Reviewer #2 (RC2)

The present manuscript (MS) compares the performance of a lumped and a landscape-explicit version of a conceptual DOC catchment model. While both versions could satisfactorily simulate streamflow DOC, low groundwater DOC and increased C-input could only be simulated by the more complex, landscape-explicit model version. The paper is nicely written and gets to the point that a more complex model structure and additional information, i.e. low groundwater DOC, adds to the realism of model simulations.

We thank the reviewer for positive and encouraging assessment of our manuscript.

However, these results seem expectable at first sight and so far the contributions to general knowledge which go beyond this particular model and beyond this particular application to four specific German basins seem rather limited. Eventually, a more detailed representation of DOC formation, but for sure a more detailed data analysis are warranted to justify the model structure: is the presented model really a valid compromise between required complexity and computational efficiency and therefore might be regarded as a straight-forward tool for practitioners? As follows three major concerns are listed.

Thank you. We started with our specific models and catchments as a demonstrative example. While we acknowledge a certain uniqueness of space, we would like to stress that the catchments are also part of initiatives comparing their riparian wetland state and functioning to other established experimental catchments. More specifically we refer to Ledesma et al. (2025) and to the data newly provided in Trojahn et al. (2026). We will embed these references into the manuscript to make more clear how the catchments are positioned in the international research on riparian zone functioning. For our replies to the three major concerns see below.

References

Ledesma, J. L. J., Musolff, A., Sponseller, R. A., Lupon, A., Peñarroya, X., Jativa, C., & Bernal, S. (2025). The riparian zone controls headwater hydrology and biogeochemistry, doesn't it? Reassessing linkages across European ecoregions. Global Biogeochemical Cycles, 39, e2024GB008250. https://doi.org/10.1029/2024GB008250

Trojahn, S.; Lilly, A.; Baggaley, N.J.; Davies, J.; Gagkas, Z.; Haygarth, P.M.; Laudon, H.; Musolff, A.; Pihlblad, J.; Watson, H.; Stutter, M. (2026). Soil characterisation data from UK riparian observatories and international observation sites, 2023-2024. NERC EDS Environmental Information Data Centre. https://doi.org/10.5285/4781c0ed-d5b4-41f7-bbfd-94a6a11a77b5

1. Simplified representation of DOC origin

The conceptualization of carbon transformation follows the well-known INCA-C model by (Futter et al., 2007) but is even simplified by single net transformation between the soil organic carbon pool and DOC. While the authors state that this reduces equifinality, this very simple assumption combines various individual multicomponent reactions. An existing example in HESS shows that more physical basis is possible with reasonable computational effort (Wen et al. 2020, https://doi.org/10.5194/hess-24-945-2020). Those authors incorporated coupled elemental cycling, stoichiometry, thermodynamics and kinetics in their DOC catchment model already 6 years ago. This means that a more sophisticated representation of DOC formation is possible and might be warranted also in the present model. If the authors decide to maintain their simplified approach, this needs strong justification and more detailed checks.

We agree with the reviewer that the simplified representation of C transformation requires justification. More mechanistic DOC formation models, such as Wen et al. (2020), can explicitly represent coupled elemental cycling, stoichiometry, thermodynamics and kinetics. However, implementing such processes requires data to constrain internal transformation pathways and associated parameters, which are not available for the present study and even more hard to find in other, less monitored, catchments. Our objective was therefore to balance process representation with parameter identifiability and (available) data support. A simplified, yet reasonable net transformation between soil organic carbon and DOC was chosen to avoid introducing poorly constrained processes that could increase equifinality without demonstrably improving model robustness. We will add these points to the revised manuscript as justification for the choice of our C transformation model.

2. Missing carbon mass balance

In the introduction, the authors criticize the model by Birkel et al. 2014 for not closing carbon mass balances. But in their own model application, they only study runoff and DOC concentrations separately, but do not calculate DOC loads or carbon mass fluxes. This would also be valuable for their "scenario" of forest dieback: Is their landscape-explicit model version really superior when it comes to a realistic carbon mass balance? By the way, also for drinking water reservoirs, realistic DOC loads are more important than reproducing DOC concentration patterns.

Yes, the carbon mass balance is indeed close in our case (Equations (5) - (12)). The concentration fluxes were not shown in these equations, but they are indeed derived from the mass fluxes divided by the hydrological fluxes. We will add underlying equations to the model description, regarding the linkage between the mass fluxes and concentration.

We believe that both DOC concentration and load are equally important. In this study, however, we focus on DOC concentration because it is more challenging to model it than DOC load. Once the hydrological model performs well, as is the case here, with median KGE values for streamflow ranging from 0.7 to over 0.9 (Figure 3), the simulated load is also likely to be good, even with constant DOC concentration. Therefore, the performance of the DOC model should be evaluated based on concentration rather than load. This also aligns with the principle of obtaining the "right answers for the right reasons". Since all models are ultimately mathematical abstractions of reality, model evaluation should target the faithful representation of the controlling processes, rather than relying on potentially compensating effects that may still produce acceptable load estimates.

3. DOC-export during different flow conditions

The authors only test their models by overall performance during a multi-year period. They do not study DOC simulations during different flow conditions. Again the study of Wen et al., 2020 might be relevant here. Their study showed that DOC-stocks are formed during periods of high temperature, while the main DOC export occurs during following wet conditions or during high magnitude runoff events. They also showed that streamflow DOC equals groundwater DOC during dry conditions, riparian zone DOC during intermediate conditions, and hillslope DOC during real wet conditions. These results could easily be checked or challenged by the present application. This might also prove the physical soundness and robustness of the present approach. Potentially, a shortcut of riparian buffer zones during high magnitude events might also play a role which is not included in the present model so far. Especially in the "Warme Bode", the landscape-explicit model fails to predict single DOC peaks. Those are particularly evident following the 2015 European drought which was characterized by high temperatures and below average rainfall. The different behavior between of the four basins and how an improved model adequately represents this could be another test here.

Thank you for the suggestion to further evaluate our model under different flow conditions. Here, we showed some demonstrating examples of evaluating the simulated internal DOC dynamics rather than an extensive evaluation. The main messages here are that streamflow DOC concentration is not sufficient to constrained internal DOC dynamics and the internal DOC dynamics should be explicitly calibrated/evaluated. Nevertheless, we put into the discussion that future studies could use other DOC models and evaluation, for example, model performance for different flow conditions, and contribution of DOC from different model compartments to stream during different periods (high versus low flows) if these variables are of interest and observed data are available.

In the Wame Bode and other catchments, the observed peak DOC concentrations during high-flow events were underestimated. This may be because high runoff events generate rapid transport of DOC-rich water from the topsoil to the stream. However, the current model represents the hillslope with only a single soil layer (lumped model structure) and the riparian zone as a single unit in the landscape-explicit model. A more vertically refined soil representation, including multiple soil layers, could improve model performance under these conditions. We will add these points as future avenues as to further incorporate other processes in the proposed modelling concept.