

Reviewer 2

We greatly appreciate the very useful feedback from Reviewer 2. Below we address each of the comments.

The manuscript by Quichimbo et al. presents an overview of the newest version of the DRYland water Partition model – a gridded, process-based hydrologic model that simulates the water budget and relevant fluxes for arid regions. Updates to the model include the simulation of water partitioning for the vegetation canopy, groundwater-lake interactions, ponds, and more. The authors also state that the new version of the model has improved computational efficiency compared to previous versions. Two synthetic applications of the model are shown, including simulations illustrating groundwater-lake interactions, and variable transmissivity functions for subsurface water fluxes. Results from an uncalibrated realization of the model are also compared to remote sensing data for the Horn of Africa Drylands, and the authors evaluated the model to match the data well.

Evaluation:

The formulation and conceptualization of the DRYP 2.0 model as described in the manuscript are novel and may provide valuable insights for researchers interested in understanding hydrologic budgets in arid areas. The conceptualization is within the general scope of GMD. With this being said, I have three primary issues with the manuscript that should be addressed/clarified prior to the manuscript being accepted.

1. Although the introduction situates the paper within the context of ephemeral river networks, the manuscript does not assess the model's performance in capturing these processes. I would recommend reworking the introduction to avoid giving the impression that the paper evaluates the model's ability to simulate ephemeral river networks.

In DRYP v1.0 (Quichimbo, et., al. 2021) we already demonstrated the model's ability to capture ephemeral river networks. This aspect of the model has not changed in DRYP v2.0 and therefore this is still a key feature at regional or larger scales. Following the reviewer's comment, we will clarify this point in the introduction.

Quichimbo, E.A., Singer, M.B., Michaelides, K., Hobbey, D.E.J., Rosolem, R., Cuthbert, M.O., 2021. DRYP 1.0: a parsimonious hydrological model of DRYland Partitioning of the water balance. *Geoscientific Model Development* 14, 6893–6917.

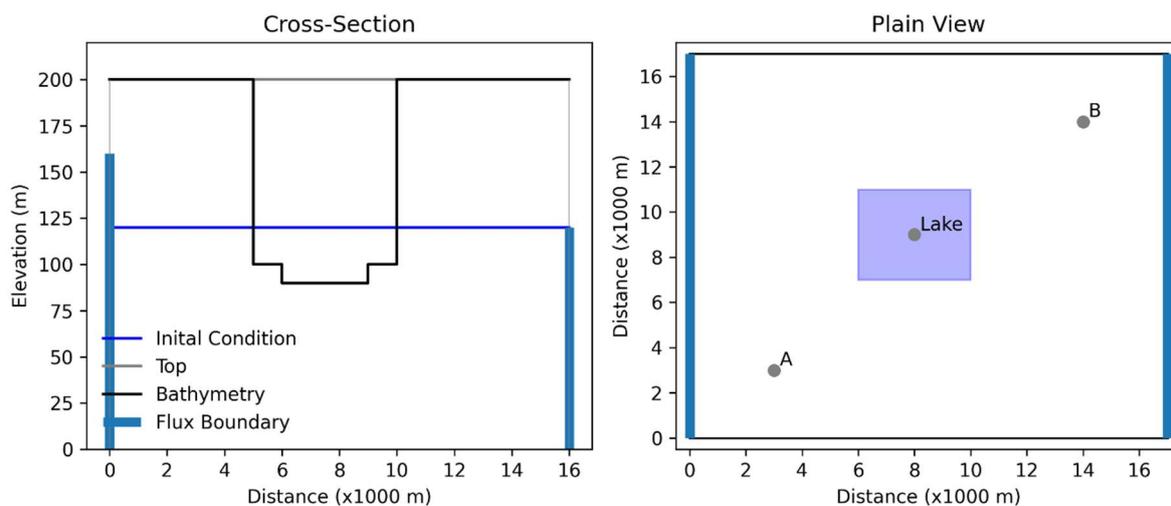
<https://doi.org/10.5194/gmd-14-6893-2021>

2. While I agree with the authors that synthetic numerical experiments are useful for understanding model behavior under hypothetical conditions, I would argue that it is necessary for the synthetic test to still demonstrate that the newly

introduced model features adequately reflect expected physical behavior. Sometimes the literature will refer to these as ‘laugh tests,’ because they provide the most basic evaluation of whether a model behaves in a physically plausible manner (see Clark et al., 2021, <https://doi.org/10.1175/JHM-D-20-0175.1>). Common approaches include comparisons with analytical solutions to simplified forms of the governing ODEs, or benchmarking against an established numerical model. Here are some examples where this has been previously done: <https://doi.org/10.2113/4.1.206>, <https://doi.org/10.1002/2016WR019672>, <https://doi.org/10.1002/hyp.11476>, <https://doi.org/10.1175/JHM-D-16-0284.1>, and <https://doi.org/10.1175/JHM-D-20-0175.1>. While the qualitative evaluation of the model presented herein is informative, I would encourage the authors to include an experiment that more objectively evaluates the ability of the model to represent expected hydrologic behaviors.

Below, we have added a comparison between the DRYP model and the lake package of the widely used groundwater model, MODFLOW, which has been used here as a reference. We have run a synthetic simulation for the lake model domain indicated in the figure below. The domain consists of 17x17 grid size of 1 km square cells. The boundary conditions of the model are set as constant head boundaries at two opposite sides of the model domain (left 160m and right 120m a.r.l.). The remaining boundaries are specified as ‘no flux’ boundary conditions. Recharge is assumed zero, so the only sources of water are flow from the constant head boundary.

Hydraulic characteristics of the aquifer are assumed to be from an alluvial aquifer system with saturated hydraulic conductivity of (Ksat) 24 m day<sup>-1</sup> and specific yield (Sy) of 0.01. The simulation was run for a 15-year period, which corresponds to the period at which the water table and the lake reached steady-state in DRYP.



*Figure 1. Model domain and boundary conditions, virtual observation points are also included in the figure.*

Figures 2 and 3 show the results of the simulation for both DRYP and MODFLOW.

Figure 2 shows the water table elevation at the end of the time simulation period, when the water levels of the aquifer and the lake have reached almost the steady-state. Contour levels (Fig. 2 left panel) show that the model has similar results to the reference values from MODFLOW for the right side of the lake, which is also confirmed in right panel of figure 2, where all values below the lake stage match the reference data. Discrepancies are apparent in the upstream side of the lake where the water table is slightly but systematically underestimated. However, it still follows the same slope of the reference values.

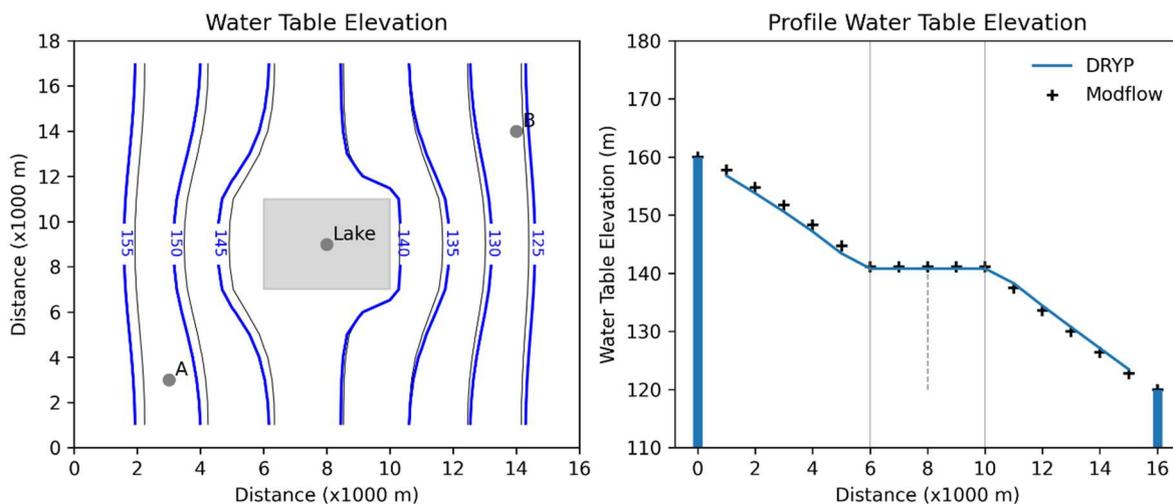


Figure 2. Left panel, contour plot of simulated head/stage using DRYP (blue lines) and MODFLOW (grey lines) at the end of the simulation period. Right panel, cross section across the centre of the lake in the x-direction at the end of the simulation period.

Figure 3 shows the temporal variation of water table and lake stage over the simulated period. The figure shows how the water table at point B follows the almost the same path of the MODFLOW simulation. Water table at point A also shows a similar trajectory but its increase occurs earlier than for the MODFLOW reference values. The lake stage also closely matches the reference values with only some slight discrepancies during the lake rising stage. However, the lake stage trajectory closely matches the long-term path of MODFLOW values.

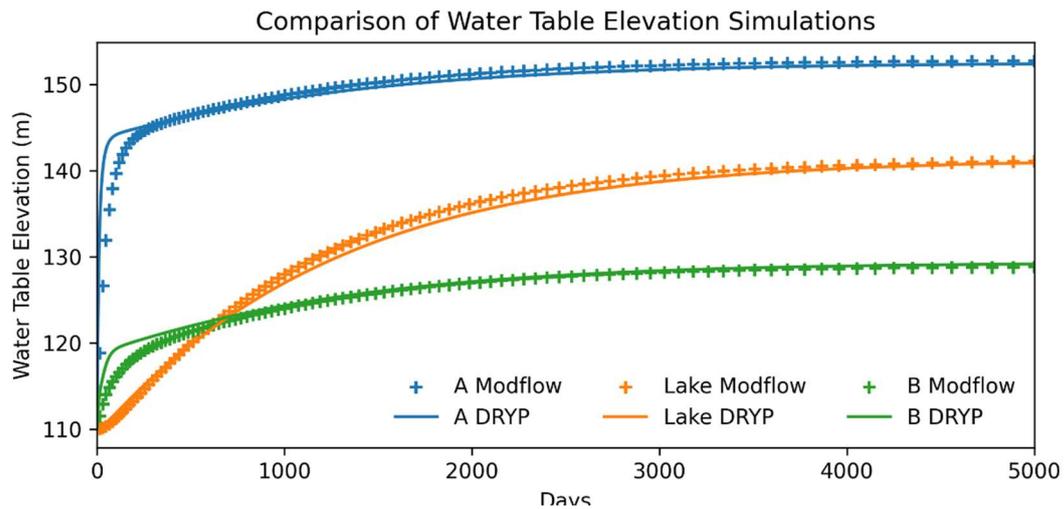


Figure 3. Comparison of water table/lake stage between DRYP and MODFLOW for 12-year simulation period. Location of points A, lake, and B are shown in figure 1.

We will add this example to the appendix, as well as a detailed description of the difference between the two models. We will also expand the conclusion section to indicate the limitations of the approach, as well as the future research to address the current limitations of the approach used in the model.

- There are several instances in the description of the model architecture where I would have appreciated more information about how several of the fluxes were parameterized. This is especially true for the description of the riparian UZ store and its respective fluxes. Note that GMD states that for model description papers, the expectation is that it should be theoretically possible for an independent scientist to construct a model that, while not necessarily numerically identical, will produce scientifically equivalent results. In the manuscript's current form, I'm not sure that the reader is provided with enough information to support this level of reproducibility. I have called several of these out in the specific comments below.

We welcome the reviewer's comments; in the manuscript we point to the initial publication of the DRYP 1.0 model whenever a detailed description is not provided. Following the reviewer suggestions, we will clarify and provide more details for the new features as well as referencing all the components already available in DRYP 1.0.

We also want to emphasize that the code is publicly available at Zenodo, therefore, the user can access to the source code to ensure reproducibility. The user also has access to the source code as well as additional examples via GitHub, which were already added in the corresponding section of data availability.

Specific comments:

L68: simulating 'small' headwater catchments at a scale of 500-m actually sounds quite coarse to me.

We agree with the reviewer, in fact representing the complex groundwater surface water interaction in headwater systems requires high spatial resolution, far less than 500 m (Verkaik, et., al. 2021). However, for large domains such as regional and continental scale, achieving that resolution requires considerable computational resources which are hardly difficult to access (Verkaik, et., al. 2024),

We will rewrite this statement to clearly indicate the requirement of a high-resolution representation and the limitation in achieving this.

Fig 1c: do the numbers shown here correspond with those in Fig 1a? It's not clear. And if so, why aren't all 11 processes included?

The panel c of Figure 1 is trying to represent the spatial discretization of the model rather than the processes itself. However, we will clarify the description on the figure legend as well as improve the figure with more descriptive labels.

Fig 1d: Is there no capillary rise from the SZ to the RUZ? Is SZ not connected to the SW?

The SZ is connected to the RUZ.

L123: Sometimes RUZ is described as 'adjacent' to streams, other times it is described as 'below' streams. I think the latter is correct if I understand correctly.

Yes, the RUZ is below the streams, we will clarify this in the corresponding section as well as in the entire document.

L127: the 'bi-directional water exchange' isn't always clear, especially between different stores and the SZ.

We refer to 'bi-directional water exchange' as the feedback of fluxes between stores in different model components. We will clarify this point along the text.

L135: What is the routing method? Is it kinematic wave? Something more simplified?

We use simple flow accumulation approach combined with a linear reservoir model to account for storage along river networks. For hillslope cells, only a flow accumulation is used to move water to the downstream cell. We will add the reference for this approach, which was already described in DRYP version 1.0.

L174: What about throughfall?

Throughfall is not included in the water balance of streams, throughfall is only included in the water balance of the unsaturated zone.

L180: It's not clear how a predefined stream network simulates ephemeral channels.

The term "ephemeral" refers to stream cells that become dry at any time during the simulation. Stream cells need to be predefined by the user in order to account for transmission losses along stream networks.

L183: It seems to bury the lede to reference transmission losses in the subtitle and then refer the reader to another paper.

We feel that it is important to signpost to readers (that may be unfamiliar with the original DRYP 1.0) that transmission losses are simulated in DRYP 2.0 - not many hydrological models incorporate this process which is especially key in drylands. However, since this component is already developed, a repeat description of the approach is not necessary and we instead reference the publication of DRYP 1.0. Inevitably when a model is extended or updated, there will be some important existing components that need highlighting and citing to the original version but not described again in detail (which would result in a very large manuscript).

L187: this mentions that RUZ is beneath the stream, but other places mention "adjacent" to the stream.

As has been clarified above, RUZ is beneath the stream.

L191: It seems like your schematic shows that the SZ can transport water to the UZ via capillary rise, but I'm not sure if this is reflected here.

Groundwater via capillary rise is available for plants transpiration when the water table is above the plant extinction depth.

L191: Many of the fluxes in the equation are not described in the manuscript. It seems important to include. From my understanding RUZ is a new component of DRYP 2.0. I especially would like to see how  $Q_{BF}$  is parameterized because it seems very important to streamflow. Same for recharge for riparian zones.

We will edit the manuscript to ensure that all terms in the equation and all model updates/extensions are clearly defined and described. The RUZ is already included in DRYP 1.0. Regarding  $Q_{BF}$ , we will expand the description in the Appendix.

L199: Is this AET parameterization for RUZ and UZ? There's also a typo at the end of this line.

Yes, both, RUZ and UZ, use the same approach to calculate AET. We will clarify this in the text.

Regarding the typo, we will add the missing reference, which is the FAO-56 report.

L213: again, it'd be nice to include information on how these flux equations were parameterized.

We will expand and clearly explain all the terms of the equation and how they were parameterised.

Fig. 3: doesn't seem to be referenced anywhere in the main body of the manuscript.

The reference of the figure will be added in the corresponding section, which is the Line 249.

L281: Typo

We will add the missing figure reference which is the figure 5b.

Table 1: Why is there an asterisk next to 0.083? For regional stream networks, assuming a constant stream width of 10m doesn't seem reasonable. How is  $K_{ch}$  incorporated in the model? Why is it a constant value?

Regarding the \*, a footnote at the end of the table is missing so we will add this in the revised version of the manuscript.

We acknowledge that 10 m does not represent the channel width, however, it is set as a default value for the modelled example used in the manuscript. The initial values have been updated after each simulation of the warming up period by using similar approach described in Verzano, et., al., (2012). This approach is based in global datasets of measured values combined with geomorphological information. We will add a detailed description of the steps followed in the present simulations as well as the reference to the methodology in the corresponding section.

Regarding  $k_{ch}$ , we refer the reader to the initial publication of the model for a detailed description of the implementation. However, we will add a more consistent description on the approach used for transmission losses and baseflow where the parameter  $K_{ch}$  is used.  $K_{ch}$  is a spatially variable parameter and needs to be calibrated. Here, we have kept it as the default value for this uncalibrated version, but we can add a brief explanation of this parameter and its parameterisation in future applications.

L400: It feels like the model isn't evaluated against any datasets with a time step that reflects the 'temporally dynamic' conditions of arid systems, as mentioned in the introduction.

The model outputs have been compared to regional datasets at monthly time scales, as this is an uncalibrated version of the model. As discussed in the reply to Reviewer 1, model calibration and evaluation is beyond the scope of the manuscript, but future research will carry out a comprehensive calibration and evaluation of the model.

We will expand the description of the results and expand the discussion about the scale of evaluation as well as the calibration. We also add references to the evaluation of the model at different scales (e.g. Quichimbo, 2021).

## References

Verkaik, J., Hughes, J.D., van Walsum, P.E.V., Oude Essink, G.H.P., Lin, H.X., Bierkens, M.F.P., 2021. Distributed memory parallel groundwater modeling for the Netherlands Hydrological Instrument. *Environmental Modelling & Software* 143, 105092.

<https://doi.org/10.1016/j.envsoft.2021.105092>

Verkaik, J., Sutanudjaja, E.H., Oude Essink, G.H.P., Lin, H.X., Bierkens, M.F.P., 2024. GLOBGM v1.0: a parallel implementation of a 30 arcsec PCR-GLOBWB-MODFLOW global-scale groundwater model. *Geoscientific Model Development* 17, 275–300.

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Verzano, K., Bärlund, I., Flörke, M., Lehner, B., Kynast, E., Voß, F., Alcamo, J., 2012. Modeling variable river flow velocity on continental scale: Current situation and climate change impacts in Europe. *Journal of Hydrology* 424–425, 238–251.

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<https://orca.cardiff.ac.uk/id/eprint/149409/>