What keeps rivers close to the threshold of sediment transport?

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Understanding how rivers adjust to the sediment load they carry is critical to predicting the evolution of landscapes. Presently, however, no physically based model reliably captures the dependence of basic river properties, such as its shape, on the discharge of sediment, even in the simple case of laboratory rivers. Here, we develop a theory to show how the balance between fluid stress and gravity acting on the sediment grains, along with cross-stream diffusion of sediment, determines the cross-sectional shape and sediment flux profile of straight laminar rivers which carry sediment as bedload. Our model reliably reproduces the experiments without any tuning, suggesting that we have correctly identified the essential mechanisms for river formation. Using this model, we show that rivers are restricted to exist close to the threshold of sediment motion (within about 20%). This limit is set by the fluid-sediment interaction and is independent of water and sediment load carried by the river. Thus, as the total sediment discharge increases, the intensity of sediment flux (sediment discharge per unit width) in a river saturates, and the river can only transport more sediment by widening. We find that it is the cross-stream diffusion of momentum in the flow that permits sediment transport, as first hypothesized by Parker [1]. Our model provides a base state upon which various morphological instabilities in rivers, such as meandering or braiding, may develop.

[1] Parker G (1978) Self-formed straight rivers with equilibrium banks and mobile bed. part 2. the 744 gravel river. Journal of Fluid mechanics 89(1):127–146.