Landscape evolution models and challenges in formulating earth-surface transport laws

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Much research in geomorphology over the past decade has been devoted to formulating rate laws for the main processes of weathering, erosion, and sediment transport that shape the earth's surface. In this talk we review the current state of the art in landscape dynamics and discuss some of the key challenges in formulating and solving these transport rate laws, particularly as they relate to stochastic aspects of erosion and transport. Most transport laws, either separately or in combination, can reproduce observed landforms. In nearly all cases, however, the link between the macroscopic law and the underlying microphysics remains poorly understood. This gap in part reflects strong heterogeneity in both driving forces (e.g., rainfall and runoff) and material properties (e.g., grain size, rock structure). A related issue concerns differentiability. Geomorphic transport laws are commonly written in terms of average fluxes over periods of centuries or millennia, leading to a local differential equation for mass continuity. Some processes, such as soil creep, clearly involve particle motions that have short space and time scales relative to those of the system as a whole (e.g., a hillslope), and therefore differentiability is satisfied in the infinitesimal limit. Other processes, such as debris flows, involve large translation distances relative to system size, and the resulting long-term flux laws are therefore non-local and differentiability may be called into question. For example, the rate of valley erosion by debris-flow scour depends on both the frequency of flows and on their velocity distribution. Both of these in turn depend on upstream topography, soil thickness, surface roughness, and other non-local variables. A third issue concerns mixing and dispersion during transport. Relatively little is known about the nature of long-term sediment dispersion in river networks, and the conditions under which dispersion is normal versus anomalous. Continuous-Time Random Walk (CTRW) theory predicts that dispersion will be anomalous if the sediment grain resting-time distribution has a heavy tail. We examine controls on resting-time distribution using a Gambler's Ruin analogy for meandering river systems, and test this analogy using two physically based models of meandering river valley evolution. This analysis implies that a heavy-tailed resting-time distribution is favored in valleys that wide relative to the channel.