7. Steps of a sampling project

These guidelines have presented the various topics of bed-material sampling in a hierarchical order such that basic topics required for the understanding of higher topics were described first. However, in order to guide the user through the temporal sequence of sampling, a summary section is provided that explains the steps that may be taken before, during, and after a sampling project. The summary also highlights the principle points that should be followed or avoided when sampling in a gravel-bed stream in order to obtain successful field results.

Preliminary work:

State the study objective clearly.
Specify the target population of bed material to be sampled in the study project and explain why sampling that particular population is assumed to solve the study question. Bed-material populations may be the surface or the subsurface sediment, sediment representing the entire reach or sediment from specified geomorphological locations such as riffles, pools or bar heads. Stating the study objective is critical toward making a worthwhile field effort and dictates the more pragmatic decisions of the sampling project.

Get to know the stream.
Walk as much of the stream as possible. View the stream in its environmental context (note hillslope conditions and evaluate sources of sediment supply or sediment sinks). Obtain large-scale maps and areal photographs for an overview of the stream and its watershed. This is particularly important if the stream cannot be visited prior to the sampling project. Obtain hydrologic data such as mean daily flow and annual hydrographs.

Select a suitable study site.
The proximity to sediment sources or sinks is an important factor to consider when selecting a study site. Off-stream sediment supply from banks or tributaries, or sediment retention in beaver dams or diversion structures may have to be avoided in some studies, while sampling in their vicinity may be the focus of other studies. Environmental sensitivity of the stream to the disturbance that may be caused by bed-material sampling should be considered. Vehicle access may be a crucial factor. All these factors should be part of study-site selection.

Familiarize yourself with the stream in the sampling area.
Walk the sampling area and determine the morphological units (e.g., riffles, pools, and bars, Section 3.2.1), their particle sizes (Section 3.2.3), and the stream type (e.g., plane-bed, riffle-pool, 1.3). Does large woody-debris affect the degree of spatial variability of bed-material size (Section 3.2.5)? Does the particle-size distribution change within the sampling area (e.g., heterogeneous or homogeneous reach?). Dig a few small pits and determine whether the streambed is armored (Section 3.3.1). Draw a sketch plan (Section 6.1.4) which may include visually estimated mean or maximum particle sizes, the amount of fines, geomorphological (Section 3.2) or sedimentary units (Section 6.3.2.1-6.3.2.3), bed-surface structures (Section 3.4), large woody debris and other parameters of concern.

Select the sampling methods needed to accomplish the study objectives.
If the study objective is met by analyzing the surface sediment, use a pebble count (Section 4.1.1). Combine a pebble count with areal samples (Section 4.1.3) if the bed contains areas with large amounts of fine gravel and sand interspersed with coarser particles. Restricted field time may warrant a photo sieving approach (Sections 4.1.2.2, 4.1.3.3), but requires that the bed has a negligible amount of fine sediment (or the fines are irrelevant to the study), and that surface particles are well visible and not embedded or imbricated. In addition to saving time during field work, photographic close-ups or areal overviews of the bed are useful for analyzing bed-surface structures (Section 4.1.3.4). Use volumetric samples if the armor (Section 4.2.1), or the subsurface/subarmor and the vertically unstratified bulk sediment (Section 4.2.2) are the focus of the study. Consider whether the stream site(s) are accessible by vehicle when selecting sampling equipment.

Determine the desired/tolerable sampling precision.
Each study requires a specific sampling precision in order to meet the study objective and make the sampling effort worthwhile. Precise sampling is particularly important when attempting to detect a change in bed-material size over time or space (Section 4.1.1.2). For example, two samples with D_{50} sizes of 40 and 59 mm are not statistically different if each result has a 20% sampling error (Section 4.1.1.5). Remember also, operator errors add to the statistical error, but are not included in the computation of statistical errors. Finally, note that sampling errors propagate through the computations for which the results are used. If the D_{50} particle size has a 20% error, this error increases to a factor of 2.25 if D_{50} is raised to a power of 2.

Conduct a pilot study.
A pilot study can verify the feasibility of a selected sampling method (e.g., Are the particles too wedged into the bed for retrieval? Is the stream wadable? Is the bed too fine for a pebble count? Should areal samples be collected to better account for the distribution of fine sediment? Is the bed too coarse for a volumetric armor layer or subarmor/subsurface sample?) Evaluate whether the anticipated equipment is appropriate for the bed-material particle size and a dry or inundated streambed (Sections 4.2.3, 4.2.4).

A pilot study is also needed to estimate the standard deviation or sorting coefficient (Section 2.1.5.4) of the particle-size distribution. The standard deviation largely determines the sample size needed for a preset precision (Section 5). Finally, a pilot study is needed to determine the degree of spatial variability of the reach, which determines the sampling scheme and the length of the sampling reach (Section 6.1.4).

Estimate the necessary sample size (number of particles, sample mass, or number of subsamples) for obtaining the desired sample precision.
Estimate the necessary sample size based on data from the pilot study. Use statistical methods that assume a normal distribution of particle sizes (ϕ-units), if neither the distribution of a pilot sample, nor the study objective interfere with this assumption. If assumptions cannot be made about the underlying distribution type, determine sample size from methods that are not contingent upon this information. Table 7.1 provides sample-size procedures for pebble counts, volumetric, and areal samples for particle-size distributions for which either a normal or no underlying distribution is assumed. Compute sample size using both procedures if you cannot decide on a particular distribution type at this stage in the analysis.

The sample size required for a desired precision may be large. For pebble counts, this is usually not a problem (sampling 400 or more particles is doable), but gathering volumetric samples of several tons may be difficult. Evaluate your options before reducing the sample size. There may be ways to increase the feasibility of large samples (e.g., field sieving (Section 2.1.3.10), or collecting samples from a larger area). Optimize the information that can be obtained from a specific sample mass (by truncation and readjustment of the samples at the coarse end (Section 5.4.1.4), and by collecting grab samples (Section 6.4.4)). Increase the sampling accuracy by delineating and sampling homogeneous sedimentary units (Sections 6.3.2, 6.5.2) instead of a heterogeneous reach. Consider computer resampling of a parent sample (Section 5.4.2.2). Consider whether the study objective might even be met with a lower sample precision.

Consider using statistical analyses not described in this document. This document provides a variety of statistical analyses suitable for various study objectives, but these descriptions by no means exhaust the fund of statistical analyses. A statistical procedure might be available that satisfies your study objective with a lower sample size, or a higher precision than indicated by the analyses in this document. Consult with a statistician to find out whether a statistical procedure exists that is exactly tailored to suit the needs of your study.

Determine the appropriate spatial sampling scheme (Section 6).
Sample-size statistics require that all subsamples be derived from the same population. For bed-material sampling, this means that the area from which subsamples are collected must be more or less homogeneous so that all samples that are collected may be considered together. All samples must be collected from random locations. Regular

sampling patterns such as a grid with a random starting point (Sections 6.2.1, 6.2.2, 6.4.1) are preferable over completely random sampling, particularly if the bed is not exactly homogeneous (which gravel beds rarely are). Heterogeneous streambed areas may be sampled by collecting several subsamples, each along a reach-covering grid system that is slightly shifted against the other (Sections 6.2.3, 6.4.3, 6.4.4). This procedure results in a large sample size. Sample size can be reduced without compromising the sampling accuracy if a heterogeneous sampling area is (visually or statistically) delineated into several sedimentary units (e.g., a coarse, medium fine, and a bimodal facies) which are then basically homogeneous (Sections 6.3.2, 6.5.2). The reach should be sufficiently large so that each facies occurs several times. If sedimentary units are large, collect subsamples from representative locations instead of covering the entire unit.

The study objective may require that bed material be collected from a specific geomorphological unit, such as a riffle (Sections 6.3.1; 6.5.1) or a pool (Section 6.6.2), or that sampling is focused on a stream location with a particular interaction between flow hydraulics and sedimentation (e.g., bar head, backwater area, wake deposit). These samples are often used for a comparison over time or space (Section 6.6). Note that samples from individual geomorphological units or from "special" locations are usually not representative of the bed material in the reach.

Establishing a sampling plan and schedule.
Allocate the number of sampling points for pebble counts or the locations of volumetric samples over the reach. Estimate the field time necessary based on the estimated sample size. Would more operators be helpful or is the operator variability for the specific sampling method so high that employing more operators is counterproductive? Can the logistics be improved? Decide whether to sieve in the field or in the lab (Sections 2.1.3.10, 2.1.3.9). Consider photo-sieving (Sections 4.1.2.2, 4.1.3.4) if the field time is very limited. Assemble all necessary equipment and estimate the lab time required for analysis.

Design field forms (Sections 4.1.1.7, 4.5). This is a worthwhile effort even if the forms are not ultimately used because the process of designing the forms helps to visualize the sampling project.

The planning process of a bed-material sampling project may require frequent revisions because a decision or a fact made or encountered at some point may not be compatible with a decision or fact encountered at some other point.

While collecting bed material:

Surface sampling with pebble counts (Section 4.1.1)
Tips for reducing (operator) errors.

- Use a sampling frame when selecting particles to reduce operator preference for "handy" particles (Section 4.1.1.6), or sample along a tape measure on dry beds.

- Sample along a strictly determined grid pattern that covers the sampling area to prevent operators from omitting "unappealing" streambed locations (Section 4.1.1.4).
- Space sampling points by at least the D_{max} particle size in order to avoid counting large particles multiple times which results in a serially correlated sample (Section 4.1.1.4).
- Sample from high-flow bank to high-flow bank and record all particle sizes for each transect in sequential order (e.g., from left to right bank). Include the location of the current water line. Such a record helps to determine a systematic spatial variation of particle sizes and allows a deferred decision on whether particles from the high-flow bed are included or excluded from the study (Section 4.1.1.7).
- One operator should select and retrieve all particles. A second person may assist by taking over the template measurements.
- The use of templates (usually in 0.5 ϕ gradation) to measure particle sizes avoids measurement errors (Section 2.1.3.6) but requires that the size distribution approximates normality in ϕ-units. Use calipers only if the measured range of particle sizes is small (less than 0.5 or 1 ϕ units), if particle sizes are definitely not normally distributed (ϕ-units), or when measuring all particle axes for an analysis of particle shape (Section 2.1.3.7).

Areal surface sampling, sample conversion and combination.
Use areal samples if the sampling area is too small for a pebble count or when the bed contains a large amount of fines (Section 4.1.3). Select an adhesive for areal samples that will provide the optimum penetration depth for a given particle-size distribution (Section 4.1.3.2). If used to augment pebble counts, areal samples must be converted to equivalent grid-by-number distributions (Section 4.3). This conversion may not always be clear-cut. Pebble counts and converted areal samples need to be combined to obtain the complete particle-size distribution for the sampling area (Section 4.4).

Volumetric samples.
Determine the bed-material layer(s) to be sampled (armor, subarmor/subsurface or bulk) (Sections 3.3, 4.1) and the thickness of the sample (Sections 4.2.1, 4.2.2). Note that the sampling result is affected by the methods and the equipment used for sampling. Therefore, select methods and equipment that corroborate the study objective (Sections 4.2.4, 4.2.5) and avoid methodological changes. It is recommended that a three-sided plywood shield be used to define and contain the sampling area unless an undisturbed sediment core is needed. Remember to collect a sufficiently large sample mass.

Post collection analysis:

Sieving
A standard sieve set in 0.5 ϕ gradation is usually adequate for gravel- and cobble-beds, although well-sorted distributions may require sieving in 0.25 ϕ units (Section 2.1.3.1). Sieving the cobble and coarse gravel portion at the field site reduces the sediment load

hauled back to the laboratory. Split the fine part of the sample and sieve only a sufficient portion for size analysis. Large samples may require splitting the entire sample before sieving (Section 2.1.3.10).

Using square-hole sieves for the gravel portion is recommended for two reasons: Sieve results for gravel may directly be combined with sieve results for sand (typically obtained from square-hole sieves), and gravel sieve results are directly comparable with template measurements (Section 2.1.3.1). Results from square-hole sieves must be converted before they are compared with results from round-hole sieves (Section 2.1.3.5). This conversion varies with particle shape. The same conversion is necessary before comparing particle-size measurements performed with a template and a ruler or calipers.

Analysis of particle shape and other particle parameters.
Particle shape affects the transportability of particles and may indicate the fluvial transport distance (Section 2.2.2). If a visual classification of particle shape is not sufficiently accurate (Sections 2.2.3, 2.2.4), all three particle axes need to be measured for a computation of particle shape (Sections 2.2.1, 2.2.3). Be sure to correctly identify the three particle axes (Section 2.1.1) and use calipers rather than a ruler to obtain accurate measurements when appropriate. Measure particle axes and any other particle properties (density, volume and mass (Section 2.3) and bulk density (Section 2.4)) directly at the field site if particle sizes and sample mass are large.

Statistical analysis:
The gradation curve and descriptive statistics
Compute the frequency per size class either by weight (for volumetric samples) or by number (for pebble counts) and plot the histogram. Compute the cumulative frequency distribution and plot the gradation curve (sum curve). Determine the distribution type (Section 2.1.4) and evaluate whether the distribution is “normal enough” to warrant the use of statistics based on a normal distribution. This is a judgement call. Treat bimodal distributions (Section 2.1.5.9) as two separate distributions.

Use either a graphic approach or the moment method (Section 2.1.5) to compute the particle-distribution parameters. A graphic analysis is recommended when analyzing only a few data sets and particularly for the novice user because this method makes it easy to see the connection between computation and statistical results. Compute the seven percentiles (D_5, D_{16}, D_{25}, D_{50}, D_{75}, D_{84}, D_{95}) and the descriptive statistical parameters (mean, sorting, skewness and kurtosis). The moment method computes the moments (which are largely equivalent to the graphic distribution parameters) directly from the frequency distribution. This procedure is recommended for a fully computerized analysis of a large number of data sets.

Statistical precision of a sample (Section 5)

The first estimate of the relation between sample size and precision was based only on a pilot sample. The actual precision is determined after all samples are collected. Table 7.1 indicates the sections in this document that discus sample-size procedures used for pebble counts, volumetric, and areal samples. Either a normal distribution is assumed, or the procedure makes no assumptions regarding the distribution type.

Table 7.1: Document sections explaining sample-size procedures for pebbles counts, volumetric, and areal samples, for an assumed underlying normal distribution, or for no assumed distribution type.

	Normal distribution assumed	No distribution type assumed
Pebble count	5.2.2	5.2.3, 5.2.4
Volumetric sample	5.4.3	5.4.1.1, 5.4.2
Areal sample	5.3.1	5.3.2, 5.3.3

If attaining a preset sampling precision is crucial to the sampling project, compute sampling precision at the field site as soon as samples are sieved and analyzed. Use a laptop computer and pre-designed spreadsheets for rapid field computations (Sections 5.2.2.9, 5.4.3.1, 5.4.3.2). Continue sampling (during the same field season) until a tolerable sampling precision has been reached.

More statistical analyses than described in this document are available in the statistical literature. Consult with a statistician to identify the statistical analysis that satisfies your sampling objective as best as possible.