Gravel transport and flow competence curves in mountain streams vary systematically with basin, channel, flow, and bedmaterial characteristics

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Abstract. Rates and sizes of gravel transport are difficult to predict in mountain streams that differ in their sediment supply, in bed stability and are ruled by complex flow hydraulics. Equations currently available to compute bedload transport or incipient motion cannot account for those effects and predict similar results for streams that differ widely in sediment supply and hydraulic complexity. This study takes an empirical approach and explores the prediction of bedload transport and flow competence curve from watershed, flow, channel, and bedmaterial properties based on results from measured transport relations. The study is based on detailed measurements of gravel transport and flow competence made with bedload traps in coarse-bedded Rocky Mountain streams. Together with other suitably sampled data sets retrieved from the literature or provided by researchers, 44 study sites are analyzed. The sites span a wide range of basin area sizes (1-260 km^2), stream gradients (0.006-0.11 m/m), and bed D_{50} (20-108 mm) and D_{84} (90-360 mm) sizes. Most sites exhibit plane-bed and step-pool morphology, some have occasional pool-riffle sequences. Power functions are fitted to measured gravel transport curves $Q_B = a{\cdot}Q^b$. Their b-exponents range within 2-18, while coefficients span 15 orders of magnitude (10^{-14} to 10^1). Similarly, g-exponents from power function flow competence curves $D_{max} = f{\cdot}Q^g$ range within 0.4-5, while f-coefficients are within 0.004-127. Gravel transport curves steepen with basin area and stream width, as well as the width/depth ratio, and flatten with bankfull unit runoff yield and bankfull sediment yields per basin area as well as with the percentage of subsurface fines and the degree of bed armoring. Transport curve b-exponents have a non-monotonic relation with stream gradient S and are steepest (b = 5 to 18) in steep plane-bed streams where S = 0.014 to 0.04 m/m, but are flatter in step-pool streams (b = 2.5 to 9) where S > 0.04 mm and plane-bed streams with pool-riffle sequences (b = 4 to 12) where S < 0.014 m/m. Exponents b and g of gravel transport and flow competence curves are directly and tightly related, so the relations of g-exponents with channel, flow, watershed and bedmaterial parameters mirror those for b-exponents. The concomitant steepening of transport and competence curves shows that transport rates grow more with flow when larger flows transport not only more particles but are able to mobilize increasingly larger particles. Coefficients of power functions are inversely related to exponents. Hence positive relations of exponents b and g with a parameter turn into negative ones for the coefficients a and f, respectively. Overall, coefficients are most tightly related to parameters that scale with stream size. The study demonstrates that bedload transport and flow competence curves systematically vary with watershed, flow, channel, and streambed properties. Scatter in the relations of exponents and coefficients with stream parameters can be reduced when relations are stratified by stream type as well as by detailed characterization of bedmaterial size distributions.