Interactive comment on “Climate uncertainty in flood protection planning” by Beatrice Dittes et al.

Author comment on the comment of anonymous referee #2

The authors would like to thank the referee for the comments. In the following, we respond to the individual suggestions, with referee comments highlighted in *blue*.

> *The quantification of the different uncertainty sources, which is a central part of the methodology is only very briefly described (Section 2.5). / Section 2.5. This section needs to be elaborated. There is very little explanation of how the different error sources are estimated.*

Uncertainty quantification is not one of the main goals of the paper. As we discuss in our general author comment, we realize that we were not sufficiently clear about the goals of the paper, which causes this misunderstanding. This we have improved in a revised version of the manuscript. In fact, the numbers given in Sect. 2.5 are ball-park figures, based only on the sources and considerations presently stated there. Furthermore, the results of the case study show that the sensitivity of the planning recommendation to variations in uncertainty is low (see Sections 4.2 and 5), thus an exact quantification is not necessary. We added a sentence to clarify this: *“Note that this is done as a rough estimate, since uncertainty quantification is not the focus of this paper. As will become clear in Sect. 4.2 and 5, an exact quantification is also not necessary for the proposed decision making process.”* We also enhanced the statement of goals in the abstract (see respective comment).

> *… for the optimisation framework applied reference is made to an unpublished paper by the same authors, and it is difficult to grasp from the description given in the paper.*

We included a download link to the cited paper. Furthermore, we improved the description of the framework and the overall methodology in various places (see revised paper). In particular, the previously brief description in Sect. 1 was extended as follows:

„We have previously proposed a fully quantitative Bayesian decision making framework for flood protection (Dittes et al., 2017). Bayesian techniques are a natural way to model discharge probabilistically (Coles et al., 2003; Tebaldi et al., 2004). They also make it easy to combine several sources of information (Viglione et al., 2013). Furthermore, Bayesian methods support updating the discharge distribution in the future, when new information becomes available (Graf et al., 2007). Our framework probabilistically updates the distribution of extreme discharge with hypothetical observations of future discharge, which are modelled probabilistically. This is an instance of a sequential (or ‘preposterior’) decision analysis (Benjamin and Cornell, 1970; Davis et al., 1972; Kochendorfer, 2015; Raiffa and Schlaifer, 1961). This enables a sequential planning process, where it is taken into consideration that the measure design may be revised in the future. Furthermore, it naturally takes into account the uncertainty in the parameters of extreme discharge. The output of the framework is a cost-optimal capacity recommendation of flood protection measures, given a fixed protection criterion (such as the 100-year flood). To protect for the 100-year flood is common European

practice (Central European Flood Risk Assessment and Management in CENTROPE, 2013) and is also the requirement in the case study.

In this paper, we show how to incorporate into the flood planning process the visible uncertainty from an ensemble of climate projections as well as hidden uncertainties that can not be quantified from the ensemble itself but may be estimated from literature. When combining uncertainties, special care is taken to account for uncertainty and bias in projections as well as dependencies among different projections. We provide reasoned estimates of climatic uncertainties for a pre-alpine catchment, followed by an application of the previously proposed Bayesian decision framework, sensitivity and robustness analysis. The process is shown in Fig. 1: 1) Projections of annual maximum discharges (see Sect. 2.2) and 2) an estimate of the shares of various uncertainties that are not covered by the projection ensemble (see Sect. 2.5) form the inputs to the analysis. 3) For each projection individually, a likelihood function of annual maximum discharge is computed. This is done such that bias is integrated out and projections later on the horizon are assigned diminuishing weights, making use of the hidden uncertainty shares (see Sect. 3.2). 4) The likelihoods of individual projections are combined using the method of effective projections (Pennell and Reichler, 2011; Sunyer et al., 2013) *in order to account for dependencies among them (see Sect. 3.3). 5) The Bayesian decision framework of Dittes et al. (2017) is used to obtain 6) a protection recommendation based on the likelihood of extreme discharge. The qualitative basis of the framework is outlined in Sect. 3.4.*

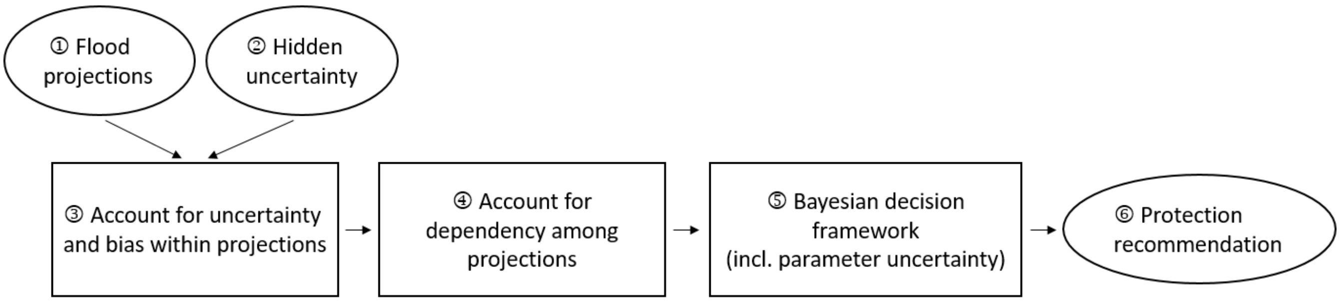

Figure 1. Process of finding the recommended planning margin from projections and hidden uncertainty estimate.*“*

The title of the paper is not very informative.

We agree and hence change the title to *“Managing uncertainty in flood protection planning with climate projections”*. This should highlight that the goals is not to quantify uncertainty but to manage its impact in planning.

Main results should be summarised in the abstract.

We added the following passage on results: *„The results show that hidden uncertainty ought to be considered in planning, but the larger the uncertainty already present, the smaller the impact of adding more. The recommended planning is robust to moderate changes in uncertainty as well as in trend. In contrast, planning without consideration of bias and dependencies in and between uncertainty components leads to strongly sub-optimal planning* *recommendations.“* Note that the main goal of the paper is to present methods, not results. We clarified the goal further in the abstract: *“This paper focuses on climatic uncertainty. Specifically, we devise methodology to account for uncertainty associated with the use of discharge projections, ultimately leading to planning implications.”*

> *Section 2.3. In the explanation of internal variability it is stated that "it cannot be predicted with certainty what amount of discharge will be recorded on a given day". But is this an issue here? Internal variability should be related to the problem of estimation of a design discharge.*

It is true that it would be more helpful to refer to annual maxima – from which the design discharge is estimated – rather than days. We rephrased as *„…even with perfect knowledge, it cannot be predicted deterministically what the annual maximum discharge of a year will be, and thus how the design flood estimate will change.“.*

> *It is also stated that the internal variability is the dominant source of uncertainty, but no documentation for this statement is provided.*

The citatiation is located at the end of the corresponding sentence: (Maraun 2013).

> *Section 2.4, p. 8, l. 5-6. It is stated that "the error from the hydrological model is small, in particular for high flow indicators (Velazquez et al., 2013)". Velazquez et al. (2013) conclude that high flow indicators are less sensitive to the choice of hydrological model. This is not to say that the uncertainty in the simulation of extreme discharge events is small. Often you see quite large uncertainties in the simulation of extremes. This can be quantified from the hydrological model simulation in the case study.*

When evaluating the hidden uncertainty, the question is „how much would the result differ, if a different model had been chosen“, hence the results of (Velazquez et al., 2013) are applicable. (It is presently stated as an example of hidden uncertainty in the introduction: *„For example, if the same hydrological model has been used for all projections, then the hydrological model uncertainty is 'hidden', since one effectively has only a single sample of hydrological model output.“*) To make this clear also in the sentence highlighted by the reviewer, we rephrase it as *„the error from the choice of hydrological model…“.*

> *Section 4.2. The results are difficult to interpret. The relation between the estimated 100-year pdfs and the planning margins in Table 2 is not clear.*

The 100-year PDFs are the result of the methodology described in the presented paper. Using these as input to the optimization framework (the description of which was revised, see respective point) leads to the recommendations in Table 2. Sect. 3.4 aims to give an intuitive understanding of the relationship between the 100-year PDFs and the recommendations (simply speaking, more spread in the PDF = more uncertainty = higher planning margin). We added a sentence to clarify: *„The PDFs shown in Fig. 5 are used as input to the optimization framework of (Dittes et al., 2017) to obtain recommendations for the planning margin. Sect. 3.4 gave an intuitive understanding of how these relate to the 100-year PDF.“*

> *It does not seem that the planning margins correspond to the current estimate of the 100-year design discharge of 480 m3/s.*

We assume that the reviewer wanted to write *„100-year PDFs"* (referring to the Fig. 5, which was formerly Fig. 4) instead of *„planning margins"*. The 100-year design discharge of 480 m^3/s is the official figure used by the city of Rosenheim based on a GEV-fit of historic annual maxima, without consideration of uncertainties. The accuracy of this number is not evaluated by us. However, what one can see in Fig. 5 is that it is in agreement with the historic data (with a very large uncertainty margin) while the projections overestimate the 100-year discharge. Therefore, we state in Sect. 3.4 (previously in Sect. 1): *„Note that, since there is often a discrepancy between the level of observed past discharge at a specific gauge and the corresponding regional climate projections, we take the commonly used approach (Fatichi et al., 2013; Pöhler et al., 2012) of computing relative rather than absolute values from the climate projections. Here, this means that we find a planning margin γ based on the projection ensemble and uncertainty estimates from literature, which may then be applied to the absolute protection (100-year flood) as estimated from historic records."*

> *Section 4.2, p. 18, l. 9-11. Does this trend relate to the mean discharge? I would expect this trend to be different from the trend of annual maximum discharge.*

It refers to the annual maxima. We clarified this by replacing *„projections"* with *„projected annual maxima"* in the mentioned lines (before and after these, it is already made explicit).

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