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Discussions

Interactive comment on "Estimating flood damage to railway infrastructure – the case study of the March River flood in 2006 at the Austrian Northern Railway" *by* P. Kellermann et al.

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Response letter to the comments of Referee #2 (Jaroslav Mysiak)

Thank you very much for your comprehensive review and your valuable suggestions to improve our study. We carefully revised the manuscript according to your comments. Please find below our specific responses.

Specific comments:

Comment 1: The RAIL model is applicable to track's cross-sections and leaves out other rail infrastructure elements. More importantly it distinguishes only three damage categories that are suitable, as the authors acknowledge, for 'fast and practical in-field damage assessments' (page 2634, para 2). Given the recent technological advances of the remotely piloted aircrafts (drone), one can reasonably expect that extensive photographic material can be collected and processed at rather modest costs. To exploit the full potential of these technological advancements, a more detailed categorisation of damage would be needed, similar to one in Koseki et al. (2012) for railways damage caused by earthquake.

Response 1: Indeed, the potential of the innovative technology of drones to enhance the event and damage documentation procedures on alpine hazards and railway damage has already been discussed by the authors. However, there are considerable difficulties in the practical implementation of this approach. The main one is the current legal situation regarding the operation of drones in Austria (and Germany). In every case an unmanned aircraft (drone) is planned to be utilized, a special permit is required, particularly when infrastructure is involved. In case of an event, regulations are even stronger and such a permit can usually not be requested in reasonable time and, thus, does not satisfy the demand of 'fast and practical in-field damage assessments'. Furthermore, among other regulations, it is not allowed to use drones e.g. in populated areas which considerably limits the potential ranges of application. Hence, different obstacles have to be overcome both with respect to practical implementation in the standard practise of event and damage documentation as well as with respect to experimental research.

Moran et al. (2010) defined five damage classes for the cross-section and we initially adopted this classification for the study at hand. However, the (statistical) results on the basis of that classification were not satisfactory. One explanation is that the approach of Moran et al. (2010) also considers the possibility that the track segment is fully inundated without causing structural damage. However, both from the engineering and the economic perspective, this sequence of damage grades is not optimally adjusted since only structural damage (particularly at the substructure) will lead to the necessity of reconstructing the track segment and will cause significant economic losses. Hence, after discussing and evaluating the initial results with railway experts, we revised the classification of Moran et al. (2010) and reduced the number of categories from five to three with the aim to focus more on structural damage to the substructure being the most important and expensive element of the standard cross-section. This approach led to a markedly increase in the statistical correlations of flood impact and structural damage. Generally, we think that a finer classification of structural (and economic) damage is not required, since there is no significant difference between certain grades of damage to the track, e.g. minor, medium and major erosion damage to the substructure, at least from the engineering perspective. In case the substructure is (at least somehow) damaged, the train service is disrupted and the segment has to be repaired anyway. Indeed, from the economic perspective, the repair costs are to some extent dependent on the damage grade of the standard cross-section. We address this aspect by calibrating the cost estimation of damage class 2 (= damage to substructure is expected) on the basis of the recorded repair costs in 2006. This resulted in a derivation of a coefficient of 0.25 being added to the calculation of repair costs for damage class 2. In other words, the costs of full restoration of 100 m of a track segment's substructure are quartered, which corresponds to the average repair costs of all (partly) damaged substructures in 2006.

Comment 2: A critical point in the RAIL model development is the linking of determined damage with the (simulated) flood characteristics. The authors opted for matching flood grid to polygons obtained as buffers to linear, 100m-long rail segments that were previously assigned to a damage category. The ensuing non-parametric (Spearman's rank) correlations between aggregated flood characteristics and predetermined damage categories are highest for flood depth (h) and Energy head (E) and 5m-wide polygon buffers. The authors however chose to use 10m-wide buffer polygons and discarded the better performing 5m-wide polygons as a result of 'technical consideration', not further explained. Arithmetic mean as an aggregation function of flood grid cells within the buffered rail segments outperformed the max values in terms of estimated correlations. I wonder whether grids with different resolutions would confirm the authors' choice. In principle, the highest structural damage to rail subsection determines the attribution of the rail segment to a damage category. Intuitively, this would mean that the max value of the aggregated flood grid cells for the relevant rail segment should be preferred to the arithmetic means. I would recommend analysing the correlations more in depth also using the flood grids with different resolutions, so as to determine whether or not the Spearman's rho is subjected to a bias resulting from the modifiable areal unit problem (MAUP).

Response 2: The 'technical considerations' reflect the fact that a 5 m buffer is regarded as being too narrow to represent a multi-track railway line like the Northern Railway. Since the inner boundary of the buffer is set to the centre of the track lane, the buffer width of 5 m would be insufficient to cover the entire rail embankment and, thus, to enclose all elements of the cross-section adequately. This decision was also discussed with railway engineering experts. This information will be added in the revised manuscript.

We performed the more in-depth analysis of correlations according to your suggestion. For this, we aggregated the original resolution of the flood grid (1 m) to three different resolutions, i.e. 2 m, 5 m, and 10 m. The results indicate that the Spearman's rho is not subjected to a bias resulting from the MAUP, since the new correlation coefficients do not significantly differ from the coefficients presented in our manuscript, neither on the basis of the aggregation using the mean flood impact value, nor using the max value. In fact, only one slight improvement could be achieved using the flood grid resolution of 10 m. Herein, the correlation coefficient of the mean flood impact and the damage categories increased from 0.5 to 0.563 ($p=0.001$). Due to this marginal effect, we would not include this analysis in the revised paper.

Comment 3: Another important point in the RAIL model is the estimation of thresholds in simulated flood characteristics used for determining the damage category. The authors opted for using the intersection points of Gaussian kernel density estimations

(KDE) for different damage classes for this purpose. The KDE for the lowest damage class is determined by using only 3 observations. The relatively low correlations between chosen flood characteristics and the analysed damage classes result in overlapping kernel density estimates which casts a doubt about whether or not the definition of damage categories is the most suitable one. The need to re-calibrate the damage values for each of the three categories when applied for the 2006 March flood (see also the technical comments) may pinpoint to the fact that the threshold values are not representative enough.

Response 3: In our opinion, the bias resulting from the low statistical population used for the KDE of damage class 1 can be accepted, since damage class 1 is the least important category both in engineering and economic terms. Herein, no structural damage has to be expected and only minor cleaning costs are incurred.

The substructure is the most important element of a railway track‘s standard cross-section both in engineering and in economic terms. Hence, if the substructure is (partly) damaged, the railway service will be disrupted due to the risk of instability, the substructure needs to be repaired and significant economic losses must be expected. To address this aspect, the damage values were only calibrated for damage class 2, which represents damage to the segment‘s substructure (see also Response 1).

Comment 4: More in general terms, I was wondering whether the assumption of constant value for the total damage along the railway track really holds true (page 2640, para 2). Intuitively I would expect that beside the standard material, machinery and labour costs what matters is also the remoteness and accessibility of the damaged railway segment.

Response 4: The model RAIL is currently assumed to be particularly applicable in (rather flat) regions, where the railway infrastructure is exposed to floods showing similar characteristics as the one of the March river flood of 2006.

Indeed, the restoration of a railway track e.g. in steep, hardly accessible (mountainous) terrain can be notably more expensive. However, in such areas the fluvial events often show characteristics that are significantly different to those of a “classic river flood”, i.e. rather low flow velocities and low solid fractions in the inundation area. Nevertheless, in case that higher repair costs due to difficulties of accessibility must be expected, the underlying loss values in RAIL can easily be adapted to the specific circumstances.

Technical comments:

Comment 5: The text on pages 2637 (para 2), 2642 (para 1) and 2643 (para 1) suggests that the initial damage values for each damage category (reported in Table 1) have been adjusted in Table 4 so as to better fit the reported damage in the aftermath of the March 2006 flood. In fact, however, the values reported in Table 1 and 4 are the same. In addition, the description of the table 1 does not fit the content of the table (only costs per segments and not per running meter are reported).

Response 5: We deliberately only present the “final” values not to confuse the reader with redundant numerals. The fact that the values in Tab 1 are already calibrated is mentioned in the description of Tab 1. Thank you for pointing out the mismatch of the description of Table 1 and its content. This will be corrected in the revised version of the paper.

Comment 6: The authors have chosen to consider values of Spearman’s rho exceeding 0.5 as ‘significant’ (sic) ones. This is confusing as the statistically significant values are highlighted by the reported p values. Rather, the authors may use verbal description of the strength of the correlation (moderate or strong).

Response 6: Thank you for highlighting this potential confusion. We are going to improve the wording according to your suggestion.

Comment 7: Figure 3 should be improved as it is hardly readable in the current form.

Response 7: An improved version of Figure 3 will be available in the revised version of the manuscript.

Comment 8: Although not important for the core of the paper, it was not very clear to me how the simulated 2006 flood could have been calibrated on the basis of the previous (1997 and 1999) floods (page 2635, para 1).

Response 8: To calibrate a hydraulic model by means of previous flood events is a well-accepted procedure in hydraulics. Different model parameters have been calibrated using data from these historical flood waves, e.g. bank and stream bed roughness. Additionally, the model boundary conditions have been set according to the 1997 and 1999 data, in particular at the Danube estuary, since the flood wave of the Danube is significantly influencing the gauge data in the downstream of the March. It is assumed that a so calibrated model can reliably simulate other flood wave along the same river reach, too.

Comment 9: It would be valuable to revise the text so as to make it easier to follow, and describe briefly the final structure of the RAIL model at the onset of the article. There are some typos in the text which I can pass to the authors directly.

Response 9: We will improve the introduction of the article according to your suggestion. Thank you also for correcting the typos.

Interactive comment on Nat. Hazards Earth Syst. Sci. Discuss., 3, 2629, 2015.