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Probabilistic approaches to the modelling of fluvial processes

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Fluvial systems generally exhibit sediment dynamics that are strongly stochastic. This stochasticity comes basically from three sources: (a) the variability and randomness in sediment supply due to surface properties and topography; (b) from the multitude of pathways that sediment may take on hillslopes and in channels, and the uncertainty in travel times and sediment storage along those pathways; and (c) from the stochasticity which is inherent in mobilizing sediment, either by heavy rain, landslides, debris flows, slope erosion, channel avulsions, etc. Fully deterministic models of fluvial systems, even if they are physically realistic and very complex, are likely going to be unable to capture this stochasticity and as a result will fail to reproduce long-term sediment dynamics.

In this paper I will review another approach to modelling fluvial processes, which grossly simplifies the systems itself, but allows for stochasticity in sediment supply, mobilization and transport. I will demonstrate the benefits and limitations of this probabilistic approach to fluvial processes on three examples.

The first example is a probabilistic sediment cascade which we developed for the Illgraben, a debris flow basin in the Rhone catchment. In this example it will be shown how the probability distribution of landslides generating sediment input into the channel system is transposed into that of sediment yield out of the basin by debris flows. The key role of transient sediment storage in the channel system, which limits the size of potential debris flows, is highlighted together with the influence of the landslide triggering mechanisms and climate stochasticity. The second example focuses on the river reach scale in the Maggia River, a braided gravel-bed stream where the exposed sediment on gravel bars is colonised by riparian vegetation in periods without floods. A simple autoregressive model with a disturbance and colonization term is used to simulate the growth and decline in the sediment covered area of the floodplain. The stochastic arrival of floods which erode riparian vegetation is a key ingredient of the dynamics in this model. This example will be used to illustrate how potential effects of flow regulation on sediment dynamics in rivers may statistically be quantified. The third example is a cellular automaton model of individual grain transport and storage in a steep mountain stream which captures the formation and collapse of step-like structures in the channel. In this model stochasticity is included in the input of grains, the probability that individual grains will be blocked by others in transport and form a step, and the probability that that step will collapse. It will be illustrated how this simple model generates complex behaviour in the sediment output, where periods of stasis and sediment storage are punctuated by rapid evacuation of grains as steps collapse.

The three examples have one thing in common: the dynamics of sediment output depend not only on stochastic disturbance events but also on the state of the system at the time of the event. Both of these ingredients are needed to statistically describe sediment output in the models, and likely in nature as well. I will conclude by arguing that in the context of stochasticity, traditional notions of stability and equilibrium, of the attribution of cause and effect, and of the timescales of process and form in geomorphic systems, become increasingly difficult.