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Hydrology and Earth System Sciences Discussions

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Interactive Comment

Interactive comment on "Quantifying water and salt fluxes in a lowland polder catchment dominated by boil seepage: a probabilistic end-member mixing approach" *by* P. G. B. de Louw et al.

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Reply to comments of referee #2:

We thank referee #2 for the constructive comments. Below we respond to each of the comments raised by the referee.

GENERAL COMMENTS Generally, the idea to apply a probabilistic end-member mixing approach to quantify water and salt fluxes in the study catchment is interesting.

The finding that preferential seepage via boils is the main salinization pathway in this particular environment is of high importance and has direct practical implications. The conducted scenario analysis adds further value to the paper. However, given the complexity of the system (unique environment, large number of model parameters), the appropriateness of the applied methodology/ chosen model needs to be demonstrated in more detail to support the drawn conclusions.

Reply: According to the suggestions of the referee, we will describe in the revised version the applied methodology in more detail following the specific comments given by the referee below. En general this means that the measurements and their uncertainty (e.g. chloride concentration of the seepage types / end members) and the different choices of the EMMA and GLUE method (e.g. prior parameter ranges) are described in more detail in the revised paper.

SPECIFIC COMMENTS 1: The probabilistic end-member mixing approach heavily relies on adequate measurements of the end members. In this respect there are some questions/ remarks:

Comment 1a) One main outcome is that preferential seepage via boils is the main salinization pathway. At the same time boil flux and concentration were found to be the most sensitive parameters (page 171). The authors conducted a parameter sensitivity analysis to determine for which parameter the quality of field measurements should be improved. Given the importance of boil flux and concentration a better assessment of boil seepage in the field would have been desirable. The location of 48 boils is presented in Fig. 2 – so the boil locations are known (?!). Was there no possibility to measure boil flux/concentration for few example boils to get a better picture? This would have helped to validate the EMMA approach since the model is then used for a scenario analysis.

Reply: We agree that, given the dominance of boil seepage in the salinization of surface water, it would be desirable to have a better field assessment of the total flux of

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this preferentially seepage form. However, the number of boils is unknown and it is an impossible task to map them all (see also reply to comments of Vandenbohede, P155). This uncertainty in the number boils, their flux and their concentrations is in fact one of the reasons we applied a combination of GLUE and EMMA (see introduction P153 L28 – P154 L15).

The following illustrates the difficulty of assessing the boil flux from field data. As boils are rather small, concentrated and mainly underwater phenomena, they are hard to find. In fact every ditch should be inspected to find all boils. With a total length of more than 400 km of ditches and watercourses this is an enormous task which we couldn't carry out within (the boundaries of) our research. Besides this, boils in the larger and deeper canals can not be seen directly and other methods should be applied to map them. We are sure that we only mapped a small part of the boils in the polder. Within the available time and budget, we were able to map 49 boils from which we determined their chloride concentration. This is described in more detail in our previous work (De Louw et al., 2010). The 49 chloride concentration measurements give us an idea about the chloride concentration of this end member within certain ranges. At 15 boils were we able to measure the boil flux, which varied between 0.5 and 100 m3/d (see De Louw et al., 2010). Although this gives us a better picture about individual boil fluxes and the variation between boils, the total number of boils is unknown and therefore also the total boil flux in the polder. A better assessment of boil fluxes is possible but takes a lot of field work. We are currently experimenting with different mapping techniques (air borne thermal infra-red, temperature and conductivity measurements of surface water, temperature measurements with DTS fiber optic cable) to improve the boil mapping.

In the revised paper, we will describe in more detail the uncertainty of the boil flux and salinity and the measurements we have performed to estimate their concentration and discharge.

Comment 1a: Considering boil concentration measurements once over the two years – how about representativity over longer time scales?

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Reply: This is a very interesting question and one of our research questions we are still busy with. As boil seepage water comes from below the confining layer (deeper than 7 meter) the seasonal variation is negligible (see also reply to comments of Vandenbohede, P155). This is confirmed by our current measurements where we measure boil salinity of 3 boils continuously for a period of 2 years now. Therefore we assumed a constant concentration of boil seepage for the 2 years of water and salt flux observations and simulations in our EMMA model. How boil salinity will develop over longer timescale, lets say 50 to 100 years, is not known at this moment. Numerical groundwater model calculations show that for the Dutch deep polders the salinity of diffuse seepage will increase due to the process called autonomous salinization (= the increase of seepage salinity by the upward flow of deeper and more saline groundwater) (Oude Essink et al., 2011: Effects of climate change on coastal groundwater systems: A modeling study in the Netherlands. Water Resources Research, 46, W00F04, 2010.). The increase of boil salinity by autonomous salinization is less likely to occur or at least will the increase be less because boils are already abstracting groundwater from larger depth (30-40 m).

Comment 1b): 150 small inlets of "boezem" water (according to Table 1) are controlled by farmers (as stated on page 165). Is there information available about the management of these small inlets? Since the sensitivity analysis later shows that admission of "boezem" water in summer and winter are sensitive parameters (page 168 and Table 5) - is this something that should be considered in the model?

Reply: There is some information available about the management of the small inlets. Some farmers leave them open (day and night) during the summer and some farmers only open them when they need water during dry periods. Most farmers close the inlets during the winter when no additional water is needed. Based on this information (and about the management of inlets by the Water Board), we made a distinction in our model between admission in winter and in summer. To improve the reliability of the model calculations, it is useful and not too difficult to collect more data about the management and quantities of the admission of 'boezem' water as we described in our recommendations for the water management of the polder section 3.3 (P169 L1-5).

Comment 1c): Many measurements are point measurements in time: Is the sampling frequency adequate? How about diurnal variation? Are the measurements always taken at the same time? It would be nice to have a pre-analysis of representativeness of point measurements for continuous time series.

Reply: We think that the sampling frequency was adequate to simulate the dynamic water and salt fluxes out of the polder and to quantify the sources. The most dynamic water fluxes are polder water discharge (measured by total pumping times at the two pumping stations = cumulative flux), precipitation (2 locations, also cumulative) and evapotranspiration which we calculated by the Makkink formula (gives a daily value). From the cumulative measured polder water discharge and cumulative precipitation, we derived daily values (midnight to midnight). Discharge weighted concentration of the pumping water and salt loads pumped out of the polder were measured every 3 to 7 days. (The pumping water was sampled automatically with a frequency proportional to the discharge. The samples were mixed automatically into one bulk sample and collected every 3-7 days; they were analyzed in the laboratory for their chloride content). Because we measured cumulative discharges and discharge weighted loads, diurnal cycles in concentration or discharge would not affect the outcome of our analyses. In the monitoring section 2.2 we will add more detailed information about the high frequency measurements of these dynamic fluxes.

Comment 1d): For clarity – there are 12 clusters of monitoring wells with 4 groundwater wells each and one upper aquifer hydraulic head measurement?

Reply: There are 14 clusters of monitoring wells with 2 to 4 groundwater wells each and one upper aquifer hydraulic measurement (see Fig. 2). This text will be added in the revised paper (section 2.2).

Comment 1e): How exactly is the chloride concentration of boils, paleochannel seepage, and diffuse seepage measured?

Reply: Because it is indeed difficult to measure these concentrations, this is one of the reasons to incorporate the uncertainty of end-members concentrations in the EMMA by applying GLUE. We measured the chloride concentrations at 49 boils which gives us an idea about the variation of boil salinity (Table 1). The chloride concentration of diffuse seepage is determined from 11 piezometers in the upper aquifer (see for location fig. 2) and varies between 33 and 281 mg/l. The chloride concentration of paleochannel seepage is the most uncertain of the three seepage types since we have only three locations where we measured the groundwater in the upper aquifer (varying between 438 and 675 mg/l). In our previous work (De Louw et al., 2010) we described the determination of the chloride concentration of the three seepage types in detail. However, we agree that this information is important and missing in the current paper and therefore we will add a brief summary of this in the revised paper.

Comment 2): The GLUE method is an essential part of the study's approach. To assess whether the conclusions drawn from the analysis are valid the methodology has to be clear and easy to follow. There are several assumptions and subjective decisions within the applied GLUE method that are not well described in the present manuscript. The steps in the GLUE procedure that require subjective decisions have to be elaborated in detail. Moreover, terminology that is different from the standard GLUE method should be clarified.

Reply: Following the suggestions of the referee, we will describe the GLUE method (our assumptions and subjective decisions) clearer and in more detail.

Comment 2a): How were the cut-off criteria for behavioural parameter sets (Table 3) determined? Why these threshold?

Reply: We set the cut-off criteria by trial and error to fit most of our observations between the modelled uncertainty ranges and to keep these ranges as small as possible (see P163 L10-11). This is a rather subjective choice (which we tried to make as ob-

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jective as possible) and one of the disadvantages of the GLUE method.

Comment 2b): Why do you choose two different parameter ranges for the uncertainty and the sensitivity analysis?

Reply: For the simulation of the water and salt fluxes and quantification of the salt sources, we used (smaller) ranges based on our measurements to keep the model input and output uncertainty as small as possible. For the sensitivity analysis we are interested in the sensitivity of the parameters within the full range of plausible values for the water system under consideration. The use of 2 different prior parameter ranges gives also the opportunity the compare the model output uncertainty for a situation with (small ranges) and without (broad ranges) the availability of measurements. This is described in section 3.3. In the revised paper we will describe in more detail why we used the 2 different parameter ranges.

Comment 2c): "The interdependencies of the model parameters were quantified by an autocorrelation analysis between the behavioural parameter combinations." (page 163) Please Explain. Autocorrelation analysis in this context is not common. Fig 6: Are these graphs not simply dotty plots of two parameters? Why auto-correlation?

Reply: We used the wrong word 'autocorrelation analysis' for the analysis we did. What we actually did is the determination of the correlation between all parameter combinations (behavioural values). The parameter combinations which showed the strongest correlation (expressed in R-squared) are plotted in Fig. 6. The graphs of Fig. 6 are indeed scatter diagrams of the behavioural values of 2 parameters. We will change this in the revised version.

Comment 3): Scenario analysis: The scenarios 1 and 2 are well selected since they have direct practical applications. However, is scenario 3 not solely underpinning the already known great influence of boil seepage?

Reply: We agree that scenario 3 shows the already known large influence of boil seepage. But the scenario gives additional information. It shows when effects of reducing boil seepage on surface water salinity are the largest. As reducing surface water salinity during the summer period is the main objective of the water managers of deep polders, this scenario is also of practical use. Side information: currently we are carrying out a field experiment together with the Water Board to study the possibility and effects of sealing boils (3 locations).

Comment 4): Is Figure 5 necessary? Isn't the relevant information summarized in Table 5?

Reply: We think that Figure 5 is necessary because it gives additional information, namely the distribution of the posterior behavioural values of the model parameters whereas Table 5 only shows the sensitivity of the parameters.

TECHNICAL CORRECTIONS 1) p. 157 line 14-15: Sentence structure unclear. 2) p. 157 line 19: "of" instead "the driving force for" 3) Figures 1 and 2: enlarge font size 4) Table 2: I suggest you add parameter names to the abbreviations 5) Table 5: Why are both small and capital letters used for concentration? (e.g. Cs,d and ca,w)

Reply: we will apply the technical corrections 1-5 given by the referee.

6) Figures 3 and 7: It is hard to identify details concerning shorter time scales in Fig. 3 – maybe select only one example year? The differences between scenarios in Fig. 7 are also not easy to identify – generating separate graphs might help.

Reply: According to the suggestion of the referee we will use a shorter time scale (July 1999 to April 2001) in Fig. 3. To easier identify the different scenario's we will enlarge Fig. 7.

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