Referee comment on "Coupling saturated and unsaturated flow: comparing the iterative and the non-iterative approach" by Natascha Brandhorst et al., Hydrol. Earth Syst. Sci. Discuss., https://doi.org/10.5194/hess-2021-15-RC3, 2021

This article proposes two approaches for coupling saturated and unsaturated zones in a hydrological model. An explicit representation of the 3D flows is time consuming and a 1D approach to represent the unsaturated zone with a 3D approach to represent the saturated zone is an alternative which however raise the question of the representation the interface between these two environments which evolves over time. This lead, among other feature to variation in the specific yield. Two innovative approaches, one iterative and the other non-iterative, are presented in this article and compared to a 3D reference model.

We thank the reviewer for the effort and time to revise our manuscript and the constructive comments. We will make clearer in the revised manuscript that the focus is on only one of the two approaches, while the other one is used as a fast, but more ad hoc reference approach (see also comments to the first reviewer). In the following, we will respond to all comments in detail.

General comments :

Even if the article is based solely on synthetic data, the presentation of the approach is clear and the results are convincing both in terms of the quality of the results and the efficiency of the calculation times. This makes it an interesting article that deserves to be published. My main concern is the conclusions on the lack of sensitivity of the unsaturated zone. To my point of view the constant monthly inflow may lead to a steady recharge of the saturated zone. It might be possible that with pronounced short term drying-wetting cycles, the role of surface parameter might be stronger, which could be amplified by the coupling between surface flux and soil water content due to transpiration regulation. In Figure 14 we can see that soil parameter have their strongest effect when changing the inflow regime (except the model warming period). I think the conclusion could be tempered on the prominent sensitivity of KGW

We thank the reviewer for this rating. Regarding the lack of sensitivity of the unsaturated zone, we understand the concern and agree that our conclusions are not general enough. In Fig. 14 we see only a small influence of the unsaturated zone on the groundwater table position. This influence increases with larger depth to the groundwater table (not shown). We assume that this is because the unsaturated zone (especially the drier part close to the surface) has a stronger impact on the recharge under such conditions, which to us seems to be in line with the reviewer's argumentation. We will show this dependency in the revised manuscript and make clear in the discussion that the dominance of KGW is specific for the flow conditions and there is a sensitivity of the unsaturated zone parameters under other conditions (drier soil, stronger impact on recharge).

specif comments :

The shape of the equation is unusual. Considering that θ=S(hp)*Φ, I have difficulty to understand how d(θ)/dt lead to left member of equation 2 (θ being the volumetric soil water content). Can the author give reference. The specific storage Ss is not clear (dS/dhp ?)

The left member of Eq. 2 is derived from the time derivative in the volume balance (we assume incompressibility of water):

$$\frac{\partial V_w}{\partial t} = \frac{\partial\left(S(h_p)\phi V_t\right)}{\partial t} = \phi V_t \frac{\partial S(h_p)}{\partial t} + S(h_p)V_t \frac{\partial \phi}{\partial t} + S(h_p)\phi \frac{\partial V_t}{\partial t}$$

$$= V_t \cdot \left(\phi \frac{\partial S(h_p)}{\partial t} + S(h_p)\frac{\partial \phi}{\partial t} + \frac{1}{V_t} S(h_p)\phi \frac{\partial V_t}{\partial t}\right)$$

$$= V_t \cdot \left(\frac{\partial (S(h_p)\phi)}{\partial t} + S(h_p) \frac{\phi}{V_t} \frac{\partial V_t}{\partial h_p} \frac{\partial h_p}{\partial t} \right)$$
$$= V_t \cdot \left(\frac{\partial (S(h_p)\phi)}{\partial t} + S(h_p) S_s \frac{\partial h_p}{\partial t} \right)$$

with subscripts *w* and *t* denoting *water* and *total.*

The specific storage is in general defined as $S_s = \frac{1}{V_t} \frac{\partial V_p}{\partial h_p} = \frac{\partial \phi}{\partial h_p} + \frac{\phi}{V_t} \frac{\partial V_t}{\partial h_p}$ with $V_p = \phi V_t$ being the pore volume. This definition is used when the change of porosity is written in dependence of the change in water pressure head (so $\frac{\partial \phi}{\partial t} = \frac{\partial \phi}{\partial h_p} \frac{\partial h_p}{\partial t}$). One then also gets a slightly different formulation of Eq. 2: $\frac{\partial V_w}{\partial t} = V_t \cdot \left(\phi \frac{\partial S(h_p)}{\partial t} + S(h_p) S_s \frac{\partial h_p}{\partial t} \right)$.

In our case, we maintain the time derivative of porosity (or rather water content, as $S(h_p)\phi = \theta$) and therefore the specific storage formulation reduces to $S_s = \frac{\phi}{V_t} \frac{\partial V_t}{\partial h_p}$, which is equivalent to assuming that $\frac{\partial \phi}{\partial h_p} \cong 0$.

This formulation of Richards' equation can be found in e.g., Kavetski et al. (2001), Kollet and Maxwell (2006); Fahs et al. (2009). We understand the reviewer's comment that there are more common formulations of this equation and will therefore clarify the definition of the specific storage in the revised manuscript.

L154 : How the saturation determined into the new cells (is water mass in the unsaturated layer preserved?

In the non-iterative approach, the saturation in the unsaturated cells is kept the same before and after resizing. In effect, this means that the amount of water in a cell is changing, as the saturation remains but the volume it relates to changes. We see that this needs to be better explained in the revised manuscript.

L162 1 ratio and three terms. Not clear

We agree that this is formally not correct. We give a ratio of two quantities here: the recharge or better the volume of water coming in from the unsaturated zone model ($R \cdot \Delta t_c$) and the volume of water added to (or subtracted from) the groundwater ($\boldsymbol{\phi} \cdot \Delta H_{GW}$). Our formulation where we relate three terms is misleading here. We will reformulate this in the revised manuscript.

In Table 3 : Are KGW and KUZ conductivity at saturation? Here there is a decoupling of K Values. What happen in area that might belonging to the two domains.

Yes, they are the saturated hydraulic conductivity for the groundwater and the unsaturated zone model, respectively. We will introduce them properly in the manuscript at their first appearance. In the area belonging to both domains, KGW is used as the overlapping part is always the saturated domain. We will make this explicit as well.

L393-396 Is the feature described here expected? May be can be addressed when discussing the yield values in part 4.5.

One cannot really say at this point what is expected because the heterogeneities have a strong impact which is hard to evaluate. We see a different behavior for the homogeneous second test case. More tests, maybe starting with a less complex layered soil structure, would be needed to be able to make a solid statement on the specific yield values.

Figure 12: errors are located in particular areas. Is there some explanation (boundary conditions, but not everywhere, heterogeneity patterns)?

Unfortunately, we made a mistake during the postprocessing of the data. The larger discrepancies occur at the lower Dirichlet boundary (so along x=400m, not y=800m). These differences are then again due to the low groundwater table and strong gradient of the water tables along that boundary (as in the second test case). We will of course correct the figures and the corresponding discussion part.

L397 not clear what the ration is

We mean the ratio of the run times of the three compared models (two coupled and one fully integrated). This will be made clearer.

Section 4.4 Are the parameters leading to exfiltration (data removed) cover particular domain, that might be meaningful

Yes, flooding occurs only for low values of the saturated hydraulic conductivity of the groundwater model KGW. Hence, the water table curvature needs to be higher to compensate for this, and therefore the groundwater table reaches the surface at the center of the domain. This will be outlined in the revised paper.

Fig 14-16 : is t[a] correspond to year unit (you may consider t[y]

We prefer to stick to the SI recommendation of using "a" for year.

REFERENCES

Fahs, M., Younes, A., and Lehmann, F.: An easy and efficient combination of the Mixed Finite Element Method and the Method of Lines for the resolution of Richards' Equation. Environmental Modelling & Software 24.9: 1122-1126, 2009

Kavetski, D., Binning, P., and Sloan, S. W.: Adaptive time stepping and error control in a mass conservative numerical solution of the mixed form of Richards equation. Advances in Water Resources 24.6: 595-605, 2001

Kollet, S. J., and Maxwell, R.M.: Integrated surface–groundwater flow modeling: A free-surface overland flow boundary condition in a parallel groundwater flow model. Advances in Water Resources 29.7: 945-958, 2006