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Hydrology and Earth System Sciences Discussions

Interactive comment on "Quantifying the impact of groundwater depth on evapotranspiration in a semi-arid grassland region" *by* M. E. Soylu et al.

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We would like to thank "Anonymous Referee #2" for their constructive review. We have worked hard to improve the organization of the paper and remove inconsistencies pointed out by the reviewer. Specific point-by-point responses to the reviewer's comments are provided below.

Point-by-point responses General Comments

1. in Line 18 Page 5, the authors stated that the potential water extraction was often taken as the potential rate of transpiration. However, referring to the same literature the authors cited, the potential water extraction was actually expressed as the ratio of

the potential transpiration to the root zone depth.

Authors' Response (AR): We now state that the potential root water uptake is the potential volume of water removed from a unit volume of soil per unit time, as we agree that our original statement was somewhat misleading. We also now state that equality with PET only comes once the root water uptake term is integrated over the root depth.

2. in Line 24 Page 4, the authors stated that two modified forms of G-E model were used. However, in Line 18 Page 9, the authors stated that the original G-E model and a modified version of it were used.

AR: In this study we used two forms of the G-E model. In the first form, we use the original G-E model formulation, and in second form we modified its upper boundary conditions. Even though we kept the original model formulation in the first form, we considered it to be "modified," in the sense that it is coupled to the bucket type model. However, the sentence explaining the various forms of the G-E model has been improved to prevent further confusion.

Specific Comments 1. COMMENTS FOR SECTION 2.2

1.1 What is the model used for soil water retention and unsaturated hydraulic conductivity? It should be stated clear, considering three different simulators are used

AR: In all of the model simulations, we used the model of Clapp and Hornberger (1978) to relate soil matric potential to soil moisture and unsaturated hydraulic conductivity, as was stated in Line 3 Page 6 and eq. (4). We changed the phrase to "all of the model simulations" instead of "our model simulations" to increase the clarity of the statement.

1.2 What is the expression or concept for the water uptake fraction and the potential transpiration? It is important to understand the concept of the water uptake fraction and the potential transpiration in IBIS, considering that the study focuses on the relationship between the groundwater depth and the ratio of actual evapotranspiration to potential evapotranspiration.

AR: The formulation of transpiration is given in the (new) Eq. (11), which this takes into account stomatal resistance, but not available water content in the root zone, nor root distribution. Rather, these latter two factors are handled by the water uptake fraction. Considering the reviewer's comment, we added some additional explanations and formulations to section 2.2 about how IBIS calculates water uptake fraction (e.g., Eqs. 7-10). To estimate potential evapotranspiration inputs for Hydrus-1D (for comparison with the IBIS simulations), we performed a set of IBIS simulations with all soil layers saturated and then used this simulated ET as PET for Hydrus-1D. This calculation is stated in section 3.3.

1.3 How are the parameters in Equation (7) determined? Although most of the details could be checked when referred to the relevant literature, it is important to point them out directly, because they are fundamental for this simulation study. The same reason applies also for the above two points listed.

AR: We have added additional explanation and equations for the important variables relating to Eq. (7). However, given space limitations and the large number of equations contained in the appendix section of Pollard and Thompson (1995), we did not consider it appropriate nor necessary to comment on the origin of every parameter in the LSX scheme.

1.4 Line 17 Page 7 The authors stated that "IBIS originally has 11 soil layers with varying thicknesses from 5 cm to 50cm. It means that the thickness of soil column could reach at least 5.5m. Why 2.5m was used for the thickness? And, if 2.5m is used, what is the note spacing in IBIS?

AR: IBIS uses the CONUS soil database, which is based on the USDA State Soil Geographic Database (pointed out on page 16, line 24), and so the soil layer thicknesses for IBIS are based on this dataset. The thicknesses of the 11 soil layers (in cm) are 5, 5, 10, 10, 10, 20, 20, 20, 50, 50, and 50 from top to bottom. We have added this information to section 2.2.

1.5 Line 20 Page 7 The author stated that "in our model simulations, the water table is positioned by saturating the soil layers below the specified water table depth . . . " Is this for all three simulators? It is always necessary to state more specifically for readers.

AR: This statement refers only to the IBIS simulations. The lower boundary of Hydrus-1D has a variable pressure head. For the bucket model coupled with the G-E model, constant capillary flux is added to the root zone as a function of the depth to water table. We have now outlined more clearly in a table (Table 3) most of the model details, parameters, and boundary conditions and added more explanation about the lower boundary condition in IBIS in section 2.2.

2 COMMENTS FOR SECTION 2.3

2.1 Line 21-23 Page 9 What is the model used for soil water retention?

AR: As noted earlier in our response to comment 1.1, we use the Clapp and Hornberger (1978) model in all simulations.

2.2 From equation (10) to (15), the same symbol, n, is used to express soil index and porosity at the same time. Clarify it. There is another symbol, s, which is used in equation (7) as the heat/vapor transfer coefficient between canopy and air, but also is used to express saturation degree in equation (15). Change the symbol.

AR: The symbols have been corrected.

2.3 How is the ETp in equation (18) determined?

AR: ETp was calculated by using the Priestley-Taylor equation. This is now defined and stated more clearly in this and other sections. Moreover, we added a table showing which ETp method was used in each simulation.

2.4 Why grass is used as the prescribed plant parameters? What is the parameterization scheme for grass as the plant?

AR: Grass is selected as the vegetation type for all simulations in this study. The reason why grass is selected is that it is: 1) typical for many semi-arid regions, 2) the most common vegetation type at our field site, and 3) one of the most commonly studied vegetation types. Since studying the impacts of a large variety of land cover types on surface evapotranspiration is beyond the scope of this study, we have kept the plant parameters fixed for all simulations.

2.5 Is there any reason, literature or mathematical derivation for the assumption in Line 5 Page 11?

AR: The assumption that capillary flux occurs between the water table and the bottom of the root zone is the verbal explanation of the boundary conditions in Eq. (9) (Eq. 13 in the revised manuscript). The moisture content of the root zone is assumed to be uniform. When capillary flux enters the root zone, the water is distributed uniformly through the whole root zone. Bogaart et al (2008) made a similar assumption to couple the G-E model with a bucket model.

3 COMMENTS FOR SECTION 3.2

3.1 Line 11-15 Page 12 The direct comparison between the measurement and the simulation by HYDRUS-1D and IBIS should be conducted for validating model. As for the G-E model, it is acceptable to use averaged value, but not for the model that can provide outputs at observed depths.

AR: The original paper does, indeed, include comparisons of model results with field observations for all models used in this study (Fig. 3 and section 3.2). Moreover, we have explained in the same section that observation points for IBIS and Hydrus-1D were chosen at the same depths as the field soil reflectometers to present the most realistic comparison. We have examined the soil moisture values at each of the three, individual depths, and we find that separate "validation" at each of these depths does not lend any additional insight beyond the depth-averaged values.

3.2 Line 24 Page 12 Instead of pre-defined soil type, the real test of the soil physical

parameters in lab or in situ is required for validating a model.

AR: The study area used for model validation purposes is a wetland. As is characteristic of wetlands, the soil is highly heterogeneous, includes organic and mineral layers or horizons, and has significant spatial heterogeneity. Thus, field-derived soil samples would likely be highly variable and not necessarily more representative than the soil parameters that we have already chosen, particularly for the bucket model, which uses vertically homogeneous parameters for the entire root zone. Furthermore, the primary goal of this study is not to perform a detailed field-site validation, but rather to highlight the sensitivity of simulated groundwater-ET interactions to various soil parameters and model formulations.

3.3 Line 26-27 Page 12 Why were the parameters in models adjusted? What was the mechanism behind?

AR: The soil parameters were not adjusted to do any calibration in this study, and the soil type in the models for the wetland site was set to sand using the texture-specific, class-averaged, soil parameter values from Rawls et al. (1982). Also the same plant parameters are used in both the model evaluation and long-term sensitivity simulations. More explanation about the model parameters are given in sections 3.2 and 3.3 in the revised manuscript.

3.4 Line 28 Page 12 In figure 1, only daily data was shown, how were the hourly input data generated?

AR: Hourly data were not generated - they were directly measured at both the meteorological station at the wetland field site and the HPRCC observation station. We have added this information to section 3.1.

3.5 Line 11 Page 13 In the first paragraph of section 3.2, the averaged value of soil moisture content (by the way, the original word "soil moisture value" should be revised as soil moisture content) is used in IBIS and HYDRUS 1D. Then, the explanation here for the strong response to precipitation is not correct.

AR: Yes, the depth-averaged soil moisture contents are plotted in Fig. 3. We have removed the statement in question and revised the discussion in section 3.2 to focus more on the models' relative response to the inclusion of groundwater.

4 COMMENTS FOR SECTION 3.3

In the third paragraph of this section, the author stated that ETp is calculated using the Priestley-Taylor method. However, in the last sentence of the fifth paragraph, the ETp in HYDRUS 1D is taken from Eta in IBIS with all soil layers saturated. It confused readers. Is this the reason for the difference in ratios of Eta/ETp in Table 3?

AR: In this study, ETp is calculated using the Priestley-Taylor method when comparing Hydrus-1D with the G-E model (which is done on daily timescales). On the other hand, IBIS does not use ETp as an input for the upper boundary condition, but rather requires hourly incoming solar radiation, air temperature, relative humidity, precipitation, and wind speed as inputs to calculate evapotranspiration. To ensure the use of similar atmospheric forcing in both IBIS and Hydrus-1D, we perform a set of IBIS simulations with all soil layers saturated (and for various soil textures) and then use the IBIS-simulated ETa as ETp inputs for Hydrus-1D (when comparing with IBIS). Thus, the use of IBIS-derived ETp in Hydrus is only used when comparing directly with the IBIS results. This is now explained more clearly in the text and summarized in Table 3. The difference in ratios of ETa/ETp in the (new) Table 4 is suspected to be due to differences between the solution schemes of the models, as stated in section 4.2.

4.1 Line 20 Page 14 How is water table increased from 2m to the surface?

AR: In our sensitivity analysis, we fixed the water table at defined depths of 2, 1.5, 1.25, 1, 0.75, 0.5, 0.25, 0.1, and 0 m, and for each depth the model was run for 10 years using the observed climate data. We have clarified some of this information in section 3.3.

4.2 Node spacing effect should be checked with a higher resolution, in order to show the trend of the effect more convincingly.

AR: The purpose of this paper was to illustrate the effects of shallow water table depths on surface evapotranspiration. Detailed node spacing effects on model results has been studied before by van Dam and Feddes (2000) – which we reference – and so we only applied node spacing for two different cases – small (1.5 - 2.5 cm) and large (30 cm) – to illustrate the possible magnitude of differences in model results, rather than repeat what has already been done in previous studies.

5 COMMENTS FOR SECTION 4.1

Different soil physical parameters will definitely influence the calculation results, so does different node spacing. There is nothing innovative in this section, in terms of sensitivity analysis. What is the concept of “critical zone”? Does it have anything to do with rooting depth of the vegetation?

AR: There are relatively few previous studies that have shown that “small decisions” like choosing one soil parameter dataset over another have such a significant effect on surface evapotranspiration. Moreover, we have illustrated the sensitivities to various soil types and node spacing, as well as shown how the depth and thickness of the critical zone changes based on these decisions. Kollet and Maxwell (2008) describe the “critical zone” as the region in which a strong connection between ETa and water table depth exists. We have kept the rooting depth fixed in all our model simulations and, therefore, do not assess the impact of rooting depth on the thickness of the critical zone. However, this would be an interesting avenue to explore in future studies, and we note this in the revised text.

6 COMMENTS FOR SECTION 4.2

6.1 Line 16-17 Page 17 Of course, they will converge when the water table gets closer to the surface, because the same ETp is used for both IBIS and HYDRUS 1D according to Line 1-2 Page 15. As long as the potential evapotranspiration is calculated with the same scheme, when the soil is saturated, the ETa/ETp should equal to one unless the calculation scheme is not correct.

AR: Yes, we agree. The statement in question (that ETa/ETp converges to 1.0) is not meant to be a "surprising" one, and we do not present it this way in the text. We are simply describing the figure results, including the more important point that the model simulations diverge in the critical zone. Nevertheless, this section of the text has been revised for clarification.

6.2 Line 15-18 Page 18. Considering that the equations for unsaturated hydraulic conductivity are not the same in these two simulators, the discrepancies between HYDRUS and G-E model can be explained in more details. The different schemes for calculating actual evaporation in these two simulators could also contribute to the difference in figure 6.

AR: We agree with the referee that the discrepancies between Hydrus-1D and the G-E model mainly stem from the difference in the solution schemes of the two models. Unsaturated hydraulic conductivity is calculated using the Clapp and Hornberger (1978) model in both simulations. Even though both Hydrus-1D and G-E-bucket model use the same unsaturated hydraulic conductivity formulations, Hydrus-1D assigns a value to each layer depending on soil moisture availability, while the G-E-bucket model assigns only one value for the entire root zone. This might contribute to the difference in Fig. (6). In sections 2.1 and 2.3, the descriptions of the two models are given in relation to this issue.

In Fig. 1, what is the representativeness of the meteorological station some 150 km away?

AR: In this study, we used two different observing stations for model evaluation and sensitivity analysis purposes. To evaluate the models, we used meteorological, soil moisture, and groundwater level data from one, 6-month growing season at the wetland

field site. For the sensitivity analysis simulations, we used data from a station that is further away but has a much longer record (10 years). We also find that it is a good, representative station for the semi-arid climate of the region. This is now explained more clearly in the text.

In Figs 4-6, what does measurement say?

AR: We don't understand what the reviewer is asking, since we do not have measurements of ETa or groundwater level at the HPRCC station (which was the reason for using the more intensive, but shorter data record at the wetland site for the field evaluation). Nevertheless, it is worth noting that the "Results and discussion" section explains all three figures in detail.

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