Monitoring and modelling the dynamic behaviour of rainwater lenses and soil-, ground- and drain water salinities

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ABSTRACT

Thin rainwater lenses near the land surface are often the only source of freshwater in agricultural areas where saline groundwater migrates to the surface by upward groundwater flow. The dynamic behaviour of salinities within these rainwater lenses and the soil moisture in the unsaturated zone above them is of great importance from an agricultural perspective. Saline groundwater can reach the root zone via capillary rise, affecting crop growth.

The seasonal dynamics of these thin rainwater lenses are poorly known. The transient behavior of rainwater lenses in areas with upward saline seepage was studied beneath two tile-drained agricultural fields in the Netherlands. Evidence of rainwater lens dynamics was systematically collected by monthly ground- and soil water sampling, in combination with daily observations of water table elevation, drain tile discharge and drain water salinity. SEAWAT was used to simulate the dynamic mixing processes between rainwater, soil water, groundwater and drain water. The combination of field observation and numerical modeling allowed us to develop of a conceptual model of rainwater lens dynamics.

INTRODUCTION

In many coastal areas, groundwater is brackish to saline which may pose problems for the sustainable exploitation of fresh groundwater. Thin rainwater lenses near the land surface are often the only source of freshwater in agricultural areas upward saline seepage. Due to their limited size and nearby position to the surface, these thin rainwater lenses (further referred to as RW-lenses) are very vulnerable to changing recharge patterns (climate change). Also, it is expected that the characteristics and dynamics of RW-lenses may have an important impact on soil water salinities in the root zone of agricultural crops. To address the knowledge gap that exists on the temporal dynamics of RW-lenses and their relation to soil water salinity, RW-lens dynamics was monitored at two agricultural fields in the southwestern delta of The Netherlands. SEAWAT was used to simulate the dynamic behavior of these rainwater lenses to understand the mixing processes in RW-lenses. Parts of the results presented in this extended abstract were taken from De Louw et al, (2013). In the presentation and the extended abstract the focus will be on the method of simulating the observed dynamic processes with SEAWAT.

METHODS

The study area was the south-western delta of the Netherlands. Time varying field data was collected at two agricultural fields to monitor the dynamic salinization processes. For a period of 3 years we collected monthly ground and soil water salinity in combination with hourly observations of water table elevation, drain tile discharge and drain water salinity. Soil water was collected from soil moisture samplers (rhizons) at depth 0.15 m, 0.30 m, 0.45 m, 0.60 m and 0.75 m below ground level (BGL). Ground water salinity was collected from piezometers with 0.16 m long screens at depths (bottom of screen) of 0.8 m, 1.0 m, 1.3 m, 1.6 m, 2.0 m, 3.0 m and 4.0 m BGL.

SEAWAT version 4 (Langevin et al., 2007) was used to simulate the dynamic mixing processes between rainwater, soil water, groundwater and drain water. A RW-lens between two drain tiles was simulated with a length of 10 m and a thickness of 4.5 m. Since the RW-lenses are found near the surface, conditions of the unsaturated zone play an important role in their dynamic behavior and need to be accounted for in the model. Parameter values were adopted into SEAWAT in such a way (as described below) to account for the most important processes in the unsaturated zone. The moving water table was simulated through MODFLOW's cell wetting and drying option. For the highest active cells a specific yield (*S*) was used to account for storage changes due to a fluctuating water table. *S* was quantified based on measured water table fluctuations and rainfall amounts. A relation was found between *S* and the water table depth, which was implemented in the model by letting the specific yield vary with depth. By doing so, the dynamic conditions in the unsaturated zone were partly accounted for in SEAWAT. A constant value of *S* of 0.12 was applied at a depth below 0.7 m BGL and above this depth, S decreases to 0.05 for the upper 0.3 m. Cracks were observed in at the agricultural fields facilitating fast infiltration and drainage of rainwater. To simulate this process accurately we assigned a relatively-high K_h value (2.5 m /d) to the upper 0.4 m of the clayey subsoil. In combination with the adopted small values of *S* (0.05 – 0.09) the observed rapid response of the water table elevation and drain discharge were adequately reproduced. Evapotranspiration (negative recharge) constitutes a sink for both water and solutes in SEAWAT. Conceptually, negative recharge is considered to represent water loss from the saturated zone by capillary rise. In the field, depending on the salinity of groundwater at the water table, variable amounts of solutes are thereby moved into the unsaturated zone and temporarily stored. During recharge events, the solutes residing in the unsaturated zone are flushed. To replicate this behavior in the model, a Cl concentration of 1.25 g L^{-1} was assigned to the water entering the system as recharge. This value was chosen such that the total salt mass leaving the model by capillary rise equaled the total salt mass entering the model by recharge.

RESULTS

Figure 1 shows the monthly observed groundwater and soil water salinity depth profiles. The results showed that variations in the position of the mixing zone and mixing zone salinities are small and vary on a seasonal timescale. Figure 2 shows the comparison between observations and model results. The observed dynamics of the water table, drain discharge and the groundwater salinity depth profiles could be reproduced quite well with the numerical model. However, the observed dynamics of drain water salinity could only be partially reproduced by the model. The largest discrepancy occurred directly after the summer period when drain tiles start discharging again. The lower simulated values of drain water salinity than observed is believed to be attributable to the fact the salinity of the recharge water after a period of drought is higher in the field than the constant Cl concentration of 1.25 g L^{-1} used in the model.

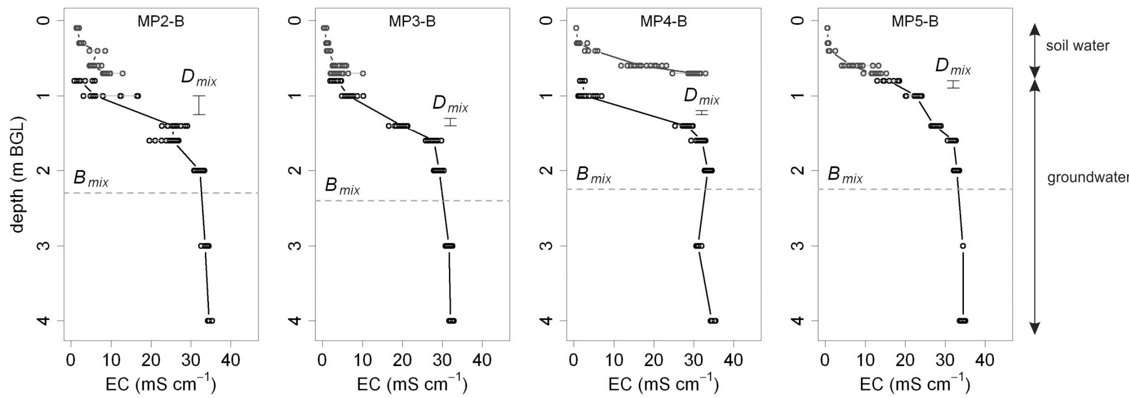

Figure 1. Depth profiles of soil water salinity and groundwater salinity based on monthly measurements during the period March 2009 – December 2010. The individual measurements are indicated by dots and median values are connected by a full line. The amplitude of the displacement of D_{mix} during the monitoring period and the depth of B_{mix} is indicated for each measurement point (adapted from De Louw et al., 2013).

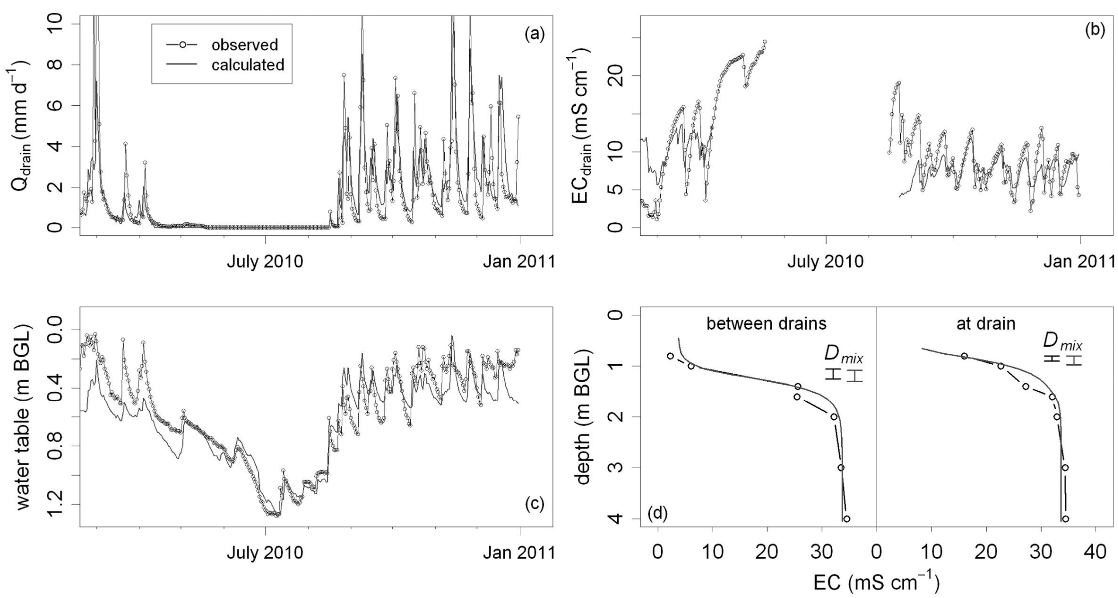

Figure 2. Comparison between observed and calculated (a) drain water discharge (Q_{drain}), (b) drain water salinity (EC_{drain}), (c) water table between the two drain tiles, and (d) salinity-depth profiles at and between the two drain tiles (from De Louw et al., 2013).

Based on both the field measurements and numerical simulations the following conceptual model of rainwater lens dynamics could be derived. Variations in the position of the mixing zone and mixing zone salinities are small and vary on a seasonal timescale, which is attributed to the slow transient oscillatory flow regime in the deepest part of the lens. The flow and mixing processes are much faster near the water table, which fluctuates on a daily basis in response to recharge and evapotranspiration, and conditions alternate between saturated to unsaturated. Although the mixing processes are fast, the temporary storage of salt in soil water has an important damping effect on groundwater salinity variations when the RW-lens grows due to the recharge by rainwater. Salinities of soil water can become significantly higher than in the groundwater (MP4-B in Figure 2), due to the unsynchronized effects of capillary rise of saline water during dry periods and the flow of infiltrated rainwater during wet periods being restricted to cracks in the soil. Preferential flow through cracks is thought to play also an important role in the rapid response of the drain tile discharge to individual rain events. Modeling showed that groundwater of variable salinity, originating from different parts of the RW-lens, as well as infiltrated rainwater, contributes to the drain tile discharge in proportions that vary on a timescale of hours to days, and this causes the highly dynamic behavior of drain water salinity.

CONCLUSIONS

The observed dynamics of RW-lens salinities, water table fluctuations and drain water discharge could be well simulated by the numerical model SEAWAT. Although SEAWAT is a saturated flow model, the effect of the unsaturated zone on the shallow groundwater system (i.e. temporary storage of water and salt in the vadose zone and effects of cracks), could satisfactorily be reproduced by the model. As we now have unravelled the dynamic behavior of RW-lenses, the next step will be to predict soil water salinities in the root zone as they may limit the growth of agricultural crops. The challenge will be to obtain more field data of groundwater and soil water salinities and to correctly simulate the interaction between RW-lens dynamics and soil water salinity in the root zone using a variable saturated zone model that also incorporate the effect of cracks.

REFERENCES

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