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Analytical evaluation of bed load transport in a river subject to backwater effect: the case of the River Trombetas

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Abstract The calculation of bed load transport in a river is a problem that is difficult to solve. There are many formulae, based on tractive force, that estimate bed load discharge. These values are overestimated and generally inconsistent among themselves; in addition, this methodology does not take account of the velocities near the bottom. To overcome these problems, we recommend the application of impact forces theory in the calculation of bed load transport. The basic difference between these two methodologies is that, while in the first one the critical velocity is unique, the second one yields an interval throughout which velocity is critical, and in which movement can occur according to a probability distribution. The utilization of these two methodologies allows the technician to have available an interval whose lower limit is the result obtained by the impact forces method, while the upper limit is given by the formulae based on tractive force.

Evaluation analytique du transport solide par charriage dans un fleuve sujet à remous: le cas du Trombetas

Résumé Le calcul du transport solide par charriage dans un fleuve est un problème difficile à resoudre. Bien qu'existent plusieurs formules basées sur la force tractive pour déterminer le transport solide par charriage, les valeurs obtenues sont surestimées et incohérentes entre elles. De plus, ces valeurs ne considèrent pas les vitesses près du fond. Pour minimiser ces problèmes, la théorie des forces d'impact a été utilisée dans le calcul du débit solide de charriage. Cette théorie admet une bande de vitesse où le mouvement est imminent. La différence fondamentale entre les deux méthodes est due à ce que la première considère une vitesse critique, alors que la deuxième admet une bande où la vitesse est critique et associe le

where α is a density factor, A is the cross-sectional area through which the bed load moves (m^2) and V_{hv} is the mean virtual travel rate of the bed load ($m\ s^{-1}$).

For actual calculation the cross section of the river bed should be subdivided into parts by verticals, just as in the area-velocity method of streamflow calculation.

The bed load discharge Q_B should be calculated for each vertical and the total bed load discharge in the cross section is obtained as ΣQ_B (Fig. 2).

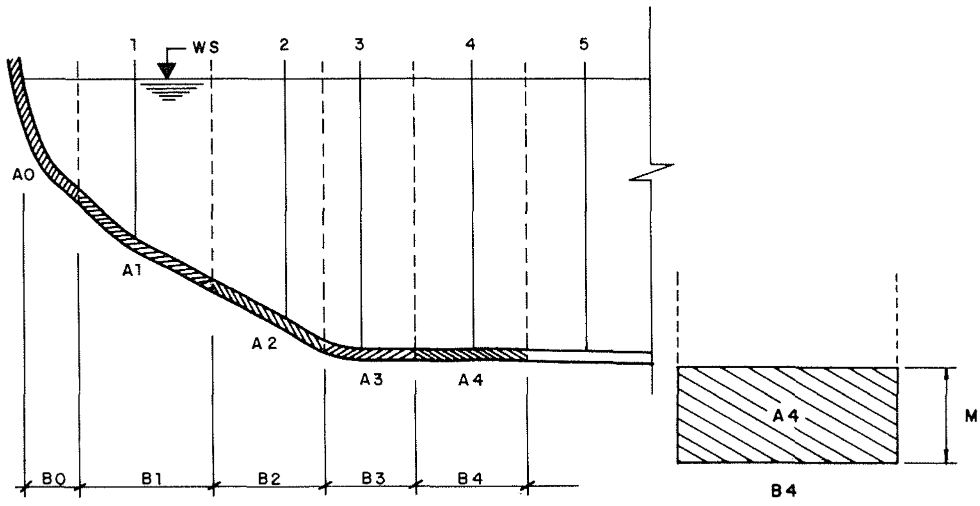

Fig. 2 Schematic representation of bed load discharge calculation by Stelczer.

The mean virtual rate of travel ($\bar{V}_{hv}$) of bed load is found as

$$\bar{V}_{hv} = b(V_f - V_{fc})$$

where V_f is bottom velocity; V_{fc} is the mean critical bottom velocity; b is a constant equal to 0.004 35 if the bed material is "soft"; and equal to 0.015 70 if the bed material is "hard".

The cross-sectional area through which the bed load moves is $A = B\ M$. The width B (m) is the spacing of the verticals, whereas the height M (m) of the cross-sectional area is:

$M = 4\ d_{80}$ if the bed material is "soft"
$M = 2\ d_{80}$ if the bed material is "hard"

where d_{80} is the particle diameter corresponding to 80% passing. The density factor is obtained from the utilization of the normal distribution function considering that the standard deviation of the velocities is invariable and equal to 0.06.

CASE STUDY

These two methodologies were used at the determination of bed load discharge in River Trombetas. This river, a left-bank tributary of River Amazon, has at its lower part a series of alternate bars where the Amazon terrapin *(Podocnemis expansa)* lays its eggs and nidify. This study of bed load transport in this river aims at the evaluation of river bed degradation and the conservation of the alternate bars after the construction of a hydroelectric power plant upstream of these beaches, at a place called Cachoeira Porteira.

A very important aspect is the fact that, downstream of Cachoeira Porteira, River Trombetas is permanently subject to a backwater effect caused by River Amazon. Due to this fact, the calculation of bed load discharge through the tractive forces method is not very appropriate for, according to this method, the slope has a direct influence in motion quantification.

The Meyer-Peter & Müller and Einstein formulae were selected for the calculation of bed load transport in this river according to tractive forces

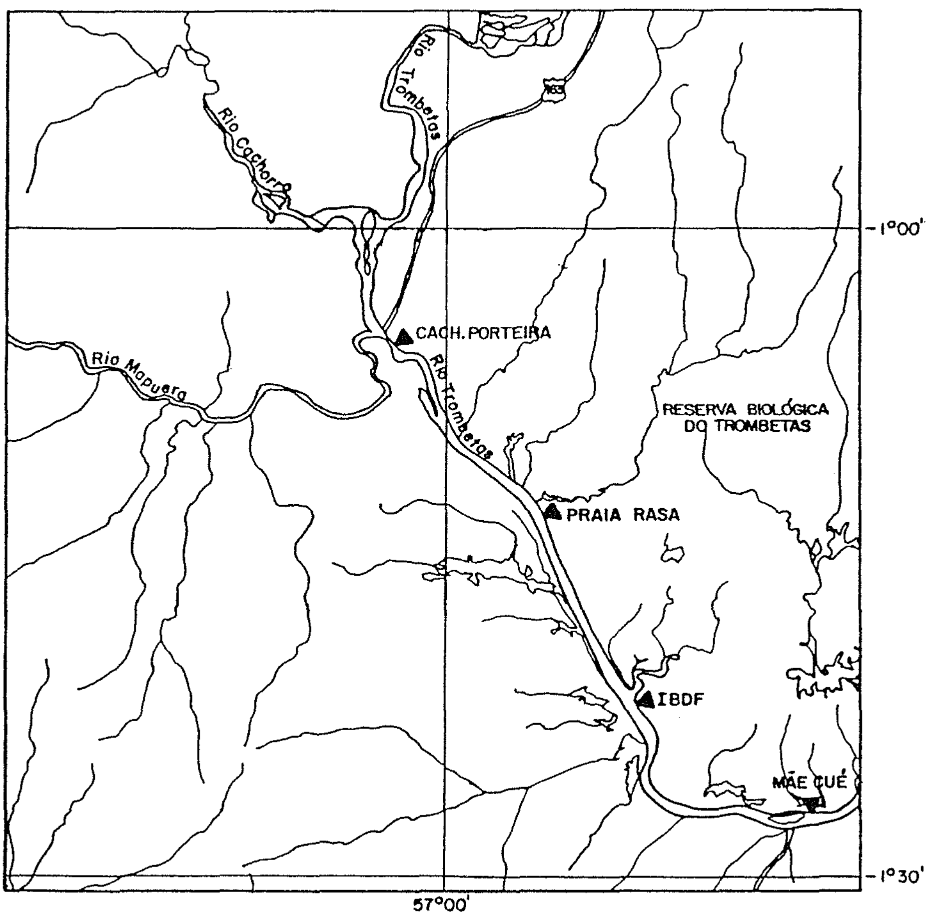

Fig. 3 Location of the streamgauges.

theory, and to compare this movement with the results obtained through the impact forces method. This was done at the streamgauges situated at the river segment being studied, that is: Cachoeira Porteira, Praia Rasa, IBDF and Mãe Cué. The alternate bars at issue are located near IBDF streamgauge.

The location of these streamgauges can be seen in Fig. 3.

The utilization of the three formulae resulted in the values of annual mean total bed load discharge shown in Table 1.

Table 1 *Annual mean total bed load discharge (10^3 t year^{-1}) estimated by various methods*

Method	*Cachoeira Porteira*	*Praia Rasa*	*IBDF*	*Mãe Cué*
Meyer-Peter & Müller	*5056*	*2460*	*2983*	*3153*
Einstein	*7658*	*1791*	*3211*	*1446*
Impact Forces	*138*	*3*	*153*	*249*

The results obtained lead to the conclusion that the bed load discharges obtained through the impact forces method are plausible. The suspended load, found to be near 1 300 000 t year^{-1} leads to the conclusion that Meyer-Peter & Müller's and Einstein's formulae overestimated bed load transport. But, through the impact forces method, the bed load found is very coherent, the proportion bed load/suspended load usually found, i.e. 10 to 30%, being maintained.

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