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Reply on RC3

Samuel Schroers et al.

Author comment on "Hortonian Overland Flow, Hillslope Morphology and Stream Power I: Spatial Energy Distributions and Steady-state Power Maxima" by Samuel Schroers et al., Hydrol. Earth Syst. Sci. Discuss., https://doi.org/10.5194/hess-2021-79-AC4, 2021

We sincerely thank Hubert Savenije for his thoughtful and constructive assessment of our manuscript.

First, we agree that energy conversion and dissipation in hydrological systems happens essentially also a) within the partially saturated soil and b) by in-/exfiltration affecting the energy balance. In fact, water infiltration into the soil and subsequent soil water dynamics is associated with conversion and dissipation of potential energy and matric/capillary potential energy. While the former grows with growing soil water content and elevation above ground water, the latter grows non-linearly with declining soil water content (Zehe et al., 2019). Particularly in cohesive soil, capillary potential energy may become very large during dry spells and flow resistances/ frictional dissipation grow non-linearly. Macropores considerably reduce dissipative losses and allow for a faster recharge of dry soil, which implies a faster depletion of matric potential energy gradients (Zehe et al. 2010). The fact that during infiltration gravitational potential energy of soil water grows and the non-linear shape of the retention curve, implies the existence of an infiltration capacity that maximizes dissipation of total free energy in soil water (Zehe et al., 2013). We therefore want to stress, that the main objective of our study was not a complete assessment of dissipation in hydrological systems. Rather, we want to point out that free energy conversions associated with surface runoff on hillslopes differ distinctly from the energetics of stream flow. The latter is associated with downstream potential energy loss while on the hillslope potential energy first builds up in downslope direction until reaching a local maximum and declines afterwards. Note that this implies that frictional laws like Darcy Weißbach are not well defined upslope of the maximum, as $dE_{pot}/dx > 0$, and it might imply a much stronger erosion upslope as will be shown in the revised manuscript.

The second comment made by Hubert Savenije points to one of the objectives of this study. Kirkby (1971) suggested that commonly observed hillslope forms are related to the dominant erosion processes while Emmett (1970) points out that a sinusoidal hillslope profile is the result of the transition from laminar to turbulent surface runoff. It seems that due to the complexity and amount of interacting processes it is difficult to single out any process alone. Yet all hydrological processes are in its essence the result of energy conversion, dissipating free energy. Therefore we think it is especially interesting considering a thermodynamic perspective for hillslope development. The hillslope profiles in our study have been chosen in line with these preceding investigations and have been analyzed with surface runoff only. Nonetheless our results show that the location of energetic maxima, the magnitude of the energy gradient and the emergence of a power maximum are directly linked to these forms. A conclusion on how complex hillslope profiles in nature relate to their energy conversion processes would require an additional study and was beyond the scope of this paper.

However, in perspective to the third comment made by Hubert Savenije (as well as Rev 2), we agree that the study will benefit from the incorporation of some experiments and a subsequent analysis, applying our theory. Therefore, we have already prepared the results of some field experiments of surface runoff and erosion processes on 12m x 2m plots from the Weiherbach catchment, which we would gladly analyze and test in a revised manuscript.

We greatly appreciate the comments and observations made.

Additional Sources:

Zehe, Erwin; Blume, Theresa; Blöschl, Günter (2010): The principle of 'maximum energy dissipation': a novel thermodynamic perspective on rapid water flow in connected soil structures. In: Philosophical transactions of the Royal Society of London. Series B, Biological sciences 365 (1545), S. 1377–1386. DOI: 10.1098/rstb.2009.0308.

Zehe, Erwin; Loritz, Ralf; Jackisch, Conrad; Westhoff, Martijn; Kleidon, Axel; Blume, Theresa et al. (2019): Energy states of soil water – a thermodynamic perspective on soil water dynamics and storage-controlled streamflow generation in different landscapes. In: Hydrol. Earth Syst. Sci. 23 (2), S. 971–987. DOI: 10.5194/hess-23-971-2019.