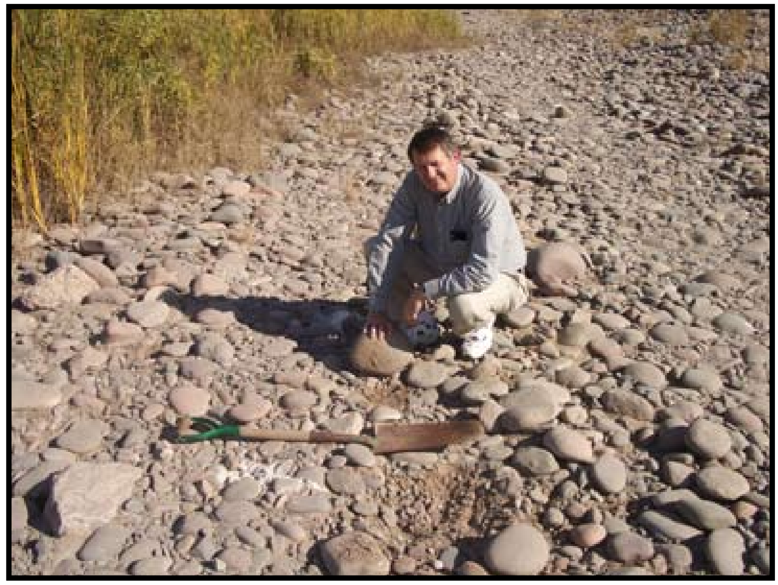
Technical Supplement 13A

Guidelines for Sampling Bed Material



Issued August 2007

Cover photos: *Top*—Bed-load sediment may be poorly graded or well graded. Armoring layers may also be present.

Advisory Note

Techniques and approaches contained in this handbook are not all-inclusive, nor universally applicable. Designing stream restorations requires appropriate training and experience, especially to identify conditions where various approaches, tools, and techniques are most applicable, as well as their limitations for design. Note also that product names are included only to show type and availability and do not constitute endorsement for their specific use.

Technical Supplement 13A

Guidelines for Sampling Bed Material

Contents

Tables

Figures

Technical Supplement 13A

Guidelines for Sampling Bed Material

Purpose of bed-material sampling

The characteristics of a given stream are linked to the composition of the material that comprises its channel bed, bank, and sediment flow. Knowledge of streambed material is necessary for a variety of engineering and environmental purposes. The size and gradation of the streambed material may affect the source, transport, and fate of pollutants; fish habitat; resource management; morphological trends; and stream restorations.

Bed-material sampling programs must be carefully designed to meet the particular needs of a specific study. Studies may include objectives related to the following:

- Contaminants—Typically attach to cohesive sediment and, therefore, are distributed over a wide area, especially in areas where flow velocity is low. Sampling for a contaminant concentrates on depositional zones in the stream and overbank.
- Aquatic habitat—Fish habitat studies may focus on the suitability of the streambed for spawning. Sampling for this type of study is often extensive, identifying lateral, longitudinal, and temporal variations in the surface layer over a wide area of the stream. An assessment of vertical variations may also be of critical importance, as the composition of the material immediately below the surface, especially the fines content, may be of importance in the evaluation of spawning habitats for some species.
- Gravel mining—Resource management studies are frequently concerned with the need or feasibility of sand and gravel mining. Core or substrate sampling that identifies vertical variation of the streambed is essential for this type of study.
- Stream assessment and design—Morphologic and engineering studies are concerned with changes in the character of the river over time. These studies require knowledge of the grain size distribution of both the bed surface material and subsurface material for sediment transport calculations, critical shear stress determinations, determining potential for particle sorting and armoring, and determining hydraulic roughness.

Complex studies may need to secure data to meet a combination of objectives and purposes. However, sediment data collected for one purpose will not necessarily be applicable for another. While the issues and recommendations presented here are generally applicable, the focus is on bed sampling for stream assessment and design.

Site selection for representative sampling

Sufficient sampling of the streambed should be conducted to determine the spatial variability, size, and gradation of the bed material. No simple rule exists for locating representative sampling sites or reaches. The general rule is to carefully select sampling locations and avoid anomalies that would bias either the calculated sediment discharge or the calculated bed stability. Sampling locations must be representative of the hydraulic and sedimentation processes that occur in that reach of the river. The site should be morphologically stable. To ensure data reflect reach-averaged river conditions, there should be no tributary inflow in the proximity of the site, as it may interfere with the homogeneity of the section by supplying sediment for deposition. The site should not be located adjacent to a zone of active bank erosion, as the material deposited in the channel near the eroding area may not be representative of the reach. Although bridges provide good access, bridge crossings are typically not appropriate sampling sites because either they are located at natural river constrictions or their abutments and piers create constrictions and local scour. Dead-water areas behind sand bars or other obstructions should be avoided, as these are not representative of average flow conditions.

The location of the bed sample should be chosen with the target analysis in mind. Table TS13A–1 provides guidance for where a bed-material sample might be taken as a function of the type of geomorphologic or engineering analysis to be conducted. This list is not inclusive, exhaustive, or absolute. Ideally, bed-material samples should be taken at different times during the year to account for seasonal variations.

Sand-bed streams

Sand-bed streams have relatively homogeneous bed-material gradation. Vertical and temporal variability are normally insignificant in stable sand-bed streams. Longitudinal variability typically occurs over distances of many kilometers. However, lateral variability, especially in bends, can be significant. In sand-bed rivers, sampling of bed material is most frequently done in the low-flow channel. The sampling equipment and methodology used depend on the river depth and velocity. The task can be accomplished in flowing streams either by wading or from a boat or in ephemeral and intermittent streams in the dry. Vertical variations in the bed material are usually insignificant in flowing water, and samples are collected from the surface. However, in standing water or on dry beds, a layer of fine material is sometimes found deposited on the bed surface during the recessional part of a flood hydrograph. It is standard practice to remove this fine surface layer before collecting a bed-material sample in this location.

Einstein (1950) recommended using only the coarsest 90 percent of the sampled bed gradation for computations of bed-material load. He reasoned that the finest 10 percent of sediment on the bed was either material trapped in the interstices of the deposit or a lag deposit from the recession of the hydrograph and should not be included in bed-material load computations.

Representative bed-material sampling in sand-bed streams may be accomplished by one of two methods. Employing the cross-sectional approach requires selecting a site and time for sampling where and when the bed characteristics are typical. This method requires considerable experience. Unanimity of opinion about where and when the typical condition occurs cannot be expected, even among experienced river scientists. Frequently, judgment is influenced by the type of streams the sampler has experienced and by the intended use of the data. Employing the reach approach, where samples from several systematically selected cross sections are averaged to obtain a representative sample, may eliminate some uncertainty associated with the cross-sectional approach.

Cross-sectional approach

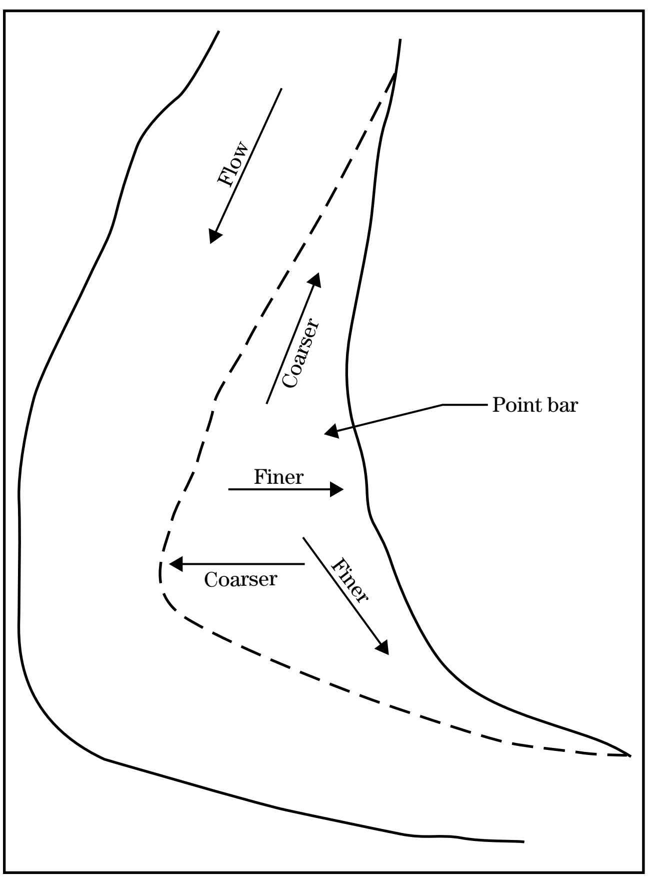
This approach requires the selection of a representative cross section for a reach. In streams with relatively uniform depths, between three and five samples should be taken across the section to account for lateral variations. In streams with variable depths, more samples are required. Twenty verticals are commonly taken along the cross section in braided streams. Taking bed-material samples at crossings where flow distribution is more uniform reduces the lateral variation in the samples. However, at low flow, crossings may develop a surface layer gradation that reflects sediment transport conditions at the lower discharge, which may be coarser or finer than the bed gradation at bankfull discharge. Also, crossings are typically submerged, and more elaborate sampling equipment is required than at exposed bars, where a

Table TS13A–1 Bed-material sampling sites

Purpose of analysis	Sample location
To estimate the maximum permissible velocity in a threshold stream	Riffle
To estimate the minimum permissible velocity in a threshold stream	Areas of local deposition
To estimate sediment yield for an alluvial stream	Crossing or middle bar
To quantify general physical habitat substrate condition	Bars, riffles, and pools

shovel is usually a sufficient sampling tool. However, samples collected on a point bar or alternate bar may exhibit considerable variation. Figure TS13A–1 illustrates typical bed-material gradation patterns on a point bar. Note that although the typical grain sizes found on the bar surface form a pattern from coarse to fine, no single sampling location always captures the precise distribution that represents the entire range of sedimentation processes.

Figure TS13A–1 Gradation pattern on a point bar



Reach approach

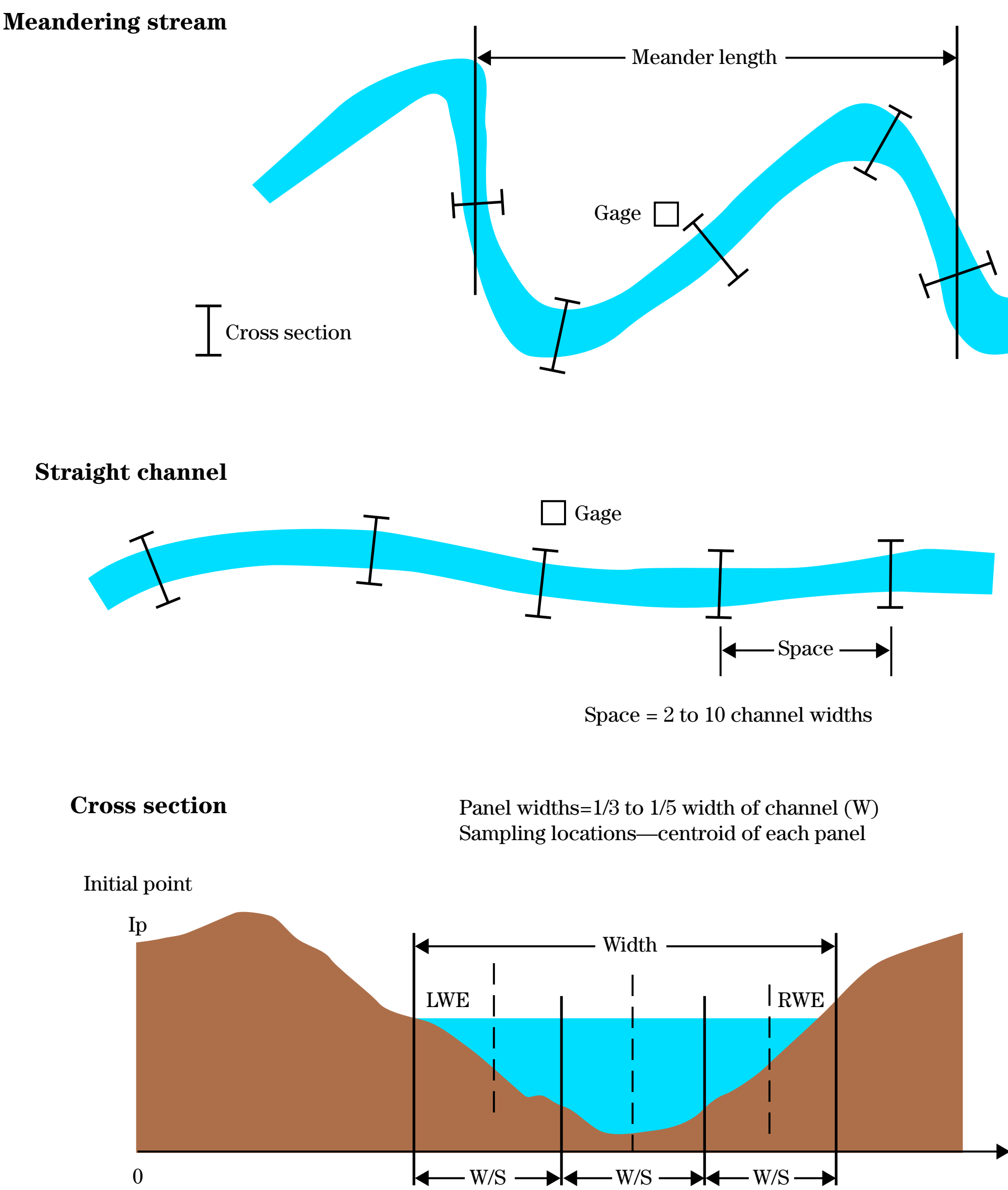
An alternative to the cross-sectional approach is the reach approach. A reach is defined as a portion of the stream with similar morphology (identified by its homogeneity). Generally, five cross sections are laid out in the homogeneous reach. If there is a gage in the reach, locating the center cross section near the gage is preferred. This facilitates relating the sediment data to measured hydrologic and hydraulic data. If the stream reach is straight, the spacing of the cross sections should be approximately two to five stream widths, and if the reach is meandering, the spacing should occur within one meander length (fig. TS13A–2). The same criteria used in the cross-sectional approach to determine the number of verticals to take along each section are applied here. The reach approach applies best to rivers with meanders of different wavelengths and amplitudes.

Gravel-bed streams

Coarse beds (gravel, cobble, and boulder) are characterized by significant vertical, spatial, and temporal bed-material variability. A vertical stratification in the bed material can be formed as the finer material is winnowed from the surface. A sketch of the resulting sediment profile is provided in figure TS13A–3. Another distinctive characteristic of gravel-bed streams is a coarse surface layer that may form in both the low-flow channel and on bars. Frequently, the low-flow channels of coarse bed streams are armored with large cobbles and boulders, while bars consist primarily of sand and gravel.

Since the spatial variability in most coarse bed streams is high, securing representative samples is difficult. River bars are frequently chosen as sampling sites because they are considered the most representative of the sediment moving in the stream, and they are usually dry during sampling. Specific bar types have been determined to be more representative than others.
A bar type hierarchy established to aid site selection (Bray 1972; Yuzyk 1986) is shown in figure TS13A–4. Mid-channel and diagonal bars are most ideal sampling sites because they are exposed to the highest velocities, which transport the largest materials. Point bars are not as ideal because velocities are highly variable,

Figure TS13A–2 Bed sampling locations for sand-bed streams



decreasing toward the inside bank. Channel side or lateral bars are least desirable because they exist in zones of low velocities due to boundary and bank effects. In small streams with no bars and a pool-riffle sequence, the riffles may be sampled to characterize bed-material size. However, the bed material in a riffle is normally much coarser at low flow, when sediment transport is typically negligible, than at bankfull flow when sediment transport is active.

Based on the assumption that the coarsest materials in the bed exert the predominant effect on channel behavior and flow resistance, some practitioners recommend that samples be collected at the upstream end of a bar (Bray 1972; Church and Kellerhalls 1978; Yuzyk 1986). Sediments at this location are indicative of the sediments in the main channel, are readily identifiable, and generally exposed. The upstream end of a bar usually consists of the coarsest material in the channel and not the average size in the reach. This is because the upstream end of a bar is the location most frequently exposed to the highest stream velocities.

Finally, it is helpful if the bed-material sampling location is near a stream gaging station to better relate the sampled sediment data to measured hydrologic and hydraulic data.

Figure TS13A–4 Coarse bed stream sampling hierarchy

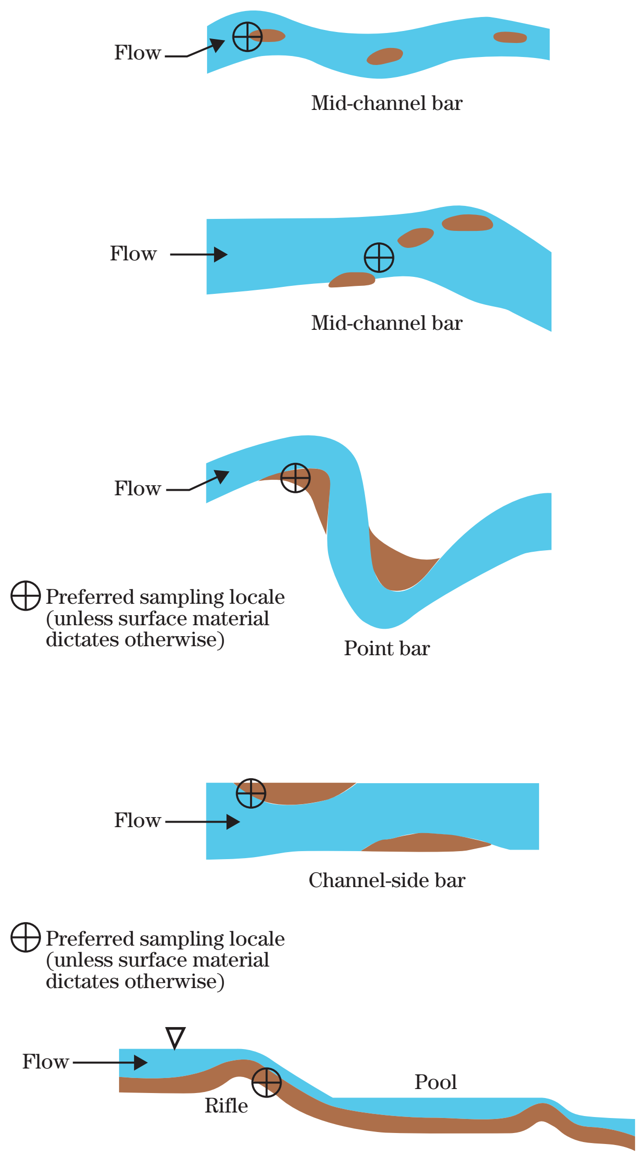
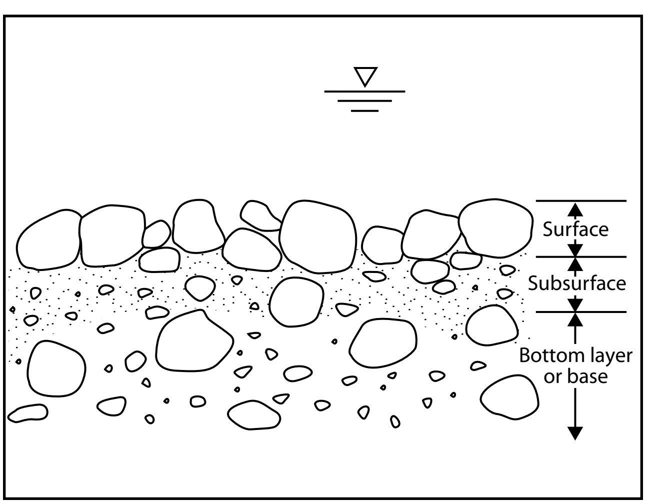


Figure TS13A–3 Gravel-bed sediment profile showing vertical variation



Surface sediment sampling

Bulk or volumetric sampling is generally considered to be the standard sampling procedure. It involves the removal of a predetermined volume of material large enough to be independent of the maximum particle size. In general, the minimum depth of a volumetric sample should be at least twice the diameter of the maximum particle size, and the minimum weight should be 200 times the weight of the largest particle of interest (Diplas and Fripp 1992). This can lead to unrealistically large samples for many gravel-bed streams, and extrapolation may be necessary. The sample is then sieved, and the analysis is interpreted as a grain size frequency distribution by weight.

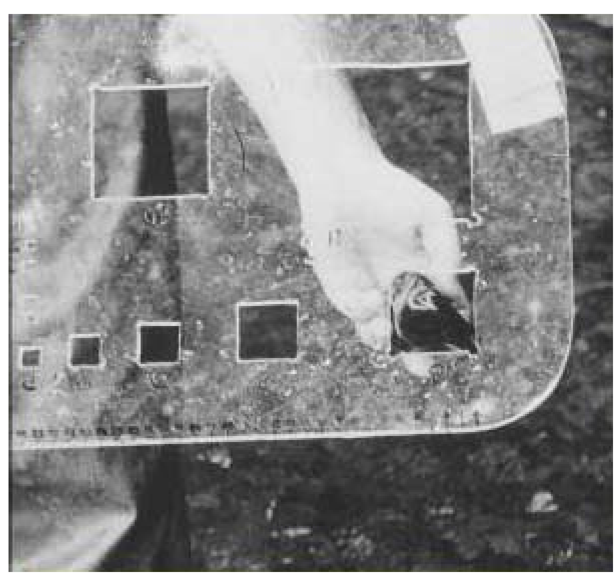
As previously noted, in coarse or gravel-bed streams, the top layers may be stratified by size due to armoring effects. Typically, bulk sampling is employed to characterize the subsurface or base layers. However, to quantify the particle size of the surface, a surface sampling technique is typically used.

Surface or areal-surface sampling is used to characterize the surface of a gravel bed. This coarse surface layer correlates to such important characteristics as hydraulic roughness, critical shear stresses, armoring, and sediment transport. A common methodology for surface sampling is a pebble count (Wolman 1954), where individual particles are collected at random by hand, and the intermediate axis is measured. The random walk method devised by Wolman can easily be employed on a dry bed or in wadeable flow, and with more difficultly by divers in deeper water. To obtain a sample, a team member paces along a selected path, stopping to collect a pebble with each step. The pebble is selected with closed or averted eyes. Other forms of this sampling include laying out a linear tape and selecting the pebble at a designated interval, laying out a preconstructed rectangular grid, and selecting the pebble at grid point intersections. The spacing of the sampling points must be at least two times the diameter of the largest particle in the sampling area. This reduces the influence of nearby particles.

At least 100 particles should be included in the hand-collected surface sample. However, to be very precise or to accurately measure small percentiles, the number of sampled particles should be increased. For example, if the D_{10} and D_{90} size fractions are of importance, the sample size should consist of at least 200 stones (Fripp and Diplas 1993). The gradation curve developed from these data is based on the number of particles in each size class, not their weights or projected surface areas. However, the resulting gradation curves are identical to those developed using sieve analysis because the selected particles all represent the same surface volume, and therefore, the same weight. The measuring process may be streamlined in the field by using a gravelometer or template (fig. TS13A–5) with standard sieve sizes to measure the sieve diameter of each particle immediately after the particle is selected. The sieve diameter for each particle is recorded as the maximum size of the opening on the template that the stone will not fit through.

Studies have shown that particles smaller than 2 millimeters are typically missed, and particles below 8 millimeters are underrepresented with Wolman or hand-based surface sampling (Fripp and Diplas 1993). This truncation is especially prevalent if the bed surface is submerged. When a sizable fraction is missing or underrepresented, the percentage of the remaining size fractions is increased, and the distribution

Figure TS13A–5 Gravelometer held above stream



becomes biased towards the larger sizes. Even gross measurements, such as median grain size, can be affected. As a result, the use of the sampled distribution can result in erroneous results. Typically, adhesive-based areal sampling is required to accurately sample surface particles.

Adhesive surface sampling uses clay, tape, or wax to remove the surface particles. Clay is generally preferable for underwater sampling. The plans for a typical clay sampling device are shown in figure TS13A–6. The clay is placed on the piston and pressed firmly onto the gravel bed. It is then drawn up into the cylinder so that the sample is protected from the stream flow as it is brought to the surface. The clay and sample material are then removed, washed to free the clay, and the sample is then sieved. The analysis is interpreted as a grain-size frequency distribution by weight.

In general, the minimum areal sample should be 100 times the area of the maximum particle of interest (Diplas and Fripp 1992). It is important to note that areal samples, which are interpreted by weight, are not directly comparable to volumetric samples, as they are biased in favor of the coarser sized material (Kellerhals and Bray 1971). The equation for converting a clay-based areal sample to its volumetric equivalent is provided below:

$$P(V-W)_i = Cp(S)_i D_i^{-1} \qquad \text{(eq. TS13A–1)}$$

where:

$P(V–W)_i$ = percentage of the frequency distribution by weight obtained for volumetric sampling

$p(S)_i$ = percentage obtained from the areal/surface sampling technique

D_i = mean diameter between size interval i and i+1

C = a proportionality constant that is unique for each sample and is calculated as

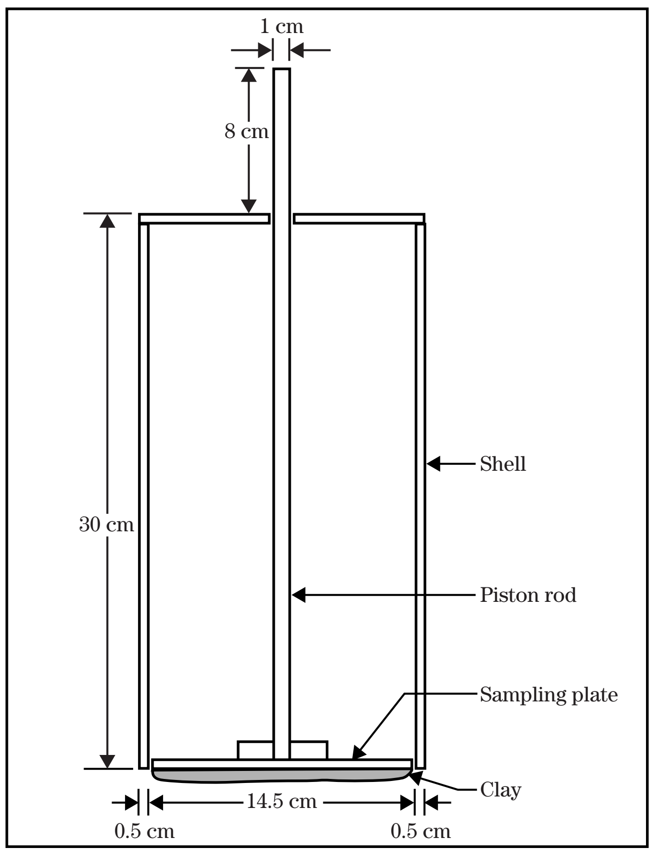
$$C = \frac{1}{\sum p(S)_i D_i^{-1}} \qquad \text{(eq. TS13A–2)}$$

Techniques for converting the material from various types of areal samples into equivalent volumetric samples are described further in Proffitt (1980); Diplas and Sutherland (1988); and Diplas and Fripp (1992).

Adhesive sampling using clay is typically limited to particles which are smaller than 40 millimeters in size (Diplas and Fripp 1992). If clay areal sampling is applied to samples containing larger material, the clay will not consistently attach to the larger size fraction, and the sample will be biased towards the smaller size fractions. Truncation can limit the obtained information and also bias the distribution.

The problem with truncation of either the smaller sizes (resulting from hand-based techniques) or the truncation of the larger sizes (as occurs with adhesive techniques) can be overcome with a combination of the two approaches. Results from an adhesive areal sample can be combined with the results of a pebble count, where the bed gradation influences significant

Figure TS13A–6 Piston sampler



amounts of both coarse and fine size fractions of material. This is done by matching the percentages where the two samples overlap. This is typically between 15 and 40 millimeters. More detailed information on this approach can be found in Fripp and Diplas (1993).

Sediment intrusion into spawning gravels

Sediment intrusion into the bed of gravel streams is an important ecological issue, as it can adversely affect fish reproduction. Sands, silts, clays, and organic matter that are deposited in gravel spawning beds, referred to as redds for salmonids, can adversely affect egg survival. The clogging of gravel beds by sands, fines, and organic matter reduces the availability of dissolved oxygen needed by salmonid embryos and fry. These deposits also restrict intergravel flows that are necessary to remove toxic metabolic wastes produced by incubating salmonid eggs. As a result, there is a need to quantify the degree of fine sediment and organic matter intrusion in gravel-bed streams.

One way to assess sediment intrusion into spawning gravels is to conduct freeze-core sampling over time (Rechendorf and Van Liew 1988, 1989). This sampling technique can be conducted for salmonids in an artificial redd built into the streambed prior to salmonid spawning. The artificial redd is constructed by excavating a depression 12 to 18 inches into the stream bed. The bottom of the depression is then lined with colored rocks or marbles. It may also be advisable to place a 2- to 3-inch piece of lead in the bottom of the hole so that a metal detector can be used to locate the site. A weighted piezometer is inserted on the floor of the depression. The piezometer can be a perforated copper pipe cast inside a Dixie® cup-sized piece of concrete, with a plastic tube on top. The plastic tube is corked and held up while the hole is backfilled. The backfilling is done by waving a shovel back and forth (winnowing) along the bottom of the channel upstream of the excavated hole. Upon movement of the backfill material upstream of the artificial redd, a small trough remains above the redd. This helps to establish flow into the upstream side of the artificial redd. This process is repeated across the stream, as well as upstream and downstream. The result is that three rows, each containing three artificial redds are constructed.

After the artificial redds are constructed and their location documented, a freeze-core sample should be taken. This should be done as soon after construction as possible to represent the prespawning clean redd condition.

Freeze-core sampling involves installing three metal probes (preferably copper) into the streambed and then freezing the rods. It is often necessary to divert high velocity water around the sample site. A 5-gallon bottomless bucket is then worked a few inches into the streambed at the sample site. The metal rods are then driven 12 to 18 inches into the bed in a triangular pattern within the bucket. The rods should be 3 to 6 inches apart. A tether to a bottle of compressed carbon dioxide is placed to each copper rod, and the rods are frozen for approximately 20 minutes. A heavy aluminum tripod is then placed over the bucket, and a winch is used to remove the frozen sample from the streambed.

The frozen sample should be placed in a box with adjustable separators so that depth increments below the surface can be established. As the sample thaws, the material will fall into the compartments. The bottom of the artificial redd is established by colored rocks or marbles. Each depth increment can then be dried and sieved. Stream freeze-core sampling is repeated with one sample at each location, progressively through the sediment runoff season. Periodic dissolved oxygen measurements can be made by extracting water through the piezometer. More information on the use of this technique can be obtained in Castro and Reckendorf (1995).

Selection of a sampling procedure

Several factors influence both sampling site selection and sampling procedure. The most significant factor is the data necessary to meet the objectives of the study at hand. The objective of a bed-material sampling program may be to determine a representative bed gradation for a particular reach of a stream, or it may be to determine the variability and diversity of the sediment bed. Data needs should be clearly defined before the sampling program is planned. The second factor to consider is field conditions. Different samplers and sampling procedures are appropriate for different environments. Therefore, it is necessary to know the general streambed characteristics before the sampling program is established. Such reach-specific questions need to be addressed such as:

- Will the bed of the stream be wet or dry?
- Is the site accessible by road, boat, trail, or only by helicopter? Field conditions will determine both the practicality and type of sampling equipment to be used in the sampling program.
- What is the nature of the bed material to be sampled? Sand-bed streams typically have a more uniform bed gradation and therefore require a smaller volume sample than gravel-bed streams. Typically, equipment appropriate for sampling sand-bed streams is inappropriate for gravel-bed streams.

Once these physical issues are assessed, the available resources must be considered as a limiting factor when establishing a bed sampling program. Equipment, manpower, and funds are frequently limited, and therefore, priorities must be established.

Step-by-step field sampling procedures

Step 1 Select and mark out the required cross sections and the sampling locations. Use as many of the site-selection criteria outlined above as possible. The fixed permanent initial point should be on the left bank (looking downstream). Establish the control (horizontal and vertical) and reference all points.

Step 2 Sketch the site on data forms and reference the control points. If the streambed contains a mixture of sand and gravel deposits, map areas and record deposits of different size material. Develop a sampling strategy that will sample each zone.

Step 3 Collect a photographic record of the reach, controls, cross sections, sample locations (if possible), bed material (use a scale for reference), and bank conditions.

Step 4 Select appropriate sampler for the task (based on depth, velocity, and sample requirements). Verify that the sampler is operational.

Step 5 Collect sample as follows:

Surface bulk sample: sand bed. Move to a sampling location. In shallow streams, use a tape to measure from the permanently fixed initial point (IP), and wade to a sampling vertical on the section. Approach the sampling verticals from the downstream side to prevent disturbing the bed at the sampling section. In deep streams, using a boat and some type of positioning system (tag-line in narrow streams, electronic distance measurement (EDM) in wide streams), hold the boat steady over the sampling location. Obtain a sample of about 250 grams at each chosen location using the selected sampler.

Surface areal sample: coarse bed. To obtain a surface areal sample in a coarse bed stream, several techniques are employed. These can include random walks, setting up square or linear grids, or removing all the surface particles within a specified area. Hand-based techniques are typically employed, but they can be biased towards the larger size fractions. Collecting the entire surface layer within a specified area generally requires a specialized sampler.

Surface bulk sample: coarse bed. To obtain a surface bulk sample, carefully remove and collect all sediment in the surface layer to a thickness of the intermediate axis of the largest particle in the area. Care should be taken to ensure that fine sediment is not washed out of the sample. The required sample mass is a function of the largest particle.

Subsurface bulk sample: coarse bed. If the surface layer has not already been removed, then scrape away the surface layer of coarse material to the thickness of the intermediate axis of the largest particle in the area. The required sample mass is also a function of the largest particle.

Step 6 (Field sieving—this step is an alternative to transporting large bulk samples to a laboratory.) Set up a weighing station. This may consist of a tripod with a scale suspended for weighing pails of material. Assemble field sieve sets, and insert correct sieves. Collect pails, spades, template, labels, field note forms, sturdy plastic bags, and tarpaulins. Spread out two tarpaulins. Obtain tare weights for the pails. Shovel subsurface material into pails, weigh, and record. Pour material into top of the field sieves (8, 16, 32, 64, 128 mm sieves). Rock and shake the sieve set until material has moved to its retained size sieve. Weigh material retained on each sieve and on the pan. Record the results in the field notes. Save the material passing the finest sieve size for laboratory analysis. Save the 10 largest particles. Repeat the process until the required mass has been sieved. Measure the three perpendicular axes of the 10 largest particles. Retain up to 10 kilograms of the combined material from the pan and discard the rest of the sample.

Step 7 Complete and attach a label and sediment field note form for each sample. Specify the stream, station, cross section, vertical location, date, time, bedform and flow conditions, personnel on crew, type of sampler, sample number, and sample depth.

Other bed-material characteristics

While deposited bed material is often characterized by grain size, other characteristics can be of concern, as well. Such particle characteristics include shape, specific gravity, lithology, and mineralogy. In addition, data that describe the distribution of the various particles sizes and of specific contaminates are frequently required. Characteristics of the sediment deposit itself include: stratigraphy, density, and compaction. For some of these purposes, a sample can be disturbed; others require undisturbed sampling.

When the sediment particles are noncohesive, mechanical forces dominate the behavior of the sediment in water. The three most important properties that govern the hydrodynamics of noncohesive sediments are particle size, shape, and specific gravity. A discussion of these properties is found in Sedimentation Investigations in Rivers and Reservoirs, EM 1110–2–4000 (U.S. Army Corps of Engineers (USACE) 1995c). The boundary between cohesive and noncohesive sediments is not clearly defined. It can be stated, however, that cohesion increases with decreasing particle size for the same type of material. Clays are much more cohesive than silts. Electro-chemical forces dominate cohesive sediment behavior. The three most common clay minerals that have electro-chemical forces causing individual particles to stick together are illite, kaolinate, and montmorillonite. The dispersed particle fall velocity, flocculated fall velocity of the suspension, clay and nonclay mineralogy, organic content, and cation exchange capacity characterize cohesive sediment. The fluid is characterized by the concentration of important cations, anions, salt, pH, and temperature. More detailed information is presented in Tidal Hydraulics, EM 1110–2–1607 (USACE 1991c).

Bank material

Many channel stability issues result from a combination and interaction of a number of different causes. These causes can include not only fluvial erosion forces but also seepage problems, as well as properties of the soil. In addition, the bank material can help define the stability of the channel section and may be responsible for a significant percentage of the total sediment load. Therefore, it is often important to determine the characteristics of the stream bank. This is often done coincident with the bed-material sampling. More information on issues related to the assessment and analysis of bank material is provided in NEH654.09.

Conclusion

Bed-material sampling is frequently conducted to make sediment transport calculations. For this purpose, the sampling program should identify not only a representative bed-material gradation, but also any lateral, longitudinal, vertical, and/or temporal variation in bed-material composition. Water depth, velocity, and bed-material size are the most important factors used to identify appropriate samplers and sampling procedures. In sand-bed streams, the sample is typically taken from the upper 5 centimeters of the bed surface. In gravel-bed streams with coarse surface layers, samples of both the surface and subsurface layers are required. Surface sampling of large particles can be done by hand using a pebble count method. However, a pebble count can be biased if there is a significant size fraction that is below 8 millimeters in size. For smaller particles, an adhesive surface sampling approach is often considered necessary.