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Suspended load and bed load transport in mountain streams determined by different methods

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ABSTRACT Investigation of suspended and bed load transport have been made in some mountain streams in South Poland.The field measurements of suspended load have consisted of detailed examination of turbidity in the gauge profiles.The frequency of them was fitted to the hydrological conditions. Measurements of the bed load transport parameters were carried out by using the radioactive tracer methods. The data had been interpreted by some known sediment transport formulas. In general,close agreement exists between observed sediment transport rates and transport estimate from the Meter-Peter & Mueller modified formula.Other interpretation of these data have been made to determine the Shield parameter, basing on the natural armoring layer when standard deviation of grain-size distribution being bigger than 1.3. As the consequence of the present investigations an expression of the ratio of suspended load to bed load amount has been obtained. Conclusions drawn from these investigations should extrapolate to other similar streams.

NOTATION

A - cross sectional parameter
B - width of flow
d_i - fractional grain size
d_m - mean grain size
f_m - the Shields parameter suitable to grain size d_i and the mean grain size d_m
g - acceleration of gravity
g_{si} - fractional discharge of bed load
G_u - mass of suspended load
G_w - mass of bed load
h - depth of flow
Δp_i - proportional content of grain size d_i fraction
s - slope
γ - specific weight of water
γ_s - specific weight of solid grains

ε - forestage parameter
ρ - density of water
δ - standard deviation of grain size distribution
ϕ - function

INTRODUCTION

Sediment transport monitoring in mountain streams creates a greater problem than for low-lying rivers. Usually, significant process of sediment transport by mountain streams occurs during floods. The total amount of load carried by the rivers is the sum of the bed and suspended load. The main difference between them is found in the mechanism of movement and its sources. It is connected with the type of measurements.Duration of floods is short,but the changes of water discharge and turbidity is very sharp. During floods it is not generally possible to measure directly the critical flow stress,the velocity profile or turbidity. Therefore, it was necessary to find some methods to research sediment transport under a given set of flow conditions.

In this paper, the results of the integrated investigations of suspended and bed load transport in mountain streams and rivers are presented.

INVESTIGATIONS OF SUSPENDED LOAD

Suspended load consists of very fine dusty soil, loam and sand (during flood) and can be considered as a product of soil erosion. Partly, it is a product of abrasion of sand grains in rivers too. But the amount of suspended load depends mainly on the processes occurring out of the river in the cathment area. The main source of supply of the river in suspended load in the water, flowing over the basin surface, causing its erosion.

Field researches have been carried out two basins of mountain rivers. They included six small catchment areas (Madeyski, 1983).Generally in a investigated area,many sedimentological characteristics,are typical of the Polish Carpathian Region. The field measurements consisted of detailed examination of turbidity in the gauge profiles. During three years of measurements, in the periods of low flow, the turbidity was measured every two days, and in the periods of rainfall, suspended sediment samples were collected every two hours. An expression for suspended load transportation has been defined for the small catchment areas of rivers in the mountain region.

Some parameters of those areas and the results of investigations are presented in Table 1. These data have been interpreted to determine the ratio of suspended load amount to bed load amount; it is described in one of next paragraphs.

TABLE 1 Annual amounts of suspended load transported in some catchment areas.

River	Catchment area (km²)	E (%)	Rain-wash parameter (t/km²*year)	Annual rainfall (mm)	Annual amount out of waves (t)	Annual amount in waves (t)
Poniczanka	33.1	43.4	66.86	901	234.47	1978.56
Mszanka	52.0	39.3	84.06	879	1116.96	3170.31
Kasinka	32.0	44.4	46.19	914	86.04	1392.33
Lubieńka	48.7	36.7	71.07	931	233.76	3227.80
Bystra	77.0	53.5	22.55	853	279.25	1457.30
Skawica	48.6	79.2	32.05	1189	635.17	905.61

INVESTIGATIONS OF BED LOAD TRANSPORT

Movement of bed load in mountain streams is possible under a determined set of flow conditions. Bed materials of relatively uniform sizes appear very rarely. Usually, their grain-size distributions show a large scale of grain diameters. The bed load transport is possible if the water discharge is bigger than the one reported as critical for the break down of armor stability.It is not easy to determine flow discharges or bed stresses which refer to the beginning of motion.

(i) MEASUREMENTS OF THE BED LOAD TRANSPORT

For some years, the bed load transport rate was measured in a small mountain river.The grain-size composition contained the grain diameters d_i = 0,001-0,20 m. The radioactive tracer method which Courtois (1970) suggested, was adapted. The results of measurements have verified the usefulness of the bed load transport equations for the river. It was found that the Meyer-Peter&Mueller formula modified by introduction of the Wang (1977) relations for non-uniform bed load, has given good accordance with the experimental data (Gładki et al., 1981).
This formula has the following form:

$$g_{si} = \left(\frac{\gamma h_i S - f_i d_i (\gamma_s - \gamma)}{0,25 \left(\frac{\gamma}{g} \right)^{1/3}} \right)^{2/3} \Delta p_i \qquad (1)$$

The investigations of bed load transport in the other mountain rivers have shown that the dimensionless shear stress is f_m = 0,30 (from the Shields diagram it would be

f_m = 0,047). In this situation, the measurements of the threshold condition for motion of some fractions were under taken (Michalik & Bartnik, 1986). They were carried out in three mountain rivers simultaneously with the radio-isotope measurements of the bed load transport rate. It can be seen that the initial motion conditions of particular fractions in both Wisłoka and Dunajec Rivers are described by the same function:

$$\frac{f_m}{f_i} = \left(\frac{d_i}{d_m} \right)^{0,44} \qquad (2)$$

with f_m = 0,030, and for the Raba River, the function is:

$$\frac{f_m}{f_i} = \left(\frac{d_i}{d_m} \right)^{0,94} \qquad (3)$$

There exists a similarity between investigated rivers,some parameters are shown in Table 2.

The results of these measurements were used in the Meyer-Peter & Mueller formula. In this way it has been compared with the measured bed load transport rate.

Applications of the radioisotope methods allow to obtain the fractional bed load transport rate, in compliance with the grain fractions, transported during the measured flood. Data from the investigated rivers have been shown that determination of bed load transport conditions in mountain streams should have based on the local parameters rather than on the flow`s mean stress from the Shields diagram.

TABLE 2 Bed load transport parameters.

River	S (‰)	Q (m^3/s)	h (m)	B (m)	d (m)	σ
Wisłoka	0.35	20.00	0.80	30.0	0.0031	4.00
Dunajec	0.35	100.00	1.30	65.0	0.0247	2.77
Raba	2.75	150.00	1.80	60.0	0.0700	1.95
Skawa	3.60	132.00	1.50	30.0	0.0700	2.25
Dobka	8.00	6.18	0.60	4.0	0.0720	2.32
Mszanka	12.30	15.30	0.75	9.0	0.5000	1.85
Lubieńka	13.80	13.80	0.50	12.0	0.0600	2.15
Kopydło	7.00	9.00	0.70	8.0	0.0420	2.58
Targaniczanka	16.00	7.30	0.60	6.0	0.1200	2.06

(ii) OTHER METHOD OF DETERMINATION OF f_m AND f_i

In mountain rivers,where there is an armour of the bottom.

basing on the Gessler (1970) method, changes of bed granulation are possibly scheduled after passing of flood. In connection with above, there is possibility to determine the f_i Shields parameter for the known diameter of grain.

On the grounds of the grain-size distributions studies carried out before and after flood, the changes of bed granulations have been determined for the Targaniczanka river $f_m/f_i = \varphi\ (d_i/d_m)$, Wang relations were used as follows:

$$f_i = f_m/1.78\ (d_i/d_m)^{0.947} \quad \text{for } d_i/d_m < 0{,}6 \quad \text{and}$$

$$f_i = f_m(d_i/d_m)^{0.314} \quad \text{for } d_i/d_m > 0{,}6 \qquad (4)$$

The grain size distributions have been reconstructed by this method and they have been compared with the measured ones (Fig.1).

The Shields parameter allowed to determine, once more, the fractional bed load transport rate (Fig.2).

This method has been applied to the other rivers. The grain-size distribution and the flood hydrograph being known. As a result of these calculations, the relations between the bed load and water discharges have been reached (Fig.3).

In the same way, the amounts of bed load have been determined for the streams presented in Table 1(Bartnik & Madeyski, 1991). It has been possible to find the ratio of suspended load to bed load. This relation has the following form:

$$G_u/G_w = A\ Q^{0{,}69\ +\ 0{,}016\ \varepsilon} \qquad (5)$$

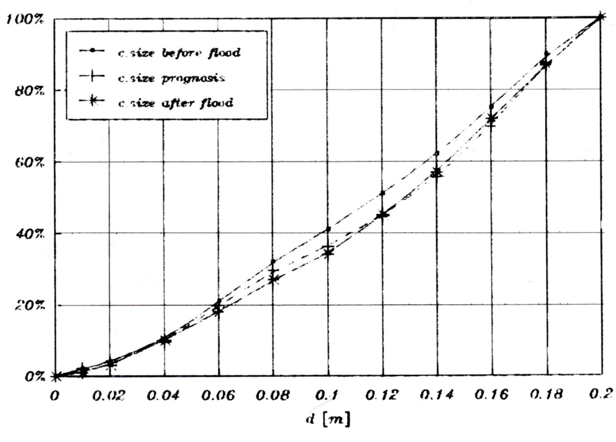

FIG. 1 Targaniczanka Stream grain-size distribution.

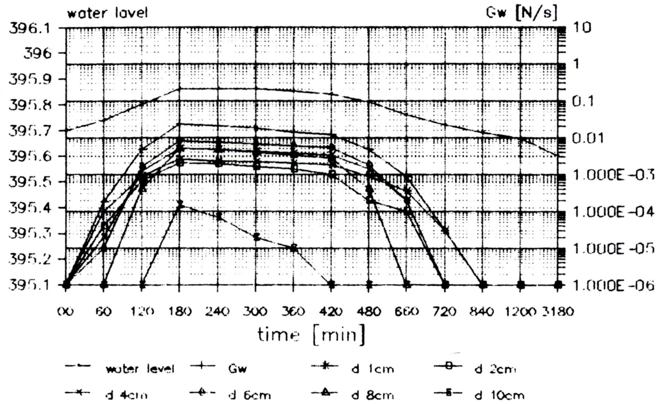

FIG. 2 The fractional bed load transport.

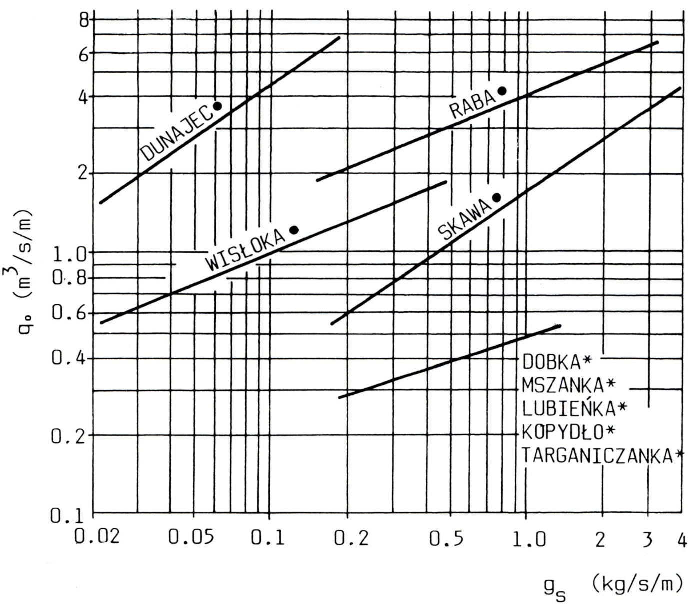

FIG. 3 Bed load vs. water discharge (rivers •, streams *).

This formula can be used for the others streams belonging to the Polish Carpathian Region.

CONCLUSIONS

The studies which have been carried out are not enough to conclude generally. Never-the-less it can be said as follows:

(a) the presented methods of investigations may be applied to any stream when the determination of the total sediment transported by its cross section is needed;

(b) if the hydrological and hydraulic parameters of any stream and the grain-size distribution are well recognized there is a possibility to determine the critical conditions of the bed load motion. But grain size distribution of bed material should be measured before and after the flood.

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