Response to Editor´s decision and comments by reviewers.

The authors thank the Editor and reviewers for the thorough work on the manuscript. Their efforts are highly appreciated. Below find comments and actions taken by the authors.

Editor Initial Decision: Reconsider after major revisions (23 Jul 2015) by Graham Fogg

Comments to the Author:

Thank you for your thorough responses to the reviewers' comments. Because these proposed revisions are fairly substantial, and because I would like you to consider a few additional points, I am recommending that the manuscript be reconsidered after these revisions. I do not, however, anticipate sending the manuscript back out to reviewers. I ask that you revise the paper in accordance with the reviewers' and my comments.

Despite your response to Reviewer 1, I still agree with them that the methodology in your paper is not particularly new. Importantly, I do not believe the main contribution of the paper should be methodology. Instead, I think the main contribution can be (1) insights gained regarding climate change impacts in an arid region such as your study area and (2) insights gained regarding advantages of using a process-based groundwater model in this type of study, as compared to some of the other, less processed-based models or methods that have been used. I suggest you revise the paper in accordance with this alternative view of the contribution of your work.

Below are some additional comments with respect to your responses to the reviewers:

Reviewer 1:

1. In your response to item 3, at the bottom of the 3rd paragraph you state: "In contrast, it can be concluded that this is an inappropriate approach for assessing GW resources impacted by climate change in arid environments." You need to state why this is so.
As we mentioned in the manuscript: ''*In most arid and semiarid environments, direct recharge from rainfall is considered to be less than 1% of total rainfall. Thus, GW recharge mainly takes place during runoff and infiltration process''*.
''*According to this method, the predicted recharge is mainly based on direct precipitation, which may not be accurate, particularly, in arid regions where the direct rainfall recharge is expected to be less than 1.0% of the corresponding rainfall amount (Dugan and Peckenpaugh, 1985; Bedinger, 1987; Bouwer, 1989; 2000).''*

However the authors agree and we have deleted the sentence ''In contrast …'' from the manuscript.

2. In your response to item 4, you could point out that while it would be advantageous to use additional GCMs, you are focusing on system response, hence the key contribution of the paper can still stand if using only one GCM.
Thank you very much for the suggestion. The below text was added to the discussion section.
We agree and have modified the text according to:
''It should be mentioned that the ideal case for climate change impact studies on groundwater resources is to consider the outputs from different GCMs and compare the deltas derived from different models and apply either individually or as an average to hydrological models. However, in this study the choice of using only one GCM output is related to the scope of this study 1) to develop a methodology using a process-based GW model that is capable of evaluating climate change impact on GW resources in arid areas and 2) focusing on system response to different climate change and management scenarios.''

3. Uncertainty analysis under item 5: Recommend you rewrite your uncertainty discussion to include discussion of how uncertainty in the GCM and in your hydrologic models could affect the observed system response.
Thank you very much for your suggestion. We have rewritten the section according to below:

''Uncertainty analysis
Dams et al. (2012) argue that the uncertainty in climate change projections is rather high due to the uncertainties in future greenhouse gas emission prediction. The uncertainty is even larger when the climate change projection scenarios are integrated into hydrological models as the uncertainty accumulates at each step of the coupled approach. Therefore, there are many sources of uncertainty in climate change impact studies (Kay et al., 2009). However, in the present study, we only address the four crucial sources of uncertainty associated with various elements and approaches used in climate change projection and how uncertainty in these sources could affect the observed system response.

1) Uncertainty associated with climate model, which can be reduced by comparing the output of different climate model projections as they give the highest probable outcome. Thus, the multi-model average projection results are applied for each climate variable in the hydrological models (e.g. Serrat-Capdevila et al., 2007; Stoll et al., 2011; Dams et al., 2012; Barron et al., 2012). This methodology could have been an appropriate approach for reducing the climate model uncertainty in our study as we only used a single GCM output. Furthermore, reducing climate model uncertainty could have improved projections of our future water availability leading to better planning and adaptation responses. However, our study's contribution to the field of climate change impact studies is to apply a methodology by using a fully process-based GW model for assessing the GW reserve impacted by projected climate change scenarios rather than reducing climate change projection uncertainty.

Nevertheless, reducing the climate model uncertainty is a new research area for further study by applying the same methodology.

2) Emission scenario uncertainty for which there is no universally accepted methods of reducing the uncertainty, as the future world economy is still uncertain (Wilby and Harris, 2006). The terrestrial system response to the emission scenarios can vary substantially as there are significant differences between climate scenarios for a particular climate variable, e.g. precipitation. This would require having different water resources planning and adaptation policies in the future as system response to different scenarios.

3) Uncertainty in adaptation of the projected scenarios to the studied area, i.e. the delta-change. Studies (e.g. Hay et al., 2000; Kay et al., 2009) have shown that the delta-change approach is likely to under-estimate the range of uncertainty simulated from GCMs. This is because the delta change method is based on the changes in mean climate. In addition, the delta-change approach does not capture the drivers of extreme events and the precipitation distribution within storm events, resulting in uncertainty in the magnitude of surface runoff in the future projections. However, it is worth mentioning that in this study we used a process-based GW model that is able to simulate flood recharge based on the assigned flood period and not the magnitude of flood.

4) Hydrologic model structure and parameters uncertainty. Uncertainty and model sensitivity analyses regarding the GW recharge model were documented by Hashemi et al. (2012; 2013). Regarding the rainfall-runoff model, there is a degree of uncertainty mainly associated with input parameters, as they are collected from an adjacent basin, however, with great similarity to the studied basin. Nonetheless, agreement between the simulated and observed discharge values for the river, yielded convincing model calibration and validation results, therefore, less uncertainty (Fig. 8). It should be mentioned that uncertainty in the model results might cause over-estimation or under-estimation of predicted flood. This would have an impact on the policy of managing water resources and adaptation in the future.''

4. Under item 10 you mention that full details of the GW model have been published elsewhere, but please make sure you state this clearly in the manuscript. Furthermore, you still need to include at least a short paragraph indicating how representative of the hydrogeologic system the model is, and how you know this. In other words, you need to say something about how good you think the model is and what general calibration results you achieved to demonstrate this.

According to your suggestion we have rewritten the Groundwater modeling section (4.2.2).

''GW flow and recharge model was developed for the GBP using Groundwater Modeling System 9.1 (GMS). GMS is designed to provide tools throughout all aspects of the modeling process, e.g. pre-processor and post-processor, which can be used for various GW numerical modeling operations (Owen et al., 1996). To provide an integrated environment within GMS, a complete graphical user interface for the MODFLOW-2000 (Harbaugh et al., 2000), among other models, has been developed within GMS. For estimating aquifer hydraulic parameters and simulation of GW flow in the studied hydrogeological basin, a conceptual numerical model was created using

the MODFLOW-2000 finite-difference model. The available GW data for this study were observed hydraulic head for 6 monitoring wells since 1993. A 3-dimensional model was developed representing the studied aquifer and run for both steady-state and unsteady-state conditions. Then the model was calibrated and verified against observed hydraulic head in the boreholes.

In the steady-state modeling, ten different steady-state conditions were simulated and calibrated against the water table measured in observation wells. Accordingly, GW flow and boundary conditions were simulated and horizontal hydraulic conductivities were estimated. The results showed a consistency over a fourteen-year simulation period with estimated hydraulic conductivities ranging between 0.07 and 0.1 m day^{-1} (Hashemi et al., 2012). The outputs of the steady model were thus transferred to the unsteady model to estimate specific yield (S_y), recharge rate, and recharged water volume, through both natural river channel and artificial recharge system. The model period spanned between 1993 and 2007. In the first step, S_y was estimated in three different transient time intervals with no recharge but active pumping wells. The estimated S_y in different zones ranged from 0.008 to 0.10 with an average of 0.05. The average value of S_y was then transferred to the next transient intervals to estimated recharge rate for various recharge sources in the studied aquifer e.g. artificial and natural recharge areas (Hashemi et al., 2013). In the recharge simulation and in the case of flood events, all the artificial recharge areas plus river channel are considered to be fully flooded. It was estimated that during extreme rainfall events (three events during a 14-year period) more water was recharged through the ephemeral river channel (natural recharge) relative to artificial recharge areas (FWS). However, in the case of normal rainfall events, artificial recharge areas showed a significant contribution up to 80% while the natural river channel recharge contributes about 20% in the total recharge of GW. Full details concerning the development of the conceptual GW model, model design (e.g. discretization, definition of boundary conditions, and model input parameters), calibration and verification, and simulation results (e.g. GW flow and estimated hydraulic parameters) are documented in Hashemi et al. (2012; 2013).''

5. Also under item 10, the entire Qbox section needs citations.

Reference was added.

''Iritz, L.: Conceptual Modelling of Flood Flow in Central Vietnam. Department of Water Resources Engineering, School of Engineers, Lund University, Sweden http://www.imh.ac.vn/b_tintuc_sukien/dc_hoinghi_hoithao/L888-thumucuoi, 2014 (accessed 25.09.14).''

6. Under item 11 the authors proposed insertion still misses the point. "Wetter" does not necessarily mean more floods. Suggest inserting "possibly" before "resulting."

Thank you very much for the suggestion. The text was modified accordingly.

7. Reviewer comment 11800, 2-5: Authors change is not responsive to reviewer's comment.

We have added two references that address creating time series of projected recharge periods. Also, we have added the definition of recharge period and its modeling procedure in the ''Groundwater modeling section''. The added text is as follows:

''For the future recharge projections, the output of the rainfall-runoff model (future projections) was assigned as the input to the GW model. The projected flood events (inundation of ephemeral river channels and FWS basins) were considered as recharge periods in the GW model. For this, the recharge package in MODFLOW was used to simulate the recharge flux distributed over the area, i.e. recharge basins and river channels, and specified in units of length/time i.e. flood period or flooding time. It is noted that the magnitude of flood, i.e. flood discharge rate per time unit, cannot be specified in the recharge package, however, can be incorporated into simulation by extending or diminishing the recharge areas.''

8. Throughout: "couple modeling" is incorrect usage and should be replaced with "coupled modeling".
Thank you; they were corrected all throughout the manuscript.

9. The revised figure 1 has text in the inset window that is too small to be legible.
The figure was modified.

10. Response to reviewer comment 11817, 19-20: Authors revised text is still too strong, especially given the uncertainties, including those stemming from not using more than one GCM.
We have re-revised the text according to below:

''In general, the climate variable projection showed slight and not significant increase in rainfall under B1 and A2 scenarios in the near and far future, respectively. However, based on emission scenarios and the delta-change approach, the future climate is likely to replicate the climate pattern of the last 20 years (1990-2010). On the other hand, the studied region has suffered by severe droughts during the last decades (1990-2010). Annual precipitation has decreased by 40 mm in comparison with the average recorded rainfall from 1971 to 1990 (Fig. 7). The projections reveal that reduced rainfall amount is likely to be the predominant condition up to 2050. Thus, water stress will probably continue to substantially affect the studied region.

It should be mentioned that the ideal case for climate change impact studies on GW resources is to consider the outputs of different GCMs and compare the deltas derived from different models and apply either individually or as an average to the hydrological models. However, in this study the choice of using only one GCM output is related to the scope of this study 1) to develop a methodology involving a process-based GW model capable of evaluating climate change impacts on GW resources in arid areas and 2) focusing on system response to different climate change and management scenarios.''

Reviewer 2:

1. Reviewer suggests changing the title, which I agree with because I think the main

contribution is not the modeling method, but rather, insights on the system response derived from a process-based gw model. In response to this reviewers suggestion, the authors assert it is better to not change the title because the paper is already published in HESSD. This is not an appropriate reason for not changing the title.

The title was changed to ''*Coupled modeling approach to assess climate change impacts on groundwater recharge and adaptation in arid areas*''.