Geophysical Research Abstracts
Vol. 13, EGU2011-5740, 2011
EGU General Assembly 2011

Modelling of overland flow and tracer transport experiments under simulated rainfall at plot scale

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Overland flow and transport of sediments, dissolved nutrients or contaminants in runoff water depth are key processes involved in water erosion and pollution. Thus an accurate calculation of flow velocity is mandatory to model transport of sediments and chemicals. The Saint-Venant equations have consistently proved capable of simulating hydrographs at plot scale. However, recent works showed that even though the hydrograph is satisfyingly reproduced, the flow velocity field within the plot might be wrong, with the highest velocity largely underestimated. Moreover, the choice of roughness models to be used in the Saint-Venant equations is most often done in the purpose of increasing the hydrograph quality, while the actual travel time of water is ignored.

In order to test various roughness models, an experiment was held in Thies, Senegal, with a 10-m by 4-m rainfall simulator. The experiment aimed at measuring both local flow velocity within the plot and breakthrough curves of point-source injections of tracer. Four roughness models have been tested: (i) the Darcy-Weisbach's model, (ii) the Lawrence's model, (iii) the Manning's model with a constant roughness coefficient, and (iv) the Manning's model with a variable roughness coefficient which decreases as a power law of the runoff water depth. Models with a constant friction factor largely underestimated high velocities. Moreover, they were not able to simulate tracer travel-times. Lawrence's model correctly simulated low and high velocities as well as tracer breakthrough curves. However, a specific set of parameters was required for each breakthrough curve from the same experiment. The best results were obtained with the Manning's model with a water-depth dependent roughness coefficient: simulated velocities are consistent with measurements, and a single set of parameters has captured the entire set of breakthrough curves, as well as tracer mass recovery.

The study reported here brought the following findings: (i) roughness coefficient is flow-dependent, (ii) faithful simulation of the velocity fields does not imply a good prediction of travel time and mass recovery, (iii) the best model is a Manning type model with a roughness coefficient which decreases as a power law of water depth. The full data set used in this work is available on request. It can be used as a benchmark for overland flow and transport models.