JOHNS HOPKINS
Center for Environmental & Applied Fluid Mechanics

SPRING 2021 CEAFM VIRTUAL SEMINAR

"The Coevolution of Landscape Morphology and Shallow Groundwater"

Presented by David G. Litwin

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Hosted by Ciaran Harman (JHU - EHE)

Watersheds are dynamic fluid systems, in which the subsurface porous media flow and overland flow are coupled across the landscape topographic surface, driven by meteorological forcings that change rapidly over minutes to days. Simultaneously, the topographic boundary separating these fluid systems changes over 10s of years to 100,000s of years as the landscape geomorphology evolves in response to climatic, tectonic, and lithologic drivers. Despite vast timescale differences, the hydrologic dynamics and geomorphic evolution are coupled: runoff generation and water storage respond to topography and subsurface properties, while also affecting these properties through surface erosion and subsurface weathering. Because of the challenges created by such a large disparity in timescales, there is little systematic understanding of this topographic coupling. How could the coevolution of hydrologic and geomorphic processes through time lead to the emergent hydro-geomorphic properties (hillslope length, drainage density, relief, extent of surface saturation) that we observe in natural landscapes? Is it possible that we could use this knowledge to make quantitative predictions of a landscape's hydrologic function from its topography? In this study, we develop a new groundwater-landscape evolution model to explore how subsurface-mediated runoff generation affects long-term catchment evolution, and analyze numerical results using a nondimensional scaling framework. The model solves hydraulic groundwater equations to predict the water table location given prescribed groundwater recharge. Water in excess of the subsurface capacity for transport becomes overland flow, which generates shear stress on the surface and may detach and transport sediment. This affects the landscape form that in turn affects runoff generation. We show that (1) three dimensionless parameters describe the possible steady state landscapes that coevolve under steady recharge, (2) subsurface flow capacity exerts a fundamental control on hillslope length and relief, and (3) analytical solutions derived from the governing equations provide insight into emergent geomorphic properties and provide a basis to recover key model parameters (including subsurface transmissivity) from topography. We conclude with preliminary results showing that intermittency and stochasticity of precipitation also strongly affect emergent topographic properties. This provides a vivid example of how process variability at fine temporal scales can be crucial for understanding long-term behavior of natural systems that exhibit memory and hysteretic effects. These results open possibilities for topographic analysis of humid upland landscapes that could inform quantitative understanding of hydrological processes at the landscape scale.

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https://wse.zoom.us/j/93762992307