Sub-pixel scale effects of Hortonian overland flow

Nick van de Giesen[1], Tjeerd Jan Stomph[1], and Nico de Ridder[1]
1. Center for Development Research, University of Bonn, Walter-Flex-Strasse 3, D-53113 Bonn, Germany
2. Wageningen University, Department of Plant Science, P.O.Box 341, 6700 AH Wageningen, The Netherlands

Abstract. Infiltration-excess, or Hortonian, overland flow is known to have an important scale dependency. The longer the slope, the less runoff per unit area is measured at the bottom of the slope. Usually, the cause of this phenomenon is sought in the variability of infiltration and surface roughness parameters. During experiments on a West African catena slope, we also found pronounced scale effects but here the slopes were very homogenous. In our case, the temporal dynamics of rainfall, infiltration, and surface flow caused the differences in runoff per unit area between short and long slopes.

A common way to model Hortonian flow in distributed hydrological models is to calculate infiltration excess in a pixel as if the pixel is a point and to subsequently route the excess as overland flow to downstream pixels. The resolution of Digital Elevation Models used in such models varies but usually pixel sizes lie between 30 m and 100 m. In this presentation, it is shown that pixels of this size may produce an order of magnitude less runoff per unit area than 1 m^2 runoff plots. We can clearly not treat pixels as points in these cases.

In West Africa, we compared runoff coefficients from plots of 1.25 m length with runoff coefficients from 12 m plots. Runoff coefficients (mm runoff/mm rainfall) from 12m plots were found to be consistently lower than runoff coefficients from 1.25m plots. For plots with heavily crusted soils, the total runoff from the small plots was 37% of total rainfall and from the long plots 21%, a reduction of 43%. For less crusted soil, the coefficients were 29% and 6% respectively, a reduction to one fifth! On the crusted soils, the ratio between long- and short-plot coefficients ranged between 0.8 and 0.2 for individual rainstorms. Comparable coefficients and reductions could be simulated with a simple model that combines a Philip two-term infiltration routine with a kinematic wave routine for overland flow. This model was validated with hydrographs from a specially designed segmented artificial slope. Analyses show that the scale dependency comes from temporal variability in rainfall intensity, infiltration, and the velocity with which the water flows downhill. The phenomenon seems to be common on granite and gneiss geologies in West Africa and should also be found in other areas with relatively high rainfall intensities and infiltration rates. For extrapolation purposes, we distinguish three scenarios. In the first scenario, the depth and velocity of the runoff are relatively small and scale effects are mainly caused by spatial variability. The second scenario represents the West African situation with more homogenous slopes and intermediate depth and velocity of runoff. The third scenario covers situations without appreciable scale effects where runoff is not affected by spatial variability and infiltration excess lasts long enough to even out differences between long and short slopes. Future research is geared towards exact scaling and paramaterization of these processes in order to predict where different scenarios dominate and apply appropriate aggregation schemes for distributed models accordingly.