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Numerical experiments on the coevolution of bed surface patchiness and channel morphology

Peter Nelson (1,2), Richard McDonald (3), Jonathan Nelson (3), and William Dietrich (1)

(1) Department of Earth and Planetary Science, University of California, Berkeley, United States (peteranelson@gmail.com), (2) Department of Environmental and Civil Engineering, University of Genoa, Genoa, Italy, (3) Geomorphology and Sediment Transport Laboratory, U.S. Geological Survey, Golden, Colorado, United States

River beds frequently display a spatial structure where the sediment mixture comprising the channel bed has been sorted into discrete patches of similar grain size. These patches can be freely mobile sorting features that migrate downstream, such as bedload sheets, or they can be temporally stable features that persist for long periods of time, even though a considerable sediment load may pass over and through them. The local bed surface grain size, and therefore bed surface patchiness, exerts substantial influence on local bed mobility, bedload transport rates, hydrodynamic roughness, and benthic microhabitats. Despite the ecological and morphodynamic importance of bed surface patchiness, we have little understanding of how patches form, evolve, and interact.

Here we present a two-dimensional morphodynamic model that is used to examine in greater detail the mechanisms responsible for the development of forced bed surface patches and the coevolution of bed morphology and bed surface patchiness. The model implements standard equations describing depth-averaged channel hydrodynamics, mixed-grain size sediment transport, and bed evolution (by coupling the river morphodynamic model FaSTMECH and the Parker (1990) surface-based bedload transport equation). As a test case, we use the conditions and observations from a near-field scale flume experiment in which a large (55 m long, 2.74 m wide) straight, sediment recirculating flume was supplied with a constant water discharge and a unimodal sediment mixture ranging in size from 2-45 mm. In the experiment, the bed developed a sequence of alternate bars and temporally and spatially persistent forced patches with a general pattern of coarse bar tops and fine pools. Comparisons between model results and experimental observations suggest that the model predicts bed morphology and sorting patterns similar to the observations. Our observations suggest that size-selective cross-stream bedload transport is a mechanism responsible for the development of forced bed surface patches in gravel-bed channels that have topographically-forced heterogeneous flow fields. However, discrepancies between model results and observations suggest that better predictions may depend on a) keeping track of the vertical distribution of grain sizes in the bed and b) accounting for grain-to-grain interactions in sediment entrainment and deposition. Additional model simulations were designed to explore the coevolution of both free and forced bars and bed surface patches. Simulations incorporating roughness feedbacks between the bed surface and flow field produced flatter, broader, and longer bars than simulations using constant roughness or uniform sediment. Our results suggest that forced bed surface patches are not a mere byproduct of bed topography, but they interact with the evolving bed and through their effect on the flow field they can profoundly influence morphologic evolution.