Hydrol. Earth Syst. Sci. Discuss., 11, C274–C278, 2014
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Hydrology and Earth System Sciences Discussions

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HESSD

11, C274–C278, 2014

Interactive Comment

Interactive comment on "Is the groundwater reservoir linear? A mathematical analysis of two limiting cases" *by* G. H. de Rooij

Anonymous Referee #2

Received and published: 4 March 2014

The author discusses whether the outflow from a confined aquifer in one-dimensional flow can be written as Q_out = C * (H_avg – H_stream) where C is the conductance between the average head in the aquifer and the head in the stream. If this would be the case, the outflow from the aquifer may be simulated with a linear reservoir. The analysis is apparently motivated because Fenicia et al. (2006) reported that they found that the groundwater reservoir in their conceptual catchment models could be simulated accurately with a linear reservoir for several cases (with one notable exception).

The author bases his analysis on analytic solutions for one-dimensional flow in homogeneous confined aquifers that he published in WRR in 2013. In that paper he found that the conductance C (which he calls, confusingly, the upscaled hydraulic conductivity) is a function of time. Only for large time (when boundary conditions remain

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Interactive Discussion

Discussion Paper

constant) does the conductance become a constant.

I don't understand what the contribution of this paper is. No new equations are presented (they all appear in other papers, many in the 2013 WRR paper of the author). Both conclusions of the paper follow directly from the author's 2013 WRR paper. They are mentioned, although not as explicitly, in that same paper. A brief summary of the WRR paper (without copying all the formulas) and explicit statement of the conclusions could be presented in a one-page paper.

In conclusion, I don't see the contribution of this paper and cannot recommend it for publication.

Detailed comments are provided below:

Abstract. Why is it interesting that the storage-discharge relationship can be described with a linear reservoir 'when forcings remain constant for a sufficiently long time' (p.84, line 9-10). Repeated again on line 16: 'they behave non-linearly up to several weeks after a change in recharge'. Does this mean the approach is only applicable where recharge events are at least a few weeks to months apart? What parts of the world would that be? 'The characteristic time ... depends on whether ... the aquifer is leaky and recharge is non-zero' (p.84, line 12-13). I think the author means that the equation for the characteristic time is different for the case of a leaky aquifer or non-zero discharge. The characteristic time itself is not a function of these variables. 'It is concluded ... recharge' (p.84, line 13-16). Seems a repetition of what is said in lines (p.84, 8-11). The final finding (p.84, lines 17-20) is an explanation of what goes wrong when a catchment model simulates the groundwater reservoir as a linear reservoir: the model tries to correct for this incorrect representation of the groundwater reservoir. This is not a new finding: if a process in a model is implemented incorrectly, the other processes try to correct for this.

Section 1. The author states that his analysis concerns horizontal aquifers (line 26, p.85). This should be reflected in the title of the paper.

Section 2. The author presents equations in terms of ‘hydraulic potential H’ (starting p.86, line 8). It is never defined what that is. In the papers the author refers to (De Rooij 2012, 2013), H is hydraulic head. Please use that common terminology. Section 2 is a repeat of the author’s 2013 paper in WRR. All presented equations appear in that paper. Besides, I object to the terminology ‘aquifer-scale hydraulic conductivity’ for k_up. I realize that the author used this term in his 2013 WRR paper, but it is simply not correct. A hydraulic conductivity is defined to give the discharge per unit area when multiplied with (minus) the head gradient. What the author does is, he multiplies k_up with a head difference given a discharge per unit length: Q = k_up * (H-H_A). That is fundamentally different. The proper term is ‘conductance’ when Q is a discharge or ‘conductance per unit length’ when Q is a discharge per unit length. Furthermore, Fig. 1 doesn’t show an aquifer bounded by a no-flow boundary on one side and a stream on the other side (p.88, line.7). All the author needs to present is Eq. 2 as his approximation of how the system works.

Section 3. No new information is presented in Section 3 either. Eq. 5 is the dimensional form of the dimensionless equation 3 in the author’s 2013 WRR paper. What bothers me is that the author states that ‘the thickness of the saturated zone drops to zero’ (p.89, line 10) when the surface water level is at the aquifer bottom. This is obviously not true. When the surface water level is at the aquifer bottom, water can still leave the aquifer through the seepage face. What surprises me even further is that the author continues to set the saturated thickness of the aquifer equal to a constant value D (line 4, p.90) (incidentally, the statement H(x)=D is not correct – the saturated thickness is equal to D, not H(x)) and continues his discussion with a constant aquifer thickness. Why then does the author still consider the case where the surface water level is at the aquifer base? Setting the saturated thickness to D is obviously not reasonable for that case.

Section 4 starts with a recap of the results of the famous Brutsaert and Nieber (1977) paper (all equations up to p.92, line 5, are from that paper). The author ends by concluding that the solution for zero aquifer thickness at the outlet never behaves like a linear reservoir. Then the author shifts to his own results and repeats the results of his 2013 WRR paper (Eqs. 12 – 18 all appear in that paper). The author starts talking about 'characteristic time', but never really explains what is 'characteristic' about it.

Setion 5. p.96, line 1-3. Here, the author talks about the 'non-linearity that arose in the analysis of Fenicia et al. (2006)', while he started by saying that the reservoirs in Fenicia et al.'s analysis 'trended toward linear behavior' (p.85, line 20). This confuses me. What is the author trying to show?

Section 6, first line: 'In the above it has been established that aquifers of constant thickness can behave like linear reservoirs if the recharge and surface water level are constant for a sufficiently long time'. This was already concluded by the author in his 2013 WRR paper.

Continuing to the Conclusions (Section 7). The author starts by drawing conclusions about 'strongly curved phreatic level', but the author never analyzed such aquifers – he discussed solutions where the saturated thickness was constant. Only the final conclusion is somewhat precise: the groundwater reservoir behaves like a linear reservoir (my interpretation) when slopes are small (the author showed it for zero), aquifer thickness is constant, surface water level is constant for 2 characteristic times and recharge for 8 (p.100, line12-15). The characteristic times include the distance L, which raises the question what L is in a real (2D or 3D) aquifer, where streams are not parallel. This conclusion could be drawn from the author's 2013 WRR paper in a one-page description. The second paragraph of the Conclusions incudes a warning on the use of K_up as K_up is a function of the leakage. The final paragraph talks about the implications of the findings for the conceptual models of Fenicia, but it is only concluded that when a linear reservoir is used while that is not appropriate, other model components will try to substitute the correct behavior. This is not shown in the paper but may logically be expected for any model where the wrong process is modeled.

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