Response to Referee #1 comments

by J. Jarsjö et al., 2011, regarding HESSD paper "Hydrological responses to climate change conditioned by historic alterations of land-use and water-use"

- From the manuscript it is unclear how the authors consider the seasonality of changes in precipitation, temperature, runoff and discharge and the possible biases in seasonality of temperature and precipitation calculated by GCMs. The timing of precipitation and evaporation maxima and their coincidence will also have a major impact on resulting river discharge. Were the GCM projections applied on a monthly time-scale to the CRU precipitation and temperature? The authors should consider this change in timing and seasonality and its impact as well.

→ The model independently quantifies three principal outflow components of lake drainage basins, namely the discharges of the principal rivers into the lake, the diffuse flows along the shoreline of the lake (from groundwater and small, transient streams) and evapotranspiration over the land and water surfaces of the lake drainage basin. The quantifications are based on input of long-term average conditions. The methods section has been considerably extended, explaining how these flows (e.g. evapotranspiration, surface water, groundwater) are modelled. The adopted Langbein (1949) model performance in the specific case of the Aral Sea Drainage Basin has previously been compared with the Thortwaite (1948) method, which uses monthly data as input (7602/25-27). The comparison showed that the ET and R of the two methods were equally consistent with *historical observations*. In response to the above question, we have now performed new model runs with the Thortwaite method on a monthly time-scale, considering conditions of the here studied *future climate projections*. Results showed that the predicted total ET of the ASDB given by the adopted Langbein method differed by approximately 3% from corresponding Thortwaite results, which for instance is considerably smaller than the ET differences caused by the differing output of the considered GCMs. The characteristics of the presented ET change and runoff change results are hence relatively robust with regard to ET model choice.

- Page 7600, section 2: In this section a description of the basin is given. According to this section river flow is only depleted by irrigation. Is there any other water use (drinking water, industrial, domestic) in the basin. And if so, what percentage of total water use is covered by irrigation?

→ The water diversions for agriculture have a relatively constant share at around 90% of the total diversions, since at least the 1960's. In addition, in contrast to many other sectors, the agricultural diversions result in actual water consumption (physical loss of water from the surface of the basin through evapotranspiration ET, leading to river depletion) to larger extent than many other sectors, due to the fact that water is spread over extensive agricultural areas, which makes it relatively available for ET. We make these points clear in the revised manuscript.

- Page 7602, section 3.1,line 10: ET is calculated with the Turc equation. Given the relevance of ET for this study, please give the equation and the motivation for using this equation. The references to work of Shibuo et al. 2007 and Asokan et al 2010, do already give enough information on the impact of the uncertainties in ET equations.

→All the used ET equations are now given in section 3 (Langbein, Thorntwaite, Turc). They have in previous studies been shown to independently reproduce long-term (multi-decadal) hydrological changes in the Aral Sea Drainage basin, caused by irrigation expansion.

Specifically, for both pre-irrigation conditions and post-irrigatrion conditions, the model was found to match river flow (Q) observations without need of calibration; the modelled ET differed by only 2% from the ET derived from water balance closure. We now also explain explicitly in the manuscript that this observed agreement provides support for the model's predictive capacity of slow boundary-condition driven, future changes (such as the hydro-climatic changes at focus in this study), in which the system has had time to respond to the changed forcing conditions.

- Page 7602, section 3.1, line 8: "network-routed sum of locally created average precipitation surplus". What routing technique is applied? Is a routing scheme included?
Is there a realistic delay in river flow, which is certainly of relevance in a basin of this size. Is open water evaporation from the river considered? And would this impact the results of the study?
→ Flow directions are estimated on the basis of the digital elevation model. Each grid cell is associated with a unique flow direction (N, NE, E, S., SW, W, or E, for a grid that is oriented in the N-S and E-W directions), into the neighbouring cell with the lowest elevation. The delay in river flow is small relative to the multi-decadal scales that are at focus in this study and are not explicitly considered. In response to the evaporation question, we performed new simulations, in which the handling of free water evaporation was refined. More specifically, this was done by using the expression for potential ET (ETp) at river water and reservoir grid cells, instead of the precipitation-limited Turc expression for actual ET. Results showed only minor differences in predicted total ET of ASDB due to this refinement, on the order of 0.1-0.2%. The revised manuscript provides a more detailed methods description and also includes the new sensitivity analyses.

- Page 7603, section 3.2, line 27: "Results for the future period are then based on adding the GCM change projections". Please clarify how this was done. Were the changes projected on an annual or monthly base? Were the changes projected for each GCM individually and were the resulting ET, R and Q results averaged or were the GCM average P an T projections used?
→ We clarify that projections of long-term, average conditions were used, and that the hydro-climatic modelling was performed individually for each of the considered GCMs (20 different), time periods (2 different), and water application scenarios (2 different), also duplicating the number of model runs by use of two alternative approaches to hydro-climatic model coupling (i.e., the uncalibrated and calibrated approaches; in the revised manuscript re-named to approaches with and without bias-correction in response to comment of reviewer #2). This hence resulted in the total number of 2*20*2*2=160 hydro-climatic model simulations. On top of this, more simulations were performed in an iterative way in order to quantify water application – climate change interaction effects (7604/9-13). Furthermore, in the revised manuscript, new simulations were performed on a monthly basis with the alternative Thorntwaite ET method, in order to further assess the adopted Langbein (1949) ET model performance. We also investigated the potential influence of open water evaporation from rivers (see above).

- Page 7604, section 3.2, line 5: Unclear, see comment above, ET change for each GCM individually or ensemble average ET change?
→ The hydro-climatic modellig was performed for each GCM individually, see above.

- Page 7605, section 4, line 5: The authors state that the GCMs projected quite different changes in P. Did they consider the fact that averaging opposite changes will result in

→ Since the results from the different GCMs were treated individually (see above), we did not average the input to the performed hydro-climatic modeling.

→ A main reason for this non-linear response is that the basin-scale ET approaches P in magnitude. This means relative changes in runoff R must become considerably larger than the corresponding relative changes in P or ET, as can be understood from the basin-scale, long-term water balance R=P-ET (since R→0 as ET→P, it can change by orders of magnitude for relatively modest ET changes). For the considered historical period 1960-1991, we have ET <(<) P, both according the observations and GCM results. Hence, combining the historical GCM results, the future GCM projections and the above analytic perturbation analyses, we can conclude based on GCM data alone that the responses were much less non-linear in the past. This is now made clear in the revised manuscript. It hence shows that the behavior cannot be explained by use of observational data for the historic period and use of GCM data for the future period.

→ The no-irrigation scenario is a limiting case of irrigation reduction. As we now explain in the manuscript, it is however clear that irrigation could be largely reduced in the basin also in practice. This is because the irrigation system counts as one of the world´s most inefficient, e.g. having several times higher water diversions per arable area than similar areas in other parts of the world, due to inefficient irrigation techniques and losses in the distribution system. This means that water application could be reduced even if the water demanding cotton and rice production is maintained. The water application could be reduced even more if alternative, less water demanding crops were introduced. This is now discussed in the end of the revised manuscript.