Response to short comments on submission to Earth Syst. Dynam. Discuss., 4, 355-392, 2013 (doi:10.5194/esdd-4-355-2013)

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

First of all, we would like to thank Prof. Petra Döll for her constructive comments and thoughtful suggestions on our paper. They helped us to substantially improve the quality of the manuscript. Our detailed responses to the comments are presented below.

Response to short comments (reviewer's comment in italics, changed text between quotation marks):

SC1. I would like to make some suggestions which aim at making the article more informative. I think the article could be improved by explaining more clearly the new modeling algorithm, and the motivation for choosing the algorithms. This refers to, for example, equations 6 to 8. More importantly, please add information on how you compute the soil water balance, in particular how you compute runoff. In addition, I suggest showing the computed consumptive (irrigation water use) as compared to (gross) IWR.

A1. Similar points were also raised by the Anonymous Referee #1 and #2. To clarify the new aspects and major goals of this study, we have revised Section 1 (Introduction) and 2 (Methods). We have also added further discussion about our new framework compared to previous approaches to clarify the advantages of our approach and to highlight the major and new findings in Section 5 (Discussion and conclusions). As suggested, we have added the information on how we calculate the soil water balance and runoff. In addition, we have added the information on simulated consumptive irrigation water use in Table 2.

SC2. Regarding data, what is the source of the saturated and residual/wilting point water contents? For the temporal development of irrigation, did you use FAOSTAT data of time series of irrigated areas per country?

A2. The data of the saturated and residual water contents are based on the Digital Soil Map of the World (DSMW; FAO, 2003) and the WISE dataset of global soil properties (ISRIC-WISE; Batjes, 2005). The wilting point ($\theta_{E\_wp,j}$) for each soil layer (j) was calculated with matric suction (m) at wilting point (ψ_{wp}), matric suction (m) at air entry value ($\psi_{ae,j}$) according to Clapp and Hornberger (1978), and pore size distribution parameter (β_j) (varies on average between 4 and 11 over the range from sand to clay) according to Clapp and Hornberger (1978):

$$\theta_{E_{wp,j}} = \left(\frac{\psi_{wp}}{\psi_{ae,j}}\right)^{\left(\frac{-1}{\beta_j}\right)} \qquad \text{(S1)}$$

We estimated the historical growth of irrigated areas by downscaling country specific statistics for ~230 countries (FAOSTAT; http://faostat.fao.org/) to 0.5^o by using the distribution of the gridded irrigated areas for 2000 (Wada et al., 2011a).

Batjes, N. H.: ISRIC-WISE - Global data set of derived soil properties on a 0.5 by 0.5 degree grid (Version 3.0), Report 2005/08, ISRIC – World Soil Information, Wageningen, The Netherlands, 2005. Available at http://www.isric.org/data/isric-wise-global-data-set-derived-soil-properties-05-05-degree-grid-ver-30

Clapp, R. B., and Hornberger, G. M.: Empirical equations for some soil hydraulic properties, Water Resour. Res., 14(4), 601–604, doi:10.1029/WR014i004p00601, 1978.

Food and Agriculture Organization of the United Nations (FAO): Digital Soil Map of the World, Version 3.6. FAO, Rome, Italy, 2003. Available at http://www.fao.org/nr/land/soils/digital-soil-map-of-the-world

SC3. In particular, even though section 2.6 is titled "Water allocation and return flow", nothing at all is mentioned about return flows even though the assumptions made on return flows are important for the estimation storage and flow changes. Regarding the description of water allocation, please clarify, if Qbase is the long-term average value or not. Please clarify also what "predominantly" and "available groundwater storage" means in the case of existing reservoirs: "We first allocated surface water predominantly to meet the water demand, and the remaining water demand was met from available groundwater storage or S3".
A3. We have revised Section 2.6 (Water allocation and return flow) and added explanations of the calculation of return flows and the assumptions therein. Q_{base} is the simulated daily baseflow, rather than the long-term average. We have revised the section to clarify our allocation algorithm.

SC4. With the allocation algorithm, you compute (page 370 line 15) that "during the recent period 1990-2010, the rate of groundwater withdrawal increased to 3% per year (or rather "groundwater withdrawals" increased yby 3% per year), ...". But unless there are upstream reservoirs, groundwater is, in the model, abstracted first (with a fixed percentage of total water demand), so that gw abstraction and sw abstraction should change at the same rate as total water demand. So the stronger increase of gw use after 1990 is calculated due to water demand increases in grid cells downstream of reservoirs? Is the percent changes in groundwater and surface water withdrawals just a function of changing reservoir numbers? In the model, do you take into account the construction date of all the 6800 reservoirs? What happens in your allocation scheme if available surface water on day x is smaller than demand for it? Please explain how certain you are about the computed temporal changes in the fraction of groundwater withdrawals (in particular as you include this result prominently in the abstract.
A4. The amount of simulated groundwater withdrawal varies depending on the fraction of baseflow to average discharge (that varies daily) and available surface water that is subject to climate variability and the number of reservoirs based on the GRanD. As noted by the Referee, the number of reservoirs (downstream/upstream) and downstream demands largely affect the amount of groundwater withdrawal in our allocation scheme. In addition, increase in upstream withdrawals (~demands) and

change in upstream surface water availability also affect the amount of baseflow and groundwater storage (S3), which in turn influences groundwater withdrawals from groundwater storage downstream. The reservoirs were placed over the drainage network according to their construction years based on the GRanD. As noted by the Referee, the temporal increase in simulated groundwater withdrawal is driven strongly by the increase in total water demand and the variability in surface water availability (including reservoirs) over the period 1979-2010. If available surface water is smaller than demand, the demand is imposed over available groundwater storage (S3) and then nonrenewable groundwater (if the demand exceeds the available groundwater storage). Trends of our simulated groundwater withdrawals were compared to those of reported values per country over the period 1980-2005 (Figure 3). The results generally show good agreement over 19 countries where the reported values were available. We have revised Section 2.6 (Water allocation and return flow) and 5 Discussion and conclusions to clarify these points.

SC5. When comparing modeled groundwater and surface water withdrawals with data (as in Fig. 2 and Table 3), a clearer picture of the fit can likely be obtained by comparing the modeled groundwater withdrawals (or surface water withdrawal) as a fraction of total water withdrawals to the respective ratio computed for the independent data. In Fig. 2/Table 3, both the ability of the model to compute total water withdrawals (which is at least partially covered already in Fig. 1) and the source fractions are confounded.
A5. This is a very good point. We thank for the Referee for the suggestions. As suggested by the Referee, we have revised Figure 2 and added panels comparing the fraction of simulated groundwater withdrawals over simulated total water withdrawals to that of the independent data. We have also created another figure/table comparing simulated total water withdrawals to reported values over the global and each region listed in Figure 2.

SC6. On page 373 line 27, I think you wanted to refer to Döll et al. 2012, not Döll et al. 2009.
A6. We have changed to Döll et al. (2012). Thank you for pointing out this.