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Discussions

Interactive comment on "Theory of the generalized chloride mass balance method for recharge estimation in groundwater basins characterised by point and diffuse recharge" *by* N. Somaratne and K. R. J. Smettem

Anonymous Referee #1

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The manuscript by Somaratne and Smettem attempts to develop a new approach to Cl interpretation from groundwater, and aims to discredit the current use of this method, stating that recharge is under-estimated by factors up to 7 for systems in South Australia. The research follows closely from a recent HESSD submission - Somaratne et al. - which received a largely negative response from referees.

The response from the authors to my first round of review comments was verbose and did not address the basic issues of the manuscript. Hence, I provide here additional

comments, given that most of the previous ones were refuted or not properly dealt with. In the interests of providing clarity for readers and the authors, only the most fundamental errors in the manuscript are identified, with a scope to writing in the clearest possible manner:

1. The background literature on the topic of the paper is misrepresented. It is not the case that previous authors discount saturated zone CMB where preferential flow occurs. Only the authors' prior discredited HESSD manuscript attempts this. It is unsaturated zone CMB that does not apply where unsaturated zone preferential flow occurs. The authors use one method to undermine a different one.

2. The investigation assumes that there is no mixing in either the unsaturated zone or the saturated zone, between preferential flow and diffuse flow. This assumption must be acknowledged. Regardless, it is entirely indefensible to consider this a valid assumption for all systems with preferential flow, because despite unsaturated zone preferential flow, there may be saturated zone mixing of waters originating from diffuse and bypass flows. The no-mixing assumption is most certainly not applicable to Uley South (calcrete capping underlain by sand). The relatively small variations in Cl from dozens of sample sites across this aquifer are testament to that.

3. Equation 10 is in direct contradiction to the conceptual model. Equation 10's Cg is clearly the mixed groundwater Cl concentration, whereas Figure 5 (and much of the case study descriptions) refer to distinct and separate high Cl-low Cl water bodies ("bubbles") that somehow defy dispersion processes. Which case is it - mixing or no mixing in the groundwater?

4. Eq 10 is wrong. A "flow across the watertable" would need inflows of RuCu + QpCs, and groundwater outflows of (Ru+Qp)Cg. This is not withstanding the lack of lateral groundwater flows here, which is equally problematic for the analysis. There is simply no way that the different water inflows at a point are somehow able to remain isolated as they discharge below the watertable.

5. There is considerable confusion expressed by the authors regarding equation 10. For example, “initial” and “at the end of delta-t” don’t apply to a steady-state analysis. They are trying to do a mass balance across a plane (the watertable), and hence the LHS derivative term has no meaning, because a plane has no volume. That is, Cgd = Cu, and the RHS is obviously zero, which one would expect. The inference from equation 10 is that diffuse and point recharge crossing the watertable are somehow able to remain immiscible, and remain in the aquifer with their unsaturated zone concentrations. This is entirely non-physical.

6. Regardless of point 5. above, equation 10 is not needed to continue through the authors’ mathematics. Equation 11 is simply PCp+D = RuCgd + QpCs (Equation R1) and does not require Eq. 10 as suggested. Hence, despite what the authors say, there is no groundwater mass balance included in their investigation. It is misleading to suggest this. To obtain Eq. 11, they simply drop the Qo term from eq. 9.

7. Following from this, equation R1 above is rearranged to Ru=(PCp+D – QpCs)/Cgd (Equation R2), which requires that the Cgd or Cu (which are the same) be known – i.e. that the Cl in the unsaturated zone immediately above the watertable is characterised. Hence, the once-simply and elegant saturated-zone CMB method now requires unsaturated zone measurements, not to mention some estimate of Qp (point recharge). Equation 13c is then simply the RHS of equation R2 plus Qp.

8. The approximation to produce eq. 13d from eq. 13c is both unnecessary and has important implications. It assumes that all the Cl load to the aquifer occurs via diffuse flow, despite preferential flow occurring. That is, it is eliminating the QpCs term from the mass balance RuCgd = PCp+D – QpCs. Note that, despite what is suggested by the authors, eq. 13d and eq. 3 are not the same, because firstly eq. 3 is a water balance and eq. 13d is a salt balance, but also one would assume that an extension to eq. 3 would involve properly diverting salt into its constituent pathways. Dropping QpCs from the mass balance will have only small implications in some cases only.

9. Notwithstanding the problems with the theoretical development and the conceptual model, plus the misrepresentation of previous literature, arguably the most important errors are introduced into the manuscript by the manner of applying equation 13d. The problem here is two-fold. Firstly, runoff Cl is not known - it is likely higher than rainfall Cl. Secondly, Somaratne et al. do not know Cgd - especially for Uley South, but probably this is almost impossible or prohibitively expensive to properly characterise in most systems. The average of monitoring wells near the inland boundary is certainly not adequate. For the case of Uley South, limestone aquifers occur to the north of the inland boundary, across which there is inflow from these. Hence, the Cgd used by Somaratne and Smettem is a value that reflects preferential and diffuse flows into other aquifers, and in no way will reflect diffuse flow only. By using this lower value, they are grossly over-estimating "diffuse recharge" - by their definition of this process.

10. In no way should gross basin-scale runoff estimates, intended for other applications, be used to calculate Qp. The southeast of South Australia is littered with wetlands that are underlain by clay, and serve to contain runoff much of which eventually evaporates. Even the layered nature of Uley South sediments will act to retain, mix and diffuse runoff infiltration.

11. Combining the over-estimate of diffuse recharge, and the over-estimate of preferential recharge (i.e. making the assumption that all runoff becomes recharge and neglecting any surface retention, unsaturated zone perching, the evaporation of smaller rainfall events, etc), can only lead to the highest possible estimate of recharge by the authors, at least for the Uley South case. Whereas other authors prefer to offer plausible ranges, using various methods, the current paper is producing an upper bound and a single value. The biased nature of this research cannot be under-stated. It is especially worrying that the research described here might influence management practices, to the commercial benefit (at least in the short term; notwithstanding the collapse of other basins on the Eyre Peninsula due to over-estimation of recharge and over-extraction) of the lead author’s organisation.

12. It is worth considering some additional evidence in regards to the basic claim by the authors that Uley South recharge ought to be doubled. Uley South has been pumped at rates between about 4 and 7 GL/yr in the recent decade or so. Across the area of the basin (113 km2), this is the same as 35 to 62 mm/year of outflow. Despite claims to the contrary, the groundwater storage has most certainly declined (from 1970s to early 2000's - see attached figure from an honours thesis by D. Alcoe showing the average watertable response from several observation wells), then stabilised, and then shown signs of recovery (after 2010), and these stages correspond to periods of higher pumping and then reduced pumping. At its lowest, the water levels in Uley South were marginally higher near the coast to density-corrected sea level, and hence if we consider that discharge to the sea at that time was perhaps small, it seems unreasonable to accept a recharge estimate of 120 mm/year (i.e. twice the high-pumping rate during a period of watertable decline) across the basin, in this semi-arid environment and considering the significant proportion of this uninhabited basin that is thick with vegetation cover. It simply doesn't add up. We can at least infer that recharge has exceeded the lower pumping rate of 35 mm/year, given evidence of watertable recovery.

13. The ability to correctly apply this method is essentially precluded by the need for separate preferential flow (from the total recharge) and a characterisation of lower unsaturated zone Cl concentrations. This is complexifying the CMB (saturated zone) approach, which otherwise integrates catchment processes. Ultimately, any groundwater Cl concentration is likely to represent the historical recharge of a particular sample, and adding runoff to recharge that is derived from a groundwater Cl value is simply violating mass balance and creating water.

14. I wish to thank the authors for their suggestion to contact Dr Werner at Flinders University. This produced a significant number of useful documents and references, which informed significantly the current review.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 11, 307, 2014.

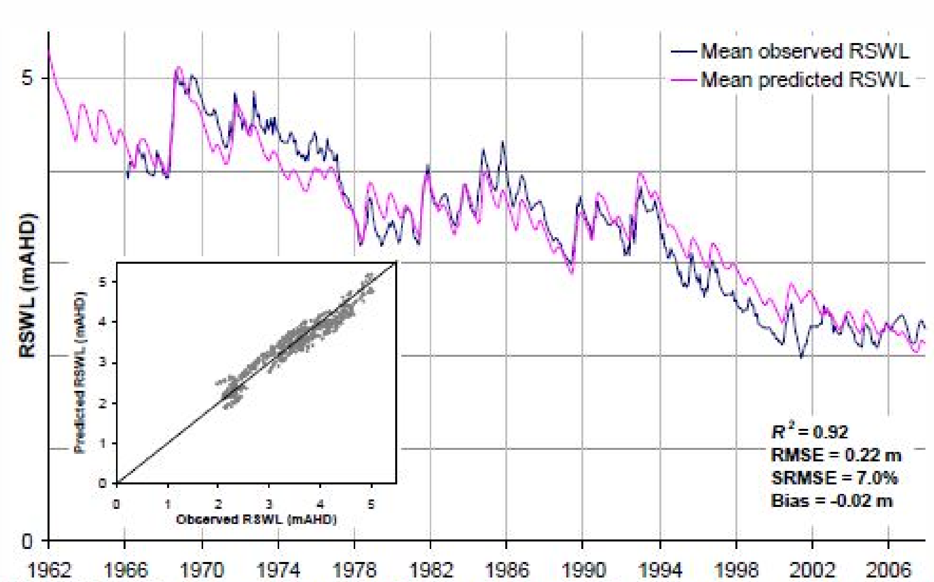

Figure 4.2. Calibration curve, constructed using mean predicted and mean observed groundwater levels (ULE099; ULE101; ULE102; ULE114; ULE134; ULE145). ***Inset*****: Scatter plot of mean observed and mean predicted groundwater level data. Individual calibration curves for each well are shown in Appendix C.**

Fig. 1.