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Effect of macro-roughness on between-site variation of flow velocity

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The macro-roughness of riverbeds in steep mountain streams is typically characterized by large immobile boulders or channel-spanning bedforms such as step-pool sequences. How these elements affect resistance, flow velocity and sediment transport is not well understood, and appropriate field parameters for representing macro-roughness in flow velocity equations have not been identified. Predicting flow velocity and sediment transport in steep streams is therefore challenging. To study the effect of macro-roughness on river currents, we measured flow velocities for a large range of discharges in six reaches of Swiss mountain streams. We also measured several macro-roughness parameters (boulder concentration, boulder diameter and protrusion, and roughness of longitudinal channel profiles) of stream reaches characterized by plane bed/riffle, step-pool and cascade channel morphologies. For a given water discharge the reaches exhibited different flow velocities. We then normalized measured flow velocity and unit discharge by the channel slope and a characteristic roughness length. The resulting dimensionless variables, previously introduced by Rickenmann and Recking [2011], led to a similarity collapse of the entire data set around a simple power-law relationship in which the dimensionless velocity was approximately proportional to the 0.6 power of dimensionless discharge. As roughness length we used various measures of macro-roughness (a characteristic grain size, the standard deviation of long profile elevations, the step height, and the boulder protrusion), all of which explained most of the observed between-site differences in flow velocity. The remaining differences in flow velocity among the reaches were most significantly related to the boulder concentration, a dimensionless measure of macro-roughness. Including boulder concentration in a simple regression-based equation for flow velocity resulted in more precise predictions than those derived from the variable power law equation (VPE), which was proposed by Ferguson [2007] and used by Rickenmann and Recking [2011]. This shows that channel slope and macro-roughness are important factors that explain differences of flow velocity between sites.