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Modeling the cross-sectional shape of bedrock channels at steady state: the role of the dominant erosion process (plucking vs attrition) on channel concavity

Jerome Lave
CRPG-CNRS, Vandoeuvre les Nancy, France (jlave@crpg.cnrs-nancy.fr)

Bedrock river incision is a key process in mountain denudation, which has driven substantial modeling efforts, particularly to model long river profile geometry and its response to tectonic, climatic forcing or base level change. The evolution of channel cross-section has comparatively received much less attention. Nevertheless channel width and cross section are also important variables that control water and sediment transport and participate in river response to external forcing. Previous studies have tried to model cross-sectional either by considering a stream power model but applied to the whole wetted perimeter, or by only considering bedload erosion on the channel bottom but without accounting for banks erosion.
In order to tackle this issue, we propose a semi-physical model accounting for both channel and banks erosion by bedload and suspended load attrition, or/and by plucking and block detachment. An initial 1-D model was derived from experimental measurements (dependency of abrasion rate vs impacting particle size) and from observations made during 7 monsoon seasons along the Bakeya river (Frontal Himalaya). In this model, bank erosion by attrition and plucking is expressed as non-linear functions of instantaneous fluvial shear stress and sediment flux, and successfully tested both in terms of timing (i.e. vs the discharge history) and amplitude of the erosion along the surveyed sandstone bars (Lavé et al., in review). The initial model was then extended to 2-D numerical modeling by including a 2-D flow model (Kean and Smith, 2004), a modified finite difference Rouse suspension model, and complemented by an incision model derived from previous formalisms (Sklar and Dietrich, JGR, 2004; Lague, JGR, 2010) that reasonably predict average incision rate of the Bakeya. Our model enables exploring the influence of different variables (sediment flux, uplift rate, dominant erosional process ...) on channel cross-sectional geometry. The distinct functional forms of the two main erosion processes (attrition by impacting sediments vs plucking), whose predominance is related to the lithologic characteristics of the bedrock, may lead to relatively different cross-sectional channel geometries: dominant plucking favours concave-up cross-sectional geometry, whereas dominant attrition favours box-shaped geometry. Model predictions agree relatively well with channel cross sections observed in different lithologic setting along the frontal Himalayas, and therefore represent a novel step toward introducing more physical rules in landscape evolution models.