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Hydrology and Earth System Sciences Discussions

Interactive comment on "Reconstructing 20th century global hydrography: a contribution to the Global Terrestrial Network- Hydrology (GTN-H)" *by* D. Wisser et al.

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Reply to specific comments from Anonymous Referee #2

-1. Equation 1: the snowmelt equation comes from where? A regression based on empirical data? Was a physically-based method not used because with a daily timestep, snowmelt dynamics cannot be properly simulated?

The snowmelt equation was empirically derived by Willmott (1985) from daily observations representing three dissimilar drainage basins around the globe. We are convinced that the use of such an empirical approach is appropriate for the type of water

balance model and its temporal and spatial result ions. We did not apply a physically based snowmelt method because it would require sub-daily time stepping and more physical datasets. To clarify we have added the sentence "This relationship was derived from 113 daily observations representing three dissimilar drainage basins around the globe."

- 2. 2685, 7: Why was 5 degrees C used? Is there a reference? 3. 2685, 10: the growing season starts 1 month before month with max rainfall that year. What is the basis for this assumption? How reasonable is it?

To clarify the approach we changed the paragraph to "To determine the onset of the growing season we used agro-meteorological conditions (Groten and Ocatre, 2002) based on temperature and precipitation. In the temperate zone, we used a simple temperature threshold and assumed that the growing season starts when the mean monthly air temperature is above 5 °C that is frequently used to define the onset of the growing season (Linderholm et al., 2008;Menzel et al., 2003). In regions where crop growth is no limited by temperature we assumed that the growing season starts in the month before the maximum monthly rainfall occurs". The onset of the growing season is depicted in the supplement figure in this reply.

-4. Section 2.3: How are beta and gamma parameterized? Empirically? From the literature? Are the results sensitive to these values?

Model parameters are based on previous studies and an understanding of model behavior to changes in parameters. To analyze the uncertainty in model predictions related to variations in model parameters we added a discussion on parameter uncertainty that was performed for two contrasting river basins. Model parameters γ and β control the dynamics of fast and slow components of runoff have minimal effect on annual values; the sensitivity of model results to variations in gamma and SF is small compared to the uncertainties arising from differences in precipitation data sets. See also reply to reviewer #1.

-5. Section 2.5.1: You need to somehow demonstrate that not using an objective function specific to the purpose of the dam is not significantly affecting your results. If it is, by how much? Actually, I think it would be possible to increase the sophistication of this model by assigning a purpose to each of the major dams, as the ICOLD database generally includes purpose. Reservoirs that have 2 or more purposes are not a problem, as a multi-criteria objective function can be created for these. However, if doing this does not impact your results, this is not important at this time. Later, this sophistication should probably be added to the model, as you and/or others may want to use the model to start understanding processes at finer temporal and spatial scales. Furthermore, why is reservoir evaporation neglected? If the water balance model is already simulating evaporation, it should be straight forward to include reservoir evaporation, which can be significant in drier, warmer climates.

We are grateful for this suggestion. We performed additional simulations using the release function of Hanasaki (2006) for non-irrigation reservoirs which assumes that release equals mean annual inflow. We found that the changes in the calculated age of water entering the oceans were < 10% and added the respective results in the discussion section. Evaporation from reservoir could be significant for individual reservoirs in warmer climates. However, even for large reservoirs, like the High Awan Dam (Egypt), (Sadek et al., 1997) found that only a bit more than 4% of the annual flow below of the flow is evaporated. Evaporation from reservoirs will be included in future versions of the model.

-6. Section 2.5.2: How is h = 2m chosen?

The average depth of small reservoirs is not known. We chose 2 m based on literature values for which we have now added references to the text, so that the sentence reads: "For simplicity, we assumed that small reservoirs in this study have a rectangular cross section and a constant depth of h = 2m which is a typical depth of small reservoirs, for example in the semi arid regions of India (Gunnell and Krishnamurthy, 2003;Mialhe et al., 2008)."

-7. Section 2.6: In allowing irrigation, there is no treatment of water laws, regulations, and policies (e.g. water rights system in the western US). Although a rigorous treatment would be way beyond the scope of the project, this point should at least be mentioned, and there should be some kind of sensitivity analysis to determine whether or not some kind of a water rights system might impact the results (e.g., all perennialgrowers have senior rights versus field-crop growers all having junior rights – as a very simplistic assumption that can be explored for the Columbia River Basin, for example). However, with the current model configuration, the crops never experience any kind of water shortages as all of the shortages are met with deep groundwater resources. This should also be subjected to a sensitivity analysis by letting some or all crops experience water shortage during dry years, which is much more realistic.

We agree that including socio-economic constraints into the water demand model would be a major improvement to help understanding the role of different constraints on different type of crops. However, we believe that including such conditions into the model would be a challenging task as it would require a detailed crop growth model that simulates yield response to water. Such a model is well beyond the scope of our application of a simple water demand model at the global scale. We will address this question in future version s of the model.

-8. Section 3.2: An assumption is being made that the change in irrigated areas is spatially uniform across each country.

To clarify the approach changed the sentence to " We rescaled the values in each grid cell on a country-by-country basis using the time series of irrigated areas per country recently compiled from national statistics by Freydank and Siebert (2008), assuming that the changes in irrigated areas are uniform across each country."

-9. Section 3.2: crops were aggregated into 4 groups: perennial, vegetables, rice, and others) – what is the rational for this grouping? For example, field crops like wheat, barley, and alfalfa will be placed in the "others" generic category. Does this make sense for such a wide-spread group of crops?

The grouping of 175 crops into 4 groups was based on crop physiological properties that affect the crops' water demand. We grouped the crops according to the length of the growing season for individual crops and the kc value, both taken from Allen et. al. (1998). Barley, wheat and other cereal are not very different in this regard. Rice is different as it requires additional water for flooding. For clarification we changed the sentence to "Based on average of kc values and the length of the growing season, taken from Allen et al. (1998), we aggregated the crops into 4 groups (perennial, vegetables, rice, others), determined average values, and assumed a constant distribution of crops in each irrigated grid cell over the entire simulation period "

Specific Comments:

-1. 2680, 12: "variations in the volume of water entering the oceans" – at what timescale?

Refers to variation in the annual mean values. We changed the sentence to "Variations in the volume of water entering the oceans annually, however, are governed primarily by variations in the climate signal alone with human activities playing minor role."

-2. 2681, 10: "for example in the temperate zone" – why? Because water is unfrozen?

The term was meant to refer the northern hemisphere winter and just causes confusion. We have changed the sentence to "The abstraction of water for irrigation purposes lowers the volume of water entering rivers but has also been shown to impact the seasonality of river flow by increasing winter river discharge should water returning from irrigated areas become runoff (Kendy and Bredehoeft, 2006)." . -Section 2.2.2: What other models use this approach? This might help defend your use of it..

We added " (e.g. de Rosnay et. al. (2003)) and global scale applications (e.g. Döll and Siebert (2002))."

-?? Soil water balance in WBM ?? 4. 2684, 22-24: How is this different from how the

model handles infiltration elsewhere over the land surface?

It is assumed that water percolates out of the root zone at t constant rate in rice areas. For clarification, we changed the sentence to "Rice irrigation is conceptualized by assuming that an additional amount of water is needed to maintain a constant water layer (50 mm) throughout the growing season, and that water percolates out of the root zone at a constant rate into the groundwater."

-6. 2685, 7-10: How did you differentiate between areas that are limited by precipitation versus temperature?

see reply to previous comment on determing the onset of the growing season.

-7. 2685, 17: To clarify things, state at this point that deep groundwater dynamics are not included.

To clarify, we have added the following sentence to the discussion on the runoff detention pool (line 20): " It is important not note that WBMplus, like most global water balance models does not account for the dynamics of horizontal groundwater flow or deep groundwater."

-8. 2689, 3-4: "but their combined storage capacity. . ." – is this from the McCully paper? If so, clarify.

"The number of small reservoirs (not counting innumerable small farm ponds) globally could be as high as 800,000 (McCully, 1996). However, given the storage distribution of dams (e.g. Graf (1999)) their combined storage capacity is significantly less than the total installed reservoir volume in large reservoirs."

-9. 2689, 13-15: It is not completely clear exactly what mu is from this description. Should "can" be replaced with "should"? Also, "reservoirs" is misspelled.

Corrected.

-10. 2689, 19-21: This is unclear. Either clarify with words or show it in equation form.

“A design parameter for those system is the ratio of the area that is needed to collect runoff to supply one unit of irrigated area. For the present study, we assumed that this fraction must not be greater than 10 based on design recommendations and case studies from a number of regions (Critchley et al., 1991;Srivastava, 1996, 2001).”

-11. 2689, 23-25: Use “E” not “ET” for reservoir evaporation, as an open water surface has zero transpiration. Also, why not use the model’s evaporation algorithm rather than a coefficient that is constant?

Corrected. The model uses computed potential evapotranspiration and an empirical factor to convert it to open water evaporation. See reply to comment by reviewer #1.

-12. 2690, 19-22: from this sentence, it looks like this comparison has been performed. It would be interesting to either show this figure or give quantitative estimate of differences between the two.

The sentence refers to the spatial differences between different global precipitation data sets that are amply documented. Results using three different precipitation data sets were included.

-13. 2690, 21-22: under-representation of precipitation at higher elevations: this can occur anywhere in the globe where there are mountains, not just in the high latitudes

"This product is not corrected for the effects of errors in gauge-based measurement of precipitation. Significant spatial differences between this product and climate model output data are evident in regions where gauge under catch of solid precipitation and under-representation of precipitation at higher elevations introduce a significant bias on observations (Adam et al., 2006;Tian et al., 2007)“

-14. Why were gauge-corrected data not used for this study? These data do exist on a global scale. Rather than discuss the shortcomings of not using the data, it would make much more sense to go ahead and use them.

We have performed model simulations with three additional global precipitation data

sets that represent a wide range of source data, bias corrections, interpolation method and temporal and spatial resolution. GPCCmon is not bias corrected for systematic biases and is interpolated from a limited number of stations (around 7000). GPCP is available at daily time steps and represents data measured by satellites. VASClimO that is based on a larger number of station. The CRU data set is inconsistent in the sense that some of the underlying station data was corrected and some station data was not corrected.

-15. 2691, 1: Precipitation trends can also be affected by gauge undercatch biases (the bias changes in time as the fraction of precipitation that is snow changes), as well as changing station networks used for gridding (Rawlins et al. 2006).

We are grateful for the comment and added a sentence that states the dependence of those trends on the precipitation monitoring network: “It is important to note that those trends can be affected by changes in the undercatch biases as a result of changes in the partitioning of snowfall and rainfall over time as well as changes in the distribution of the monitoring network (Rawlins et al., 2006). “

-16. 2691, 24-25: I do not think it is defensible using the2002 daily sequencing (within months) for all of the months in the historical record. The least that could be done is sampling from random months from the GPCP period – this would remove the biases that you would have from using the same daily sequencing. This method is used by Wood et al. (2002) in downscaling monthly GCM data – the daily sequencing is taken from random from the historical period. (Wood, A.W., Maurer, E.P., Kumar, A. and D.P. Lettenmaier, 2002, Long range experimental hydrologic forecasting for the eastern U.S. J. Geophys. Res., 107(D20), 4429, doi:10.1029/2001JD000659.) This method has been tested. An alternative, of course, is to use global reanalysis data. 17. 2691, 27: “differences in model predictions were small” – at what spatial and time scales? Show results.

We used both approaches and compared monthly predictions of large river basins.

The differences were smaller than the differences from using different precipitation data sets. We will address the downscaling issues in a separate paper but are not convinced that the different daily sequencing will substantially affect our results.

-18. 2692, 12: “Adequately reflects. . .” – how do you know? Did you perform some sort of evaluation?

The development of irrigated areas in the last century was governed by the four countries India, China, Pakistan, and the USA contributing to more than 50% of the total area over the entire period. Despite differences within countries (arising from the assumption of a constant growth rate per country), the created data set therefore reflects the large scale pattern adequately. To clarify, we added the sentence "The four countries India, China, Pakistan, and the US contribute more than 50% of the total irrigated area for the entire period. "

-19. 2695, 9: “<4% on observed runoff” – over what time-scale? Annual average?

These values refer to annual average. We changed the sentence to (<4% on annual average observed runoff when applied to the conterminous US)

-20. Section 5.1: How many of the observed stations are for regulated basins? How much does adding in reservoirs and irrigation improve the simulations (in comparison to observed) over the naturalized simulation?

We computed those values and added the sentence: “In basins with one or more registered reservoirs (n=219), the model performance increases slightly when the model run is performed under disturbed conditions (d increase from 0.684 to 0.694) and the coefficient of variation (CV) of monthly discharge decreases from 1.2 under natural conditions to 1.1 under disturbed conditions (compared to an observed CV of 0.97). As the area under irrigation represents less than 1% of the catchment area for the majority of the basins changes in model performance will not be seen for most basins but is significant for individual river basins (Section 5.5). “

-21. Equation 21: What is the purpose of j? Is the “2” in the denominator also supposed to be “j”?

Since we used j=2 we replaced j with 2 in the equation to avoid confusion.

-22. 2698, 3-5: Only 0.2% of groundwater stocks are utilized, but it this is not the same as the percentage of readily available groundwater stocks. For example, areas needing additional GW may not be the same areas with plentiful GW.

The paragraph was meant to put our estimate of non-sustainable water withdrawal over the last century into perspective by relating it to the total estimated stock of all groundwater.

-23. 2698, 13-15: So this sentence would suggest that evaporation over all of the land areas is primarily water-limited. Is this defensible?

This means that changes in ET are governed by changes in precipitation rather than changes in temperature.

-24. 2698, 24: “predicted natural runoff” Changed.

-25. Section 5.4: Introduce this section with a description of what it could mean if runoff is changing: changing precipitation, changing ET, or change in delS/delT because of reservoir storage or groundwater pumping.

"The changes in the climate drivers alone, increased evapotranspiration due to irrigation, and the changes in groundwater storage and reservoir operation translate to changes in the predicted terrestrial discharge into the Oceans and to endorheic basin receiving waters (e.g. Aral and Caspian Seas).“

-26. 2699, 23: what are the values from the earlier estimates? (or range of values)

The sentence was changed to “ . . .for the last century is 37405 km3a-1 and is consistent with earlier estimates that range between 35400 and 39300 km3a-1 (Dai and Trenberth, 2002;Döll et al., 2003;Fekete et al., 2002;Sitch et al., 2003;Vörösmarty et al., 2000;Vörösmarty et al., 2005)”

-27. “natural” and “pristine” are used interchangeably. Perhaps it would be better to stick to just one of these consistently.

We have changed the use of pristine to natural.

-28. 2701, 10: so the reservoirs were constructed in the early 1980s?

This means that we show a period of dry years in the 1980’s that followed a period of wet years. To avoid confusion, we changed the sentence to Figure 7 shows the modeled time series for the Okavango river with high flows during the 1970’s that was followed by a series of dry years in the mid 1980’s.

-29. 2702, 3: Cite literature demonstrating that this is realistic for those areas, if it is.

The use of fossil groundwater in the Mediterranean is amply documented. We have added three references to case studies, so that the sentence now reads “As the local runoff in these regions is close to zero, water is primarily supplied from fossil groundwater sources and the return flow from irrigated areas eventually increases runoff (e.g. (Abderrahman, 2005;Al-Weshah, 2000;Wheida and Verhoeven, 2006). “

-30. 2703. 2: but climate has nearly as large an impact – they both decrease together.

As stated in the previous sentence, discharge under both natural and disturbed conditions decrease. For clarification, we changed the sentence to “Figure 7 illustrates the gradual reduction of discharge under natural and disturbed conditions over the last century for the Ganges river. “

-31. 2703, 17: percentages not given for each basin, independently.

We changed the sentence to "Flow into the Arctic Ocean is dominated by the Yenisei (17%), Ob(13%), Lena(10%), Mackenzie(7%), and Dvina (4%) rivers contributing to more than half of the total flow.“

-32. 2704, 1: also, glacier and permafrost melt was not considered

As mentioned in the conclusions, WBMplus, like many other macroscale models does not consider permafrost and glacier dynamics. Those processes could partly explain the discrepancies between modeled and observed values for the Artic basin. We therefore changed mentioned this shortcoming of the model in line 1f on page 2704. “Also, as WBMplus neglects glaciers and permafrost, these processes could partly explain the differences between modeled and observed values. “

-33. 2708, 6-9: where was this shown, just in figure 8 for 6 basins?

The good agreement observed and modeled discharge refers to the general performance of the model when compared to a large number of observed discharge stations. For clarification we added a reference to Figure 1 that shows the bias of model predictions for 663 gauging stations.

-34. 2708, 21: What is dramatic?

The sentence was changed to: “Despite dramatic impacts in individual river basins, the annual discharge entering the oceans is governed by variations in the climate forcings over the last century and is not significantly altered by water abstractions for irrigation (Dai et al., 2008;Milliman et al., 2008). “

-35. Table 2: Do the Fekete 2002 data indicate observed? They are not mentioned in the caption. Also what period are these for?

The Fekete et. al. (2002) data sets were developed using climatologies for precipitation and temperature for the period 1961-1990) and observed runoff (varying time periods). We have added “climatologies” to the table.

-36. Figure 3 caption: change runoff to ET

Corrected.

-37. Figure 6: mention in the caption what “land” represents

We changed to caption to Annual time series of modeled discharge to the ocean and to endorheic basins under natural (gray line) and disturbed (black line) conditions 1901-2002. Land refers to internally draining (Central Asian Drainage basin, Caspian Sea, Aral Sea, and major endorheic lakes in Africa)

-38. Figure 7: add observed to these plots

Figure 7 shows river flow at basin mouths for major drainage basin. It is meant to exemplarily show the variations in river flow and shows one river hydrograph under disturbed and pristine conditions for each ocean drainage basin. For none ofthese river basins is observed discharge data available at the basin mouth from the Global Runoff Data Center (GRDC).

Technical Corrections were done as the reviewer suggested.

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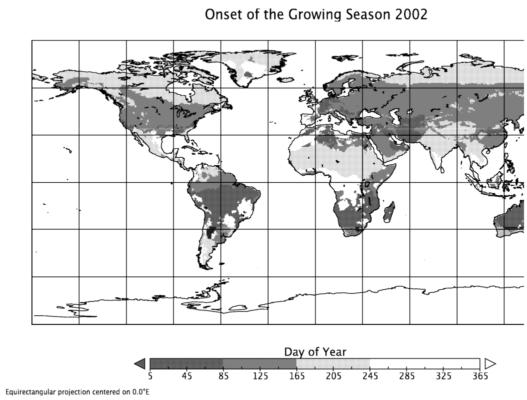
Onset of the Growing Season 2002
Day of Year
5
45
85
125
165
205
245
285
325
365
Equirectangular projection centered on 0.0°E

Fig. 1.