# Linking point scale process non-linearity, catchment organization and linear system dynamics in a thermodynamic state space

Zehe, E; Loritz, R.; Ehret, U; Westhoff, M.; Kleidon, A; Savenije, Huub

**Publication date**
2017

**Document Version**
Final published version

**Published in**
Geophysical Research Abstracts (online)

Geophysical Research Abstracts
Vol. 19, EGU2017-14651, 2017
EGU General Assembly 2017


# Linking point scale process non-linearity, catchment organization and linear system dynamics in a thermodynamic state space

Erwin Zehe (1), Ralf Loritz (1), Uwe Ehret (1), Martijn Westhoff (2), Axel Kleidon (3), and Hubert Savenije (4)

(1) Institute of Water Resources and River Basin Management, Karlsruhe Institute of Technology KIT, (2) VU University Amsterdam, (3) Max Planck Institute for Biogeochemistry, Jena, (4) Delt Technical University

It is flabbergasting to note that catchment systems often behave almost linearly, despite of the strong non-linearity of point scale soil water characteristics. In the present study we provide evidence that a thermodynamic treatment of environmental system dynamics is the key to understand how particularly a stronger spatial organization of catchments leads to a more linear rainfall runoff behavior. Our starting point is that water fluxes in a catchment are associated with fluxes of kinetic and potential energy while changes in subsurface water stocks go along with changes in potential energy and chemical energy of subsurface water. Steady state/local equilibrium of the entire system can be defined as a state of minimum free energy, reflecting an equilibrium subsurface water storage, which is determined catchment topography, soil water characteristics and water levels in the stream. Dynamics of the entire system, i.e. deviations from equilibrium storage, are 'pseudo' oscillations in a thermodynamic state space. Either to an excess potential energy in case of wetting while subsequent relaxation back to equilibrium requires drainage/water export. Or to an excess in capillary binding energy in case of driving, while relaxation back to equilibrium requires recharge of the subsurface water stock. While system dynamics is highly non-linear on the 'too dry branch' it is essentially linear on the 'too wet branch' in case of potential energy excess.

A steepened topography, which reflects a stronger spatial organization, reduces the equilibrium storage of the catchment system to smaller values, thereby it increases the range of states where the systems behaves linearly due to an excess in potential energy. Contrarily to this a shift to finer textured soils increases the equilibrium storage, which implies that the range of states where the systems behaves linearly is reduced. In this context it is important to note that an increased internal organization of the system due to an elevated density of the preferential flow paths, imply a less non-linear system behavior. This is because they avoid persistence of very dry states system states by facilitating recharge of the soil moisture stock. Based on the proposed approach we compare dynamics of four distinctly different catchments in their respective state space and demonstrate the feasibility of the approach to explain differences and similarities in their rainfall runoff regimes.