampler—US BM–54

Except for streams with extremely high velocities, the 100-pound cable-and-reel suspended BM–54 sampler (fig. 10) can be used for sampling bed material of streams and lakes of any reasonable depth. The body of the BM–54 is of cast steel. Its physical configuration is nearly identical with the cast aluminum BMH–60, 22 inches (56 cm) long and with tail vanes. Its operation is also similar to the BMH–60 in that it takes a sample when tension on the cable is released as the sampler touches the bed. The sampling mechanism externally looks similar to that of the BMH–60, but its operation is somewhat different.

After 1956, the BM–54 units were equipped with a safety bar which can be rotated over the front or cutting edge of the bucket when cocked into the open position. The bar then keeps the bucket in the open position, even though the catch mechanism operated by tension on the cable is not engaged. These safety bars should be obtained from the F.I.A.S.P. for use on units issued before 1956. Again, **please note that even though a safety bar is used, it is necessary to keep one's hands away from the bucket cavity.** The power of the bucket is demonstrated by the fact that upon release, it has been observed to lift the 100-pound (45 kg) sampler from a hard surface.

The driving force of the bucket comes not from a constant-torque spring, but rather from a conventional coil-type spring. The tension on the spring is adjusted by the nut-and-bolt assembly protruding from the front of the sampler to obtain a bite powerful enough to obtain a sample from the bed of very compacted sand. It is suggested that the tension on the spring be released during extended periods of idleness even though the bucket is closed. Maximum tension need be used only when the streambed is very firm. Unlike the BMH–60, the spring and cable assembly rotates the bucket from the back to the front of the sampler. Again, the trapped sample is kept from washing out by a rubber gasket. (See F.I.A.S.P. (1963b, 1964, and 1966) for more complete description and details.)



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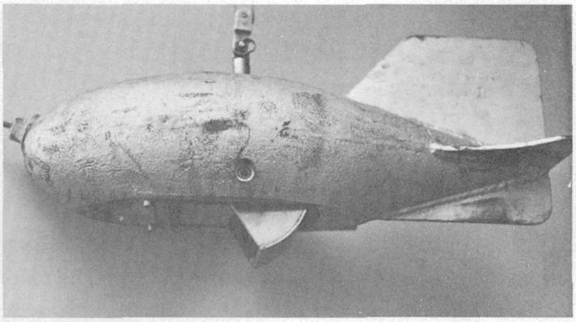


Figure 10.—Elevation sketch (top) and photograph (bottom) of a cable-and-reel spring-driven rotary-bucket 100-pound bed-material sampler, US BM–54. Dimensions on sketch are in inches. Adapted from F.I.A.S.P. (1959, p. 29 and 30).

In the event that core samples are needed in deep flowing water, a sampler has been developed and extensively used in studies of the Columbia River Estuary by Prych and Hubbell (1966). This cable-suspended sampler collects a 1⅞-inch-diameter by 6-foot-long core by a combination of vibration and an axial force derived by cables from a 250-pound streamlined stabilizing weight.

Bedload samplers

At this time the reader may wish to note the difference between bedload and unmeasured load. Bedload is the sediment that moves in the stream at velocities less than the surrounding flow by sliding, rolling, or bounding on or very near the streambed. The size of particles moving as bedload is identical with samples of bed material in the movable part of the streambed. Unmeasured load is that sediment which is not measured with the suspended-sediment samplers and consists of bedload particles and particles in suspension in the flow below the sampling zone of the suspended-sediment samplers. (See fig. 1.)

Bedload is difficult to measure for several reasons. Any mechanical device placed in the vicinity of the bed will disturb the flow and hence the rate of bedload movement. Another reason why bedload is difficult to measure is that the sediment movement and the velocity of water close to the bed vary considerably with respect to both space and time; and therefore, if a good sample could be obtained at a given point, it may not be representative of the entire cross section for a reasonable interval of time. In testing one bedload sampler on the Middle Loup River at Dunning, Nebr., Hubbell (1964) found the sampling rate to range from 11 to 112 cc per minute at one point. This variation in sampling rate results from the fact that the bed particles move intermittently at an average mean velocity much less than that of the water, a most important consideration with respect to bedload measurement. The bedload discharge, therefore, cannot be determined in the same manner as suspended-sediment loads through computation by use of suspended concentration and water discharge data. Thus, a bedload sampler must be able to effectively trap all particles moving along the bed when and if they pass over an area of the undisturbed bed in a specified period of time.

Many investigators in several countries have tried numerous methods to trap and measure this material but have not succeeded in developing a device that is reliable, economical, and easy to use. (Hubbell, 1964). Attempts are still being made, however, to develop instruments and methods which will measure bedload directly or indirectly (Lean and Crickmore, 1966, and Hubbell, 1964, p. 39–69). Rather than direct measurement, bedload movement is usually computed by one or more of several different formulas. The most notable and used of these have been described by Colby and Hubbell (1961), Einstein (1950), Chang, Simons, and Richardson (1965), and Meyer-Peter and Muller (1948). For these reasons, only one bedload sampler is described in this manual.

The Arnhem or Dutch pressure-difference bedload sampler is the best known (Hubbell, 1964, p. 15). This sampler consists of a 2- by 4-inch rectangular entrance joined by a rubber section to a wire mesh collecting vessel with 0.2 or 0.3 mm openings. The pressure drop to maintain sampling velocity is obtained by use of a flared section (3.5 by 5 inches) at the rear of the rubber connection. The 2- by 4-inch sampling head is held on the bed by adjustable springs extending from an external tubular frame. A tail-fin assembly orients the sampling head into the flow.

Some modifications of standard equipment

The following describes some examples of modified samplers and special equipment considered valuable for use in special situations.

Suspended-sediment samplers

Depth-integrating samplers

Several districts are using DH–48's with a "foot" placed near the front of the sampler body to prevent the nozzle from traversing too close to the bed. (See fig. 11.) This is especially helpful in sand-bed streams in dune regime where it is easy to gouge or dip the nozzle into the downstream face of a dune. The sampler modified with a "foot" then helps to avoid the problem of undue contamination of the normal stream concentration or particle size of samples. (J. C. Mundorff, written communication, May 1968.)

To permit the DH–48 to be used in situations where stream depths are too great or velocities too swift for wading, the standard wading rod is replaced by heavier and stronger pipe to withstand the greater forces. The instrument then is

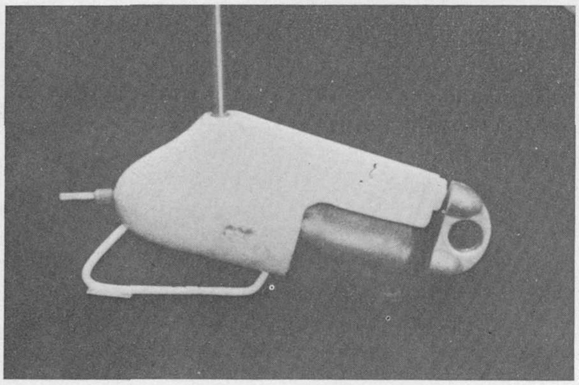


Figure 11.—US DH–48 suspended-sediment sampler modified with a "foot" to prevent gouging the nozzle into the streambed.

used in conjunction with guides attached to a low bridge or other structure to steady the sampler when taking samples. The use of such guides restrict the movement of the sampler to a specific vertical path. (See fig. 12.) Note in figure 12 (upper photograph) that the guides are fixed in position and in figure 12 (lower photograph) the guide itself is movable for depth integration at any vertical. The movable guide in this case is workable only because there is a slot in the control structure to hold the bottom of the guide against the force of the flow. This kind of installation makes it possible to sample total sediment discharge of particles up to about 4 mm in size including the bedload of particles up to about 4 mm in size because the nozzle of the sampler can traverse the entire depth of flow to the sill over which all sediment is transported. The use of fixed guides at other installations may not necessarily assure that total-load concentration will be obtained if the nozzle cannot traverse to a fixed bed and if particles larger than the inside diameter of the nozzle are moving.

The DH–48 was also modified into a handline sampler some 3 years before the DH–59 was constructed. (See fig. 13.) Some units having this modification included a pen flashlight and a reflecting plate to make the sampler more easy to use at night. The modified DH–48 sampler weighs about 10 pounds and is used today at sites where wide slow-moving water and or very high bridges make the use of the 22-pound DH–59 tedious and tiresome. When more weight is required, a 15-pound Columbus weight is sometimes added to the hanger bar; but it is better to obtain a DH–59 for use when the 10-pound modified DH–48 drags downstream excessively (Mundorff, 1957).

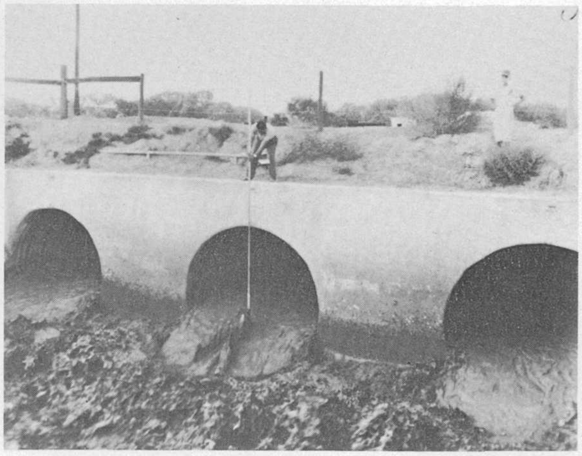


Figure 12.—US DH–48 suspended-sediment sampler reinforced with steel pipe for use where a stream cannot be waded. Upper photograph: Sampling at outlet of circular culvert with a fixed-position guide of J- and Y-bolts extending from the retaining wall. Lower photograph: Sampling at downstream edge of a concrete control with a double-rod movable guide set into a slot at the bottom.

The cable-and-reel suspended samplers (D–49, P–61, P–63, and so forth) have had few modifications. If major alterations or improvements were needed, the F.I.A.S.P. generally constructed a new sampler or line of samplers to incorporate the desired requirements. For example, the D–49 as mentioned before is an improved model of the D–43, the P–61 is the improved model of the P–46, and the P series is used where the physical limitations of the D series are exceeded or is used for special investi-

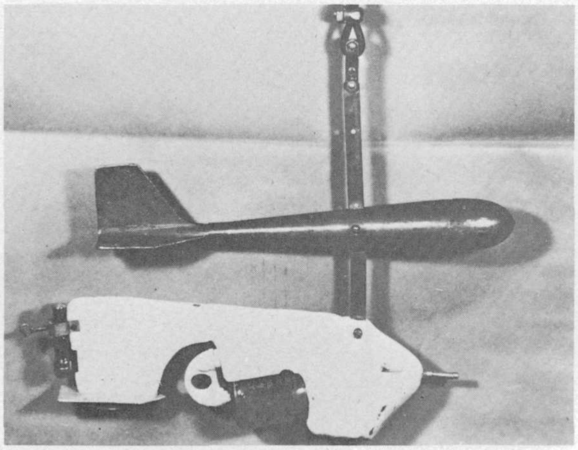


Figure 13.—US DH–48 suspended-sediment sampler modified into a 10-pound handline sampler for use on very slow moving streams. A 15-pound sounding weight is attached to hanger bar. Note small flashlight mounted on tail vane for nighttime use.

gation studies. An exception to the general statement above is the P–46, whose original valve mechanism was changed from a spring-driven system to a more simple and positive rotary solenoid.

Single-stage samplers

As mentioned earlier, the F.I.A.S.P. designed four models of the U–59 in an attempt to cover a range of sampling conditions. However, the single-stage samplers were not field tested, and many field conditions where this type sampler is most wanted and needed exceed the recommended velocity and surge limitations. From this and the fact that placement facilities vary considerably from location to location, a wide variety of samplers and sampler installations has resulted. (See fig. 14.) Most significant of all the modifications is the fact that several districts are using valves on the air exhausts to prevent circulation, despite the unfavorable results of tests on several valves as noted in F.I.A.S.P. (1961, p. 48 and 74). The reason expressed by those using valves is that the physical uncertainties such as surge and velocity existing at most such installations warrant the use of the valves, even though on occasion they may stick or inhibit air exhaust. The questionable results from installations with valves should be checked a few times against the results from standard samplers.

The long tube models C and D (see F.I.A.S.P., 1961, p. 71) require considerable vertical installation space which may not always be available. Also, the long open tubes as well as short open ones may encourage nest building by some insects; the assembly of long tubes tends to catch more trash than short tubes. The long tubes may be more easily bent out of shape by the moving debris or by cattle scratching their hides. Hence, through the need for use of shorter tubes and other requirements, the valves, though they do not always function correctly, have been accepted as a necessary addition to the single-stage sampler.

Automatic pumping-type samplers

As noted in the Inter-Agency Report "Catalog" (F.I.A.S.P., 1966), automatic pumping samplers are still in the experimental stage. They should prove most useful at streamsites where cost or some physical limitation prohibits the use of observers or fieldmen to obtain samples manually. The most severe limitation to the use of pumping samplers is that they only collect samples of the water-sediment mixture at a fixed point in the stream, and therefore, they are most effective in streams carrying predominantly fine sediments.

If the reader is interested in obtaining current information on pumping samplers, he should contact the F.I.A.S.P., whose address will be found in their latest report.

Bed-material samplers

As indicated later, the preferable amount and location of bed material to be collected when using the BMH–53 is usually the upper 1 inch (25 mm) of streambed material at each vertical. It is then necessary to expel all but the upper 1 inch of the 8-inch column of material collected at each point (p. 14). When two men are present while sampling, the required procedure to obtain this 1-inch sample offers no problem; but for one man, this is usually an awkward and time-consuming process. Figure 15 shows how an addition to the BMH–53, consisting of an

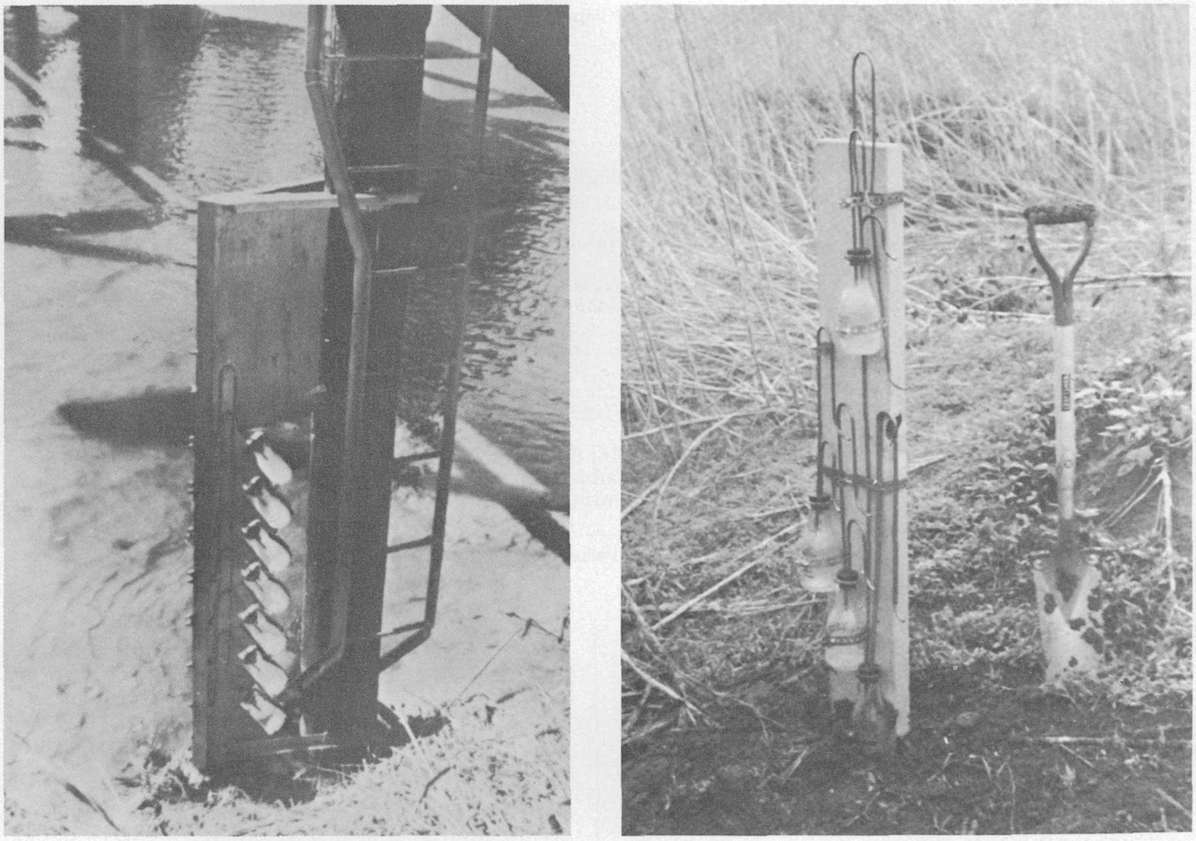


Figure 14.—A "bank" of U–59 samplers installed on a bridge pier (left) and on a plank post (right) to obtain sediment samples near the water surface during the rising part of a hydrograph. Photographs by J. C. Mundorff.

aluminum lever and steel cable, is used to expel all but the desired amount of material from the cylinder and to easily eject the sample into a container in a carrier strapped to the observer's waist.

Even with the 100-pound BM–54, bed material is sometimes difficult to sample in streams having extremely high velocities and depths. Premature slacking of tension on the cable due to uneven lowering, extreme turbulence, or roughness on the bed may trip the closing mechanism and result in bucket closure before the bottom of the sampler makes a firm contact with the bed. Sometimes a sounding weight can be attached above the BM–54 to help insure a steady descent to the streambed. Care should be exercised when using this arrangement because the hanger bar may be bent or broken by the momentum of the large weight.

None of the inter-agency samplers can sample only the top few layers on the surface of the bed. Mundorff (1957) attempted to solve this problem as well as the problem with the very swift flow by use of a sampler that collects particles only at or near the bed surface. As shown in figure 16, the Mundorff surface sampler is a circular disk 2½ inches (6 cm) in diameter and three-quarters of an inch (2 cm) deep, filled with white petroleum jelly. This disk can then be attached to sounding weights in the manner shown or to a rod for hand sampling. Upon contact with the bed, the material on the bed surface adheres to the jelly. After withdrawing the sampler, the disk is removed and returned to the lab for particle analysis.

A summary of the more important characteristics of most of the samplers mentioned thus far is found in table 2.

Table 2.—Summary of important sampler statistics

Sampler type	Sampler	Suspension	Weight (lb)	Nozzle distance from bed (ft)	Theoretical maximum sampling depth (ft)
Depth integrating	U.S. DH-48	Wading rod	4½	0.29	15
	Modified DH-48 with foot.	do	5	.29	15
	Modified DH-48 with weight and tail vane.	Handline	10	.29	15
	U.S. DH-59	do	22	.33	15
	U.S. D-43	Cable-and-reel	50	.40	15
	U.S. D-49	do	62	.33	15
Point integrating	U.S. P-46	do	100	.40	75-120
	U.S. P-61	do	105	.35	[1] 120
	U.S. P-63	do	200	.50	[1] 120
	U.S. U-59	Fixed		Variable	Surface
Bed material	U.S. BMH-53				04-.8
	U.S. BMH-60	Handline	30, 35, 40		.14
	U.S. BM-54	Cable-and-reel	100		.17
	Surface sampler	Variable	Variable		Surface

[1] Most P-61 and P-63 samplers are used to obtain a quart sample but when modified to obtain only a pint sample, the maximum sampling depth can be 180 ft.

Support equipment

It was intended by F.I.A.S.P. that much of the equipment used in stream-gaging procedures, such as cranes and reels, would also be used as support equipment for routine handling of the sediment samplers. However, alterations to this equipment are sometimes desirable to make operations more effective and more efficient, and above all, to improve safety and ease of maintenance.

Sediment investigations by their nature require that personnel collect samples under a wide variety of field conditions, often in bad weather, under conditions of cold, wind, rain, and darkness. The work is usually inherently dangerous, and under certain conditions malfunctioning equipment can easily cause injury or death. Improper maintenance of equipment may result also in poor or untimely samples. Because fieldwork is expensive and often costly in terms of lost data, time spent in the field to repair faulty equipment is highly undesirable. For these and perhaps other reasons, it is essential that all field units be properly equipped and maintained for immediate use.

A simple but significant and necessary alteration is usually made on the C-type hanger bar which is used to link the cable to the sampler. It was designed to rigidly support the current meter above the sounding weight. For routine use with suspended-sediment and bed-material samplers, its length is reduced from the standard 12.7 inches (32 cm) to about 4 inches (10 cm) to facilitate or eliminate the awkward and hazardous task of hand lifting the sampler over high bridge rails and to make it possible to construct smaller and less expensive shelters at permanent installations.

Several different types of cranes have been constructed to effectively maneuver current meters and sampling equipment for local or statewide conditions. These are too varied to be discussed here. However, as a safety measure, it is important to emphasize that adjustable metal "dog ears" can be placed on the three-wheel base of the type-A crane to help insure that when the crane is tipped against the bridge railing the two supporting wheels will not slip toward the fieldman.

Bed-material sampling with the BM-54 or the BMH-53 is made more simple and safe by the attachment to the crane of a simple bracket to support the sampler. (See fig. 17.) This bracket is often used to support other kinds of samplers (F.I.A.S.P., 1964, p. 6). For economy reasons the two-conductor cable used on the observers reels at fixed sampling installations is often replaced with $\frac{5}{64}$- or $\frac{1}{10}$-inch non-conductor cable.

For permanent sampling installations used by many observers, the type-A reel is generally mounted on a platform extending out from

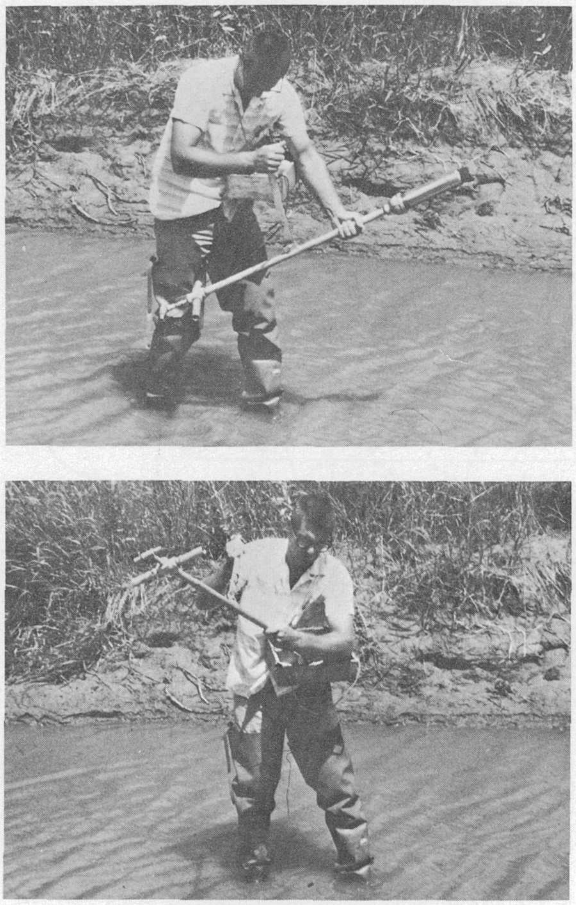


Figure 15.—The use of a BMH–53 bed-material sampler modified with lever-operated ejection system to make sample collection easier as a one-man operation. Upper photograph: Ejection of unwanted lower 6 inches of sample into stream. Lower photograph: Ejection of upper 1 inch of sample into sample container. (C. D. Albert, written commun., May 1968.)

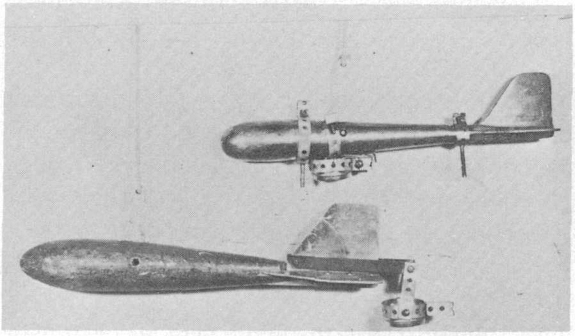


Figure 16.—Examples of two ways to mount a petroleum jelly bed-surface sediment-sampling disk to a sounding weight. (J. C. Mundorff, written commun., May 1968.)

the bridge railing. (See fig. 18.) As seen in the figure, the reel is mounted on the far side of the hole through which the sampler passes. This makes it easier to insert and remove the bottle from the sampler. The alteration is accomplished by turning the cable spool end for end in the reel framework so that the cable guide is toward the user and the reel handle is still on the right-hand side.

The Instrument Development Unit, Water Resources Division, Columbus, Ohio can supply a modified type-A reel without the electrical connections and (or) a 14-inch drum to increase the cable capacity. The large cable capacity is essential for installation on high bridges.

As mentioned, the equipment used in handling and using all the sampling instruments, including power reels, boats, and trailers, is the same as that used in making water-discharge measurements. Questions concerning the support equipment should be directed to the report, "Discharge Measurements at Gaging Stations" (Buchanan and Somers, 1969).

It should not be implied that equipment modifications must be limited to those mentioned above. Many unusual situations and problems arise that require individual evaluation and solution in order to obtain desirable results. Time nor space does not permit the compilation of solutions to many sediment equipment problems in this manual, even though such a comprehensive compilation would lend ideas and concepts which could aid in the solution to other problems.

Sediment Sampling Techniques

The requirements for knowledge of suspended sediment in streams make it necessary to obtain a sufficient number of depth-integrated samples to define the concentration on either a periodic or a continuous basis, depending on the nature of the stream and the accuracy required. At locations for which a daily or continuous concentration record is desired, much of the routine sampling is accomplished by local observers hired to collect samples at one or more verticals in the stream cross section and at one or more times each day. These observers usually require

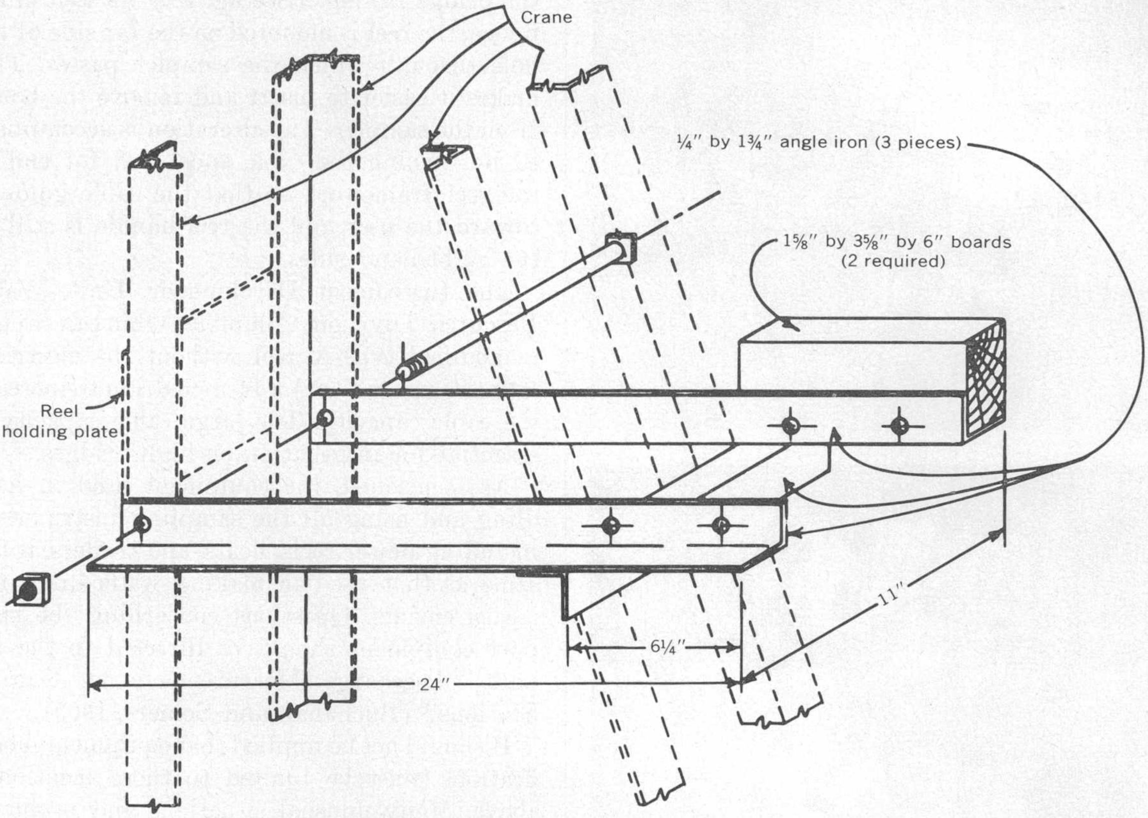


Figure 17.—A sampler support that can be attached to a crane. This is especially useful with the BMH–53 and the BM–54 for safe and easy removal of the sample. It can be used to stabilize all samplers while the crane is being moved. Adopted from F.I.A.S.P. (1964, fig. 3).

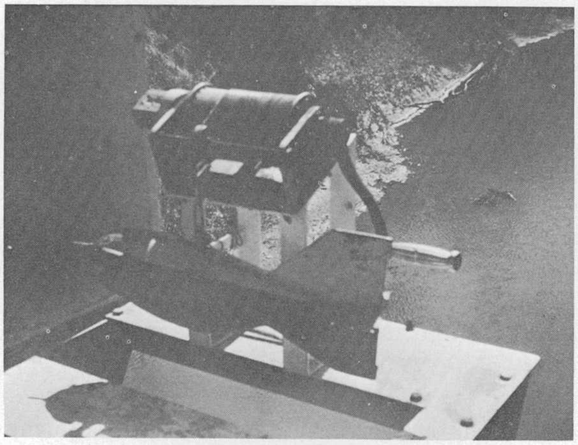


Figure 18.—Type-A reel mounted for sampling suspended sediment. The cable spool has been reversed in the reel framework so that the cable guide is toward the user and the reel handle is on the right side.

considerable supervision if they are to accomplish the goal of obtaining the desired number and frequency of samples to define a good suspended-sediment concentration record.

In addition to the supervision given the observer, it is necessary to maintain a periodic program to obtain additional samples for use in conjunction with the observer's samples. These additional samples are used to insure that the observer's samples can be adjusted to the real cross-sectional concentration. Such a program requires that a technically trained person from the field office visit the site on a periodic basis to make a complete sediment-discharge measurement. Such a measurement must include two or more sets of sediment samples to define the sediment concentration across the stream section, two or more bottles at the routine sampling vertical collected in the same manner as used by the observer, and a water-discharge measurement either from an established rating or from an actual current meter measurement. The person making such measurements also would be responsible for obtaining timely suspended- and bed-sediment samples suitable for quality and particle-size analysis.

The purpose of this section on sediment sampling techniques is to discuss some aspects of site selection, equipment selection and maintenance, location and number of verticals to be sampled, method of making sediment-discharge measurements, depth integration with a point sampler, sampler transit rates, quality control, timing of samples, sample quantity required, field inspection of samples, recording information on the bottles, instructions for taking water temperatures and reading water-stage gages, suggestions for cold-weather sampling, observer relations, total sediment-discharge measurements, and techniques for bed-material sampling. This section then deals with the decisions that need to be made and the instructions necessary to obtain the quantity and quality of samples required for computation and compilation of the desired sediment records.

Site selection

The sediment sampling techniques to be used in a given situation will depend not only on the data needs, but also on the nature of the flow and other conditions at the site to be used for making the measurements. The site must often be located at a specific gaging station; but sometimes, especially for large basins that have a number of gaging stations, there may be some choice as to location. Where there is a choice between measurement sites, then an analysis should be made of the data needs and program objectives to maximize the returns in consideration of the relative costs, data accuracy, and the physical limitations. The perfect site is rarely available, and therefore, it is necessary to recognize as many limitations as possible and then to build a program that will minimize the disadvantages and maximize the advantages.

As indicated, the site should be at or near a gaging station because of the obvious relation of sediment movement to the flow of the stream. If the sediment-measuring site is more than a few hundred feet from the water-stage recorder, then it may be desirable to install a simple nonrecording stage indicator at the site so that a correlation of the flow conditions between the sediment and the distant water-measuring sites can be developed. The obvious difficulties with inflow between the sites from small tributaries should also be avoided, if possible.

The normal stage-discharge relation at a gaging station upstream from the confluence with another stream may be disturbed at times because of unusual water-surface slope conditions resulting from partial backwater effects. The unusual slope condition will likewise affect the normal movement of sediment and thereby require many additional sediment measurements.

A sediment-measuring site downstream from the confluence of two streams may also require extra sediment measurements. The downstream site may be adequate for water-discharge measurement because the lateral water surface across the stream section is stable regardless of the differences between the quantity of flow for the two tributaries. Though the surface level of the flow may be stable, the flow from the two tributaries does not readily mix, and the sediment may be moving almost as two streams in proportion to the inflow from the two tributaries. As indicated in Book 3, Chapter C1, "Fluvial Sediment Concepts" (Guy, 1970, p. 24), the distance downstream from a confluence for complete mixing depends on the stream velocity, depth, and mixing width. If the flow at a sediment-measuring site is not mixed, then extra samples will be required on a continuing basis because the relative flow quantity and sediment concentration from the two tributaries will change with time.

Aside from the confluence or tributary problem, the type of cross section for both flow in the channel and on the flood plain may be important to the ease with which data can be obtained and to the quality of the samples. The ratio of the suspended to total load and its variation with time can be greatly affected by the width-depth ratio, especially for sand-bed streams. For sites where the data are expected to be correlated with channel properties and the landforms of the region, a normal or average section should be used. When a fixed-routine sampling installation is used, a measuring section at a bend may provide a more stable thalweg and hence a more uniform adjustment coefficient with respect to time than one at a crossover. Sites in areas of active bank erosion should be avoided, however.

By economic necessity, most sediment-measuring sites are at highway bridges. These bridges are often either constructed so that they restrict the flow width, or they may be located at a section where the channel is naturally restricted in width. Figure 19 (Culbertson, Young and Brice, 1967) illustrated the conditions at several kinds of natural and artificially induced flow constrictions. As expected, the sand-bed type of stream causes the most serious flow problems with respect to scour in the vicinity of such constrictions. Even if the bridge abutments do not interfere with the natural width of the stream, it may be supported by several midstream piers that can interfere with the streamflow lines and thereby reduce the effective cross-sectional area. As indicated in figure 19*F*, midstream piers can catch debris and thereby seriously interfere with effective sediment sampling.

Because sediment samples must be obtained more frequently during floods, it is imperative that a site be selected where it is feasible to obtain data during times of flooding. That is, particular attention should be given to the ease of access to the water-stage recorder and a usable bridge or cable during a flood. Such access takes on much more importance when a sediment station is involved than when the interest is only for a water-discharge station. Also, because of the need to collect samples frequently during floods, many of which occur at night, sites accessible only by poorly maintained back roads or trails should be avoided, if possible. Sometimes the choice of a sediment-measuring site may be determined by the availability of a suitable observer to collect the routine samples.

In choosing a sediment-measurement site, it should be emphasized that samples should be collected at the same cross section throughout the period of record, if possible. This is not to say that separate sections may not be used during the low-water wading stage and the higher stages that require the use of a bridge or cableway. In this connection, sites should be avoided where highway or channel realinement or other construction is anticipated during the period of record. It should be emphasized that good photographs of proposed or selected sediment-measuring sites are necessary to help document such features as channel alinement, water surface conditions at various stages, composition of bed and bank material (at low flow), and natural or man-made features which could affect the water discharge and (or) sediment-discharge relations. Such pictures are particularly useful when deciding on alternatives among sites and in later consideration of environmental changes at the site(s).

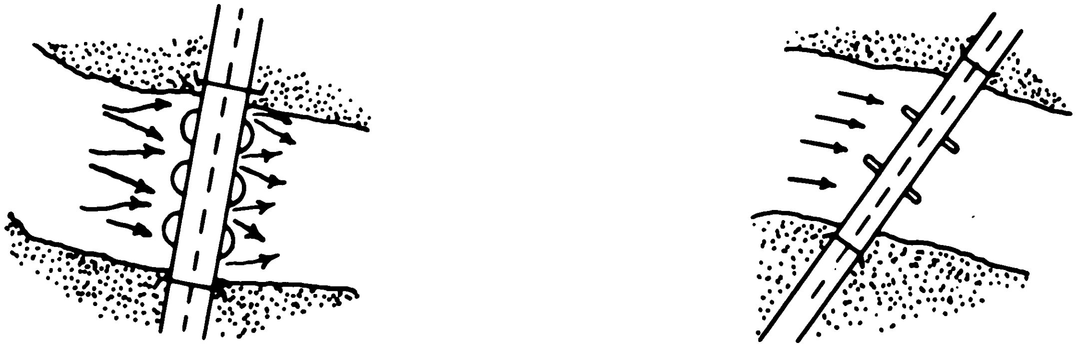
Equipment selection and maintenance

Before a fieldman departs on a sediment-data collection trip, he should know what specific information is desired in order to assemble the proper equipment to collect the best samples and related measurements. For example, if data are needed for total load computation, equipment is needed for water-discharge measurement, suspended-sediment sampling, and bed-material sampling. If suspended-sediment concentration and particle-size profiles are required, point samplers and water discharge-measuring equipment will be needed. Some of the special equipment used only at one location may be stored at the station in the gage house, with the observer, or in special storage shelters or boxes. It is possible, however, that a sampler or some support equipment may be damaged or stolen without the observer noticing or reporting it. Hence, it is necessary for the fieldman to carry repair equipment, spare parts (including nozzles) and perhaps even an extra sampler.

The streamflow conditions and sampling structures (bridge, cableway, or other) determine more specifically which sampler or samplers should be used at a station. Stream depth determines whether hand samplers such as the DH–48 or the BMH–53 or cable-suspended samplers such as the D–49 or the P–61 should be used. Depths over 15 feet (4.6 meters) should theoretically require the use of point samplers

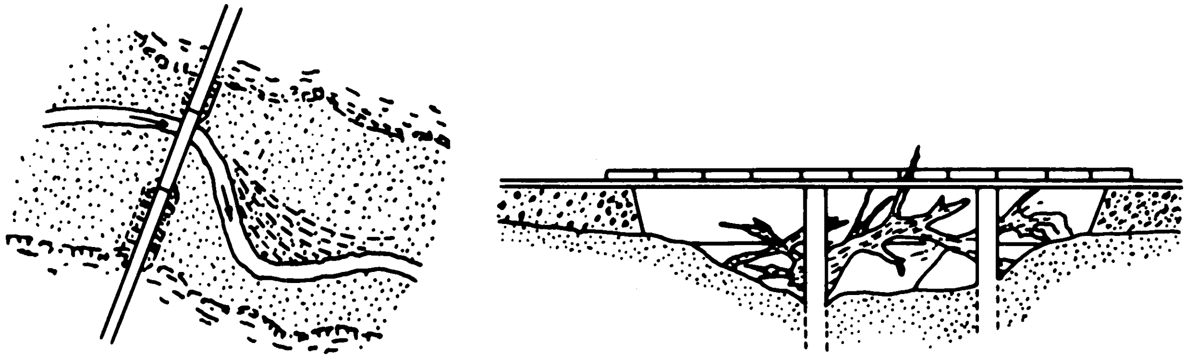
A. NATURAL CONSTRICTION OF CHANNEL AT BEND

B. NATURAL CONSTRICTION OF CHANNEL BY RESISTANT BEDROCK



C. CONSTRICTION OF CHANNEL BY MASSIVE PIERS

D. EFFECTIVE CONSTRICTION OF CHANNEL BY LONG SKEWED PIERS



E. CONSTRICTION OF FLOOD PLAIN BY EMBANKMENTS

F. CONSTRICTION OF FLOW BY ACCUMULATION OF DEBRIS

Figure 19.—Examples of natural and artificially induced streamflow constrictions encountered at sediment-measurement sites. From Culbertson, Young, and Brice (1967, p. 23).

as one-way depth-integrating samplers to avoid overfilling or using too fast a transit rate. See pages 34 to 37. Stream velocity as well as depth are factors in determining whether or not a stream can be waded. When the product of depth in feet and velocity in feet per second equals ten or greater, a stream's wadability is questionable. Application of this rule will vary considerably among individuals according to weight and stature and to the condition of the streambed.

The depth-velocity product also affects the action of each sampler. The larger the product, the heavier and more stable the sampler required to collect a good sample. At a new station or for inexperienced persons, considerable trial may be necessary to determine which sampler is best for a given stream condition. For example, if a sand-bed stream is wadable, it would be wise to use the DH–48 modified with the "foot" to avoid touching the downstream face of a sand dune with the sampler nozzle.

Before departing on the field trip or even before using equipment at the site, it is desirable to check several items, such as nozzles, gaskets, and air exhausts on samplers as well as the other necessary equipment. One needs to be certain that the nozzle in the instrument belongs to that instrument or series. See the guidelines presented in table 1 to determine whether the nozzle is correct. The correct size of nozzle to use for a given situation must often be determined by trial. As mentioned in the previous section, it is best to use the largest nozzle that will permit depth integration without over filling the sample bottle or without exceeding the maximum transit rate (about 0.4 the mean stream velocity). See page 34.

If a sample bottle does not fill in the expected time, the nozzle or air-exhaust passages may be partly blocked by such things as bug nests, organic material, or ice. The flow system can be checked by blowing through the nozzle with a bottle in the sampler. It is desirable to use a short length of ¼-inch rubber tubing to blow into the nozzle because of contamination by polluted water and because of possible freezing to the lips during cold weather. If air does not circulate easily, or not at all, check the nozzle first to see if it is clear and remove and clean if necessary. If the air exhaust is closed for reasons other than being damaged or frozen, it can generally be cleared by using a flexible piece of multistrand wire. Suggestions for clearing ice from the nozzle and (or) air exhaust are given on page 50. In checking the flow system of a point sampler, always be certain the valve mechanism is in the sampling position.

All support equipment to the samplers such as cranes, waders, taglines, and current meters should be examined periodically, and as used, to insure an effective and safe working condition. For example, be certain that the supporting cable to the sampler or current meter is fastened securely in the connector; if worn or frayed places are noted, the cable should be replaced. Power equipment used with the heavier samplers and point sampler needs a periodic operational check and battery charge. The point sampler should also be checked on the shore immediately before use to determine, among other things, if the valve is opening and closing properly. Such precautions will avoid unnecessary exposure to traffic on the bridge and will avoid lost time if repairs and adjustments are necessary.

Maintenance of samplers and support equipment will be facilitated if a file of instructions for assembly, operation, and maintennace of equipment can be accumulated in the field office. Such a file could include reports of F.I.A.S.P. (1958, 1964, 1965) as well as reports on support equipment from the Instrument Development Unit, Water Resources Division, Columbus, Ohio.

Routine suspended-sediment sampling methods

Number of verticals

Some of the details of equipment selection and maintenance previously mentioned may depend on the required location and number of suspended-sediment sampling verticals at a measuring site, which in turn, may depend on the kind of information needed in relation to the physical aspects of the river. For example, if it is desired to determine the distribution of sediment concentration or particle size across the stream, then it is necessary to sample at several verticals. The number of verticals for such a cross-sectional distribution depends on the accuracy being sought and on the variation of sediment movement across the stream.

It was noted previously (p. 5) that suspended-sediment samplers are designed to accumulate a sample that is directly proportional to the stream velocity. The accumulated sample may be from a point in the stream section, a vertical line between the surface and the stream bed, or several such vertical lines across the entire stream section. Such a sample can then be considered to be representative of some element of cross-sectional flow whether it be a few square feet adjacent to the point sample, a few square feet adjacent to both sides of a vertical line, or the area of the entire flow summed by several vertical lines. Samples of sediment concentration obtained by integration with the flow can then be used with the flow rate in the given cross section to compute the sediment discharge. For example

$$Q_s=Q_wC_sk$$

where Q_s=sediment discharge in English short tons per day,

Q_w=water discharge in cubic feet per second,

C_s=discharge-weighted mean concentration in mg/l, and

k=0.0027 (for concentration in mg/l).

A discharge-weighted mean concentration is different from a spatial concentration (Guy and Simons, 1964). A spatial concentration, while not routinely obtained, requires only the average of several point concentrations representing equal areas of the stream cross section. Such a spatial concentration is sometimes used to define the specific weight of the water-sediment mixture over the bed of the stream. Depth-integrated samples cannot be used to determine spatial concentration; however, the reverse is true because point samples can be used to compute the rate of sediment discharge moving through a cross section if the flow rate at each sample point in the cross section is known.

In addition to the need to determine the quantity of suspended sediment in transport, or perhaps the spatial concentration, it is also necessary to determine some of its other characteristics, such as particle-size gradation. For determination of the particle-size distribution, the suspended-sediment sample must contain enough sediment for the laboratory analysis (p. 43. Also, a number of verticals must be sampled to adequately represent the cross section in the sample. The number of sample bottles to be collected will depend on the kind of analysis to be made in the laboratory, and the location of the sampling verticals will depend on the concentration and size distribution of sediment moving across the stream cross section.

Streamflow and channel conditions may change considerably with time, and therefore, adjustments in any prearranged program must be made as necessary. This requires not only a check on the observers' past work, but also considerable communication with the observer to insure that proper adjustments can be made as necessary to obtain the desired record. Such communication and checking, usually oral, may be useful in determining corrections needed for possible bias in the observers' samples. It is usually easy to assess the nature of the stream changes because nearly all sediment-measuring stations are located at or very near water-discharge measuring stations.

Single vertical

For streams with a stable cross section and a rather uniform lateral suspended-sediment distribution, sampling at a single vertical usually will be adequate. If the sampling site is at a highway bridge, the sampler may be housed at a fixed installation extending from the bridge rail. When a cableway site is used, the fixed vertical at which the sample is to be taken is painted on the tram cable.

Most observers use fixed vertical installations from which to take their samples during almost all conditions of flow. After opening the box or sampler housing, the observer inserts a clean sample bottle into the sampler and as previously mentioned, checks to see that there are no obstructions in the air and exhaust tubes. The sampler is then lowered to the water surface so that the nozzle is above the water and the tail vane is in the water for proper upstream-downstream orientation of the sampler. After orientation of the sampler, depth integration is accomplished by lowering the sampler to the streambed at a constant or uniform transit rate.

When the bottom of the sampler touches the streambed, the operator immediately reverses the sampler direction and raises the sampler to clear the surface of the flow at a constant transit rate. The transit rate used in raising the sampler need not be the same as the one used in lowering, but in order to obtain a velocity or discharge-weighted sample, both rates must be constant. The rates should be such that the bottle fills to near its optimum level (approximately 3 inches below the top or 350–400 grams for the pint milk bottle). When a stream is shallow or the velocity is low, it is generally easier and more accurate to make the round trip from the surface to the bed and return more than once to obtain the desired quantity of sample.

For streams that transport heavy loads of sand and perhaps in some other streams, the observer should take at least two bottles or complete depth integrations as close together in time as possible. Each bottle constitutes a sample, but for the purposes of the record, two or more bottles are sometimes composited in the laboratory, or otherwise averaged, whereby they are called a set. This set is then a sample in time with respect to the record. Individual bottle analyses that yield two or more samples for a given observation are useful to indicate the variation between bottles—an obvious advantage in the event that one bottle is in error with respect to concentration. Every bottle or sample should be inspected visually immediately after collection by swirling the water in the bottle and observing the quantity of sand particles collected at the bottom. If there is an unusually large quantity or a difference in the quantity of sands between bottles, then another sample from the same vertical should be taken immediately. The sample suspected of having too much sand should not be discarded; but instead, an explanation such as "too much sand" should be clearly written on the bottle. If by chance a bottle is overfilled, that is closer than 1½ inches (4 cm) from the top or if a spurt of water is seen coming out of the nozzle when the sampler is raised past the water surface, then the sample should be discarded. A clean unused bottle is to be used for each sample. Further discussion concerning field inspection of samples is given on page 45.

To help avoid the problem of striking the nozzle into a dune or settling the sampler too deeply into a soft bed, it is recommended that a slow downward integration be used after which a more rapid upward integration can then be used. Because most of the sand is transported near the bed, it is essential that the sampler transit be immediately reversed after it has touched the bed.

Pertinent information as shown in figure 20 must be available with each bottle for use in the laboratory and for compilation of the record. As shown in figure 20, most districts provide an etched area on each bottle on which a medium-soft lead (blue or black) or wax pencil can be used. Other districts use plain bottles and attach tags for recording the required information. The required information may be recorded on the bottle cap if there are no other alternatives, but this should be avoided because of the small writing space and because of the possibility of putting the cap on the wrong bottle. See page 11 for further information concerning bottles.

During high flows when the depth exceeds the theoretical 15-foot limit, the observer should try to obtain a sample even though the recommended transit rate may be somewhat exceeded. The practical sampling depth limit can be more than the theoretical limit if the stream velocity is not too high and especially if the suspended sediment is mostly silt and clay. Under these conditions the intake velocity in the nozzle may be somewhat different from the stream velocity, and therefore a true depth integration may not be obtained and the resulting sample may contain some error in the concentration of the sand-sized particles.

The best location in the cross section for a single-vertical sediment sample is determined by trial. Generally each new sediment-record site is carefully investigated by means of several detailed sediment-discharge measurements to determine the concentration of sediment across the stream at different times. The sediment-discharge measurement to determine the cross-sectional distribution of concentration can be made using either the equal-discharge-increment (EDI) method or the equal-transit-rate (ETR) method. Details of these methods are explained on pages 31 to 33.

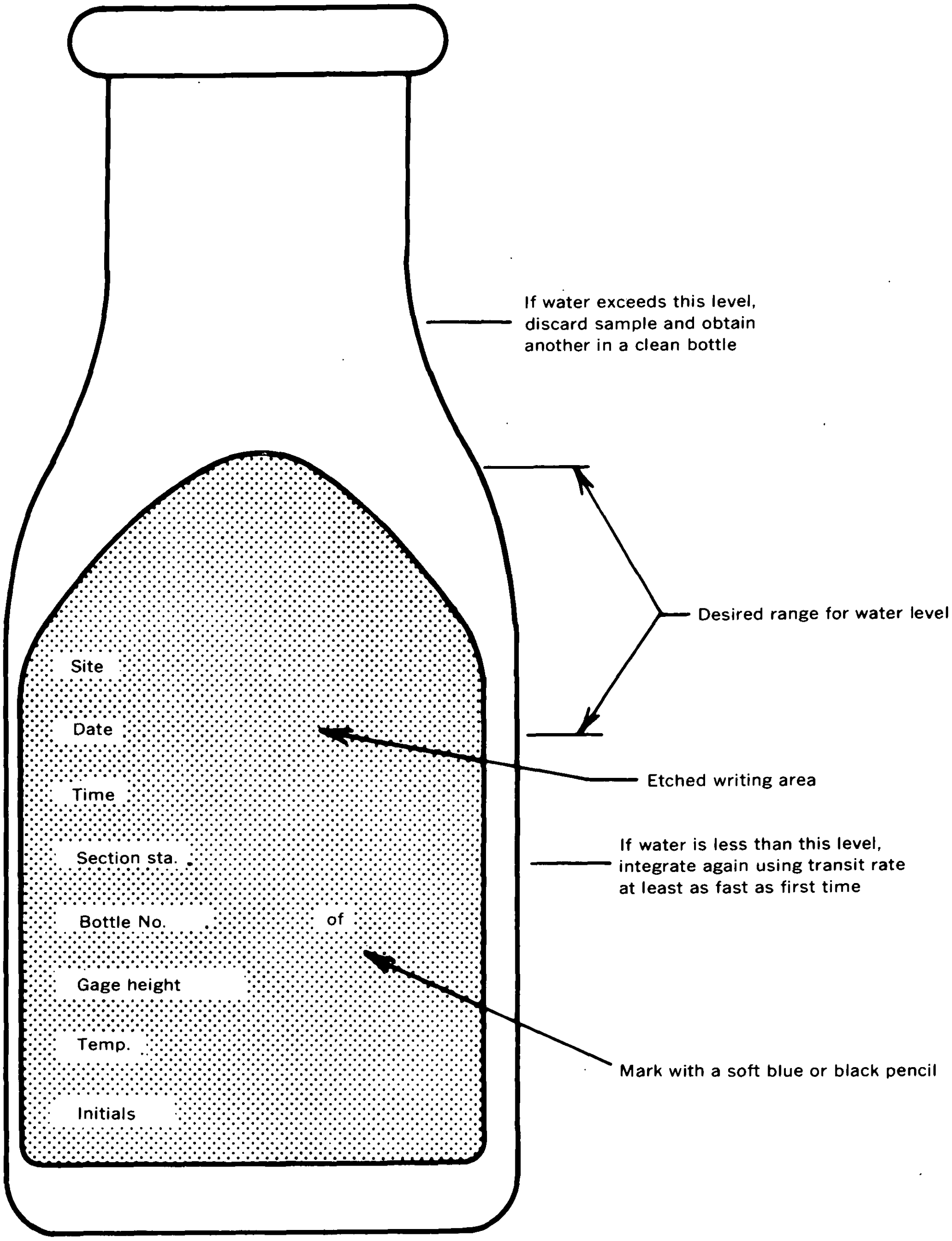


Figure 20.—Diagram of sample bottle showing desired water levels and essential recorded information. Sometimes other information concerning type of sampler used, the section location, and stream conditions should also be noted.

The sample concentrations from the sediment-discharge measurement are plotted, and a vertical, or stationing point that yields a concentration most nearly equal to the average is determined. The routine sampling vertical should be located at or near this point, but at least 10 feet (3 m) from any supporting pier. For the first several months of sampling at a station, the results from the fixed vertical should be compared to frequent cross-sectional sampling by technical or professional field personnel.

The number of verticals required in the cross section for the sediment-discharge measurement depends on the width and discharge of the river as well as the concentration variation across the width at the time of sampling. See page 40. Additional samples are collected at the single vertical, both before and after each cross-section sample. These samples then form the basis of a coefficient that may be needed to adjust the concentration of the fixed vertical samples. This adjustment coefficient, or comparison of the routine single vertical with the cross section, is determined by computing the ratio of the average concentration of cross-section samples to the average concentration of single-vertical samples. This ratio can then be applied, if necessary, to the daily samples taken between sediment-discharge measurements. If the coefficient is consistently above or below unity, it may be desirable to change the position of the fixed routine sampling installation to a location where the coefficient would be at or near unity. Generally, coefficients within five percent of unity are not applied unless they are consistently high or low for long periods of time. Guy (1968) illustrated methods for determining the quality of the coefficient and the number of samples needed in a sample set. (See pages 37 to 40.) Porterfield (1970) gave further detail on how coefficients are used in the computation of sediment records.

After the initial trial period, detailed sediment-discharge measurements by either the EDI or ETR methods are generally needed only during and following periods of flood flow or following other events that may cause channel changes. More frequent measurements are necessary during high water periods when a major change in the coefficient may occur and when additional samples are needed for particle-size analysis.

Multivertical

The distribution of sediment concentration and bed roughness across sand-bed streams can vary markedly with distance across the stream and with time because of changes in the bed form that may vary from a smooth firm surface to a very pronounced dune or antidune form (Simons and Richardson, 1966; Guy, Simons, and Richardson, 1966). Thus, it is often unrealistic to try to relate sediment concentration for the entire cross section to concentration at a single vertical in a sand-bed stream.

A realistic "daily" sampling program for a wide sand-bed stream may require sampling at two to five or more verticals. When samples are taken from a bridge structure, it is common practice to use a movable sampling crane which can be housed in a small shelter at the end of the bridge. Locations of the routine multisampling verticals can be determined in the same manner as already described for the single-vertical locations, or they may be located at the centroids of equal increments of the stream discharge. As the stream changes with flow rate or with season, it may be necessary to move the sampling stations from time to time. For some streams, the ETR method should be used routinely (p. 32) if a high level of accuracy is required for the sediment record.

On sand-bed streams where an accurate sediment-discharge record is needed, the observer may be required to sample the stream several times each day with the specified multivertical sets of samples. On streams where the sampling effort is more limited, the observer may be instructed to use his discretion in the number of observations to be made and in the number and location of verticals to be sampled. Regardless of the intensity of the effort, the observer would sample verticals located at the estimated centroids of equal discharge or use the ETR method. Each sample or bottle then, represents the sediment being carried by each particular increment of discharge across the section.

Sediment-discharge measurements

The previous discussion was concerned with the way in which routine suspended-sediment samples are obtained on a daily or more frequent basis. As implied, the routine samples may or may not yield concentrations truly representative of the mean suspended-sediment concentration for the entire cross section. A representative suspended-sediment concentration for the entire cross section is desired for the purpose of determining instantaneous concentrations and sediment discharges at monthly or intermittent stations, for comparing cross-sectional suspended-sediment concentrations with that obtained by observers at one or more verticals, and for computations of total sediment transport or bed load.

Ideally, the best procedure for sampling any stream for sediment concentration, as related to discharge, would be to collect the entire flow of the stream for a given period of time, evaporate the water, and weigh the sediment. Obviously, there are few instances where such a method could be employed. Instead, the sediment concentration of the flow is determined by obtaining depth integrated suspended-sediment samples either by the method of the centroids-of-equal-discharge increments (EDI) across the stream, or the method of equally spaced verticals across the stream and an equal-transit-rate (ETR) at all verticals.

The EDI method

The EDI method, in which samples are obtained at the centroids of equal discharge increments, is usually limited to streams with stable channels where discharge ratings change very little during a year. The method requires that the fieldman have some knowledge of the streamflow distribution in the cross section before sampling verticals can be selected. If such knowledge can be obtained, the EDI method can save time and labor over the ETR method, especially on the larger streams, because fewer verticals are required.

To make the EDI measurement when prior flow knowledge is not available or applicable, it is necessary to determine first the total discharge of the stream in increments across the channel. This is done in accordance with methods described by Carter and Davidian (1968) and Buchanan and Somers (1969). From a discharge measurement, a graph is drawn of cumulative discharge in percent of total discharge versus distance from the left or right bank or the station numbers on the cableways or bridges. (See fig. 21.) A decision is then made, or was made in the office, as to the number of verticals required to adequately define the suspended-sediment concentration across the stream. For example, if only four verticals are needed, then a sample would be taken at the stations where for a given discharge, the mid-

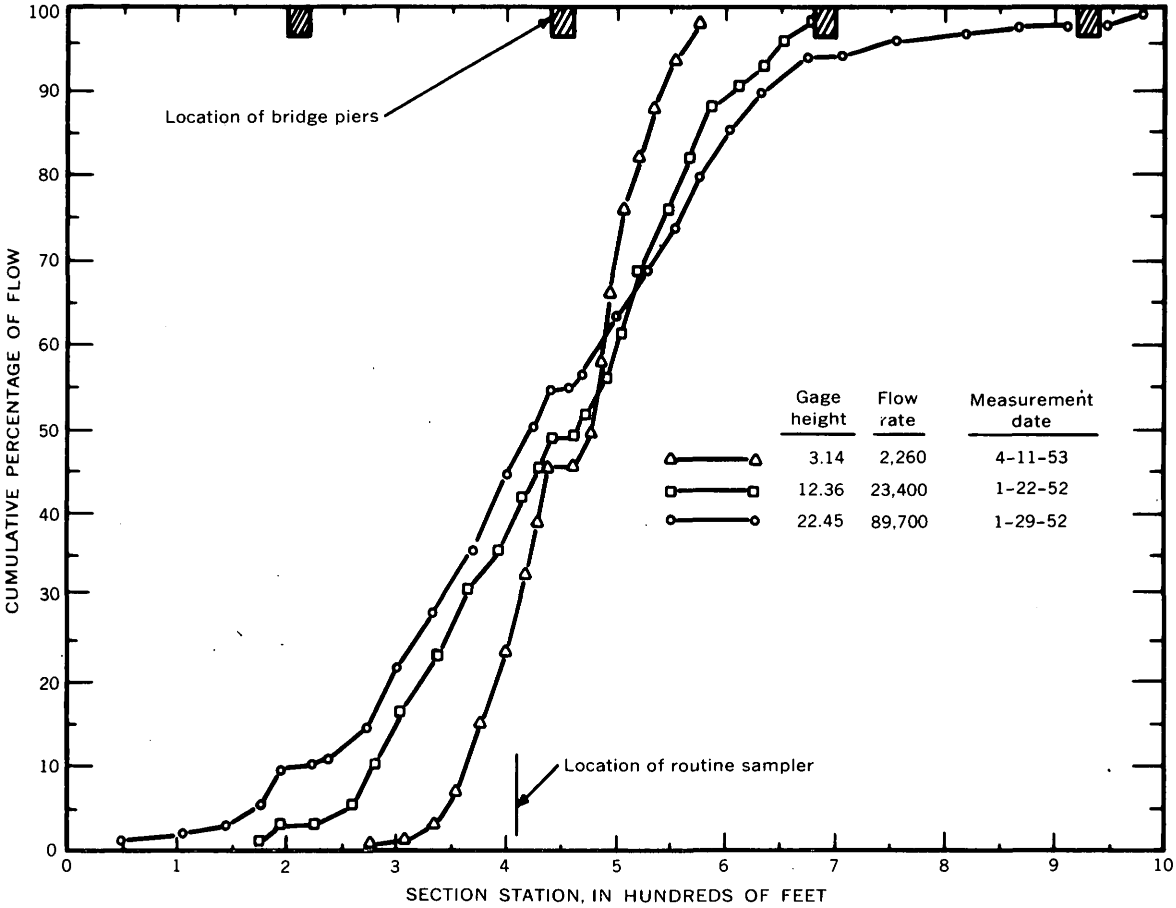


Figure 21.—Cumulative percentage of the total water discharge for three rates of flow with distance across a stream section. The graph is used to estimate the location of the centroids-of-equal-discharge increments. Gage height in feet; flow rate in cubic feet per second.

point of accumulation (centroids) of discharge increments of 25 percent occur, that is, at stations of cumulative discharges of 12, 38, 62 and 88 percent.

At each of the desired centroid stations, two or more bottles are taken by the depth-integration method to represent two or more cross-section samples. Thus, the contents of each bottle is proportional to 25 percent of the water discharge for each respective sample. If the two (or more) sets of samples are to be analyzed only for the total concentration across the stream, then laboratory time can be saved if each bottle has nearly the same quantity of sample so that the four bottles representing the total flow (each sample) can be composited. The EDI method is also discussed in "Inter-Agency Report 14" (F.I.A.S.P., 1963b, p. 41).

On most streams, where the EDI method is used many times each year, a set of curves is drawn for several rates of water discharge or stages of flow. These can then be transformed into a set of sampling instructions which are kept in the stage-recorder shelter at the site or in the field vehicles.

Sand-bed streams characteristically shift radically at single points and from one side to the other, both over a period of weeks or in a matter of hours. This not only makes it impossible to establish percentage-discharge curves applicable from one visit to the next, but one cannot be certain the discharge distribution does not change between the water-discharge measurement and the sampling for the sediment measurement. (See Guy, 1970, fig. 15.) Obviously, for sand-bed streams and for new sediment-measuring sites, the main disadvantage to the EDI method is that a water-discharge measurement must precede the sediment-discharge measurement. However, in some instances where detail is not required, it may be possible for the fieldman to estimate equal increments of flow and sample at their centroids without a detailed water-discharge measurement.

The ETR method

A cross-sectional suspended-sediment sample obtained by the ETR method requires a sample volume proportional to the amount of flow at each of several equally spaced verticals in the cross section. This equal spacing between verticals across the stream and an equal transit rate (ETR), both up and down in all verticals, yields a gross sample proportional to the total streamflow. Obviously, it is necessary to keep the same size nozzle in the sampler for a given measurement. This method was first used by B. C. Colby in 1946 (F.I.A.S.P., 1963b, p. 41) and is used most often in shallow and (or) sand-bed streams where the distribution of water discharge in the cross section is not stable.

The number of verticals required for an ETR sediment-discharge measurement depends on the streamflow and sediment characteristics at the time of sampling as well as on the desired accuracy of the result. On many streams, both statistical approaches and experience are needed to determine the desirable number of verticals. Until such experience is gained, the number of verticals used should be on the high side for each set, even though the result may be oversampling. Through general experience with similar streams, the fieldman can estimate the required minimum number of verticals to yield a desired level of accuracy. For all but the very wide and shallow streams, twenty verticals are usually ample. See page 40 for more explanation on determining the number of verticals to be used for the ETR method.

The width of the segments to be sampled or the distance between verticals is determined by dividing the stream width by the number of verticals decided upon. The stream width, of course, is determined from a tagline stretched across the stream or from station markings on cableways and bridge railings. For example, if the stream width is 174 feet and the minimum number of verticals needed is 10, then the width of segment to be sampled is 17.4 feet. To be practical, and since 10 verticals is the minimum number of verticals, the fieldman would use a vertical spacing of 15 feet. The location of his first vertical would theoretically be at station 7.5 feet. However, again to be practical, he might take the first sample at 7 feet. Then, the second vertical would be at 7+15=22 feet and so on, thus sampling at the midpoint of flow segments 15 feet wide. The next to last segment would end at 11×15=165 feet leaving a final segment of 9 feet wide versus the initial segment of 14 feet. The last sample would then be taken at $165+\frac{9}{2}=169$ feet. A final section of 9 feet versus the standard 15 feet is not ideal; but usually, the sampling results will not be measurably affected because the amount of flow in the segments near the banks is usually small in comparison with the midstream segments.

Because the maximum transit rate must not exceed $0.4V_m$ (fig. 22), and because the minimum must be sufficiently fast to keep from overfilling any of the sample bottles, it is evident that the transit rate to be used for all verticals is limited by conditions at the vertical containing the largest discharge per foot of width (largest product of depth times velocity). A discharge measurement can be made to determine where this vertical is located, but generally it is estimated by sounding for depth and acquiring a "feel" for the relative velocity with an empty sampler or wading rod. The transit rate required at the maximum discharge vertical must then be used at all other verticals in the cross section and is usually set to fill a bottle in a round trip. At verticals containing less than half the flow of the maximum vertical, it is possible to sample two or more such verticals in a given bottle.

In slow-moving water it is sometimes tiring and awkward to use an extremely slow transit rate, especially when using a handline or when wading. Under such circumstances, it may be advisable to increase the transit rate and make two or more trips in each vertical. This generally results in a more "natural" transit rate and provides a better averaging of possible variations. In streams with very low velocities in the maximum flow section, the sediment is generally fine material and the sampled concentration would be unaffected by a possible transit rate somewhat faster than $0.4V_m$ in some verticals.

The ETR method has some important advantags over the EDI method. First, it is apparent that a previous water-discharge measurement is not required. In fact, the method makes it possible to compute an approximate water-discharge rate for the stream if the vertical spacing, the stream depth at each vertical, the length of time the sampler is in the water, and the volume of sample is recorded. This is possible because the water enters the sample bottles at the immediate stream velocity and thus, the gross sample volume is proportional to the integrated velocity in the verticals. The mean velocity of the flow sampled in the vertical or verticals, V_m, can be determined by the equation

$$V_m=\frac{V/T_t}{A_n}$$

where V= volume of the sample,
T_t= total transit time to obtain sample, and
A_n= cross-section area of nozzle.

If transit rates near $0.4V_m$ are used, it might be desirable to adjust V_m for the angle at which the velocity of stream enters the nozzle by the formula

$$V_{mc}=V_m \cos \partial$$

$$\text{where } \partial=\text{Arcsin } \frac{2\times\text{depth at vertical}}{V_m\times\text{time of transit}}.$$

The discharge of the stream is then simply the summation of the velocity and area product for each sampled segment of the stream. Another advantage of the ETR is that analysis time and effort can be saved in the laboratory because the sample bottles can be composited to give one cross-sectional sediment concentration and (or) particle-size gradation. (See Guy, 1969) The ETR method can often be taught to daily observers more easily than the EDI method.

Point-sampler techniques

Point samplers are used in streams where depth exceeds the recommended 15 feet for a round trip with depth integrating samplers and where the combination of depth and velocity cause the bottle to overfill at the maximum allowable transit rate. Sometimes the velocity is too high for the lighter samplers to be stable. It is seldom practical for local observers to use the point samplers.

Either the EDI or ETR sediment-discharge methods are applicable for the point sampler when it is used for depth integration. Stream depths as much as 30 feet can be handled with point samplers by integrating the depth in only one direction at a time. Generally, the sampler is first lowered to the streambed (with the intake closed) at which time the depth is determined. This then makes it possible to estimate a transit rate to yield the desired sample quantity. Upward integration from the bottom is maintained at a given transit rate immediately upon opening the intake nozzle.

At least two bottles should be obtained at a given vertical. If the first is from bottom to top, then the other should be taken on a descending trip because it has been shown by tests in the Colorado River (United States F.I.A.S.P. 1951, p. 34) that downward integration increases the intake ratio by about 4 percent and upward integration decreases the intake ratio by about 4 percent. As already mentioned, the upward and downward transit rates at a given vertical for the EDI method need not be the same; but for the ETR method they must logically be identical.

Depths between 30 and 60 feet are sampled in four steps by using four bottles instead of two. The first step is accomplished by lowering the closed sampler to the bottom and noting the depth. After opening the nozzle, the sampler is raised at a predetermined transit rate to an even foot at about one-half the depth, at which point the nozzle is immediately closed. The remaining trip to the surface can be made at any desired speed. The bottle is then removed and labeled. For the second step, a clean bottle is inserted and the sampler is again lowered, but only to that depth where the nozzle was closed on the ascending trip. At this point, the nozzle is again opened, and the upper part of the flow is sampled while ascending at the identical transit rate used in the lower part. The third and fourth steps are to sample the upper then the lower parts of flow in descending trips at a transit rate dictated by the method being used. For depths of over 60 feet, more steps must be used, as needed.

In addition to the usual information (fig. 20), the label on each bottle should indicate the segment or range of depth sampled and whether it was taken on a descending or ascending trip.

Point-integrating samplers are sometimes used to obtain sample concentration at several points or levels in the vertical from which the distribution of sediment concentration in a vertical can be defined. A weighted sediment concentration can be obtained by integrating the concentration curves from such point samples with the velocity distribution. This method of computing the mean sediment concentration and discharge is very time consuming and expensive, and therefore, point sampling is usually reserved for special studies. See F.I.A.S.P. (1963b, p. 46–51) for detailed discussion on methods of point sampling.

Transit rates in suspended-sediment sampling

The sample obtained by passing the sampler throughout the full depth of a stream is quantitatively weighted according to the velocity through which it passes because suspended-sediment samplers take in water and sediment at the immediate stream velocity. If the sampling vertical can represent a specific width of flow, the sample is considered to be discharge weighted because with a uniform transit rate each increment of velocity or discharge in the vertical is given the same amount of time to enter the sampler. Logically, then, this is the reason that in previous writings the point was made to keep the transit rate of the samplers constant throughout at least a single direction of travel.

Also, as mentioned previously, if the sampler were held in a stationary position in the stream, then the lines of flow entering the nozzle would make a zero angle to the nozzle. However, because a rigidly held sampler is in vertical motion during sampling, the lines of flow must enter at an angle greater than zero whereby the effective velocity of the water entering the nozzle is reduced. This reduction in velocity affects the concentration of the sample and becomes important when the transit rate (V_t) exceeds four-tenths the mean velocity ($0.4\ V_m$) in the vertical. In addition to the limit by the angle, the downward transit rate is also theoretically limited by the rate of air compression in the bottle. If the air compresses at a rate faster than the bottle is filled on a downward trip, hydrostatic pressure will force an increase in the intake velocity, or perhaps entry of water through the air exhaust.

An alinement graph is given in figure 22 for which the average sampler transit rate and transit time from the stream surface to the bed and return can be determined, given the depth of the sampling vertical and the mean volocity of the flow in the vertical. The example on the graph shows that a vertical 7.8 feet deep flowing at 4.0 fps (feet per second) requires a transit rate of 0.85 fps if a 3/16-inch nozzle is used and 1.5 fps if a 1/4-inch nozzle is used. The total transit time for each nozzle would be 11 and 18 seconds, respectively.

When the sampler touches bottom during round trip integration, one-half of the time allotted to filling the bottle should have passed. When using the EDI method for a sediment discharge measurement or when sampling at a single vertical, if more or less than one-half the time has elapsed, the sampler can be raised at a constant but somewhat faster or slower rate than on the downward trip in order that the average for the round trip will be the desired rate. This assumes that the transit rate limitations with respect to approach angle at the nozzle and air compressibility are not exceeded. When water-discharge data are not available, the first bottle of a sediment-discharge measurement in a cross section for the EDI method is taken by trial and error, and the transit rate at succeeding verticals can be adjusted according to the estimated conditions (depth and velocity).

Additional explanation and qualifications with respect to the transit rate for suspended-sediment sampling include:

1. For cable-suspended samplers, the instantaneous actual transit rate, V_{ta}, may differ considerably from the computed rate, V_t, if V_m exceeds about 6 fps and if the sampler is suspended from more than 20 feet above the water surface. Under such conditions, the sampler is dragged downstream and the indicated depth is greater than the true depth. Corrections for indicated depth are given by Buchanan and Somers (1969, p. 50–56) for various angles and lengths of sounding line used for suspension of a weight in deep, swift water. The corrected depth would then be used to enter in figure 22 to determine the needed transit rate.
2. The allowable V_t may be greater than 0.4 V_m and sampling depth thereby increased if the sampler is cable suspended and capable of tilting itself somewhat in the direction of vertical movement. On the other hand, where the sampler cannot tilt, where the velocity at the bottom of the vertical is much less than V_m, and where there is a heavy concentration of suspended sand near the bed, the use of a V_t value that nears this limitation may cause V_t to approach or even exceed the actual V near the bed and thus cause an excessive error in the intake of sand particles. The approach-angle theoretical depth limits will of course be less if either the downward or the upward transit rates, V_{td} or V_{tu} are different from V_t.
3. The indicated lower limit, because of air compression, is based on the assumption of a uniform velocity distribution in the vertical. Where the velocity is considerably greater than the mean in the upper part of the vertical, the lower limit can be increased somewhat. The air compression lower limit can also be increased by using a downward transit rate, V_{td}, that is less than the indicated V_t and then to compensate for the extra filling of the bottle on the downward trip by using an equally greater upward transit rate, V_{tu}. For example, 19.5 feet may be sampled with an 1/8-inch nozzle if where $V_t=1.2$ is indicated (for $V_m=5$) by using $V_{td}=0.9$ and $V_{tu}=1.5$
4. Because of possible greater deviation from the ideal relation of intake velocity to stream velocity of 1.0, the 1/8-inch nozzle should not be used if there are significant quantities of sand larger than 0.25 mm in suspension. The 1/8-inch nozzle is also less reliable than the larger nozzles where small roots and other organic fibers are suspended in the flow.
5. In the event that the sampler accommodates a quart-sized bottle, half the indicated V_t can be used. With the quart-sized bottle,

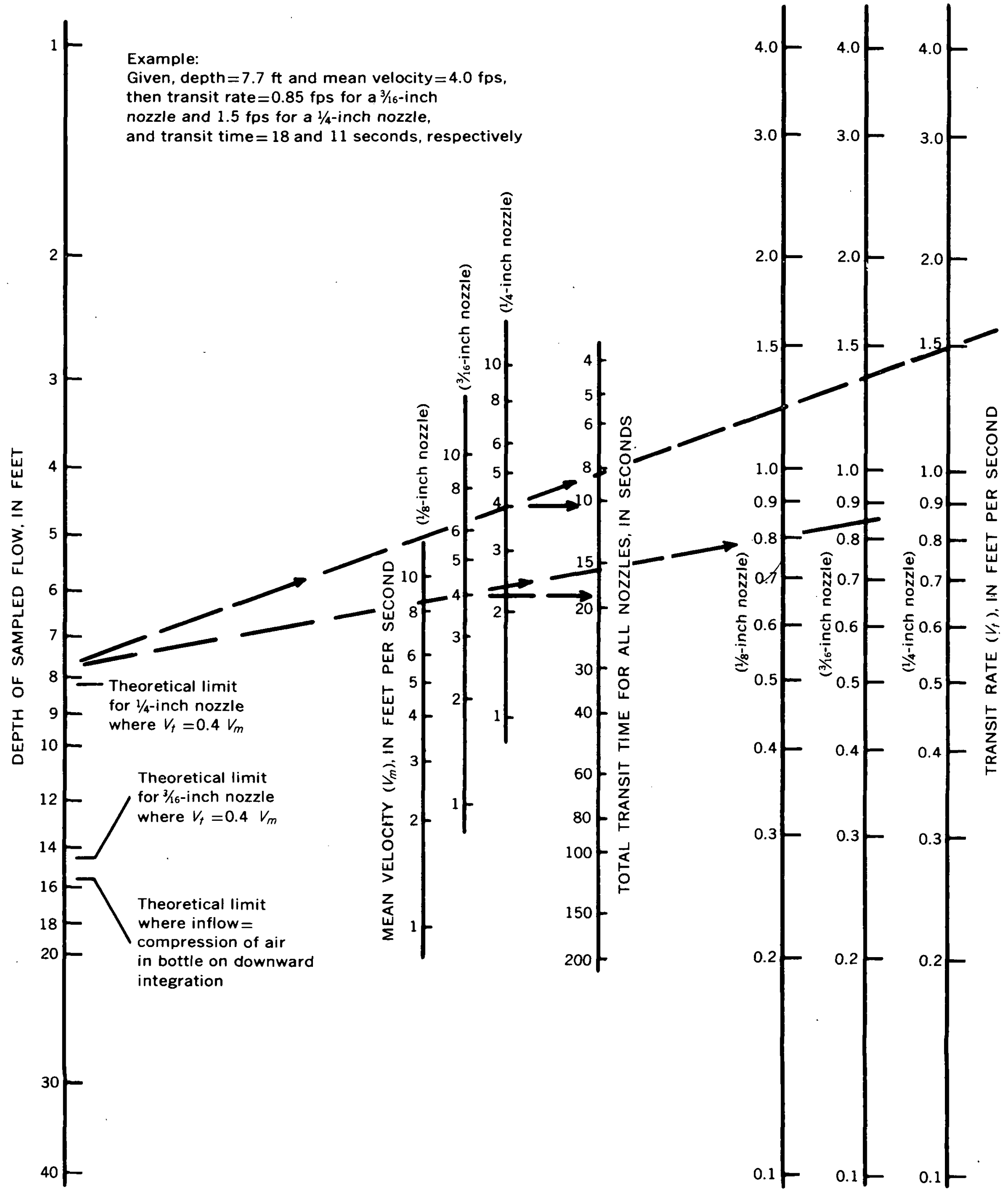


Figure 22.—Round trip (stream surface to bed and return) suspended-sediment sampler transit rate and transit time for 1/8-, 3/16-, and 1/4-inch intake nozzles, given the sampling depth and mean velocity of flow. The assumed volume of sample is equal to 395 cc and the sampling ratio is equal to 1.0.

the depth limit for the ¼-inch nozzle, where $V_t \leqq 0.4\ V_m$, may be computed to be 16.4 feet. In practice, however, the 15.5-foot limitation because of air compression should apply unless the exceptions indicated in 3 (above) can be applied.

Sometimes, when sampling suspended sediment for a bed-load or total-load computation, unusual cross-section and streambed conditions may require a change or break in the transit rate used in an ETR measurement. This is desirable where a small part of the section carries a large part of the total discharge and where the stream can be divided into two parts and analyzed as "two" streams. Two or more transit rates may also be desirable in a section where a marked change in bed-material size from one side to the other or where a braided stream occurs. However, it should be kept in mind that the practice of changing transit rates in the "middle of the stream" is not desirable unless it will improve the resulting data. Bottles and field notes should be labeled with a full explanation of why and how the change was made. Also, if such a change in transit rates is necessary, no part of the sample from the two different transit rates should be accumulated into the same bottle.

Quality control for suspended-sediment sampling

Suspended-sediment samples collected at a given time and location will vary one from another depending on many factors, the most important of which is the relative amount of sand moving in the sampling zone. The sand transport is most variable when the bed is in the dune regime. The fine-sediment concentration will not vary appreciably, in a random way, at a section where the flow from upstream tributaries is well mixed. The fine-sediment concentration is more likely to vary systematically with time, that is, gradually increasing or decreasing according to its rate of input to the stream system and its routing with the flow to the sampling site.

Most stream measuring sites include a mixture of both fine and coarse sediment in the sampling zone. Therefore, even though the mean concentration is relatively uniform, we can expect a natural concentration variation that will affect the quality of the mean concentration computed from two or more observations of such concentration. A convenient method for evaluating the quality of the mean of a group of samples is given by Guy (1968). Likewise, the quality of the mean of the two different groups of samples used to compute the adjustment coefficient affects the quality of the coefficient. The quality of the coefficient is determined from a simplified computation procedure and an alinement chart.

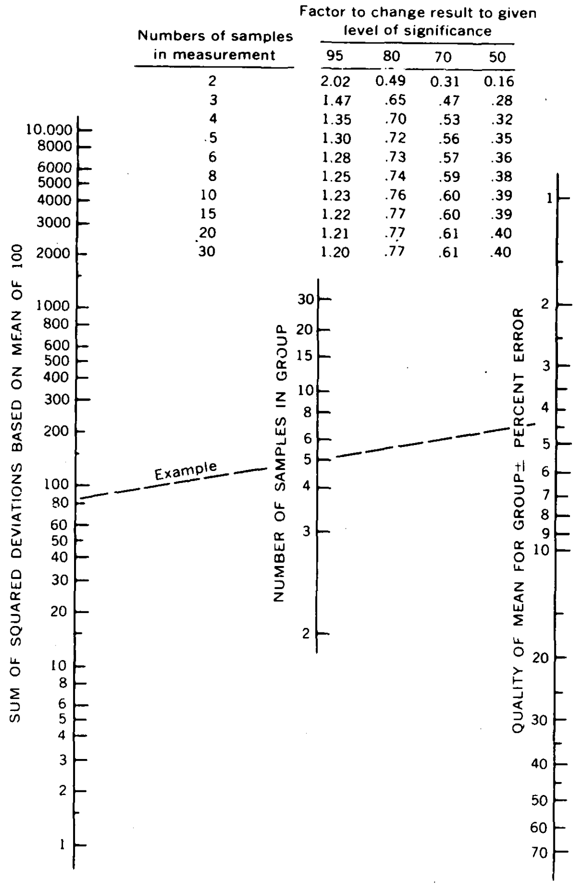
Quality of a group mean

The procedure outlined by Guy (1968) to determine the quality of a mean of a group requires only that the data be tabulated as illustrated below, the data converted to a base of 100 (the percentage each observation is of the mean), the sum of the squared deviations from base 100 be determined, and these data entered on the alinement chart (fig. 23). The resulting quality of the mean for the group is at the 90-percent level of significance. Other levels can be computed by use of the factors given on the alinement chart.

	Measured observations	Base of 100	
		Observations	Squared deviations
	643	104	16
	618	100	0
	593	96	16
	649	105	25
	587	95	25
Sum	3090		82
Mean	618		

Quality of a coefficient

As previously mentioned, two groups of data are involved if it is desired to compute the quality of a coefficient for adjusting the concentration of daily or routine samples. The groups, of course, would consist of a list of the concentrations of the single-vertical samples and the concentrations of sediment-discharge measurements. Study of the following example and other sets of data show that when either or both of the groups have considerable internal variation, then the coefficient must be rather large to



Numbers of samples in measurement	Factor to change result to given level of significance			
	95	80	70	50
2	2.02	0.49	0.31	0.16
3	1.47	.65	.47	.28
4	1.35	.70	.53	.32
5	1.30	.72	.56	.35
6	1.28	.73	.57	.36
8	1.25	.74	.59	.38
10	1.23	.76	.60	.39
15	1.22	.77	.60	.39
20	1.21	.77	.61	.40
30	1.20	.77	.61	.40

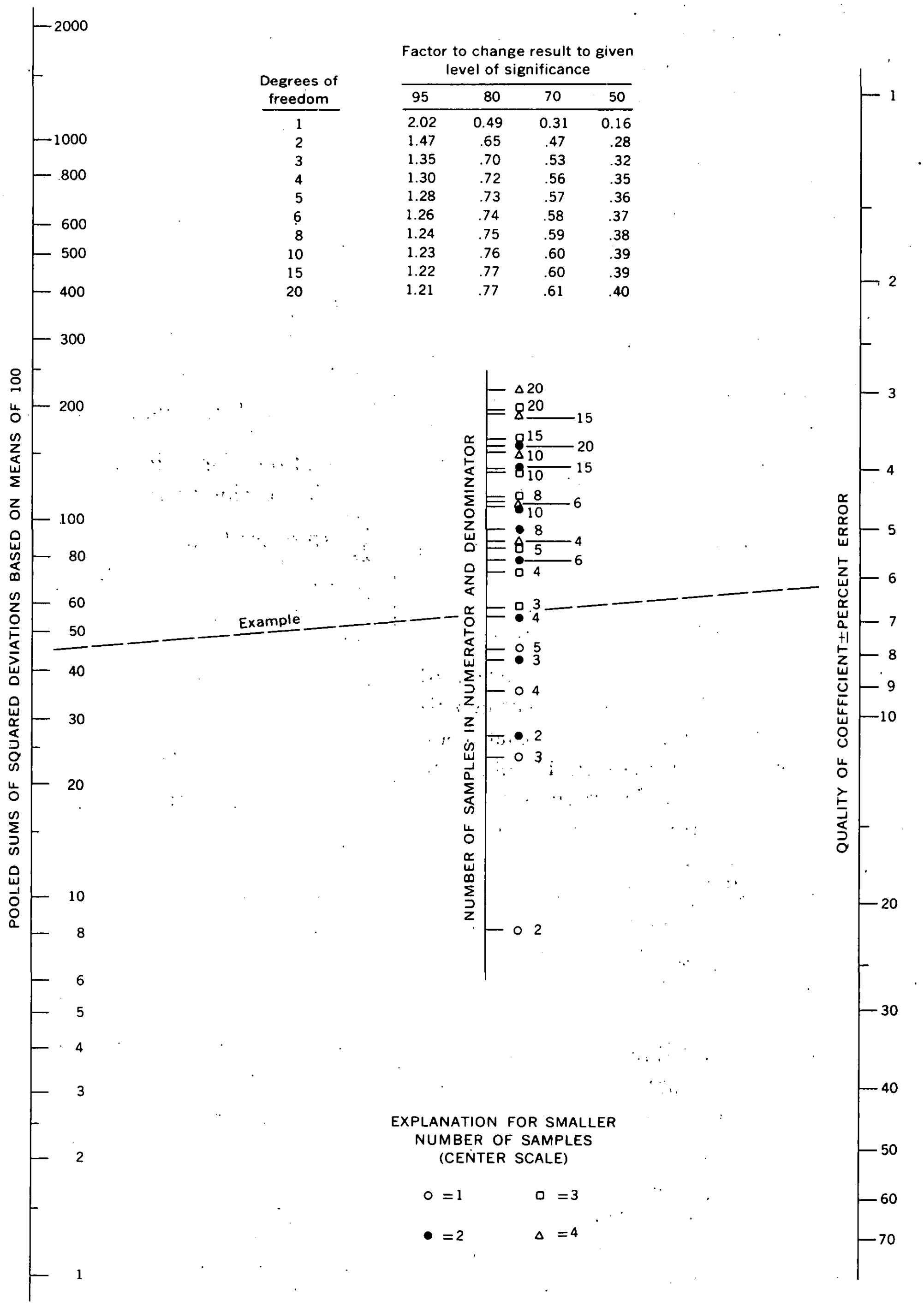
Figure 23.—Alinement chart to determine the quality of the mean for a group of samples given the sum of squared deviations at the 90-percent level of significance. The quality of the mean for other levels is obtained by use of the factors shown. After Guy (1968, p. B166).

be significant. Also, it is evident that when only one or two samples are available for each group, the results of a coefficient may be questionable. Therefore, when making a sediment-discharge measurement for the purpose of defining a coefficient, it is desirable to obtain the samples so that two or more mean concentrations can be determined for the cross section. Also, since it is relatively easy to obtain and analyze samples at the routine or daily vertical, it is desirable to obtain at least two bottles before the measurement and at least two afterward, thus giving at least four concentrations at the routine sampling vertical for application to study and definition of the coefficient.

The quality of the coefficient is determined by expansion of the methods just used to determine the quality of the mean of a single group. The tabulation below and the alinement graph (fig. 24) are sufficient to illustrate the method. In this example, two cross-section concentrations and four single-vertical concentrations are used. Again, figure 24 gives the quality of the coefficient in terms of the 90-percent level of significance, and a table of factors is given to convert to other levels. The term "degrees of freedom" is defined as two less than the total number of samples or concentration observations in both groups.

The variation among samples for the determination of the quality of a coefficient can be used with figure 24 to estimate the number of samples or concentration determinations needed to yield a coefficient of a different quality. The results from the above example using two and four samples have a pooled sum of squared deviations $\Sigma d^2=44$ and a quality of about ±6 percent. It is expected that a given stream will yield a similar variation from time to time and therefore Σd^2 will be directly proportional to the number of sample concentrations. On the basis of this example, if a coefficient quality of 4 percent instead of 6 percent is desired, then it is possible to determine the number of samples

Sample groups	Measured concentrations (mg/l)	Mean	Base of 100	
			Concentrations	Sum of squared deviations
Cross section	715 725	720	99 101	1 1
Single vertical	624 606 600 570	600	104 101 100 95	16 1 0 25
				44 (total)



Degrees of freedom	Factor to change result to given level of significance			
	95	80	70	50
1	2.02	0.49	0.31	0.16
2	1.47	.65	.47	.28
3	1.35	.70	.53	.32
4	1.30	.72	.56	.35
5	1.28	.73	.57	.36
6	1.26	.74	.58	.37
8	1.24	.75	.59	.38
10	1.23	.76	.60	.39
15	1.22	.77	.60	.39
20	1.21	.77	.61	.40

Figure 24.—Alinement chart to define the quality of a coefficient for a given sampling design and pooled sums of squared deviations at the 90-percent level of significance. The quality for other levels is obtained by use of the factors shown. The explanation used on the center scale indicates the smaller number of the two groups of samples used.

needed by working backward through trial and error in figure 24. A line roughly parallel to the example line from 4 percent gives a Σd^2 of about 80 to 100 and indicates that about twice as many samples are needed as used in the example yielding the 6 percent error. Therefore, the combinations of numbers of samples for satisfactory use would be 3 and 8, 4 and 6, and 2 and 10. These combinations would theoretically yield Σd^2 of $\frac{11}{6}\times 44=81$, $\frac{10}{6}\times 44=73$, and $\frac{12}{6}\times 44=88$. The alinements from these Σd^2 values through the respective sample combination show the first two (3 and 8, and 4 and 6) to be less than the 4 percent value and suitable for use, whereas the third combination (2 and 10) would provide a quality of about 4.2 percent and therefore is of more questionable use.

Number of sampling verticals needed

In the quality comparisons of the means of sample groups and the adjustment coefficients already discussed, it was assumed that comparative groups or coefficients would be obtained from similar random samples of the same kind of population and sampling technique. Because of the possible systematic variation of sediment concentration at different verticals across the stream, an important question remains as to the number of sampling verticals needed for a sediment-discharge measurement of a desired accuracy.

Both the EDI and ETR methods of sediment-discharge measurement obtain a volume of sample at each vertical weighted with the water discharge for that vertical. The volumetric sum from all verticals yields a sample volume proportional to the water discharge for the stream. Remember, as mentioned previously, that all or nearly all the concentration variation at different verticals across the stream will be the result of sand-sized material, and that finer sediments are uniformly dispersed throughout the section unless the section is close to a tributary and mixing is not complete. Measuring sections near such tributaries should be avoided.

Colby (1964) showed that the discharge of sand varies as about the third power of the mean velocity for constant temperature and particle-size distribution within a range of velocity from about 2 to 5 feet (0.6 to 1.5 m) per second and within some reasonable range of depth. Thus, $q_s=k_1V^3$, in which q_s is the discharge of sand per unit width, k_1 is a constant for a given depth, and V is the mean velocity. The sand discharge can be written as $q_s=k_2\ CVD$, in which k_2 is another constant, C is the mean concentration in the sampled vertical, and D is the total sampled depth. Solving for C gives $C=\frac{k_1}{k_2}\cdot\frac{V^2}{D}$. Thus, the variability of concentration for different sampling verticals should be closely related to the variability of $\frac{V^2}{D}$. In order to have a $\frac{V^2}{D}$ index useful for comparison among all streams, the compound ratio $\frac{V^2/D(\text{max})}{\overline{V}^2/\overline{D}}$ is suggested, where (V^2/D) (max) is the ratio from the vertical having the maximum V^2/D, and $\overline{V}^2/\overline{D}$ is the ratio of the mean velocity squared to the mean depth of the whole stream. The mean velocity and mean depth are computed and available from water-discharge measurements.

Based on the V^2/D index concepts of variability, P. R. Jordan (written communication, 1968) using data from Hubbell (1960), prepared a nomograph (see fig. 25) that indicates the number of sampling verticals required for a desired maximum acceptable relative standard error based on the percentage of sand and the V^2/D index. In the example illustrated by figure 25, the acceptable relative standards error is 15 percent, the sample is 100 percent sand, the V^2/D index is 2.0, and the required number of verticals is seven. Notice that if the sediment were 50 percent sand, the same results could be obtained with three verticals, or if seven verticals were used with 50 percent sand, the relative standard error would be about 8 percent. When the discharge of sand-sized particles is of primary interest, the 100-percent line should be used regardless of the amount of fines in the sample.

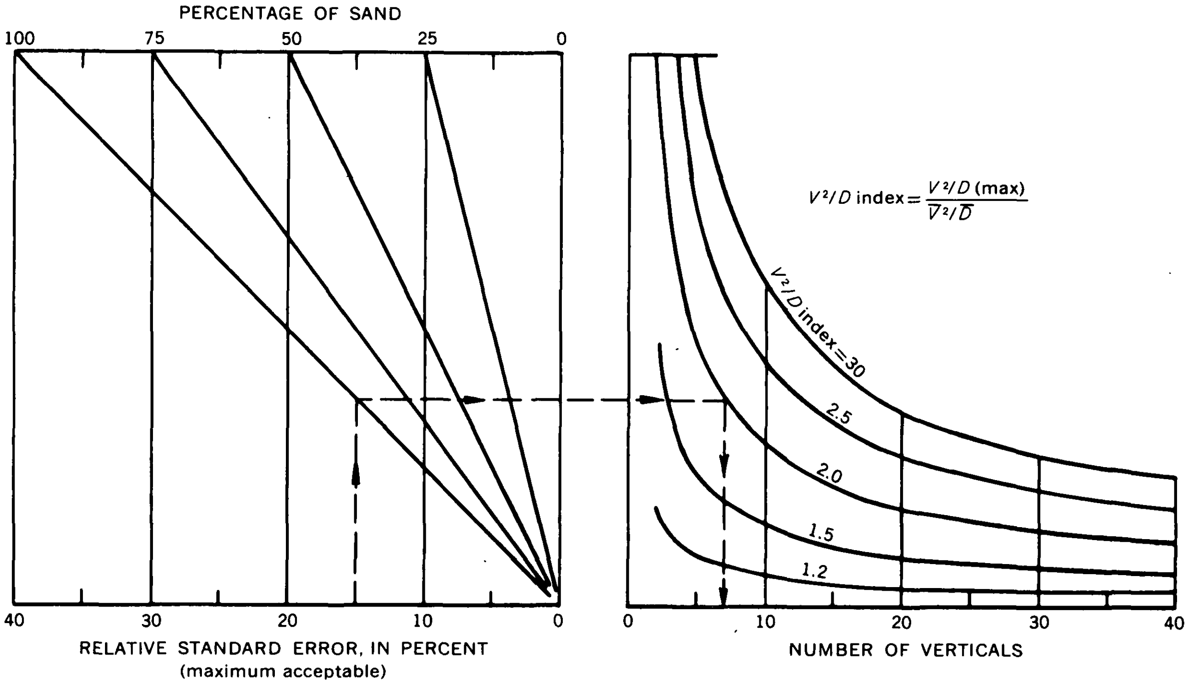


Figure 25.—Nomograph to determine the number of sampling verticals required to obtain results within an acceptable relative standard error based on the percentage of sand in the sample and the V^2/D index. Best results are obtained when V is between 2 and 5 fps and D is greater than 1.5 feet.

Surface and dip sampling

Circumstances are sometimes such that surface or dip sampling is necessary. These may include (1) stream velocity too high for the sampler to integrate, (2) large floating and moving submerged debris, (3) when a regular sampler is not available, and (4) very shallow depths.

A surface sample is one taken on or near the surface of the water, with or without a standard sampler. At some locations, stream velocities are so great that even 100-pound samplers cannot penetrate the water more than a short distance before they are dragged downstream and out of the water into an erratic movement. Under such conditions, it can be expected that all except that largest particles of sediment will be thoroughly mixed with the flow and therefore a sample near the surface is very worthwhile. Extreme care should be used, however, because often such swift velocities occur during floods when much large debris is moving, especially on the rising part of the hydrograph. These debris may strike or become entangled with the sampler and thereby damage the sampler, break the sampler cable, or injure the fieldman. Of course, a full explanation of sampling conditions should be noted on the bottle and in the field notes in order that special handling may be given the samples in the laboratory and in computing the records. The amount of debris in the flow decreases considerably after the flood crest; even the velocity will decrease somewhat, at which time every effort should be made to obtain, with caution, the scheduled depth-integrated samples.

If, for some reason, a sampler is lost or equipment is not available, a sample obtained by lowering an uncapped bottled tied to a rope into the water is better than no sample at all. Sometimes a bottle holder used for obtaining chemical quality samples can be used if other techniques fail.

In wadable water when no sampler is at hand, a "depth-integrated sample" can sometimes be taken by holding the bottle in one hand with one or two fingers of that hand placed in the bottle opening to form an enlongated hole for the water to enter below the fingers and another such hole above the fingers to allow the air to escape. The remaining fingers should be extended below the bottle to avoid getting the mouth of the bottle too close to the streambed and thereby collecting some particles directly from the streambed. The fingers in the opening keep the water from entering too quickly and thus prevent circulation of the water and sediment in the bottle if overfilled.

There are many bad features about surface and dip sampling that should be avoided, especially for flows with a velocity insufficient to mix the sands in the flow. If possible, any dip sampling of such moderate or low flows should be followed and correlated, if possible, with standard sampling equipment and techniques. Because the quality of the surface and dip samples is likely to be inferior to those obtained with the regular samplers, they should always be appropriately identified.

Timing, quantity, inspection, and labeling of suspended-sediment samples

Time distribution

When should suspended-sediment samples be taken? How close can samples be spaced in time and still be meaningful? How many extra samples are required during a flood period? These are some questions that must be answered, because timing of sample observations is as important to record computations (see Porterfield, 1970) as is the technique for taking them. Answering such questions is relatively easy for the person who computes and assembles the records because he has the "history" before him and can easily see what is needed. The fieldman, on the other hand, frequently has no "record" experience and certainly cannot know what the conditions will be for the remainder of the record in the future.

Observers should be shown typical hydrographs or recorder charts of their stations, or nearby stations, to help them understand the importance of timing their samples so that each sample yields maximum information. The desirable time distribution for samples depends on many factors such as the season of the year, the runoff characteristics of the basin, the adequacy of coverage of previous events, and the accuracy of information desired or dictated by the purpose for collecting the data.

For many streams, the largest concentrations and certainly the largest sediment loads occur during spring runoff; on other streams, the most important part of the sediment record may occur during the period of the summer thunderstorms or during winter storms in the Pacific Northwest. The frequency of suspended-sediment sampling should be much greater during these periods than during the low flow periods. In the north and east parts of the United States many of the streams usually carry an average of 70 to 90 percent of the annual sediment load during the spring runoff. During some parts of this period, hourly or even bihourly sampling may be required to define the sediment concentration accurately. During the remainder of the year, the sampling frequency can be stretched out to daily or even weekly sampling for adequate definition of concentration. Hurricane or thunderstorm events during the summer or fall require frequent samples during short periods of time. Streams in the midwest and west have long periods of low or intermittent flow and thus each storm event should be sampled frequently, because most of the annual sediment transport occurs during these few events.

Most streams, during long periods of rather constant or gradually varying flow, have concentrations and quantities of sediment that vary slowly and may therefore be adequately sampled every two or three days; or in some streams, one sampling a week may be adequate. For some streams, several samplings a day may occasionally be needed to define the diurnal fluctuation in sediment concentration. Fluctuations in power generation and evaportranspiration cause such diurnal fluctuations. Sometimes, daily temperature changes cause snow and ice to melt, and thereby a considerable rise and fall in stage may occur each day. Diurnal fluctuations have also been noted in sand-bed streams when water-temperature changes cause a change in flow regime and a drastic change in bed roughness (Simons and Richardson, 1965).

The temporal shape of the hydrograph is an indicator of how a stream should be sampled.

Sampling twice a day may be sufficient on the rising stage if it takes a day or more for a stream to reach a peak rate of discharge. During the peak, samples every few hours may be needed. During the recession, sampling can be reduced gradually until normal sampling intervals are sufficient.

Intermittent and ephemeral streams usually have hydrograph traces whereby the stage goes from a base flow or zero flow to the maximum stage in a matter of a few minutes or hours, and the person responsible for obtaining the samples frequently does not know when such an event is to occur. Ideally, samples should be obtained as follows: during the rising stage, sample small streams every few minutes and large streams every half hour or hour. After the peak rate of flow passes, if this can be determined, the sampling frequency may be reduced somewhat. During the recession, the sampling rate should gradually be reduced to the normal daily schedule as the preceding base flow is reached, or as the flow stops. Generally, adequate coverage of such a peak is obtained if samples on the rising limb are four times as frequent as are the samples needed to define the recession limb. Thus, if the recession is best sampled on a bihourly basis, then the rising limb should be sampled every one-half hour. (See fig. 26.)

Elaborate and intensive sampling schedules are not required for each and all events from small streams that drain basins of rather uniform geologic and soil conditions because similar runoff conditions will yield similar concentrations of sediment for the different runoff events. Once a concentration pattern is established, then samples collected once or twice daily may suffice even during a storm period. (See Porterfield (1970) for explanation of such curves.)

Streams which drain basins having a wide variety of soils and geologic conditions and receiving uneven distributions of precipitation cannot be adequately sampled by a rigid predetermined schedule. Sediment concentration in the stream depends not only on the time of year but also on the source of the runoff in the basin. Thus, each storm or changing flow event should be covered as thoroughly as possible, in a manner similar to that described for intermittent and ephemeral streams. Figure 27 shows the difference in pattern of daily streamflow for Swatara Creek at Harper Tavern for water years 1956–57 and 1957–58 and illustrates the complicated flow pattern that may be expected from a complex basin.

The accuracy needed in the sediment information also dictates how often a stream should be sampled. The greater the required accuracy and the more complicated the flow system, the more frequently will it be necessary to obtain samples. This, of course, with the added costs of laboratory analysis, greatly increases the cost of obtaining the desired sediment information. Often, however, the final cost of the record is less when adequately sampled than when correlation and other synthetic means must be used to compute segments of a record because of inadequate sampling.

In a general way, stream-sediment stations may be operated or sampled on a daily, weekly, monthly, or on an intermittent or miscellaneous schedule. Only those operated on a daily basis are considered adequate to yield the continuous record. One should be mindful that each sample at a specific station costs about the same amount of money, but the amount of additional information obtained often decreases with each succeeding sample after the first few samples are taken. Sometimes samples obtained on a monthly basis yield more information for the money than a daily station even though there is danger that too little information may be of no value or may even be misleading. For a given kind of record, the optimum number of samples should be a balance between the cost of collecting additional samples and the cost of a less precise record.

Sediment quantity

Previous sections discussed the number of sampling verticals required at a station to obtain a reliable sediment-discharge measurement or a sample of the cross-sectional concentration. The number of cross-sectional samples required to define the mean concentration within specific limits has also been discussed. The requirements in terms of quantity of sediment for use in the laboratory to determine particle-size gradation

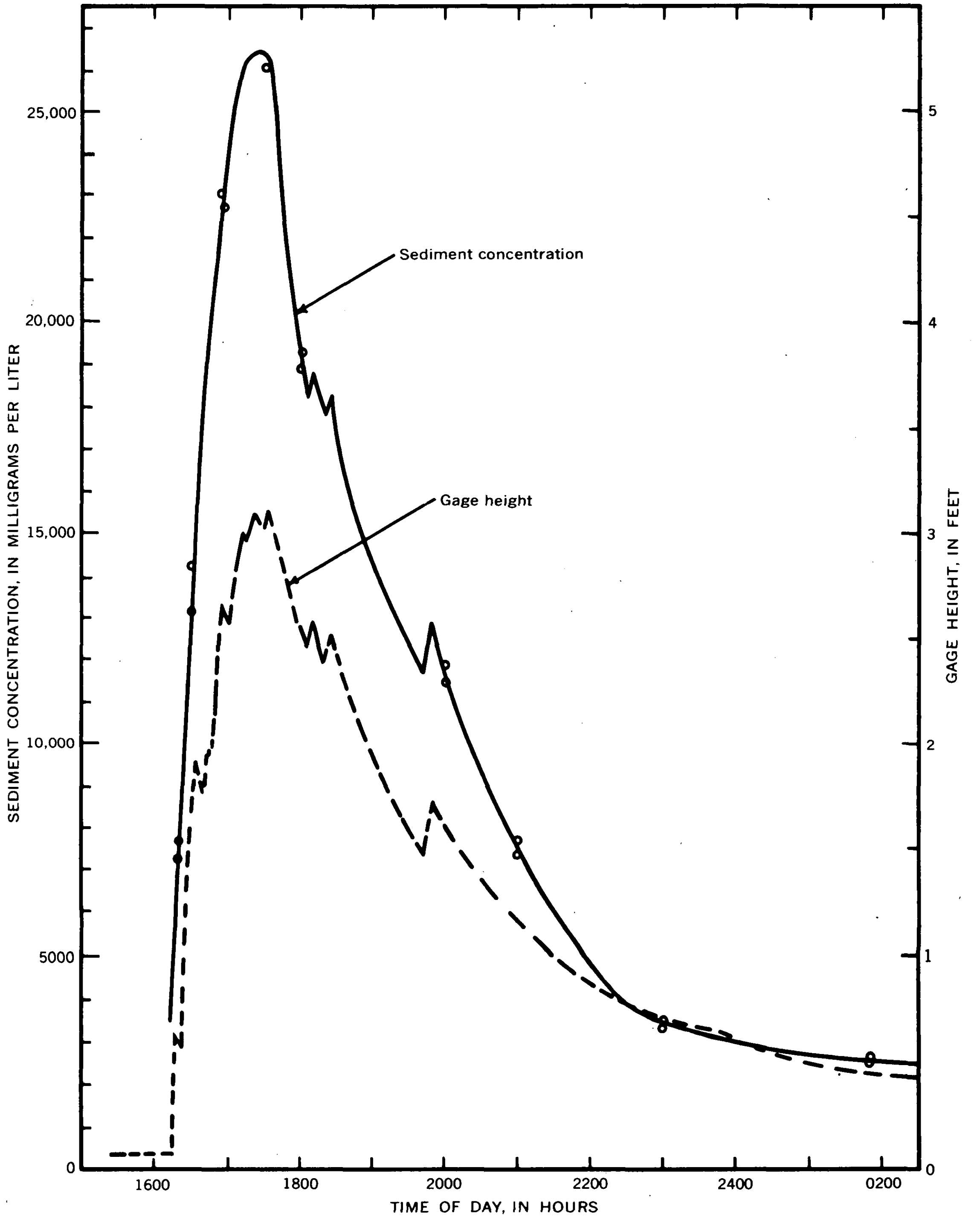


Figure 26.—Gage height and sediment-concentration graph typical of many ephemeral streams showing desirable sample distribution.

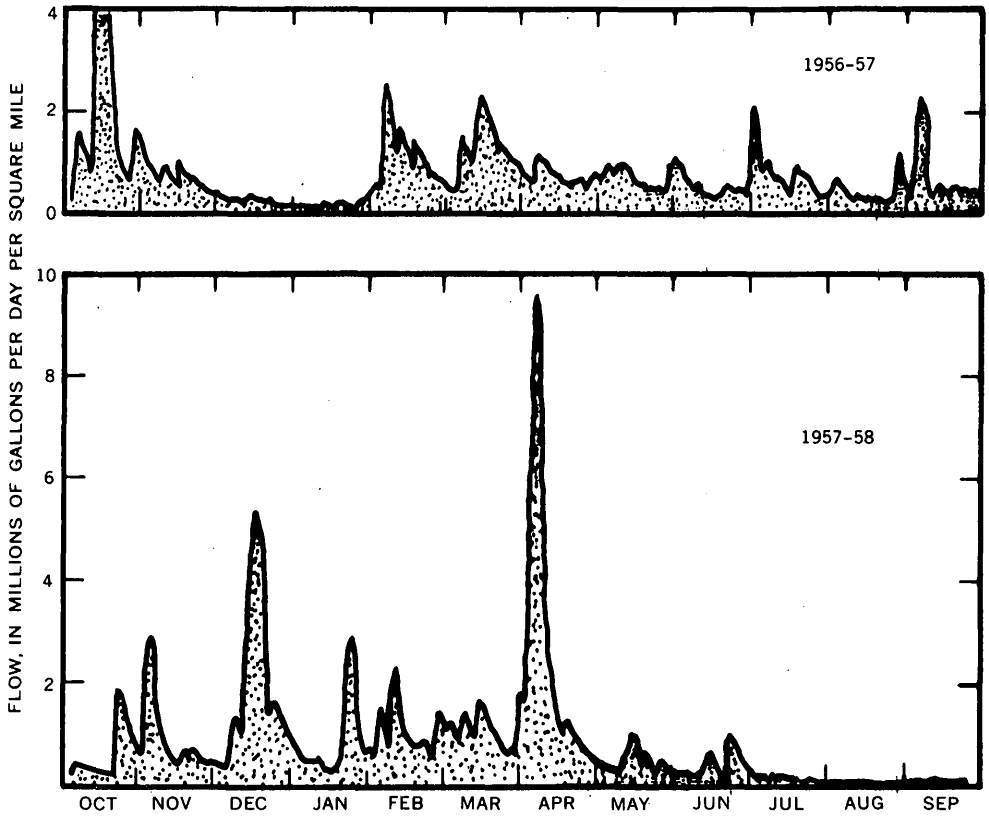


Figure 27.—Differences in pattern of daily streamflow, Swatara Creek at Harper Tavern, Pa., for water years 1956–57 and 1957–58. From Stuart, Schneider, and Crooks (1967, p. 34).

may, at times, exceed the other requirements for concentration. The size range and quality of sediment needed for the several kinds of sediment analyses in the laboratory are given in table 3. The desirable minimum quantity of sediment for exchange capacity and mineralogical analyses is based on the requirements for radioactive cesium techniques described by Beetem, Janzer, and Wahlberg (1962).

To estimate visually the quantity of sediment entrained in a sample or series of sample bottles requires considerable experience. It is also difficult to determine what portion of the total sample is sands (>0.062 mm) because the proportion can be different from stream to stream and from time to time in the same stream. To aid in estimating such sediment quantities, it is helpful to have reference bottles with various known quantities and concentrations in the office or laboratory for visual inspection. Figure 28, from Porterfield (1970), shows how many bottles of sample are needed for a given kind of analysis, amount of sand, and sample concentration.

Though it is possible to conduct the laboratory operation for particle-size analysis in a manner that will also give the sediment concentration, it is best to obtain separate samples for size analysis and concentration analysis. Such "special" samples should be plainly labeled. Generally, it is desirable to instruct the observer to collect additional samples for particle-size analysis.

Field inspection

Every sample taken by a fieldman, as previously implied, should be the best possible considering the stream conditions, the available equipment, and his time. Also, as previously indicated, sampling errors frequently occur on sand-bed streams in the dune regime where the nozzle of the sampler will accidentally pick up sand from the downstream side of a dune. Therefore, each sample bottle must be inspected

Table 3.—The desired quantity of suspended sediment required for various sediment analyses

Analysis	Size range (mm)	Desirable minimum quantity of sediment (g)
Size:		
Sieves:		
Fine	0.062- 0.5	0.07
Medium	.25 - 2	.5
Coarse	1.0 -16	20
VA tube:		
Smallest	.062- .5	.05
Largest	.062- 2	5
Pipette	.002- .062	[1].8
BW tube	.002- .062	[1].5
Exchange capacity:		
Fine	.002	1
Medium	.002- .062	2
Coarse	.062- 2	10
Mineralogical:		
Fine	.002	1
Medium	.002- .062	2
Coarse	.062- 2	5

[1] Double the quantities shown if both native and dispersed settling media are required.

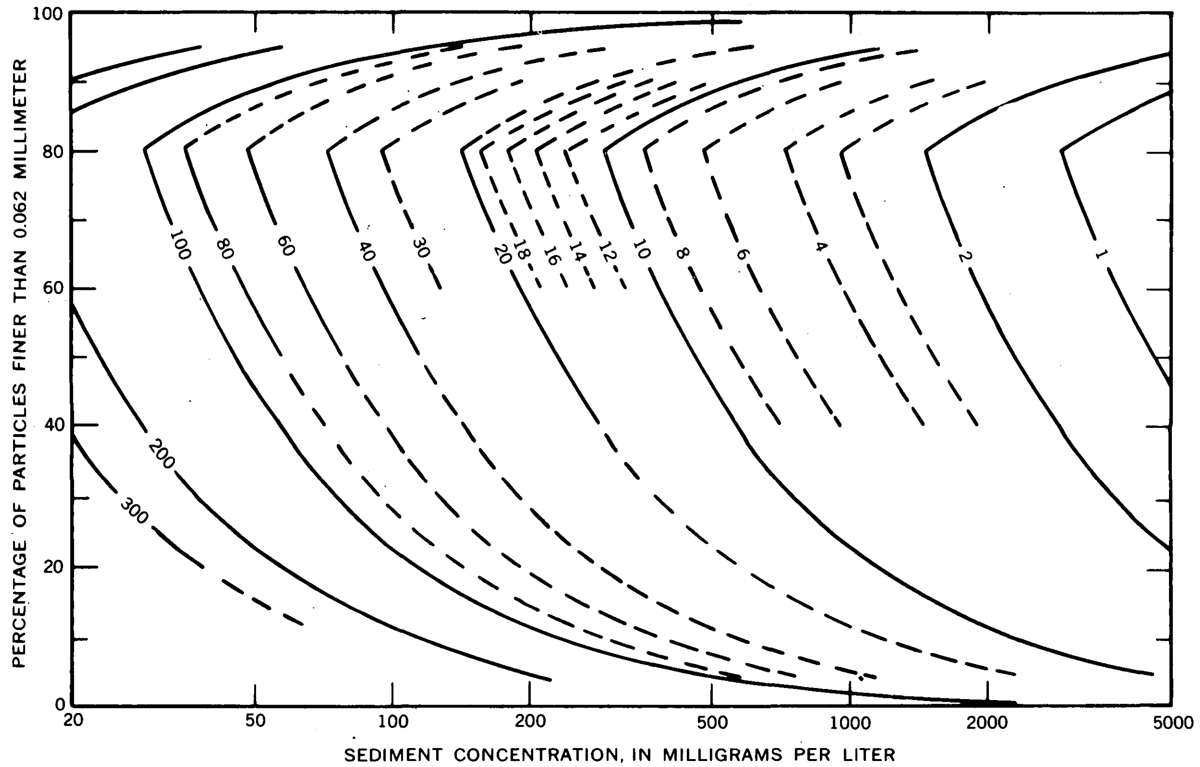


Figure 28.—Minimum number of bottles of sample to yield sufficient sediment for size analyses. From Porterfield (1970). Data is based on 350 grams of sample per bottle; a minimum of 0.2 gram of sand for sieve or visual accumulation tube analysis, and 0.8 gram of silt and clay for pipet analysis in 400 ml suspension. For analysis by the bottom-withdrawal tube method the number of bottles needed for less than 80 percent finer is five-eighths of the indicated number. Instructions: Estimate sediment concentration and percentage of particles finer than 0.062 mm based on knowledge of stream and (or) examination of first bottle. The number of bottles required is the value of the line to the left of the intersection of the sediment concentration and the percentage of particles finer than 0.062 mm. Interpolation of number of bottles may be made along abcissa.

in the field immediately after removing it from the sampler. The cost of the field and laboratory work, to say nothing of the embarrassment of a bad record, is sufficient incentive to make this simple check; and if necessary, to collect another sample.

After the first bottle is taken, it can be checked by swirling the contents of the bottle, then holding the bottle where the sand on the bottom can be seen moving. A mental note is made of the quantity of sand contained in the bottle. The second and remaining bottles can then be examined and compared with the previous bottles. Any vertical or verticals should be carefully resampled where a bottle or bottles contain a significantly different quantity of medium and coarse sand than in the remainder of the set. If the "check" sample also contains a noticeably different amount of sand in comparison to others in the set, retain both bottles and note that the high or low concentration of sand is consistent at the vertical or verticals in question. If the check sample contains a smaller or more representative amount of sand, or if the quantity of sand is different from the first but still not "normal," it may be desirable to wait several minutes to take a third bottle on the assumption that the dune face would move beyond the sampling vertical.

A more subtle error in sample concentration may occur when a bottle is overfilled. This error also results in too high a concentration. The error caused by overfill may occur wherever the bottle is filled to less than 1½ or 2 inches (4 or 5 cm) from the top. Such a sample should be discarded and another sample obtained by use of an increased transit rate. If the transit rate or the nozzle must be changed to avoid overfilling during an ETR measurement, then it is best to discard any previous samples and resample in clean bottles. The computations required to make use of an ETR measurement having two transit rates are more costly and error prone than the minor expense of discarded samples.

Sample labeling

Most of the information needed on sample bottles is indicated by figure 20. Other information may be helpful in the laboratory and in records processing. Therefore, the fieldman will need to keep the requirements for such processing in mind so that other explanatory notes can be recorded on the sample or other inspection sheets. See figure 29. Such notes, some of which have been mentioned previously, may include:

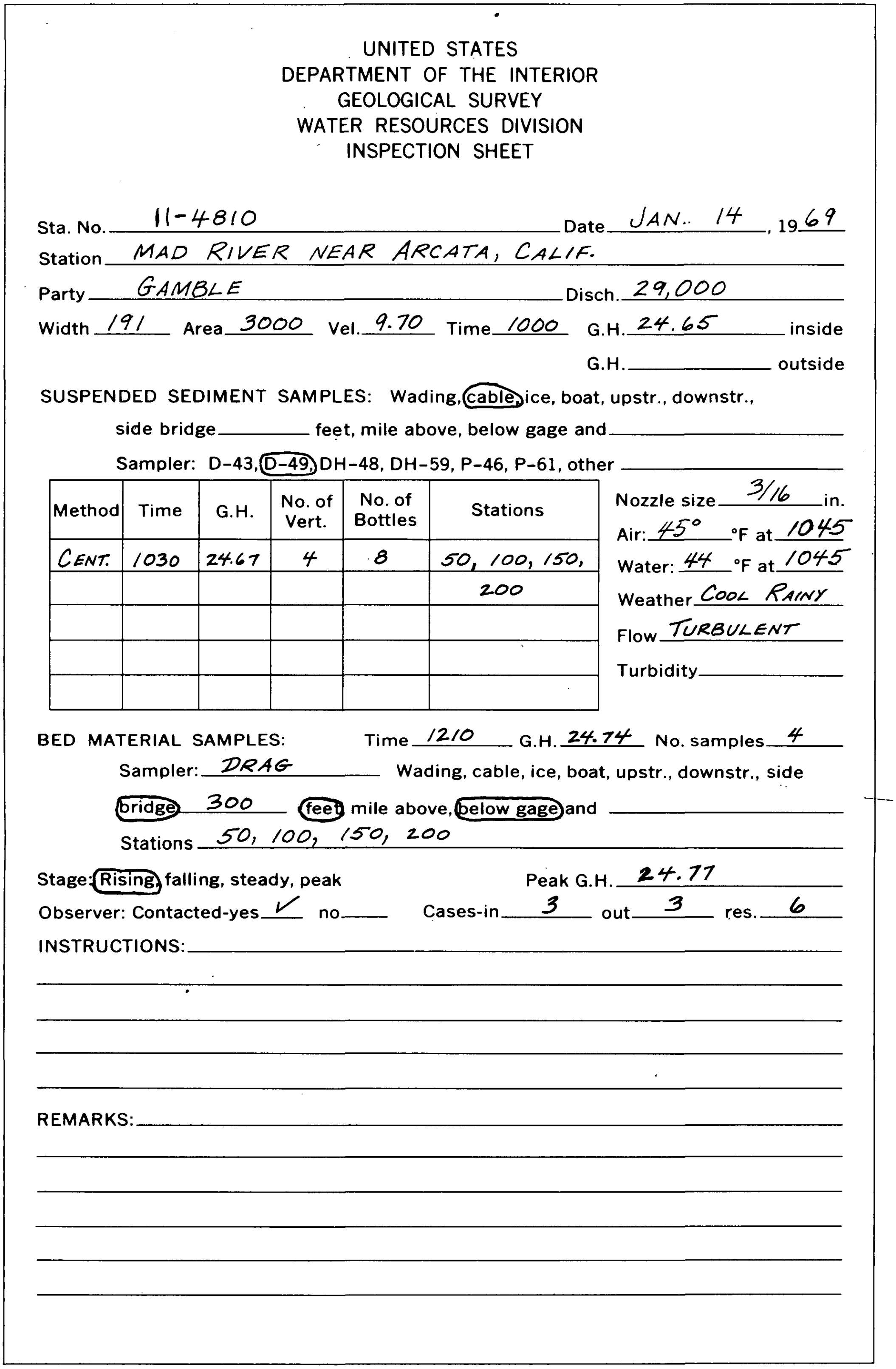
1. Time—Sometimes operations cross-zone boundaries, or the use of daylight time may cause confusion.
2. Method or location—Routine vertical, EDI or ETR cross-section sample.
3. Stationing—One location or sampling vertical, or is the sample an accumulation of several verticals at different locations? Was bridge, cable, or tagline stationing used?
4. Unusual sample conditions—Consistent sampling of sand at this location, surface sample, or dip sample.
5. Variation of desired technique—Change of transit rate, sampling vertical location, depth somewhat beyond capacity of instrument, or transit rate may have exceeded $0.4V_m$.
6. Condition of stream—Boils noted on water surface, soft dune bed, swift smooth water, braided stream, sand bar in cross section, or slush ice present.
7. Location in the vertical—If point sampler is used for one way integration, mention which direction the sampler was moving, the depth dividing the integrated portions, and the total depth.
8. Gage height—Inside or outside gage used. Note any unusual conditions that may affect reading.

Sediment related data

Water temperature

Water temperature data may seem unimportant in comparison with the sediment data. However, it has a growing list of uses besides the need to help evaluate the sediment-transport characteristics of the stream. The temperature or viscosity of the flow affects sediment suspension and deposition and may affect the roughness of a sand-bed stream.

In October 1967 the Geological Survey began to record and publish water temperature in



UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES DIVISION
INSPECTION SHEET

Sta. No. 11-4810 Date JAN. 14, 1969
Station MAD RIVER NEAR ARCATA, CALIF.
Party GAMBLE Disch. 29,000
Width 191 Area 3000 Vel. 9.70 Time 1000 G.H. 24.65 inside
G.H. ______ outside

SUSPENDED SEDIMENT SAMPLES: Wading, [✓ cable], ice, boat, upstr., downstr.,
side bridge ______ feet, mile above, below gage and ______
Sampler: D-43, [✓ D-49], DH-48, DH-59, P-46, P-61, other ______

Method	Time	G.H.	No. of Vert.	No. of Bottles	Stations
CENT.	1030	24.67	4	8	50, 100, 150,
					200

Nozzle size 3/16 in.
Air: 45° °F at 1045
Water: 44 °F at 1045
Weather COOL RAINY
Flow TURBULENT
Turbidity ______

BED MATERIAL SAMPLES: Time 1210 G.H. 24.74 No. samples 4
Sampler: DRAG Wading, cable, ice, boat, upstr., downstr., side
[✓ bridge] 300 [✓ feet] mile above, [✓ below gage] and ______
Stations 50, 100, 150, 200

Stage: [✓ Rising], falling, steady, peak Peak G.H. 24.77
Observer: Contacted-yes ✓ no ______ Cases-in 3 out 3 res. 6
INSTRUCTIONS: ______

REMARKS: ______

Figure 29.—Inspection sheet for use by fieldman to record the kinds of measurements made and the stream conditions during a visit to a sediment measurement site.

degrees Celsius (0° corresponds to 32° F, and 1° C equals to 1.8° F). Table 1 in Porterfield (1970) may be used for conversions.

The best or preferred method to obtain the correct water temperature is to submerge the thermometer while wading some distance out in the stream. The thermometer is held beneath the water until sufficient time (about one-half minute) has passed to allow the temperature of the thermometer to equalize with the water temperature. The stem or the scale of the thermometer is raised out of the water and held so that the etched scale on the stem is at right angles to the line of sight and then the temperature should be read to the nearest one-half degree. The bulb of the thermometer should always remain in the water until after the reading is obtained. The reading of a wet thermometer when exposed to the air may decrease several degrees in a matter of seconds because of evaporation if the air is dry or the wind is blowing. Be certain that the location in the stream where the temperature is taken is not affected by the inflow from a spring or tributary.

When it is not possible to wade out into a stream, the water temperature may be taken from a sample bottle. The thermometer should be inserted into a bottle from near midstream to let the thermometer adjust to the approximate temperature. Then, immediately after removing the next bottle from the sampler, transfer the thermometer from the previous bottle and allow about 15 seconds for the temperature to stabilize. The thermometer should be read while the bulb of the thermometer is submerged. When removing the thermometer from a bottle, it should be shaken slightly after lifting about 2 inches from the bottom to remove sediment from the case of the thermometer. Most "fresh" waters freeze at 0° C; therefore, if a negative reading is obtained, an error is indicated. Brackish and brine waters freeze at temperatures somewhat less than 0°C depending on the kind and concentration of ions present.

Stream stage

As with temperature, stream-stage data may seem insignificant but in reality can be very important. The data at times may be used to construct missing gage-height records for periods of recorder failure and to verify time of sampling or who collected the sample. Gage heights may also serve to indicate whether the observer actually obtained a sample at the time and in the manner indicated by available notes.

Remember that the gage height is defined as the water surface elevation referred to some arbitrary gage datum. In order for the gage height to be considered correct, the observer and fieldman should always note which gage is read. The streamflow and sediment records are computed on the basis of the inside or recording gage. The observer usually is instructed to read only the outside or reference gage. Because of differences in location and the effect of velocity head, it is not expected that both gages will read the same at a given time, though some relationship may exist between them as the stage changes (Buchanan and Somers, 1968, and Carter and Dividian, 1968). The fieldman should record all stream-stage information on the inspection sheet (fig. 29).

The outside reference gage may be one of two general kinds. The most common of the kind exposed continuously to the flowing stream is the staff gage and the slope gage. Under turbulent flow conditions these exposed gages should be read by noting the average of several "high" and "low" readings that may occur within a period of 10 or 15 seconds. It is necessary to make certain that the observer understands that the scale is divided into hundredths of a foot and not feet, inches, and fractions of an inch, or that he understands the divisions of the metric system if that is used. The other general kind of outside gage is the wire-weight gage or the chain gage that is usually attached to the bridge railing. The weight from this type of gage is lowered so that its bottom breaks the water surface about half the time when there are water waves or ripples. For the wire-weight gage, the gage height is read on the scale of the drum at the pointer. For the chain gage, the reading is obtained on the scale provided.

The inside gage height is usually referenced by tape from a float in a stilling well to a pointer. The stilling well is connected hydraulically to the flow of the stream. The inside reference gage should correspond to the gage height being recorded, but as mentioned previously, it may vary somewhat from the outside gage. If the variance between inside and outside gages is unusually large and the inside gage is lagging the actual gage height of the stream, then the intake should be flushed to remove any obstruction, usually caused by sediment accumulation.

The fieldman should record the inside gage reading at least once each visit to the station to insure that the gage is working properly. Also, if the observer uses the outside gage, the fieldman should record the readings from both the outside and the inside gages.

Cold weather sampling

Subfreezing temperatures can cause surface ice, frazil ice, and anchor ice to form on or in a stream and create many difficulties in regard to suspended-sediment sampling. The surface ice usually forms at the edges of the stream first and covers the midstream part last. If it is necessary to use surface ice for support to make holes for sampling, extreme caution should be exercised because such ice can be deceivingly weak, especially during alternating freezing and warm periods. A wooden or some other low-cost insulating cover can be used to protect sampling holes drilled or chopped at a daily station from badly refreezing. It is recognized that the cover may be lost if the weather warms sufficiently for the ice to break up. In some situations it may be possible to attach the cover to the sampler cable so it may be removed without walking out on the ice. The sampler would have to be removed and protected from loss at the sampler shelter. Suspended-sediment samplers should never be used to break through seemingly thin ice by dropping the sampler more than 3 or 4 inches. The sampler and nozzle can be damaged by such forces. If the ice will not break by the sheer weight or very gentle drop of the sample, then a hole must be opened by some other means.

If the ice is too thin to safely support a person's weight, it is best not to obtain a sample for one or even more days, because winter samples are generally low in sediment concentration, and therefore, most certainly are not worth taking chances of on an accident. When the spring breakup occurs, the large slabs of floating ice can easily cause damage to the sampler, the support equipment, or the operator. In this case, a surface sample (see page 41) may be all that can be obtained between cakes of floating ice. Every effort should be made to obtain such a surface sample because the sediment concentration can and usually does change considerably under such conditions.

Frazil ice is composed of the small ice crystals formed at the surface in the turbulent part of the stream. The crystals are formed in a variety of shapes from slender needles to flat flakes. They do not freeze together because of the swift current but may bunch together to form a soft mass. This kind of ice may partly or completely clog the intake nozzle of the sampler. Sampling may best be accomplished by swiftly moving the sampler through the layer of frazil ice and then use a normal transit rate to sample the relatively ice free region below. Often when such ice obstructs the nozzle, it will remove itself when the sampler is out of the water and the only indication that the sample is in error is that the quantity of water in the bottle is significantly smaller than would be expected under normal circumstances.

Anchor ice is formed on the bottom in shallow streams by radiation of heat during the colder nightime hours. Incoming radiation and the warmer temperatures during the day allow this ice to break loose from the bottom and float to the top to mix with the frazil ice. Sometimes when the nozzle contains frazil or small pieces of anchor ice when the sampler is brought out of the water, a subfreezing air temperature will cause the ice to freeze tight in the nozzle. If the ice freezes tight to the nozzle or if the sample bottle freezes to the sampler casing, it will be necessary to heat the sampler either by warming with a car heater, soaking the sampler in a container of warm water, or heating the nozzle and head with a small propane torch. Care must be taken with the last method because the rubber gaskets in the head can be damaged by the heat. Some of these problems can be avoided by the use of two samplers, so that while one is thawing the other can be used to sample.

If the sampler or samplers are kept beneath the car heater between stations or while the observer drives to his station, the first one or two verticals can be more easily sampled. The observer should be advised and encouraged to remove the nozzle from the sampler and leave the sampler head in the open position when he finishes his sampling. This will allow the gasket, nozzle, and air vent to dry more completely and may avoid a frozen nozzle or head frozen shut on the next visit.

Aside from the problems with plugged nozzles, a very cold sampler may cause freezing of water between the sample bottle and the inside of the sampler. This problem can be minimized by removing the bottle as quickly as possible from the sampler after the integration is complete; otherwise, it may be necessary to heat the sampler as described above. It is also obvious that samples in glass pint bottles must be protected from freezing after the measurement and in transport to the laboratory. Freezing itself does not harm a sample for sediment analysis but a broken bottle will obviously result in loss of the sample.

Bed-material sampling

Data on the size of material making up the streambed are useful for study of the long range changes in channel conditions and for use in computations of unmeasured or total load. (See page 54.) Research studies also require information on bed material, but the reasons for and the need of such information is specialized.

For materials finer than medium gravel

The selection of a suitable bed-material sampler is primarily dependent on stream depth and velocity. When a stream can be waded, the most practical of the standard samplers (see page 14) is the BMH–53. Its use can be extended somewhat to about 4 feet in depth by the use of a boat.

To use the BMH–53, it is placed in a vertical position on the streambed with the piston extended to the open end of the cylinder. The cylinder is then pushed the full 8 inches into the bed while the piston is held at the bed surface. Complete filling of the cylinder will help insure a minimum of disturbance of the top 1 or 2 inches when the sampler is raised through the flow. When coarse sand or gravel material is being sampled, it is often necessary to pull on the piston rod while pushing on the cylinder. By pulling on the piston, a partial vacuum is created above the sample which helps draw the sample into the cylinder and may also reduce some of the required cutting pressure. The sampler is then withdrawn from the bed and held in an inclined position above the water with the cylinder end highest. For most purposes only the upper inch of material nearest the surface of the streambed is desired or needed in an analysis. This is obtained by pushing on the piston while the sampler is still inclined until only 1 inch of material remains in the tube. (See fig. 15.) Any excess material is removed by smoothing off the end of the cylinder with a spatula or a straight pencil. The material left in the sampler is ejected into a container (usually a paper or plastic carton). An experienced fieldman can composite samples or observations from the entire cross section into just a few cartons as indicated by differences in flow conditions and differences in bed material size and composition. The inexperienced fieldman would do well to use a separate container for each vertical. Before storing the sampler, it should be rinsed by stroking the piston a few times in the stream to remove sediment particles from the cylinder and piston seal.

If the stream is too deep or swift for the BMH–53, then the BMH–60 or the BM–54, or a surface sampler must be used. The 30-pound BMH–60 is easiest to use when stream velocities are under 2 or 3 feet per second and depths are less than about 10 feet. To use the BMH–60, suspend the entire weight of the sampler by the hanger rod and cock the bucket in the open position with the allen wrench provided. The energy thus imparted to the spring and the sharp edge of the bucket make it obvious that one must keep his hands away from the bucket opening at all times. If necessary, the safety yoke may be fastened around the hanger bar while opening and cocking the bucket. After the safety yoke is removed and fastened to the tail, the sampler can then be lowered by hand or by cable and reel to the surface of the stream bed. Any jerking motions made while lowering the sampler that would cause the cable to slack may release the catch and allow the bucket to close prematurely. This can happen if the water surface is struck too hard. After the cocked sampler touches the streambed and tension is released on the line, the sampler should be lifted slowly from the bed so the bucket will scoop a sample even if the spring tension is not sufficient to force the bucket through the bed upon contact.

To remove the sample from the bucket, the sampler is positioned above a carton or container and the bucket opened with the allen wrench. The sampler need not be held by the hanger bar during sample removal unless considerable material is clinging to the flat plate within the bucket cavity. If removal of such material is required, the bucket should be cocked in the open position and the sample brushed into the container with a stick or small brush. When moving the sampler between verticals and when storing it in the trunk, the bucket should be in the closed position to avoid an accidental closing and to reduce the tension on the spring.

The 100-pound BM–54 is needed for velocities that are above 2 or 3 feet per second and depths that are greater than about 10 feet. The BM–54 action, described on page 15, is similar to the BMH–60 except that the bucket opens front to back. It is used only with a reel-and-cable suspension and is rather awkward to handle when removing the sample. The techniques for taking a sample with the BM–54 are essentially the same as for the BMH–60. One important difference in operation involves the use of a safety bar on the BM–54 to hold the bucket in an open position instead of the safety yoke on the BMH–60. As noted earlier, the sampler should be stored with the bucket in a closed position and if extended storage is anticipated, the tension on the spring should be further reduced.

When extremely high velocities are encountered and samples are unobtainable with the BM–54, there may be two other alternatives. Either an additional C-type weight can be placed on the hanger bar above the BM–54 or the disk-type surface sampler can be used. If additional weights are required with the BM–54, extreme care should be taken to avoid bending and possibly breaking of the hanger bar between the sampler and the C-type weight.

To use the surface sampler described on page 19, the white petroleum jelly (vaseline) disk is strapped onto a heavy sounding weight (up to 200 pounds) so that the disk is on the bottom side of the weight. The sampler is lowered to the streambed at any speed desired. Upon striking the bed, the sounding weight forces the petroleum disk against the streambed and assures adherance of the streambed surface particles. After raising the sampler from the water, the disk is removed from the sampler and another disk is attached for the next vertical.

The surface sampler can sometimes be used where the standard samplers will not collect a sample. When only the surface bed material is desired in wadable streams, the disk can also be attached to the bottom of a wading rod.

For materials coarser than medium gravel

Gravels in the 2 to 16 mm range can be analyzed by mechanical dry sieving, and in order to obtain a representative size, the size of the sample to be collected must be increased with particle size. Large sediment sizes (>16 mm) are difficult both to collect and analyze. The methods now in use in the determination of these very large sizes involve hand or manual collection and measurement of at least 100 pebbles on a wadable streambed. There are no methods by which the size of coarse particles can be determined in a non-wadable stream. A grid pattern locating the sampling points can be paced, outlined by surveys, or designated by small floats. At the intersections of the grid pattern, the "pebble" underlying the toe is retrieved and a measurement is made of the long, intermediate, or short diameters, or all three. The measurements are tabulated as to size interval and the percentage of the total of each interval is then determined (Wolman, 1954).

Because the pebble-count method entails the measurement of the dimensions of randomly selected particles in the field, it is laborious and usually limits the number of particles counted. Too often, therefore, this results in an inadequate sample of the population.

Another method for analyzing coarse particles is being evaluated at this time and involves the use of an instrument about the size of a typewriter known as the Zeiss Particle Size Analyzer (Ritter and Helley, 1968).

For the Zeiss technique, a photograph of the streambed is made during low flow with a 35-mm camera supported by a tripod about 2 m above the streambed—the height depends on the size of the bed material. A reference scale, such as a steel tape or surveyor's rod must appear near the center of the photograph.

In the laboratory (Guy, 1969), particle diameters are registered cumulatively or individually on exponential or linear scales of size ranges. After the data are tabulated, the sizes registered on the counter of the particle size analyzer must be multiplied by the reduction factor of the photograph which is calculated from the reference scale in the photograph.

Location and number of sampling verticals

Bed-material samples are often needed in conjunction with a water-discharge measurement and (or) a set of suspended-sediment samples. If the discharge measurement and (or) the suspended samples are taken first, then the bed-material samples should be collected at the same stations, but not necessarily the same number of stations. By taking them at the same stationing points, any change in bed material or radical change in discharge across the stream that would affect the sediment-discharge computations can be accounted for by subdividing the stream section at one or between two of the common verticals.

For wadable streams, it is often best to obtain the bed-material samples prior to the water- or suspended-sediment measurements to avoid excess disturbance of the bed. Also by taking the bed material first, radical changes across the section in bed-material size and water discharge can be used as a basis for choosing desirable verticals for the other measurements.

The techniques used to define the quality of a group mean (p. 37) can also be used to determine the number of bed-material samples required at a cross section. The logical procedure is to use the results from a rather detailed set of 10 to 20 bed-material samples at the measuring section—each sample is analyzed individually for all desired statistics such as d_{15}, d_{50}, and d_{85}. For example, assume that the most used information involves the d_{50} statistic, and that there are 15 samples available with d_{50} of 0.91, 0.70, 0.80, 0.64, 0.63, 0.56, 0.53, 0.50, 0.47, 0.51, 0.43, 0.45, 0.90, 0.69, and 0.81 mm with a mean of 0.635 mm. If this mean were 100, then the d_{50} observations would be 143, 110, 126, 101, 101, 88, 84, 79, 74, 80, 68, 71, 142, 109, and 127, respectively. The sum of the squared deviations from 100 for these would be 8,980, and based on the data in figure 23 the mean observed d_{50} (0.635) will predict the population mean within ± about 12 percent at the 90-percent level of significance.

To illustrate how this information can be used to predict the desired number of bed-material samples in the cross section, assume that prediction of the d_{50} mean within ±20 percent and the 90-percent level of confidence is acceptable. Then the required number of observations can easily be determined by projecting a line across the chart (fig. 23) from 20 percent that is parallel to the line 8,980 "deviations" and 12-percent error. The new line would be 3,200 "deviations" and 20-percent error and therefore the required number of samples would be six.

If prediction of the mean within ±20 percent at the 80-percent level of confidence is acceptable, the base line is 8,980 "deviations" and 12/0.77 or 15.6. A line parallel to this at 20/0.73 or 27.4 percent indicates that five samples will be satisfactory.

The above analysis to determine the required number of bed-material samples then has two important requirements. First, that data from a representative detailed observation be available that will indicate the natural variability among the samples for the commonly used data; and second, that the requirements with respect to the future use of the data be known so that a reasonable allowable error may be used.

The use of a calculated number of sampling verticals required does not imply that one must ignore practical considerations when sampling bed material. Dead water areas behind sand bars or bridge piers should be avoided for both bed material and suspended sediment, as well as the water-discharge measurement. If sand bars or islands are located within the cross section, the stream should be sampled and measured as two or more separate streams. The verticals as calculated above should ordinarily be spaced uniformly, but when most of the discharge is at one side or section of the stream, it may be desirable to decrease the spacing between verticals in that section and thus treat the area of maximum discharge as a separate stream.

Most results from bed-material samples will not be noticeably affected, but it should be remembered that the sample taken with the BMH–53 is different from that of the BMH–60 and the BM–54. The cross section of the BMH–53 is constant with depth so that each increment of sample with depth is equally represented by volume. The curved buckets of the BMH–60 and BM–54 do not sample equal volumes of material with depth, but rather the bottom one-half inch of the 2-inch-deep bucket contains only 15 percent of the total sample whereas the upper one-half inch contains 33 percent of the sample.

Sample inspection and labeling

As samples are obtained across the stream, the fieldman should visually check and compare each sample with the previous samples to see if the material varies considerably in size from one location to the next. If a given sample does contain considerable coarser or finer material, another sample should be obtained about a foot from the original location. After two or three tries in the vicinity of the first sample with no appreciable difference, the first sample should be retained. Small deposits of material that is coarser or finer than most of the bed material are not considered representative of the bed-material size for the stream cross section.

Proper labeling of bed-material samples is not only necessary for future identification but also provides important information useful in the laboratory analysis and the preparation of records. Information desired on each bed material carton should include:

Station name
Date
Time
Gage height
Water temperature
Stationing number
Bed form and flow conditions
Carton number of the set
Kind of sampler used
Purpose of sample or special instructions for analysis and computations
Initials of fieldman

Measurements for total sediment discharge

As noted in the previous discussions, the sediment sampling equipment is limited mostly to the collection of suspended-sediment and bed-material samples from streams. The suspended-sediment sampler can sample to only within a few tenths of a foot of the streambed. (See table 2.) The sampled part is referred to as carrying the measured load and the unsampled zone as carrying the unmeasured load (fig. 1). The unmeasured load contains both unmeasured suspended-sediment load and the unmeasured bedload. (Bedload is that material transported in a stream by sliding, rolling, or bounding along the bed and very close to it, that is, within a few grain diameters.) Total load, then, is the sum of the measured and unmeasured load.

There are some sand-bed streams with sections so turbulent that nearly all sediment particles moving through the reach are in suspension. Sampling the suspended sediment in such sections with a standard suspended-sediment sampler then very nearly represents the total load. Several streams with turbulent reaches are described in Benedict and Matejka (1953). Further discussion concerning total-load measurement can also be found in Inter-Agency Report 14 (F.I.A.S.P., 1963b, p. 105–115). Turbulence flumes or special weirs can be used to bring the total load into suspension. Total load can usually be rather accurately sampled where the streambed consists of an erosion resisting material such as bedrock or a very cohesive clay. In such situations, the majority if not all the sediment being discharged is in suspension or the bed would contain a deposit of sand.

Benedict and Matejka (1953) and Gonzales, Scott, and Culbertson (1969) have described some structures used for artificial suspension of sediment to enable total load sampling. However, most total load sampling is usually accomplished at the crest of a small weir, dam, culvert outlet, or other place where the sampler integrates throughout the full depth of flow and where only the nozzle of the sampler touches the weir over which coarse material may be moving.

Where such conditions or structures are not present, the unmeasured load must be computed by various formulas. The unmeasured load can be approximated by use of a bed-load formula such as Colby and Hubbell (1961), Einstein (1950), Chang, Simons, and Richardson (1965), or Meyer-Peter and Muller (1948). The Colby and Hubbell method (modified Einstein) determines the total load in terms of the amount transported for different particle-size ranges. Because the Colby and Hubbell technique is widely used, essential data required for its use at a particular time and location are listed:

1. Stream width, average depth, and mean velocity.
2. Average concentration of suspended sediment from depth-integrated samples.
3. Size analyses of the suspended sediment included in the average concentration.
4. Average depth of the verticals where the suspended-sediment samples were collected.
5. Size analyses of the bed material.
6. Water temperature.

Reservoir trap efficiency

The efficiency with which a body of water will trap sediment depends mostly on its size with respect to the rate of inflow. Other factors may include the reservoir shape, its operation, the water quality, and the size and kind of inflowing sediment. Except for small detentions with bottom outlets, all of the sand-sized and much of the silt-sized particles would be expected to be trapped. An evaluation of reservoir trap efficiency must then involve measurements of the quantity and size characteristics of the sediment entering and leaving the reservoir (Mundorff, 1964 and 1966). Sometimes measurements of sediment accumulation in the reservoir plus the sediment output are used as a practical method of evaluating the input and sediment yield of the drainage basin.

Inflow measurements

On many reservoirs, trap efficiency cannot be evaluated in sufficient detail from measurements of accumulation and sediment outflow. Therefore, it is necessary to measure the mean particle size and concentration of sediment in the flow entering such reservoirs. This then requires that the inflow station be operated as a daily or continuous-record station for streams feeding into reservoirs of several thousand acre-feet. Trap efficiency on a storm event basis can be determined if several samples adequately define the concentration of the inflow and outflow hydrographs. For small detention reservoirs, it may be difficult or impractical to measure the inflow on a daily basis. If a continuous record is not possible, then the objective should be to obtain observations sufficient to define the conditions for several inflow hydrographs so that a "storm-event sediment rating curve" can be constructed for use in estimating the sediment moved by the unsampled storms (Guy, 1965).

If it is impractical to obtain sufficient data to define the sediment content of several storm events, the least data for practical analysis should include 10 or 15 observations per year so that an "instantaneous sediment rating curve" can be constructed (Miller, 1951). It is expected that the instantaneous curve will yield less accurate results than the storm-event curve, which in turn will be less accurate than the continuous record. Each of the rating-curve methods may require data for a range of conditions so that adjustments can be determined for the effect of time of year, antecedent conditions, storm intensity, and possibly the storm location in the basin (Colby, 1956; Jones. 1966).

As for most new sediment stations, particle-size analysis should be made on several of the inflow observations during the first year. These particle-size observations then will form a base from which, hopefully, it will be possible to reduce the number of analyses required in the future years.

Outflow measurements

The outflow from a reservoir is drastically different from the inflow because of the attenuating effect of the flow through the reservoir or because of possible willful control in the release of water (Mitchell, 1962; Carter and Godfrey, 1960). Logically, the smaller reservoirs that are likely to have a fixed outlet and the poorest trap efficiency require the most thorough outflow measurement schedule. If an inflow-outflow relation for sediment discharge can be constructed, then it may be that such a relation will change considerably in the direction of greater sediment output (lower trap efficiency) as the reservoir fills with sediment.

Normally, the particle size of sediment outflow is expected to be finer than for the inflow, and therefore the concentration of outflowing sediment should not fluctuate as rapidly as that of the inflow. The normal slowly changing outflow concentration may not occur if the outflow is from the vicinity of the interface involving a density current.

A desirable sampling schedule for outflow may vary from once a week for the large reservoir to several observations during a storm event for a small reservoir. The need for outflow particle-size data will also depend on the scale of the stream and reservoir system, the trap efficiency, and how well the inflow is defined. In respect to quality control, if the trap efficiency of a reservoir is expected to be more than 95 percent and if the sediment inflow can only be measured to the nearest 10 or 15 percent of its expected true value, then it is not necessary to measure the sediment outflow in great detail, unless of course, there is a need to accurately know the amount of sediment in the flow downstream of the reservoir.

Sediment accumulation

The small reservoir or detention basin can be used, if trap efficiency can be estimated or measured, to provide a measure of the average annual sediment yield of a drainage basin. This method is useful in very small basins where the inflow is difficult to measure and where the amount of water inflow and sediment concentration data are not important.

For small catchment basins or reservoirs on ephemeral streams (dry most of the time), the determination of sediment accumulation involves a planetable or other detailed survey of the reservoir from which stage-capacity curves can be developed—usually 1-foot contours for the lower parts of the reservoirs and 2- to 5-foot intervals for the upper parts, depending on the terrain and size of the reservoir (Peterson, 1962). The accretion of sediment can then be measured either by monumented range lines in the reservoir or by resurvey for a new stage-capacity curve.

For reservoirs not dry part of the time, the sediment accumulation is usually measured by sounding on several monumented range lines spaced so they will provide a representative indication of the sediment accumulation between measurements. Methods for reservoir surveys are described by Heinemann (1961) and Porterfield and Dunnam (1964). A summary of reservoir sediment deposition surveys made in the United States through 1965 was compiled by Dendy and Champion (1969).

In order to convert the measurements of sediment volume found in reservoirs to the usual expression of weight of sediment yield, it is necessary that the sedimentation surveys of reservoirs include information on the volume-weight of sediment. Heinemann (1964) reports that this was accomplished in Sebetha Lake, Kans., using a gamma probe and a piston sampler. From his data obtained at 41 locations, he found that the best equation for predicting volume-weight is $V_w=1.688D-0.888C+98.8$, where V_w is the dry unit volume-weight in pounds per cubic foot, D is the depth of sample from the top of the deposit, and C is the percentage of clay smaller than 2 microns.

On the basis of 1,316 reservoir deposit samples, Lara and Pemberton (1965) found the unit volume-weight to vary according to changes in reservoir operation and to the percentage of clay, C, silt, M, and sand, S. For type I (262 observations), where sediment is always submerged or nearly submerged,

$$V_w=26C+70M+97S.$$

For type II, (462 observations), where moderate to considerable reservoir drawdown occurs,

$$V_w=35C+71M+97S.$$

For type III, (405 observations), where the reservoir is normally empty,

$$V_w=40C+72M+97S.$$

For type IV, (187 observations), where the deposit is essentially a continuing part of river-bed sediments,

$$V_w=60C+73M+97S.$$

The standard error of estimate for the four equations is 12.3, 14.0, 12.4, and 11.0 pounds per cubic foot, respectively.

Summary

In retrospect, it must be emphasized that field methods for fluvial sediment measurement have evolved toward a system that must be coordinated with other hydrologic and environmental measurements. With the ever-increasing requirements of a thorough data acquisition system, together with advances in technology, it must be expected that much evolution will continue into the future. For example, in the foreseeable need for increasing water-pollution-surveillance studies with respect to stream quality standards, it is apparent that a continuous recording of some indicator of sediment conditions is badly needed at a very large number of sites. Consequently, the F.I.A.S.P. has undertaken the development of turbidity-indicating recorders with a view toward recording at least the concentration of fine sediment moving in streams. The development of such automatic equipment is likely to enhance rather than detract from the need for conventional "manual" observations.

The writers sincerely hope that the material presented herein on the equipment and techniques for sampling will stimulate the development of better equipment and techniques for the future while at the same time help to "standardize" and make more efficient the day-to-day operations. The opportunity certainly exists for many innovations at the field office for improving the end product or the sediment record. Some fieldmen, for example, may like to carry a copy of the station stage-discharge rating curve on which all particle-size analyses are recorded showing date and kind of sample for each measuring site. As communications and river forecasting become more sophisticated, it may be possible to have better dialogue between the field office and the fieldman, who is trying to obtain the maximum information at many sampling sites, or even directly to the local observers. Such communication is especially critical during periods of flooding when timely data are most important.

In addition to increasing coordination of sediment-data activities with other related measurements, it is important to stress that adequate notes be obtained (including pictures) so that those involved in the laboratory analysis of the samples, those responsible for preparing the record, and especially those responsible for interpreting the data can properly "read" what happened at the stream. Needless to say, the amount of new information to be obtained from data interpretation is seriously affected by the quality of the information with respect to timing and representativeness of the sediment measurements.

It also seems desirable in this summary to further emphasize the need for a concerted and continuing effort with respect to safety in the measurement program. Aside from the hazards of highway driving, the work usually requires the use of heavy equipment during floods or other unusual natural events, often in darkness and under unpleasant weather conditions. Even though the hazards of working from highway bridges and cableways are mostly self-evident, there are many opportunities for the "unusual" to happen and therefore a great deal of effort must be expended to insure safety. Such effort, of course, must be increased when it is necessary to accomplish the work in a limited time and with fewer than the desired number of personnel.

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