Response to Referee #2 (Howard Reeves) comments on HESS-D paper (Sutanudjaja et al., 2011, doi:10.5194/hessd-8-2555-201)

Response to the general comment:

We are very grateful and would like to thank Dr. Reeves for his high appraisal of our paper and valuable suggestions and comments.

Response to the specific comment #1:

RC: I would encourage the authors to expand the discussion on the uses and limitations of this type of modeling. In particular, because of scale it does not simulate the impact of pumping in the region. The authors could address the major uses of this type of model for data-poor areas.

AC: We agree to expand the discussion on these issues. We indeed agree that the model has some limitations; particularly it did not include groundwater abstraction by pumping activities as there are no global- or globally available- datasets on pumping activities that can be meaningfully resolved at our model resolution, which is 30 arc seconds. As far as we know, Wada et al (2010) is the only study estimated global groundwater abstraction, however, at a very coarse resolution of 30 arc minutes. Thus, we acknowledge that our model may not be suitable for areas under heavy anthropogenic water extraction and represents a situation of "natural" aquifer re- and discharge. However, we argue that our model is still very useful to assess impacts under an uncertain future climate, such as changing precipitation and temperature. Moreover, if such information of groundwater abstraction is available, it can be easily incorporated in our model.

Response to the specific comment #2:

RC: On page 2578, the authors state that MODFLOW was run with constant KD and Sy, which will circumvent problems with dry or flooded cells. I suggest making this assumption more explicit in the discussion of the MODFLOW model at the beginning of section 2.4. Challenges to handling simulated water levels above land surface in the coupled model could also be discussed.

AC: We indeed assumed constant *KD* (transmissivity) and *Sy* (specific yield or storage coefficient) for our single aquifer layer for MODFLOW simulation. We agree to make this assumption more explicit in our revised manuscript. The reason behind this assumption is mainly to speed convergence of MODFLOW's iterative solving process. To be more technical, please note that in our BCF package, we imposed a "LAYCON = 0" layer (see McDonald and Harbaugh, 1988, Chapter 5) that assumes the following conditions.

1) The transmissivity *KD* is constant in time, independent of the actual thickness of the water table or the saturated zone. This condition is suitable for our study because groundwater head fluctuation is mostly expected to be only a small fraction of thickness of our single aquifer layer. This condition also implies that our MODFLOW cells will never be "dry", i.e. its groundwater head will never fall below the aquifer bottom elevation, of which the situation should hardly occur within our single aquifer layer.

2) Moreover, the rate of change in storage of each cell was calculated by using a constant storage coefficient and ignoring the fact that there might be a "transition" from a "confined groundwater head" situation to a "water-table groundwater head" situation, or vice versa. Here we mean the "confined groundwater head" is the situation when groundwater head has risen above the aquifer top elevation, but there is a confining layer above the aquifer. The "water-table groundwater head" situation is defined for groundwater head fluctuating in a phreatic aquifer (without confining layer) or for groundwater head fluctuating under aquifer top elevation (or under confining layer bottom elevation). This second assumption is also suitable for our model because the model does not simulate the impact of pumping activities, especially the ones with on-off switching creating extreme head fluctuation (and introducing the aforementioned "transition" condition).

Therefore, we can conclude that this layer type ("LAYCON = 0") is reasonable to be used for our model. In addition, the other advantage using this layer type is the fact that it circumvents the problem of having to define the top and bottom elevations of an aquifer, of which information is not globally available.

Indeed, as pointed by the referee, the current model cannot handle properly simulated water table above the land surface elevation. In the reality, if groundwater heads (or water tables) rise above surface levels, groundwater should seep into the unsaturated zone and may occur as overland flows above the surface level (especially in phreatic aquifer cells). Such overland flow phenomena might be accommodated by means of various additional MODFLOW packages (e.g. Restrepo et al., 1998). However, they are currently irreconcilable with PCR-GLOBWB-MOD in its current form as the capillary rise from the groundwater has been disabled.

However, this limitation does not mean that the current groundwater model tends to simulate unreasonable water table above surface elevation. Provided surface water networks modeled by the RIVER and DRAIN packages (see Sect. 2.4.3 on our original manuscript: Sutanudjaja et al., 2011), the simulated groundwater heads are controlled by the calculated surface water level elevations (HRIV, see Eqs. 47-48) and their drainage properties (conductance CRDR, river bottom elevation RBOT and median drain elevation DELV, see Eqs. 47-50). Therefore, if reasonably correct drainage properties are provided, the simulated groundwater heads should not exceed the surface elevation as long as the calculated surface water levels are below the surface or bank elevation.

Response to the minor technical corrections/comment #1:

RC: In the title and the text, the authors refer to the model as "large-scale"; but large-scale refers to detailed maps. This regional model would be "small-scale" in the terminology used in geography.

AC: We agree that the term "large-scale" is not really appropriate to be used here. A better term that can replace it is "large-extent", where Bierkens et al. (2000) define "extent" as "*the area (or volume) or time interval over which observations are made, model outcomes are calculated or policy measures are to be made*". However, it is a pity that the hydrological communities prefer to use the wrong one ("large-scale"), as used for a session topic in the last EGU meeting (2011):

"Large-scale hydrology: observations and modeling"; and a topic in the last AGU meeting (2010): "Mega-scale hydrogeology: the promise and challenge of examining groundwater systems at regional and continental scales." For the revised manuscript, we will keep using "large-scale" (because it is more familiar for the readers) but add the aforementioned explanation.

Response to the minor technical corrections/comment #2:

RC: In bullet 7 on page 2578, the authors refer to Sy as porosity. I suggest using specific yield or storage coefficient (as used in the following paragraph).

AC: We agree that *Sy* must be defined as specific yield or storage coefficient.

Response to the minor technical corrections/comment #3:

RC: I found the discussion of equations 42-44 a bit confusing. I understand that the area of the cell computed in MODFLOW by multiplying Dx × Dy is not the true area of the (30" x 30") non-rectangular cell. The equations, however, do not appear to be dimensionally consistent. Instead of (30" x 30") in the denominator, perhaps a variable for 'apparent' MODFLOW area could be used A_{MF}. With that change the equations would look dimensionally consistent. A small sketch showing a (30"x30") cell and a rectangular cell also would be helpful but maybe more detailed than necessary.

AC: We agree to use the 'apparent' MODFLOW area A_{MF} in the denominators of Eqs. 42-44. This is a very good suggestion. However, we think it is superfluous to provide the sketch of a 30" cell.

References:

Bierkens, M. F. P., Finke, P. A., and de Willigen, P.: Upscaling and downscaling methods for environmental research, Kluwer Academic Publishers, Dordrecht, 190 pp., 2000

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Restrepo, J. I., Montoya, A. M., and Obeysekera, J.: A Wetland Simulation Module for the MODFLOW Groundwater Model, Ground Water, 36 (5), 1745-6584.

Sutanudjaja, E. H., van Beek, L. P. H., de Jong, S. M., van Geer, F. C., and Bierkens, M. F. P., Large-scale groundwater modeling using global datasets: a test case for the Rhine-Meuse basin. Hydrology and Earth System Sciences Discussions 8 (2), 2555-2608, 2011. http://www.hydrol-earth-syst-sci-discuss.net/8/2555/2011/

Wada, Y., van Beek, L. P. H., van Kempen, C. M., Reckman, J. W. T. M., Vasak, S., and Bierkens, M. F. P.: Global depletion of groundwater resources, Geophys. Res. Lett., 37, L20402, doi:10.1029/2010GL044571, 2010. 2556