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Hydrology and Earth System Sciences Discussions

Interactive comment on “What drives flood trends along the Rhine River: climate or river training?” *by* S. Vorogushyn and B. Merz

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We thank Jose Luis Salinas for his keen comments and suggestions on our manuscript. Below the point-by-point response is provided with original comments quoted in italic.

Overall, this is a paper with relevant results for the river Rhine and potential to be extrapolated to many large rivers around the world (especially European ones), in terms of quantitative effects of river training on peak flow trend and flood wave acceleration.

The title itself is quite ambitious. It refers to a science question not directly addressed in the paper, but only partially answered, in the sense that after quantifying and removing

the effect of river training there are still remaining significant trends. These need to be attributed to other causes, as is accurately stated in the Conclusions (Page 13555, lines 8-11), and not exclusively to climate change. The title could remain, but some comments on the fact that only the part of the question concerning river training is answered could be included in the Conclusions.

Response: We agree with the reviewer that the question posed in the title of the manuscript is not fully answered. However, we would prefer to keep the title as it is because it points out exactly to the question which is currently debated in the hydrological community, particularly in the case of the Rhine River, of how much of the flood changes are caused by climate variability and how much is anthropogenically driven. We believe that our work substantially contributes to the answer of this question. We will rework the conclusions and indicate that the posed question is only partly answered in the presented manuscript.

- (abstract) Page 13538, lines 20-21 There is a strong language bias if under “large scale driver”, only the example of climate is included, especially in the abstract. The formulation of the last sentence of the abstract (“... by factors other than river training...”) or more explicitly the one of Page 13555, lines 8-11 is more rigorous.

Response: We agree that the statement in the abstract with regards to the residual signal should be made more rigorous. This is also suggested by the first reviewer. It would be better to discuss the potential influence of climate variability/change on residual trends in the results/conclusion part where it can be explained in more details. It is indeed already strong evidence now for a large-scale driver that even after the isolation of river training effect the spatially coherent trends at Rhine gauges remain, and moreover the tributary flows show consistent positive trends.

- (section 2.2) Page 13543, line 22 “By simulating a number of historical floods...”. The step of the hydraulic reconstruction and flood flow homogenisation is crucial for the implications in the rest of the analysis. The statements could be more quantitative

answering questions like: how many historical events were used for calibrating the the hydraulic models in each period (an why, maybe data issues...)?, was the entire Rhine basin calibrated and simulated, or gauge per gauge?, why do the numbers of events in Table 1 differ for the same periods? where the historical events for calibration selected or discarded after some criteria?

Response: We agree with the reviewer that more details about the setup of the routing models used for homogenisation would be appropriate. Since we did not carry out the setup and calibration of the models ourselves we abstained from repeating the details from the cited publications. We will provide more details in the revised version of the manuscript.

Two routing models were applied for homogenisation of the Rhine flood flows: the hydrological routing model SYNHP, which simulates the translation of the flood waves through a storage cascade and considers the effect of river engineering on channel morphology through the calibration of the storage coefficients, and the hydrodynamic model SOBEK that explicitly describes channel geometry with cross-sections and uses calibrated roughness coefficients and detention basin storages to capture river training effects. The routing models for respective reaches SYNHP (Basel-Cologne) and SOBEK (Andernach-Lobith) use flow hydrographs of the main channel and tributaries as boundary conditions and were calibrated in previous respective studies at gauges of the Rhine main channel. The homogenisation of flood flows was carried out in different studies for different parts of the Rhine (HWSG, 1993). In these studies different collections of representative flood waves were used. Therefore the numbers of used events differ from each other for the homogenisation of flows in the period from 1955 to 1977. Moreover, for the homogenisation of flows in the period after 1977, only flood events were considered which exceeded a certain threshold and were affected by detention basins. We will explain this in the manuscript in more details.

- (section 2.2) Page 13543, line 24 "..., the relationships between the observed and reconstructed..." There is no explicit mention on the text that linear regressions (one can

extract this information only looking at the table, not at the description of the method) were performed. In Page 13544, line 1, only "regressions" is mentioned, these could refer also to analytical relationships different to linear.

Response: Thanks. Indeed linear regressions were used to relate the original and reconstructed flood peak flows. We will correct this in the revised version of the manuscript.

Another technical question related to the linear regression, are the coefficients of determination shown in Table 1 in validation (e.g. leave-one-out jackknifing) or in calibration (then it is equal to the linear correlation coefficient between y-x)?

Response: The numbers of r^2 given in Table 1 represent the coefficient of determination and not the Pearson correlation coefficient. This will be clearly articulated in the manuscript.

If one analyses the values of estimated slopes in the linear regression formulas, they are all very similar to the unity, with a couple of exceptions, meaning that the relationship consists basically in a shift. This could indicate that perhaps linear regression is not the best choice; have other alternatives been tested? Why not simulate hydraulically all the new events with the past conditions? Is it a matter of computational time?

Response: Other relationships than linear were not tested, but besides very high correlation coefficients also the visual inspection strongly suggests the linear relationship between original and reconstructed flood peak flows. This work builds on the existing hydraulic models and hydraulic simulations that were carried out by HWSG (1993) and BfG (1999). It was not possible to receive these models and carry out the detailed reconstruction of all annual flood peak flows.

- (section 2.2) Page 13544, line 6 "... typically showed very high coefficients of determination." The statement could be quantitative, e.g. "showing values between 0.89 and 0.99".

Response: This will be changed in the revised version of the manuscript.

*- (section 2.3) Page 13545, line 25 and Page 13546, equation (1) "... between the years 1952 and 2009 given by..." Do the differences always refer to the control period 1952-2009 of observed data, or for all different 30-yr combinations between 1952-2009. Should the equation then be, more generally, "Q*last – Q*first"?*

Response: Indeed, equation (1) should have a more general form as suggested by the reviewer. The relative change is computed for different periods with at least 30 years length. The equation will be reformulated.

- (section 2.3) Page 13546, line 20 What is a "10-yr running mean of the coefficient of variation"? Does it refer to the calculated sample coefficient of variation over a moving window of 10 years of data (i.e., sample size of 10)?

Response: "10-yr running mean of the coefficient of variation" refers to the coefficient of variation computed over a moving window of 10 years.

- (section 3.1.1) Page 13548, lines 9-10 (and Page 13554, lines 12-13) Being not familiar with the method, I could be completely wrong, but couldn't be the significant chnage-points in the 50s and the 2000s due to an artifact, being at the beginning and the end of the sample?

Response: The reviewer raises an important issue with regards to the interpretation of the change-points detected in the beginning and the end of the time series. Indeed, these changes towards lower flood flows could be affected by the proximity to the start and end-point of the time series. The Pettit-test proves the hypothesis that two pieces of a time-series separated at a certain point come from the same population (or distribution). If the hypothesis is rejected under a certain confidence level, the point is considered to be a change-point. The length of the two time-series and the presence of extreme values in short series may indeed affect the results. We will therefore not further interpret these results in the context of change-point detection.

- (section 3.1.2) Page 13548, lines 7-11 (and Figure 5b) In order to assess the stationarity of flood wave travel times in the Neckar River, the difference in arrival times of flood peaks between Rockenau (Neckar) and Basel (Rhine) was calculated. By looking at Figure 1, one can see that these two gauges are located more than 200 km away. This could imply that the flood peaks in the two stations could be originated in different points in time during the same rainfall event, due to spatial and temporal heterogeneity of rainfall, particularly during large-scale storms, such as the ones affecting the entire Rhine river basin. A closer gauge in the river Rhine should be used in order to investigate the stationarity of celerities in the Neckar River, possibly Maxau or Worms.

Response: Indeed the heterogeneity of rainfall over the Rhine catchment may introduce some variability in the arrival time of Rhine and Neckar flood waves at their confluences. But we assume that the spatial rainfall variability did not significantly change over time and thus did not caused systematic shifts in the relative arrival time of flood waves in the main channel and the tributary. Moreover, the closer gauges such as Maxau and Worms cannot be used for investigation of the Neckar celerity because they themselves were affected by the weir cascade and exhibit non-stationarity in flood travel times.

References:

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HWSG: Der Einfluß des Oberrheinausbaus und der am Oberrhein vorgesehenen Retentionsmaßnahmen auf die Hochwasser am Mittelrhein von Kaub bis Köln, Report, Hochwasserstudiengruppe für die Rheinstrecke Kaub-Rolandswerth, Ministerium für Umwelt Rheinland-Pfalz, 1993.

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