Interactive comment on “Representation of Water Management in Hydrological and Land Surface Models” by Fuad Yassin et al.

Anonymous Referee #1

Received and published: 19 February 2019

The manuscript provides a review of the representation of reservoir operation in a range of hydrology models, then presents a reservoir operation model which explicitly represents storage zones. The optimization scheme AMALGAM is then used to optimize the releases and reservoir zones parameters toward reproducing observed operation. Authors evaluate the models over 37 reservoirs globally and with respect to other previously established reservoir operations schemes. Authors conclude that this explicit representation of storage zones increases the accuracy of representation of reservoir operation. Caveats include the need for data to support the optimization of the operations and the reliance on good calibration of hydrology models to reduce biases in inflow.

We would like to thank the reviewer for the time spent to carefully review our manuscript. We greatly appreciate the important points raised. We present our response to reviewer’s comments below. The reviewer comments are listed below in regular, black text, and our response in regular blue text.

The paper is very well written. The introduction summarizes the use of reservoir operation models to complement a range of hydrology models. The representation of reservoir storage zones, optimized/calibrated to match existing reservoir operation is very sound. While the introduction is nicely put together and provides a good review of water management models associated with different scales of hydrology models, it does not support the title. The contribution of the science is mostly in the representation of those new rules. In brief, this model has a very sound and promising concept for reservoir releases, but the models comes out as “oversold” because it lacks the representation of important processes (withdrawals, return flow, dynamic operations etc.) and can only applied on a fraction of reservoirs. A discussion how it could be implemented in conjunction with existing simplified representation where data is not available, including other driving dynamics such as water withdrawals would increase the impact of the paper and its leverage by others. As presented, the paper seems to be better suited for a journal presenting geophysical models development and validation, and some clarification of its usage would be necessary.

Accurate representation of water management is still a major challenge for land surface/hydrology models. In this study, we focused on reservoir representation as one of the core water management components regulating streamflow and our aim and contribution was to introduce an improved parameterization for reservoir operation under the condition of sufficient data availability. The minimum requirements for data are time series of reasonable length for reservoir storage and release. Finally we integrate the reservoir model into a land surface model.

We agree that the title is much wider than the objective and contribution of our work and, therefore, we suggest changing the title to: "Representation and Improved Parameterization of Reservoir Operation in Hydrological and Land Surface Models".

Since the reviewer comments will not be addressed by changing the title only, we would like to improve the manuscript by adding discussion on the following issues as suggested by the reviewer: 1) How to integrate and use the presented reservoir operation scheme with other existing reservoir operation schemes that requires less data. 2) How to link different component of water management such as water withdrawals for irrigation, return flow, prioritization among competing demands.

The responses and clarifications given below include the scope and direction of the discussion and clarification we have been adding to the revised manuscript.

1 Discussion/contribution on the science

The specification for Hanasaki et al. (2006), Haddeland et al. (2006) and other models were specifically to not rely on observed reservoir operation due to the data challenge, and the biases in reservoir inflow estimates. The author provide some arguments on how satellite data and well calibrated hydrology models are available now. The "why it can be done now" seems to be justified yet the availability and accuracy of those required storage and release observation are not available yet and their accuracy still require research in order to meet water management requirements. This reality decrease the impact of this new model; this data challenge allowed only 37 reservoirs to be represented out of 6000+ reservoir globally with other models.

Thanks for raising this point. As demonstrated in section 2, the methods of Hanasaki et al., (2006) and Haddeland et al. (2006) and other reservoir models derived from these two require no major data. Due to limitation of data, we are not suggesting by any means to fully replace existing methods such as Hanasaki et al. (2006) with the presented reservoir model, but instead they can be used together to make better use of the data when they exist.

The challenge we are trying to highlight is that there is a lack of reservoir sub-models within land surface and large scale hydrological models that can potentially utilize existing data to appropriately represent reservoir operation across storage zones. We agree that the data requirement limits the application of DZTR at global scale, but as demonstrated in our results, for reservoirs with only limited data support, the results of DZTR method are superior to the existing ones in terms of simulating both reservoir storage and releases. Further, in the case where inflow data are not available, the generalized parameterization can be used effectively and gave generally better results than other reservoir models at the scale of application. Part of the discussion in the revised manuscript is directed to show how to effectively use the presented (DZTR method and parameterization) approach in case of data unavailability as detailed in the coming paragraphs.

One approach is to integrate our proposed method in land surface/catchment models along with other reservoir operation methods (e.g., Hanasaki et al., 2006). Then, within the land surface/catchment models, identifier flags can be used to indicate which method applies to which reservoirs. The DZTR approach can only be activated for reservoirs with data support, while the remaining reservoirs can use other approaches as dictated by data availability. We have been following such an implementation within the MESH model. As shown in our results, reservoir regulation has a huge impact on downstream flows if the reservoir is highly regulated and/or is of multi-year type (c>0.5). Thus, more emphasis can be put on those reservoirs with c>0.5.

At the moment, such methods will be more effective at the regional than global scale (for example for Saskatchewan River Basin in our case), because modellers at regional scale have better access to storage-inflow-outflow data and have better understanding of the system to acquire the necessary reservoir data. In a land surface hydrologic model, important reservoirs are those causing large changes on the downstream flows and those tend to be the larger ones with generally better data availability.

We collected data for 37 reservoirs, as examples, to assess the scheme and showed that the generalized parameterization performed better than the other methods. Data on reservoir storage, inflow and release exist for most reservoirs but sometimes they are not made publically available. The generalized parameterization requires storage and release data. Storage data can be obtained from water level data which is generally available for major reservoirs, and release data can be deduced from the nearest downstream station. Data on reservoir water levels can be easily converted to storage as mentioned at the end of Section 2 in the manuscript. Initiatives are needed to gather and archive such reservoir datasets and move beyond information on reservoir characteristics that is currently available in databases (e.g. GRanD database - Lehner et al., 2011). One of our recommendation is that the target release and storage data be archived for public use at least for highly regulated and multi-year type dams (c>0.5). We intend to expand the discussions on this in the revised manuscript.

The possibility of estimating storage and release data from different satellite data products was mentioned in the manuscript to highlight an optimistic view that such types of data will be more available in the future for successful expansion of use of methods like the presented reservoir operation (optimized or generalized). More recently, Busker et al. (2019) showed an estimation of volume for 130 reservoirs using surface water dataset and satellite altimetry, which is encouraging. These will be discussed further in the revised manuscript.

The new model is presented to be better for multi objective purposes yet is compared with reservoirs for flood control mostly (Hanasaki models) because of the lack of water demand information. This is actually huge deficiency of the new model. All other models explicitly represent not only reservoir operation but also spatially distributed withdrawals and return flow.

Again, the concept is of multiple zones is very sound and appreciated. The valuation of the model as one that can replace existing models which have been looking at drivers of spatio-temporal redistribution of water resources, does not seem adequate nor properly supported.

Water demand data is needed to use the Hanasaki et al. (2006) method for irrigation dams. In the case of the DZTR approach, the idea is that the DZTR model operates in such a way to infer existing operational rules which cater for those demands. Thus, the release from DZTR accounts, implicitly, for downstream demands as per the intended purpose of the reservoir whether it is for flood control, irrigation, hydropower, etc. or any combination of these. The case study dams in our study include reservoirs with different purposes as shown in Table 1 (reservoirs summary). The DZTR approach showed good performance for reservoirs with different purposes.

If the reservoir purpose is irrigation, the target releases from DZTR are to satisfy irrigation demands because the parameterization is optimized based on observed releases. The release from an irrigation dam will be available for abstraction at the predefined abstraction points downstream of the dam. The abstraction and distribution are separate modules within our land surface model (not discussed in the original manuscript) which take care of (1) actual irrigation demand for the dependant an irrigation area, (2) water abstraction from defined abstraction point along the river below the dam and (3) distribution across the irrigation fields. Regarding the return flow, the excess water flows from the irrigation areas are assumed to join the nearest stream (the grid cell each irrigation tile belongs to). These modules are currently under investigation within the MESH framework which we used as an example to show how the DZTR model can be integrated with hydrological land surface models. However, the paper only focuses on reservoirs and the title will changed to reflect that. Thus, these issues are out of the paper scope and can be only touched upon briefly in the revised manuscript.

In case of multi-purpose reservoirs, e.g. a reservoir that is used simultaneously for hydropower generation, irrigation water supply, and flood control (e.g. High Aswan Dam in Egypt which is one of the studied reservoirs), the DZTR provides the release based on the inflow, and storage conditions and that will be available for irrigation downstream. Hydropower does not consume water but returns it back to the river (except in rare cases where it returns to a different channel).

Flood control is already accounted for in the scheme and becomes relevant when storage is within the flood storage zone. The flexible formulation of DZTR allows to implicitly change the priority for selected time periods (e.g. months or seasons) by changing the target storage values during flood periods (e.g. the storage target before the onset of snowmelt). During these flood months, lowering the target storage would increase the buffer for flood control. Conversely increasing the target storage during other months would be desirable to store water and release during irrigation months. When the scheme is optimized using inflow, release, and storage data, the parameterizations capture these priorities implicitly as expressed in the data. When inflow data are lacking, the generalized parametrization will set the storage zones based on the suggested exceedance probabilities (that were based on all reservoirs used in the study) and the priorities can be assumed as pre-defined. These points are being elaborated in the discussions in the revised manuscript.

2 Technical comments:

Title is not adequate because the paper is mostly about the new model

We agree that the title is misleading. We, therefore, suggest to use the following title for our revised manuscript: “Representation and Improved Parameterization of Reservoir Operation in Hydrological and Land Surface Models”.

Literature review needs some clarification

We will expand the review to include more recent work as directed by reviewer #2.

Note that for catchment model, the inflow is often bias corrected before input into the models.

Our understanding is that a catchment model simulates the inflow. In some cases bias correction is applied to precipitation or other climatic variables. In operational models, inflows may be corrected by data assimilation, but these types of models are generally more detailed and case specific. These are not the target for our DZTR reservoir model.

In cases where bias correction of inflow to reservoir is needed, it is possible to achieve it through introducing inflow multiplier parameter with in the reservoir algorithm to adjust the inflow with constant multiplier factor.

RiverWare, MODSIM and OASIS are widely used across the US. Note that all those models require foresight to decide on the reservoir releases. In that context, this is how Haddeland et al. (2006) differs from Hanasaki et al. (2006): Haddeland et al. (2006) also uses foresight to decide on the reservoir releases. How is this new model handling foresight?

We appreciate this information. The models mentioned are detailed water management models that can include explicit operating rules which are not usually available. Our scheme attempts to infer those rules from the inflow (if available), storage, and release data which are more readily available. The manuscript is being updated to clarify the difference between Haddeland et al. (2006) and Hanasaki et al. (2006).

Regarding handling foresight, the manuscript is being revised to clarify how the DZTR approach handles the foresight as:

The target release does not use long-term forecasts to decide the operational year inflows (e.g. dry year and wet year). Instead, it uses the simulated reservoir storage value to determine the zone to use to calculate the release. That means the operation with multiple zones helps buffer the dry and wet year inflows. For a dry year, the release is automatically reduced as storage will be lower due to less inflows. Conversely, it will increase for wet year as the higher inflows will increase the storage and even move it to a different zone. However, in reality some more preparation is taken to determine dry and wet years. For instance in cold regions, the snow water equivalent upstream of the dam is often monitored to determine the inflow forecast, prioritize release and adjust the water sharing among different sectors. The DZTR scheme is aimed to be included in land surface models to mimic reservoir operation in scenario simulations, not in operational models to aid the decisions on reservoir operation.

Existing reservoir operations model in a catchment model: Zhao, G., H. Gao, B.S. Naz, S.-C. Kao, N. Voisin, 2016: Integrating a reservoir regulation scheme into a spatially distributed hydrological model". Advances in Water Resources, 98, 16-31. 2016. doi : 10.1016/j.advwatres.2016.10.014

Note that Hanasaki et al. (2006) follow one priority use. Voisin et al. (2003) introduced storage-and-release targets toward combining flood control and irrigation, i.e. multi objective use.

Although non explicit – storage zones were already implicitly represented in Hanasaki et al. (2006) and other models (Wada, Biemans, etc); Spilling when overflowing (i.e. max reservoir at 95% full), and no release when storage gets below 10% of maximum storage. The contribution is in the explicit representation of those storage zones and their calibration, which, again, is a very sound idea and approach.

Thanks for these points with which we fully agree. The idea of having zones originates from the classic methods for reservoir design and operation. Our approach attempted to make it as flexible as possible by increasing the number of zones and defining them dynamically. While the dead storage zone is usually physically constrained by the dam design, the flood control zone is subject to management decisions based on several considerations. Release from other intermediate zones are related to demands. We compared our approach to Hanasaki et al. (2006) because their releases are strongly determined based on demands for different sectors, inflow, and forecasted inflow. The only reason we decided to put the approach Haddeland et al. (2006), Hanasaki et al. (2006) and their derivatives is that, the releases are strongly determined based on demands for different sectors, inflow, and forecasted inflow. Clarifications along those lines are being included in the revised manuscript.

Line 20: the time steps seem off in the equation. Given the time delay between precipitation and when runoff is available to drain, the equation does not seem right for an assumed time step ranging from days to half hours.

The precipitation and evaporation terms in Equation (1) are the direct quantities over the reservoir, not those over the catchment draining into the reservoir. Runoff reaching the reservoir is simulated by a hydrological model of the upstream catchment that would account for delays in the precipitation-runoff generation and routing. We regret that this point was not clear in the original manuscript, and the manuscript is being revised to reflect those clarifications.

Initial storage and inflow sensitivity section – I am not sure about the information brought up by the sensitivity to initial storage. A significant warm up is always required and is larger for large reservoirs. This model is expected to have storage data available so why are those not used? The use of the section needs some clarification.

The initial storage at the beginning of the simulation is an input that needs to be specified to the model. As you mention, the initial values can be prescribed form the observations if available. However, the simulation of a hydrological/land surface model could start at any different time period where there is no observation to prescribe, such as in the case of a future scenario simulation or a hypothetical historical scenario. Additionally, in a long-term simulation, the initial storage may result from a previous model simulation and may not be as close to observations as desired. The aim of the experiment is to examine and show to what extent the initial storage value affects the simulation performance. The outcome at least shows it is better to start with any historical observation for the same starting month of the simulation as well as to what extent the warm-up period needed for large vs smaller reservoirs. The text in the manuscript is being modified accordingly to clarify the purpose of sensitivity to initial storage. We acknowledge that it is well known that longer warm-ups are needed for larger reservoirs and the analysis can be used as a guide for the required warm-up period when regressed against the storage capacity. The application of the scheme in a large scale modelling framework can benefit from those guidelines.

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