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

Book 3, Applications of Hydraulics

Chapter C2

Field Methods for Measurement of Fluvial Sediment

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

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

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

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

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

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

Single-Stage Samplers

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

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

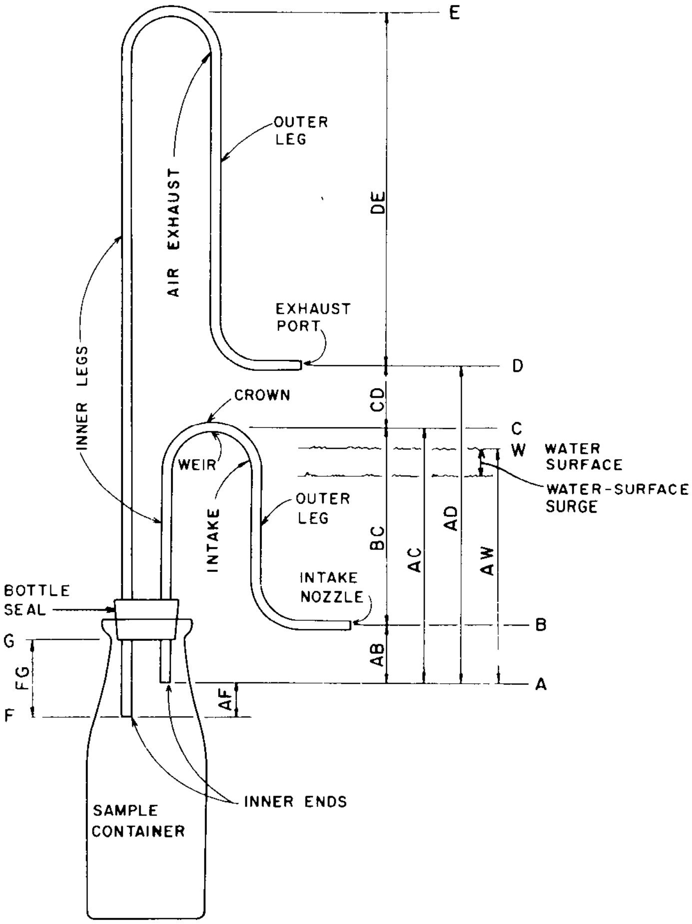


Figure 13. US U-59 single-stage suspended-sediment sampler. Sampling operation using designated letters is described in text (see also Federal Inter-Agency Sedimentation Project, 1961).

sized to fit and seal the mouth of the sample container. There are two general types of this sampler, one with a vertical intake and the other with a horizontal intake. The horizontal-intake type is further divided into three versions, each distinguished from the others by the height of the intake and air-exhaust tubes. Under some conditions either type could be used, but the two are not always interchangeable.

The vertical-intake sampler is used to sample streams carrying sediments finer than 0.062 mm. The vertical-intake sampler has the advantage of somewhat less tendency to fouling by debris and deposits of sediment in the intake nozzle than does 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 is described by F.I.S.P. (1961, p. 17):

> When the stream surface rises to B, 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 elevation 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 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 alter 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 manually collect samples. Besides being automatic, it is inexpensive; 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, the U-59 has many limitations. Following are the most important:

1. Samples are collected at or near the stream surface, so that, 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; 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.
10. Under high velocities, circulation of flow into the intake nozzle and out the air exhaust can occur. This will increase the concentration of coarse material in the sample and can make the sample concentration several orders of magnitude higher than stream concentration.

To cover a wide range of operating conditions, four "standard" models of the U-59 are available. The many specific details of these are further described in F.I.S.P. (1961).

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

The U-73 (fig. 14) is a more sophisticated single-stage sampling device. The sampler's design configuration solves several of the problems characteristic of the U-59. Specifically, this sampler (1) can be used to sample either a rising or falling stage, (2) has no problem of condensation in the sample container before the spring-loaded stoppers are tripped, and (3) features an exterior design that allows for a degree of protection from trash or drift without additional covers or deflection shields. Aside from these few advantages, the U-73 has the same limitations and should be used under the same conditions as the U-59.

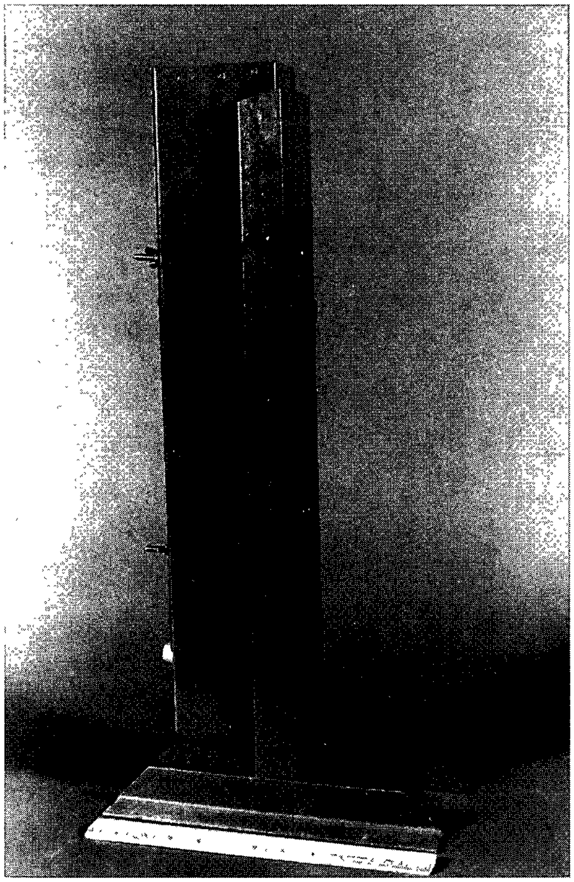


Figure 14. US U-73 single-stage suspended-sediment sampler.

The investigator using either the U-59 or U-73 may find protective measures necessary to avoid blockage of intakes or air exhausts due to nesting insects. In freezing climates, precaution may be warranted against sample-container breakage due to expansion of a freezing sample. Samples for water-quality analysis can be collected using the U-73-TM version of the U-73. However, do not use insecticides or antifreeze solutions if samples are to be analyzed for water quality because these will obviously contaminate the sample.

Bed-Material Samplers

Limitations

To properly sample bed material for interpretation, it is first necessary to establish what constitutes bed material and understand its relation to transported load, especially to bedload. Bedload is best defined as sediment that moves by sliding, rolling, or bouncing along on or near the streambed (Hubbell, 1964; Leopold and others, 1964; Emmett, 1980a). Bed material, on the other hand, is best defined in the Office of Water Data Coordination (1978) National Handbook, chapter 3, p. 3–5, which describes bed material as "the sediment mixture of which the bed is composed." In alluvial streams, bed-material particles are likely to be moved at any moment or during some future flow conditions. From the perspective of Leopold and others (1964), the streambed is composed of two elements, distinguished one from the other by particle size and their reaction to stream velocity. The first element consists of particles frequently transported as part of the suspended load or bedload, but considered as bed material when at rest. The second element consists of particles and aggregates of particles that compose definite structures on the streambed and reside there indefinitely or at least for long periods of time. The size fractions comprising the second element may only be moved by the most extreme flow events during which streambed erosion and scour occur.

The samplers described in this section can only accommodate bed material consisting of particles finer than about 30 or 40 mm in diameter. These bed-material samplers cannot accurately collect representative samples of particles larger than 16 mm, however. As noted in the description of individual samplers, there also may be limitations with respect to some very fine sediments because of poor sealing of the sampler after collection. This limits bed-material sampling, with standard US type samplers, to fine material that might be transported in suspension or as bedload at higher flows. The collection and analysis of material larger than coarse gravel are more difficult and costly because other techniques are required to handle heavy samples. Due to this difficulty in collecting large particle sizes, little information regarding bed-material size distribution is available for 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 for sampling large particles is unavailable. The interested investigator is directed to several references on direct and indirect methods of sampling and analysis of coarse bed materials, however, and is encouraged to contact Chief, Office of Surface Water, Reston, Virginia, or the F.I.S.P. for information (Lane and Carlson, 1953; Kellerhals, 1967; Wolman, 1954).

Hand-Held Samplers—US BMH-53, US BMH-60, and US BMH-80

Three types of instruments for hand sampling of bed material finer than medium gravel have been developed for general use. The BMH-53 (fig. 15) is designed to sample bed material in wadable streams. The instrument is 46 inches long and is made of corrosion-resistant materials. The sample container 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 that passes through the handle to the opposite end. The piston creates a partial vacuum above the material being sampled. This vacuum aids in overcoming the frictional resistance required to force the sampler into the bed. When sampling fine-grained material, this partial vacuum also aids in retaining the shallow core in the cylinder when the sampler is removed from the bed. The piston then serves to remove the sample from the cylinder by forcing it downward toward the bottom of the cylinder. In soft cohesive beds, this technique generally provides shallow cores with a minimum of distortion, from which sediment variations with depth and subsamples can be obtained. (See Federal Inter-Agency Sedimentation Project, 1963b and 1966, for more detailed information.) A version of this sampler, developed by the F.I.S.P. incorporates a "core catcher"

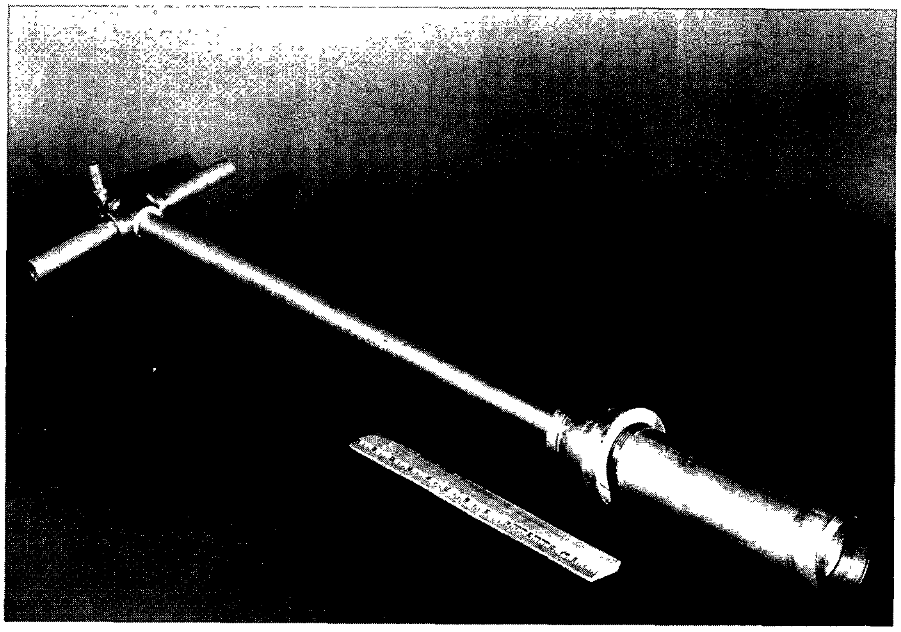


Figure 15. US BMH-53 bed-material sampler.

mechanism in the cylinder to retain samples containing a high percentage of sand.

The bed material of some wadable streams or lakes can be sampled with the US BMH-60 (fig. 16). This handline sampler is about 22 inches long, is made of cast aluminum, and weighs 30 pounds. Because of its light weight, it is useful only in streams of moderate depths and velocities. The bed material must be moderately firm and contain little or no gravel.

The sampler mechanism of the US BMH-60 consists of a scoop or bucket driven by a constant-torque 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 and can hold approximately 175 cubic centimeters 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, retract it into the body), the sampler must first be supported by the handline, then the bucket can be rotated (back to front) with an allen wrench to an open cocked position.

The hanger rod to which the handline is attached 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 because 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 to the inside of the sample bucket. (See Federal Inter-Agency Sedimentation Project, 1963b and 1966, for more detailed information.)

After the safety yoke is removed, the bucket closes when tension on the handline is released, which occurs as the sampler strikes the streambed. A gasket on the closure plate prevents sampled material from being contaminated or being washed from the bucket.

Another bed-material hand-sampling instrument available for general use is designated BMH-80 (fig. 17). This sampler is 56 inches in total length and is used to sample the bed of wadable streams. The sampling mechanism is a semi-cylindrical bucket, resembling the BMH-60 bucket assembly, which is operated by positioning the lever on the handle to open or close the bucket. When the bucket is closed and a sample volume of approximately 175 cubic centimeters of bed material is captured, the closure is sufficiently sealed to prevent erosion of the sample while the instrument is lifted through the water column.

An additional handline sampler, used successfully for bed-material chemistry sampling on the Willamette and Columbia Rivers in Oregon, is the Ponar sampler.

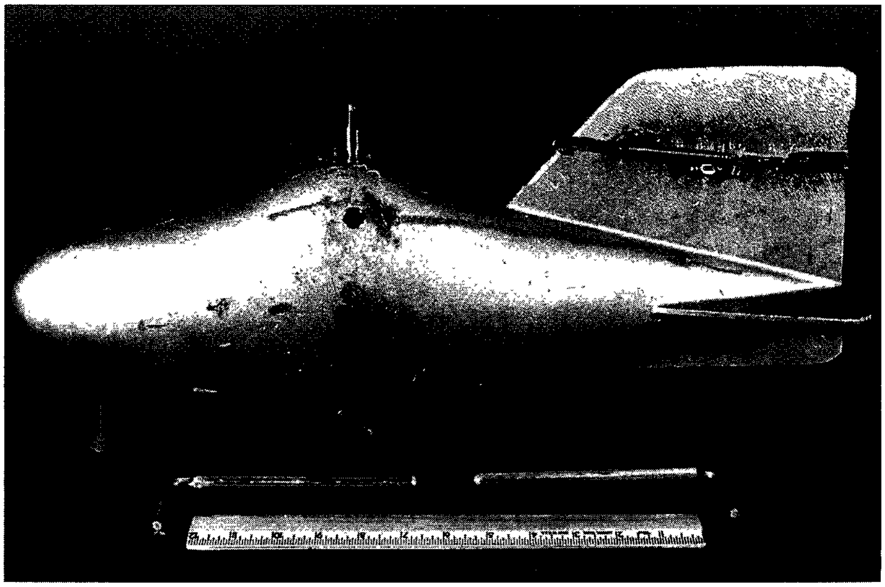
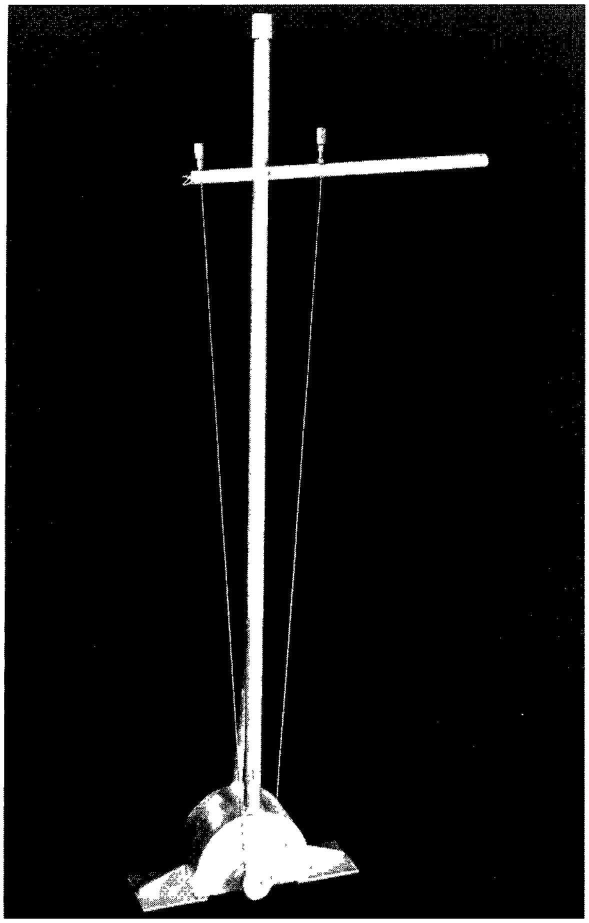


Figure 16. US BMH-60 bed-material sampler.



This is a clam-shell type sampler, consisting of two quarter-cylinder sections hinged together at the top. The sampler, which is constructed of galvanized or stainless steel, weighs about 25 pounds and can be suspended on a handline. The jaws of the instrument are held in the open position by a system of solid-notched bars and by the downward force created by the weight of the sampler on the suspension line. Gravity provides the necessary force for bottom penetration during sampling. The solid-notched bars holding the sampler jaws open are released when the downward force of the sampler's weight is released from the suspension line as the sampler strikes the bed. The sampler then closes as an upward force is applied to lift the sampler with the captured sediment. This sampler is particularly effective where bottom sediments consist of unconsolidated fines with no armoring present. Under these conditions, bottom penetration is 6 to 8 inches, resulting in a sample volume range of 8,000 cubic centimeters to 10,000 cubic centimeters of material. Some protection against erosion of the captured sediment is provided by an overlapping lip on the bottom and sides. However, a watertight seal does not exist, so care must be exercised when raising the sampler to the surface.

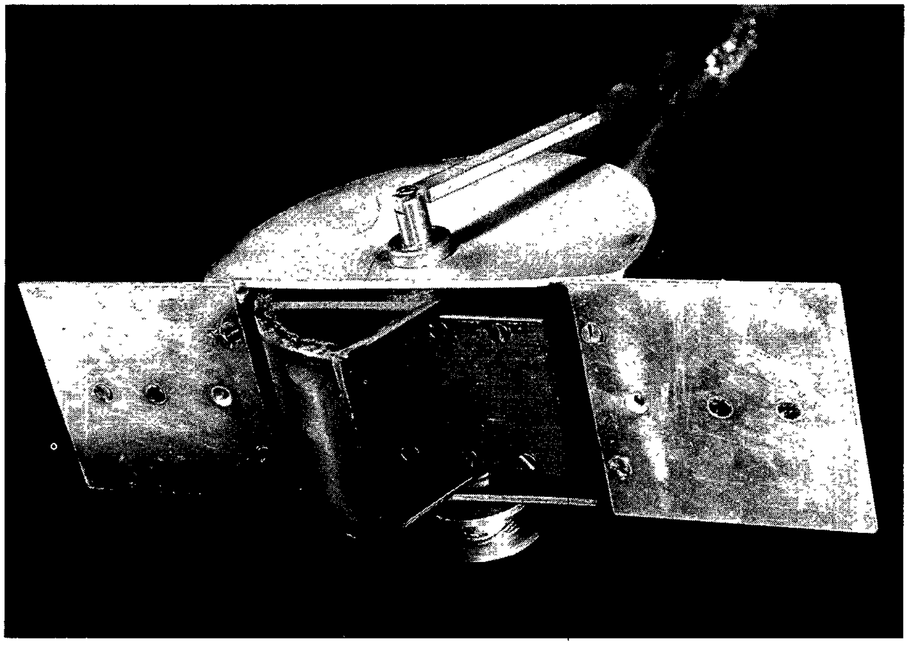


Figure 17. US BMH-80 rotary-scoop bed-material sampler. *A*, complete hand-sampling instrument (approximately 5 feet tall). *B*, Rotary-scoop assembly (approximately 12 inches long).

Cable-and-Reel Sampler—US BM-54

The 100-pound cable-and-reel suspended BM-54 sampler (fig. 18) can be used for sampling bed material of streams and lakes of any reasonable depth, except for streams with extremely high velocities. The body of the BM-54 is cast steel. Its physical configuration is similar to the cast aluminum BMH-60, 22 inches long and with tail vanes. Its operation also is 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.

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. The spring is powerful enough to obtain a sample from a 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. The trapped sample is kept from washing out by a rubber gasket. (See Federal Inter-Agency Sedimentation Project, 1963b, 1964, and 1966, for more complete description and details.)

BM-54 samplers obtained after 1956 are equipped with a safety mechanism similar to the safety yoke used on the BMH-60. This safety bar can be rotated over the cutting edge of the sample bucket when cocked into the open position. The bar keeps the bucket open when in the safety position, even if there is no tension on the hanger bar. As with the BMH-60, the cable tension on the catch mechanism holds the bucket open while the sampler is lowered. Safety bars can be obtained from F.I.S.P. and should be installed on any unit that does not have one. Again, personnel operating these samplers are cautioned to KEEP ONE'S HANDS AWAY FROM THE BUCKET CAVITY EVEN IF A SAFETY BAR IS IN USE. The power of the bucket is demonstrated by the fact that upon release, it has been observed to lift the 100-pound sampler from a hard surface.

A bed-material sampler incorporating the heavy streamlined body of the P-61 sampler and the spring-driven bucket of the BM-54 has been developed (C.W. O'Neal, Federal Inter-Agency Sedimentation Project, written commun., 1998). This sampler, the BM-84, is intended for use in large, swift rivers.

Prych and Hubbell (1966) developed a core sampler for use in deep flowing water in studies of the Columbia River estuary. This cable-suspended

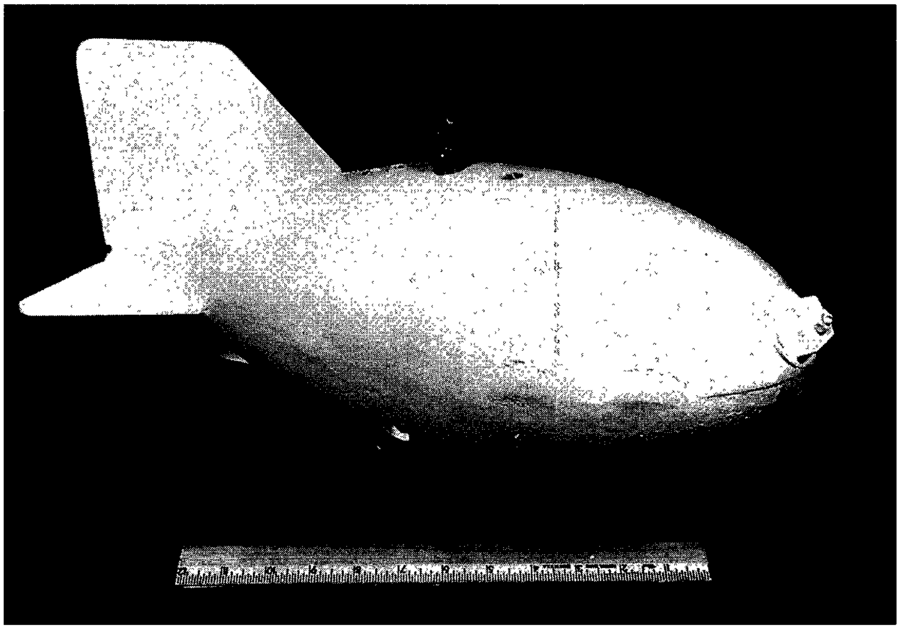


Figure 18. US BM-54 bed-material sampler.

sampler (fig. 19) is used to collect a 1 7/8-inch diameter by 6-foot-long core, by means of the combined action of vibration, suction, and an axial force derived through cables connected to a 250-pound streamlined stabilizing weight that rests on the streambed.

Smaller estuaries along the Oregon coast and other places have been successfully sampled using the Gravity Corer available from Benthos, Inc. This sampler is allowed to plunge to the bottom where, under the force of the gravitational pull on the sampler coupled with the momentum of its 250-pound total weight, it can penetrate up to 5 feet deep in soft bed material. However, much less penetration can be expected if the bed material consists of sand or gravel. The sampler is retrieved from the bed using a cable-reel boom assembly. The 2 5/8-inch diameter by 5-foot long core is retained in a core liner held in place by a core catcher at the bottom and protected against sample washout by a watertight valve at the top. The length of core and depth of penetration depend upon the degree of hardness of the bed being sampled. Other slightly more crude devices have been used with some success to sample bed material and thus deserve mention here. The two most notable of these devices are (1) the pipe dredge, which is lowered to the streambed and dragged a short distance to collect a sample; and (2) the "can on a stick" sampler, consisting of a rod with a scoop connected to the end, which can be used in wadable streams by lowering it to the streambed and scooping bed material from the bottom.

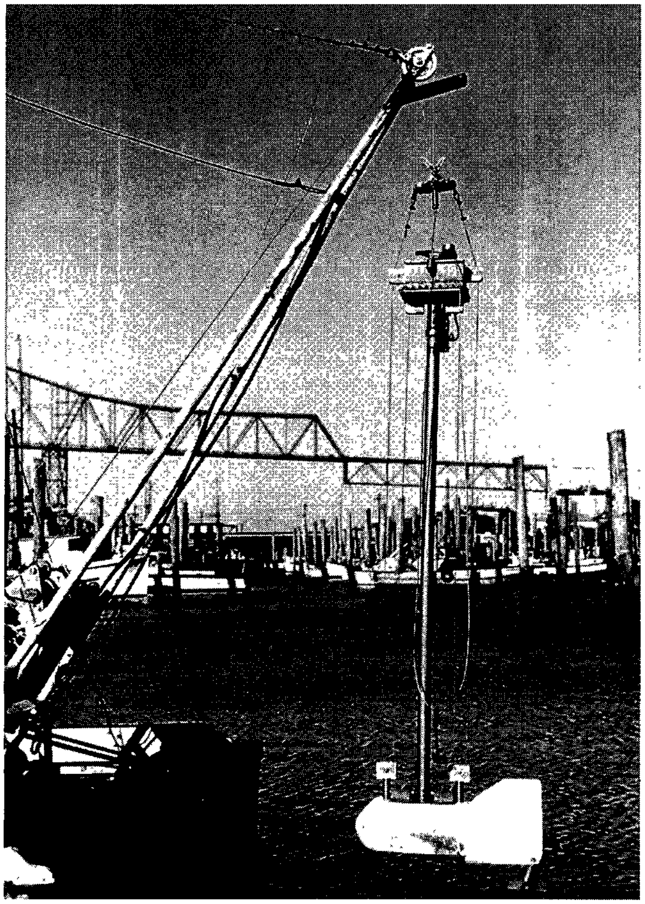


Figure 19. Vibra-core sampler prepared for coring (barrel approximately 5 feet long). From Prych and Hubbell (1966, plate 1).

Bedload Samplers

At this time, the reader should note the difference between bedload and unmeasured sediment. Remember from the bed-material section that bedload is the sediment that moves by sliding, rolling, or bouncing along on or very near the streambed. Unsampled sediment is comprised of bedload particles and particles in suspension in the flow below the sampling zone of the suspended-sediment samplers (fig. 1).

Bedload is difficult to measure for several reasons. Any device placed on or near the bed may disturb the flow and rate of bedload movement. More importantly, bedload transport rate and the velocity of water close to the bed vary considerably with respect to both space and time. Therefore, any sample obtained at a given point may not be representative of the mean transport rate for a reasonable interval of time because the bed particles move intermittently at a mean velocity much less than that of the water. Thus, a bedload sampler must be able to representatively sample, directly or indirectly, the mass or volume of particles moving along the bed through a given width in a specified period of time if bedload discharge is to be accurately determined.

Prior to 1940, most bedload was measured using some type of direct-collecting sampler. Bedload samplers developed during this era can be grouped into four categories: (1) box or basket, (2) pan or tray, (3) pressure difference, and (4) slot or pit samplers (Hubbell, 1964). Essentially, box or basket samplers consist of a heavy open-front box or basket apparatus, which is lowered to the streambed and positioned to allow collection of bedload particles as they migrate downstream. The basket type, displaying various sampling efficiencies, has been used preferentially over box types. Pan or tray samplers consist of an entrance ramp leading to a slotted or partitioned box. These samplers also have varying sampling efficiencies. Pressure-difference samplers are designed to create a pressure drop at the sampler's exit and thus maintain entrance velocities approximately equal to the ambient stream velocity. Sampling efficiencies may be higher with this type of sampler than with others, and the deposition of sediments at the sampler entrance, inherent with basket or tray samplers, is eliminated. The best known early pressure-difference sampler is probably the Arnhem or Dutch sampler, after which the Helley-Smith bedload sampler is designed. Ideally, the best measurement of bedload would occur when all of the bedload moving through a given width during a specific time period was measured. The category of samplers that most closely meet this ideal is the slot or pit sampler. This type of sampler has efficiencies close to 100 percent. The slot openings of these pits are 100- to 200-grain diameters wide to ensure the high sampling efficiency. However, samples collected in the pits are removed only with great difficulty or by use of an elaborate conveyor device. A variation of this technique, consisting of a collection trough accessed by a series of hydraulically operated gates, extends from bank to bank at a site on the East Fork River, near Pinedale, Wyoming (Emmett, 1980a). Sediment trapped in the trough during sampling is removed by means of a continuous conveyor belt, which carries the sample to a weighing station on the stream bank.

The original Helley-Smith bedload sampler, introduced in 1971, was a variation of the Arnhem pressure-difference sampler. This sampler consists of an expanding nozzle, sample bag, and frame (fig. 20). The sampler design enables collection of particle sizes less than 76 mm at mean velocities to 9.8 ft/s. The sampler has a 3-inch by 3-inch square entrance nozzle, an area ratio (ratio of nozzle exit to entrance area) of 3.22, and a 295-square-inch polyester mesh sample bag that is 18 inches long with mesh openings of varying sizes (0.25 mm most commonly used), attached to the rear of the nozzle assembly with a rubber "O" ring. The total weight of the original sampler design is 66 pounds, requiring the use of a cable-reel suspension system. However, a lighter version incorporating a wading rod assembly also is available. Heavier versions weighing 99 pounds, 165 pounds, and 550 pounds (used on the Amazon River) have been used by USGS personnel (Emmett, 1980a). A scaled-up version of the sampler having a 6-inch by 6-inch square entrance has been used to sample streams with large particle sizes.

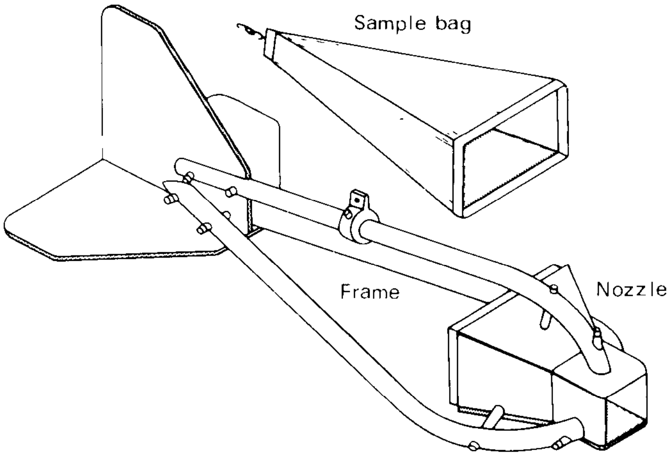


Figure 20. Helley-Smith bedload sampler. From Emmett (1980a, p. 2).

The standard 3-inch by 3-inch sampler has been calibrated in two different laboratory studies and in an extensive field study. Results of one laboratory study (Helley and Smith, 1971) indicated an average sampling efficiency of about 160 percent. Emmett (1980a) concluded from his field study that the overall sampling efficiency was close to 100 percent. A laboratory investigation (Hubbell and others, 1985) of varying bed materials and a range of transport rates indicates that the sampling efficiency of the standard 3-inch by 3-inch sampler varies with particle size and transport rate, displaying an approximate efficiency of 150 percent for sand and small gravel and close to 100 percent for coarse gravel. The standard 6-inch by 6-inch sampler had generally higher efficiencies. Tests of a Helley-Smith type sampler, which has a 3-inch by 3-inch nozzle with less expansion than the standard nozzle (an area ratio of 1.40), resulted in fairly constant efficiencies close to 100 percent for all transport rates and particle sizes. In May 1985, the 1.40 nozzle was approved by the Technical Committee on Sediment as a provisional standard sampler for use by U.S. Federal agencies. After some modifications to the frame, the 3-inch by 3-inch nozzle with 1.40-area-expansion ratio was designated the BL-84 sampler. The Water Resources Division of the USGS endorses the use of this new sampler with the 1.40-area-ratio nozzle; however, until additional testing is done, data obtained using the original 3.22-area-ratio Helley-Smith sampler will continue to be accepted.

Automatic Pumping-Type Samplers

Development and Design

Some sediment studies require frequent collection of suspended sediment at a site. Site location, flow conditions, frequency of collection, and operational costs frequently make collection of sediment data by manual methods impractical. For these reasons, F.I.S.P. and USGS personnel have developed and evaluated several models of automatic pumping-type samplers. The US PS-69 sampler is probably the best known of these samplers to be designed, tested, and used by USGS personnel. The US CS-77 (designed and tested by the Agricultural Research Service in Durant, Oklahoma) and the US PS-82 (Federal Inter-Agency Sedimentation Project, 1983) have been used. A number of automatic pumping-type samplers also have been designed by and are available through commercial sources. The Manning S-4050 and the ISCO 1680 are common commercially used samplers. (Manning Corp. is no longer in business.)

Automatic pumping-type samplers generally consist of (1) a pump to draw a suspended-sediment sample from the streamflow and, in some cases, to provide a back flush to clear the sampler plumbing before or after each sampling cycle; (2) a sample-container unit to hold sample bottles in position for filling; (3) a sample distribution system to divert a pumped sample to the correct bottle; (4) an activation system that starts and stops the sampling cycle, either at some regular time interval or in response to a rise or fall in streamflow (gage height); and (5) an intake system through which samples are drawn from a point in the sampled cross section. Ideally, this combination of components should be designed to meet the 17 optimum criteria as set forth by W.F. Curtis and C.A. Onions (U.S. Geological Survey, written commun., 1982).

1. Stream velocity and sampler intake velocity should be equal to allow for isokinetic sample collection if the intake is aligned with the approaching flow.
2. A suspended-sediment sample should be delivered from stream to sample container without a change in sediment concentration and particle-size distribution.
3. Cross contamination of sample caused by sediment carryover in the system between sample-collection periods should be prevented.
4. The sampler should be capable of sediment collection when concentrations approach 50,000 milligrams per liter and particle diameters reach 0.250 millimeter.
5. Sample-container volumes should be at least 350 milliliters.
6. The intake inside diameter should be 3/8 or 3/4 inch, depending upon the size of the sampler used.
7. The mean velocity within the sampler plumbing should be great enough to exceed the fall velocity of the largest particle sampled.
8. The sampler should be capable of vertical pumping lifts to 35 feet from intake to sample container.
9. The sampler should be capable of collecting a reasonable number of samples, dependent upon the purpose of sample collection and the flow conditions.
10. Some provision should be made for protection against freezing, evaporation, and dust contamination.
11. The sample-container unit should be constructed to facilitate removal and transport as a unit.
12. The sampling cycle should be initiated in response to a timing device or stage change.
13. The capability of recording the sample-collection date and time should exist.
14. The provision for operation using DC battery power or 110-volt AC power should exist.
15. The weight of the entire sampler or any one of its principal components should not exceed 100 pounds.
16. The maximum dimensions of the entire sampler or any one of its components should not exceed 35 inches in width or 79 inches in height.
17. The required floor area for the fully assembled sampler should not exceed 9 square feet (3 feet by 3 feet).

Installation and Use Criteria

The decision to use a pumping sampler for collection of sediment samples is usually based on both physical and fiscal criteria. These are real considerations; yet it should be understood that automatic pumping samplers can be as labor intensive and costly as the manual sediment-data collection they were designed to supplement. Installation of an automatic pumping sampler requires intensive planning before installation, including careful selection of the sampler-site location and detailed background data, to ensure the collection of useful pumped sample data.

Before installation of an automatic pumping-type sampler, many of the problems associated with installing stream-gaging equipment must be dealt with. In addition, much data concerning the sediment-transport characteristics at the proposed sampling site must be obtained and evaluated prior to emplacement of the sampler and location of the intake within the streamflow. Logistically, the sample site must be evaluated as to ease of access, availability of electrical power, location of a bridge or cableway relative to the site, normal range of ambient air temperatures inherent with local weather conditions, and the availability of a local observer to collect periodic reference samples. The sediment-transport characteristics should include detailed information on the distribution of concentrations and particle sizes throughout the sampled cross section over a range of discharges.

Placement of Sampler Intake

The primary concept to consider when placing a sampler intake in the streamflow at a sample cross section is that only one point in the flow is being sampled. Therefore, to yield reliable and representative data, the intake should be placed at the point where the concentration approximates the mean sediment concentration for the cross section across the full range of flows. This idealistic concept has great merit, but the mean cross-section concentration almost never exists at the same point under varying streamflow conditions. It is even less likely that specific guidelines for locating an intake under given stream conditions at one stage would produce the same intake location relative to the flow conditions at a different stage. These guidelines would have even less transfer value from cross section to cross section and stream to stream. For these reasons, some very generalized guidelines presented by W.F. Curtis and C.A. Onions (written commun., 1982) are outlined here and should be considered on a case-by-case basis when placing a sampler intake in the streamflow at any given cross section.

1. Select a stable cross section of reasonably uniform depth and width to maximize the stability of the relation between sediment concentration at a point and the mean sediment concentration in the cross section. This guideline is of primary importance in the decision to use a pumping sampler in a given situation; if a reasonably stable relation between the sample-point concentration and mean cross-section concentration cannot be attained by the following outlined steps, the sampler should not be installed and an alternate location considered.
2. Consider only the part of the vertical that could be sampled using a standard US depth- or point-integrating suspended-sediment sampler, excluding the unsampled zone, because data collected with a depth- or point-integrating sampler will be used to calibrate the pumping sampler.
3. Determine, if possible, the depth of the point of mean sediment concentration in each vertical for each size class of particles finer than 0.250 mm, from a series of carefully collected point-integrated samples.
4. Determine, if possible, the mean depth of occurrence of the mean sediment concentration in each vertical for all particles finer than 0.250 mm.
5. Use the mean depth of occurrence of the mean sediment concentration in the cross section as a reference depth for placement of the intake.
6. Adjust the depth location of the intake to avoid interference by dune migration or contamination by bed material.
7. Adjust the depth location of the intake to ensure submergence at all times.
8. Locate the intake laterally in the flow at a distance far enough from the bank to eliminate any possible bank effects.
9. Place the intake in a zone of high velocity and turbulence to improve sediment distribution by mixing, reduce possible deposition on or near the intake, and provide for rapid removal of any particles disturbed during the purge cycle.

Because of the generalized nature of these guidelines, it will often be impossible to satisfy them all when placing a pumping sampler intake into naturally occurring streamflows. The investigator is encouraged, however, to try to satisfy these guidelines or, at the very least, to satisfy as many as possible and to minimize the effects of those not satisfied.

Sampler Advantages and Disadvantages

Automatic pumping-type samplers are very useful for collecting suspended-sediment samples during periods of rapid stage changes caused by storm-runoff events and in reducing the manpower necessary to carry out intensive sediment-collection programs (Federal Inter-Agency Sedimentation Project, 1981b). However, it should be noted that pumping samplers quite often require more man-hours and cost more to operate than a conventional, observer-sampled type of station. Pumping samplers, because of their mechanical complexity, power requirements, and limited sample capacity, quite often require more frequent site visits by the field personnel than would be required at the conventional observer station. In addition, problems associated with collecting high-flow, cross-section samples are still present.

In streams with significant amounts of suspended-sand loads, the problems associated with using a pumping sampler are so great that two records may have to be calculated, one for the silt-clay size fraction load and one for the sand-size fraction load. This requires that most of the samples collected with the pumping sampler, as well as the samples collected manually, be subjected to a full particle-size analysis. Extensive laboratory work of this type increases the cost of analysis and computation of the sediment-discharge record. Another disadvantage is that the pumping lift for most samplers is relatively small and may be less than the normal fluctuations in stage at some sites. This is especially true on western rivers, where stage ranges may exceed 50 feet, making it necessary to locate the pump outside of the sampler's shelter in order to maintain a manageable pumping lift.

Intake Orientation

The orientation of the pumping sampler intake nozzle can drastically affect sampling efficiency. There are five ways in which an intake could be oriented to the flow (fig. 21): (1) normal and pointing directly upstream (fig. 21*A*), (2) normal and horizontal to flow (fig. 21*B*), (3) normal and vertical with the orifice up (fig. 21*C*), (4) normal and vertical with the orifice down (fig. 21*D*), and (5) normal and pointing directly downstream (fig. 21*E*). Of these five orientations, 1, 3, and 4 should be avoided because of high sampling errors and trash collection problems. Orientation 2, with the nozzle positioned normal and horizontal to the flow, is the most common alternative used. The major problem with this orientation is that sand-size particles may not be adequately sampled (see the following section on pumped-sample data analysis). Orientation 5, pointing directly downstream, appears to have an advantage over orientation 2 (Winterstein and Stefan, 1983). When the intake is pointing downstream, a small eddy is formed at the intake, which envelops the sand particles and thus allows the sampler to collect a more representative sample of the coarse load. Winterstein and Stefan (1983) also have demonstrated that nozzle orientations at angles to the flow other than those illustrated in figure 21 do not improve the resultant sample and, therefore, do not represent any useful advantage.

Data Analysis

A major concern when evaluating sediment data collected by automatic pumping-type samplers is the relation between the data and the true mean suspended-sediment concentration in transport at the time of sample collection. In order to determine this relation, concentrations determined from the pumping sampler must be compared with the corresponding concentrations determined from a complete depth-integrated cross-section sample over the full range of flow. This relation then is used to adjust the pumped sample data.

It must be remembered that samples collected by pumping samplers are taken from a single point in the flow. Although attempts are made to ensure that cross-sectional mean sediment concentrations are obtained, in reality this rarely happens. However, if a stable relation between the concentration at the sample point and the mean concentration in the cross section exists, the sample can be considered as representative as possible. In addition, pumping samplers do not collect samples isokinetically (as do standard US depth- or point-integrating samplers), due to the pumping rate and the orientation of the intake orifice. Not sampling isokinetically introduces concentration errors, particularly for particles greater than 0.062 mm.

Pumping samplers rely on pump speed to create a velocity in the intake tube greater than the settling velocity of particles in suspension. This higher velocity is necessary to deliver the sample to the sample container without reducing the concentration of coarser particles by depositing them within the sampler's plumbing. The pumping action at the intake

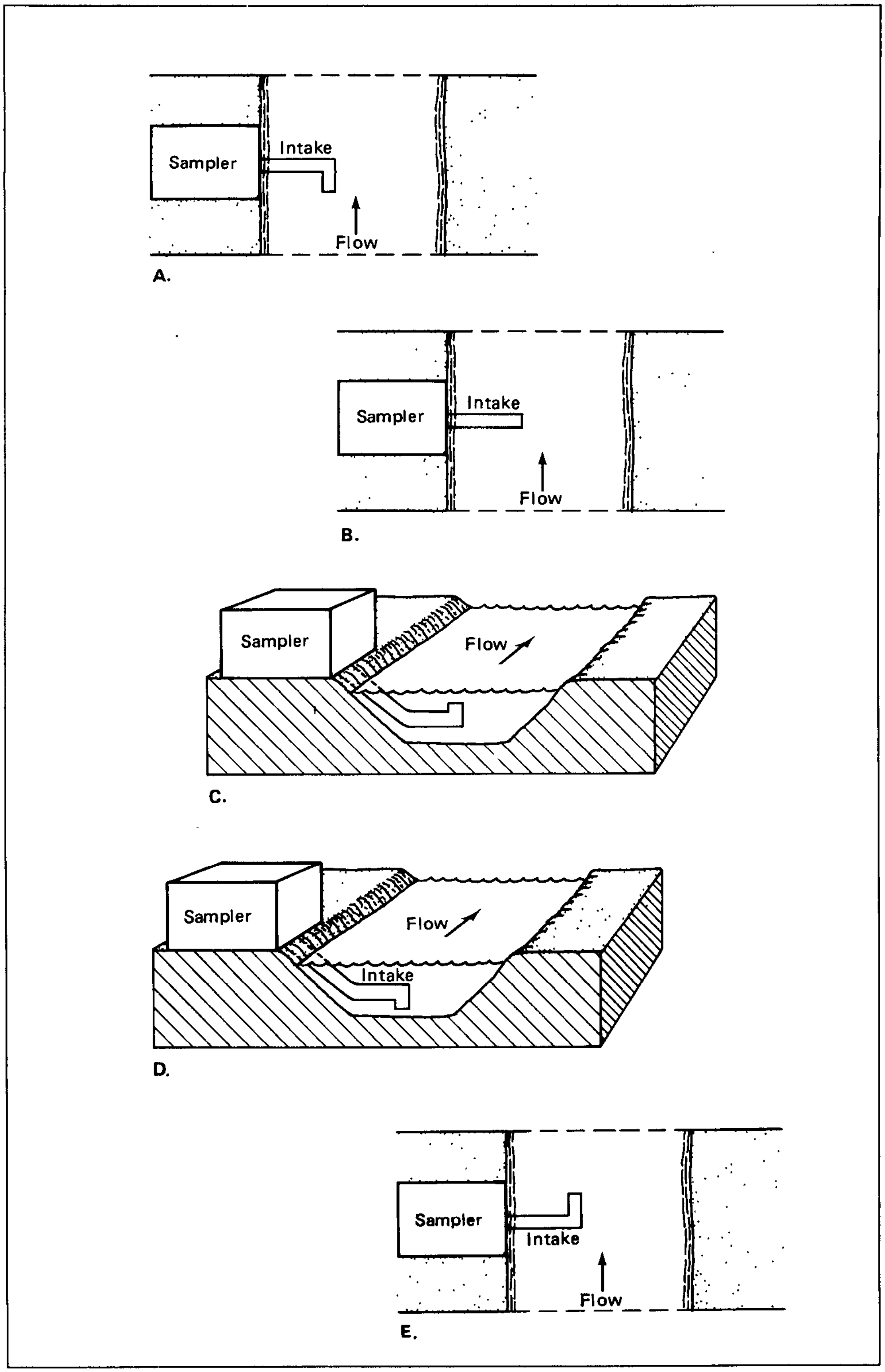
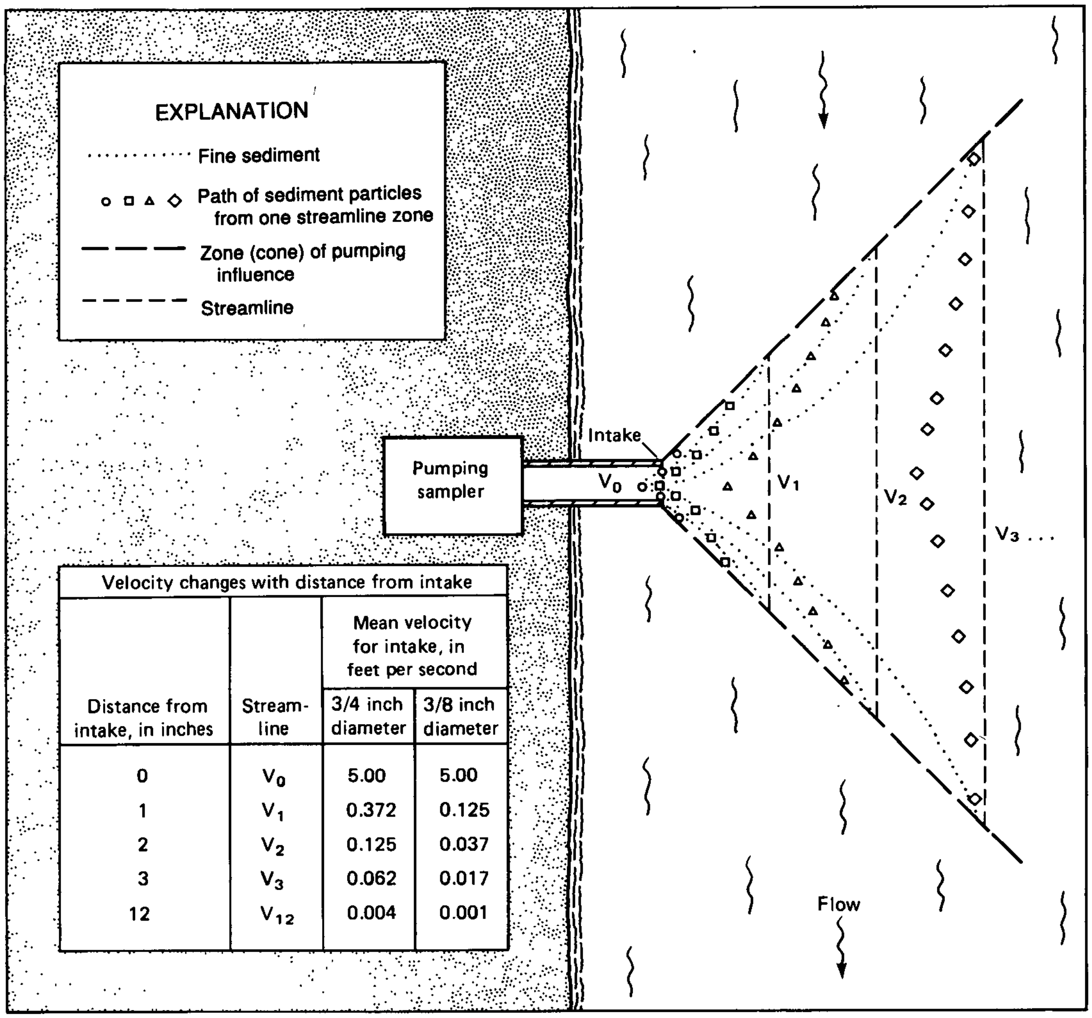


Figure 21. Examples of pumping-sampler intake orientations. *A*, Normal and pointing directly upstream. *B*, Normal and horizontal to flow. *C*, Normal and vertical with the orifice up. *D*, Normal and vertical with the orifice down. *E*, Normal and pointing directly downstream.

orifice bends the streamlines of sediment-laden flow as a sample is drawn into the intake and as particles are propelled through the sampler to the sample container. This force acts on particles carried past the orifice with varying results, dependent upon particle size and velocity (Federal Inter-Agency Sedimentation Project, 1941). That is, the pumping force attempts to pull particles laterally from their streamlines and accelerate them in the direction of the intake. At low stream velocities, when only fine silts and clays are being transported, this is not a problem. However, as stream velocity increases and particles larger than 0.062 mm begin to move in suspension, the pumping force must overcome the momentum of these larger particles, due to their mass and acceleration in the downstream direction, in order for a representative sample to be obtained. A decrease in sampling efficiency can result in a biased sample because fewer and fewer large particles are drawn into the intake as the distance from the intake increases (fig. 22). This figure shows that only those sediment particles passing directly in front of the intake, a short distance away, are greatly affected and subject to capture. It also should be realized that the zone (cone) of influence is an idealized concept, and pumping influence is much greater on sediments approaching the intake from upstream than on those sediments that have passed to the downstream side. As mentioned previously, this problem may be relieved somewhat by orienting the intake directly downstream.



Velocity changes with distance from intake

Distance from intake, in inches	Streamline	Mean velocity for intake, in feet per second: 3/4 inch diameter	Mean velocity for intake, in feet per second: 3/8 inch diameter
0	V_0	5.00	5.00
1	V_1	0.372	0.125
2	V_2	0.125	0.037
3	V_3	0.062	0.017
12	V_{12}	0.004	0.001

Figure 22. Pumping effect on sediment streamlines within the zone (cone) of influence and velocity changes with distance from intake (cone) of influence and velocity changes with distance from the intake oriented normal and horizontal to the flow for 3/4-inch and 3/8-inch diameter intakes with pumped velocity of 5 feet per second (from Federal Inter-Agency Sedimentation Project, 1966; W.F. Curtis and C.A. Onions, written commun., 1982).

Intake Efficiency

To facilitate accurate interpretation of data collected by automatic pumping-type samplers, some comparison between sediment concentration of the pumped sample (C_p) and mean sediment concentration of the streamflow (C_s) must be made. This comparison is made in terms of intake efficiency, which is the ratio of the pumped-sample sediment concentration to the mean concentration of the stream at the intake sampling point (Federal Inter-Agency Sedimentation Project, 1966), or:

$$\frac{C_p}{C_s}(100) = \text{intake efficiency.}$$

In reality, this relation is based on comparison of the pumped sample to sediment concentration of a point sample collected as close to the intake sampling point as possible, using a standard US depth- or point-integrating sampler.

Intake efficiencies should be determined for pumping samplers as soon as possible after installation-related sediment disturbances have stabilized. Additional efficiency values should be established over a broad range of flow conditions to determine actual effects of variations in particle sizes at a given sample site. These data then can be used to evaluate the sediment concentration of pumped samples and check their credibility.

Cross-Section Coefficient

Determining the degree of efficiency with which a pumping sampler obtains a representative sample is one step in the interpretation of suspended-sediment concentration data. These data should be further assessed relative to the cross-sectional mean suspended-sediment concentration. A coefficient should be determined based on how well the pumping sampler's data represents the cross-sectional mean, and this coefficient should be applied to the pumping sampler data.

From previous discussion, it should be evident that sediment samples taken at a single point of flow within a cross section seldom represent the mean sediment concentration. Therefore, cross-section coefficients must be determined to relate pumped-sample sediment concentration to the mean sediment concentration in the cross section. Because no theoretical relation exists between these parameters, an empirical comparison must be made between concentrations obtained from pumped samples and concentrations obtained from depth-integrated, cross-sectional samples collected at the same time. Obviously, it is impossible to collect an entire cross-sectional sample in the length of time it takes to cycle the pumping sampler to collect a single sample. Therefore, it is recommended that a sample collected with the pumping sampler be taken immediately before and after the cross-section sample. This procedure will help bracket any changes in concentration that might occur during the time period necessary to collect the cross-section sample. If it is suspected that the concentration is changing rapidly during the collection of the cross-section sample, try to collect one or more samples with the pumping sampler during the time that the cross-section sample is being collected. These data will help in the development of the cross-section coefficient. Collection and comparison of these check samples should be repeated during each station visit, as well as during rising and falling stages, and at peak flows for all seasonal periods (snowmelt runoff, thunderstorms, and so on). A more detailed discussion on development of cross-section coefficients is available to the interested reader in Guy (1970) and Porterfield (1972).

Description of Automatic Pumping-Type Samplers—US PS-69, US CS-77, US PS-82, Manning S-4050, and ISCO 1680

The US PS-69 pumping sampler (fig. 23) is a time- or stage-activated, electrically driven, suspended-sediment sampler capable of collecting up to 72 samples at volumes to 1,000 mL. Standard pumping lifts are to 17 feet vertically, but repositioning the pump or using multiple pumps in series can increase lift capabilities for extreme situations. This sampler must be placed in a shelter and protected against inclement weather and temperature extremes.

Particle sizes sampled range to 0.250 millimeter with some decrease in sampling efficiency for the larger particles. Sediment concentrations to 160,000 milligrams per liter have been sampled by USGS personnel in New Mexico, using an air-driven pump with the PS-69 (J.V. Skinner, written commun., 1985); extremely high concentrations also have been sampled in the vicinity of the Mount St. Helens volcano in Washington.

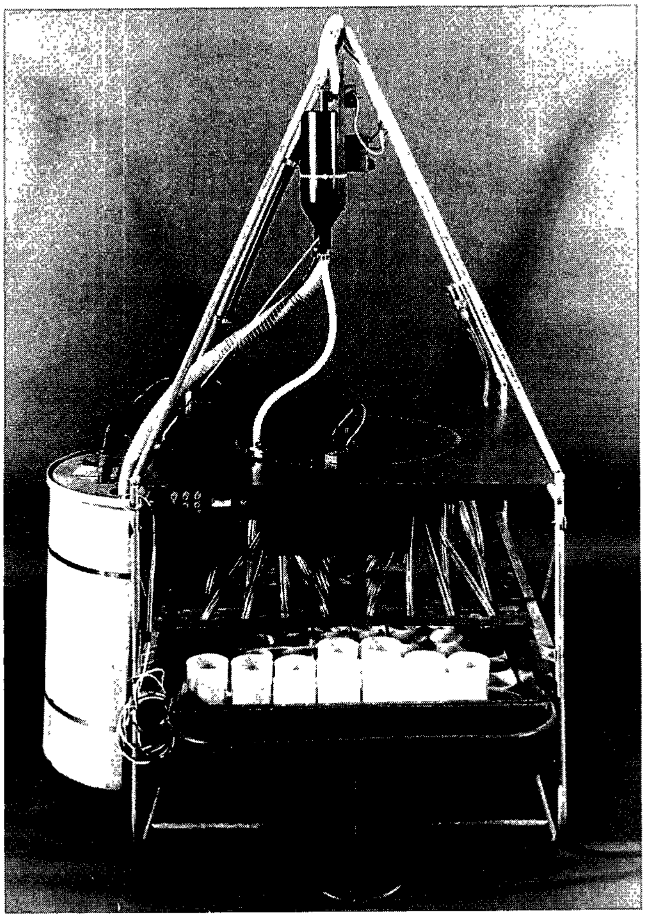


Figure 23. US PS-69 pumping sampler.

The PS-69 was evaluated by W.F. Curtis and C.A. Onions (written commun., 1982) by comparing the sampler's attributes to the 17 criteria previously listed. Results of this comparison are included in table 2.

The US CS-77, or Chickasha, sediment sampler (fig. 24) was designed and developed by the Agricultural Research Service, Durant, Oklahoma. This sampler was fashioned after an earlier design (US XPS-62, developed by F.I.S.P.) but has not been widely used by USGS personnel.

Like the PS-69, this sampler is time- or stage-activated to facilitate sampling on a predetermined schedule as well as during runoff events. Sampling times are recorded during the sampling procedure as part of the standard sampler's design of operation, in lieu of add-on modules and recording devices common to other samplers discussed here.

Table 2. Automatic pumping-type sampler evaluation

[A, US PS-69; B, US CS-77; C, US PS-82;D, Manning S-4050; E, ISCO 1680; mg/L, milligrams per liter; mL, milliliter; mm, millimeter; ≥, greater than or equal to; <, less than; >, greater than]

Evaluation criteria	Samplers meeting criteria
1. Sample collection isokinetic	None
2. Sediment concentration constant stream to sample container	A^1, B^2, C^2, D
3. Cross-contamination prevented	A, B, C, D
4. Collects concentrations to 50,000 mg/L and particles to 0.25 mm	A^1, $B^{2,1}$, C^1, D^1, E^2
5. Sample volume >350 mL	A^3, B^3, C^3, D^3, E^3
6. Intake diameter 3/4 inch	A
7. Mean velocity at intake and in internal plumbing great enough to ensure turbulent flow with a Reynolds number of 4,000	A^3, B^2, C^1, D^3, E^3
8. Vertical pumping lift >35 feet	A^2, B^2, C^2
9. Capable of collecting an adequate number of samples to accomplish the purpose of sampling	A^3, B^3, C^3, D, E
10. Sampler protected against freezing, evaporation, and dust	A^2, B^2, C, D^2, E^2
11. Sample-container tray removable single unit	A, D, E
12. Sampling cycle activated by timer or stage change	A, B, C, D, E
13. Capable of recording sample date and time	A^2, B, C^2, D^2, E^2
14. AC or DC power capability	A^2, B^2, C^2, D^2, E^2
15. Sampler or principle components <100 pounds	A^2, B^2, C^3, D^3, E^3
16. Sampler dimensions <35 inches wide by 79 inches high	A^2, B^2, C^3, D^3, E^3
17. Required floor space <9 square feet (3 feet by 3 feet)	C^3, D^3, E^3

[1] Sampler shows a reduction in capacity with particle sizes >0.250 mm.

[2] Sampler requires modification to meet criteria.

[3] Sampler exceeds criteria.

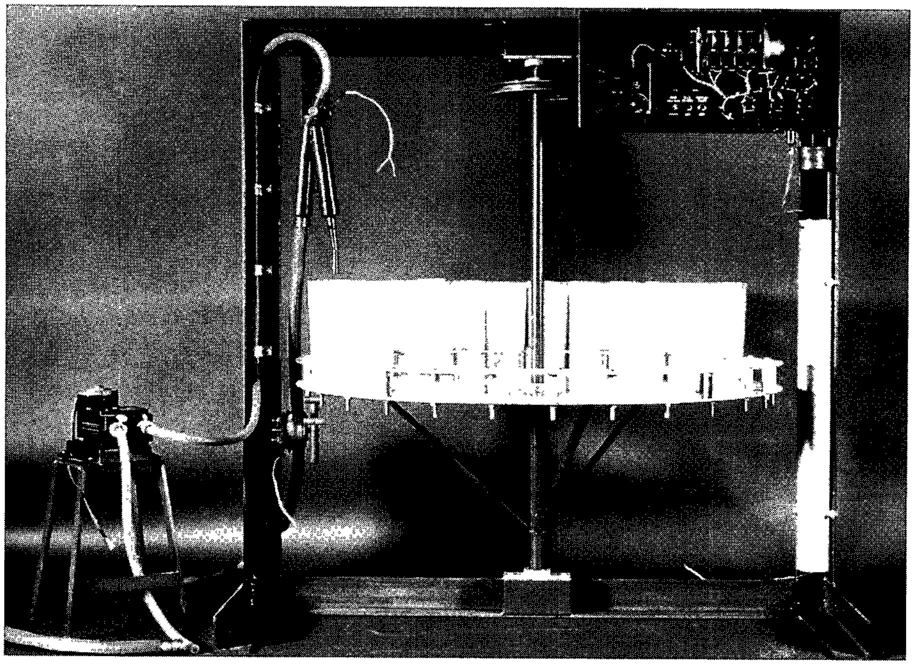


Figure 24. US CS-77 (Chickasha) pumping sampler.

Pumping lift attained by the standard CS-77 sampler configuration is 16 vertical feet; however, relocation of the pump unit to a lower elevation will establish a pull-push sequence, enabling greater sample lifts.

Further modification is necessary to improve the sampling efficiency for high concentration flows carrying greater than 10 percent sand-sized material. Additional information regarding this sampler may be obtained from the evaluation in table 2 and by contacting personnel at the F.I.S.P.

The US PS-82 automatic pumping-type sampler (fig. 25) was made available in March 1984 from F.I.S.P., but it is not widely used under field conditions. The Federal Inter-Agency Sedimentation Project (1983) describes the PS-82 as a lightweight portable pumping sampler, driven by 12-volt battery power, which is used to sample streamflows transporting particles ranging to fine sand size. These samplers weigh 35 pounds and can be housed under a 55-gallon oil drum. An evaluation of this sampler is included in table 2. For more specific information concerning the technical aspects of this sampler and its availability, the interested reader should contact the F.I.S.P.

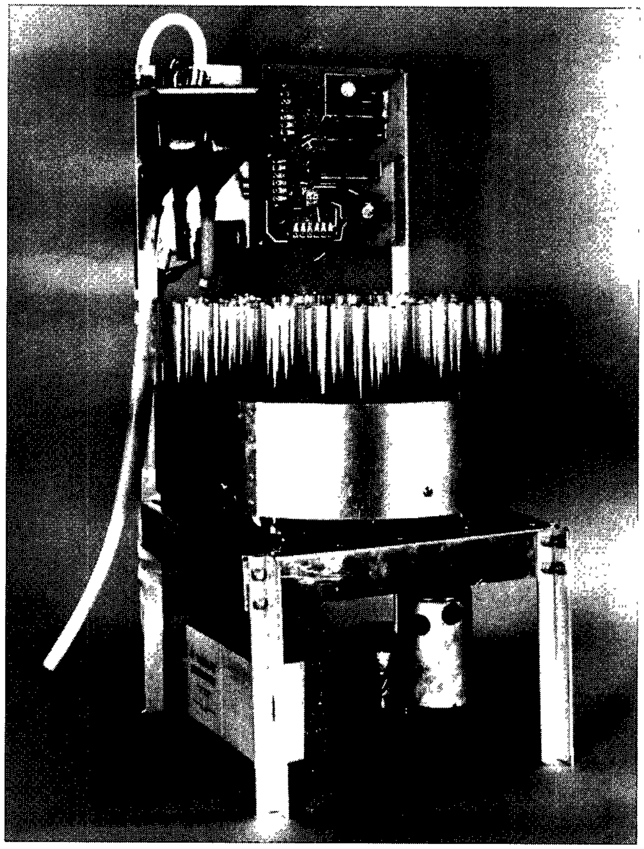


Figure 25. US PS-82 pumping sampler.

The aforementioned samplers were developed by Federal agencies concerned with the collection of suspended-sediment data in a timely, cost-effective manner and are available to the interested investigator from the F.I.S.P. at Waterways Experiment Station, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199.

The following discussion is a description of the Manning S-4050 and ISCO 1680 automatic pumping-type samplers, which are not available through F.I.S.P., but may be obtained from the individual manufacturers. These samplers are described because they represent the types of samplers that are commonly available from commercial sources and used by the USGS.

The Manning S-4050 portable sampler was originally designed as a lightweight unit for sampling sewage. Modifications to this sampler have rendered it useful as a suspended-sediment sampler.

The sampler features a time- or stage-activated electric compressor, which purges the sample intake using the pressure side and draws a sample through the intake using the suction side to create a vacuum in the line, allowing atmospheric pressure to push the sample up to a maximum of 22 feet during the sampling mode. Particle suspension within the sampler is maintained by swirling action of the sample as it passes through the measuring chamber to the sample container.

Evaluation of this sampler in the same manner used for the previously discussed samplers indicates that this instrument is well suited to conditions where extreme pumping lifts are not necessary. Results of this evaluation are included in table 2.

The ISCO 1680, with a super-speed pump sampler, was originally developed as a sewage or wastewater sampler, like the Manning sampler. Normally, wastewater does not carry significant amounts of sediment. Therefore, representation of particle distribution was not a considered criteria during its design and testing stages. The sampler features an electrically driven peristaltic pump, which is activated on a predetermined schedule by an internal timer or in response to stage change. The intake tube is purged before and after each pumping period by automatic reversal of the pump.

The ISCO sampler demonstrates two major shortcomings regarding sediment collection: (1) continuity of sediment concentration from stream to sample container is not maintained efficiently, and (2) a possibility of cross contamination exists from sample to sample as a result of residue remaining in the system after the purge cycle. These problems can be minimized by the installation of a high output pump, available as an option with recent models. A sampler evaluation included in table 2 shows less than acceptable results for representative sediment-data collection.

Support Equipment

Sediment-sampling equipment has been designed by F.I.S.P. to facilitate the use of existing support equipment normally used in stream-gaging procedures. Other than wading rods and hand lines, support equipment is generally necessary for the proper operation of the heavier versions of sediment samplers. In general, support equipment consists of steel cable, hanger bars, reels, and cranes. However, specific conditions at a site may dictate modifications to these pieces of equipment to improve ease of handling in response to the local conditions. Modifications of support equipment necessary to facilitate the handling of samplers and improve safety are encouraged. Investigators are cautioned against alterations that might adversely affect sample collection, either by disturbing the streamflow in the cross section or by changing the sediment-trapping characteristics of the sampler. To ensure sample integrity, specialists should be consulted before any modifications of this type are made.

Commonly used support items include C-type hanger bars; type-A, type-B, and type-E reels; and portable cranes with 2-, 3-, and 4-wheel bases. The C-type hanger bars can be shortened to eliminate awkward and hazardous handling. Type-A reels can be used to suspend lightweight to medium-weight samplers and have been widely used at permanent single-vertical observer sites. Type-B and type-E reels are typically used with medium and heavy samplers. The type-B reel can be used manually or with an available power unit, allowing the sampler to be lowered by releasing the brake mechanism and letting it slip until the sampler reaches the water surface, then manually integrating the sampled vertical and raising the sampler, either manually or by activating the DC-powered motor to drive the reel. The type-E reel is a DC-powered reel that lends itself more readily to permanent installations where heavy sampling equipment is required. Cranes are used to provide a mechanical advantage over hand-line or bridge-board suspended equipment, for more effective maneuvering of a sampler. The 2-, 3-, and 4-wheel base cranes are useful when sampling from a bridge deck; however, safety precautions should be taken to warn approaching traffic and to avoid blocking the roadway. Boom assemblies also are used in some instances, such as with truck- and boat-mounted installations. Reels, cranes, and powered hoists can be purchased from HIF. HIF can provide information on the availability, installation requirements, and operation of this equipment. Some additional information also may be obtained from the report "Discharge Measurements at Gaging Stations" (Buchanan and Somers, 1969).

SEDIMENT-SAMPLING TECHNIQUES

The sediment-sampling method and frequency of collection are dictated by the hydrologic and sediment characteristics of the stream, the required accuracy of the data, the funds available, and the proposed use of those data collected. When sampling sediment moving through a stream cross section, emphasis should be placed on the collection of a statistically representative population of the sediment particles in transit. To acquire a representative sample, one must first obtain a sample that adequately defines the concentration of particles over the full depth of the sampled vertical. Secondly, a sufficient number of verticals must be sampled to adequately define the horizontal variation in the cross section. The type of sampler used to collect the sample, the method of depth integration, the site at which the samples are collected, and the number of verticals needed to define the stream's concentration depend on the flow conditions at the time of sample collection, characteristics of the sediment being transported, the accuracy required of the data, and the objectives of the program for which the samples are being collected. The purpose of this section is to discuss site selection; equipment selection and maintenance; depth integration; sediment-discharge measurements; point integration; surface and dip sampling; transit rates; sample frequency, quantity, integrity, and identification; sediment-related data; cold-weather sampling; bed-material sampling; bedload sampling; total sediment discharge; and reservoir sedimentation. This section then deals with the decisions 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 selection procedure for establishing a sampling location should emphasize the quest for a stream-data site. A stream-data site is best defined as a cross section displaying relatively stable hydrologic characteristics and uniform depths over a wide range of stream discharges, from which representative water-quality and sediment data can be obtained and related to a stage-discharge rating for the site. This is a rather idealized concept because the perfect site is rare at best. Therefore, it is necessary to note the limitations of the most suitable site available and build a program to minimize the disadvantages and maximize the advantages. Most often, sampling sites are located at or near existing gage sites, which may not always be well suited to water-quality and sediment-data collection. For this reason, future sites selected for stream gaging should be carefully assessed for suitability as a water-quality and sediment-sampling site.

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 or at a site other than where the water-discharge measurement is made, 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 also should be avoided where possible. Sites that may be affected by backwater conditions should be avoided whenever possible. Backwater affects both the stage-discharge and velocity-discharge relation at the site. Therefore, a given discharge may have varying stage and mean stream velocity and thus have varying sediment transport rates. If a site is affected by backwater, samples will have to be collected more frequently, and the cost in both man-hours and money will be significantly higher than for more "normal" sites.

A sediment-measuring site downstream from the confluence of two streams also may require extra sediment measurements. The downstream site may be adequate for water-discharge measurement, but could present problems if used as a sediment-measuring site due to incomplete mixing of the flows from the tributaries. Therefore, it might be desirable to move far enough downstream to ensure adequate mixing of the tributary flows. As indicated in Book 3, Chapter C1, "Fluvial Sediment Concepts" (Guy, 1970, p. 24), the distance downstream from a confluence that is required for complete mixing depends on the stream velocity, depth, and mixing width. If the flow at a sediment-measuring site is not mixed, 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 flow both in the channel and on the flood plain may affect the ease with which data can be obtained and the quality of the samples. The ratio of suspended load 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.

As a result of economic necessity, most sediment-measuring sites are located at highway bridges. These bridges are often 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 26 (Culbertson and others, 1967) illustrates 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, the bridge 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 26*F*, midstream piers can catch debris and, thereby, interfere with effective sediment sampling.

Because sediment samples must be obtained more frequently during floods, it is imperative that a site be selected where obtaining data during times of flooding is feasible. That is, particular attention should be given to the ease of access to the water-stage recorder and to a usable bridge or cable during a flood. Because of the need to collect samples frequently during floods, many of which occur at night, sites accessible only by poorly maintained backroads or trails should be avoided. Sometimes the choice of a sediment-measuring site also must be determined by the availability of a suitable observer to collect the routine samples.

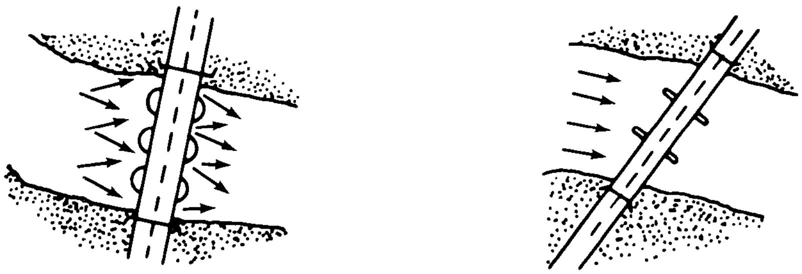
In choosing a sediment-measurement site, it should be emphasized that samples need to be collected at the same cross-section location throughout the period of record. Different sampling cross sections can be used, if absolutely necessary, during the low-water wading stage and the higher stages requiring the use of a bridge or cableway. Although the total sediment transported through the different cross sections is probably equal at a given flow stage, the percentage of that total load represented by suspended-sediment load may be drastically different from one cross section to the other, due to differences in hydraulic and sediment-transport characteristics. When data computations are performed, these differences must be considered because the data may not be compatible, and the usefulness of the data in answering the objectives of the sampling program could be threatened. Sites where highway or channel realignment or other construction is anticipated during the period of record should be avoided. Good photographs of proposed or selected sediment-measuring sites are necessary to help document such features as channel alignment, 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 and extensive field notes 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 departing on a field trip where sediment data are to be collected, a field person should assemble and check all equipment needed to collect the best samples and related measurements. For example, if data are

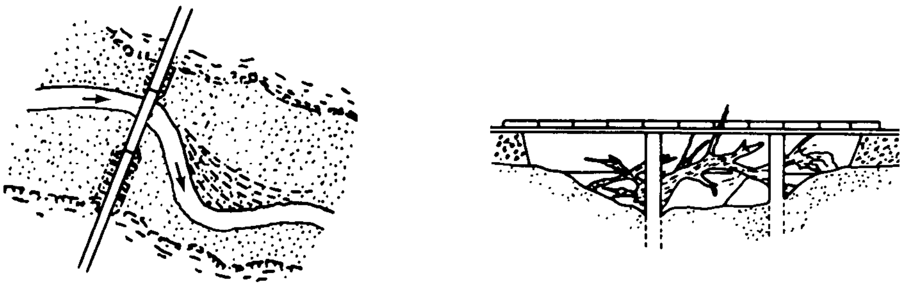
A. Natural constriction of channel at bend

B. Natural constriction of channel by persistent 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 26. Examples of natural and artificially induced streamflow constrictions encountered at sediment-measurement sites. Modified from Culbertson and others (1967).

needed for total-load computation, equipment is needed for water-discharge measurement, suspended-sediment sampling, bedload sampling, and (or) 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 in the station gage house, with the observer, or in special storage shelters or boxes. However, a sampler or some support equipment could be damaged or stolen without the observer noticing or reporting the loss. Hence, it is necessary for field personnel to carry repair equipment, spare parts (including nozzles and gaskets), 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-74 or the P-61, should be used. Depths over 15 feet will require the use of point samplers as depth-integrating samplers to avoid overfilling or using too fast a transit rate. Stream velocity as well as depth are factors in determining whether or not a stream can be waded. A general rule is that when the product of depth in feet and velocity in feet per second equals 10 or greater, a stream's wadability is questionable. Application of this rule will vary considerably among field persons according to an individual's stature and the condition of the streambed. That is, if footing is good on the streambed, a heavier field person with a stocky build will generally wade more easily than will a lighter, thinner person when a stream depth-velocity product approaching 10 exists.

The depth-velocity product also affects the action of each sampler. The larger this product, the heavier and more stable the sampler must be to collect a good sample. At a new station or for inexperienced persons, considerable trial and error may be necessary to determine which sampler is best for a given stream condition.

All sampler nozzles, gaskets, and air exhausts, as well as the other necessary equipment, should be checked regularly and replaced or serviced if necessary. Sampler nozzles in particular should be checked to ensure that they are placed in the appropriate 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 possible that will permit depth integration without overfilling the sample bottle or exceeding the maximum transit rate (about 0.4 of the mean velocity in the sampled vertical for most samplers with pint containers).

If a sample bottle does not fill in the expected time, the nozzle or air-exhaust passages may be partly blocked. The flow system can be checked, as described in the section titled "Gaskets," by sliding a length of clean rubber or plastic tubing over the nozzle and blowing through the nozzle with a bottle in the sampler. This procedure should be performed carefully, avoiding direct contact with the nozzle, thus eliminating the possibility of ingesting any pollutant that might exist on the sampler. When air pressure is applied in this manner, circulation will occur freely through the nozzle, sample container, and out the air exhaust. Obstructions can be cleared by removing and cleaning the nozzle and (or) air exhaust, using a flexible piece of multistrand wire. This procedure should be adequate for most airway obstruction problems. However, if blockage results from accumulation of ice or from damage to the sampler, a heat source must be used to melt the ice or the sampler must be sent to the F.I.S.P. or HIF repair facility. Point samplers can be checked using the same technique, if the valve mechanism is placed in the sampling position while air is forced into the nozzle and through the air exhaust.

All support equipment required for sampling, such as cranes, waders, taglines, power sources, and current meters, should be examined periodically, and as used, to ensure 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 samplers need a periodic operational check and battery charge. Point samplers should be checked immediately before use to determine, among other things, if the valve is opening and closing properly. By exercising such precautions, the field person will avoid unnecessary exposure to traffic on the bridge and will avoid lost sampling time should repairs and adjustments be required.

Maintenance of samplers and support equipment will be facilitated if a file of instructions for assembly, operation, and maintenance of equipment can be accumulated in the field office. Such a file could include F.I.S.P. reports as well as other pertinent information available from HIF.

Suspended-Sediment Sampling Methods

Sediment-Discharge Measurements

The usual purpose of sediment sampling is to determine the instantaneous mean discharge-weighted suspended-sediment concentration at a cross section. Such concentrations are combined with water discharge to compute the measured suspended-sediment discharge. A mean discharge-weighted suspended-sediment concentration for the entire cross