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Preferential flow in connected soil structures and the principle of "maximum energy dissipation": A thermodynamic perspective

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"There is preferential flow at all scales"? This was a key message in a talk on ?Idle thoughts on a unifying theory of catchment hydrology? given by Bloeschl (2006). In this context ?preferential flow? was used to address rapid water flow along spatially connected flow paths of minimum flow resistance. Preferential flow seems in fact rather the rule than the exception. It occurs locally in non capillary macropores, at the hillslope scale in surface rills or through subsurface pipes. Rapid flow in connected biopores or sometimes shrinkage cracks is today accepted to play a key role for transport of agrochemicals in cohesive soils. The spatial distribution of worm burrows in the landscape may, furthermore, exert crucial control on rainfall runoff response and sediment yields at the hillslope and catchment scales.

However, even if the population of connected biopores/macropores is known in soil we struggle in predicting onset, timing and strength of preferential flow events. Preferential flow is an intermittent, threshold phenomenon. Onset and intensity seems to be determined by the strength of the rainfall forcing and the wetness state of the soil. Furthermore, burrows of deep digging aenecic earthworms can ? even when being abandoned ? persist over decades as suggested by accumulation of clay particles or even radio nuclides. Thus, these structures ?survive? severe rainfall and subsurface flow events and still remain functional in the hydrological system. Why is it sometimes ?favourable? to take flow paths of minimum flow resistance and sometimes not? Why do these flow paths/ structures persist such a long time?

Following Kleidon and Schimansky (2008) we suggest that a thermodynamic perspective ? looking at soil water flow as dissipative process in an open, non equilibrium thermodynamic system ? may help unrevealing these questions. However, we suggest a complementary perspective on soil water flow focusing rather on entropy production but on dissipation of Helmholtz free energy. Thermodynamic equilibrium is a state of minimum free energy. The latter is determined by potential energy and capillary energy in soil, which in turn strongly depends on soil moisture, pore size distribution and depth to groundwater.

The objective of this study is threefold. First, we will introduce the necessary theoretical background. Second we suggest ? based on simulations with a physically based hydrological model ? that water flow in connected preferential pathways assures a faster relaxation towards thermodynamic equilibrium through a faster drainage of ?excess water? and a faster redistribution of ?capillary water? within the soil. The latter process is of prime importance in case of cohesive soils where the pore size distribution is dominated by medium and small pores. Third, an application of a physically based hydrological model to predict water flow and runoff response from a pristine catchment in the Chilenean Andes underpins this hypothesis. Behavioral model structures that allow a good match of the observed hydrographs turned out to be most efficient in dissipating free energy by means of preferential flow. It seems that a population of connected preferential pathways is favourable both for resilience and stability of these soils during extreme events and to retain water resources for the ecosystem at the same time. We suggest that this principle of ?maximum energy dissipation? may on the long term help us to better understand why soil structures remain stable, threshold nature of preferential as well as offer a means to further reduce model structural uncertainty.

Bloeschl, G. 2006. Idle thoughts on a unifying theory of catchment Hydrology. Geophysical Research Abstracts, Vol. 8, 10677, 2006 SRef-ID: 1607-7962/gra/EGU06-A-10677 European Geosciences Union 2006
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