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Self-organisation of fluvial obstacle marks

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Obstacles in fluvial environments, like large boulders, cause flow separation and the generation of turbulent flow patterns, which can lead to local sediment movement and the formation of fluvial obstacle marks. Typically, obstacle marks consist of a frontal, crescent-like scour hole and a leewise, streamlined sediment ridge. The ultimate morphometry is determined by various system elements like obstacle shape and size, flow velocity and depth, sediment size and texture. As fluvial obstacle marks are spatially bound to the obstacle, they provide ideal objects to investigate self-organising formative processes of geomorphic systems.

To study these processes as well as the dynamics of fluvial obstacle marks, a set of 60 laboratory flume experiments was conducted. Thereby, different submerged obstacles, with shapes ranging from simple to natural-like, were placed in a layer of uniform sand and exposed to different flow conditions. Runtimes varied between 8 to 72 hours, until a near-equilibrium condition (= attractor) was reached. Flow fields were analysed with an ADV-probe and visualised with a special tracer dye. The morphodynamics were measured with an ultrasonic and a laser distance sensor. These methods enabled to detect and quantify the dynamic process-process interactions between water and sediment movement (= self-organisation), which ultimately lead to the emergence of obstacle marks.

In previous studies the morphometric variable 'maximum scour depth' has proven to be a useful order parameter, characterising the macroscopic structure of the system. Focusing on formative process-interactions thereby facilitates to define this macroscopic structure. Furthermore, an analytical model, based on the obstacle Reynolds number, proved to be an adequate control parameter.

The trajectories of scour depth developments during the experiments show a non-linear progress toward an attracting condition, provided that the critical threshold for scour hole development is exceeded. This threshold can be quantified using the analytical model. It marks the transition between two system states, where in each case different formative processes prevail. The resilience against such a phase-transition is increased by a streamlined obstacle shape.

In spite of the system being emergent itself (in a qualitative sense), the experimentally simulated obstacle marks also include emergent behaviour, like the random ratio between maximum and mean lengths of leewise sediment depositions or slightly asymmetric scour holes. These emergent properties may be quantified with statistical methods, however.

Eventually, the outcomes of this study show that very complex processes-interaction can in fact result in rather simple forms. The use of simplified order and control parameters enables a transfer of results attained in the laboratory to natural obstacle marks in the field.