Review of: Controls on managed aquifer recharge through a heterogeneous vadose zone: hydrologic modeling at a site characterized with surface geophysics, by Perzan et al

Summary and Recommendation

The paper describes a methodology for inferring coarse vs. fine grained fractions of the subsurface based on towed subsurface resistivity mapping (tTEM) calibrated to cone penetration test (CPT) data, in an almond orchard in the Central Valley California. Using various spatial and multi-variable statistics, this mapping is transformed to subsurface coarse-grained-fraction 3D realizations. Variably saturated flow model that simulates managed aquifer recharge by flooding part of the orchard in the spring is used to test hydrological (infiltration and recharge) and agricultural (root-zone saturation periods) farmers' interest. Results showed that coarse-grained structures accommodate the rapid recharge. Fine-grained sediments in the root zone are probable to cause long –term saturation affecting yield. Fine grained-blocks in the deeper unsaturated zone may retain significant volumes of the MAR operation water for years after the flooding. Infiltration, recharge and root-zone saturation were found sensitive only to the fine-grained fraction's hydraulic properties, therefore the authors conclude that better characterization of the fine-grain end member is needed to reduce uncertainty in similar Agricultural-MAR operations.

The innovative technical procedure including non-invasive and invasive geophysical methods, geostatistical, Monte-Carlo and multivariate statistics, and 3D variably saturated flow simulations, is of new and advanced nature and very well described, therefore a good fit for publication in HESS. I have some arguments on the overall understanding of recharge under thick unsaturated zone and the practical conclusion for Ag. MAR operation which I would like the authors to discuss and perhaps rethink. Therefore, I recommend moderate revisions.

Major Comments

1) As the authors describe nicely recharge is correlated good with surface input (precipitation, irrigation, flood-MAR) due to the pressure wave that propagates fast in the unsaturated zone and push deep-unsaturated older water to the water-table (sometimes called by old groundwater hydrologists as "the train-car model"). Today we can deal with the unsaturated-zone's retention and avoid the simplistic recharge coefficients used in many groundwater models. Nevertheless, in the life-time of an almond-grove (20-50 years) the result of retention of ~ 1/3 of the MAR water in the deep unsaturated zone after 2 years, is no news and hardly important and shouldn't be highlighted as a main result in the abstract. Higher storage in the deep unsaturated-zone will increase recharge in 1 of the following years of high input either due to a rainy year or MAR operation. The authors should discus and maybe reconsider the important implication of their analysis in the scope of Ag–MAR in orchards.

   More-ever, recent 3D simulations in heterogeneous variably saturated medium concerning transient flow from a drywell showed that fine-grained layers at the bottom of a dry well contribute to faster downward flow in the unsaturated zone and faster recharge - see Russo et al., 2022, WRR**,** **https://doi.**org/10.1029/2021WR031881. This phenomena is due to the turn over in unsaturated hydraulic conductivity during drying, where at increasing negative pressure head, fine-grain medium becomes more permeable than course-grain.

2) Although used often, the term "deep vadose-zone" is awkward, as vadose comes from Latin meaning shallow. I suggest to use deep unsaturated zone for the domain between the bottom of root zone and the water table (especially if it is of tens of meters thick).

Specific comments

1) L71 see also Rudnik et al., 2022, WRR for use of stochastic approaches in MAR
2) L76-77 as discussed in major comment 1, in transient heterogeneous unsaturated flow fine-grained layers can increase flow in drying periods. Perhaps change "restrict flow" to impact flow.
3) L113-126,Why not define the recharge of a 40 m deep aquifer as the downward flux at 39 m depth and stay with fluxes:1) it is straightforward and simpler; 2) the saturated zone part of a model may include sources and sinks (pumping wells) or transient head boundary conditions which have impact on the lateral flow not related to the MAR operation. Discuss.
4) Figure 3, caption last row, change "hydraulic conductivity" to saturated hydraulic conductivity
5) L 209-210, perhaps better: Algebraically the resistivity of a tTEM cell is described by the harmonic mean of the fine and coarse grain resistivity's as:
6) L249, May be better hydraulic functions than "water retention curve" (to include the unsaturated hydraulic conductivity function as well as the retention curve).
7) L 360—370, only complete saturation? Or defined from some threshold of high saturation (e.g. 95% saturation)?
8) L414 – 415 "or from the particular …simulation." not clear, explain or discard if not important for the sensitivity analysis description.
9) L 438 "0.15 +- 0.29" 0.29 standard deviation? define explicitly
10) L 461 discard "( 7 acres)"
11) Figure 6 caption. Is it a single flooding of 0.8 m, or another scheme? Should be said in caption.
12) Figure 7: 1) What drives the Flux recharge after 6 years when the water table is back to its pre-MAR level, perhaps not a consequence of MAR (relates to specific comment # 3); 2) right hand vertical axis title - typo recharge.
13) L494-495, this is a trivial result no need for numbers and statistics.
14) L 540 "especially within the vadose zone", where else than the unsaturated zone?
15) L616-621 – conclusion 2 – As said in major comments, the significance of this result in Ag.-MAR in almond groves is minor. 63% in 2 years for free or cheap water is no good? And the rest 37% are not lost forever they will recharge in the next rainy/MAR year (unless the pre-MAR unsaturated zone was in really low water contents)
16) L 629-634 conclusion 5 – Hard to belief that 1 flooding of 80 cm did not cause more saturation in rootzone than 16 inundations of 5 cm with 1 week between inundations. Check! A weekly 5 cm irrigation should not cause saturation of the entire root-zone unless very poor percolation in the soil.
17) L633 saturated hydraulic conductivity rather than "hydraulic conductivity"