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Effect of threshold relations in subsurface flow on hillslope connectivity: a percolation model approach

P. Lehmann (1), C. Hinz (2), G. McGrath (2), H.J. Tromp-van Meerfeld (3) and J.J. McDonnell (4)

(1) Institute of Terrestrial Ecology, ETH Zurich, Switzerland, (2) School of Earth and Geographical Sciences, University of Western Australia, Perth, Australia, (3) School of Architecture, Civil and Environmental Engineering, Ecole Polytechnique Fédéral de Lausanne, Switzerland, (4) Department of Forest Engineering, Oregon State University, USA (peter.lehmann@env.ethz.ch / Fax: +41 1 633 11 23)

Generation of water and solute flux from hillslopes to streams is often determined by how patterns of transient saturation connect in time and space. This paper tests the hypothesis that such threshold behavior can be modeled with percolation theory. In percolation theory, a system is described as a composite of elements arranged on a regular grid. Each element can be in one of two states and is connected to a certain number of neighboring soil volumes. To model hillslope subsurface runoff with percolation theory, the hillslope can be modeled as a system containing several hundreds of similar soil volumes. We use the hillslope trench site at the Panola Mountain Watershed in Georgia, USA as our test case. Recent work at Panola has shown that transient saturation at the soil bedrock interface is patchy in space. With increasing rain amount, greater connectivity of transient groundwater occurs, until it forms a connected cluster that spans the whole system and subsurface stormflow at the slope base begins. This value is equivalent to the percolation threshold in the corresponding theory. The existence of macropores increases the connectivity of the soil volumes and runoff efficiency. Adapting the size and the connectivity of the grid in the percolation model, the measurements could be reproduced in absolute terms. In more general applications, we quantify the threshold amounts of rainstorm and the volume of the subsurface outflow for different types of connectivity and flow processes. Finally, we discuss the application of percolation theory to derive the spatial and temporal patterns of transient saturation in the hillslope from the measured subsurface outflow at the slope base.