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Discussions

Interactive comment on "**Aggregation effects on tritium-based mean transit times and young water fractions in spatially heterogeneous catchments and groundwater systems, and implications for past and future applications of tritium**" *by* M. K. Stewart et al.

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Dear colleagues,

I think most of what Jim Kirchner reproaches to my strident claim is due to our different perspectives. To a hydrogeologist like me, "many real-world situations" means "aquifers with exploitable yields" while a hydrologist such as Jim Kirchner may think of flashy catchments or maybe even of a hill slope.

This explains for instance why I prefer the exponential to the gamma model for certain applications, and why I take Luther and Haitjema's work very seriously.

There is indeed abundant evidence that the exponential TTD does not fit the spectral signature of conservative tracers in many catchments, while the gamma distribution does. As far as I know, however, all studies showing this were catchment studies. I have never yet read an article where the spectral signature of the tracer signal of a permeable aquifer (and not of a whole catchment) has been studied. Since a number of papers (not just Luther and Haitjema, but also Haitjema 1995, or Etcheverry, 2001) come to the conclusion that the exponential model describes exactly the transit time distribution of piecewise homogeneous aquifers, one cannot dismiss it as lacking scientific evidence.

Jim Kirchner's objection that confined aquifers should not allow vertical recharge, and that such an assumption clearly demonstrates the lack of realism of Luther and Haitjema's paper, can be answered very simply. In fact, Luther and Haitjema modelled a semi-confined (also referred to as leaky) aquifer, which is an aquifer bounded at the top and the bottom by aquitards, aquitards being geological units permeable enough to transmit water vertically in significant quantities over large areas and long periods. Such semi-confined formations are quite common all around the world and known to all hydrogeologists . As an example, here's a citation from South Africa's Water and Sanitation Department: "Most aquifers in South Africa are semi-confined or semi-unconfined in character" (https://www.dwa.gov.za/Groundwater/Groundwater_Dictionary/index.html?introduction_semi_confined_aquifer.htm). Furthermore, for permeable aquifers that are not topography controlled (and they are far from being a rarity, including in published groundwater dating studies. But they are not the type of catchments hydrologists are studying), the range of variation in transmissivity or porosity adopted by Luther and Haitjema is quite typical, and the lack of spatial correlation for transmissivity or porosity not uncommon either at the scale of pumping tests (see for instance Krasny, 1993).

These technical issues aside, I wish to stress that my comment was not an attack, but a criticism, which together with the possibility offered to anyone to respond to it and disagree or modify it, seems to me the very stuff of scientific peer review. A discussion over the phone instead of this public debate might have been just as profitable to Jim Kirchner and me, but would have excluded other potentially interested colleagues (probably very few) as well as the authors of the manuscript under review.

I find Jim Kirchner's efforts to assess the effect of heterogeneities on the calibration of lumped parameter models extremely interesting and useful, and I was not in the least criticizing him for asking that question, nor was I suggesting we should not care about it and smugly assume homogeneity everywhere. What I was pointing out is this: since the MTTs as the toy model's parameters ("toy model" was never meant to be derogatory, by the way. It is a very standard term in physics) cannot be constrained by experience or observation, one is forced to adopt a conservative stance and use a large range. This is fine, but it is nonetheless a problematic flaw, because unless one is careful in interpreting the results, it leads to a radical rejection of methods that are most probably fine in particular but important cases. Such a particular case for tritium-based estimations has now been explored by Stewart et al.. So we are making progress thanks to that toy model, and progress also means being aware of the limitations of whatever tool one uses, and encouraging others to test it further. To put it concisely, one should be careful neither to claim that heterogeneities do not matter, nor come to the conclusion that they have has such weight that lumped parameter models are fundamentally unreliable. Empirical evidence may one day allow such a radical rejection, but I do not think that Jim Kirchner's conceptual model actually does that, given that the range of MTTs assumed for the subcatchments is for now completely unconstrained. So here is my question again: "what degree of heterogeneity, and hence how large a difference in subcatchments' MTTs can usually be expected in real world catchments ?" As long as this question cannot be answered , even approximately, the toy model will be an interesting thought provoking tool, but hardly one that can lead to radical conclusions concerning the reliability of lumped parameter models. And I find Stewart

et al.'s answer, as praiseworthy an attempt as it is, insufficient in that regard.

Finally, I do not see how the question as "whether the toy model adopted is appropriate at all to study the effect of heterogeneities on the transit time distribution and hence on the estimates of the mean transit time" is a "misrepresentation" of Jim Kirchner's analysis. We simply do not agree, which is altogether different. It is perfectly clear that only the estimation of the catchment's MTT was of interest in his article. I think this is a methodological mistake and that one should have a good look at the different shapes of the synthetic TTDs and compare them to the best fit from lumped parameter models calibrated on the catchment's output signal. This is why is agree with Stewart et al. when they suggest the use of compound lumped parameter models, since this shifts the emphasis back to the shape of the TTD and away from the MTT as characteristic measure of a catchment's mean transit time.

Best regards,

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