Authors comments in reply to the reviewers' comments on "Small farm dams: impact on river flows and sustainability in a context of climate change"

Response to reviewer P. Dumas

The authors are grateful to P. Dumas for his useful comments on our paper.

"The paper on the modelling of small dams effect on inflow in France is interesting and handle correctly the issues inherent to modelling small reservoirs that are not present in statistics. Overall, the paper is well written, cites appropriately existing literature and present interesting results and methodologies. There is a major issue, however, on methodology description. Indeed, an element of the methodology remains unclear, namely, whether the water collected by small dams is only the runoff from precipitation or also rivers runoff for river going through the cell. The description of the methodology seems to imply that only the runoff from precipitation is collected by the small representative reservoir, but since it is also said that water from rivers is used, it remains unclear. A sentence says: The small farm dam module was connected to SIM with a daily time step by collecting both the simulated surface runoff and infiltration (Fig. 2). But at other places, there is a reference to water from rivers being collected. This should be stated more clearly.

Indeed, the text could be misleading. The small farm dams are expected to collect water that flows in brooks. Such brooks are too small to be simulated by the model explicitly. However, it is expected that the runoff and infiltration simulated by the model can be used to estimate the flow that is captured by the small farm dams. As these fluxes are the inflow of the main rivers the fact that part of these fluxes are stored in small farm dams directly impact the flow of the main rivers (river that are large enough to be simulated by the model).

To improve this point, it is now written:

- Introduction: *"Although irrigation dams can be large, most of them are associated with reservoirs of small storage capacity located on farms, and thus usually not connected to the main rivers, but connected to small brooks."*
- section 2.2: *"Although it is not always the case, the reservoirs are considered to be filled up by capturing small brooks (even, temporary brooks). These brooks are not explicitly represented in the model, but the water that flows in such brooks can be estimated by considering the surface runoff and infiltration produced on the corresponding watersheds. Such approach is not fully compatible with the small farm dams that fill up by pumping from rivers. Such dams are then able to collect water from a larger area than the small dam's catchment, and the chosen modelling approach will then tends to underestimate their filling ability."*

Another related issue is that what determines the quantity of inflow is collected by the representative dam is never clearly said. My understanding is that the share of cell covered is translated to a share of inflow collected, but it is not said anywhere, or not clearly enough.

The dams are supposed to collect all the water from that flow in their catchments during the filling period, as long as the dams are not filled up. Indeed, this hypothesis is compatible with the management of these small farm dams, since there is no commitment to assure a minimal flow in the collected brooks (as they may be temporary brook). However, a maximum inflow was set to 1 m^3/s (p 7, line 25). This maximum inflow was set in order to be compatible with those small farm dams that fill up by pumping. However, this limit is not a big constraint, as this threshold is barely reached in the small catchment area of the dams.

To make it clearer it is now stated at the end of section 2.2: *"The small farm dam module was connected to SIM with a daily time step by collecting both the simulated surface runoff and infiltration that flow in their catchment areas (Fig .2). All the flow can be captured as long as it is below the 1* m^3/s *threshold and that the dam is not yet filled up."*

Also there are reports of significativity all over the paper, it is unclear to me how it is computed. It would be relevant to explain it formally once.

It was written section 3.3.3 "The significance of the results was estimated using a bootstrap approach." To better explain this part, a section 2.3 Assessment method is added. It is now stated in this section: *In order to establish if the impact of small farm dams is statistical significant, a statistical method was used. As the presence of small farm dams is always reducing the river flows, in order to test the statistical significativity of the results, a bootstrap approach was used. Such approach allows verifying that the differences between the cases with and without dams are statistical significant compared to a random rearrangement of the distribution obtained with the two cases. To do so, the two samples are rearranged a thousand times with mixed values, and the differences between the two rearranged sets are computed, and their distribution is analysed. The results are statistical significant at the 5 % level if the probability to reach the results in the distribution is lower equal to 5%. The same approach was used to infer the statistical significativity of the results in the context of climate change.*

Minor comments

P9, 1st paragraph. This sentence is now rewritten: *However, the characteristics of the existing small farm dams are not well known. An investigation in 1997 reported less than 180 dams larger than 2000* m^3.

In section 3.1, it could have been relevant to include the existing 0.186 % of small dams already existing. My understanding is that they are not included, maybe a word explaining why they have not been added for the evaluation could be added here

It is correct that section 3.1 is devoted to the assessment of the modelling without small farm dams, while section 3.2 is focussing on the impact of the small farm dams in the hydrosystem. Indeed, the assessment is made on a 30 years period, from 1970 to 2000, and the development of the small farm dams during this period is not well-known. By assuming no dams at all during this period, it is expected to get an overestimation of the flow. Such overestimation is indeed found and discussed in this section.

To make this point clearer, prior section 3.1, the following text was added: *"As the development of these dams along the period 1970 to nowadays is not well-known, it is chosen to run a simulation without small farm dams, and to compare such simulation with the observations. It is expected that the model will overestimate the observed flow, especially during the filling period. Then, the inclusion of the small farm dams in the model allows to account for the reduction of the river flow linked to the storage of the runoff in the dams, such water being considered as a lost for the hydrosystem since it is then used for irrigation.* Then, the text was sligthly modified in section 3.1: *Although it is clear that part of the error is linked to a poor estimation of the parameters describing the basin characteristics and to the physics of the model, part of the error is expected to be linked to the presence of small farm dams. Indeed, between 25 and 50 % of the error can be linked to the water intake (depending on the period of reference for the water uptake).*

P12, second paragraph explanation of figure 6. There is a mismatch between the figure with a 0.2 and the text with 20%. Thanks for noticing this mistake. There was an error in the yaxis caption of Figure 6: the values were not expressed as a percentage, but as a fraction, 0.2 meaning thus 20%. This is now corrected.

p 12,4 second paragraph, for the Seine and maybe Loire basin, the presence of aquifers could be mentioned

Done, it is not stated: *Moreover, in some regions like part of the Seine basin, the Rhine and Rhone alluvial valleys, pumping from regional aquifers might be preferred to small farm dams.*

p15 second paragraph in 5.2 "and they are not affected by the same regulation on the filling period". This is a bit unclear. Is the regulation of farm dams different or the regulation of water more generally (because of hydroelectricity, probably)?"

Yes, hydropower dams are not affected by the same regulations than small farm dams. Indeed, they do not intercept brooks, but rather large rivers. Hydropower dams are usually not constrained by fixed filling period, but they have to assure a minimum riverflow. Therefore, section 3.2.1 it is now written *"Actually, numerous hydro-power dams exist in these mountainous regions, with quite different filling periods, since the captured flow is provided by snowmelt rivers."*

and section 5.2 *"However, as stated before, hydro-power dams are present nowadays in these mountainous regions, and they are not affected by the same regulation than the small farm dams, and especially, their filling periods are not fixed."*

Response to Reviewer #2

This paper discusses the hydrological impacts of small farm dams on river flows in France as a function of spatial variations in hydrometerological conditions, primarily precipitation patterns. The hydrological impacts sere explored utilizing a small farm dam model connected to a hydrometerological model, with several scenarios related to different filling capacities, catchment size and filling period being utilized. Although the perceived need for such dams in western France is high, the model results suggest that the creation of such dams, particularly in NW France, would result in significant impacts on river flows as well as relatively inefficient filling of the ponds, particularly in the context of climate change. The ability of the dams to increase irrigation water availability is limited by the decreased ability of the tanks to fill up under climate change. In general, it is shown that areas where the impact of small farm dams on streamflow is the greatest, the filling efficiency of the dams is also the lowest. General Comments The authors make an important point that the use of small surface-water retention ponds such as the farm dams of southwestern France will impact the water balance of a basin. While increasing the availability of irrigation water, the dams can decrease river flows or provide very inefficient filling. It is also correctly noted that while the need for increased irrigation water is most acute during drought years, and may increase further in the face of climate change scenarios, such structures are least able to provide adequate adequate levels of supplemental irrigation during drought years. The overall contribution of such structures may therefore be overestimated.

We would like to thank the reviewer for his/her careful analysis of our works. We realize that such clear summary was not provided in the article, and we have modified the conclusion to include it: *" In these regions, the dams are less able to fill up, and thus to supply water to the farmers, and the presence of the dams lead to a decrease of the flow larger than in other regions. The impact of such dams is exacerbated during dry years, even though they are barely filled up at more than 50% in these regions."*

The paper, however, has a number of points that should be addressed: 1) Although the above points are made, they could be made more clearly. For example, the authors often note "impacts" on streamflow, but don't clarify what these impacts are, or the implications of the impacts."

It is completely true that the word "impact" is often used whereas a more specific term could be used. Some corrections are made, especially in order to explain which are the expected impact of the small farm dams. Modifications are listed below:

- abstract: *"Although such dams are small, their accumulation in a basin affects the river flows, since the water collected in those small farm dams is used for irrigation and thus does not contribute to river flow. In order to gain more insight into their impact on the annual and monthly discharges, especially during dry years, a small farm dam model was built and connected to a hydrometeorological model. Several scenarios with different volume capacity, filling catchment size and filling period were tested for such dams"*

- abstract: the word decreases is used instead of impacts, and some more details are given in *"It was found that, due to the hydrometeorological conditions (mainly precipitation), the development of small farm dams in north-western France would lead to larger decreases on the riverflows and to less efficient filling of the small farm dams than in other regions of France, so that in these regions, such dams might no be as efficient as expected to supply water to the farmers when they need it.."*

- introduction: a new sentence is added: *"Indeed, it is expected that water withdrawals or derivations to fill the small farm dams lead to a reduction of the discharge during the filling period (that is restricted to the high flow period), allowing the use of the stored water for irrigation in summer without affecting the discharge during low flow."*

- introduction: *"a reduction of the winter flood"* is used instead of "impacted the winter flood"
- introduction: *"the small farm dams induced a decrease of the annual discharge that could reach 10%"*
- introduction: *"and found that the decrease of the riverflows is limited to the downstream basin."*
- introduction: the main questions are now more detailed: *" What is the maximum water volume that can be stored in the irrigation dams without having too great an impact on the annual and monthly discharges ? Especially, what are the impacts on the floods occurring in autumn, that are important for the migration of fish and for their morphogenic contributions ? Are those dams really able to provide water to the farmers during the dryer years, and what are then their impact on the dry year river flows? "*
- introduction: *"The impacts of the small farm dams on the river flows of the Layon basin are detailed below, as well as the ability of these dams to fill up in various climate conditions"*
- section 2.2 "The small farm dam model": the sentence was clarified: *" Focusing on the river-flow at the outlet, it was found that it is rather similar to take into account few larger dams aggregated on an 8-km grid as to simulate several small dams as long as they are sparsely distributed in the basin (i.e. not all located on the same tributary)."*
- section 2.3 "Assessment method": The variables of interest are more detailed in the new section "Assessment method". *"The variables of interest are the filling efficiency and the impacts on the riverflows. The filling efficiency of the dams is estimated based on their maximum filling stages simulated each year according to the climatic conditions (including the dry years) compared to their maximum volume capacity, The expected decrease of the river flows associated to the presence of the small farm dams is quantified on monthly and annual time scales, with a special attention on the low and high flows for the local scale, and on the dry years. Indeed, in case of drought, water use may be restricted by law, to the point of requisition water stored in dams to sustain river flow. However, the large number of small dams makes it difficult to apply this law to small farm dams, which reinforces the interest to quantify their impact on flows during dry years."*
- section 3 "simulation of the Layon basin": *" Then, the inclusion of the small farm dams in the model allows to account for the reduction of the river flow linked to the storage of the runoff in the dams that is considered as a lost for the hydrosystem since the water is then used for irrigation. The simulated river flows are then expected to be closer to the observations, and the comparison between the two simulations allows quantifying the impact of the dams on the discharge"*
- section 3.2.2 "Impact on river flow": *" Thus Fig 5. shows, quite logically, that the reduction of the discharge due to the presence of the dams is greater in the first month of the filling period..."*
- section 3.2.2 "Impact on river flow": *" The frequency distribution of the decrease of the annual discharge associated to the presence of the small farm dams is presented in Figure 6"*.
- section 3.2.3 "Focus on a dry year": *"The decrease of the annual discharge is considerable, -40% and -30%, respectively, for the two-dam implementations discussed above."*
- section 4 "Results over France": *"More surprising, the mean decrease of the annual discharge is also lower than 2% in south-western France even though the dams there have a high mean annual filling ratio."*

- section 4 "Results over France": *" In contrast, the decrease of the mean annual discharge are larger than 5% in most parts of the Seine basin,...*

- section 5 "Projection in a context of climate change": *"Fig. 16 shows the impact of small farm dams in the annual discharge in 2050 compared to the simulation in 2050 without small farm dams"*

- section 5.1 "Combined impacts of small farm dams and climate change on the Layon basin": *"Although the climate projections show considerable dispersion, the impact of climate change and small farm dams in the first month of the filling period is large, with a decrease of the discharge ranging from -40% to -80%."*

- section 6 "Discussion": *" By using a simple model of small farm dams and several hypotheses, this study was able to estimate the impact on the river flows of extended small farm dams spread over the Pays de la Loire region..."*

- section 6 "Discussion": it is now specified that the impact is a decrease of the discharge

- section 6 "Discussion": *"The Pays de la Loire region was shown to be one of the regions of France where the decrease of the river discharge due to the presence of the small farm dams is the greatest and where the ability of these dams to supply water to the farmers is the lowest."*

2) For the volume calculations, it is assumed that all irrigation water in the Pays de la Loire region currently comes from small farm dams. A reference should be given to support this assumption.

It was stated section 3 that *"The declared irrigation volume reached* $3000000 m^3$ *in 1998 SAGE (2002a) and had almost doubled by 2010, the water being mostly stored in small farm dams or being directly pumped from the river or alluvial aquifer SAGE (2002a)."* To be more precise, it is now stated that the irrigation from dams represents about 80% of the irrigated water in the Layon.

It was also stated in section 2 that *"The small farm dam fraction can be estimated using the present day irrigation water volume in the Pays de la Loire region, by considering that all the irrigation water taken from the surface water comes from small farm dams".* It is now added *"as it is the case in the Layon basin (SAGE (2002a))."*

3) It is stated that the impact of dams could reach 10% of the annual discharge - what is this impact? Is it meant that 10% is withheld that would ordinarily go to runoff?

Yes, that is correct, the impact of the small farm dams can reach 10% of the annual discharge in the Pays de la Loire region, and along the river Garonne. It is now clearly stated that the presence of the dams leads to a reduction of the annual discharge by 10% (cf answer to the first comment).

4) It is written that "as long as the dams were small and sparsely distributed... the impact was reduced. What impact do you mean? Please clarify.

It is true that this sentence was not clear. This sentence was modified as follow: *" Focusing on the riverflow at the outlet, it was found that it is rather similar to take into account few larger dams aggregated on an 8-km grid as to simulate several small dams as long as they are sparsely distributed in the basin (i.e. not all located on the same tributary)."*

5) The estimated pond area is based on an arbitrary depth value (3 m) and the actual irrigation water used in the region. These estimations, however, do not take into account evaporative losses from the ponds. These evaporative losses should be considered when calculating pond size.

It is correct that farmers should account for evaporation loss to estimate the size of their small farm dams if they need these dams to supply a given volume of water. However, it was not the case in our study, since we have tested different values of the extension of the small farm dams, and thus, of the volume stored in these dams. These areas were expressed as a fraction of the surface of the whole catchment, as it is requested that the total extension of the water body should not exceed 5% of the basin area in the Loire Bretagne basins (SDAGE Loire Bretagne (2009), cf section 2 lines 180-200).

6) In your discussion, you note that evaporative losses would affect the estimated impact on river flow by less than 10%, but it isn't clear why these losses were not included in the model simulations.

It is correct that evaporation losses from the small farm dams were not explicitly accounted for in the modeling. Evaporation losses from the small farm dams can be approximated using a potential evaporation formula for water body, as for instance the one proposed by Penman (1948). However, we should then correct the water balance computed by the hydrometeorological model SIM, that is computing the evaporation according to the soil and vegetation types of the full grid cell, with the atmospheric variables of the grid cell. To estimate the full water budget, we should have considered that the water budget from SIM apply on $(100 - D)\%$ of the grid cell, and then to estimate that the evaporation loss from the small farm dams is equal to the PET

$$AET_{gricell} = (100 - D)/100 AET_{SIM} + D/100 * PET_{water_body}$$

However, it is expected that the small farm dams are located in the bottom of the valley, in areas that might be quite protected from wind, and thus that the water body evaporation from the small farm dams could be reduced.

In the study we have indeed considered that the AET computed by SIM apply to the whole grid cell, which is similar to expect that the AET is close to the PET of the water body during the filling period. Such hypothesis is certainly more true for a 3-month filling period, since the AET estimated by SIM during this winter season is closer to PET than for the 5-month filling period

As the present study mostly focussed on the impact of the small farm dams on the hydrology, such assumption seems to be reasonable. However, this point was addressed in the discussion, as it is clearly an issue when considering the ability of the small farm dams to supply water for the farmers. To make this point clearer the text in section 2.2 was modified as follow: *"The increased water body evaporation from the small farm dams is neglected, and the evaporation from the dams is considered to be equal to the surrounding environment. The impact of this hypothesis will be discussed in section 6."*

The discussion was also modified as follow: *In our study, the dam's area was only sensitive via its impact on the storage volume, because the increased evaporation from dams was neglected. More precisely, evaporation from dams was considered to be equal to the evapotranspiration from the surrounded environment. As evaporation from water body is closed to the potential evaporation, the evaporation loss during the filling period was probably underestimated, especially for the 5-month filling period. Moreover, after the filling period, the evaporation losses from the small farm dams reduces the volume store, and thus, the ability of the small farm dams to supply water to the farmers is certainly overestimated in our simulations. Martínez-Granados et al. (2011) have quantified the evaporation in a semi-arid region of Spain, and they estimated that the evaporation loss could reach 8% of the water stored. As most part of France has a more humid climate, it can be considered that the loss will be lower in France, and that the stored water volume should decrease by less than 8% due to the evaporation loss."*

7) Also regarding pond size, and as noted in the discussion, power law relationships are usually utilized for area-volume relationships of such tanks. Although the authors indicate awareness of such relationships, it is not clear why they used the simpler geometric relationship for estimating tan

We did not used a area-volume relationships, because it was not clear if the relationships used in South Africa, America or Australia could apply in France. Indeed, the regulation in France is not the same for the dams that are deeper than 5 m, and most of the small farm dams have a depth smaller than 5m. The data collected on 171 small farm dams in south western France lead to an average depth of $3m$, as shown in the figure below. For these reasons, we used a linear relationship.

To make this point clearer, the text was modified as follow

- section 2: *" An average value of $d_w = 3$ m was chosen, as it is the average depth of a short database referencing 171 small farm dams in south-western France, and as it is below the 5 m for which an annual survey of the dam structure is required."*

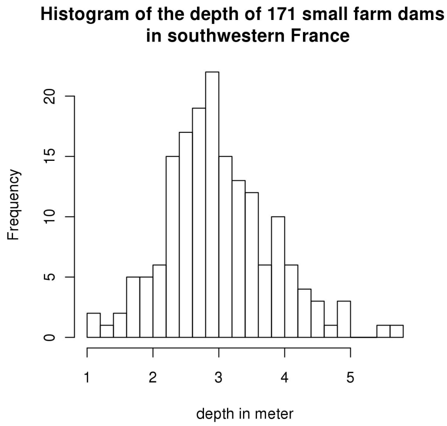

Fig. 1. Histogram of the mean depth of 171 small farm dams in southwestern France

- discussion: *" However, the depth of 3 m was used as it corresponds to the average depth of 171 small farm dams in south western France, and it is thought to be more appropriate to the France context."*

Response to Interactive comment of Andreas Güntner

The authors would like to thank Andreas Güntner for his comments. The model presented in Güntner et al. (2004) is aiming at taking into account several dams located in cascade in a basin, and one of its original aspects is to take into account several aggregated dams in a subbasin, classified according to their storage capacities. It is a rather complex situation, since the output of a dam is affecting the input of the connected dams. The study of Malveira et al. (2012) is also quite interesting. The ability to make scenarios by modifying the number of dams in each class is very efficient.

In order to refer to these studies, the following text was added in the introduction: *"Among them, Güntner et al. (2004) and Malveira et al. (2012) combined the explicit simulation of numerous small dams (lower than 100 000* m^3*) with large dams (above 50 000 000* m^3*) in Norhteast Brasil, and noticed the impact of those smaller dams in the water yield of the larger ones.*

References

Güntner, A., Krol, M. S., de Araújo, J. C., Bronstert, A.: Simple water balance modelling of surface reservoir systems in a large data-scarce semiarid region. Hydrological Sciences Journal - Journal des Sciences Hydrologiques, 49, 5, 901-918. 2004.

Martínez-Granados, D., Maestre-Valero, J.F., Calatrava J. and Martínez-Alvarez V. The economic impact of water evaporation losses from water reservoirs in the Segura basin SE Spain, Water Resour. Manage., 25 3153-3175, 2011.

Malveira, V. T. C., de Araujo, J. C., Güntner and A.: Hydrological Impact of a High-Density Reservoir Network in Semiarid Northeastern Brazil, Journal of Hydrologic Engineering, 17, 1, 109-117. 2012.

Penman, H.L. Natural evaporation from open water, bare soil and grass. Proc. R. Soc. London, 193 : 120-145 1948.

SAGE (Schéma d'Aménagement et de Gestion des Eaux) des bassins Versants du Layon et de l'Aubance, Phase I: Rapport 163p 2002.

SDAGE (Schéma Directeur d'Aménagement et de Gestion des Eaux) du bassin Loire-Bretagne 2010-2015. 252p 2009.