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Scaling and variability in steps in steep mountain streams

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Steep mountain streams with coarse bed material often develop a regular step-pool morphology. Step formation is generally connected to local hydraulic conditions, the time-sequence of bed-forming flows and hillslope sediment supply. As a result step formation is highly variable in space and time.

To be able to quantify changes in the step-pool morphology we need (1) to apply appropriate statistical procedures for analyzing step-pool structures beyond basic statistics, (2) to have repeated measurements of longitudinal profiles of streams from which steps can be identified with an objective method, and (3) to have streamflow records from which we can estimate the frequency of bed-forming floods. In this paper we focus on the first two points, by presenting and applying a statistical method to evaluate the structure of steps based on scale invariance. The scaling method tests if the sequence of steps along a stream is the outcome of a stochastic (Poisson) process with two unknowns: mean step spacing and mean step height. The stream is divided into a fine grid along the thalweg and steps are mapped onto this grid. We use an objective method to identify steps from the longitudinal profile based on segment slope. The total step height and number of steps are computed for different spatial grid resolutions (scales) along the thalweg. A scaling function describes the relationships between statistical moments of aggregated step number and height at the different scales. This scaling function is a fundamental descriptor of the complex structure of step placing.

We illustrate the application of the method on two mountain streams in the Alpthal

valley in central Switzerland (Vogelbach and Erlenbach) with very active hillslope-channel interactions and steep step-pool channels (gradient between 0.15-0.2 m/m). Steps are extracted from the longitudinal profile in three approximately 500 m long reaches, and the results between the reaches are compared. In the Vogelbach we look at the effect of substrate and bed material heterogeneity. In the Erlenbach we look at changes in time by comparing the basic step-pool geometry and scaling structure for longitudinal profiles in 2004 and 2007 for the same reach. We also look at the location of steps in connection to previously mapped landslides on channel banks, which directly influence sediment supply and channel morphology locally. The interpretation of the results focuses on the nature of the scaling in step structure and on the variability in step morphology between streams and in time.