Interactive comment on "An extended modeling approach to assess climate change impacts on groundwater recharge and adaptation in arid areas" by H. Hashemi et al.

The authors thank the reviewer # 2 for his/her time and constructive comments on the manuscript.

H. Hashemi et al. present results from an interesting case study in Iran. The topic "climate change, flash floods, recharge with impacts on groundwater management in arid areas" is important and interesting. The work seems to be well designed and the connection between climatology and hydrology is good. The manuscript, however, will need much more focus on presentation and writing style. At present, the manuscript is unclear and some sections are too long which also makes the review of this manuscript hard.

Major comments:
Section 2:
- Is this section needed? If so focus on recharge in arid environment by river flooding. This must be reviewed somewhere shortly (in Intro maybe).

The primary scope of the study is to introduce an enhanced methodology for climate change impacts on GW resources. We believe that a literature review of similar methods carried out in the past few years is necessary. However, we thank the reviewer suggesting to include some explanation regarding recharge in arid environments in the introduction section. Accordingly, the below text will be added to the revised version of the manuscript (Introduction section).

"Runoff generation highly depends on rainfall quantity and intensity, morphological and geological characteristics, and land surface coverage of the catchment. Runoff will eventually end up in terminal salt lakes, wetlands or the sea. However, there are techniques that can be employed to artificially recharge the GW by diverting runoff from a river channel to a command area, e.g., spreading basin, infiltration pond, or injection well. Moreover, the lack of perennial rivers and other permanent watercourses in most arid areas means that runoff in the form of flash flood is the main source of surface water. For instance, floodwater spreading for artificial recharge is a technique by which destructive flash flood is diverted onto the spreading basins by means of a diversion dam. High velocity turbid floodwater enters the consecutive basins, slows down, and spreads uniformly on the flat area where it infiltrates and augment the GW. The flash floodwater in arid areas is characterized by high load of suspended materials, most of which is settled in the first basins. Thus, less turbid water reaches to the next basins, subsequently, recharging the GW reservoir. Yet natural and artificial recharge systems in arid environments are, inherently, dependent on floodwater/runoff. It is important to keep in mind that climate change may influence runoff quantity and temporal variability and result in the future GW recharge."

Section 3:
- A geological cross-section should be presented.

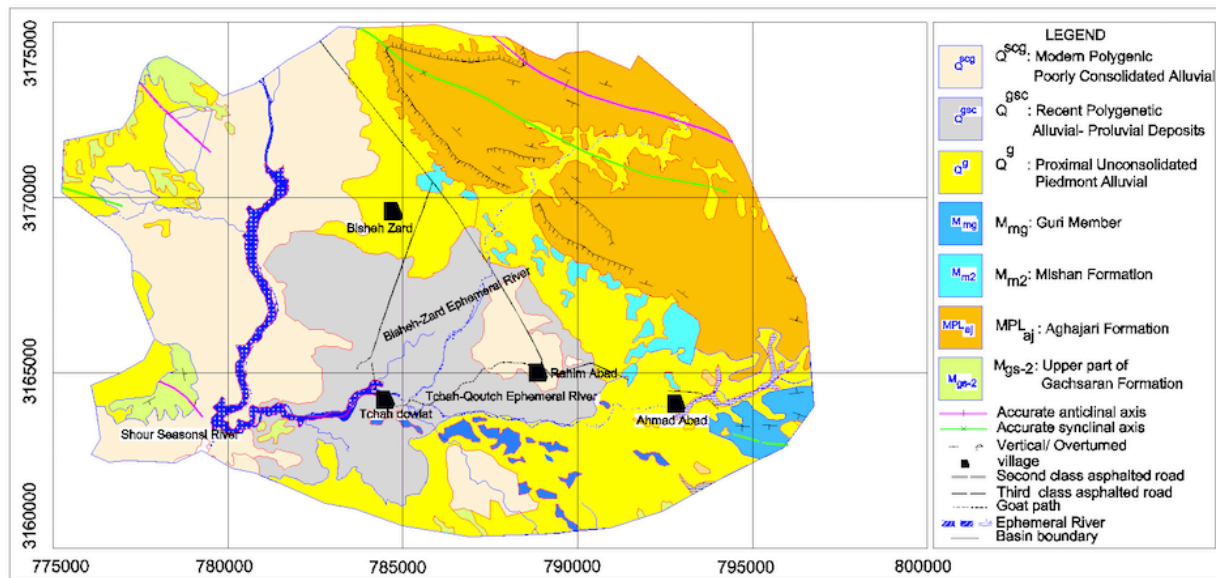*The below map will be added to the revised version of the manuscript.*

Figure X. Geological map of the Gareh-Bygone Plain and the upper basin (Bisheh-Zard).

- A conceptual model is needed to show main water fluxes.

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 (water fluxes, GW flow, and estimated hydraulic parameters) are documented elsewhere (Hashemi et al. 2012; Hashemi et al. 2013).

- The title could be improved to include some of the final outcome of this work

Thank you for the suggestion. However, since the paper is already published in HESSD, perhaps it would be better to keep the title as it is.

- The uncertainty of the modelling needs more attention.

We agree with the reviewer. Accordingly, the below section will be added to the revised version in the discussion section.

*"**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 accumulation increases of various sources of uncertainty in coupling approaches. 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 including 1) 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). 2) Uncertainty associated with climate model, which can be reduced by comparing the

output of different climate model projections as they give the highest probability 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 is an appropriate approach for reducing the climate model uncertainty in our study as we only used a single GCM output. Consequently, our study's contribution to the field of climate change impact studies is to develop a methodology 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. 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 as this method is based on the changes in mean climate variables. 4) Hydrologic model structure and parameters uncertainty. Uncertainty and model sensitivity analysis regarding the GW recharge model were documented in 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 good similarity to the studied basin. Nonetheless, agreement between the simulated and observed discharge values for the river, yielded convincing model calibration and validation results (Fig. 6)."

- A geological and conceptual model of the aquifer should be presented (an its uncertainty must also be discussed).

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 (GW flow and estimated hydraulic parameters) are documented elsewhere (Hashemi et al. 2012; Hashemi et al. 2013).

Minor comments:
- P. 11799 remove word "scholars"

Removed.

- P. 11800 line 4 Replace "hydrogeological" models with "groundwater" models.

Replaced.

- P. 11800 line 13-25 poor style and logic.

The entire paragraph has already been rewritten. Please refer to the response of the first comment.

- P. 11805 line 14 you say geology determine runoff amount??? Correct this. I suppose climate (P-ET) determine rainfall amount (or T if snowmelt).

We agree with the reviewer, however, non-vegetated steep slopes and the imperviousness of a catchment surface, i.e., covered by sandstone, siltstone or marl, can be the additional factors in affecting runoff.

Section 3.1
- The role of increase water used after MAR could be better highlighted in this work (as this is important information to the water management community, even if it is already reported in some other studies).

Thank you for the suggestion. The text was enhanced to include facts about the increase in water consumption after the artificial recharge project.

"Due to the positive effects of the artificial recharge project on GW availability, the area of irrigated farmland has increased eight-fold to 1193 ha and the number of pumping wells increased ten-fold to 120 wells as compared to the situation in 1983 (Kowsar, 2008). The region is rural and before the FWS project the residents undertook traditional animal husbandry, but subsequently converted to agriculture. At present, over 83% of the households are dependent primarily on agriculture (Ahmadvand and Karami, 2009). In general, the gain through artificial recharge, however, has decreased by too much abstraction by the numerous new-drilled pumping wells after 1996. Hence, the GW declined over 10 m in spite of the artificial recharge system."

Section 3.3
- Here you repeat information from earlier.

The first sentence will be deleted in the revised version.

Section 3.4
- Why did you not use a common empirical model to get ETP? Was you approach better?

There are various methods to derive ETP from temperature. However, we believe that a simplified method, i.e. a statistical method, which is scientifically sound, makes a lot of sense in this study for which several different techniques have been already employed to assess climate change impact on water resources.

Section 5.3
- Here also some results are repeated.

Thank you for the comment. The authors agree, therefore, the first two sentences will be omitted in the revised version.

The result section 5
- Start with a text does not seem to be related to "results".

The first sentence will be removed in the revised version.

- The result section in general is poorly written with a mix of method and results.

The authors thank the reviewer for pointing that out. We will try to eliminate the parts, which seem to be more of a method explanation rather than results presentation. We will also pay more attention to this section in order to improve the results presentation in the revised manuscript (as it was pointed by the reviewer # 1 as well).

- It seems that old CC scenarios are used which needs justification.

The new generation (5th) of GCMs was released in the mid-2014. But the climate change projection of the presented study was done in the beginning of 2014.