Reviewer 2

This paper introduces a methodology and analysis of estimating reservoir operations across 74 different catchments in the Alps using general additive models. The goals were to identify groups of catchments with similar reservoir operations and assess how catchments differ with diff operation differ in location and catchment characteristics (how do different operations affect locations and areas). The approach of using GAMS was indeed a really interesting idea, however, I found the manuscript to be too vague and light on details to be confident in the results or for the methods to be reproduced.

Reply: *Thank you very much for your careful assessment of our manuscript and for acknowledging the value of our work. We highly appreciate your constructive inputs. We substantially revised the manuscript with a particular focus on the methods and results sections. In particular, we provided an illustration of the workflow, which allowed us to deepen the methods description, we added a systematic assessment of the model's performance across all catchments, and redesigned the figures in the results section. We hope that the revised methods section provides a clearer idea of how the model was implemented and how it performs and the revised results section is easier to follow.*

Major Edits by Section:

Methods:

- General Data Section
    - Can correlations be made if we are not looking at the same time periods? Can this be expanded on?
      Reply: *We specified in the introduction that: 'The estimated transfer function calibrated on the unregulated period is applied via equation 1 to the regulated period, assuming that the relationship between climate variables and streamflow remains stable over time.'*
- Climate data was from gridded dataset, averaged over the full time period, moving time window to and replaced NA with mean flow
    - Does it make sense to replace NA with mean flow? If you want to keep mean flow, perhaps filling with monthly averages would be better.
      Reply: *Thank you for this suggestion. We replaced the few missing values with daily averages: 'If present, missing values in the time series of all variables are replaced by the daily mean over the natural period for the natural data and over the regulated period for the regulated data.'*
    - How was the disaggregation done?
      Reply: *We specified that: 'Each annual mass balance time series is dis-aggregated into daily resolution by smoothing the annual signals over 365 days.'*
    - What was done to normalize or standardize the other data used
      Reply: *We specified that 'All other variables were used on their original scales.'*
- GAMs Section

- I'm not sure subtracting the mean standardizes your streamflow timeseries. Perhaps, it would be better to normalize by subtracting the mean and dividing by the standard deviation
  Reply: *We agree that normalizing by subtracting the mean and dividing by the standard deviation would be a valid normalization alternative. However, we normalized by dividing by the mean because we wanted to prevent the creation of negative flow values. We updated the text accordingly: 'We normalize both the natural and regulated streamflow time series by dividing by the mean flow over the corresponding period.'*
- Do you test for outliers in the Streamflow data? The peak in Figure 5 a around 2000 could be a result of an extreme weather event or an outlier in the observed data. What do you do to fix these if they occur, or do you simply assume that by normalizing you remove all the outliers?
  Reply: *We are using streamflow data that has been quality checked by the national and regional data providers. Therefore, we assume that the outliers in the observed data are related to actual extreme events rather than measurement errors. The normalization does not remove outliers.*
  - Is it observed – natural for your comparison? If it is not, then the phrasing around line 140 needs to be changed.
    Reply: *We clarified the sentence by writing: 'Positive values represent storage conditions as the observed regulated signal is higher than the predicted natural signal, while negative values represent storage conditions as the predicted natural signal would be higher than the actually observed regulated signal.'*

- Signal Variation Analysis (2.3)
  - I think this section would benefit from a graphic explaining the workflow or at least demonstrating how the clustering is going as this felt like the most information rich section with a lot of steps.
    Reply: *Thank you for this great suggestion. We created an illustration depicting the different steps of our workflow (new Figure 3): (a) Input data, (b) GAM modelling and reservoir signal reconstruction, and (c) reservoir signal clustering. Panel (c) illustrates the different steps involved in the functional data clustering procedure: (1) functional data representation and (2) functional data clustering.*
  - I would also add more details on the previous Brunner et al., 2020 paper.
    Reply: *In addition to adding an illustration of the clustering workflow, we provide some more information on the functional data representation: 'B-spline functions are defined by their order of polynomial segments and the amount of knots, which determine their ability to represent sharp features in a curve (Höllig et al. 2013).*
    - My main concern is that figures 3,4,5 only focus on the single catchment and not all the catchments. Would it be possible to include all the catchments.
      Reply: *Thank you for highlighting that model evaluation had to be expanded beyond example catchments. We added a more comprehensive model evaluation by computing a range of goodness-of-fit statistics for all catchments in the dataset: 'We assess the model's performance by comparing observed with predicted streamflow values and by computing a range of different performance metrics including the Kling-Gupta (KGE) and Nash-Sutcliffe efficiencies (NSE) (Gupta et al. 2009, Nash 1970), volumetric efficiency (VE, Criss & Winston 2008), mean absolute error (MAE), root mean squared error (RMSE), and percent bias (PB).*

The model captures the observed values and their distribution quite well, as illustrated by comparisons of observed vs. predicted values (panel a), observed and predicted quantiles (panel b), and observed and predicted time series (panel c) (for an example catchment see Figure 4). This visual impression is confirmed by the goodness-of-fit statistics computed across all 74 catchments (Table 1). KGE values range between a first quartile of 0.38 and a third quartile of 0.75, NSE values between 0.23 and 0.64, volumetric efficiencies between 0.49 and 0.73, which means that mean flows and volumes are slightly better simulated than high-flows. MAEs range between 0.27 and 0.51 mm/d (normalized flow), the RMSEs between 0.45 and 0.96, and the percentage bias is 0. This performance assessment suggests that the model is suitable for predicting streamflow under natural conditions.'

- Figure 1: I would zoom out a bit from the map so we can see the full Rhine and be more oriented in the catchments, Also what are the differences between the purple and black outlines? Denote that in the figure caption
  Reply: *Thank you for these valuable suggestions. We adjusted the figure by zooming out and by adding a legend including the different map symbols.*
  - Also, may be useful to put a map of the reservoirs so we can see where they are spatially located
    Reply: *We like the idea of adding reservoir locations. However, adding all reservoirs would make the map a bit too noisy and we therefore decided to stay with catchment boundaries and outlets.*

- Figure 5: I would shade the release periods vs storage periods in panel c so that the reader has an easier visualization for what periods are storage and which ones are releases.
  Reply: *We shaded the storage and release in Figure 5c (new Figure 6c).*

Results:

- This section felt very choppy as there was one figure then a few lines of text. I think this could be more clear by grouping the results and creating panel plots. I do like that this section had all the catchments on it
  Reply: *Thank you for indicating that this section needed improvement. We substantially reduced the number of figures in the results section by removing Figure 6 and creating two new multi-panel figures. The new Figure 7 combines the results previously shown in Figures 7 and 10 and the new Figure 8 combines the results previously displayed in Figures 8 and 9.*
  - Figure 6: I'm not sure this figure adds too much to the discussion. Perhaps you could panel your reservoirs by bigger basin or by similar characteristics (ie peaks in summer, peaks in winter). Another option is to color them by region or use, although I do think paneling or grouping would be useful to the viewer.
    Reply: *We agree that the previous Figures 6 and 7 provided redundant information and think that it is a good idea to remove one of them. Therefore, we removed Figure 6 and replaced it with a workflow illustration as suggested (new Figure 3).*
  - Also, after seeing Figure 7, I think you can cut figure 6 and use that space to add a graphic about the workflow in 2.3
    Reply: *We agree that the previous Figures 6 and 7 provided redundant information and think*

that it is a good idea to remove one of them. Therefore, we removed Figure 6 and replaced it with a workflow illustration as suggested (new Figure 3).

- I would also add a legend to this plot to denote what green and blue mean. Additionally, I would pick more colorblind friendly colors to be more inclusive.
  Reply: *We added a legend to the plot and changed the colors to a colorblind-friendly color combination. In addition, we adjusted the cluster colors in all other figures.*

- Figure 8 should have a map of the larger area so we can situate ourselves a little better
  Reply: *We adjusted the extent of the figure in order to improve orientation.*

- You could combine figure 9 and 8 into one panel so this section doesn't feel as choppy
  Reply: *Thank you for this great suggestion. We combined figures 8 and 9.*

- Figure 10's results tie directly into the map created in Figure 8. I would definitely panel some of these plots (Figure 8,9,10) in order to make this section flow smoothly and not feel as choppy. I would also reorganize the results about figure 10 and the reservoir location to be next to the map.
  Reply: *Thank you for these great suggestions. We created two new figures that combine the contents of previous figures 7-10. The new Figure 7 combines the results previously shown in Figures 7 and 10 and the new Figure 8 combines the results previously displayed in Figures 8 and 9.*

Discussion:

- I do not feel that you did a strong job of linking catchment elevation to reservoir operations, Perhaps that is due in part to the shorter results section. I think main use is a bigger takeaway as you specifically state that higher elevation reservoirs are more hydropower vs lower elevation being water supply.
  Reply: *We added a summary of the reservoir purposes of catchments in clusters 1 and 2 to the results section (see Figure 5 in this response to the reviewer file). The figure shows that reservoirs in the (high-elevation) catchments in Cluster 1 are primarily used for energy production, while the reservoirs in catchments belonging to Cluster 2 are operated for a variety of purposes including energy production, flood control, and recreation.*

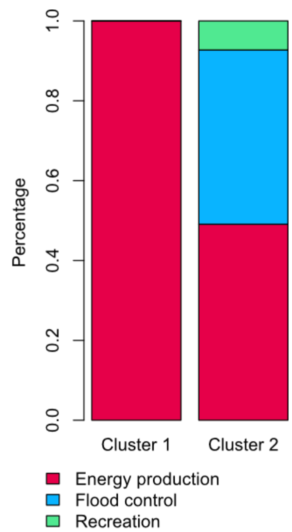

Figure 1: Reservoir purpose mix of catchments in regulation clusters 1 and 2 (see Figure 9 in the paper): Energy production, flood control, and recreational use.

Minor Edits:

- Figure 2: I would add a dashed line when the reservoir came online so we have a better idea of when those changes occurred.
  Reply: *We added a line to the plot indicating when the reservoir was constructed.*
- Figure 4: the grey on the natural flow is hard to see. Perhaps using a dashed line or something like that would be useful?
  Reply: *We changed the color to a darker grey to increase visibility.*
- Figure 3: I really liked this figure!
  Reply: *Thank you.*

Notes from HESS specific questions:

1. Does the paper address relevant scientific questions within the scope of HESS?

Yes. It looks at how humans have impacted the hydrology of certain regions by deriving reservoir operations from generalized models

2. Does the paper present novel concepts, ideas, tools, or data?

I believe it does, but I think the authors could emphasize why this is so novel.
Reply: *We reworked the introduction to highlight the two novelties of our paper: (1) we propose a statistical three-step approach for reservoir signal reconstruction in catchments where reservoir outflow but no inflow time series are available. (2) The combination of the proposed reservoir signal reconstruction approach with functional clustering allows us to provide insights into how reservoir regulation varies spatially in the Alps and to which degree these variations are related to catchment characteristics.*

3. Are substantial conclusions reached?

I personally felt that the conclusions reached could have been more direct
Reply: *We separated the conclusions from the discussion section to highlight the main conclusions: 'We find that in the Central Alps there are two groups of catchments with distinct reservoir operation strategies: high-elevation catchments with pronounced seasonal water redistribution from summer to winter for hydropower production and low-elevation catchments with weak seasonal water redistribution for different reservoir purposes. The reservoir signals reconstructed using the GAM modelling approach may be used to inform hydrological model development and calibration. Furthermore, the reconstructed signals could inform the representation of reservoir operation in hydrological models. Improving such representation is crucial to advance the field of change attribution as it will allow for a better separation of climate and regulation signals, which both influence streamflow characteristics.'*

4. Does the title clearly reflect the contents of the paper?

I think there could be a more informative title (something like "Deriving reservoir operations from streamflow using GAMS), because you make the case in your introduction that your main takeaway is the ability to derive reservoir operations directly from streamflow, climate, etc

Reply: *Thank you for this alternative title suggestion. We changed the title to: 'Spatial variability in Alpine reservoir regulation: deriving reservoir operations from streamflow using GAMs'*