How laboratory rivers transport sediment

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Understanding how rivers transport sediment is critical to understanding the evolution of landscapes. Presently, however, no model can reliably capture the dependence of basic river properties, such as its shape, on the discharge of transported sediment, even in the simple case of laboratory rivers. Here, we develop a minimal model for the cross-sectional shape of straight laminar rivers which carry sediment as bedload. In particular, we show that the balance between fluid stress and gravity acting on the sediment grains, along with cross-stream diffusion of sediment, determine the river shape. By assuming the aspect ratio of a river is large, we simplify the Stokes' flow equation and, thereby, formulate a second-order boundary-value problem (BVP) for its shape. This equation reliably reproduces the experiments. We then derive asymptotic expressions, valid in the limit of large and small sediment discharge and large water discharge, that relate the river properties to measurable quantities in a simple way. We show that, as the total sediment discharge increases, the intensity of sediment flux in a river saturates, and the river river can only transport more sediment by widening. Finally, we find that it is the cross-stream diffusion of momentum in the flow that permits sediment transport. This model could provide a base state upon which the various instabilities in rivers such as river meandering or braiding can develop.