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Interactive comment

Interactive comment on "A global-scale two-layer transient groundwater model: development and application to groundwater depletion" *by* Inge E. M. de Graaf et al.

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Gradient-based groundwater modeling at the global scale is a big challenge, and it was very interesting to me to see results of such an effort in the manuscript of de Graaf et al. I would like to make some comments and pose questions regarding 1) the groundwater modeling and its presentation in general (as there are a few aspect that need clarification) and 2) the estimation of groundwater depletion.

1 Global groundwater modeling in general

Page 5, line 20: Regarding discharge of groundwater to local springs etc. From the wording, it is not clear if water storage S3 is from PCR-GLOBWB or the elevation of the floodplain. Please clarify. How is the elevation of the floodplain determined, and where is it as compared to DEM, HRIV and RBOT? Please indicate in the manuscript how large this local drainage component is compared to total Qbf (globally).

Page 8, Line 4: If groundwater head falls below the bottom of the confining layer, is then the confined aquifer modelled as unconfined, and the storage coefficient set to the specific yield to Table 1 instead of 0.001?

Fig. 5: Typo in figure caption: Central Valley is unconfined, the Netherland confined.

Fig. 6: I was wondering whether all three graphs showing R and all three graphs showing QRE really have the same y-axis (they should!). The units for QRE are %?

Regarding QRE, model performance decreases according to Fig. 6, while the two examples in Fig. 5 show clearly the advantage of distinguishing between confined and unconfined aquifers, for the two wells shown. Why is this so? Can you localize where, in the confined parts of your model, assuming unconfined conditions leads to a better modeling of head amplitudes? I think it is necessary to include, in the conclusions (p. 14, l 12-14), that including confining layers leads to a worse simulation of head variations.

Fig. 9: In my understanding, Fig. 9 does not show flow paths but travel times. What exactly is shown? The travel time of the groundwater recharged at the grid cell shown? Please also clarify in the text on p. 12. I also think that your conclusion (page 14, lines 18-20) is not backed by Figs. 9 or 10. Fig. 9 shows shorter travel times in case of confined aquifer modeling, while Fig. 10 shows significant importing/exporting in mountainous areas (not flat confined areas). (Units are missing on y-axis of Fig. 10).

2 Simulation of groundwater depletion

Page 13, lines 20-25: Please define “volume-based” and “flux-based” approaches. Do you compute groundwater depletion by subtracting heads and multiplying with the storage coefficient? Do you call your approach “volume-based? Otherwise, I would not agree with the sentence: "Figure 14 (Online Supplementary Information) shows that effect of hydraulic properties on the groundwater depletion volumes (note volumes, not heads) is considerable, which makes estimates of groundwater depletion by volume-based methods rather uncertain."

The development of the global sum of groundwater storage loss in cells in which net recharge is smaller than groundwater abstractions (as shown in Figs. 12 and 14) shows how sensitive this estimate is to parameter settings. If depletion assuming unconfined conditions only is (in 2005-2010 compared to 1960) twice the amount of that for confined conditions, I would think the model is overly sensitive. Equally important, Fig. 12, with an increase in groundwater storage before 1980 as compared to 1960, and an actual onset of groundwater depletion only in 1998 indicates to me that what you see in the first decades may be caused by the fact that 10 years of running 1960 (climate and water abstractions) on steady-state groundwater levels was not enough to get a reasonable situation of the state of groundwater heads in depletion areas in 1960. Or that the location of the groundwater table to which interaction with surface water is very sensitive was not close enough to reality (see Fig. 7 where e.g. differences of 20 m to observations are the rule but that would already have a strong impact on gw-sw interactions). How did the flows between rivers and groundwater develop over time in the depletion areas? Regarding the temporal dynamics, your simulation results show a large depletion of 5000 km3 in only 6 years (1998-2004), with relatively little dynamic at other times. Is this due to spatial averaging?

In page 4, line 27 you state that after 10 years of running 1960, a dynamic equilibrium was reached? Do you mean that after 10 years, groundwater heads did not change by +- x%? What value did you choose for x? As a test for sensitivity of Fig. 12, I suggest you rerun your model with 100 years of 1960 initialization instead of 10 years, and show the results in Fig. 14.

Another question regarding Fig. 14: The grey recharge-abstraction curve is more or less a straight line, e.g. the annual difference between groundwater recharge and abstraction is constant between 1960 and 2010. Can you explain why, as groundwater withdrawals are known to have increased significantly during these fifty years?

In Fig. 13 C, please add observations for High Plains Aquifer, while in Fig. 13A I suggest you use the same legend/color as in 13B, for better comparability.

In Fig. 11, use mm instead of km3.

In your comparison to other estimates of global groundwater depletion, please add a comparison to the maps and global values of

Döll, P., Müller Schmied H., Schuh, C., Portmann F. T., Eicker A. (2014): Global-scale assessment of groundwater depletion and related groundwater abstractions: Combining hydrological modeling with information from well observations and GRACE satellites, Water Resour. Res., 50 (7), 5698-5720, doi:10.1002/2014WR015595.

In this study, we took into account that baseflow is reduced (and then zero) in areas of groundwater depletion (but inflow of river water into groundwater is not simulated). Also, there is groundwater recharge from surface water bodies in dry areas (very rough estimate). In addition we assumed, based on comparing our modeling results to many independent estimates including GRACE, that 70% deficit irrigation is done in groundwater depletion areas. This resulted in a best estimate of global groundwater depletion of 2240 km3 for 1960-2000, and of 3257 km3 for 1960-2009. So according to your study, gw depletion increases much faster after 2000 than in our study, and the total value is higher.

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