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A METHOD OF SAMPLING COARSE RIVER-BED MATERIAL

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Abstract--This determination of the size of material on the bed of a stream is based upon an analysis of the relative area covered by particles of given sizes. The method is applicable to those rivers which flow on coarse material and may be waded during periods of low water. Sampling consists of measuring the intermediate axis of 100 pebbles picked from the bed of the channel on the basis of a grid system. From this sample a frequency distribution is drawn from which the desired size parameters are read. The advantages of the areal sampling procedure over bulk sampling are (1) that it is applicable to very coarse materials, and (2) that it provides a more representative sample of an entire reach of a stream.

Both hydraulic and physiographic studies of rivers often require some measure of rugosity of the channel. To provide an adequate description of bed material, as it affects rugosity, a consistent method of sampling is necessary. The method described here, though applicable only to coarse material, has several advantages over the usual bulk-sample method. The present method can satisfactorily integrate the enormous range in grain size often present in a river bed, as well as the non-random areal distribution of material in pools, riffles, and bars. The author believes this method of sampling described below produces a more representative picture of the bed of the stream, as well as a better measurement of the effective plane of roughness which directly affects the flow within the channel.

Description of sampling method--The determination of grain size is based upon an analysis of the relative area covered by given sizes rather than upon their relative weights. It is essentially an adaptation of suggestions made by J. C. Griffiths, Pennsylvania State University, for obtaining representative samples of heterogeneous materials. These suggestions the author gratefully acknowledges. The method consists of the following steps:

(1) In the desired reach of the stream a grid system is established either by pacing or with actual lines. The size of the grid is determined by the length of reach which the sampler desires to describe. This may include both a riffle and a pool, a riffle alone, or a pool alone. If comparisons are to be made between reaches, the sampler must obviously be consistent in his choice of the length of reach to be included in the sample.

(2) After establishing the grid, which can be done by a pacing traverse as the sampler picks up each pebble, 100 individual pebbles are picked up from the bed. (The sampling is probably less subjective when lines or tapes rather than pacing are used to fix the individual sampling points.) Randomness in the selection of each pebble can only be obtained if the sampler tries not to look at the bed as he picks up each pebble. The author's practice is to draw each pebble from beneath the tip of the toe of his boot.

(3) The intermediate axis of each pebble is measured. The limitations of measuring small individual pebbles such as sand sizes will be discussed below.

(4) Unless the actual diameters are of interest, a rule or scale can be designed showing class limits only and each pebble tallied within a grade class immediately. For this purpose the Wentworth scale is probably the most useful.

(5) With the pebbles placed in the proper classes, it is a simple matter to plot a frequency distribution of the sample. This plot is further simplified if the Wentworth size classes are denoted by the ϕ notation [KRUMBEIN, 1936] in which $\phi = -\log_2$ diameter in mm. Using this logarithmic scale the frequency distribution can be plotted on arithmetic coordinate paper (Fig. 1). Having plotted cumulative frequency curves for the distribution, the median diameter or other desired parameters can readily be determined in the field [INMAN, 1952].

The paragraphs which follow include observations on the present range of the experimental data, a comparison of the results of this procedure with the results produced by other sampling methods, and a brief analysis of the reproducibility of the sample obtained from a given reach by one or more operators.

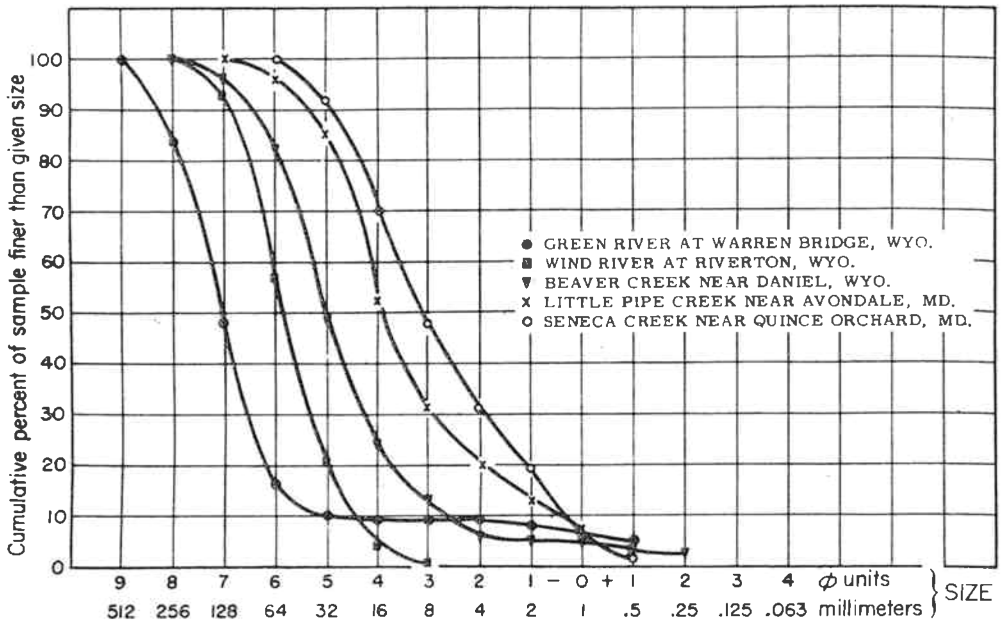

Fig. 1--Size analyses of river-bed gravels

Range of experimental data--The illustrative examples shown in Figures 1 and 2 from a large number of rivers flowing in diverse geographic regions indicate that the cumulative frequency curves of these samples resemble the distributions often shown by river gravels. Figure 2 compares these coarse bed materials with the normally distributed river-bed sands described by BLENCH [1952]. The median diameters of the samples range from 8 to 120 mm. Sorting, as measured by the ϕ standard deviations [INMAN, 1952, p. 135], ranges from 0.85 to 2.95 in the samples studied. These sorting values are lower on the whole than those listed by KRUMBEIN [1942] for comparable (possibly finer) gravels. Although it is conceivable that this method of sampling produces an apparent uniformity in the sample, the range of sorting found in the sediments thus far studied indicates that such a bias, if present, is not significant.

Comparison with other methods of sampling and analysis--It is interesting to compare samples determined from pebble counts with samples of the same material analyzed by sieving and weighing. As the example in Figure 3 shows, although the shapes of the curves are similar, the median diameter of the sample determined by the author's number frequency method is considerably larger than the median diameter of the sieved sample. The consistency of this relationship has been demonstrated by several analyses. The relationship is the reverse of the one we would expect if the comparison consisted simply of counting pebbles versus weighing the amounts of material in each sieve class from precisely the same sample. In the present instance, however, it is apparently the sampling procedure rather than the method of analysis which produces the discrepancy in median grain size.

The sample obtained from the grid represents the areal distribution of material on the bed. Each point sample actually represents a portion of the bed surface. If, for example, the sample of 100 stones contains ten in class 32-64 mm, the plotted frequency distribution actually shows that ten per cent of the surface area sampled is covered by material in the class 32-64 mm.

The distributions in Figure 3, therefore, represent analyses of samples taken from the same reach by two entirely different methods. The difference stems from the fact that the sieved sample represents a scoop of material obtained from one or more locations on the bed. If the bed contains coarse material, to be representative each sample must weigh in the neighborhood of 200-300 pounds. As a rule, in the absence of a dredge capable of obtaining a huge sample covering a wide surface area of the bed, we obtain for sieve analysis a non-representative sample from selected spots which contains a preponderance of fine material. It is the author's opinion that in most instances this defect in sampling is insurmountable if a volumetric analysis is made.

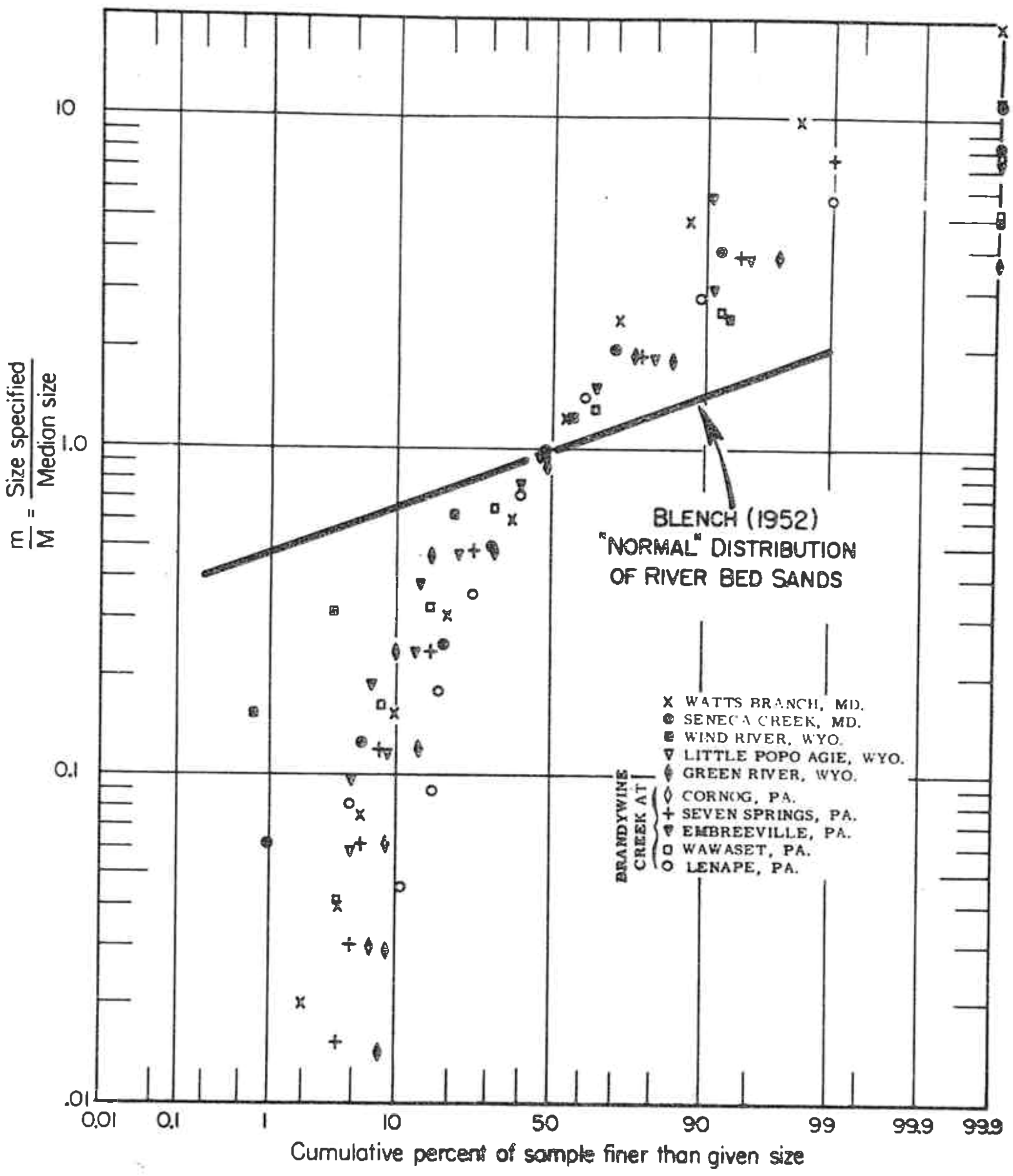

Fig. 2--Dimensionless size distribution for ten samples of river-bed gravels illustrating range of sorting and deviations from a normal distribution

Reproducibility of results--The reproducibility of results of the sampling at a given location is illustrated by the data presented in Tables 1 and 2. The three samples from Watts Branch (Table 1) were taken on separate days by the same sampler. In each case the distribution described by the cumulative frequency curves is much the same, although on one occasion the median diameter was considerably larger than on the other two. In all three samples the variance of the number of particles within the individual grades or size classes showed no systematic variation with grain size. The data from Mines Run (Table 2), a dry channel in a sandstone region in the Shenandoah Valley of Virginia, show the small amount of variation encountered at a given locality when a single operator samples 900 pebbles in groups of 100 pebbles. The standard deviation of the median diameters of these groups of 100 pebbles is 6.7 mm.

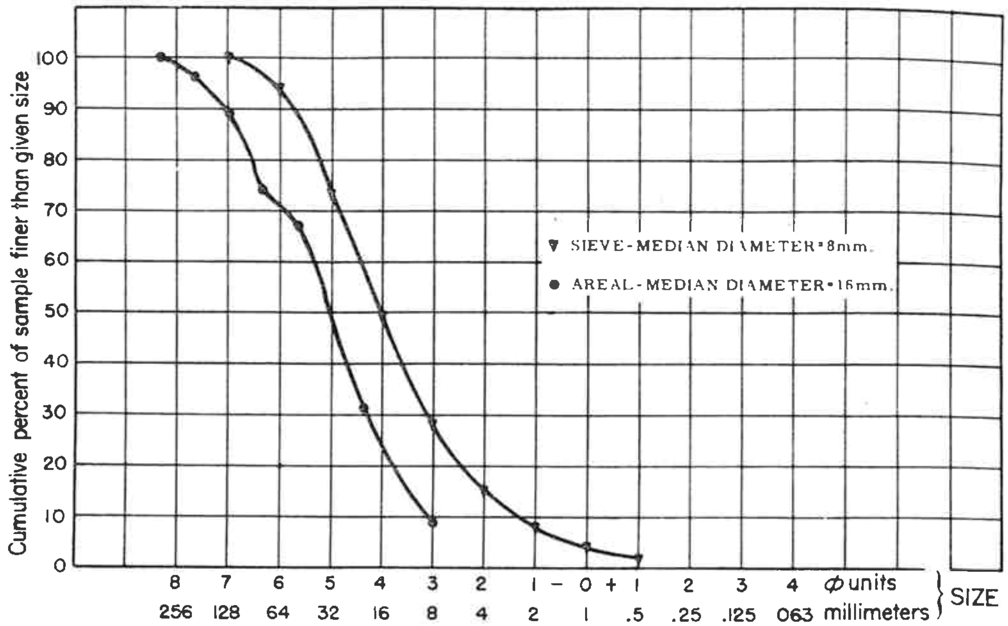

Fig. 3--Comparison of samples obtained from sieve and areal analysis

Table 1--Size distributions of three river-bed samples obtained at Watts Branch near Rockville, Maryland

Size		1953		
mm	φ	June 19	August 25	October 1
0.5	1	....	3	2
1	0	4	0	2
2	-1	5	3	2
4	-2	11	3	4
8	-3	8	5	10
16	-4	8	17	17
32	-5	16	15	17
64	-6	16	26	17
128	-7	17	21	16
256	-8	10	6	11
512	-9	....	1	3
Median diameter, mm	....	25	37	26

In addition to illustrating the reproducibility of the sample, the data from Mines Run (Table 2) also suggest the minimum number of pebbles which should be counted to produce the described result. It can be seen from the table that 100 pebbles was sufficient to describe this distribution. Using the observed standard deviation, Student's t test suggests that one sample of 100 pebbles would be required to obtain a mean median diameter within plus or minus ten mm (12 pct of the median), with a likelihood of being correct approximately two-thirds of the time. Although it is conceivable that in larger rivers a greater number would be desirable, the use of 100 pebbles makes the computation of cumulative percentages and plotting of the distribution in the field extremely easy. Pending evidence to the contrary, this method appears reasonable.

Natural river channels possess small depositional 'provinces' such as occur on bars and riffles or in pools. If there is a distinct difference in the statistical variability of the individual deposits, those having the greater variability should be more intensively sampled than those of less variability.

Table 2--Size distribution of nine samples obtained by one sampler from Mines Run, Virginia, July, 1953

Size	B2	B4	B6	B8	OA	A2	A4	A6	A8
mm									
4	1	1	2	2	...	1	1	2	...
10	2	1	2	3	3	3	4	2	...
25	6	11	9	12	14	4	7	9	8
40	8	11	8	7	8	11	11	11	9
63	15	16	16	7	9	18	14	23	17
100	22	22	18	23	26	22	26	13	20
160	19	21	27	21	19	18	15	17	23
250	19	13	14	16	15	17	13	13	12
400	5	3	1	7	4	5	6	4	9
630	3	1	3	2	2	1	2	4	1
1000	...	...	...	...	...	...	1	2	1
Median diameter, mm	94	80	82	84	83	80	79	69	87

Published data on river gravels from these depositional 'provinces,' however, show no marked differences in variability, and hence the random sampling proposed here appears to give the most significant results.

In obtaining samples from Mines Run the grid system was moved upstream and downstream at two-foot intervals in order to determine the effect of minor changes in the position of the grid on the reproducibility of the results. No systematic differences with position were observed, and, as before, the data showed no systematic variation within individual size classes; that is, the error of variation in sampling did not change systematically with change in grain sizes. The data from Watts Branch and from Mines Run suggest that an individual operator can repeat his sampling performance. Whether or not the accuracy of this repetition is sufficient for a given problem depends upon the results desired by the investigator.

The evidence available indicates that the results obtained by different operators on the same reach of channel do not differ appreciably. The three analyses obtained by different samplers from the Wind River at Riverton, Wyoming (Table 3), show extremely little variation in their median diameters and sorting. As the table shows, the median diameters were 51, 49, and 51 mm. The cumulative frequency curves for each of the samples are very similar. Data from Garner Run at Leading Ridge Gap, Pennsylvania, also show the consistent results obtained by different operators (Table 4). Although of limited value, five additional analyses indicate little variation in the results obtained by only two samplers.

Table 3--Size distribution of three samples obtained by different operators from Wind River at Riverton, Wyoming, August 6, 1953

Size		Operator		
mm	ϕ	A	B	C
8	-3	1	0	0
16	-4	4	1	3
32	-5	24	26	38
64	-6	51	56	53
128	-7	50	49	36
256	-8	10	8	10
Median diameter, mm	...	51	51	49

Table 4--Size distributions of three samples obtained by different operators from Garner Run at Leading Ridge Gap, Pennsylvania, September 31, 1953

Size		Operator		
mm	ϕ	A	B	C
2	-1	1	0	0
4	-2	4	0	0
8	-3	1	5	1
16	-4	4	6	4
32	-5	4	3	5
64	-6	16	13	17
128	-7	15	13	16
256	-8	11	13	13
512	-9	4	7	4
Median diameter, mm	...	64	77	77

Within the range of roundness normally encountered in river studies, there is little or no error introduced by the possibility of different samplers measuring different intermediate axes.

Limitations of the sampling procedure--The principal limitation thus far encountered in practice is the inability to measure accurately the fine particles. Two to four mm is about the smallest size which can be measured in the field. When the proportion of fine material is small, the smallest sizes may be lumped together or measured roughly in separate grades. Either system produces little change in the final result. Where fine material predominates, a sampling method such as this, which provides an areal coverage of the bed, requires both a sampler capable of drawing a single or a limited number of grains from the stream bed, and a calibrated magnifying glass which will permit measurements of fine particles in the field.

The difficulty of bed sampling by hand in deep water is a second limitation of the method. Thus far no satisfactory mechanical sampler has been developed for coarse material. The method is workable, however, where the water is several feet deep; and thus the importance of this limitation, which is common to all kinds of sampling beneath flowing water, is at least reduced.

Although it may not be a permanent one, the fact that the areal sampling procedure described here produces results, which are not directly comparable to the results previously obtained by bulk sampling and analysis of samples by weight, is something of a drawback. Additional work along the lines described by MARSCHNER [1953] may make it possible to convert from one system to another. It is important to remember, however, that conversion is only possible, or for that matter useful, where the samples themselves have equal validity. The primary significance of the sampling procedure suggested here is the fact that it gives a more representative sample, and hence a different one from those customarily obtained from river beds.

Conclusion--The principal advantages and disadvantages of the areal sampling procedure described here can be summarized as follows. In its favor are: (1) it is simple to perform, and indeed it is 'possible' in situations where flowing water and coarse material make other methods almost impossible; (2) the sampling method provides a reasonably representative sample of an entire reach of the stream; and (3) a sufficient range of sizes can be measured to permit some standardization of methods, making possible comparison of results obtained in studies of hydraulic roughness in one place with those obtained elsewhere. Its primary disadvantage at present is the inability to handle fine material.

References

BLENCH, T., 'Normal' size distribution found in samples of river-bed sand, Civ. Eng., v. 22, p. 147, 1952.

INMAN, D. L., Measures for describing the size distribution of sediments, J. Sed. Pet., v. 22, pp. 125-145, 1952.

KRUMBEIN, W. C., Application of logarithmic moments to size frequency distribution of sediments, J. Sed. Pet., v. 8, pp. 84-90, 1936.

KRUMBEIN, W. C., Statistical summary of some alluvial gravels, Rep. of Comm. on Sedimentation, 1940-41, Nat. Res. Coun., Ex. B, pp. 9-25, 1942.

MARSCHNER, A. W., A method for the size analysis of sand on a number frequency basis, J. Sed. Pet., v. 23, pp. 49-59, 1953.

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