Summary
This is an interesting and well-structured manuscript, investigating the role of energetically optimized preferential pathways, which minimize total dissipation in the network, on the aquifer response to recharge events. Strong emphasis is the recession behavior of such system is in line with the one of karst aquifers, and more generally on its scaling. The study is based on a very solid and partly innovative numerical simulations, comparing full 2d Darcy flow, where each cell potentially drains in all its neighbors, to preferential scenarios where water flows along the path of the steepest descent in hydraulic head. By using a finite volume approach and a function set where the pressure head h declines exponentially with time, the authors obtain a symmetrical eigenvalue problem (for constant S and recharge), which implies that they can express their solution as sum of orthonormal eigenvectors, which have different characteristic decay times (inverse of recession coefficient). Moreover, they derive organized patterns of transmissivity T and storavity S by minimizing total energy dissipation according to the work of Hergarten et al. (2014).

The authors show that the recession coefficients obtained with the full Darcy model and the dendritic flow patterns are well aligned over the range of investigated catchment sizes, in case of organized T and S patterns. In case of a homogeneous S and T, they find in contrary a strong mismatch. They also show that recession coefficients show power low decline with catchment area, when the system is a strongly preferential, while they find a much stronger dependence on catchment a homogeneous domain. A main conclusions is that the recession of Karst systems is not in accordance with a self-organized preferential flow network. This for the latter the slowest recession component controls 90% of the water that leaving the system, while this fraction is clearly smaller in Karst systems.

Evaluation: The proposed manuscript deserves without doubt publication in HESS. Yet, I made a few observations which relate to the realism of a few underlying assumption and their implication for real world system that should be addressed within a round of revisions.

- Setting the factor of proportionality to one in Eq.49 is physically not meaning full, because it must be related to recharge of the aquifer. When choosing a catchment area of 1km^2 we end up with a transmissivity of (10^6)^(2n/n+1), for n= 2 this is larger than 10^7m^2/s. What does a recharge coefficient of 1 mean, 1 m/s, 1 m/y)? I appreciate when the authors make their equations dimensionless, but this requires to normalize by characteristic areas and recharge rates, to assure that the connection to the physical world remains clear.
- I think it would strengthen the manuscript, when the authors discuss what a non-linear increase in transmissivity with catchment area does actually reflect. For river networks similar to hydraulic radius grows with catchment area, which implies a reduction specific dissipation and thus an increase in energy efficiency of the stream or the rill network (Schroers et al. 2022). Does the power law like increase in transmissivity with an exponent > 1 imply the hydraulic radius of preferential flow paths is growing at this rate (due to confluence in the network)? Or do you think that the extra-growth beyond the trivial linear increase with A comes from a related growth in K? There is work

discussing positive feedbacks between dilution and precipitation in aquifers on K (Edery etal., 2021). Maybe this can be related to catchment area as well?

- Closely related to that I wonder about the meaning of the power law dependence of K on the Darcy velocity q (Eq. 38). When solving this for q this implies q ~ K ^ (n+1/2n), in case of n=2, q~K^(3/4). To me this seems to be inconsistent with Darcy's law (q ~ K^1). So is this in fact a manifestation that Darcy flow is at best approximately valid, when dealing with preferential flow in least energy structures? I would expect that there is a little bit of the head difference/potential energy difference goes into kinetic energy of the preferential flow. So maybe Darcy-Weisbach and a dendritic pipe network would come closer to this?

Best regards,

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References

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