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Reply on RC2

Samuel Schroers et al.

Author comment on "Morphological controls on surface runoff: an interpretation of steady-state energy patterns, maximum power states and dissipation regimes within a thermodynamic framework" by Samuel Schroers et al., Hydrol. Earth Syst. Sci. Discuss., https://doi.org/10.5194/hess-2021-479-AC3, 2021

We thank KB for these thoughtful comments. We fully agree that the steady state surface runoff is rarely reached during rainfall runoff events. In fact, we plan to address this point in a follow up study (as explained below). We also share his concerns about the validity of empirical flow laws (in particular Manning's n) in case of very shallow overland flows with flow depths of a few mm. We already stressed that this is particularly delicate upslope of the potential energy maximum, in the current manuscript. Also, we acknowledge that the presented concept does indeed not provide closure of the energy balance. However, we would like to stress that in this study the presentation of the Df term is principally intended to provide a basis for the analysis of the spatial distribution thereof, not it's magnitude. The question how free energy of flow is dissipated by viscous forces goes beyond the goal of this study, but we agree that this point is important, and that a revision should at least incorporate some perspective.

Yet, solving all these issues is beyond the scope of this study, and more importantly beyond the scope of the field observations at hand. Our work is clearly only a first step, but it underpins that a closer look at the spatial pattern of the steady state energy balance of surface runoff and it's residual Df is helpful to

- identify distinct differences between hillslopes and rivers,
- single out hot spots, where the flow can perform the largest amount of physical work,
- test thermodynamic concepts (maximum power, least work, etc.) on this dynamical system .

We also like to stress that our work is not purely theoretical. We analyze overland flow measured during sprinkling experiments, which reached steady state conditions according to Scherer et al. (2012). As these experiments provide measured flow velocities in rills and back calculated values of Manning's n. Hence, we regard these experiments, despite all their short comings (very shallow flow depth and limited validity of all available flow laws) as best suited to test our framework, at least during, albeit rare, steady state conditions. Because the experiments did not provide observed flow depth along the flow path, this approach required a numerical model, as well as expanding the CATFLOW code by a rill domain.

This analysis corroborated the existence of the potential energy maxima and their sensitivity to presence/absence of rills. And we provide first evidence that the transition zone from laminar to mixed flow coincides roughly with the location of the potential energy maximum (when rills are present). We also found that kinetic energy in the sheet and rill domain are equal at the end of the stripe. This is analogue to the maximum power configuration of an electrical circuit and at least an interesting incidence. Of course, two experiments are not sufficient to conclude whether this holds in general.

All In all, we think that our work corroborates that an energetic perspective on overland flow is helpful and has practical implications which should be further explored.

The next logical step is to give up the steady state assumption and work with transient conditions. The mentioned energy residual's distribution might follow similar thermodynamic concepts in time as in space.

The framework is not restricted to the steady state, but requires numerical simulations of overland flow, ideally with the shallow water equations (as the diffusion wave approach assumes a steady state momentum balance).

Another key challenge is a proper design of experiments to disentangle viscous dissipation and energy transfer to and from the sediments. If this energy transfer is ignored during simulations, this might imply that dissipation is over- or underestimated (see explanation in last reply). And finally, the concept of maximum power i.e., an equal distribution of kinetic energy among rill and sheet flow during steady state, is a testable hypothesis.