Geophysical Research Abstracts
Vol. 15, EGU2013-7076, 2013
EGU General Assembly 2013

Rainfall-runoff relation: A physically based model to investigate interactions between rainfall duration, slope angle, soil depth and bedrock topography

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Hillslopes are one of the fundamental geomorphic unit of catchments and act as the primary interface and filter between rainfall and runoff transmission to streams. Nevertheless, hillslope response to storm rainfall remains poorly understood. Typically, a certain rainfall volume is needed to exceed an intrinsic threshold before subsurface stormflow is released. Thresholds, however, vary locally. In particular, studies showed that the subsurface topography of an impeding layer may act as first order control on runoff mechanisms and herewith subsurface runoff generation.

Thus, one of the key questions in hillslope hydrology is how slope angle, depth to bedrock or impeding layer and their topography impact the spatial and temporal evolution of subsurface storm flow. To this end, we conducted small scaled irrigation experiments (1 m2) covering intensities of 40, 50 and 60 mm/h over one hour duration in the Schäfertal catchment (51° 39′N, 11° 03′E) in the Lower Harz Mountains, Germany. During the experiments, we measured volumetric water contents at five depths (0.15, 0.30, 0.45, 0,60, 0,75 m) at intervals of 60 s. These measurements were used to develop a physically-based model to investigate subsurface flow.

Here, this model was applied on an artificial hillslope segment (10 x 5 m) with varying slopes and depth to the local impermeable layers. In addition, rainfall duration changed with each simulation. Finally, the impact of the spatial position of a topographical depression in the impermeable layer was analyzed. Assuming vertical water flow to the impeding layer followed by subsequent lateral flow along this boundary, the recorded water content increase owing to irrigation was modelled based on a coupled approach combining both Stokes flow with elements of kinematic wave theory. Bases on this model, gravity drives flow while viscosity counteracts. Since capillarity is neglected, this approach is applicable to a certain soil moisture range between Darcy′s saturated flow and a lower degree of saturation where capillarity dominates.

Assuming a hillslope segment with constant depth to the impeding layer, our first results indicate that the response time (here defined as ‘beginning of outflow’) and time to peak discharge are linearly related to the depth of the impeding layer while peak discharge increased non-linearly with the slope angle. In consequence, different temporal evolutions of runoff response show up. Further results, accounting for the topography of the impeding layer, will be presented.