

## Referee #1

The article analyses climate change impacts on runoff regimes in 93 rivers in Switzerland. The study is based – like a companion paper by the same authors (submitted as hess-2020-516) – on the results of a large Swiss research project, which provided consistent downscaled local climate projections under three emission pathways. While the earlier paper presents seasonal and yearly changes in the mean discharge, this contribution analyses the same data (simulated daily runoff for the period 1981-2099) with respect to moderate runoff extremes, both high and low flows. The dataset is available in a publicly available data repository (Zenodo), and is described in a corresponding paper in Geoscience Data Journal, which is under review.

After some careful revisions, which refer mainly to a clearer and more consistent style, the article certainly deserves publication, also because it complements the previous companion paper.

*Reply: Thank you very much for your thorough review. We very much appreciate your inputs and suggestions.*

My review is provided in 2 documents: 1) a PDF document with rather general remarks and recommendations, and 2) detailed PDF annotations directly in the manuscript.

### General remarks

Summer/winter: there are several “seasonal” analyses, referred to as “extended summer” or “extended winter”, which are actually half-years. In some places, just “summer” and “winter” is used. I suggest to use the terms “summer half-year” and “winter half-year” consistently throughout the text to avoid confusion with the common meaning of a season. This is important, because in the context of seasonality shifts, you also refer to the usual seasons, like “late summer” and “early autumn” (e.g. L 24). Please rewrite first paragraph in section 3 accordingly.

*Reply: Thank you for this suggestion. We will refer to summer half-year and winter half-year in the text to avoid confusion.*

Low and lowest flows: In the results and discussion sections, there are frequent uses of the terms “low” and “lowest” flows, which most likely refer to the same. If that is true, use “low flow” consistently. Analogously, for the high and highest flows.

*Reply: The intention to use a distinction between low flows and lowest flows (and for high/highest flows accordingly) was based on the seasonality of low and high flows. For example, low flows in summer in Alpine catchments are not absolute low flows but relative low flows. That’s why we highlighted the absolute low/high flows with triangles in Figure 2. We tried to make this clear by using “low flows” for absolute low flows and “lowest seasonal flows” for relative low flows in the season. In the revised manuscript we will refer to annual low/high flows and low/high flows in the summer/winter half year, respectively.*

“alpine or Alpine”: lower case refers, in my opinion, to “mountainous”, while upper case Alpine means “within the perimeter of the Alps”. Since several of the north-western catchments (Jura) are outside the perimeter of the Alps, a clear distinction of the terms is necessary.

*Reply: We agree with your definition and will make this clear to avoid confusion.*

It may help to improve readability, if, e.g. in Fig. 1, you add a classification to the legend which indicates the “lower lying catchments”, the alpine and high alpine (Alpine?) catchments. (could be added to the mean altitude classification in the legend).

*Reply: Thank you for this suggestion. This has also been raised by the other reviewer. We will adapt figure 1 according to your suggestions.*

## **Abstract**

Paragraphs 2 and 3 are difficult to read. L 14 says that annual low flows will increase in Alpine catchments. L 15-16 says that “... annual high flows are projected to slightly increase in most catchments but to decrease in high Alpine catchments.” Are the “high Alpine catchments” a clearly different subset of catchments than the “Alpine catchments” in L 14? L 16-19: the discussion on the contradiction between moderate extremes and extremes takes too much space in the abstract, since also in the text it is rather a side note (L 298-300).

*Reply: The abstract will be rewritten according to your suggestions and the suggestions raised by the other reviewer. Catchments showing a clear decrease in high flows (more than -5% & strong model agreement) have a mean altitude greater than 1800 m.a.s.l. , with one exception. The sentence referring to the decrease in “high Alpine catchments” will be changed accordingly.*

Please consider reorganizing the abstract to discuss all effects of low flows (magnitude, time of emergence, shifts in seasonality) first and then analogously for the high flows.

*Reply: Thank you for your suggestions. The organization of the abstract will be changed according to your suggestion.*

## **Section 2 – Data**

L 111-115: You should point out that RCP 8.5 is considered a worst-case climate change scenario, and therefore possible changes are most severe. The number of simulations is certainly the least important reason.

*Reply: The reasons for using RCP8.5 will be discussed in more detail. Several reasons led to the decision to use RCP8.5. For example, RCP8.5 is the worst-case scenario and changes in low and high flows are stronger than under other scenarios which makes the interpretation easier. Also, the number of simulations available in the Hydro-CH2018-Runoff ensemble differs between the RCPs which may affect some of the results. And last, a large number of simulations within an emission scenario increases the robustness of our results, particularly for the analysis of the time of emergence.*

## **Section 3 – Methods**

See first general remark above.

More remarks are given in the manuscript PDF.

*Reply: We copied your remarks from the manuscript and answer them later in this file.*

## Section 4 – Results

Please check for “Alpine” or “alpine”. Are all the lower lying catchments outside of the Alps?

*Reply: We will adapt figure 1 to make a distinction between the lower lying catchments and high-elevation catchments. All catchments outside the Alpine area have a mean elevation below 1500 m.a.s.l. (also catchments in the Jura mountains have a mean altitude below 1500m.a.s.l.) A clear distinction between “Alpine” and “alpine” will be made.*

I agree with the outline discussing low flows first and then the high flows. However, Fig. 2, 3 and 6 present both together, i.e., section 4.2 refers back to parts of a previous figure. Consider putting the sub-figures in a grid and label the columns clearly “low” and “high flows”. Fig. 2 might benefit if you also label the rows with “Reference” and “Future”. Since in sections 4.2 and 4.3 there is no direct confrontation of “low” and “high” with respect to these figures, it might have advantages to split them, i.e. put 2a and 2c in one Fig. to be discussed in section 4.2, 2b and 2d in a separate one to be discussed in section 4.3. Similarly, figures 3 and 6.

*Reply: Thank you for this suggestion. We will add a grid and label the figures 2, 3, and 6 according to your suggestions to make a clear distinction between low and high flow results.*

## Section 5 – Discussion

Large parts of this section (at least 5.1) appear to continue the presentation of results rather than a “discussion”. Real discussion is the last paragraph of 5.1 (which could be enhanced).

*Reply: The summary and explanation of the results in the discussion section will be shortened and more emphasis will be given to implications of our results on other areas.*

Uncertainties (5.5): I am afraid, that this paragraph is not very helpful, since it is purely qualitative. Without having said anything about uncertainties before, you start “... are larger for moderate high flows than for moderate low flows”. I would appreciate a statement why you believe that the message of your results is valid, despite various uncertainties, whose quantification certainly would exceed the scope of this paper.

*Reply: We agree that the quantification of uncertainties would exceed the scope of this paper. But we will discuss the associated uncertainties in more detail and add a statement on the validity of our results.*

## Section 6 – Conclusions

In my opinion, this is more a Summary than Conclusions. In fact, the only clear “conclusion” is from L362-365. I suggest to name the section “summary and conclusions” and add some conclusions also related to the high flows.

*Reply: We will rename the title of this section to “summary and conclusions” and will include conclusions related to high flows.*

Evaluation of review criteria (more details are provided by annotations in the PDF manuscript):

1. Does the paper address relevant scientific questions within the scope of HESS? Yes. The focus is on rivers in Switzerland, but methods and results are certainly of interest for other (alpine) countries.
2. Does the paper present novel concepts, ideas, tools, or data? Yes.
3. Are substantial conclusions reached? Yes.
4. Are the scientific methods and assumptions valid and clearly outlined? Yes.
5. Are the results sufficient to support the interpretations and conclusions? Yes.
6. Is the description of experiments and calculations sufficiently complete and precise to allow their reproduction by fellow scientists (traceability of results)? All directly used datasets are publicly accessible. Therefore, the reproduction of the specific results in this paper should be possible.
7. Do the authors give proper credit to related work and clearly indicate their own new/original contribution? Yes.

**Detailed PDF annotations directly in the manuscript.**

*Reply: Thank you for the annotations in the manuscript. We copied the comments which need some more discussion and answer them point by point below.*

L16: To avoid confusion, I suggest to use "summer half-year" and "winter half-year" consistently throughout the text.

*Reply: The terms "summer half-year" and "winter half-year" will be used.*

L37: A streamflow drought is defined as a period when the discharge is below a given threshold level. A distinction is made between the minimum low flow discharge of a drought event, and the corresponding deficit volume and duration of the event.

Did you really mean "streamflow drought" or rather "minimum low flow discharge ..."?

*Reply: Thank you for the explanation. We will refer to "extreme low flows" in line 37.*

L56: "Central Europe" is not a proper opposite to "Alpine" - the Alps are certainly part of Central Europe.

*Reply: We fully agree with your point and will rephrase this sentence.*

L60: I don't understand the meaning of this phrase.

*Reply: We will remove the sentence "Past events can help to put potential future changes into perspective."*

L100: It is certainly not a specific issue in this paper, but I have concerns about this calibration/validation strategy. I learned to use an independent time period for validation. If consecutive years are used for calibration and validation, then, e.g. a possible trend of the model's output or system state is compensated by this choice of interwoven calibration/validation periods.

*Reply: The calibration and validation of the hydrological model is described in detail in Muelchi et al. (2021): "The intention of using every second year within 30 years for calibration is to minimize the potential effect of random and non-random trends by using too short calibration periods. Climate change is already observed in the period 1985–2014. PREVAH is therefore trained to also simulate runoff under changing conditions. During the calibration process, PREVAH was run for the whole period while comparing the simulations with observations only for even years. We intentionally chose*

*uneven years for the validation period since some of the years include periods of extreme weather such as very dry summer (e.g. 2003), severe floods (e.g. 2005, 2011) or winters with extreme snowfall and thus extreme snowmelt in spring (e.g. 1999). This leads to the assumption that if the model performs well in uneven years (validation), the calibrated parameters produce stable results also for more extreme or changing conditions. “*

*Muelchi, R., Rössler, O., Schwanbeck, J., Weingartner, R., & Martius, O. (2021). An ensemble of daily simulated runoff data (1981–2099) under climate change conditions for 93 catchments in Switzerland (Hydro-CH2018-Runoff ensemble). Geoscience Data Journal.*

And - I think that the correct opposites are "even" and "odd"!

**Reply:** *The term “odd” will be used instead of “uneven”.*

L112: The most important reason, in my opinion, should be that RCP8.5 is considered the worst-case scenario.

**Reply:** *This is indeed one of the most important reasons. We refer to the answer under “data” above.*

L126: This is inconsistent. As I understand, MAM7 uses the same rules, whether it is for a year or a half-year. Therefore, you should not use the superlative "highest" or "lowest" for the half-year values, if the yearly values are called "moderate high (or low)"

**Reply:** *We refer to the answer above. The intention was to make a distinction between absolute and relative low/high flows.*

L129: Is it obvious, that this the median of 20 means?

**Reply:** *We will add an explanation here. “The multi-model median of the relative changes by end of the century in 20 simulations is regarded as the best estimate. “*

L141: This needs clarification similar to the previous companion paper.

**Reply:** *This will be rewritten similar to the revised version of the companion paper. The concept of time of emergence is based on a statistical test between two distributions (reference vs future). However, changes in low/high flows may not be linear over time. Even though changes in low/high flows are tested as significant in one period, they may not be significant in all periods afterwards (e.g., due to non-linear effects of enhanced snow melt, decreasing snow cover, increasing glacier melt and decreasing glaciation).*

L218: This is the first time that you mention the Jura. So far, the catchments in that region seemed to be just "the lower-lying catchments"? Or do I miss something?

**Reply:** *We will remove the term “Jura” and only mention “catchments in north-western Switzerland”.*

L234: This section title is not clearly describing its content. What about: Changes in frequency and co-occurrence of low and high flow events? (as in L235-236)

**Reply:** *We will change the section title according to your suggestion, thank you.*

L237: Do you mean a value with a return period of 2 years? "occurring every second year" is certainly not correct

**Reply:** *We agree with your point. This sentence will be changed to “The threshold discharge value is defined as the median in the reference period.”*

L252: I would move this definition to the begin of the section

**Reply:** *The definition will be moved to the beginning of the section.*

L271: what is "very high"? Since the study refers to 93 Swiss catchments, it should be possible to give a threshold altitude

**Reply:** *A threshold altitude (>2300 m.a.s.l.) will be given.*

L316: is "robust" the correct word for this?

**Reply:** *This will be changed to "However, not all climate models show such an increase and moderate high flows only partially reflect severe floods."*

Figure 1: It would help to add to the altitude legend a classification that is used in the text, like "low lying ..", "high alpine ...", etc.

Also, "Jura" and "Alps" should be appropriately labelled.

**Reply:** *Figure 1 will be changed according to your suggestions and the suggestions raised by the other reviewer.*

Figures 2/3: You may consider to organise the figures as a grid and label columns clearly "low" and "high", rows "reference" and "future".

Or maybe split in 2 Figures, one for low, and one for high.

**Reply:** *Thank you for this suggestion. We will add a grid and label the figures 2, 3, and 6 according to your suggestions to make a clear distinction between low and high flow results.*

Figure 4: The scales at the left of each fig must be labeled! I assume, it is intensity, but don't know for sure what this really means. Is it discharge, or specific discharge?

Labeling of the color bar "year" should start with 1980 and end with 2100.

Applies also to figs 5, 7, 8!

**Reply:** *Thank you. Figures 4, 5, 7, 8 will be changed according to your suggestions.*