



# Sampling Surface and Subsurface Particle-Size Distributions in Wadable Gravel- and Cobble-Bed Streams for Analyses in Sediment Transport, Hydraulics, and Streambed Monitoring

Kristin Bunte  
Steven R. Abt



## Abstract

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This document provides guidance for sampling surface and subsurface sediment from wadable gravel- and cobble-bed streams. After a short introduction to streams types and classifications in gravel-bed rivers, the document explains the field and laboratory measurement of particle sizes and the statistical analysis of particle-size distributions. Analysis of particle parameters, including shape, density, and bulk density are also discussed. The document describes the spatial variability of bed-material particle sizes as well as the horizontal and vertical structure of particle deposits. The discussion of sampling procedures and equipment helps the user to make appropriate selections that support the sampling objective. Sample-size estimates may be obtained from empirical data or computed from statistical relationships between sample size and accuracy. The document explains a variety of methods, their usage and prerequisites. A detailed discussion of sampling schemes guides the user to select appropriate spatial sampling patterns necessary to produce representative samples.

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**Keywords:** Particle-size analysis, spatial variability of bed-material size, sampling procedures, sampling equipment, sample size, spatial sampling schemes.

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**Kristin Bunte  
Steven R. Abt**



Prepared in support of the National Stream Systems Technology Center mission to enable land managers to “secure favorable conditions of water flows” from our National Forests.



## **Preface**

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The Stream Systems Technology Center of the Rocky Mountain Research Station, U.S. Forest Service, initiated the generation of this compendium of methods because National Forest System streams are dominated by gravel caliber material and sound guidelines for characterizing the bed material of gravel- and cobble-bed streams are needed by hydrologists, fisheries and aquatic biologists, and geomorphologists. This project was initiated to meet Forest Service needs and at the same time provide an encyclopedia of approaches as a basis for the Federal Interagency Sedimentation Project Task Committee to adopt selected methods as standard approaches in the future. Work on this reference was initiated by an ad hoc team convened by Larry Schmidt of the Stream Systems Technology Center. The team included Ron Copeland, U.S. Army Corps of Engineers, Phil Zrymiak, Environment Canada, Randy Parker, U.S. Geological Survey, and Jim Fogg, Bureau of Land Management.

Streambed analysis and sampling in gravel-bed rivers have received increasing attention, especially over the last few years. Publishing activity reflects this trend. During the late 1970s and the 1980s, one or two papers were published per year on gravel-bed sampling procedures, sample size estimates, or sampling schemes. This number has risen to about five to seven papers per year during the 1990s. Despite the interest in the topic, a comprehensive compilation of these approaches is lacking and users need a reference to guide them through the multi-layered aspects of bed-material sampling.

The work presented is intended to fill this gap. Obviously attempting to comprehensively synthesize a rapidly evolving technology is impossible. This effort represents our knowledge at this point in time. Consequently, the user must exercise judgment in applying the approaches provided herein to specific sampling projects. To make the best choice of methods, the user should have knowledge about gravel-bed rivers and the processes forming them. The selection of a sampling program (where, how, and how much to sample) significantly influences the outcome.

## **Acknowledgments**

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## List of Notations and Units

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$a$	Particle $a$ -axis, the longest axis	mm
$a$	Coefficient	—
$a, \beta$	Confidence levels	—
$b$	Particle $b$ -axis, the intermediate axis	mm
$b$	Coefficient	—
$A$	Area	$\text{m}^2, \text{mm}^2$
$A_p$	Area covered by one particle	$\text{m}^2, \text{mm}^2$
$A_s$	Sampling area	$\text{m}^2, \text{mm}^2$
$B$	Bimodality index (Wilcock 1993)	—
$B^*$	Bimodality index (Sambrook Smith et al. 1997)	—
$c$	Particle $c$ -axis, the shortest axis	mm
$C$	Corey shape factor, similar to particle sphericity $\psi$	—
$b_m$	Mean particle $b$ -axis size	mm
$b_{m(sq)}$	Mean $b$ -axis size of particles retained on a square-hole sieve	mm
$b_{m(rd)}$	Mean $b$ -axis size of particles retained on a round-hole sieve	mm
$d$	Diameter (e.g., of a freeze core)	m
$d_p$	Penetration depth of adhesive in areal sampling	mm
$d_{Smin}$	Minimum sampling depth	cm
$D$	Particle size or particle sieve size	mm
$D_{cm}$	Particle size of the coarse mode of a distribution	mm
$D_{ci}$	Particle size of the center of the $i$ th size class	mm
$D_{dom}$	Dominant large particle diameter within an area of concern (reach)	mm
$D_e$	Vertical extent of particle embedded or buried below the bed	mm
$D_f$	Height with which a particle protrudes above the bed	mm
$D_{fm}$	Particle size of the fine mode of a distribution	mm
$D_{gm}$	Geometric mean particle size of a distribution	mm
$D_i$	Particle size of the $i$ th size class	mm
$D_{ic}$	Center of class particle size computed from the geometric mean of the upper and lower border of the size fraction (equal to logarithmic mean, or arithmetic mean of particle sizes in $\phi$ -units)	$\phi$
$D_{i(sq)}$	Particle size of the $i$ th size class on a square-hole sieve	mm
$D_{i(rd)}$	Particle size of the $i$ th size class on a round-hole sieve	mm
$D_m$	Mean particle size of a distribution	mm
$D_{max}$	Largest particle	mm
$D_{mc}$	Particle size of the weight midpoint of a sieve class; i.e., particle size that halves the particle mass per size class	mm
$D_{min}$	Smallest particle	mm
$D_{mode}$	Mode of particle size distribution	mm
$D_n$	Nominal particle diameter, $(a \cdot b \cdot c)^{1/3}$	mm
$D_p$	$p^{\text{th}}$ percentile of a particle-size distribution	mm
$D_{pass}$	Smallest sieve size through which a particle passed	mm
$D_{pass(i)}$	Smallest sieve size passed by all particles of the $i$ th size class	mm
$D_{pm}$	Mean of $p^{\text{th}}$ percentile obtained from several subsamples	mm
$D_{ret}$	Largest sieve size that retained a particle	mm
$D_{ret(i)}$	Largest sieve size retaining all particles of the $i$ th size class	mm
$D_s$	Size of sieve opening	mm
$D_t$	Total vertical extent of a particle	mm
$D_{50}$	Median particle size of a distribution	mm
$D_{84}$	84 <sup>th</sup> percentile of a particle-size distribution (subscript number refers to percentile)	mm
$D_{84m}$	Mean particle size of the $D_{84}$ in subsamples	mm
$e$	Void ratio, ratio of volume of voids to total volume	—
$e\%D_m$	Percentage error around the mean particle size in mm ( $D_m$ )	mm
$e_{\pm\phi m}$	Absolute error around the mean particle size in $\phi$ -units ( $\phi_m$ )	$\phi$

$e_{\% \phi_m}$	Percentage error around the mean particle size in $\phi$ -units ( $\phi_m$ )	$\phi$
$e_{\pm D_p}$	Absolute error around the mean particle size for the $p^{\text{th}}$ percentile in mm.	mm
$e_{\pm \phi_p}$	Absolute error around the mean particle size for the $p^{\text{th}}$ percentile in $\phi$ -units	$\phi$
$E$	Embeddedness	—
$E\%$	Percent cobble embeddedness	%
$F$	Particle form factor distinguishing between platy, bladed and elongated particle shapes	—
$f$	Frequency by weight or number of a particle-size class	—
$f_{\%}$	Percent frequency by weight or number of a particle-size class	%
$G_{\phi_i}$	Frequency of an equivalent Gaussian distribution of $\phi_i$	—
$G_{\%i}$	Percent frequency of an equivalent Gaussian distribution of $\phi_i$	%
$g$	Acceleration due to gravity = 9.81	m/s <sup>2</sup>
$i$	$i^{\text{th}}$ size class	—
$k$	Total number of size classes	—
$K$	Particle size of the bottom particle	mm
$ku$	Arithmetic kurtosis of a distribution	—
$ku_g$	Geometric kurtosis of a distribution (hypothetical)	—
$l$	Length (e.g., of a freeze core)	m
$L_{D_i}$	Frequency of an equivalent lognormal distribution of $D_i$	—
$L_{\%i}$	Percent frequency of an equivalent lognormal distribution of $D_i$	%
$m$	Mass	g, kg
$m_{D_{max}}$	Mass of the $D_{max}$ particle size	g, kg
$m_{mi}$	Mean weight of particles retained on the $i^{\text{th}}$ size class	g, kg
$m_i$	Mass of particles retained on the $i^{\text{th}}$ size class	g, kg
$m_s$	Mass of all particles contained in a sample	g, kg
$m_{ss}$	Mass of all particles contained in a subsample	g, kg
$m_{tot}$	Mass of all particles contained in the total sample	g, kg
$m_{\%i}$	Percent frequency of particle mass for the $i^{\text{th}}$ size class	%
$m_{\%cmi}$	Percent frequency of particle mass for the $i^{\text{th}}$ size class that is part of the coarse mode of the distribution	%
$m_{\%fmi}$	Percent frequency of particle mass for the $i^{\text{th}}$ size class that is part of the fine mode of the distribution	%
$n_{emb}$	Number of embedded particles	—
$n_{exp}$	Number of particles exposed on the bed surface	—
$n_i$	Number of particles retained for $i^{\text{th}}$ size class	—
$n$	Total number of particles per sample	—
$n_{\% exp}$	Percent of particles exposed on the bed surface	%
$n_i$	Number of particles retained in the $i^{\text{th}}$ size class	—
$n_{ph}$	Number of particles contained within a photographed area	—
$n_r$	Number of particles at the reference site	—
$n_s$	Number of particles at the study site	—
$n_{tot}$	Total number of samples	—
$n_2$	Second sample	—
$n_{\%i}$	Percent frequency of particle numbers for the $i^{\text{th}}$ size class	%
$\Sigma n_{\%i}$	Cumulative percent frequency of particle numbers for the $i^{\text{th}}$ size class = $p_i$	%
$p$	Porosity, ratio of volume of voids to total volume	—
$p_{i,a-w}$	Weight fraction ( $m_i/m_{tot}$ ) of the $i^{\text{th}}$ size class of an area-by-weight particle-size distribution	—
$p_{i,0}$	Weight fraction ( $m_i/m_{tot}$ ) of the $i^{\text{th}}$ size class of a volume-by-weight size-distribution converted from an area-by-weight distribution	—
$p_{i,v-w}$	Weight fraction ( $m_i/m_{tot}$ ) of the $i^{\text{th}}$ size class of a volume-by-weight particle-size distribution	—
$p_s$	Proportion of fines in bed material at a study site	—

$P_r$	Proportion of fines in bed material at a reference site	—
$P_{v,0}$	Porosity, ratio of volume of voids to total sediment volume (bulk)	—
$p$	Probability associated with $z_p$ values	—
$p$	Percentile (in decimals)	—
$P_i$	Percentile of a cumulative distribution for $i^{\text{th}}$ size class (in decimals)	—
$P_{Ai}$	Percentile for $i^{\text{th}}$ size class of an areal sample	—
$P_{Gi}$	Percentile for $i^{\text{th}}$ size class of a grid sample	—
$P_{ri}$	Percentile for $i^{\text{th}}$ size class of a sample using a rigid combination method	—
$P_{fi}$	Percentile for $i^{\text{th}}$ size class of a sample using a flexible combination method	—
$P$	Particle roundness index	—
$P_m$	Mean particle roundness index for a deposit	—
$P_{cm}$	Proportion of sediment contained in the coarse distribution mode	mm
$P_{fm}$	Proportion of sediment contained in the fine distribution mode	mm
$P_{1m}$	Proportion of sediment contained in the primary distribution mode	mm
$P_{2m}$	Proportion of sediment contained in the secondary distribution mode	mm
$q$	Number of subsamples	—
$r$	Number of replicate samples for a given sample or subsample size	—
$r$	Largest radius of a circle that can be inscribed into a corner of a particle	mm
$R$	Largest radius of a circle that can be inscribed into the entire particle	mm
$R_{Di}$	Frequency of an equivalent Rosin distribution of $D_i$	—
$R_{\%i}$	Percent frequency of an equivalent Rosin distribution of $D_i$	%
$s$	Sample standard deviation, or sorting coefficient of an approximately normal distribution	mm or $\phi$
$s_{Dm}$	Standard deviation of the mean particle size in subsamples	mm or $\phi$
$s_{50}$	Standard deviation of the median particle size $D_{50}$ in subsamples	mm or $\phi$
$s_g$	Geometric standard deviation or sorting coefficient of a sample distribution	—
$sk$	Arithmetic skewness of a distribution	—
$sk_g$	Geometric skewness of a distribution	mm, mm <sup>2</sup>
$s_p$	Standard error around percentile $p$	mm or $\phi$
$s_R$	Sorting coefficient for a Rosin distribution	mm or $\phi$
$s_I$	Sorting coefficient as computed by Inman (1952)	$\phi$
$S$	Particle compactness	—
$V$	Volume (e.g., of a freeze core)	m <sup>2</sup>
$V_s$	Volume of sediment without pores	m <sup>3</sup> , liter
$V_t$	Total volume of sediment	m <sup>3</sup> , liter
$V_v$	Volume of voids or pores in sediment	m <sup>3</sup> , liter
$z_p$	Values of the x-axis of a true, bell-shaped normal distribution	—
$\Phi$	Pivot angle, angle of repose, intergranular friction angle	°
$\phi$	Particle size unit = $-\log_2(D)$	$\phi$
$\phi_m$	Arithmetic mean particle size of a distribution	$\phi$
$\phi_i$	Particle size in $\phi$ -units of the $i^{\text{th}}$ size class	$\phi$
$\phi_{ci}$	Particle size in $\phi$ -units of the center of the $i^{\text{th}}$ size class	$\phi$
$\phi_{m1}$	Particle size of the primary distribution mode	$\phi$
$\phi_{m2}$	Particle size of the secondary distribution mode	$\phi$
$\phi_{50}$	Median particle size of a distribution	$\phi$
$\phi_{84}$	84 <sup>th</sup> percentile of a particle-size distribution (subscript number refers to percentile)	$\phi$
$\phi_p$	$p^{\text{th}}$ percentile of a particle-size distribution	$\phi$
$\gamma$	Specific weight $\rho \cdot g$	g/cm <sup>2</sup> ·s <sup>2</sup> , kg/m <sup>2</sup> ·s <sup>2</sup>
$\mu$	Distribution mode	mm or $\phi$
$\pi$	Dimensionless constant, 3.141	—

$\rho$	Density	$\text{g/cm}^3, \text{kg/m}^3$
$\rho_f$	Fluid density	$\text{g/cm}^3, \text{kg/m}^3$
$\rho_s$	Density of a sediment particle	$\text{g/cm}^3, \text{kg/m}^3$
$\rho'_s$	Submerged particle density	$\text{g/cm}^3, \text{kg/m}^3$
$\rho_b$	Sediment bulk density	$\text{g/cm}^3, \text{kg/m}^3$
$\rho_{sub}$	Subsurface sediment bulk density	$\text{g/cm}^3, \text{kg/m}^3$
$\sigma$	Standard deviation of the population distribution	any unit
$\Sigma$	Sum	any unit
$\psi$	Particle size unit, = $\log_2(D) = -\phi$	$\psi$
$\psi$	Particle sphericity	—
$\psi_r$	Effective particle settling sphericity	—