Responses to the comments of Reviewer #3:

We would like to thank reviewer 3 for the detailed comments. Below we give a detailed response to all comments. We cite first the comment, this is followed by our response and often by a section how the text will be revised in the manuscript. The text in blue are changes and additions in the original text. For clarity we do not show any of the removed text.

Major comments:

Comment1. L78-100: The introduction discusses about Darcy based and simplified models for soil moisture simulations. In which class does the model developed in this manuscript belong? Assuming the latter (simplified), why is this class chosen for this work?

Response: The introduction seemed to have a good logic when we wrote it. At the end of the paper we conclude that the exact value of the hydraulic conductivity is irrelevant for daily predictions of moisture content in areas for shallow groundwater. In other words Darcy's law was only important for the long-term behavior of the groundwater. The idea was to convey this information about Darcy's law in the introduction, but this was obviously a bad idea given the reviewers' comments

We have, therefore, completely rewritten the introduction In the revised manuscript. The part that relates to class of the model is below

> Modeling moisture contents
>
> There is tendency with the ever increasing computer power, to include all processes and the highly heterogeneous field conditions in hydrological models (Asher et al 2015). In case of simulating moisture contents these models become complex and often fully distributed in 3-D (Cui et al. 2017). Examples of these fully developed models are HYDRUS (Šimůnek et al., 1998), SWAP (Dam et al., 1997) and MODFLOW (Langevin et al., 2017) These models have long run times when applied to real world problems, In addition, calibration effort increases exponentially with the number of model parameters (Rosa et al., 2012; Flint et al., 2002).. This makes the use of the complex models for real time management and decision support cumbersome where many model runs are needed (Cui et al 2017).
>
> To overcome the disadvantages of the full and completer models, computationally efficient surrogate models have been developed that speed up the modeling process without sacrificing accuracy or detail. Surrogate models are known under several names such as metamodels reduced models, model emulators, proxy models and response surfaces (e.g., Razavi et al., 2012a;

Asher et al., 2015). The complex models we will call “full” or comprehensive models.

Computational efficiency is the main reason for applying surrogate models in place of full models. Other advantages of surrogate models are shortening the time needed for calibration; identifying insensitive and irrelevant parameters in the full models [Young and Ratto, 2011]; Most importantly, surrogate models allow investigating structural model uncertainty [Matott and Rabideau, 2008] Finally, surrogate models might be able to deal with better with the self-organization of complex system prevalent in hydrology than the full models (Hoang et al., 2017. For example, full models based on small scale physics (Kirchner, 2006) not necessarily can model the repetitive wetting patterns observed in humid watersheds and for that reason simple surrogate models often outperform their complex counterparts in predicting runoff when a perched water table is present in sloping terrains (Moges et al, 2017; Hoang et al 2017)

Surrogate models can be classified in two categories (Todini, 2007; Asher et al., 2015): data driven and physics derived. Data driven surrogates analyze relationships between the data available and physically derived surrogates simplify the underlying physics or reduce numerical resolution. In recent years, most emphasis in the research literature has been data driven surrogate approaches (Razavi et al. 2012a). Relatively little research has been published on physically derived approaches. Despite its popularity, data-driven surrogates can be an inefficient and unreliable approach to optimizing complex field situations especially when data is scarce such as in ground water systems (Razavi et al. 2012b) The physically derived surrogates overcome many of the limitations of data-driven approaches and are therefore superior over data driven methods (Asher et al., 2015)

In the Yellow River basin various models have been developed to simulate the soil water content and water fluxes. Full models that have been used are the HYDRUS-1D (Ren et al., 2016), and finite difference model application by Moiwo et al., (2010). Surrogate models for the North China plain where the groundwater is more than 20 m deep have been published by Wang et al. (2001); Kendy et al (2003); Chen et al. (2010); Ma et al. (2013); Yang et al. (2015, 2017); Li et al., (2017). In these models, the matric potential is ignored, and the hydraulic potential is equal to the gravity potential and thus the thus the gradient of the hydraulic potential is unity (at least when it is expressed in head units). Under these conditions the water flux becomes negligible when

> the soil reaches field capacity at -33 KPa (equivalent to -3.3 m in head units) at what point the hydraulic conductivity becomes limiting . These models are not valid for irrigation projects along the Yellow river with shallow groundwater because the matric potential cannot be ignored over the short distance between the water table and the surface of the soil. Since the gravity and matric potential are of the same order, the water moves either down to the groundwater or up from the groundwater to the root zone depending on the matric potential at the soil (Gardner 1958; Gardener et al, 1970a,b). In summary, thus for shallow ground water at less than 3.3 m from the surface equilibrium is reached (i.e. fluxes negligible) when hydraulic gradient is zero (i.e., matric potential and gravity potential add up to constant value) and thus not when the conductivity becomes limited at a matric potential of -33 KPa

Comment2.L88-89"The disadvantage is that each landscape type has a different set of regionalized landscape parameters is not very clear and explicit. Please make the motivation of choosing the specific modelling approach clearer for the broad readership of the journal.
Response: We found that the soil characteristic curve and the groundwater depth determine the moisture content in the soil some times after irrigation. So, these two regional characteristics determine the value of the regionalized parameters for finding the moisture contents. Determining the two parameters that determine the upward flux from the groundwater is not simple and more research is needed how to define these parameters a priori.

Comment3.L108-113: The modelling approach in the manuscript assumes that lateral groundwater flow is negligible (i.e., groundwater dynamics is based on water input at the land surface and ET). This is a very strong assumption and should be discussed clearly in the manuscript. This is especially important because the authors mentioned
Response: It was an oversight not to include this information in the original manuscript. We added the following in section "Calculating the fluxed in the soil" in the revised manuscript.

> The groundwater in Hetao irrigation district has a small hydraulic gradient of 0.10-0.25% (Ren et al., 2016). In addition, the soils vary from a silt loam to a clay loam (Table 4) that has a saturated hydraulic conductivity of less than 2 m/day. This means that the lateral fluxes are small compared the vertical fluxes and can therefore neglected for the calculation of the groundwater depth. Based on this assumption, the net change in groundwater depth, Δh, can be calculated on days without rainfall or irrigation as
>
> $$\Delta h = \frac{U_g^h}{\mu^h} \qquad (13a)$$
>
> and days with rain or irrigation as

$$\Delta h = -\frac{R_5}{\mu^h} \qquad (13b)$$

> where the upward flux, U_g^h, is calculated with Eq 9, the percolation of the bottom layer R_5 with Eq 12 and the drainable porosity, μ^h with Eq 7…….

Comment4. "This is curious and could be due to water originating from irrigation in a nearby field (L331-332). Which gives an impression that lateral flow affects hydrology over the study area. Despite that, only vertical movement of water is considered in this study.
Response: As we explained in the last comment, the hydraulic gradient in this irrigation district is very small (0.1-0.25%). In the original manuscript, we wrote that irrigation in a nearby field affected the groundwater table in the beginning of growing season (lines 328-336).

> "In general, groundwater rose during an irrigation event and then decreased slowly due to upward movement of water to the plant roots to meet the transpiration demand. However, in the beginning of the growing season, we can see that the water table increased without an irrigation event. This occurred on Field A on June 24, 2016 and Fields C and D on June 20, 2017 (Fig. 5). This is curious and could be due to water originating from irrigation in a nearby field."

One of the hypotheses of the increase in groundwater level due to irrigation in a nearby field is that early in the season the cracks in the structured clays were not fully closed and these could have transported some of the water across the field. It is not something that can be predicted by a standard finite difference or element model since the conductivity is so small for this site. So it is unexpected (or curious).

Another is that that a wetting front can proceed rapidly laterally through the root zone when the groundwater is near the surface. In this case only a very small amount of water μ is needed to bring the soil from nearly saturated to fully saturated. It could be as little as 0.1 cm3cm-3. The wetting front velocity can then be found by v=q/μ. Thus the wetting from can move faster by the ratio of θs/μ which could be in the order of hundreds greater than the bulk of the water. Moreover, when the soil has been plowed the conductivity of plow layer could be greater than the bulk density. So, taken both effects together, we can imagine a wetting front movement of 10-20 m/day through the root zone. Although the effect on the groundwater table is significant flux wise only a small amount of water is involved.

Since this "curious effect" only occurs with the first irrigation we believe that water movement either through cracks or root zone somehow plays an important role. Finally we should point out that our surrogate model cannot predict it, but it is also unlikely that any "full" model will have the required equations and more importantly the input data to simulate this phenomena.

Comment5. How is evaporation calculated? Please make that clear in Section 2.
Response: In the revised manuscript we describe how the evaporation is calculated as follows in

Evapotranspiration

1. The plant evapotranspiration was calculated in two steps. First the daily reference evapotranspiration (ET_0) was calculated Penman-Monteith equation (Allen et al., 1998). We assumed that the moisture content was limiting therefore the plant evaporation rate was obtained by multiplying the reference evapotranspiration by a crop coefficient. Values for the crop coefficients were calibrated according to the water balance in the soil and found to agree with published values for stage of crop development and soil salinity .

2. (a) On days without rain or irrigation, the evapotranspiration lowers the water table and the moisture content in the soil decreases due to upward movement of water to the plant roots and soil surface.

   (b) On days with rain or irrigation, the potential evaporation is subtracted from the irrigation and/or rainfall and water moves downward

Comment6. Under section 2.3.2, maximum and potential evaporation are mentioned. How are they calculated/represented? Without this information, the results presented in the manuscript are not reproducible.
Response: The rewrite of section 2.3.2 concerning the calculation is given in the response to the previous comment.

Comment7. The conclusion section of the manuscript is very weak. It is basically an incomplete summary of the work and fails to present the necessary elements that a conclusion section requires (e.g., usefulness and limitations). "This model is simplified, so it can be used for management purposes" is vague and does not add value.
Response: We are grateful for your suggestion. We revised the conclusion section as follows:

"A novel surrogate vadose zone model for an irrigated area with a shallow aquifer was developed to simulate the fluctuation of groundwater depth and soil moisture during the crop growth stage in the shallow groundwater district. To validate and calibrate the surrogate model we carried out a two-year field experiment in the Hetao irrigation district in upper Mongolia with groundwater close to the surface. Using meteorological data and the soil characteristic curve and upward capillary movement, the surrogate model predicted the soil water content with depth and groundwater height on daily time step with acceptable accuracy during validation and was an improvement two previous models applied in the Hatao district that could predict the overall water content in the root zone but not the distribution with depth.

The surrogate modeling results show that after an irrigation event as long as the upward flux from the groundwater to the root zone was greater than the plant evaporation rate, the moisture contents in the vadose zone could be found directly from the soil characteristic curve by equating the depth to the groundwater with the absolute value of the matric potential. When plant evaporation rate exceeded the upward movement moisture contents became less than indicated by groundwater depth and was predicted by a root zone function.

Another finding was that the daily moisture contents were simulated without using the unsaturated hydraulic conductivity function in the surrogate model. For a daily time step equilibrium (defined as the hydraulic potential being constant) in moisture contents in the profile was attained so that precise unsaturated conductivity was not needed. Of course, for shorter time steps, predicting the transient fluxes and groundwater the conductivity function is needed. For management purposes a daily time step is acceptable"

Minor comments

Comment1.I would suggest replacing physical-based with either physics-based or physically-based.
Response: Thank you for your suggestion and we settled on "physically-derived" in the revised manuscript**.**

Comment2. Please use "groundwater" consistently throughout the manuscript. Currently, both groundwater and groundwater have been used.
Response: We used "groundwater" consistently in the revised manuscript.

Comment3. L74-77: This paragraph (just one sentence!) does not fit with the previous or next one. Please re-structure and merge.

Response: Thank you. The paragraph was amended as

"Central to modeling irrigation management practices under shallow groundwater conditions (such as in the Yellow river basin) is simulating the soil moisture content accurately (Batalha et al., 2018, Gleeson et al., 2016; Jasechko and Taylor, 2015; Venkatesh et al., 2011a) because the moisture content plays a critical role in the growth of crops (Rodriguez-Iturbe, 2000), groundwater recharge (Hodnett and Bell, 1986), upward movement of water to the rootzone in areas (Gleeson et al., 2016; Jasechko and Taylor, 2015; Venkatesh et al., 2011a; Batalha et al., 2018). The latter is unique to shallow groundwater areas where the moisture content and thus the unsaturated conductivity are high and where the drying of the surface soil sets up hydraulic gradient that causes the upward capillary movement from the shallow groundwater (Kahlown et al., 2005; Liu et al., 2016; Luo and Sophocleous, 2010; Yeh and Famiglietti, 2009). The upward moving water contains salt that is deposit in the root zone and at the surface. "

Comment4.L264: "the groundwater will be recharged and increase in depth". Generally, recharge decreases the depth to groundwater table from the surface.

Response: This is poorly worded. The total depth of the groundwater is increasing. To make the writing clear, we formulated it as follows:

> "The rules for downward flux on days with the effective rain and/or irrigation are relatively simple. If the net flux at the surface (irrigation plus rainfall minus actual evaporation) is greater than needed to bring the soil up to equilibrium moisture content, the groundwater will be recharged and the distance to soil surface decreases and the moisture content will be equal to the equilibrium moisture content at the new depth. "

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