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Total load transport in gravel bed and sand bed rivers case study: Chelichay watershed

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Abstract

Field experiments were conducted on total load transport in the Chelichay River Basin, a mountainous catchment (1,400 km^2) located in north eastern of Iran, to evaluate total load formulas including four gravel bed rivers and a sand bed river (Qaresoo River). Gravel bed rivers in Chelichay River Basin can be grouped into two types; steep slope rivers with high shear values (Chehelchay River and Khormaloo River) and mild slope rivers with low shear values (Narmab River and Soosara River). Two depth integrating suspended load samplers (DH-48 and D-49), and two bed load samplers (Helley-Smith and BLSH) were used to measure total load. The performance is tested of 8 total load transport formulae including 4 macroscopic and 4 microscopic methods. A systematic and thorough analysis of 59 sets of data collected from sand bed river indicate that Yang and Engelund and Hansen reach to the better results, and from four gravel bed rivers confirmed that the methods of Karim and Kennedy and Engelund and Hansen yields the best results for steep slope rivers, and the methods of Einstein and Bijker are ranked highest in gradual slope rivers.

Key Words: Sediment, Total Load, Gravel, Sampling

1 Introduction

A knowledge of the rate of total sediment transport for given flow, fluid and sediment characteristics is necessary in the study of many alluvial-river processes. Engineers always need to bear in mind the fact that alluvial streams carry not only water but also sediment and that the stability of a stream is closely linked with the sediment transport rate.

In alluvial streams the particles move in different modes depending on the flow conditions, the ratio of densities and the size of the sediment. One mode of movement is contact load. Contact load is the material rolled or slid along the bed in substantially continuous with the bed. A second mode of sediment movement is saltation load. In this mode the material bouncing along the bed, or moved directly or indirectly by the impact of bouncing particles. Saltation is an important mode of transport in case of noncohesive materials of relatively high fall velocities, such as gravel in water. The third mode of transport is suspended load. In suspended load material moving in suspension in a fluid, being kept in suspension by the turbulent fluctuations.

Contact load and saltation load are grouped together and called bed load, thus bed load is the material transported on or near the bed. On the other hand, in natural streams wash load is invariably present, then, the total load is the summation of the bed load, suspended load and wash load.

Numerous sediment transport formulas have been proposed in the past fifty years and subsequent modifications of original formulations have been prescribed. In engineering practice, several formulas are compared with field observations to select the most appropriate equation at a given field site. Existing sediment transport formulas can be classified into several categories owing to their basic approaches: (1) formulation based on advection; (2) formulation based on energy concepts in which the rate of work done for transporting sediment particles in turbulent flow is related to the rate of energy expenditure; and (3) graphical methods and empirical equations based on regression analysis (Jullien, 2010).

The use of prototype data allows a more realistic evaluation of total load formulas. In many of the evaluations, the data employed had originally been used for derivation of the formulas, chiefly for bed load formulas. A recent review (Wilcock, 2001) highlights the reasons why we cannot expect highly predictive power under selected prototype conditions. Generally, there is a lack of field data with which to test and to verify formulas.

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The shortage of measuring suspended load and bed load simultaneously, and using their summation to assess total load formulas led to the lack of comprehensive and appropriate total load transport studies.

Van Rijn (1984b) used 486 sets of river data to verify the methods of Engelund-Hansen, Ackers-White, Yang and Van Rijn. Bed material sizes were in the range of 100 to 400 μm. Flow velocities were in the range of 0.4 to 2.4 m s^{-1}. the results have been expressed in terms of a discrepancy ratio (r) defined as the ratio of the predicted and measured transport rate. The method of Van Rijn yields the best results for field data with 76% of the predicted transport rates within a range of 0.5-2 of the measured values (known as factor 2). The method of yang yields excellent results for small-scale river data, but very poor results for large-scale river data. White et al. (1973) examined various transport formulae using about 1,000 flume data and 260 field data. The method of Ackers-White yields the best results with 68% of the predicted transport rates within a factor 2 of measured values. The method of Bagnold yields poor results with a score of 22%.

Shah-Fairbank (2009) developed the series expansion of the modified Einstein procedure (SEMEP) to calculate total load from depth-integrated suspended load samples. SEMEP procedure tested on several laboratory and sand-bed river data from the Niobrara to Mississippi River. These data are considered to be total load data sets because they contain both depth-integrated and Helley-Smith measurements.

Although there is a shortage of total load predictor analysis, but there are more studies on bed load analysis. Billi (2011) measured sediment transport in a steep, sand bed, ephemeral stream in northern Ethiopia, and used a few equations to predict bed load. Haddadchi et al. (2011) compared 14 sets of bed load data from Node River, North of Iran, with 13 bed load equations. Their results showed that the Equations of Van Rijn and Meyer-Peter and Mueller may adequately predict bed load transport in the range of field data. Yang et al. (2009) used Artificial Neural Network and some total bed material load sediment transport formulas to indicate the importance of variables which can be used in developing sediment transport formulas. Results show that the accuracy of formulas in descending order are those by Yang (1973), Laursen (1958), Engelund and Hansen (1972), Ackers and White (1973), and Toffaleti (1969). Yu et al. (2009) measured bed load transport in Diaoga River, southwest china, to study the variation of bed load transport with varying sediment supply. They concluded that the rate of bed load transport is affected by incoming sediment load and sediment size, and the relation of the bed load transport rate versus flow intensity appears to have similar characteristics as a clockwise looped-rating curve.

Therefore, the aims of this paper are to

- Describe methods of excluding wash load and bed material load
- Describe difference in grain size parameter of sand and gravel bed rivers
- Describe the influence of river bed slope as significant input parameter
- Compare total load transport formulas with prototype data
- Compare the ability of formulas in sand and gravel bed rivers
- Analyze advantages and disadvantages of formulas

2 Total load formulas

The methods of computation of the total sediment transport rate can be broadly classified into two categories. The methods under the first category, described as microscopic methods, subdivide the total sediment load into suspended load and bed load. In microscopic methods, the total load transport of bed material particles can be obtained by summation of the bed load ($q_{b,c}$) and suspended load ($q_{s,c}$) transport, as: $q_{t,c} = q_{b,c} + q_{s,c}$

The microscopic formulas of the following researcher utilized in this study were:

Bagnold (1977, 1980), developing from earlier work (Bagnold, 1956, 1973), provided a departure from all of the foregoing by utilising an approach based on stream power rather than on the tractive stress. His 1977 paper utilised flume data from Williams (1970) and field data from the East Fork, Snake and Clearwater Rivers of the USA. These rivers have a bimodal bed material distribution (a mixed sand-gravel bed), and are probably of limited value in developing an equation for fully gravel channels.

The suspended load method of Bagnold (1966) is based on energy balance concept relating the suspended load transport to the work done by the fluid. Kachel and Sternberg (1971) have shown that the efficiency factors of Bagnold suspended load formula are not constant, but are strongly related to the bed shear stress and the particle diameter.

Van Rijn (1984a) followed the approach of Bagnold (1977) assuming that the motion of the bed load particles is dominated by particle jumps under the influence of hydrodynamic fluid forces and gravity forces. The saltation characteristics have been determined by solving the equations of motions for an individual bed load particle. To compute the bed load transport rate Van Rijn used 130 flume experiments with particle diameters (d_{50}) ranging from 200 to 2,000 μm, water depths larger than 0.1 m and a Froud number smaller than 0.9 were selected from the literature. To calculate suspended load transport, Van Rijn introduced a simplified and complex approach that we used the latter (Van Rijn, 1993).

Einstein (1950) bed load transport approach is based on the assumption that in steady uniform flow there is equilibrium between the number of particles eroded and deposited per unit area and time. With measurements from