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Coupling groundwater to sediment transport in ravines

Olivier Devauchelle[1], Alexander P. Petroff[1], Daniel H. Rothman[1]

[1]*Earth, Atmospheric and Planetary Sciences, MIT, Cambridge, MA, USA*

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The formation of a ravine network by seepage of an aquifer can produce a highly complex pattern, even when sediment properties and precipitation are uniform. The steephead streams of the Apalachicola Bluffs and Ravines Preserve on the Florida Panhandle are a simple example of this type of landscape formed in a homogeneous sand plateau, in the apparent absence of runoff. We investigate the mechanism of their formation by means of a two-dimensional model for the aquifer, based on both Darcy's law and the shallow-water approximation: the square of the water table elevation satisfies Poisson's equation. Once a tip is formed, water flowing through it transports sediment removed from the tip, allowing the ravine to grow forward. We assume that the growth of tips is quasi-static, that is, the value of the flow-induced shear stress is close to the threshold for grain motion on the entire stream bed. The consequences of this assumption on the streams are the following: 1) Their aspect ratio and average velocity are constant throughout the network; 2) Their width is proportional to the square root of their discharge; 3) The product of their discharge to the square of their slope is constant. Field measurements show reasonable accordance with the two first relations. As for the third one, it is a boundary condition for the Poisson equation representing the aquifer, to be satisfied along the streams. One consequence of this coupling between ground water and bedload transport is that, in the tips neighborhood, stream elevation profiles increase with the distance from the tip to the power two thirds. This prediction is consistent with observation. This result raises new questions about the structure of the network and the processes involved in its formation. In particular, preliminary numerical calculations tend to indicate that the necessity for a stream to present an upward concave profile generates new solubility conditions for the system. Equivalently, the equilibrium condition would impose a strong constraint on the length of the channels, thus impacting the network properties.