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The Hairsine-Rose Soil Erosion Model: Analysis for Total Sediment Concentration

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The Hairsine-Rose (HR) model considers rainfall- and shear-driven erosion of the soil bed, overland transport and sediment deposition. Here, we consider the model for rainfall-driven erosion. The model takes account of the different erodabilities of the original soil and deposited material, as well as considering the spatial and temporal behaviour of the different sediment sizes in the eroded bed. This latter feature is crucial, as different grain sizes are transported differently due to the wide range of possible settling velocities. Nevertheless, many experiments, both in the laboratory and the field, measure only total sediment concentrations of eroded material (e.g., at the outlet of a laboratory erosion flume). The HR model equations were summed to obtain a model for total sediment concentration (HRTS model). It was found that the HRTS model includes as a parameter an integral term that gives rise to a closure problem. Consequently, in general solutions must be found by (numerical) iteration in which, essentially, discretization leads to calculation of the sediment size classes in the standard HR model. Nevertheless, we show that accurate approximations can be produced by exploiting the behaviour of the model's predictions of the deposition of previously eroded material, also known as the shield layer. That is, for circumstances where the spatial dependence of this layer can be neglected (e.g., erosion of a uniform bed by constant rainfall), the shielding of the original soil by the deposited layer can be estimated a priori. Based on this estimate, closed-form solutions for the total sediment eroded can be deduced, from which the transport of any given sediment size class can be calculated. We present closed-form approximations, which compare very well with numerical solutions of the HR model, and which are directly applicable to experiments in which the total sediment concentrations in runoff are measured.