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Discussions

Interactive comment on "Analyses of uncertainties and scaling of groundwater level fluctuations" *by* X. Liang and Y.-K. Zhang

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Response to Anonymous Referee 1's comments on "Analyses of Uncertainties and Scaling of Groundwater Level Fluctuations"

General comments: This paper deals with uncertainties in groundwater level in unconfined aquifers due to temporal variations of hydrological processes. It derives the head covariance function for 1-D transient flow in a bounded unconfined aquifer with random recharge as well as random initial and boundary conditions. Associated time-dependent spectral densities are also derived, allowing to investigate the existence of temporal scaling of groundwater level fluctuations. The topic of the note lies within the aims and scope of Hydrology and Earth System Sciences and is a valuable addition to

the existing literature. The paper is well-written and concise, and deals with a topic of considerable interest. The mathematical derivations are accurate.

Response: Thank you for the reviewer's positive comment on our study.

Specific comments: Specific suggestions to improve the quality of the paper are listed below.

1. The authors should mention specific applications of their results to real cases, to help the paper convey a take-home message.

Response: This is an excellent comment. The analytical solutions for the head variances derived in this study provide a way to quantify the uncertainty in the groundwater levels calculated with analytical and numerical solutions with uncertain recharge, source/sink, and boundary conditions. The spectrum relationship among the head, recharge and boundary conditions obtained in this study can help one to improve spectrum analysis for a groundwater level time series and to remove the erects of boundary conditions. Specific applications of the results obtained in this study are to help one to identify and quantify the sources of uncertainties in the system he/she studied. We added these in lines 375-379 of the revised manuscript.

2. I suggest to add a schematic of the system investigated for the sake of clarity. This will help clarifying the meaning of the quantity M, defined at line 152 as the average saturated thickness of the aquifer. Since h is random, M should incorporate an element of randomness.

Response: As suggested by the reviewer, we added a schematic of the system studied, i.e., the new Figure 1 in the revised manuscript. Please note that it is assumed in this study that the fluctuation of the head is relatively small as compared to the aquifer thickness and the unconfined flow equation was linearized and thus the average saturated thickness of the aquifer (M) was assumed to be constant.

3. A key assumption in the analysis is that W(t), Q(t), and H(t) are uncorrelated (see

line 137). Given the geometrical setup, this assumption is not warranted. The paper could benefit from discussing this issue, and, specifically, realistic conditions for the validity of the assumption.

Response: This is again an excellent comment. In general, W(t), Q(t), and H(t) should be correlated. It is possible to consider the relationship among W(t), Q(t), and H(t) by assuming some theoretical correlation functions but the problem is that 1) it is unclear what kind of correlation exists among these variable, 2) there is little observed or measured data to support any type of the correlation assumed, and 3) simple analytical solutions would be difficulty to derive when considering such a correlation. Therefore, we studied the case in which such correlation is weak or no correlation in order to derive some simple analytical solutions. We believe this is an important first step towards solving this complex problem and more research in needed in this direction, especially about the correlation among the recharge, flux, and boundary conditions. We hope to relax this assumption in our future study.

4. (a) Temporal scaling of groundwater level fluctuations is shown to exist at intermediate and late times, and to be dominated by the effect of random recharge as opposed to that of random boundary conditions. Why? Is this valid only for the specific parameters examined? (b) When spectra associated with one random effect at a time are examined, different scalings (1/f, 1/fËĘ2) are found. Why does this happen?

Response: a) We think the reason that the temporal scaling of groundwater level is dominated by the random recharge is that the areal recharge occurs over entire the aquifer and thus affect the groundwater level everywhere in the aquifer while the boundary conditions affect a relatively small area near the boundaries in most aquifers. The specific parameters used in this study are typical for a real aquifer. The effect of the boundary conditions or the area of the influence by the boundary conditions would be enhanced in a more permeable aquifer. However, in most aquifers areal recharge should be the dominating force affecting groundwater level fluctuations and its scaling. b) We do not totally understand this comment. That the groundwater level fluctuates

as a 1/f noise only at x'=0 under the random flux boundary, and it fluctuates as a 1/f2 noise at most locations only under random recharge when the characteristic time scale (tc) is large, i.e., tc > 400 days .

Minor points: 1. Check keywords.

Response: We revised the keywords as: Uncertainty of groundwater levels; Temporal scaling; Random source/sink; Random initial and boundary conditions.

2. Check line 75.

Response: We checked but didn't find any problem in this line.

3. Check equation (12).

Response: We checked the Eq. (12) in our original submission (now is Eq. 11 in the revision) and didn't find any error. However, there are two typos in Eq. (8) and (9): one is that the Eqs. (8) and (9) are actually one equation, and the other is in the first term on the right hand of the equation. We corrected these typos. The correct Eq. (8) was given in the revision.

4. Check Line 173, 'is' is missing.

Response: We added it.

5. Line 175, in 'decay' a 's' is missing.

Response: We added it.

6. Line 204, check if 'the' is missing.

Response: We added "the " before "most aquifers".

7. Line 223, check if 'on' is missing.

Response: We deleted this sentence based on Reviewer 2's comments.

8. Check the sentence at lines 346-347.

Response: We added ‘s’ after ‘curve’ and ‘location’, respectively.

Please also note the supplement to this comment:
http://www.hydrol-earth-syst-sci-discuss.net/12/C1597/2015/hessd-12-C1597-2015-supplement.pdf

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Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 12, 1, 2015.