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Review and rebuttal of the paper

The 2021 flood event in the Dutch Meuse and tributaries from a hydraulic and morphological perspective

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Editor handling the paper: Hans de Moel

Response to reviewers' comments

"The 2021 floods in the Netherlands from a river engineering perspective"

We thank both reviewers for their thorough and insightful feedback. As some of the major feedback overlapped between the reviewers, we would like to give a general response on this first and outline the main revisions. After these main revisions, we reply to both reviewers comments and explain how we addressed them.

Main revisions:

- **Better describe and explain of methodology and theoretical background**. The reviewers commented on the lack of theoretical backgrounds. Information about the management of flood incidents in the Netherlands is missing. They state that the inclusion of some more methodological details would strengthen the presentation and support reproducibility.

  We will introduce a new chapter "Context" where we will add, next to the study area already, two sections that describe 1) background information about the management of flood incidents in the Netherlands with a tribute to the elements that are analysed in this paper and 2) available discharge and water level data used in this study and describes the sources of data in more detail. Furthermore, this paper comprises a fact finding that mainly focusses on presenting the facts and we try to give a more comprehensive explanation about the rationale of this study in the section Introduction and Context.

- **Add a discussion section**. The reviewers missed a discussion section in which the implications of the key findings of this study are described in a critical way and recommendations are made for follow up studies and possible improvements in the management of river basins in the Netherlands and abroad, in anticipation of events like this.

  We add a discussion section, where the limitations and implications of the key findings of this study are described. Furthermore, we add some recommendations for follow-up studies that improves the understanding and management of floods.

- **We will revise the paragraph with statements about the effect of retention measures on flood attenuation**. The reviewers comment that the explanation presented in our paper on the effect of retention areas is limited. Illustration of their link with the data at hand is missing and more information about the retention area (geographic location, size and mechanisms).

  We will remove the statements about the effectiveness of two specific retention areas. We highlight the impact of storage basins in general, as they attenuate the peak discharge (as shown in figure 6). We provide further elaboration on peak attenuation and explain why the attenuation of the 2021 flood wave is stronger compared to 1993/1995

Below, we reply to all reviewer comments and explain how we will address them. The reviewers' comments are shown in *Italicized text in gray*, our responses are shown in blue. Part of their comments are already covered by the main revisions and are ~~*strikethrough*~~.

Reviewer 1

1. ~~*The article lacks a theoretical background. Information about the management of flood incidents in the Netherlands with a tribute to the elements that are analyzed in this paper is needed.*~~
   Throughout the manuscript in its current state it is not made explicit what a 'river engineering perspective' means although this is part of the title.

   Response: We agree that the word river engineering is not made explicitly in our paper. In general, 'river engineering' is broad term and we tried to be more precise throughout the paper. We will remove the word 'river engineering' out of the paper and rewrite sentences, where necessary, with more precise terminology. Furthermore, we will change the title of our paper to: "The 2021 flood event in the Dutch Meuse and tributaries from a hydraulic and morphological perspective".

2. ~~*There is no explanation of the rationale of the study. A methodology section is needed where the steps taken by the authors and the choices made in this study are explained and justified in a concise and rigorous manner. For example, in the current state of the manuscript it is not stated explicitly which are the data sources. Waterinfo is mentioned in the supplementary information, but a description of the source with references and links is necessary.*~~

3. *Throughout the analysis there are strong statements that go unreferenced or are not supported by sound arguments that illustrate their validity. The most important ones are the following:*

   a. ~~*Retention areas have played a role in mitigating the impact of this flood. This is understandable, but information about the exact location of retention areas that are present in the study area, their retention capacity and a clear illustration of their link with the data at hand is missing. A brief explanation of the mechanism behind this relationship is needed.*~~

   b. *During this event we had the highest peak discharge ever measured at St. Pieter. Although this point is stated as such in the conclusions, in the beginning of section 4.1 it is stated that this is probably the highest discharge. This shows that the information hasn't been cross referenced by the authors. Presentation of relevant data that allow to ascertain this information is needed.*

      Response: We will update the text since this data is cross referenced with other studies. This is also in line with one of the main revision, where we will add a new paragraph about "available discharge and water level data"

4. ~~*A discussion section is needed in which the implications of the key findings of this study are described in a critical way and recommendations are made for follow up studies and possible improvements in the management of river basins in the Netherlands and abroad, in anticipation of events like this.*~~

5. *The conclusions are at the moment a repetition of the authors' observations that have been presented throughout the article. This part needs to be revised when the article is supplemented*

with a methodology chapter that describes a clear rationale and a discussion section. In the revised version it needs to be clear how the objectives of the study were achieved.

Response: we will rewrite the conclusions in such a way that there is less emphasis on the observations, but more on the lessons learned.

Comments in line with text

- *Page 3, line 3-24: Information about your data source is missing here.*
  Response: We will add a paragraph on "Available discharge and water level gaugings" that gives an overview of the data used. Furthermore, we add several references to be more precise on the data sources used.

- *Page 3, line 13: Which data are you referring to? And how were they estimated?*
  Response: "the data available" will be elaborated more extensively in the previous paragraph, so we believe that this is more clear in the revised manuscript.

- *Page 3, lines 17-19: Add reference to fig.2*
  Response: We add the reference in the text.

- *Page 3, line 21: What do you mean by total discharge? Can you be more specific so that you give a reference point to the reader?*
  Response: we will rewrite this sentence and try to be more precise: we are now talking about “peak lateral inflows”. Furthermore, we will nuance the sentence that state that “the sum of the incoming (peak) discharges is therefore equivalent to approximately 12% of the total discharge at the Meuse”, since this is based on the peak discharge levels in the tributaries, but peak attenuation also lowers discharge levels in the tributaries further downstream.

- *Page 4, line 8: Where is Keizersveer? It is not shown in any of the maps. Please add visual.*
  Response: We added a map of the monitoring sites in the supplementary information.

- *Page 4, line 19: How do you define ‚rapid response systems?*
  Response: we will replace the term “rapid response” by small time of concentration. As a result, the peak water levels occur rapidly after the heavy rainfall.

- *Page 4: line 21-22: Provide source for your double peak statement.*
  Response: We will add a graph in the supplementary information that shows the time series of the water level height w.r.t. the peak at every location along the three tributaries. The double peak is clearly visible in these graphs.

- *Page 4, lines 27-28: Further explanation of the phenomenon is required here.*
  Response: we will rewrite these sentences to further explain the phenomena

- *Figure 3: It would help the reader if you gave different colours to the lines that correspond to the two trajectories.*
  Response: we will change the colors to differentiate the two lines

- *Page 5, lines 14-15: What is the cause of the peak atteniation phenomenon? Please explain the mechanism.'*
  Response: we will explain this phenomena in more detail: "Peak attenuation is the gradual decrease of the peak discharge when a flood propagates downstream. The rate of peak attenuation depends on the river geometry, such as river slope and floodplain width and available storage areas (floodplain, wetlands, lakes and reservoirs). High hydraulic roughness of the channel and the floodplain also enhances peak attenuation."

- ~~*Page 7, lines 3-7: This requires further explanation. A map that shows the retention area is needed here as well as a clarification of the mechanism that links peak attenuation with the (size?) retention areas.*~~
- ~~*Page 7, line 5: How are these numbers (35-60 m3/s and 60-120 m3/s) estimated?*~~
- ~~*Page 7, line 6: But how can this statement be ascertained?*~~

- *Page 9, lines 17-19: This shouldn't be plain text but note in your table.*
- Response: we will put this as a note under the table instead of plain text

- *Page 10, lines 13-16: This is very interesting, but it shows that the official model that the Dutch government uses has some serious flaws. It is important to provide a list of the widening projects that the model accounts for but have not been realised yet, but also a list of assumptions in the model that are not valid anymore.*
  Response: we will rewrite these lines. The main message will be that there are several factors that may results in discrepancies between models and measurements of which several are listed. Further research is necessary to understand and explain these differences. It remains challenging to develop models that represent the current state of a river at a specific moment, especially considering that these models are typically utilized for a period of one year.

- *Page 16, line 5-6: It seems in the text that this piece of information hasn't been verified by the authors.*
  Response: No, we are sure this is the highest discharge level ever measured in the Meuse. we checked the paper for consistent word usage about "highest discharge ever measured"

- *Page 19, line 4: More information about the data source is needed.*
  Response: we add a reference and more information about the data source in the main text

Reviewer E:

- ~~*An inclusion of some more methodological details would strengthen the presentation and support reproducibility.*~~
- ~~*One major critical point is the presentation of the effect of retention measures on flood attenuation. This aspect seems to be rathe speculative and should be presented with more data and supported by respective analyses. See my comments below.*~~

- *I feel the abstract is somewhat too detailed and can boiled down and shortened.*
  Response: we will rewrite the abstract and will start with a clear aim and summarizes some, but not all, findings.

- *P1 L7: More than 180 people, not 200: https://de.wikipedia.org/wiki/Hochwasser_in_West-_und_Mitteleuropa_2021*
  Response: We adjust the number and add a reference to a scientific paper

- *Figure 2: Mark gauge stations with a distinct sign and include it into the legend. I assume arrows indicate inflow from the tributaries. Include this into the legend.*
  Response: We add a new map with all gauging stations to the supplementary information to mark all gauge stations. In Figure2, we only show several main stations to keep the figure in the main text organized. Furthermore, we improve the caption where we clarify the arrows in the figure.

- *P5 L21-22: what does percentile mean in reference to the shape of a flood wave? This should be explained. How do you derive such a percentile?*
  Response: we explained the percentile in reference to the shape of a flood wave: “aligning the peak discharges and calculating percentiles of the relative discharge per day.”

- *P6 L13ff: Rather than discussing the relationship between flood duration and peak attenuation, I think it would make more sense to talk about flood volume. Flood volume controls in the first instance how effective the retention measures would be, doesn’t it?*
  Response: The flood duration and flood volume are strongly correlated and we believe that both could be used. Studies have been done for the correlation to the attenuation, but showed similar correlation to these parameters (e.g. Gerretsen, 2009). For the example of retention areas it could also be debatable. It is of course strong linked to the flood volume above the inlet level, but that does not generalize to other definitions of the flood volume.

- *P7 L3ff: This is one of the central and most interesting statements of the manuscript that the retention capacities caused a significant peak attenuation and water level reduction at the lower Meuse river. I was surprised that there is basically no analysis and data in the manuscript supporting this. This should certainly be elaborated in more details. What additional retention capacities were established after 1995? What is the total storage volume? Is the stronger attenuation of the 2021 flood wave compared to 1993/1995 due to its specific shape/volume or is it due to additional storage capacities that were built in the meantime?*
  Response: we will rewrite the paragraph about the retention areas (see major revision for more details). The retention capacities decreased after 1995 (Asselman et al., 2022) and the stronger

attenuation is solely caused by the specific shape/volume of the flood wave and not by the additional storage capacities. This will be added to the manuscript.

- ~~*If these analyses are not provided I find it difficult to accept the speculation about the role of storage capacities on flood attenuation.*~~

- *P7 L26-27: I do not understand what the factor of 2.5 means.*
  Response: we explain this factor in more details and also corrected it to the value of 3: "a decrease in exceedance probability of the discharge level near Eijsden of a factor 3, so from an exceedance probability of 1:30 per year to 1:100 per year, based on available discharge frequency lines (Hegnauer et al., 2014)."

- *P7 L29: what peak discharge did ultimately occur?*
  Response: we will made same adjustment and after further research the estimated peak discharge that ultimately occurred was 3310 m^3/s

- *Chapter 4.2: when you are talking about return periods of water levels, e.g. 1:100, are you referring to the water level corresponding to the discharge with return period of 100 years and considering actual river morphology of today? If so, this should be explicitly stated. The statement "1:100 return period water level" is misleading then. I t would be good to specify the time series and estimation method, how the return period was calculated.*
  Response: The way you state it is correct; we estimated the exceedance probability of water levels by combining the probability distribution of peak discharge levels upstream and calculated water levels by a hydrodynamic model that was forced by a flood wave with a certain peak discharge, that represent the current or future state of the river. We will adjust the misleading statements and explain the method used to calculate return periods in more detail.

- *Or was the statistical analysis carried out using water level time series? This seems to be suggested on P11 L1ff. If so, how was this done and how the homogeneity of the time series was ensured, as water levels fluctuate due to changes in river morphology. Therefore, it is quite uncommon to run the statistical analysis with water levels instead of peak discharges.*
  Response: We derived statistical information about discharge levels and then forced a hydrodynamic model to estimate water levels in the river. We rewrite this paragraph to make this more comprehensible to the reader.

- *P12 L6 Reference to Figure 12?*
  Revision: we referred to the wrong figure, so we will change the reference

- *P12L11: the reference should be to Figure 13.*
  Revision: we will correct the references to the right figures.

Gerretsen, J. H. (2009). Flood level prediction for regulated rain-fed rivers (Ph.D. Thesis). Enschede: University of Twente.