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The width (and slope) of an incising river: analytical solution and comparison with natural and experimental rivers

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Numerous field evidences show that the width and slope of mountain channels actively cutting through bedrock vary with (i) discharge (the well-known slope-area and width-discharge relationships), (ii) incision rate and (iii) rock lithology. Present-day models of river incision (the stream power law family of models) can reasonably explain the slope variations with discharge and incision rate (we built them to do so…), but the variations of width are either postulated (width increases as the square root of discharge), or neglected (dependency with incision rate and lithology). To our knowledge, there is no way to avoid these shortcomings to predict, for instance, the relationship between slope, discharge and incision rate. This underlines that we miss something fundamental in our understanding of mountain rivers lateral geometry and dynamics.

We present the first analytical derivation of the relationship between channel width (resp. slope), effective discharge, long-term incision rate and rock erodibility of a steady incising river with rectangular cross-section. Basics ingredients are: (i) a flow resistance equation (e.g., Chezy or Manning) and (ii) any shear-stress dependent incision law (with a critical shear stress of incision). Assuming that steady-state conditions are characterized by a channel geometry that minimizes the overall potential energy of the landscape, slope-discharge and width discharge power law scaling relationships are predicted (S =aQˆ-0.46, W=bQˆ0.47) whose exponents are consistent with field observations. We also predict variations in slope and channel width with incision rate and rock erodibility consistent with field data and laboratory scale incising rivers. We demonstrate how our results significantly alter the scaling between channel slope and incision rate at steady-state compared to previously published derivations.