Review report hess-2022-7.

Referee comments are shown with black text and the responses from the authors are in blue with italic font.

RC1: 'Comment on hess-2022-7', Anonymous Referee #1, 29 Mar 2022

Summary

This study aims to demonstrate the importance of bedrock conductivity pattern, bedrock slope, and soil bedrock conductivity contrast on streamflow recession using a theoretical (numerical) experiment. The authors conducted scenario analyses to explore how conductivity contrast at soil-bedrock interface, soil thickness, and porosity as well as bedrock slope impact the parameter “b” of recession analysis which shows the nonlinearity of recession response. They explored under which circumstances the homogeneous theory derived from the Boussinesq solution deems appropriate to interpret recession analysis.

Assessment

I enjoyed reading this manuscript. Bedrock conductivity pattern and soil-bedrock conductivity contrast could strongly control how catchments store, partition and release water and solute and thus they could control vertical distribution of flow-path and ultimately recession behavior. These controls are poorly understood and lack of consideration of such controls could lead to a misleading interpretation of recession analysis if one only relies on the homogeneous theory derived from the Boussinesq solution. This paper could be a very nice addition to HESS after some revisions and clarification.

A: We are thankful to the reviewer for the summary of the outcomes of our work and the positive assessment of the manuscript. The comments raised by the reviewer and its suggestions will be very helpful in improving our manuscript.

Major suggestion:

This study conducted a set of analyses on the importance of parameter alpha (the rate at which Bedrock K declines exponentially) and D (upper compartment thickness or soil thickness) on recession non-linearity. But we cannot see figure or discussion on the importance of these parameters in the paper (except one fig in the appendix for max(b) only). There is one short statement in the paper that these two have had negligible impact on “b”. I have hard time justifying this statement. Soil thickness and rate of exponential decline in K were showed to significantly control the way catchments partition and release water, particularly during low flow (see below citations). Some of the co-authors of the paper also previously showed that these two factors control recession non-linearity, using analytical solutions. I suggest that the authors further evaluate the impacts of these two and show some figures on these two parameters impact on b. Specifically, these two might be important at certain level of bedrock slope (beta) and soil-bedrock K contrast (rk). A sub-section of discussion can then discuss why and how the results of this paper are similar or different from previous literature. Knowing those levels of slope and rk that exaggerate the impacts of alpha and D on recession non-linearity could be very interesting.

A: Thank you for this very important comment. We fully agree that the impact of both upper compartment thickness (D) and hydraulic conductivity decrease K~z of the deeper compartment are important parameters in controlling flow partitioning and consequently recession behaviors. As the reviewer mentioned, Rupp and Selker [2005, 2006] have *previously investigated recession behaviors in aquifers with decreasing K and changing slope angles. Here, we have shown that, in the configuration of the considered in our study, the impact of upper compartment thickness and K~z of the deeper one have limited impact on max(b) with respect to the controls from r_K (figure 8, section A.2).*

However, we agree with the reviewer that those results would deserve to be moved to the main text and further discussed. We have simulation results for 3 values of α/ζ *and* **D** *at* $\beta = 0.2$*. In the revised manuscript, we will make sure to describe those results and further develop the discussion on the impact of those parameters.*

- *To avoid confusion, we will delete the statement on Line 120 "Note that we found that changing the parameter* α *does not significantly impact our results" from the methodology section and save discussion of the influence of parameter* α *for later in the result and discussion sections.*
- *We will add a dedicated section in 3.3 where we will describe the results for* α/ζ *and D at* $\beta = 0.2$*. We will move Figure 8 from the appendix to this section, in which we will also add a new figure showing the evolution of b vs Q for the different cases (in a similar manner as current Figure 5).*
- *We will further develop the discussion to highlight the relative importance of all parameters in controlling the variability in recession behaviors.*

Suggested citations: Below studies focused on the importance of soil-bedrock conductivity contrast and bedrock vertical conductivity pattern (and/or soil thickness) on how catchments store, partition and release water and solute. The authors may find it helpful to use some of these citations in the introduction to further emphasize the importance of their work.

[Ameli et al., 2015; Ameli et al., 2016; Ameli et al., 2018; Ameli et al., 2021; Ameli et al., 2017; Bishop, 1991; Cardenas and Jiang, 2010; Hopp and McDonnell, 2009; Janssen and Ameli, 2021; Jiang et al., 2010]

A: Thank you for these citations. Some of them are already included in the manuscript and we will make sure to include the ones that we may have missed if appropriate.

Other suggestions:

A: Thank you for raising all those points. We will take them into account in our final version of the manuscript. You'll find detailed answers below when appropriate.

Line 16: "Responsible" is a strong word. We probably cannot safely declare that yet.

Line 28-29: I don't think Tashie et al and Jachens et al suggested "strong dependencies".

Figure 1c. Unit is not correct

Line 119. Are results (and final conclusions) sensitive to the initial value of KL and porosity

A: Thanks for raising this important point. Initial values of K_L and porosity will have limited impact as long as we stay in similar flow regimes. We will include a specific comment in the revised manuscript to highlight this important point.

Line 124: Identical porosity across the interface is not a conservative assumption. Could you explain/discuss how it could impact the final result and conclusions

A: Thank you for this comment. In the initial design of the study we focused on conductivity contrast. But the reviewer is right that having joined evolution between porosity and permeability will certainly have an impact. But imposing both will also come with difficulties *in identifying which parameter exerts most of the control. Investigating the impact of porosity contrast could be a perspective to this work, with a clear impact for solute transport mechanisms and timescales. We will add a sentence on this point.*

Line 182: I think figure 4 shows as rk increases, the recessions transition from lower values of -dQ/dt to higher values. Am I missing something?

A: This sentence is indeed confusing – we will rephrase it.

Line 290: The evidence of "compartmentalized aquifer" can lead to anomalous b values is a solid conclusion obtained from this paper. But in real world, proving that anomalous b is due to "compartmentalized aquifer" could be tricky. I suggest to revise this sentence

A: We agree with this comment. Numerous factors can influence late time recession behavior and may be responsible for the emergence of anomalous behaviors. This leads to challenges when aiming to identify which factor is the most important in 'real world catchments'. However, we show, in complement to previous studies, that hillslope and catchment heterogeneities exert strong controls. We provide guidance in the discussion on key parameters/indicators that might be investigated in parallel to streamflow to identify the impact of vertical compartmentalization (lines 328-346). We will revise this sentence to highlight that this conclusion applies for the present hillslope configuration where other processes are neglected.

Line 300: But this threshold of rk was obtained given other parameters such as D and porosity and etc remained constant. So, we cannot generalize it to other situation and the threshold of rk can only be generalized for certain values of other parameters. I mean, for different D or porosity, rk might be smaller or larger than 16.

A: True – we will revise this sentence to highlight that it applies for the present hillslope configuration. We will add an opening sentence for perspectives to study the impact of \phi and D on changing the threshold in r_K.

Line 305: If I am not mistaken Fig 3 conveys different message. At later time b goes toward 1 (become smaller than earlier recession). Early recession is about 1.5 and late recession is around 1.

A: The transition from 1 to 1.5 at late times for case of \Beta = 0 is visible on figure 5a (Q<10^-6 m^2/s for r_K = 1 and 4). We will revise this sentence to specifically define the range of discharges that are concerned by those different recession behaviors.

Ameli, A. A., J. Craig, and J. McDonnell (2015), Are all runoff processes the same? Numerical experiments comparing a Darcy-Richards solver to an overland flow-based approach for subsurface storm runoff simulation, Water Resources Research, 51(12).

Ameli, A. A., J. J. McDonnell , and K. Bishop (2016), The exponential decline in saturated hydraulic conductivity with depth and its effect on water flow paths and transit time distribution, Hydrological Processes, 30(14), 12.

Ameli, A. A., C. P. Gabrielli, U. Morgenstern, and J. McDonnell (2018), Groundwater subsidy from headwaters to their parent water watershed: A combined field-modeling approach, Water Resources Research, 54.

Ameli, A. A., H. Laudon, C. Teutschbein, and K. Bishop (2021), Where and when to collect tracer data to diagnose hillslope permeability architecture, Water Resources Research, 57(8).

Ameli, A. A., K. Beven, M. Erlandsson, I. Creed, J. McDonnell, and K. Bishop (2017), Primary weathering rates, water transit times and concentration-discharge relations: A theoretical analysis for the critical zone, Water Resources Research, 52.

Bishop, K. H. (1991), Episodic increases in stream acidity, catchment flow pathways and hydrograph separation, University of Cambridge.

Cardenas, M. B., and X.-W. Jiang (2010), Groundwater flow, transport, and residence times through topography-driven basins with exponentially decreasing permeability and porosity, Water Resources Research, 46(11), n/a-n/a.

Hopp, L., and J. J. McDonnell (2009), Connectivity at the hillslope scale: Identifying interactions between storm size, bedrock permeability, slope angle and soil depth, Journal of Hydrology, 376(3-4), 378-391.

Janssen, J., and A. A. Ameli (2021), A hydrologic functional approach for improving large-sample hydrology performance in poorly-gauged regions, Water Resources Research, 57(9), e2021WR030263.

Jiang, X.-W., L. Wan, M. B. Cardenas, S. Ge, and X.-S. Wang (2010), Simultaneous rejuvenation and aging of groundwater in basins due to depth-decaying hydraulic conductivity and porosity, Geophysical Research Letters, 37(5), n/a-n/a.