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Modeling bed load transport and step-pool morphology with a reduced-complexity approach

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Steep mountain channels are complex fluvial systems, where classical methods developed for lowland streams fail to capture the dynamics of sediment transport and bed morphology. Estimations of sediment transport based on average conditions have more than one order of magnitude of uncertainty because of the wide grain-size distribution of the bed material, the small relative submergence of coarse grains, the episodic character of sediment supply, and the complex boundary conditions. Most notably, bed load transport is modulated by the structure of the bed, where grains are imbricated in steps and similar bedforms and, therefore, they are much more stable then predicted.

In this work we propose a new model based on a reduced-complexity (RC) approach focused on the reproduction of the step-pool morphology. In our 2-D cellular-automaton model entrainment, transport and deposition of particles are considered via intuitive rules based on physical principles. A parsimonious set of parameters allows the control of the behavior of the system, and the basic processes can be considered in a deterministic or stochastic way. The probability of entrainment of grains (and, as a consequence, particle travel distances and resting times) is a function of flow conditions and bed topography. Sediment input is fed at the upper boundary of the channel at a constant or variable rate.

Our model yields realistic results in terms of longitudinal bed profiles and sediment transport trends. Phases of aggradation and degradation can be observed in the channel even under a constant input and the memory of the morphology can be quantified with long-range persistence indicators. Sediment yield at the channel outlet shows intermittency as observed in natural streams. Steps are self-formed in the channel and their stability is tested against the model parameters. Our results show the potential of RC models as complementary tools to more sophisticated models. They provide a realistic description of complex morphological systems and help to better identify the key physical principles that rule their dynamics.