Sediment Budgets (Proceedings of the Porto Alegre Symposium, December 1988). IAHS Publ. no. 174, 1988.

Preliminary estimate of bed load using mean grain size distribution data

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Abstract Relationships between parameters of grain size distributions of river bed material and suspended sediments are used to obtain estimates of the importance of bed load, expressed as a percentage of suspended load. Based on mean bed material and suspended sediment grain size distributions, a total of 59 Brazilian sediment gauging stations were classified with regard to wash load/suspended bed sediment predominance and probable relative importance of bed load.

Estimation de l'ordre de grandeur du charriage à l'aide de courbes granulométriques moyennes

Résumé L'étude des caractéristiques des courbes granulométriques moyennes du matériau de fond et de la charge en suspension de plusieurs cours d'eau brésiliens permet d'évaluer la part qu'occupe la charge de fond dans la composition du débit solide et de l'exprimer en pourcentage de la suspension. La comparaison de ces caractéristiques, faites en 59 stations sédimentométriques permet de classer celles-ci selon les valeurs du rapport entre les charges de suspension en provenance du lit et du bassin versant (wash load), et l'apport de la charge de fond à la composition du débit solide.

SEDIMENT DATA AND TOTAL LOAD

When sediment yield data, generally derived from suspended discharge measurements, are used for specific projects, the determination of total load may become necessary. Procedures for the calculation of total sediment load require not only the use of additional data but also considerable computational effort, particularly when various formulas are employed to establish bed load (Q_{sa}) or suspended bed sediment discharge (Q_{ssb}). In such cases an exploration of the relative significance of the components of total load is indicated. This paper presents an example of a preliminary estimate of bed load importance for 59 Brazilian sediment gauging stations. No data on total load are available for these stations; the available data consist of mean concentration of suspended sediment together with grain size distributions of bed material and measured suspended sediment.

STRUCTURE OF TOTAL SEDIMENT LOAD AND COMPONENT GRAIN SIZE DISTRIBUTIONS

The relationships between the grain size distribution of river bed material (curve ABC in Fig. 1) and the two size populations derived from it, that is bed load (curve DEF in Fig. 1) and suspended bed sediment compositions (curve GHI in Fig. 1) have received little attention in investigations of the structure of total sediment load.

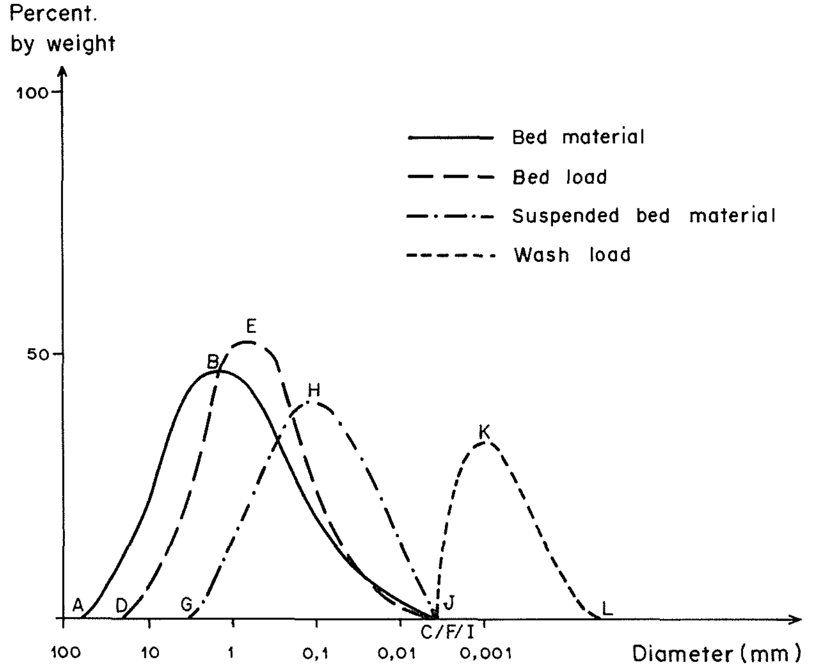

Fig. 1 Composition of fluvial sediments and solid discharge components.

Studies by Colby & Hembree (1955), Hubbell & Matejka (1959), Nordin & Beverage (1965), and Wilson *et al.* (1979) are examples where quantification of total load for sand-sizes bed material constituted the principal objective, whereas information on the structure of total load was only of secondary interest. Unfortunately, these studies do not give detailed information on the size distributions of bed material and transported sediment, indispensable for deriving general relationships. With the exception of Bogardi (1974), no published information on size distributions of bed load has been found; on the other hand, due to the procedures involved in data collection, the available data on grain-size distribution refer either to measured or total suspended sediment (Q_{ss}) as indicated by curve GHIJKL in Fig. 1. These distributions are a composite of the grain sizes of wash load (curve JKL in Fig. 1) and suspended bed sediment load, thereby complicating the identification of their individual components. However, when simultaneous size distributions of bed material and suspended load are available, it is possible to separate the two populations.

The results of laboratory investigations by Brooks (1958) and others on bed material composition and bed sediment sizes cannot be used directly to estimate the corresponding quantities for rivers. Therefore, data from some field measurements and calculated bed material discharge (IPH, 1973) were used to detect trends of some of the parameters related to bed material transport. The selection of parameters relating bed load to measured suspended load followed the empirical relations of Maddock (Vanoni, 1977).

SIMILARITY OF BED MATERIAL AND SUSPENDED SEDIMENT COMPOSITION

The parameters indicated by Maddock to estimate bed load as a percentage of measured suspended load are: suspended load ***concentration*** levels (<1000; 1000–7500; >7500 ppm), type of ***bed material***, and ***texture of suspended sediment*** (with specific references to ***similar to bed material*** and ***percent of sand***).

As neither the basic data nor the meaning of ***similarity*** are specified in Vanoni's reference, the association between bed load and several parameters related to the similarity of sediments was investigated. The parameters used to express similarity of grain size distributions (see Fig. 2) are:

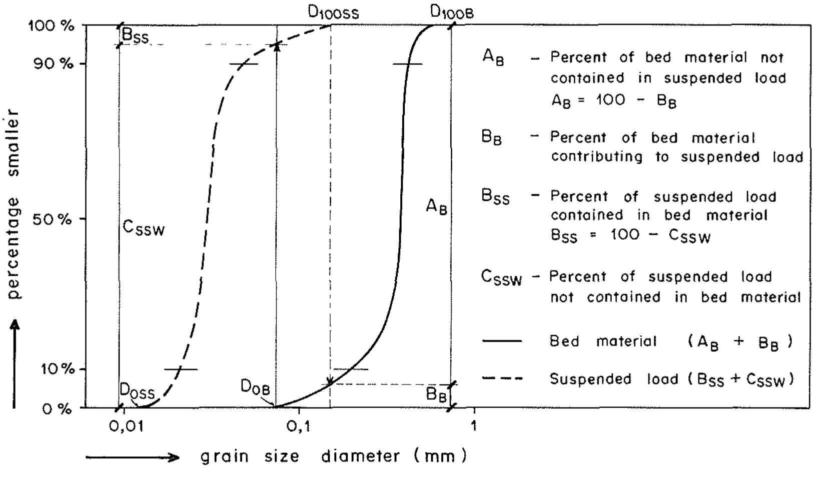

Fig. 2 Similarity of bed material and suspended load grain size compositions.

Bed material size fractions contributing to suspended load, expressed as a percentage of the bed material composition (corresponding to B_B in Fig. 2).

- Grain size fractions of suspended sediment which are contained in bed material, expressed as percentages of the suspended sediment load compositions (corresponding to B_{ss} in Fig. 2).
- Frequency (in percent) of grain sizes contained both in bed material and in suspended sediment, using the expression percentage of bed material contained/percentage of suspended sediment (corresponding to B_B/B_{ss} as identified in Fig. 2).
- Degree of uniformity of the grain-size distributions based on the relation D_{90}/D_{10} (Fig. 2).

On the basis of the first two parameters, it is possible to classify grain-size distributions according to the predominance (≥50%) of size fractions contained in river bed material or of other components of total sediment load, such as for instance, wash load. The third parameter seeks to express the similarity of two (or more) sediment size distributions when specified levels of relative importance of the size fractions, occurring in the two (or more) distributions, are observed. The last parameter seeks to characterize the nature of the grain-size distributions of bed material and the sediments derived from it. It measures the departure from uniformity of different sediments derived from a specified source material, as, for instance, bed load and suspended sediment grain-size distributions with regard to bed material.

Each of these parameters was first studied using data on grain-size distributions of bed material and solid discharge components as bed load, suspended bed sediment and wash load of the Canal São Gonçalo (IPH, 1973). This was to establish general trends of the relations between bed material discharge and related parameters. In the cases analysed, relative bed load importance covered the range of 10–60% of suspended load. The trends detected in the São Gonçalo data were confirmed using data of Wilson *et al.* (1979) for cases in which bed load varied from 7 to 35% of measured suspended load.

After selecting, from amongst the various alternatives, those relations that may be used to analyse data from 59 sediment gauging stations, for all of which mean suspended load concentration and grain-size data of bed material and suspended load are available, the following relations were found for mean concentration levels of $\bar{c} \leq 1200$ ppm.

1. A considerable degree of relative bed load importance ($Q_{sa} \geq 0.5\ Q_{ss}$) was found to be associated with the following conditions:
   - 1.1 bed material which is contributing to suspended load (expressed in percent of bed material size distributions [BMSD]), is predominant (≥50%) (B_B in Fig. 2);
   - 1.2 bed sediment is predominant (≥50%) in suspended load size distributions [SLDS], expressed in percent of suspended load (B_{ss} in Fig. 2);
   - 1.3 the relative importance of size fractions which are contained in bed material and in suspended load is similar, provided that grain sizes, occurring in both size distributions, are predominant. The expression BMSD/SLSD was found to be associated with high values of relative bed load importance for the range of 0.75 ≤

BMSD/SLSD < 1.25, with the maximum close to 1;

1.4 the degree of uniformity (DU) of the size distributions of bed material and suspended sediment load is coincident in both distributions, showing either high (DU < 5) or intermediate (5 ≤ DU ≤ 7) degrees of uniformity.

2. Moderate relative importance ($0.5\ Q_{ss} > Q_{sa} \geq 0.1\ Q_{ss}$) [Maddock specifies 12%] of bed load was found to be associated with the conditions (1.1), (1.2) and for values of the expression BMSD/SLSD, greater than 1.25 or less than 0.75.

3. Low relative importance ($Q_{sa} < 0.1\ Q_{ss}$) [Maddock specifies 5–12%] of bed load was found to be associated with predominance of wash load or reduced importance (≤50%) of those grain size fractions of bed material contributing to suspended load, together with different degrees of uniformity of sediments and bed material.

CLASSIFICATION OF SEDIMENT GAUGING STATIONS

Sediment data collected by Brazilian national, regional and state agencies (DNAEE, DNOCS, CODEVASF, CEMIG, DAEE, DNOS, SERLA, SUREHMA and others) was supplied by ELETROBRAS. Bordas *et al.* (1988) present the interpretation of data with respect to mean concentration and specific yield in connection with other parameters. From information on distributions of individual sediment samples and mean composition of cross sections, it was possible to elaborate mean grain size distributions of bed material and suspended sediment for 59 sediment gauging stations of Brazilian rivers. The average number of mean cross section distributions of bed material and of measured suspended sediment are 15 and 26 respectively for each station. Data were collected over the period 1960–1986, the number of stations varying from year to year; the maximum of 30 reporting stations occurred in 1977. Mean concentration of suspended load is less than 1000 ppm for 58 stations and $\bar{c}$ = 1184 ppm in one case.

Table 1 *Classification of sediment gauging stations*

Level of prob.relative bed load importance	Mean concentr.level of susp.load (ppm)	Wash load predominance G.Stations	Rel.freq.(%)	Susp.bed sediment predominance G.Stations	Rel.freq.(%)
1.low ($Q_{sa} < 0.1\ Q_{ss}$)	< 1000	30	50	3	5
2.moderate ($0.1\ Q_{ss} \leq Q_{sa} < 0.5\ Q_{ss}$)	< 1000			10	17
3.considerable ($Q_{sa} \geq 0.5\ Q_{ss}$)	< 1000			15	26
4.low ($Q_{sa} < 0.1\ Q_{ss}$)	> 1000	1	2		
TOTALS		(31)	52%	(28)	48%

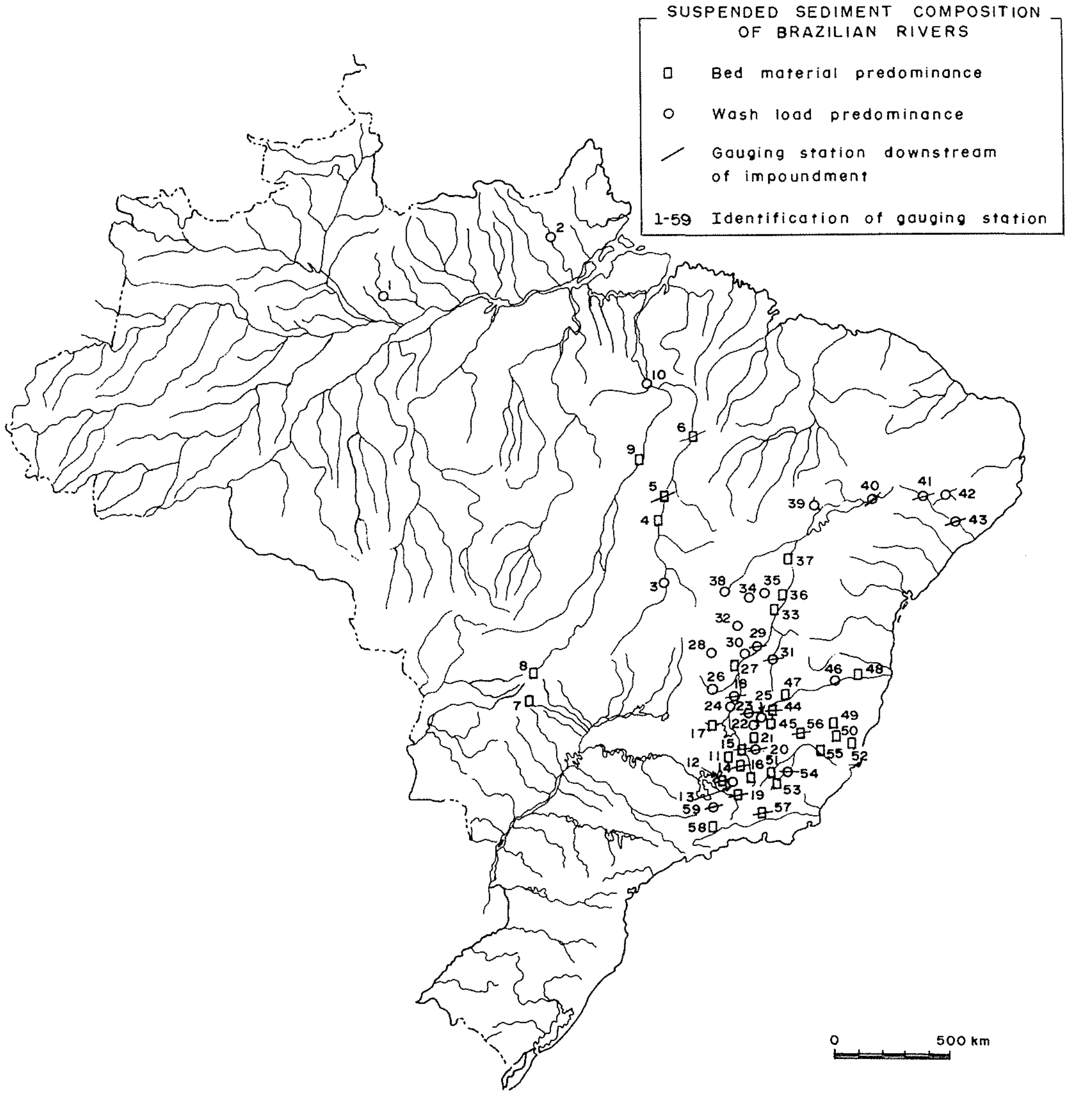

Fig. 3 Bed material and suspended sediment composition data.

During the analysis of data the sediment gauging stations were classified with regard to predominant provenance of suspended load grain-size distributions — wash load and suspended bed sediment load — as well as to probable relative importance of bed load (as a percentage of suspended load). Results are presented in Table 1.

In classifying the 59 gauging stations, the relative frequency (52%) of gauging stations presenting wash load predominance in suspended load size distributions is considered significant. All cases of wash load predominance coincide with low relative bed load importance ($Q_{sa} < 0.1\ Q_{ss}$) at the mean suspended load concentration levels observed (<1200 ppm).

High bed load contribution, in Maddock's terms meaning that $Q_{sa} \geqslant Q_{ss}$, and that $Q_{sa} \geqslant 0.6\ Q_{ss}$ in terms of the data base used in the present study, is to be expected in one case (2%), which is included in item 3 "considerable relative bed load importance" of Table 1. At this station the size compositions of bed material and suspended load are extremely similar, the degrees of uniformity of both size distributions being very close.

Considerable bed load contribution ($Q_{sa} \geqslant 0.5\ Q_{ss}$) is to be expected in 14 cases, representing 24% of the population examined. At these gauging stations, composition and uniformity of sediments were less similar.

The spatial distribution of gauging stations showing predominance of wash load, or of suspended bed sediment size distributions, is presented in Fig. 3. Gauging stations with predominance of wash load grain sizes are found in minor tributaries (stations 1 and 2) or in the lower basin of the River São Francisco (stations 39, 40, 41, 42 and 43) in the northern/ northeastern basins. Predominance of suspended bed sediment grain sizes can be detected, together with river reaches alternating between wash load and bed sediment predominance, in some basins in central-eastern Brazil. A comprehensive interpretation of the distributions requires the consideration of a great number of parameters as for instance land use patterns, soil and climatic conditions, effect of reservoirs on selective sediment retention, variation of grade and other parameters.

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