Review of HESS-2021-479/3 by Schroers et al.

This is a truly innovative paper aimed at linking hillslope surface flow, drainage structure formation, and erosion processes to Thermodynamics. The paper presents a new approach to understand hillslope processes by considering the omnipresent 1st and 2nd laws of thermodynamics. The paper is well readable, even though the concepts may be hard to grasp for the average hydrologist. The background is very well explained in 1.1.

Although there still is a lot to discover -- the authors have had to make a few simplifications to simplify their analysis -- I do consider this a landmark paper. While going through the paper, a few thoughts were triggered, which I would like to share with the authors, but which do not need to be addressed in a final version. I also found a few minor errors which I list at the end.

1. The authors consider steady state for obvious reasons of simplicity, but it makes me wonder. The hydrological environment is never in steady state; overland flow is always dynamic, and morphological change generally happens at extreme occurrences under transient conditions. Still, I agree with the authors that steady state energy patterns can inform us on the dominant processes of rill and channel formation and on the relation between resistance to flow (Manning's n), slope, hydraulic radius, flow width, sediment size and the bank full flow velocity. Can we reason why the steady state is informative? Maybe the maximum flow condition of an event, where time derivatives are also zero, is the dominant condition.

2. The approach hinges on the assumption that v=f(q). This has been found empirically, but there is also a logic in it. Let's consider a river along its convex geopotential trajectory from the hillslope to the sea. We see a gradually decreasing slope, a gradually decreasing bankfull flow velocity, decreasing transport capacity (a function of v^2.5), and -- as a result -- decreasing grain size of bed material. As the transport capacity reduces, the grain sizes that are too large to transport have to be dumped over and on the banks by exceptional flood events. The channel is thus a transporter of sediment of a certain grainsize belonging to a certain longitudinal coordinate in the channel, with a specific slope and bankfull flow velocity. To maintain a stable channel, the minimum flow velocity corresponds with the transport capacity required for this sediment and with minimum energy expenditure. Hence, there is a thermodynamic connection between roughness, slope, hydraulic roughness, flow velocity and sediment size, which we recognize in the empirical equations for resistance to flow and in the cited equation that v=f(q), implying that on a hillslope with uniform sediment particles, there is an additional relation between flow velocity, roughness, and slope, resulting in a constant velocity and constant transport capacity. There must be a thermodynamic explanation for this empirical relation. It brings to my mind Riggs' equation for open channel flow, where he found that Manning's roughness is a function of slope S, hydraulic radius and cross-sectional area A, leading to a simple function where Q=f(A,S), which performed equally food as the Manning equation where experienced hydrologists estimated Manning's n.

3. In Fig.5 the advective erosion (SW) is closest to uniform relative dissipation. In my view the convergent and advective process is the closest to the natural form of a drainage

network. Would it then be safe to assume that the uniform relative dissipation is the thermodynamic optimum for drainage networks (you observe this as well in L439-442), and that we can use this as the basic assumption for investigating the issues mentioned here under 2?

Some small errors:
L380: "is" to replace "as"
L395: I think you switched b) and c) in the caption.

Reference:
Riggs, H.C., 1976. A simplified slope-area method for estimating flood discharges in natural channels. Journal Research U.S. Geol. Survey Vol. 4, No. 3.