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Hydrology and Earth System Sciences
Discussions

Interactive comment on "Opinion paper: Linking Darcy's equation to the linear reservoir" *by* Hubert H. G. Savenije

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In this short, thought-stimulating, opinion paper, Savenije reasons how two key equations in hydrology at different scales (i.e. the linear reservoir at catchment –scale and Darcy's equation at lab-scale) are connected. Understanding the connections between scales in hydrology, and the cause of emergent catchment behavior is very valuable for hydrological sciences to progress. This paper makes an interesting contribution to this challenge. In general, I really enjoyed reading this short piece (and an earlier presentation of this work at the EGU General Assembly 2017 in Vienna, catchment similarity session).

Savenije writes that this is an "opinion paper" that "does not provide a proof of concept",

and is intended to "open a debate on how the linear drainage of groundwater from a hillslope can be connected to Darcy's law". I spirit of this comment, I have a few thoughts that are intended as thought stimulating comments that may hopefully further strengthen this paper or this overall debate.

1. Is the catchment's groundwater reservoir linear? The paper states "At catchment scale, the emergent behaviour of the groundwater system is the linear reservoir" and makes similar assertions in other places too (e.g. line 139). This key premise is qualitatively supported by Figure 1 with data from the Ourthe. However, is this premise really representative for most (/many) places?

From an empirical perspective, most studies that systematically characterized the groundwater contribution to streamflow do not find linear reservoir behavior in most catchments (e.g.: Brutsaert Nieber, 1977; Ye et al., 2014; Berghuijs et al., 2016).

From a theoretical perspective, we should also not expect the groundwater reservoir to behave linearly; several linear reservoirs assembled together will create a non-linear overall response. This can be shown using straightforward math and has been discussed in the context of hydrology by Harman et al. (2009), explaining how power law catchment-scale recessions arise from heterogeneous linear small-scale dynamics.

2. Is upscaling Darcy flow a logical choice in describing subsurface drainage networks? The paper suggests that (while difficult to observe) sub-surface drainage structures are largely preferential (e.g. "on hillslopes, individual preferential sub-surface flow channels have been observed in trenches, but complete networks are hard to observe without destroying the entire network.") To me this implies that upscaling Darcy flow is maybe not the right approach to describe flow processes, since the processes you describe the network to consist of are all preferential (instead of Darcy flow?).

3. Are areas far away from the stream contributing more to total groundwater flow reaching the streams? By assuming a constant resistance for the entire catchment, it implies that areas further away from the stream disproportionally contribute to

GW flow to stream? (since they will have a bigger head difference with the stream) Is this consistent with our perceptual model of catchments? and with tracer data-based studies?

4. Is resistance constant? Aquifer conductivities can vary by many orders of magnitude [Gleeson et al., 2011], even within an individual catchment [Ameli et al., 2016]. Is this consistent with what the assumption of constant resistance? Would this imply that aquifer conductivities are highest for the shortest flow paths? Is this something we observe in nature? It seems from Ameli that highest resistance is in deeper parts of the aquifer instead?

5. Is groundwater recharge vertical? The analysis assumes that GW recharge is vertical. In my interpretation, this assumption should also hold at other depths than the infiltration surface for the calculation to work? (call me out if I'm wrong here and stop reading this comment if that's the case. Otherwise, continue reading). However, is this realistic in most landscapes? In landscapes where horizontal flow path lengths are significant compared to vertical flow path lengths, this key assumption seems violated. A quick back of the envelope calculation of this seems to suggest that this assumption is violated in most landscapes? For example, when looking at Wang and Wu (2013) the average stream density for MOPEX catchments (approx. 1 km/km2?) implies that groundwater, on average, also travels kilometers deep (and up again) before contributing to streamflow? This seems unrealistic to me in most landscapes?

6. The paper talks about "residence time", but this term may confuse part of the community. In several parts of the paper, residence time is used to refer to the "characteristic time-scale of the linear reservoir". This is confusing because "residence time" in hydrology is commonly used to refer to the ages of water stored in a catchment (e.g. Rinaldo et al. 2011). Therefore, I recommend not to use "residence time" when you describe flow processes (instead of transport).

Overall, I really enjoyed reading the paper, and the above comments are intended

as my insignificant contribution to the "open a debate on how the linear drainage of groundwater from a hillslope can be connected to Darcy's law".

References

Ameli, A. A., J. J. McDonnell, and K. Bishop (2016), The exponential decline in saturated hydraulic conductivity with depth: A novel method for exploring its effect on water ïňĆow paths and transit time distribution, Hydrol. Processes, 30, 2438–2450.

Berghuijs, W. R., Hartmann, A., Woods, R. A. (2016). Streamflow sensitivity to water storage changes across Europe. Geophysical Research Letters, 43(5), 1980-1987.

Brutsaert, W., Nieber, J. L. (1977). Regionalized drought flow hydrographs from a mature glaciated plateau. Water Resources Research, 13(3), 637-643.

Gleeson, T., L. Smith, N. Moosdorf, J. Hartmann, H. H. Dürr, A. H. Manning, L. P. H. van Beek, and A. M. Jellinek (2011), Mapping permeability over the surface of the Earth, Geophys. Res. Lett., 38, L02401, doi:10.1029/2010GL045565.

Harman, C. J., Sivapalan, M., Kumar, P. (2009). Power law catchmentâĂŘscale recessions arising from heterogeneous linear smallâĂŘscale dynamics. Water Resources Research, 45(9).

Rinaldo, A., K. J. Beven, E. Bertuzzo, L. Nicotina, J. Davies, A. Fiori, D. Russo, and G. Botter (2011), Catchment travel time distributions and waterïňĆow in soils, Water Resour. Res., 47, W07537, doi:10.1029/2011WR010478.

Ye, S., Li, H. Y., Huang, M., Ali, M., Leng, G., Leung, L. R., ... Sivapalan, M. (2014). Regionalization of subsurface stormflow parameters of hydrologic models: Derivation from regional analysis of streamflow recession curves. Journal of hydrology, 519, 670-682.

Wang, D. and Wu, L.: Similarity of climate control on base flow and perennial stream density in the Budyko framework, Hydrol. Earth Syst. Sci., 17, 315-324, https://doi.org/10.5194/hess-17-315-2013, 2013.

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