Response review #1:

The reviewer correctly points out that the focus of our preceding study and the study at hand lies on dissipation of free energy. This already partly explains the reviewer's comment regarding a definition of stream power, which from our point of view is the magnitude of potential energy (of water) that is being converted into other forms of energy per unit time. It is correct that we have made a mistake in Fig. 1, where we neglected the dissipation term, we have corrected this figure.

Eq. 2 outlines, that dissipation is converted energy (stream power) minus the amount of energy which remains in the form of kinetic energy. Stream power alone therefore informs about the magnitudes of energy that is being converted, together with kinetic energy (and other remaining free energy which we have not considered in this study, e.g., turbulent kinetic energy) one can assess the efficiency of the conversion of a free energy gradient to flow, the movement of water.

This points to the next comment from the reviewer regarding the Manning coefficient, which currently is for most applications the only way to pinpoint this efficiency that scales dissipation. Any parameter which characterizes roughness is ultimately related to the conversion process of free energy to heat, describing the capacity of the system to create flow from a gradient of free energy. In fact, expressing this in steady state as the flux of kinetic energy over stream power with a formula that links average flow velocity and driving gradient such as the Manning equation we can derive a formula which describes the efficiency of a system to convert a gradient of free energy into kinetic energy as a function of geometry (hydraulic radius) and roughness.

This leads again to our argumentation that to understand the evolution of the dynamics of flow, e.g., in a geomorphological context for erosion of hillslopes, we need to understand the evolution of efficiencies. We argue that the underlying driving process for evolution of the structure of a system does not depend on the physical parameter of roughness but on dissipation itself.

The comment from the author regarding negative dissipation of a single hillslope in Fig. 11 is correct. We traced this to the implementation of very shallow flows in the numerical scheme, an error we corrected by allowing smaller minimum water depths for movement of water.

Regarding the rest of the comments from the reviewer we thank her/him for the thorough inspection and we have gladly incorporated the suggestions regarding readability and clarity.

We thank the reviewer for his effort and comments.

All minor comments have been addressed in the revised manuscript.

Response review #2:

We would like to answer comments 1 and 2 in one paragraph, as we believe both are related and belong together:

The reviewer correctly highlights that the calculated dissipation term does not differentiate between the type of dissipation, be it the creation of turbulence, the lift or the transport of sediment particles. First, we would like to point to our previous publication (Schroers et al., 2022) and in particular to the discussion we had with Keith Beven regarding the same issue (https://doi.org/10.5194/hess-2021-479-RC1). Among other things we presented in https://doi.org/10.5194/hess-2021-479-AC2 an extension of our theoretical framework to distinguish the energy, which is spent on erosion, but this usually goes beyond what is possible to reliably represent with field data. There are however several studies (e.g. Emmett, 1970) which estimated the type of flow regime (laminar or turbulent) on which we have elaborated in our previous study. Maybe the most interesting result is that the build-up of free energy seems to be related to laminar flow and the decrease to turbulence. As turbulence is further related to higher erosion rates, we hypothesized that the occurrence of erosional structures such as rills or gullies can be pinpointed by the free energy content of surface runoff.

On a larger scale the hillslope itself is shaped into a certain form (SC or SW), typically by intermittent surface runoff events. This led us to the idea to analyze transient events in the study at hand. We therefore defined energy efficiency of a hillslope in line with energy efficiency of a mechanical machine, the output of free energy divided by the input of free energy. A more efficient surface runoff event is therefore one which allows a larger fraction of the input energy to be conserved in the energy output. Our results show that for transient events higher efficiency typically relates to SC hillslope types and lower efficiency to SW hillslope types. In a second step we argue that a higher efficiency is downregulated through erosion to smaller efficiency (the typical evolution of hillslopes from SC to SW forms). Section 4.4 shows that this reasoning does indeed apply to the hillslopes and surface runoff events in the Weiherbach catchment. Higher relative dissipation (SW forms, less efficiency) relates to less erosion and smaller relative dissipation relates to more erosion (SC forms, higher efficiency). It is therefore correct that we made a wording mistake in line 609-611, we have corrected this sentence.

Comment 3:

We agree with the reviewer, ideally the hillslope should coevolve with the transient event. However, it was shown elsewhere (e.g. Kirkby, 1971) that hillslopes generally evolve from SC to SW profiles. In this perspective our tests consider only the beginning and the end of this evolution and we subsequently present the different energy fluxes in the presented thermodynamic framework. Our approach is therefore a simplification to highlight the differences between the start and the end point and provide a thermodynamic explanation to the direction of such hillslope evolution.

Comment 4:

We thank the reviewer for pointing out that infiltration could potentially have a large effect on the presented framework. In theory high infiltration rates would decrease the free energy of surface runoff, but at the same time it would increase the free energy of subsurface water. In this study we put our focus on surface runoff events, but the free energy content of subsurface water could certainly correlate with observed hillslope forms. As we also point out in line 546-549, Zehe et al. (2013) found for the same events in the Weiherbach catchment energy conversion rates of almost the same scale for subsurface runoff as we found in surface runoff. This highlights that surface and subsurface runoff of extreme events are likely to be co-organized. Such an analysis is however beyond the scope of this work.

All minor comments have been addressed in the revised manuscript.