November 21, 2015

Dear Dr. Hilary McMillan,

Please kindly find attached the revised version of the manuscript entitled "Modeling global water use for the 21st century: Water Futures and Solutions (WFaS) initiative and its approaches", to be considered for publication in Geoscientific Model Development.

We are grateful for the very positive reviews, and valuable and constructive comments and suggestions from the two referees. Based on these helpful reviews and comments, we have revised the previous version of the manuscript and added necessary information and discussion (e.g., irrigation sector and hydro-economic classification) to strengthen the focus of the paper. As suggested by the reviewers, we have revised Section 1 (Introduction) and 2 (Methods) to clarify the new aspects and major goals of this study, and added comparative discussion to other multi-model studies (e.g., Schewe et al., 2014). We have also added further discussion and information about the advantages and the limitations of our modeling framework, in particular for irrigation sector in Section 5 (Discussion), 6 (Conclusions) and Appendix. We have addressed all of the comments raised by the two reviewers in the revised manuscript. Please kindly refer to response to reviewers' files for the details. For convenience, implemented changes have been highlighted in yellow in a revised manuscript.

Hoping to have supplied you with the necessary information to proceed and for your positive response,

With kind regards,

On behalf of my co-authors,

Dr. Yoshihide Wada

NASA Goddard Institute for Space Studies
Center for Climate Systems Research, Columbia University
Department of Physical Geography, Utrecht University
Tel: +1 212 678 5667
Email: y.wada@uu.nl,
yoshihide.wada@nasa.gov

Response to Reviewer's comments on submission to Geoscientific Model Devlpment Discussion, 8, 6417-6521, 2015 (doi:10.5194/gmdd-8-6417-2015)

Note: textual remarks, inconsistencies and minor errors have been updated in the new text wherever applicable. References refer to those used in the manuscript.

Referee's comment in italics and our response in bolds, changed text between quotation marks

Anonymous Referee #1

Article aims to estimate the future sectoral water use over various scenarios. It provides the first multi-model analysis of global water use for the 21st century. I found the article well written and I recommend of publication after the following comments and remarks are addressed.

We wish to thank the Anonymous Referee #1 for his/her constructive comments and insightful suggestions on our paper. They helped us to substantially improve the quality of the manuscript. Our detailed responses to the comments of the Referee #1 are presented below.

1. While this is the first multi-model analysis of future water use, there are some multimodel assessments dealing with future water availability and water stress. It might be good to give a reader brief overview of these existing multi-model achievements in the introduction. And clearly state how this article uses the experiences from those, and how it extends those. Particularly the Schewe et al (2014) who assess the future water stress with model ensemble, and thus including future water use of multiple models.

We have revised Section 2 (Review of current modeling approaches for global water use per sector) and added another paragraph to discuss existing multi-model ensemble studies and uncertainty therein (e.g., Schewe et al., 2014). We wish to clarify that Schewe et al. (2014) considered only water availability and calculated water scarcity using per capita water requirement (with Water Crowding Index), and thus did not consider water use explicitly.

2. Existing studies vs this study

a) Authors provide good overview of the available studies estimating irrigation water demand (Table 1). It would be very good if you could include the setup of this study to that table

b) Table 2 provides information for domestic withdrawals; please highlight the models used in this study

c) Would it be possible to provide similar table for industrial water use sector too (existing vs this study)?

a) The setup of this study has added in Table 1. Extended explanations of irrigation sector and associated scenario assumptions have been added in Appendix A.5 (Discussion of key water dimensions in irrigation sector).

b) The models used in this study has been highlighted (with the term WFaS) in Table 2.

c) As suggested, we have added a table for industrial water use methods used in this study (Table 3 in the revised manuscript).

3. Consistency with terminology:
a) under Section 2.1.2 you first state that WRCI is total crop water requirement, and then when you list the variables in more details, you use terminology Irrigation cropping intensity. Please be consistent throughout the article with this term and all others too. Moreover, maybe you could consider introducing the variables in order you list them under the Eq 1.
b) In Section 2.2 you divide Industrial water use for electricity and manufacture. In results you use only term industrial water use. This is fine and consistent, but consider in reminding the reader at the beginning of Section 4.1 that Industrial water use includesvboth energy and manufacture, as it is not obvious from the name.
a) We have revised the terminology and used the WRCI consistently thorough the revised manuscript. We have also revised the order of the variables according to the Eq. 1.
b) We have added a sentence to explain the distinction made in industrial water use calculation for the different models in Section 4.1.

4. Irrigation:
a) I was a bit disappointed that authors were not able to provide future scenarios for irrigation water withdrawals. As it is by far the largest water consumer, it might be good to include to the discussion what is needed in future research that these scenarios could be produced
b) there are some interesting new articles published in irrigation field, and you might want to consider of including these to your article: Jägermeyer et al (2015; 10.5194/hess-19-3073-2015) assess the impact of enhanced irrigation efficiency on water use; Siebert et al (2015; 10.5194/hess-19-1521-2015) provide most up-to-date dataset for global AEI.
a) Extended explanations of irrigation sector and associated scenario assumptions for key parameters (Irrigation cropping intensity, Utilization intensity of land equipped for irrigation, Irrigation water use efficiency, and Area equipped for irrigation) have been added in Appendix A.5 (Discussion of key water dimensions in irrigation sector) to supplement the scenario development for irrigation sector. This completes the WFaS scenario development for all water use sectors. At the same time, we wish to clarify that a comprehensive assessment of irrigation water use projections will be provided in a follow-up paper.
b) Thank you for the thoughtful suggestions. We have included the reference of Jägermeyer et al (2015) and Siebert et al. (2015) in Section 2.1.2 (Irrigation) as well as Table 1, and added further descriptions about the latest development on irrigation sector.

5. Energy; do the models include hydropower energy production under the energy water withdrawals? If not, this might be good to mention and justify why not, as evaporation from reservoirs is notable in many large reservoirs.
Thank you for the thoughtful comment. The models used in this study includes thermoelectric water use. The referee is correct that evaporation from reservoirs does exist. Wiberg and Strzepek (2005) show examples of the extent of this evaporation and methods for calculating it. However, most reservoirs are multi-purpose, so not all that evaporation can be attributed to hydropower and the distinction among the purposes is not rather hard to estimate given the lack of reservoir information data worldwide. We do acknowledge the importance of

evaporative losses operating a reservoir for hydropower and have added explanations about this in Section 2.2.1 (Primary energy extraction).

6. HE scenarios:
a) Would be good if you could add global population for each HE scenario to Table A1
b) How do the HE scenarios include the increase in food demand in the future and related factors (diet change, food waste, etc)?
a) As suggested, population in 2010, 2030 and 2050 for each SSP has been provided in Table A2.
b) Scenarios are formulated by a combination of SSP storylines and HE classification. The quantification of scenario drivers, i.e. scenario assumptions, were thus formulated for the matrix of SSP and HE as described in Table 4. Future developments in food demand are key for irrigation water use. They are therefore included in the SSP storyline interpretation for agriculture/irrigation related implications (Annex A.3; section Agricultural sector). These interpretations inform global agricultural models for the estimation of future food demand and land use, in particular extents of irrigated areas. Combined with HE specific assumptions on irrigation efficiency agricultural model results determine irrigation water use.

7. Discussion: consider of including couple of sub-sections, those might help to structure that a bit.
As suggested, we have revised Discussion section, and created four sub-sections: 5.1 Sensitivity of modeling approaches on the results, 5.2 Use of different reference datasets, 5.3 Use of different socio-economic drivers, and 5.4 Spatial agreement among the models.

8. HE classification: could you briefly summarise in the article how the 'economic coping capacity' and 'hydrological complexity' are calculated for Fig A1?
We have revised and added further explanations about the calculation of HE classification using the economic coping capacity and hydrological complexity in Appendix A.2 (Hydro-economic classification for use in water scenario analysis).

9. Figures: there is different logic between the global and regional figures. In global ones (Fig 2 & Fig 4) you group the results by SSPs, once in regional ones (Fig 3&5) you group them by models. Is there a justification for that?
We intend to use a different format for regional water use figures in order to highlight the transient change in future water use projections per SSP per water model. Since the variability among the three water models (H08, PCR-GLOBWB, and WaterGAP) is larger for regional values, we believe that the presented format is easier to understand the model difference and associated temporal change over the three SSPs. For the global figure, model difference over different regions tend to be balanced out and we believe that the grouping per SSP can highlight better the variability, e.g. decreasing industrial water use projected by H08 compared to the other water use projections by PCR-GLOBWB and WaterGAP.

Minor comments:
- Page 6423, line 10-12: the sentence seems to be a bit out of place; it is not clear

whether it refers to PCR-GLOBWB, all the models used in the paper or models in general

We have revised the sentence to "It is important to note that difference among models remains significantly large due to different modeling frameworks and assumptions among different models (Gosling et al., 2010, 2011; Haddeland et al., 2011; Davie et al., 2013; Schewe et al., 2014).".

- Page 6425, line 25: sentence starting "IE is available: : :" is repetition from page 6427, line 20. It fits better there, and should be deleted from page 6425.

As suggested, we have removed the sentence in Page 6425 in the revised manuscript.

Anonymous Referee #2

I read the manuscript by Wada et al. with great interest. This is a well written article and presents interesting and important results. The paper presents the multi-model estimates of regional and global water use. Three global hydrological models are selected and the results are compared. I do not see any major issues with the article, so I believe that it can be published after minor revision for the following issues:

We would like to thank the Anonymous Referee #2 for his/her constructive comments and helpful suggestions on our paper, which substantially improve the quality of the manuscript. Our detailed responses to the comments of the Referee #2 are presented below.

- I do not see any validation of the models for the past. I assume that some of these models have been validated for certain types of water uses but no information is provided in the article. The authors note that validating models is not the aim of this paper but I think it is important to provide some information for the reader.

Thank you for your thoughtful comment. We have added one section about the model validation (for a historical period) and model uncertainty in Discussion section (Section 5).

- Results from different models are surprisingly different, and in some cases even the sign of change differs among models. For example, why does H08 model project decrease in industrial water for SSP1 over time while others project an increase? Please provide more discussion. I would be curious to know how the results of the hydrologic response to climate change, in general, look like from these different models. Please add discussion if there are any studies and you may want to relate this to provide additional explanation on whether the differences in future water use arise from the differences in model physics that results to highly different ET, runoff etc., or if the differences are mainly due to the differences in the algorithms used to calculate water use.

We have revised and restructured Discussion section (Section 5) and created sub-sections in order to provide more in depth discussion about the variability (e.g., H08) related with modeling framework of each model, use of different reference datasets, use of different socio-economic drivers, and spatial agreement among the models. We have also added explanations about the change in future water use related with climate change. Since the focus of this study is on water use, we refer to Schewe et al. (2014) for climate change impact on hydrology.

- Irrigation is the largest water consumer, so changes in agricultural demand may significantly affect the overall water use pattern in the future. However, changes in land use and irrigated areas are not taken into account in this study which I think is a significant shortcoming. Please add discussion on the potential implications of using the same land use/irrigated areas for the future.

Extended explanations of irrigation sector and associated scenario assumptions for key parameters (Irrigation cropping intensity, Utilization intensity of land equipped for irrigation, Irrigation water use efficiency, and Area equipped for irrigation) have been added in Appendix A.5 (Discussion of key water dimensions in irrigation sector) to supplement the scenario development for irrigation sector. This completes the WFaS scenario development for all water use sectors. At the same time, we wish to clarify that a comprehensive assessment of irrigation water use projections will be provided in a follow-up paper.