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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 by anonymous Referee #1

Specific comments

-Line 13-14 - Here, the conclusion is that there is no significant trend in the terrestrial discharge over the last century - is this allowing for changes in climate over that period (i.e. no trend due to human intervention) or is this combined effects of climate and water use? I suspect the later, which suggests that looking at the streamflow data only is not sufficient to permit determination of any trend. First the climate influence needs to

be removed so that the human influence can be seen. It should be noted in that case that the determination of the impact of human intervention will be model dependent. Conclusion does not seem to agree with the statement in the introduction (lines 4-7 page 2681) - the implication is that the trends seen on a regional scale reported by Milly et al (2005) is not seen when the data is evaluated on a global scale. See also comment on line 20-25, page 2681).

We recognize the difficulties in separating natural and human influence using a simple water balance model that only considers the effects of irrigation and reservoirs. We agree with the reviewer that the results of the determination of a trend will be model dependent.

-line 15-18 - is the snowmelt model of Willmott et al. applicable on a global scale? without checking the reference supplied (I don't have access at the moment), it is difficult to determine this, but presumably this is an empirical model fitted to data at a small number of locations.

This is correct. The snowmelt model was derived from data from three dissimilar river basins around the globe, which has been added for carination. See reply to reviewer #2.

-line 7 - The alpha is set to 5.0 in this application. What is the justification for this? Or is this an assumption? How sensitive is the model to the choice of alpha?

Alpha is an empirical constant that controls the amount of water that evapotranspires from the soil. It was chosen based on previous studies and our experience with the model sensitivity. For a discussion of model parameters and sensitivity, see below.

-Page 2686 line 2 - A fixed value of beta means that differences in groundwater response are not being considered in the model. That is, all aquifers have a value of 0.0167 (approxi- mating this as a time constant (really continuous time rather than discrete time) gives Tau of just under 60 days. How sensitive are the conclusions to this assumption? The constant partitioning of 50% of the excess water to runoff and 50% to groundwater is a reasonable - and necessary - one (I've used it myself at times) but it is a coarse assumption. What is the sensitivity of the conclusions to this? In the case of mean annual discharge to the oceans, this would have minimal effect, particularly since any shortfall in water for irrigation is taken from fossil groundwater resources.

The parameters γ and β have indeed minimal influence in the predicted annual values of discharge to the oceans. We have added a section on parameter uncertainty and sensitivity to the manuscript and tested the impact of parameter variations for two river basins.

-The Muskingum form usually results in one of c_0, c_1 and c_2 being negative, resulting in a negative flow on occasion. I assume this is the case in your application? Having no information on the values of C and D makes it difficult to determine this. How have you handled the negative values? Or have you constrained the values of C and D? C+D>1 1+C>D 1+D>C D-1<C<1+D if D>1 1-D<C<1+D if D<1 The sum of the c_0, c_1 and c_2 values is by definition 1, ensuring conservation of mass. The result is that transmission losses are not being considered (other than irrigation, reservoirs etc.). If there are significant losses from the streamflow (e.g. recharge), there will be a tendency to overestimate the discharge in some locations. Presumably, any such loss is assumed to return to the stream before the stream discharges to the ocean. Given the coarse assumptions made regarding the aquifer properties, this is a reasonable approximation to the system.

We do not consider losses from the stream other than irrigation. For negative values, see below.

-line 21 - How sensitive are the results to the assumed values of these 4 parameters? What is the distribution of values in Kingston, 1998?

The parameterization of river bed geometry and the resulting parameterization of Muskingum parameters is a difficult task at continental and global scales when a wide

range of topographic and hydrological conditions needs to be considered. The four parameters therefore represent average values taken from the literature. Comparing monthly values, we did not find significant differences in modeled discharge.

We added 'In the current version of the model, the Muskingum parameters C0, C1, and C2 are constrained to positive values. If any of the coefficients is negative we set C0=1, C1 =0, and C2=0 which is the equivalent of flow accumulation (ie. routing at infinite flood-wave velocity).'

Page 2688 -Line 22-25 - in addition to evaporation loss, any groundwater loss is also neglected in this equation. The usual assumption is that siltation seals the base of the reservoir relatively quickly. Concerning the evaporation loss, buffering of the temperature leads to increased evaporation in the winter, and decreased evaporation in the summer. Ignoring seasonal effects the evaporative loss from a reservoir can be over 1 m in a year This may be negligible for very deep reservoirs

see reply to comment from reviewer #2.

-Page 2689 line 24 - dam evaporation rate less than reference crop rate? Shallow depth of the small dams (2m) means the water will be approximately isothermal. Generally, water in small dams will be more turbid that water in big reservoirs, so the albedo will be higher, and hence solar heating of the water less.

The energy balance and thus the evaporation rates from small reservoirs will depend on a number of site-specific conditions such as volume and area of the pond, residence time of the water, turbidity, and others. The evaporation coefficient of 0.6 is an empirical values that was used at a river basin scale study by Arnold and Stokle (1991).

-Page 2690 Section 2.6 - what about socio-economic constraints to groundwater use? In some areas, farmers will not have access to deeper groundwater systems, leading to crop failure in extreme conditions.

We recognize that socio-economic constraints can limit the use a groundwater long before the aquifer is physically depleted. These constraints depend on a number of local conditions such as cost of energy, market prices for crops, legislative frameworks etc. We are convinced that including those factors in a modeling approach like the one we presented here will be extremely challenging if not impossible and well beyond the scope of this paper. See the reply to a comment from reviewer #2.

-Page 2691 section 3.1.1 - good to see that sensitivity analysis of the results to the 2 approaches has been done. The small difference suggests that, with respect to the conclusions at least, the spatial coherence of the rainfall is not important.

At the river basin scale, and looking at monthly values the differences were not significant. We will address this downscaling issue further in a separate paper. See also reply to reviewer #2.

-Page 2692 assuming that all areas equipped for irrigation will be irrigated in any particular year should result in an overestimation of the amount of irrigation (assuming that the estimate of the area equipped is correct). This will effectively mean that there is an unknown irrigation efficiency factor included in the model - analysis of the sensitivity of the model to the efficiency factor should enable the authors to assess the impact of the uncertainty in the area irrigated each year would have on their conclusions.

We agree that estimates of irrigation water withdrawal are highly uncertain. These uncertainties are related to the irrigated areas, the efficiency of irrigation, and many other parameters. We have addressed this issue in the uncertainty section in the discussion.

-Page 2694 line 10 - I recommend change "thus increasing runoff" to "thus increasing runoff assuming total leaf area is unchanged". The impact of increased CO_2 on plants is not just a change in the transpiration per unit leaf area. There may also be an impact on the leaf area. In both cases, the impact will be species dependent, so it is difficult to conclude that increased CO_2 will result in increased runoff unless the change in total leaf area is also addressed.

Thank you for the comment! We have changed the sentence according to your recommendation.

-Hamon (1963) is an empirical model - scale of applicability?

Hamon (1963) is an empirical, simple model to estimate potential evapotranspiration only based on the location and the mean air temperature. We added:" Vörösmarty (1998) used 11 commonly used evapotranspiration functions for a water balance model applied to the conterminous US and found that runoff estimates produced using the Hamon function had the lowest bias of all tested reference evapotranspiration functions when compared to observed values. Similar findings have been reported by Oudin et. al. (2005) who tested a set of 27 evapotranspiration functions over a large set of catchments around the globe and concluded that simple temperature dependent function produce the best results with regard to model efficiency and found no advantage in using more complex methods."

-Page 2695 line 1 - while the parameters have not been calibrated to match the observed discharge, presumably the selection of parameter values has been made based on an understanding of the model behaviour built through previous use of the model.

We added an extensive discussion on sensitivity of model results to parameters. See also reply to comment from reviewer #2.

-Page 2696 line 4 - is equation 21 constrained to be between 0 and 1? Certainly, a perfect model gives a value of 1. If the predicted value is the mean observed flow, then d_2 will be 0. If the predicted values are extremely high, then d_j will approach 0. However, if the predicted value is zero everywhere, then?

If $P_i = O_{mean}$ for all i, then d = 0.0. If $P_i = 0$ for all i, then d takes some value between 0 and 1.0. Out of the 668 gauging stations, there was only one station where P_i was zero for all i and we did not include that one in the calculations.

Figures and tables

-Page 2726 Both Fig 3 and 4 show the significant trends in modelled annual values of runoff. What is different between this figures (other than a reversal in the look-up table)?

Figure 3 shows the trends in evapotranspiration, figure 4 shows the trends in runoff. The captions for the figure have been changed. Page 2727

-Figure 5 is difficult to read. Given that Figures 3 and 4 are in colour, why not give Fig 5 in colour?

Figure 5 was indeed difficult to see. We changed it to a color figure.

-Table 3: There is an increasing trend for the Atlantic and Artic Oceans, while the Indian and Pacific Oceans show the greatest impact from irrigation. Figure 3 suggests that there is a significant increase in the discharge from Canada into the Atlantic, and also from southern Brazil to northern Argentina, as well as an increase in the Amazon. Presumably the increase for the Amazon is driven by deforestation. What is driving the increase in the natural outflow from eastern Canada and southern South America? Are these also driven by deforestation ? While the increase in the discharge from south western Australia may be significant, I would suspect this would still be very small contributor to the overall discharge given the area is arid to semi-arid. Could you give a figure showing the distribution of predicted discharge? Our study only considers two scenarios to determine trends in hydrological components; the natural conditions and the conditions that are influenced by irrigation and reservoirs. We do not consider any effects of land use changes such as deforestation in the model.

We will provide a map showing the mean calculated runoff in each grid cell. However, as we already have 11 figures, this will be in the supplementary material.

-Figure 3 also shows that the biggest impact due to irrigation is in the region of the Himalayas. Is your network model taking into account the interbasin transfers which dominate through India? I suspect this is not considered in the model. Given the

difficulty in getting streamflow data in the region, what confidence do you have in the model's performance in this region? Given the strong irrigation signal in this area, presumably this is the main contributor to the difference between the predicted natural and disturbed flows into the Indian Ocean. Is this correct? This is correct. At this point, we do not consider inter-basin transfers in our model. We have plans to do so in the future, but are aware of the challenges in mapping such transfers at large scales. We compared our predicted discharge to observed discharge for the Krishna river basin (one of the most heavily influenced basins in the region) and significantly improved those predictions when considering the effects of irrigation and reservoirs.

-The dominant contributor to global flows (Fig 6) is the inflows to the Pacific Ocean. Presumably this is due largely to the inflows from Asia (China through to Thailand). Fig 7: I suggest using the same format as for Fig 6 (i.e. a black and grey line rather than the dotted line). No obvious trend in plot for Amazon - assuming the clearing of the forest has been included in the model, the suggestion is that the amount of clearing has not yet had a significant hydrological impact (at least in terms of annual runoff). Is this correct, or is there a trend in the rainfall? There is a trend in rainfall. As mentioned above, we do not consider changes in land use other than the expansion of irrigated areas.

-Fig 8: the model does not do as well for the Amu Darya and Sr Darya rivers. For the Amu Darya, it appears there is a lag not accounted for in the model, with observed flows delayed with respect to the modelled flows. Reason?? For the Syr Darya, the model is over predicting peak flows during the wet years. Could this be a problem with the rainfall data, streamflow data or the model?

Discharge in the Syr Darya if overpredicted because for both natural and disturbed conditions. We added : " It is important to note that discharge in the Syr Darya if overpredicted because for both natural and disturbed conditions. One of the reasons is a significant loss of water (through evaporation and seepage) in both rivers during their passage through the desert) that is currently not considered in the model. Nezlin et. al. (2004) estimated that these losses amount to 30% of the flow."

Minor errors were corrected according to the reviewer's suggestions.

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