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Hydrology and Earth System Sciences
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 authors, dear editor,

The study by Stewart et al. is very thorough in that it tries to estimate the "aggregation error" systematically for different parameterisations of the gamma model. I feel however that it misses a central question (also ignored in Kirchner's paper where the method was first presented), which is whether the toy model adopted is appropriate at

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all to study the effects of heterogeneities on the transit time distribution and hence on the estimates of the mean transit time. I think the question is not as trivial as it seems (and might actually be quite important for the future development of water dating). The relationships between mean transit time and tritium activity shown on Figure 3 clearly display approximately linear segments over which the mixture of water coming in equal volume from two different subcatchments would lead to a negligible underestimation of the true MTT (for instance, on figure 3d for MTTs between 0 and 20 years). Only by assuming heterogeneities so massive as to lead to MTT subcatchments differing by 200 years (!) does one observe equally enormous underestimations of the true MTT. This observation however begs the question: what degree of heterogeneity, and hence how large a difference in subcatchments' MTTs can usually be expected in real world catchments ? While Kirchner only mentions in passing a factor 2 as characteristic for "true heterogeneity" without further elaboration, Stewart et al. provide a much more detailed analysis in paragraph 4.2, where they conclude that "aggregation error" was probably small in most published studies because the estimated MTTs mostly lie between one and two decades (a window which Stewart et al. determined to be nearly "aggregation error" free). Their conclusion however rests on estimates of headwater catchments and surface waters where tritium was sampled, which does not really give any idea of MTTs' variations and range in smaller subcatchments and subcatchment's subcatchment (and subcatchments' subcatchment's subcatchment and so on...). Another way to look at this question is this. One could be tempted to answer that since we do not know how to quantify the degree of heterogeneity, it could be anything, and consequently assuming a large difference is conservative. I am concerned however that too much conservativeness leads to confusing or over cautious results, but additionally, there IS (at least) one study that addressed this question mechanistically for a number of case in an heterogeneous aquifer, namely that of Luther and Haitjema in Journal of Hydrology (1998). The authors show that in many cases ("stratified, unstratified, confined or unconfined [aquifers]"), the simple exponential distribution (i.e. a special case of the gamme function with the alpha term being equal to 1) is a good

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approximation of the transit time distribution (TTD) of heterogeneous catchments as long as heterogeneity is “not significant and distinct” (which would obviously be the case if the resulting MTTs are respectively 1 year and 200 years as in Stewart et al.). The strength of Luther and Haitjema’s approach lies in its clear definition of heterogeneity, as it can readily be related to measurable field variables (porosity, recharge rate and hydraulic conductivity). By contrast, the conceptual model used by Kirchner and adopted by Stewart et al. offers a simple and attractive way to study the effect of mixing subcatchments’ contribution, but simultaneously, by forsaking flow equations, it excludes measurable physical quantities from the entire analysis. Of course, Luther and Haitjema’s work only pertains to groundwater systems, and one can suppose that for catchments where the contribution from surface runoff and interflow is sufficiently large compared to baseflow, the mixture of water from these different reservoirs with possibly “significant and distinct” differences in MTTs (says a couple of months for the interflow and 50 years for baseflow) will lead to a transit time distribution that sufficiently deviates from a gamma function to affect the results of the inverse modelling (i.e. the estimation of the MTT). This difference should be made clearly so as to avoid all possible confusion:

-For groundwater systems, the results of Luther and Haitjema show that the “homogeneous assumption” holds in many real-world situations. Thus, Kirchner’s conclusion that “MTT’s estimated from seasonal tracer cycles are fundamentally unreliable” is too broad and must be corrected urgently.

-For catchments where streamflow is not only sustained by baseflow (or in other cases I cannot think of), one can expect a TTD significantly different from an exponential or general gamma model due to the contribution from reservoirs characterised by largely different MTTs. But in that later case, the use of compound LPMs can help to reduce deviation by conceptually catering for it (this is a VERY important point made by Stewart et al.).

To conclude, I think the work by Luther and Haitjema should be cited prominently since

it is a serious physically-based alternative to the toy model proposed by Kirchner, while the serious weakness of Kirchner's model (its inability to relate the degree of "heterogeneity" to measurable field variables) should be emphasized as well, especialy since it leads to conclusions that are too broad and conservative concerning the robustness of simple lumped parameter models used in heterogeneous catchments.

Additional comments

-Figure 1: As far as I know, the time series of tritium in precipitation only starts in 1978 for the station Trier. Unless I am mistaken, data prior to that year have been calculated from regression, probably using the station Vienna. If that's indeed the case, it should be stated.

-Some figures have obviously been made using excel. I know they are just figures, but shouldn't excel be banned from scientific publishing altogether ?

Best regards, Julien Farlin

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