

Dear Reviewer 1,

Thank you very much for reviewing our manuscript. We found your comments very helpful for improving the overall quality and, in particular, the readability and clarity of the manuscript. Below, we provide our responses to each of your comments. Line numbers refer to the revised manuscript with tracked changes.

Reviewer 1:

The article "Enhancing global water cycle representation through two-way coupling of VIC-WUR and MODFLOW6" addresses an important gap in global hydrological modeling. The article requires minor revisions. Please address the comments below, as it would strengthen the article and improve the overall clarity. The following are my recommendations:

1. The abstract should be formatted as a single paragraph. Multi-paragraph abstracts are not typical for research articles and should be revised accordingly.

Response: Agree. We will merge the abstract and compact them into single paragraph (line 5).

2. Please add keywords after the abstract as it shows the extent and domain of the research article.

Response: Thank you for the suggestion. We checked the current Copernicus/GMD manuscript preparation guidelines and LaTeX template. The GMD template does not include a keywords section in the manuscript. Instead, relevant subject areas and index terms are provided through the online submission system. We have therefore ensured that appropriate terms are included in the submission metadata while aligning the journal-prescribed manuscript format.

3. The objective, significance, and novelty of the research should be explained in detail in the last paragraph of the introduction. Although the authors have tried to explain it, more details need to be added to make it clearer for the audience.

Response: Thank you for the suggestion. We have revised the final two paragraphs of the introduction to more explicitly describe the methodological novelty and significance of VIC-WUR 3.0. We also stated three specific objectives of the study, covering the model development, simulation assessment and evaluation of the coupling scheme (line 70-88). The revised text is:

To address these shortcomings, the present study introduces VIC-WUR v3.0, a new version of the VIC-WUR model that is coupled with a physically based groundwater flow model, i.e., MODFLOW 6 (Langevin et al., 2017). Relative to the previous VIC-WUR framework, the new version replaces the unlimited conceptual groundwater bucket with a spatially distributed groundwater model that represents transient lateral groundwater flow and river–aquifer exchange. A central methodological development is the implementation of a water-table depth-dependent capillary rise formulation constrained by soil hydraulic properties. This formulation allows groundwater feedbacks to the soil column to respond dynamically to simulated water table conditions, while limiting upward fluxes according to the water-transmitting capacity of

the soil. These developments establish explicit feedbacks among groundwater recharge, groundwater flow, capillary rise, and river–aquifer exchange.

The objectives of this study are therefore to (1) develop and document the spatial and temporal coupling between VIC-WUR and MODFLOW 6; (2) assess whether the coupled framework produces physically plausible patterns of groundwater recharge, water table depth, capillary rise, and river–aquifer exchange; and (3) evaluate simulated water tables and river discharge against available reference datasets and quantify the effects of the groundwater coupling scheme. The paper is organized as follows. Section 2 presents the VIC-WUR v3.0 modelling framework, including the core features adopted from the previous version of VIC-WUR, the key developments introduced in v3.0, the design of the underlying MODFLOW 6 groundwater model, and the technical implementation of the coupling interface. Section 3 describes the global model application, including the model setup, input data, and model execution. Section 4 presents the global simulation results, focusing on groundwater recharge, water table depth, capillary rise, and groundwater–surface water exchange. Section 5 discusses the broader implications of the results, the main sensitivities and uncertainties of the coupled modelling framework, and pathways for future model development.

4. It is mentioned in the manuscript that the “coupled configuration outperforms the uncoupled simulation at 70.5% of stations and often produces higher discharge, reflecting the role of groundwater in sustaining river flow under water-limited conditions. Improvements are also evident during the wet season, when the coupled configuration outperforms the uncoupled simulation at 81.6% of stations”. Please explain how many GRDC stations were used and what criteria were used for selecting the stations. Were any performance metrics used for the selection of the stations?

Response: Thank you for this comment. We have clarified the number of GRDC stations, the station-selection criteria, and the method used to compare the coupled and uncoupled configurations. The initial dataset contained 2,361 GRDC stations that could be mapped to the model grid and had at least 10 years of daily discharge observations. Daily observations were aggregated to monthly means. Of these stations, 2,348 had common valid data for the observations and both model configurations across all four climatological seasons and were included in the seasonal evaluation.

No model-performance metrics were used to select the stations. For each station, the wet and dry seasons were defined as the climatological seasons with the highest and lowest observed mean discharge, respectively. The coupled configuration was considered to outperform the uncoupled configuration when it produced a smaller absolute error in seasonal mean discharge relative to the GRDC observations. Using this criterion, the coupled configuration performed better at 70.5% of stations during the dry season and at 81.6% of stations during the wet season. These details have now been added to the revised manuscript (line 215-220).

5. It is mentioned in the manuscript that “The observed water tables, averaged over the model period, are largely limited to northern Europe and North America”. Please explain if the coefficient of determination performance is stronger in regions with observed water table data or globally. Conduct an analysis for bias and error distribution, as the coefficient of determination is not enough by itself. Analysis for

shallow, intermediate, and deep water tables separately will also add value to the study.

Response: Thank you for this suggestion. We clarify that the reported coefficient of determination does not represent model performance over the entire global domain. It was calculated only for the 46,733 grid cells where simulated water tables overlap with the available observation-based data. Because these observations are concentrated mainly in North America and northern Europe, model performance cannot be evaluated directly in regions without reference data (line 222-226).

To provide a more complete evaluation, we added a map of the spatial distribution of water-table residuals and calculated the mean bias, median bias, mean absolute error (MAE), and root mean square error (RMSE). Residuals are defined as simulated minus observed water-table elevation. Across all overlapping cells, the mean bias is -41.0 m, the MAE is 53.6 m, and the RMSE is 106.1 m.

We also evaluated model performance separately for shallow (<10 m), intermediate (10-100m), and deep (> 100 m) simulated water tables. Errors increase markedly with water-table depth. The MAE increases from 9.6~m for shallow water tables to 26.9~m for intermediate water tables and 187.4m for deep water tables, while R2 decreases from approximately 0.87 to 0.80. These results and the corresponding residual plots have been added to the Supplement.

6. Please add a table that summarizes the differences between VIC-WUR and VIC-WURv3.0.

Response: Thank you for this suggestion. We have added table which summarizes the principal differences between VIC-WUR and VIC-WUR v3.0 (line 124-127).

Table 1. Main differences between VIC-WUR and VIC-WUR v3.0. Components not related to groundwater coupling, including the land-surface energy balance, snow and vegetation processes, and river-routing framework, are largely retained from VIC-WUR.

Model component	VIC-WUR	VIC-WUR v3.0
Land-surface hydrology	Three-layer VIC soil scheme with coupled water and energy balances.	The original VIC land-surface and three-layer soil schemes are retained.
Groundwater flow	No explicit aquifer or lateral groundwater flow is simulated.	Transient groundwater storage and lateral groundwater flow are simulated using a two-layer MODFLOW 6 model.
Groundwater recharge	Drainage from the upper soil layers enters the lowest VIC soil layer and contributes to internally calculated subsurface flow.	Drainage across the lowest soil column in VIC-WUR is passed to the MODFLOW 6 Recharge package as groundwater recharge.

River–aquifer exchange	Subsurface flow is calculated from the lowest VIC soil layer and is subsequently included in river routing.	Surface streamflow was used to derive the river stage and head-dependent exchange is simulated using the MODFLOW 6 River and Drain packages, allowing gaining and losing conditions.
Capillary rise	No explicit upward flux from saturated zone to the VIC soil column	Water table depth-dependent capillary rise is calculated using soil-dependent maximum flux and extinction-depth parameters and is returned to the lowest VIC soil layer.
Water table	No explicit aquifer head or water table state is simulated.	Groundwater heads, water table depth, and aquifer storage are simulated by MODFLOW 6 monthly.
Groundwater withdrawals	Groundwater withdrawals are represented through water removal from the lowest soil layer and a conceptual linear unlimited groundwater bucket for non-renewable withdrawals.	Groundwater withdrawals is not activated in the naturalized simulations presented in this study. For simulations including human water use, groundwater demand can be represented as pumping through the MODFLOW 6 Well package.
Spatial coupling	All processes operate on the VIC latitude-longitude grid.	VIC-WUR and MODFLOW 6 use different grid systems, with area-consistent conversion of exchange fluxes between them.
Temporal coupling	Land-surface processes, subsurface flow, and routing are calculated internally at the daily/sub-daily time step.	VIC-WUR runs at a daily time step and MODFLOW 6 uses monthly stress periods. The two models run sequentially and exchange information monthly.

7. It would be very beneficial to add a separate section after the conclusion for “Limitations and Future Research”.

Response: We appreciate this suggestion. Limitations and future research are already discussed in dedicated Sections 5.3 and 5.4 and summarized in the Conclusions. To avoid repeating the same material after the Conclusions, we have remained the current structure while making these sections more clearly identifiable.

8. Line 141: Change “Eagleson’s capillary flux equation Eagleson (1978)” to “Eagleson’s capillary flux equation (Eagleson 1978).”

Response: Thanks for pointing it out. It has been adjusted (line158).

9. Please consider increasing the font size for labels in Figure 1, as it is very hard to read. The same applies to the arrows in Figure 2.

Response: Thanks for the suggestion. We have improved the readability of these two figures by enlarging font size, highlighting arrows and enlarging the entire canvas size of these two figures (line 163-164).

10. Please define all abbreviations when they are first used in the manuscript. Some examples include RIV, DRN, WTD, Q10, etc.

Response: Thanks for the suggestion. We have reviewed the main text of the manuscript and we made sure every abbreviations are defined at the first sight (line 97,103,105,171,189,206,210, 229,235,298,464

11. Figure B1 is very helpful, but it is very hard to read due to its size and color. Either split the figure into multiple panels or add a summary of the seasonal behavior.

Response: Thanks for the comment we have adjusted the the colorbar to make the map more visible (page 28).