

We thank Reviewer 3 for the careful reading of the manuscript and for the constructive comments. Below we respond to each comment individually. Reviewer comments are shown in black, followed by our responses in blue.

Referee #3

General Comments

This is an interesting application of the Hydrogeosphere model to simulate groundwater-surface water interactions in a small peatland system in north east Germany. The work has relevance to topical issue of re-wetting peatlands to restore them and reinstate their natural function as carbon sinks in the landscape.

The paper is generally clear and well-written, however in places better justification of the modelling decisions could be given, particularly in relation to the parameterisation and the associated calibration. It would also be good to have some explicit description of how the drain flow is managed over the course of the year and how this related to the constant boundaries that are ascribed to the ditches. In addition, there is very little consideration of the uncertainty associated with the modelling results and how this might affect interpretation. Finally, although the study is contextualised in relation to assessing peatland re-wetting, it is unclear how the study helps with that, other than provide a “proof of concept” in using Hydrogeosphere as a tool.

We thank the reviewer for these comments. In the revised manuscript we have:

Expanded the description and justification of peat hydraulic and evapotranspiration parameters, including their literature basis and calibration procedure by adding a separate subsection in the method for model calibration and validation as follows.

‘Model calibration and validation

The HydroGeoSphere model was calibrated against observed groundwater levels and eddy covariance evapotranspiration measurements using an iterative manual calibration procedure. Model parameters were adjusted manually within physically realistic ranges reported in the literature for degraded and less degraded peat soils (Wallor et al., 2018a, 2018b; Liu and Lennartz, 2019; Menberu et al., 2021; Renaud et al., 2025) until satisfactory agreement with the observed groundwater dynamics and evapotranspiration was achieved. The calibration focused primarily on peat hydraulic properties and evapotranspiration parameters. During the calibration process, peat porosity (θ_s) and the van Genuchten parameters α and β were identified as the most sensitive parameters controlling groundwater fluctuations and water-storage dynamics. These parameters strongly influence soil water-retention characteristics and therefore determine the availability of water for evapotranspiration and the response of groundwater levels to climatic forcing. Saturated hydraulic conductivity also influenced model results, particularly the timing of groundwater-level responses and lateral exchanges between the peatland and the surrounding ditch system. Model performance was evaluated using both groundwater-level observations and actual evapotranspiration estimates derived from eddy covariance measurements. The period 2016–

2020 was used for calibration because it encompassed a broad range of hydrological conditions, including both wet (2017) and dry years (2018), thereby providing a robust basis for parameter evaluation. The period 2021–2023 was subsequently used for model validation. Model performance was assessed using the Nash–Sutcliffe efficiency (NSE), Kling–Gupta efficiency (KGE), and root mean square error (RMSE).’

Added additional explanation of the ditch water-level boundary conditions and the role of water management in controlling ditch levels throughout the year. In line 114 we added:

‘The water levels in the ditches are controlled by small weirs. This ensures that water levels remain constant as long as there is sufficient water available. If the water supply is insufficient, the water levels in the ditches will fall below the target water levels.’

We included a paragraph in the discussion on model uncertainties related to evapotranspiration measurements as follows:

‘Although the observed LAI of the fen grassland reached values of approximately 7.0 during peak growing seasons, the Kristensen–Jensen evapotranspiration formulation assumes that transpiration demand reaches its maximum at LAI values of about 2.3–2.5. Consequently, increases in canopy density above this threshold do not lead to further increases in simulated transpiration. This simplification may reduce the sensitivity of the model to interannual variations in vegetation development and canopy structure. However, under the climatic conditions of the study site, evapotranspiration appears to be constrained more strongly by water availability than by canopy density during extreme drought periods. For example, during the summer drought of 2018, groundwater levels declined substantially and the peat profile dried out, limiting root water uptake despite high vegetation productivity. Similar observations were reported by Dietrich et al. (2021), who found that actual evapotranspiration remained below atmospheric demand because of insufficient water availability. Therefore, the overestimation of AET in 2018 is more likely related to limitations in the representation of drought-induced water stress and plant-accessible water than to the LAI parameterization itself. Future studies could investigate alternative canopy-resistance formulations that maintain sensitivity to high LAI values while also improving the representation of drought stress under extreme conditions. This issue may become increasingly important under future climate conditions. While shallow groundwater currently supports high evapotranspiration rates in many fen systems, more frequent and prolonged droughts could result in deeper groundwater tables and stronger soil moisture limitations. Under such conditions, accurate representation of plant-accessible water and drought-induced transpiration reduction may become more important than the representation of canopy density alone. Consequently, future rewetting and climate-change scenario analyses would benefit from improved coupling between vegetation dynamics, root water uptake, and evolving peat hydraulic properties.’

We also clarified throughout the manuscript that the present study does not simulate rewetting scenarios directly but establishes a validated hydrological baseline and modelling framework that can be used in future rewetting assessments. We also changed the title to: ‘Integrating coupled surface-subsurface modeling and field measurements in a degraded fen: insights into water balance dynamics and a basis for developing rewetting measures’.

As most re-wetting is seeking to enable rapid peat regeneration, the model would need to have a more dynamic soil parameterisation to capture this in future scenarios. Some discussion of this would be appropriate.

We agree that long-term peatland restoration can ultimately alter peat hydraulic properties through renewed peat accumulation and ecosystem development. However, we believe that such changes are unlikely to significantly affect the hydraulic properties of the peat profile over the time horizons typically considered in peatland management and rewetting studies (years to decades). Degraded peat does not rapidly recover its original physical structure following rewetting. While rewetting can quickly modify groundwater levels, surface inundation patterns, and vegetation composition, the development of new peat and the related changes in hydraulic properties occur over much longer time period. Typical peat accumulation rates are on the order of approximately 1 mm yr^{-1} , showing that substantial restoration of peat-forming layers would require centuries rather than decades. Therefore, for simulations focused on near- and medium-term hydrological responses to rewetting measures, the assumption of constant peat hydraulic properties is considered appropriate.

The paper is rich in Figures which dilutes the story somewhat. Consider moving less essential Figures to supplementary materials.

Thank you for the suggestion. We might move the Figure 4-6 to Supplementary material.

Specific Comments

L15 Species usually italicised.

Thank you. All plant species names have been revised and are now presented in italics throughout the manuscript.

L154 Sub-scripts in CO₂/H₂O

Corrected. Proper subscripts are now used consistently throughout the manuscript.

L162 What are the uncertainties with the AE estimates from the tower. There possible influence is mentioned later in the paper, but there

Thank you for this comment. We interpreted this comment as referring to uncertainties associated with the eddy covariance evapotranspiration estimates and their potential influence on model evaluation. We agree that uncertainty associated with eddy covariance evapotranspiration estimates should be acknowledged in the Methods section as well not just in the discussion. We have therefore described the main sources of uncertainty in section 2.2.

L205 So where do these parameter values come from? Literature values? Were they tuned from trial and error calibration? How are they justified?

We agree that additional clarification is needed. The hydraulic properties of the peat layers were initially selected based on published ranges reported for degraded and less degraded peat soils (Wallor et al., 2018a,b; Liu and Lennartz, 2019; Menberu et al., 2021; Renaud et al., 2025). Subsequently, parameters were refined through a manual calibration process using observed groundwater levels and evapotranspiration data. We have added a subsection in the method to explain this procedure and to better justify the selected parameter values.

L235 What is the justification of these parameter values? Why were they selected? Any likely uncertainties?

Thank you. Additional explanation has been added to methodology section. The evapotranspiration parameters were selected to represent the physiological behaviour of fen grassland vegetation under both saturated and drought conditions and were adjusted during calibration against eddy covariance evapotranspiration observations.

L323 Can you say in the methods exactly how the calibration and validation were carried out and why you split the periods as you did?

We agree that the calibration procedure should be described more clearly. A new paragraph has been added to the Methods section describing the calibration and validation strategy. The period 2016–2020 was used for calibration because it includes both wet and dry hydrological conditions, including the extreme drought year of 2018, providing a robust range of conditions for parameter optimization. The period 2021–2023 was reserved for validation to evaluate model transferability and predictive performance without further parameter adjustment.

Figure 10 Any field evidence (e.g. fixed position photography/drone imagery) to validate these spatial patterns of flooding?

Thank you for this important point. Unfortunately, spatially distributed observations such as drone imagery or systematic flood mapping are not available for the simulation period. However, repeated field observations confirmed the occurrence and seasonal evolution of surface inundation during wet periods, particularly during winter 2017/18. We have clarified in the manuscript that Figure 10 should be viewed primarily as a physically consistent model prediction supported by observed groundwater levels and field observations, rather than as a formally validated inundation map.

L445 It is perhaps a bit of an exaggeration to say ET parameterisation is still rare. It is becoming more common through ecohydrological models.

We have revised the wording. The statement now emphasizes that field-based, temporally varying vegetation parameterization using measured LAI and management schedules remains relatively uncommon in fully coupled surface-subsurface hydrological modelling studies, rather than saying that evapotranspiration parameterization itself is rare.

L448 Here the issue of uncertainty over the AET measurements comes in. Can you provide this in the methods as suggested above.

Thank you. As suggested, we have added a description of uncertainties related to the eddy covariance evapotranspiration measurements in Section 2.2.