AUTHOR’S RESPONSES TO ANONYMOUS REFEREE #2

These are the Authors’ replies to comments from Referee #2, received and published on 23rd June, 2018. We use blue color for our replies and black color for Referee’s comments.

It should be noted that the comments of the Referee make reference to pages and lines of the production paper. We use the same criteria in this reply.

RESPONSES:

Firstly, we want to sincerely thank Referee #2 for the remarks and recommendations which will undoubtedly improve the quality and scope of the paper.

Novelty cannot be demanded from a review, but I still miss some recommendations coming out of the review: What is the main findings of collecting this information, either for practice to be used for design or operation or for the research community to explore further because of lack of information on specific or cross-cutting topics. As it is I am in doubt what the purpose of the paper is.

The purpose of the manuscript is to serve as a dam safety management supporting tool when assessing how climate change may affect dam risk. With this information, long-term investments can be planned more efficiently. Indeed, the application of this tool may prevent investing in measures that would no longer be necessary in the future, or missing some measures that could reduce the future risk. As such, it is addressed to dam owners and dam safety practitioners, but also to the research community that can help improving it and filling the gaps that still remain in some aspects of the risk assessment.

Moreover, although the information collected in this work is mainly based on existing works, there is still some novelty or innovation in its processing since usually the global effects of climate change on dam risk are studied separately. The authors introduce a more comprehensive and structured approach to take them into account, which can be used to apply this same risk analysis to other critical infrastructures.

These remarks will be added to the new version of the manuscript.

Throughout the paper I am in doubt whether the safety assessment is related to upstream or downstream of the dam itself or both. The discussion on the hydrological performance seems to focus on upstream loading, but typically dam safety is also concerned with downstream consequences of failures. Please clarify the scope of the paper, also in terms of physical boundaries. When considering T=100000 downstream consequences can be catastrophic and often much higher than upstream.

Dam risk analyses focus on the downstream consequences of a dam failure but depend also on the upstream conditions or loads. Thus, in terms of physical boundaries, the dam safety assessment can be divided in two parts that correspond to 2 different components of dam risk:

- When we assess the loads of a dam in the hydrological scenario, including the incoming floods to the reservoir, we refer to upstream of the dam.
- When we assess the consequences we refer to downstream of the dam.

For clarity, this will be mentioned in the new version of the manuscript.

The comment regarding the consideration of floods of T=100'000 years return period unveils an interesting question. As mentioned by Escuder-Bueno et al. (2012), the presence of dams changes the downstream risk. Figure 1 shows how F-D curves[1] are modified when structural measures (such as dams) are implemented: compared to situations without any measures, the F-D curves show a decrease in the downstream consequences for a certain rank of annual probabilities of exceedance, but also an increase in these consequences for lower probabilities (e.g. corresponding to the breakage of the dam) which is consistent with the Referee's comment.

Moreover it is worth noting that in Risk Analysis it is common practice to deal with incremental risk, that is the part of risk exclusively due to the dam failure which is obtained by subtracting from the consequences of the dam failure the ones that would have happened anyway (even if the dam had not failed). In case of a T=100'000 flood, the consequences downstream must be contrasted with the consequences of the dam break.

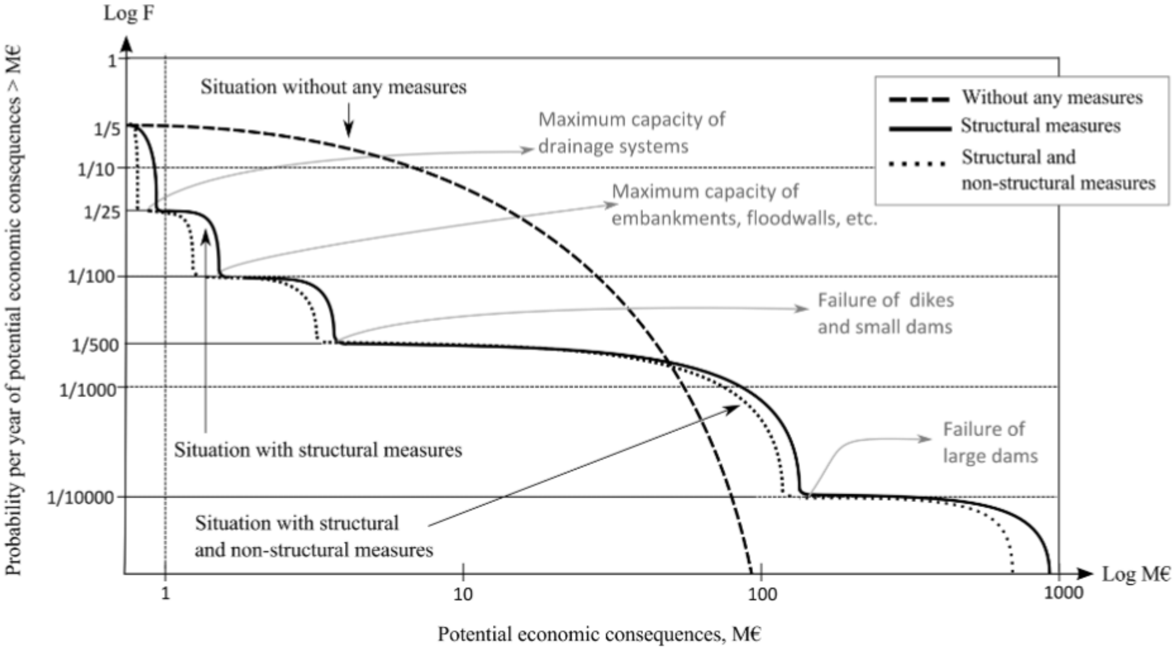


Figure 1: Effect of structural and non-structural measures on the F–D curve (from Escuder-Bueno et al., 2012).

The risk definition in Eq 1 [P3L3] is unusual and not very accurate. 'Events under study' imply a finite number of events and hence summation rather than integration. The cited ref does not give an explation and I cannot identify the ICOLD (2003) reference, which seems to be the original reference. If you wish to use that definition I suggest you start with a standard formulation as in e.g. Merz et al (2010) and then extend to the definition you wish to apply, including a discussion of Figure 1. Together they can form a precise definition. It would be nice to end the review with how this figure (that only considers stationary input) by means of this review can be converted into a diagram, that considers nonstationarity. As a community we miss a figure that combines the detailed analysis schemes corresponding to Fig01 with the soft figures from IPCC (e.g. http://www.ipcc.ch/report/graphics/images/Special%20Reports/SREX/Chapter%2001/Fig1-1.jpg from IPCC (2012)).

The risk definition concept in Eq 1 [P3L3] was set in 1981 in the classical paper by Kaplan and Garrick (1981). This definition has been used extensively across different sectors in the industry and has been discussed in Aven (2012). In the context of dam safety, it has been frequently used and can be found,

---

[1] An F-D curve illustrates the cumulative annual exceedance probability of the expected economic damages.

for instance, in Serrano-Lombillo et al. (2011). Nevertheless, reference to Merz et al. (2010) will be included in the manuscript.

Regarding the mutable aspect of Figure 1, as suggested by Referee #2 the authors will prepare a new diagram that will be included in the manuscript.

I am somewhat surprised that the review does not specifically cover the impacts in relation to the frequency domain. Climate change (and other drivers) impact both average and extreme values. Intuitively the first will impact operation, including the value of having a dam, while the second must be most important for safety. I sometimes see the paper only focusing on extremes (e.g. in the hydrology section) but other times also average impacts (e.g. socio-economic section).

The approach followed in the manuscript allows to integrate all the different types of aspects (from normal to extreme events) of dam safety that may be affected by climate change. On one hand, when performing a risk analysis focused on a hydrological scenario as proposed in the manuscript, the main loads are floods. In this case the analysis of climate change impacts on extreme hydrological conditions is required. On the other hand, other components such as the previous pool level or the population exposure downstream represent the normal state of these factors and have to be analyzed considering them as averaged values. That is why at certain point the paper focuses on extremes and other times in average conditions.

For clarity, this should be mentioned more explicitly in the new version of the manuscript.

There is an interesting mentioning on other key drivers of change such as population increase, economic development etc [P4L10] but the paper does not come back to discussing this except for a very broad discussion on socio-economic consequences. During this discussion I cannot see if it is the presence of the dam that drives changes in the socio-economic conditions or vice versa. Is there a difference between deciding on building of a dam and considering safety in relation to an existing dam?

The presence of the dam certainly represents an important driver to eventual socio-economic changes. Dams are indeed a key component when applying socio-economic scenarios and their importance may even increase under future climatic conditions (more frequent droughts and extreme events, for instance).

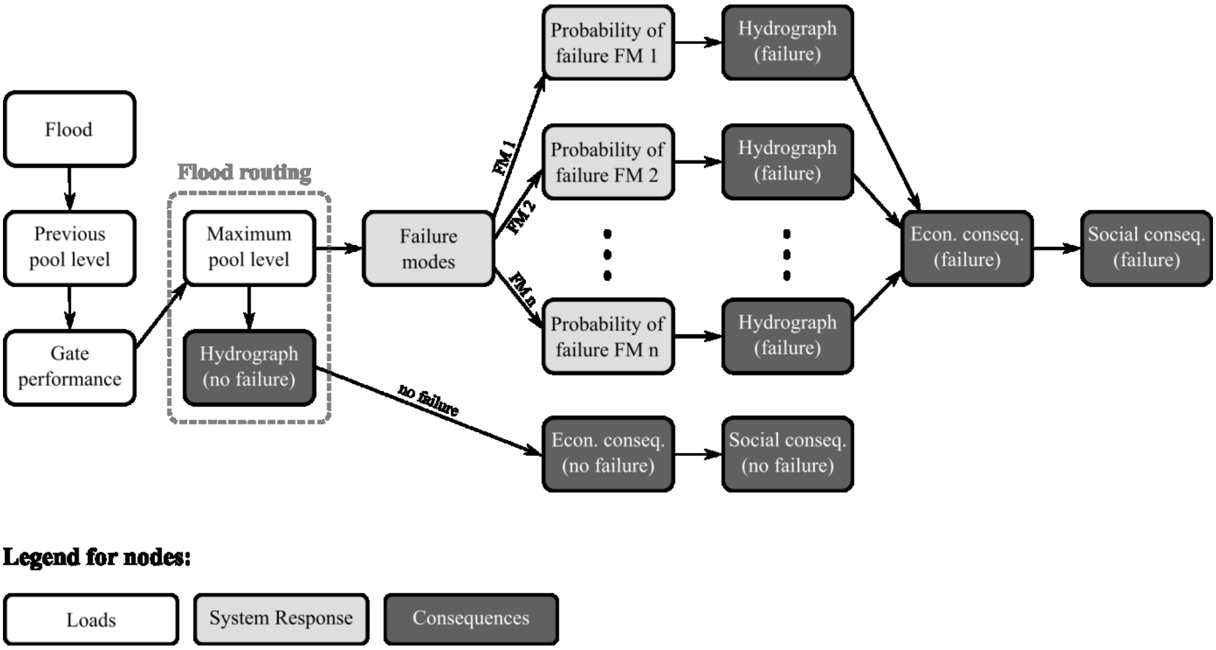
When assessing the future safety level of a dam, we could consider that there are no differences between applying the methodology to an existing dam or to a future non-existing dam. However, when assessing the safety of an existing dam, it is likely that the population in at-risk areas has already followed several safety procedure trainings which would entail a better prepared population facing inundation events thus changing their vulnerability in comparison with a non-trained population.

[Fig01] Diagram starts with a loading of Flood. Is that up- stream or downstream of the dam? A Consequence (Hydrograph (no failure)) leads to Failure modes, which seems counterintuitive. Figure needs more explanation.

The **Flood** node of Figure 1 refers to an upstream flow. Downstream flows are referred as **Hydrograph (failure and no failure)**.

The arrows in Figure 1 represent the information flow from the start until the end of the diagram. In some cases, the information transmitted is used on the connected node (for instance, some information transmitted by the node **Gate performance** is used to define the **Maximum pool level** node). However, in other cases the information is only used a little further in the diagram (for instance, the information contained in the node **Flood** is not directly used by the node **Previous pool level**, and yet they are both connected by an arrow).

It is true that this case is particularly tricky when connecting **Hydrograph (no failure)** and **Failure modes** since it may lead to a misunderstanding. That is why the authors suggest using this diagram instead, which contains the same information:



[4L15] You use the term flooding both for a high loading of the dam and for the consequences downstream. The illustrations in Fig02 seems to be unaffected by dam management, but is discussed as if it is downstream?

The use of the term flood in both cases can indeed lead to a misunderstanding of whether we refer to upstream or downstream. Thus, the authors suggest using the term flood exclusively for the upstream flow into the reservoir and outflow hydrograph or inundation when referring to downstream the dam.

Figure 2 corresponds to the floods as a load to the dam (upstream).

[P6L15] There is quite abundant literature on extracting correct projections of extremes. For single sites methods developed by e.g. Kilsby and Willems are predominant (each has many refs), while for larger regions spatially distributed methods are employed (e.g. Pereira-Cardenal et al 2014 incl. supplementary information).

The references suggested by Referee #2 cover adequately the scope of the work and will be added to the final version of the manuscript when referring to the projection of extremes.

[Fig04] This forward-propagation modelling chain deserves a reference.

This figure has not been directly extracted from any reference. It has been elaborated by the authors based on the methodologies commonly used in many studies (e.g., Chernet et al., 2014; Duan et al., 2017; Kay et al., 2006; Raff et al., 2009; Shamir et al., 2015) and serves as an example of procedure to perform frequency analysis on floods taking into account the effect of climate change.

The legend of the figure that appears in the manuscript is not accurate and should be changed to "Example of methodology for the frequency analysis of floods under climate scenarios."

[Fig05] Subfigure a and b are identical. Suggest to replace legend on yaxis on subfigure a.

The objective of showing these two figures was to highlight how the distribution of the water storage in the reservoir (and thus the loads to which the dam is subjected at the moment of arrival of a flood) varies depending on the water level regimes.

Figure 5.a) and Figure 5.b) represent the same information (relation between water pool level and probability of exceedance) but for two different cases of dams, and that is why their axes are the same:

- Figure 5.a) shows the case of a reservoir that is almost full (level above 540 m a.s.l.) almost 80 % of the time.
- Figure 5.b) represents the case of a reservoir that is half empty more than 70 % of the time.

For clarity, both curves will be plotted in a unique graphic and an explanatory legend will be included to distinguish one case from the other.

REFERENCES

Aven, T.: The risk concept—historical and recent development trends, Reliability Engineering & System Safety, 99, 33–44, doi:10.1016/j.ress.2011.11.006, 2012.

Chernet, H. H., Alfredsen, K. and Midttømme, G. H.: Safety of Hydropower Dams in a Changing Climate, Journal of Hydrologic Engineering, 19(3), 569–582, doi:10.1061/(ASCE)HE.1943-5584.0000836, 2014.

Duan, J. G., Bai, Y., Dominguez, F., Rivera, E. and Meixner, T.: Framework for incorporating climate change on flood magnitude and frequency analysis in the upper Santa Cruz River, Journal of Hydrology, 549, 194–207, doi:10.1016/j.jhydrol.2017.03.042, 2017.

Escuder-Bueno, I., Castillo-Rodríguez, J. T., Zechner, S., Jöbstl, C., Perales-Momparler, S. and Petaccia, G.: A quantitative flood risk analysis methodology for urban areas with integration of social research data, Natural Hazards and Earth System Science, 12(9), 2843–2863, doi:10.5194/nhess-12-2843-2012, 2012.

Kaplan, S. and Garrick, B. J.: On The Quantitative Definition of Risk, Risk Analysis, 1(1), 11–27, doi:10.1111/j.1539-6924.1981.tb01350.x, 1981.

Kay, A. L., Reynard, N. S. and Jones, R. G.: RCM rainfall for UK flood frequency estimation. I. Method and validation, Journal of Hydrology, 318(1–4), 151–162, doi:10.1016/j.jhydrol.2005.06.012, 2006.

Merz, B., Hall, J., Disse, M. and Schumann, A.: Fluvial flood risk management in a changing world, Natural Hazards and Earth System Science, 10(3), 509–527, doi:10.5194/nhess-10-509-2010, 2010.

Raff, D. A., Pruitt, T. and Brekke, L. D.: A framework for assessing flood frequency based on climate projection information, Hydrology and Earth System Sciences, 13(11), 2119–2136, doi:10.5194/hess-13-2119-2009, 2009.

Serrano-Lombillo, A., Escuder-Bueno, I., de Membrillera-Ortuño, M. G. and Altarejos-García, L.: Methodology for the Calculation of Annualized Incremental Risks in Systems of Dams: Risk

Calculation for Systems of Dams, Risk Analysis, 31(6), 1000–1015, doi:10.1111/j.1539-6924.2010.01547.x, 2011.

Shamir, E., Megdal, S. B., Carrillo, C., Castro, C. L., Chang, H.-I., Chief, K., Corkhill, F. E., Eden, S., Georgakakos, K. P., Nelson, K. M. and Prietto, J.: Climate change and water resources management in the Upper Santa Cruz River, Arizona, Journal of Hydrology, 521, 18–33, doi:10.1016/j.jhydrol.2014.11.062, 2015.