PREDICTION OF BEDLOAD TRANSPORT IN GRAVEL-BED RIVERS WITH STABLE ARMOR LAYER

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An extensive database of sediment transport in gravel-bed rivers developed by the U.S. Forest Service, Rocky Mountain Research Station (RMRS) in the Salmon and Clearwater Rivers of the Pacific Northwest of the United States is used to evaluate the predictive ability of a range of sediment transport formulations (*http://fs.fed.us/rm/bois/teams/soils/Bat%20WWW/index.htm*). The objective was to develop an equation that is accurate enough to evaluate the channel changes expected under different restoration alternatives for prioritizing management actions at the watershed scale and for performance assessment of implemented projects.

Many different formulas have been derived for the prediction of the bedload transport rates based on considerations that include shear stress, discharge, energy slope, velocity, probability, or empirical regression. Flume and field data for steady and uniform flow conditions were used in many cases for calibration and verification of these formulas. Applied approaches for deriving existing formulas involve only some of the known influences on transport rates. Physical mechanisms that have not been specifically included in a model are accounted for by using coefficients that have been determined through analysis of measured laboratory and field data. This means that each formula holds true under a certain set of assumptions and boundary conditions. Outside these ranges of validity, discrepancies have to be expected.

For the RMRS database, it was shown that many standard formulas for prediction of bedload transport rate developed for gravel-bed rivers are not applicable for streams and rivers under conditions of a stable armor layer and limited sediment supply (Muskatirovic and Goodwin 2003). Therefore, a more generalized approach for the prediction of bedload transport rates in gravel-bed rivers is developed for rivers with stable armor layers, which are the main type of streams and rivers in Central Idaho.

Several approaches are evaluated to develop a better predictive equation for bedload transport rates in supply limited mountain gravel-bed rivers with coarse bed material:

the simple approach adopts a form of power law, similar to a sediment discharge rating curve. Although the approach lacks a physical basis, it does provide a simple equation with known error bounds for the available data. An evaluation of the coefficient and exponent also provides a way of analyzing differences between watershed and channel characteristics. Rating coefficient and exponent are evaluated using linear- and multiple-regression analysis;

the complex approach adopts a multiple-regression analysis of bedload samples following the approach of (Brownlie 1981)) for alluvial streams. Key hydraulic and watershed parameters were analyzed by dimensional analysis and dimensionless numbers derived, that provide information on significant watershed processes and local hydraulic conditions to try and develop a predictor that would reduce uncertainty in bedload transport rates.

Bedload rating curves were determined for the 33 river sites based on the bedload transport data. Equations were developed using the least square method. The rating parameters *a* and *b* present the regression estimates of parameters obtained from measurements for each site with coefficient of determination R^2.

Rating parameters for prediction of bedload rates were estimated using two methods: linear- and multiple-regression. The main concept of the approach is to quantify the effects of the various factors influencing the bedload transport rates for a variety of stream and watershed characteristics. Establishment of a correlation between the rating parameters and watershed or stream characteristics (including drainage area, drainage area slope, average annual discharge or bankfull discharge, watershed relief, local slope, and sorting coefficient of bed material) offers an opportunity to increase the accuracy of the prediction of the bedload transport rates in streams and rivers with similar physiographic characteristics. Available data on transport rates obtained through field measurements ensured the establishment of a relatively strong inverse relationship between rating parameters *a* and *b* and establishment of relationships between these parameters and watershed and channel characteristics. The best fit relations were obtained for two proposed power law equations (PL3 and PL6). Further improvement was obtained by increasing the number of physical parameters. Multiple-regression analysis was applied using the parameters that can be important for prediction of rating parameters and which are readily available through standard databases: drainage area (DA), local slope (S), average annual discharge (Q_a), bankfull discharge (Q_{bf}), characteristic particle sizes of bed material ($d_{16\,bed}$, $d_{50\,bed}$, $d_{84\,bed}$), sorting coefficient of bed material (G), drainage area average slope (S_{DA}), watershed relief (R), and combination of these parameters ($\sqrt{DA}/R$, Q_{bf}/Q_a, Qs_{bf}/Qs_a). The regression equation (PL-MR1) with 5 parameters gave the best prediction of rating parameters. Reduction of the parameters in other equations (PL-MR2 and PL-MR3) only resulted in a decrease of R^2.

In the case of the multiple-regression analysis, bedload transport rates were estimated using above mentioned parameters and some additional dimensionless parameters that provide insight to the processes and parameters affecting transport rate. The result of this analyses are three equations of varying complexity (MR1, MR2, and MR3).

The quality of derived equations for the prediction of bedload transport rates is illustrated by the median value, and 16th and 84th percentiles of the predicted to measured bedload rates in Figure 1, for eight bedload transport equations.

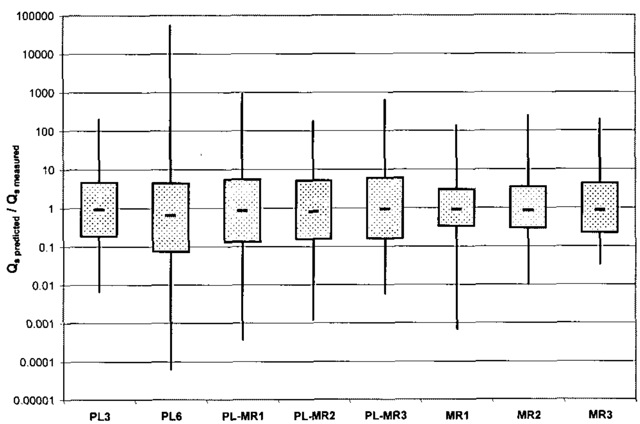

Fig. 1 Comparison of selected methods for prediction of bedload transport rates