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It's Not All About Discharge and Hydraulics: The Role of Shear Strength and Streambank Composition in Controlling Channel Width

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With the increasing use of digital-elevation and remote sensing data in landscape evolution models, there has been a tendency to rely on simple, bivariate relations that implicitly view discharge as the key variable at the expense of other controlling factors, field-verification and an understanding of mechanistic relations. This has the potential to result in uncertainties in model inputs and hinder advancement of our understanding of channel response, especially channel width, to changes in land use and climate. Whereas reasonable estimates of gradient and discharge can be obtained from DEMs and from validated hydrologic-response models respectively, variables such as shear stress which control entrainment and sediment transport are a function of channel geometry and boundary resistance. Yet estimates of channel geometry (and width) are usually obtained using hydraulic geometry equations that emphasize the role of the formative flow discharge in establishing width. However, in reality streambank erosion is not only controlled by hydraulic processes that act at the toe discharge, but by geotechnical processes acting on the bank mass. It is the latter that is usually ignored in geomorphic studies of channel adjustment. Not only is the shear strength (cohesive and frictional) critical to proper understanding and prediction of channel widening and width, but the composition of the failed bank materials, particularly the volume of the coarser fractions of sediment that is delivered to the flow, in part controls channel degradation, sediment-transport rates and equilibrium channel form.

Identifying in-stream sediment sources, dominant processes of adjustment, and morphologic change is a matter of determining the absolute and relative resistance of the bed and bank material and the magnitude and duration of the applied forces imposed by the flow and/or by gravity. Numerical simulations of sand-bed channels of varying bank resistance, and which are disturbed by reducing the upstream sediment supply by half, show identical adjustments in flow energy and the rate of energy dissipation. The processes that dominate adjustment and the ulitimate stable geometries, however, are vastly different, depending on the cohesion of the channel banks and the supply of hydraulically-controlled sediment (sand) provided by bank erosion.

A numerical model of bed deformation and channel widening was used to simulate channel response to a 50% reduction of upstream sediment supply for sand-, silt-, and clay-bank channels with an initial slope of 0.005 m/m. This scenario is similar to a real-world situation where the upstream sediment supply has been reduced by construction of a dam or where upland re-forestation or other erosion-control measures have reduced delivery of coarse sediment. Because disturbances to the three channels represented an equal, but excessive amount of flow energy relative to upstream sediment supply, adjustments were manifest by almost identical non-linear, asymptotic reductions in the rate of energy dissipation (to 0.80 of initial). Yet, adjustment of the simulated channels occurred by different processes operating at different rates and magnitudes, and resulted in different, stable channel morphologies. The essentially fixed banks of the clay-bank channel experienced 3.5 m of incision, compared to 2.7 m for the silt-bank channel and 0.4 m for the sand-bank channel. In contrast, channel widening by mass failure did not occur in the clay-bank channel, yet was 11.3 m and 13.1 m for the silt- and sand-bank channels, respectively. Resulting width/depth ratios ranged from 5.6 to 16.4 with each channel subjected to the same discharge regime. Thus, differences in bank resistance and composition resulted in different adjustment scenarios and different stable morphologies. Sole reliance on discharge to predict channel width would, therefore, be unreliable.