Dear referee,

Thank you very much for reviewing our paper titled "Simulating human water impacts on global water resources using VIC-5" and for your valuable comments and suggestions. Below we address your comments (shown in italic), with our responses in blue.

Model performance

The referee suggests that we should further evaluate model performance, such as *"flow regulation and overall redistribution of water resources and performance of the model in meeting sectoral demands"*. Later it is mentioned with respect to water stores and/or fluxes: *"there is no evaluation of the terrestrial water storage with respect to GRACE as performed in other equivalent models valuations, or in flow (Yassin et al., 2019), or in supply deficit metrics as "accounting for supply from unsustainable sources" (Döll et al., 2012) or as unmet demand (Voisin et al., 2013), which allows to evaluate the overall performance of the sectoral water management model"*, and with respect to sectoral water demands: *"The sectoral demand models: (Huang et al., 2018) provides an evaluation of the different water demand models for different sectors. The set up and computed sectoral water demands would need to be further evaluated to support the sectoral water demand models in VIC5-WUR"*, and with respect to reservoir operation: *"Appropriate figures and validation should be provided"*. These suggestions were also addressed by the other reviewer.

We agree with these suggestions and will include a rigorous evaluation of the hydrological model performance. More specifically we will compare model simulations with observations and/or reported data on discharge, total water storage, reservoir storage and sectoral water demands. The following approaches are proposed:

1. Simulated discharge will be compared with monthly timeseries and multi-year average discharge from the GRDC dataset, between 1980 and 2010. Stations are selected within the major river basins of the original VIC calibration paper of Nijssen et al. (2001b). Naturalized discharge as well as human-modified discharge simulations will be compared in this manner.
2. Simulated total water storage will be compared against monthly timeseries, multi-year-average total water storage and inter-annual water storage trends from the GRACE satellite dataset, between 2004 and 2016. To do so, a 300km gaussian filter will be applied to the simulated total water storage, as it is in the GRACE dataset. Total water storage will be compared for the same river basins as in the discharge comparison. Naturalized discharge as well as human-modified total water storage simulations will be compared in this manner. These results will also include

the unmet water demands, subsequent non-renewable groundwater abstractions and long-term total water storage exploitation.

3. Simulated sectoral water demand will be compared with monthly timeseries from the Huang et al. (2018) dataset. This is in addition to the comparison to the Shiklomanov (2000) dataset and FAOSTAT (FAO, 2016), EUROSTAT (EC, 2019) and WWDR (Connor, 2015) datasets already used in the paper. Sectoral water demands will be compared for the world and for the 5 regions used in this paper (Africa, Americas, Asia, Europe and Oceania); and separately for each sector (irrigation, domestic, industrial and livestock) separately.
4. Simulated reservoir inflow, storage and release will be compared with monthly timeseries from Yassin et al. (2019) (assuming this data is shared), Rougé et al. (2019) and Hanasaki et al. (2006) datasets. Dams are selected based on data availability and evaluation will focus on large dams.

Specific comments

"Please note that the assumption for power plants to run at maximum capacity constantly is not realistic. Capacity factors (ratio of generation over maximum capacity) and generation portfolio are available through the EIA and IEA datasets"

Thanks for this comment. Capacity factors on a per-plant basis as mentioned by the referee are not fully available to us, unfortunately. Country-based analysis, based on the EIA dataset, shows that the capacity factors vary per country (fossil: between 1% and 73%; nuclear: between 37% and 88%; biomass: between 15% and 100%) and over time (fossil: between 44% and 48%; nuclear: between 56% and 82%; biomass: between 53% and 58%). These factors may also be cooling system dependent. Due to these data limitations we will use a global mean factor of 46% for fossil, 72% for nuclear and 56% for biomass based power plants.

<u>Line 669-671</u>: "Since there was no observed data about the actual annual generation, each plant was assumed to be running at its installed generation capacity throughout the year, similar to van Vliet et al. (2016)."

Will change to: "Actual generation is estimated by adjusting the installed generation capacity by 46% for fossil, 72% for nuclear and 56% for biomass power plants (based on country-based data of the EIA (EIA, 2013))."

<u>Line 677-681</u>: "In cases where even the national industrial water demands were less than the national energy water demand (5 countries), the energy water demands were lowered instead. This could be the case in countries where power plants do not operate at their installed capacity, as globally around 45% of the installed capacity is actually generated (based on data of van Vliet et al. (2016))."

Will change to: "In cases where even the national industrial water demands were less than the national energy water demand (4 countries), the energy water demands were lowered instead."

"Enhancement of reservoir releases based on storage levels. (Yassin et al., 2019) and (Rougé et al., 2019) provided a new reservoir operation formulation that modulates releases based on storage levels. While the manuscript is not a review of existing models, the proposed citations should help further support the "model enhancement and improvement" with respect to existing models"

We have included the citations mentioned by the referee, which also describe generic dam operation schemes developed for large-scale hydrological modelling.

Line 197-199: "Due to the lack of globally available information on local dam operations, several generic dam operation schemes were developed for macro-scale hydrological models to reproduce the effect of dams on natural streamflow (Haddeland et al., 2006; Hanasaki et al., 2006; Zhao et al., 2016)"

Will change to: "Due to the lack of globally available information on local dam operations, several generic dam operation schemes were developed for macro-scale hydrological models to reproduce the effect of dams on natural streamflow (Haddeland et al., 2006; Hanasaki et al., 2006; Zhao et al., 2016; Rougé et al., 2019; Yassin et al., 2019)"

"(Nazemi & Wheater, 2015a, 2015b) provides an overview of existing challenges in large scale water management models. Those papers should be cited in the introduction to complement the authors identified challenges (the environmental flow) with other identified challenges"

We have included the citations mentioned by the referee, as well as Pokhrel et al. (2016) to include a wider range of review papers that identify the challenges in large-scale hydrological modelling.

Lines 53-54: "However, further advancements are needed to improve the integration of anthropogenic impacts into hydrological models (Döll et al., 2016)"

Will change to: "However, further advancements are needed to improve the integration of anthropogenic impacts into hydrological models (Nazemi and Wheater, 2015a, b; Döll et al., 2016; Pokhrel et al., 2016)"

"The allocation of sectoral water demand to surface and ground-water systems as well as the sectoral return flow into the surface water system seems to be equivalent to (Voisin et al., 2017), which should then be cited."

We have included the citation mentioned by the referee, as well as other studies (Hanasaki et al., 2018) that used the same approach in allocation sectoral water demands to surface and groundwater systems.

Line 150-153: "The partitioning of water withdrawals between surface and ground water resources was based on the study of Döll et al. (2012), who estimated the groundwater withdrawal fraction for each sector in around 15.000 national and sub-national administrative units."

Will change to: "The partitioning of water withdrawals between surface and ground water resources is data driven, similar to other studies (e.g. Döll et al., 2012; Voisin et al., 2017; Hanasaki et al., 2018). Groundwater withdrawal fraction were based on the study of Döll et al. (2012), who estimate fractions for each sector in around 15.000 national and sub-national administrative units."

"The description of how the supply is allocated to the different sectoral water demands needs to be specified in this manuscript. A missing description is how the priority is set between sectoral demands. For example , are thermo-electric plants getting their demand met first before domestic or irrigation demand?"

The priority between sectoral water demands was described in section 2.2.1 (water withdrawal and consumption) on lines 162-163: "When water demands cannot be met, water withdrawals are allocated to the domestic, energy, manufacturing, livestock and irrigation sector in that order". However, we will make this more clear.

Lines 162-163: "When water demands cannot be met, water withdrawals are allocated to the domestic, energy, manufacturing, livestock and irrigation sector in that order"

Will change to: "In terms of water allocation, under conditions where water demands cannot be met, water withdrawals are allocated to the domestic, energy, manufacturing, livestock and irrigation sector in that order"

"Is there any priority for supply allocation based on spatial location? Which grid cells can request water from a mainstream if the main channel is not within this grid cell?"

There is no priority for supply allocation based on location, inside or outside the delta. Water requests from the mainstream (if the main channel is not within the grid cell) are allocated based on demand. This will be explicitly stated.

Line 159-160: "Therefore, streamflow at the river mouth is available for use in delta areas to simulate the actual water availability."

Will change to: "Therefore, streamflow at the river mouth is available for use in delta areas (partitioned based on demand) to simulate the actual water availability."

"Was the Hanasaki et al. (2006) "dependence" database used?"

The Hanasaki et al. (2006) dependence method is not used in this study, which will be explicitly stated. Rather our study used the controlled discharge fraction as the fraction of downstream demands taken into account. This is described in section 7.3 (appendix c: dam operation scheme) on lines 566-567: “Water demands were based on the water demands of downstream cells. Only a fraction of water demands were taken into account, based on the fraction of upstream area the dam controlled”. However, there was an error which causes confusion; “upstream area” should read “upstream discharge”.

Line 566-567: “Only a fraction of water demands were taken into account, based on the fraction of upstream area the dam controlled.”

Will change to: “Only a fraction of water demands were taken into account, based on the fraction of upstream discharge the dam controlled.”

“While authors indicate that it will be the subject of further research, what is the default implementation that was used in the presented simulations?”

We are not fully sure if we understand the referee correctly. However, assume the referee is referring to which modules were used to generate the results in this study. We will explicitly add this information to section 3.1 (setup).

Line 299: “(...) soil layers per grid cell. Soil and (natural) vegetation (...)”

Will change to: “(...) soil layers per grid cell. The routing, reservoir, irrigation and water-use modules were all used in the simulations. The environmental flow requirements were only used where this is specifically indicated. Soil and (natural) vegetation (...)”

“the introduction is missing a range of large scale studies where such a large scale water management model has been used with the VIC model, albeit not VIC5. While the proposed set up seems more complete, it seems that the paper should still cite those studies as they represent to a certain extent an earlier version of this integrated model (Voisin et al., 2017; Voisin et al., 2018; Zhou, Voisin, Leng, Huang, & Kraucunas, 2018)”

We have included almost all of the citations mentioned by the referee as they represent a wider range of VIC model applications. Voisin et al. (2017) was excluded since this study seems to use the Community Land Model (CLM) instead of the Variable Infiltration Capacity model (VIC).

Lines 80-84: “VIC has been used extensively in studies ranging from: coupled regional climate model simulations (Zhu et al., 2009; Hamman et al., 2016), combined river discharge and water-temperature simulations (van Vliet et al., 2016), hydrological sensitivity to climate change (Hamlet and Lettenmaier, 1999; Nijssen et al., 2001a; Chegwidden et al., 2019), global streamflow simulations (Nijssen et al., 2001b), and real-time drought forecasting (Wood and Lettenmaier, 2006; Mo, 2008).”

Will change to: “VIC has been used extensively in large-scale studies ranging from: coupled regional climate model simulations (Zhu et al., 2009; Hamman et al., 2016), combined river discharge and water-temperature simulations (van Vliet et al., 2016), hydrological sensitivity to climate change (Hamlet and Lettenmaier, 1999; Nijssen et al., 2001a; Chegwidden et al., 2019), global streamflow simulations (Nijssen et al., 2001b), sensitivity in flow regulation and redistribution (Voisin et al., 2018; Zhou et al., 2018), and real-time drought forecasting (Wood and Lettenmaier, 2006; Mo, 2008).”

We hope the referee agrees with the changes made, and are open to any further suggestions or comments.

Sincerely,

Bram Droppers on behalf of all co-authors

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