Revision of the manuscript on “Scale-breaks of suspended sediment rating in large rivers in Germany induced by organic matter” by Thomas O. Hoffmann et al.

First of all, we thank Kristin Bunte and the anonymous reviewer for their constructive criticism and for taking the time to share their insightful suggestions and comments. Both reviewers do not have a general critic on the manuscript, but made many detailed suggestions how to improve it. Thus, we address their comments in the revised version of the manuscript (including track changes option) and reply to their detailed comments step by step below. For your convenience, we colored our replies to each comment of the reviewers in green letters.

Referee #1: Kristin Bunte

The manuscript presents an interesting study and is well worth publishing in e-surf. Teasing apart the different sedimentary constituents (mineral, organic) that determine rating relation between suspended sediment and discharge is an important contribution. The authors quantify the different components and their change with discharge and provide a model that appears to be applicable to streams in Germany.
The description of the three methods used to compute the breakpoint flow is a bit unclear, a bit more help is needed to enable the reader the follow all steps. More of a problem is that the authors repeatedly refer to a bootstrapping approach, but never explain why bootstrapping is undertaken, what data are used, and what the purpose of the bootstrapping approach is in the first place. This needs to be revised. The manuscript also needs clarifications all over. Most of the issues are minor and can be easily addressed. I have provided a lot of suggestions for the authors when tackling those issues.
The title reflects the topic of the study, and the abstract summarizes the study effectively.
The manuscript is generally well structured. An exception is the discussion Section 4.1 which is weaker than the other chapters. Items in Section 4.1 are discussed one after the other without connection, without introduction, and without a stated course of argument in the beginning.
Use of the English language is fair. The manuscript needs editorial improvement, the majority of which are minor corrections that can be easily addressed.
Several of the figures need improvement; Again, nothing serious, but revision would help to improve the manuscript quality.
In all, my evaluation of the manuscript is: publish with minor revisions, of which there are a lot, but most of them can be addressed in a straightforward way.

We thank Kristin for her very helpful and detailed comments on our manuscript. Before addressing the detailed comments below, we point out that in reaction to the valid criticism raised here, we changed large parts of section 4.1 to ensure a better connection between the aspects discussed therein. Furthermore, we critically reviewed the methods section with a special emphasis on bootstrapping and sincerely hope that these changes make our manuscript more to the point and easier to follow.

Comments requesting clarification:

L. 15: … identify discharge depended process regimes of suspended matter…. Please define better. Too short - jargon. → rephrased to '…discharge dependent controls of suspended matter.' to avoid jargon.

L 21: …into the first order control of discharge dynamics of suspended sediments. Sounds like jargon. Please start more clearly. → rephrased to '…into the first order control of discharge on the quality and quantity of suspended sediments.' to avoid jargon.

L 63: Please define more clearly which Q is meant. Instant Q? Mean daily Q? → basically, a whole range of "Q" can be used depending on the approach and available data. We added a phrase explaining this: … "Rating curves plot SSC as a function of water discharge Q, while the temporal aggregation (or resolution) depends on the approach and available data and ranges from 15 minutes to annual averages."

L 77: The authors get too involved in describing their plot. I think I know what the authors mean, but I think they could describe this better. SR: A first look at the plot of measured values of SSC vs Q in which data are not segregates by time or processes controlling SSC exhibits strong scatter. → we rephrased the sentence.

L 80: The authors might add that changing water supply or flow hydraulics could also be at play. → we added flow hydraulics because changing water supply is associated with changing Q and changing water sources.

L 86: The authors should add as a 4th item to the list the effects of organic material on SSC that were introduced earlier. Doing so would also give the authors the opportunity to create a connection to the thought starting in line 86 which, as written, appears out of context. SR: Recently, we have learned more about the effects of organic material on SSC, but so far, "Most monitoring studies… → We did not add a 4th item but used the SR to build a bridge between both paragraphs.

L101: Please clarify: Do the "daily" discharge measurements reflect once-a-day instantaneous measurements or are daily averages computed from or continuous measurements of Q and SSC? → We agree that more detailed infos on the measurements is needed, but not at this place. Thus, we deleted the word daily in this line and extended the description in chapter 2.2.

L 116: Here, we selected….Please explain the reasoning for the selection → done, we added more information.

L 123: …SSC was given… do you mean "computed" → yes, rephrased

L 128: (e.g., medium and finer clays?) → rephrased

L 158: It would help a reader if the authors could explain how they arrived at those units for the a-coefficient → done, given the additional information the reader should be able to reproduce the dimension analysis to highlight the dependency between a and b.

L 168: A comparison of Eq. 1 and 2 at one or two stations would be interesting. Does the steepness of the fitted rating relation change after the transformation in Eq. 2? If not, please say so. If yes, please document the change. → the steepness of the fitted relation does not change, we provide more information in the text accordingly.

L 172-179: I find this description a bit hard to follow. Could the authors provide a graphical description/explanation for their computation? → This part was strongly restructured. We hope that it is easy easier to follow now.

L 185: This comes out of the blue with no explanation. Could the authors please explain WHY bootstrapping? What values are bootstrapped and why? → We strongly rephrased this paragraph to give more insights into the WHY.
L 193: ….see Fig. 3 **a**? → done
L 195 (Fig. 3**b**?) → done
L 197: clustering around 1? Don't quite agree. Either give a range (between 1 and 1.3) or a value, perhaps 1.2. → rephrased to give the range of the first and third quantile.
L 198: …clustering around 1: don't quite agree with the statement. I'd say: …. Breakpoints of many stations are slightly higher than the geometric mean discharge → adopted accordingly
L 200: "peaks around 0..." I'd say Fig. 4 indicates that it's > 0. Why not be more specific right away: … peaks near 0.14? → done
L 205: "The differences…." Sentence sounds off as written. Lowland rivers, by definition, have less relief in their catchments. Reword this sentence such that it does not sound like stating the obvious. The term "topography" is vague, too. Is SSC larger because of a steeper channel gradient at the sampling site or due to steeper gradients in the headwater catchments? → we deleted the sentence and rephrased the paragraph!
L 208: …are characterized… sounds vague. What about indicating a direct causal relation and say "generate" → done
L 211: Fig. 7 **a** → done
L 215: …whether the rating for SSC for these two stations → done
Consider that an international reader is not aware that the Moselle joins the Rhine in Koblenz. Please reword accordingly. → it was already state in chapter 2.2. that both rivers join in Koblenz. However, we repeated it here.
L 213-216: Those two sentences could be improved. The authors approach the situation with a mindset of: we had a problem and then we solved it. Please try to reword with a standpoint "from above". Also, as written, I would expect a comparison between sites that were sampled weekly and those sampled daily. Instead the reader is shown two sites with seemingly no connection to Koblenz (mind the international reader).
Perhaps something like: A comparison between …. and ….showed that there was not systematic change in bl and bh due to the frequency of sampling. → rephrased as suggested
L 216-218: sentence is off. Place a period after …. And 1.54+- for **the** Moselle). Those values are similar…
Also: the Rhine and the Moselle → rephrased
L 219: 1000 at each station or at both stations together? → rephrased
L 220: The authors need to explain the what, where, and why of their bootstrap approach! → now explained in detail earlier in chapter 2.
L 221: The LOI -measurements…. An introductory sentence is needed here. The authors just compared the Moselle and the Rhein against other streams. Now the authors seem to compare between the Moselle and the Rhein. → rephrased
L 223: …higher LOI values during the summer months… Please show the reader where in Fig. 8 g+h that is to be seen. Sorry, the color plot shows it. → ok, nothing to correct ;-)
L 241: "…characterized…" vague statement. What about: attributed? Or caused? → rephrased to 'attributed'
L 242: "A positive rating exponent…" It is useful that the authors point to this difference in the exponents of SSC and Qs. However, this statement appears a bit suddenly. Please provide an introductory sentence. → this part is rephrased to avoid breaks in the argumentation.

L. 245: “This implies…” Sentence is poorly worded. “additional sediment sources”: external? Channel bed erosion? → reworded, additional sources are not specific at this stage, however we get back to this term later in the paragraph, indicating that the additional sources are external.

L 247: The authors just switched the discussion from SSC to QS, and I would have expected that the discussion of QS continues, but the authors are switching back to SSC. Eq. 3 and its explanation is interesting, but it appears that this point is only “squeezed in” and interrupts the thread of arguments. Please smooth → the switch is needed to argue that “additional sediment sources” need to be mobilized, this does not follow from SSC alone.

L. 248: …explained by the increasing…… the reasoning of increasing connectivity and increasing area of water-saturated soils seems to be converted: increase in saturated area causes increase in connectivity. → rephrased

L 257: Interestingly, ….An introductory sentence before diving into rating curves from the Elbe and Oder would be useful. → done

L. 261: If “reactivity” means that the flow either carries more sed. from its headwaters or pick it up from the channel bed, more explanation than “drier climate” is needed for why the Elbe and Oder do not do so. Typically, drier areas are considered to have less dense vegetation cover and therefore generate more sediment. Perhaps the authors might turn to geological conditions: Sandstone in the Thuringia Forest and glacio-fluvial deposits along Elbe and Oder may be more porous and generate less runoff than the schists in mountains and highlands along the Rhein and in central west Germany. Perhaps also consider other factors influencing runoff and sediment generation such as land use (percent urban area vs. agriculture) or number of barrages per river mile….? A detailed discussion of the causes might not be the focus of this paper. It is ok to say so, but offering an unsupported statement about the effects of a drier climate on SSC and its relation to Q is not satisfactory. → We are thankful for this suggestion on the importance of soil-saturation. We added the differences of soil porosity, after highlighting the importance of soil-moisture as a controlling factor of hillslope connectivity.

L 264-268: The authors explain that QBr is x times QGM and x times Qavg. Why is knowing this difference important? → We added the median discharge as well. We make the link to Qavg and Qmed since this is much more familiar to geoscientist and hydrologists than the geometric mean. Furthermore the median discharge allows to link the duration a river spends in the low flow and high flow regime.

L 274: 1) “Many of the tributary waterways…” The authors turn to a new subject. An introductory sentence is needed, perhaps something pertaining to a assumed relation between reservoir operation, barrages, and a break in the SSC-Q relation. 2) It sounds like the authors are reacting to some instated issue regarding barrages and SSC. Please bring the reader up to speed on that issue. → Here we just intended to support evidence that reservoir operation is not the dominant control, but that the issue is more complicated. We rephrased this paragraph slightly to build a bridge to the preceding paragraph.

L 275-276: What “reservoirs” do the authors refer to? the channel immediately upstream from a barrage or floodable reservoirs in the floodplain that serve to retain flood waters? What are weir shutters and where are they located? How does opening weir shutters prevent damage to barrages? → We basically state ‘Reservoirs upstream of the barrages…’. This should answer the question. However, to avoid confusion, we rephrased the end of this paragraph from ‘reservoir management’ to ‘operation of barrages’. Explaining the engineering details of barrages is certainly not the aim of this paper. For details the reader is referred to Hoffmann et al. (2017).

L 284: The authors should elaborate on the “Therefore”. Perhaps something like: Given that the study found this and that, and given that flow management in reservoirs and barrages does not seem to control the SSC-Q relation, …the question remains… → we rephrased this part as suggested and hope to improve the line of argumentation.
L 285: …at average discharge? In the analyses, the authors related Qbr to the fraction of Q/QGM. Here, the discussion continues with Qavg. Why this change? → because most people are not familiar with Q_GM and Q_avg is the more common used metric.
L 305: Suggest switching the second and first part of the argument: While a positive correlation between SSCtot and Q was observed for most of the year, SSCtot related negatively to Q during the low flow months, indicating the effects of dilution of SSCtot as flows just start to increase and a shift in the SSC regime… → rephrased as suggested
L. 310: …decreasing trend of bl (Fig. 6b) Should that be Fig 6a? → correct! We change it to Fig 6a
L 322: Again, what bootstrapping? → bootstrapping is a standard procedure to estimate confidence intervals of regression coefficients, as explained earlier!
L 331 and 360: …breaks slightly above Q/QGM = 1 → done, rephrased as suggested
L 377: water sampling…. Perhaps: water quality sampling? Or SSC sampling? → rephrased

Figures
Fig. 4: Instead of the four colors are not very distinctive and indistinguishable when viewed in black and white. I suggest using different line types. → done
Fig. 6: Please explain the empty circles. → done
Fig. 6: When viewed in black and white, there is no color distinction between north and south. Perhaps use a gray scale or patterned circles. → Translating the colors to gray scale will lose much of the visual information. The colored version will be available open access online! Thus, we intend not to change the colors.
Fig. 7: The small dots with different colors are not well distinguishable, esp. not in b & w. Suggest using different symbols. The x-axis title is not understandable. Suggest: (*%A S>10%*) and explaining %A… in the caption text. → points have now different color AND form. Label of x-axis was renamed as suggested
Fig. 7: The caption could be better worded: SR: Relation between rating coefficients (….) and the fraction of the catchment area with hillslopes steeper than 10% (*%A S>10%*) → rephrased
Fig. 8: In caption, replace “line” by “row”, and refer to top row and bottom row. → done
Fig. 9 is overly busy. Considering that the authors do not discus all plotted statistical information (min, max, outliers), I suggest simplifying the plot to improve its readability and emphasize the plots’ main points. For Fig. 9a I suggest:
- drawing a curve indicating the median values for each month. Surround that curve with a shading the upper and lower boundaries of which indicate the quartile values.
- Do the same for the second site in Fig. 9a but use a distinctly different color scheme.
- Do the same for Fig. 9b.
- Do the same for the inset plot and place as the third panel, the same size as the other two panels between panels a and b. → It is certainly true that Fig. 9 is quite busy and that not all of the information contained is discussed in detail in the manuscript. However, we are confident that some readers are interested in the full spread of the data. Reducing the data to median and quartile values disguises the extremes and means a loss of information that we want to keep, be it at the expense of readability.

Technical comments
Dear authors: the font size used in this manuscript is annoyingly small!

We are very sorry for that but have to pass this one to Copernicus and their journals. We used the downloadable Word-Template that uses Times New Roman in 10 pt.

SR = suggested rewording
L 10: …of suspened sediment (omit "the") ….. discharge COLLECTED at 62… → done
L 17 ff: SR.. likely results from a change of factors controlling suspension of intrinsic organic matter at low flows to extrinsic sediment supply (including mineral and organic fractions) due to hillslope erosion at high flows. → done
L 21: SR:…and facilitates new insights → done
L 24: SR: Suspended sediment dominates sediment transport → done
L 30: SR: Dynamics of suspended sediment are strongly influenced by sediment → rephrased differently
L 31: SR: Size and density → done
L 32: SR: Size and density of fine suspended particles in → done
L 34: SR: Depending on sediment sources… → done
L 35: SR… topsoil from either hillslopes or → done
L 36 + 40+41 allochthones spelling! → we used the spelling as given
L 42: SR: temperatures, light and high…. → rephrased
L 47: SR: even if light, temperature…. → rephrased
L 52-53: no new paragraph needed → removed the new line
L 57: SR: …in turn, affect transport dynamics → done
L 71: i.e., always followed by a comma → done
L 71: SR: …as proposed by Reid… → done
L 75: Q: use italics → done
L 84: after Asselmann, (2000) SR: as well as combinations of both within one event. → done
L 84: instead of "characteristics": SR: processes affecting a rating relation in a specific case are well known…
L 90: …inorganic particles in sediment rating curves… → done
L 92-93: not sure a new paragraph is needed → we would like to keep it here since we want the hypothesis to start with a new paragraph!
L 94: … behaviours that are SR: "each controlled by different and independent processes." We test this…. → d one
L 114: SR: …waterways is monitored daily using instantaneous water samples (see below) taken manually… → done
L 116: SR: …in 1965 and has accumulated long-term records
L 120: Frings et al → done
L 126: SR: The use of coffee…and facilitates measuring SSC at large numbers → done
L 129 SR: In general, suspended… → done
L 137-139: SR: Biological fluxes, namely…(Chla) have been monitored since 1997 at two sampling sites located immediately…. → done
L 146: SR: …*LOI*, we segregated … → done
L 160: …normalized by the … (….) computed for each station according…. → done
L 165: …linked to the response of SSC to changing discharge → done
L 167: SR: For most gauging stations included in this study, a and b…. → done

L 189: The rating relations for…. → done
L 199: SR: Rating exponents for the….range between → done
L 200: Sentence gets too long. SR: ….Fig 5). SSC decreases as a function… → done
L 203: Fig. 6 shows…. More information could be put into that sentence. SR: Patterns of spatial distribution become apparent (Fig. 6) for the rating coefficients…. → done
L 204: found along the Rhine → done
L 207: SR: …the fraction of hillslopes steeper than 10% in the contributing catchment area Or: the fraction of contributing catchment area stepper than 10% → done
L 213: SR: Considering that water sampling… → this paragraph has been strongly rephrased
L 214: …to daily sampling at the suspended… → dito
L 215: …rating breaks occur at … → done
L 231-232: SR: Higher Chla-values occur only during moderate flows in spring and summer. Chla-values in the Rhine peak in April, and in May at the Moselle (Figs. 8 and 9). → done
L 239: ….Poesen, 2018) and SR: the presence of this process chain is supported by… → done
L 252: SR: Our results show a clear trend of increasing bl and bh as the fractions of steep hillslopes with S>10%) increase, thus confirming the expectation. → done
L 257: SR: Furthermore, our results that show steep rating curves for the Rhine tributaries than the Rhine itself confirm results by Asselmann…. → done
L 259: SR: Assuming similar catchment topographies for a specified percentage of catchment area steeper 10%, the lower SSC generated at high Q in the Elbe and Oder may be attributable to climatic conditions. → partially rephrased
L 271: SR: "…significantly to discharge" SR: runoff. "….but water…" SR: discharge → done
L 272: SR: …from bl to bh likely reflects a change in factors controlling SSC from …. → done
L 285: …show that the contribution of organic suspended matter to total SSC… → done
L 308: SR: …org. fraction of SSC generally adds a… (or: SSC adds a substantial share to SSCtot year round, the rating… → done
L 309: SR: For instance, Hardenbicker et al. 2016 reported for the Elbe that LOI and Chla contributions to SSC increased with distance downstream, and this is reflected in the decrease of bl exponents with distance downstream. → done
L 313: organic-rich streamflows? organic-poor → organic rich!
L 327: The decrease of ….supports → done
L 346: …load is transported → done
L 351: SR: in the case of a substantial contribution of the organic SSC to ……. practice of using → done
L 358: SR: …, but show a distinct → done
L 359: SSC-Qw Q was not denoted as Qw previously. → changed
L 361: SR: …likely a result of a change in controlling…of suspended…. → done
L 363: SR: …catchment) sources → done
L 374: …paper were provided by the suspended…. → done

Anonymous Referee #2

Hoffmann et al. present a new conceptual model that allows to distinguish sediment load into organic and inorganic shares. The authors apply this model to an impressive number of gauging stations where manually sediment concentrations are estimated. Basically, the authors apply the classical sediment rating curve, though, extend it to account for varying ratios between organic and inorganic constituents. In general, I see the manuscript by Hoffmann et al. as a relevant contribution and, thus, consider it as worth being published in ESurf. → We are thankful for the many good suggestions of reviewer #2. Again, we commented on each suggestion (see text in green letters) and revised the text in most of the cases as suggested.

While reading the manuscript, several concerns and/or suggestions arise:

- The model the authors present is a way to **analyze a static system**. However, the authors mention that the model is also applicable to study river dynamics. I think it is important to highlight, what the authors refer to when analyzing the dynamics. As I understand, the authors restrict dynamics in a spatial mode, i.e. intrinsic vs. extrinsic. What the author don't study, and I think this is important to mention, is the temporal dynamics. As the authors state in the introduction, temporal dynamics may be analyzed using hysteresis loops (among other). Maybe it is too much additional work and maybe beyond the scope of this manuscript: Did the authors looked on the hysteresis loops, too? I think this is important, at least, to be discussed.
  - ⇒ We agree with the reviewer that the term 'dynamics' is misleading in our context, since we do not analyze the changes of the rating behavior, nor consider hysteresis curves (which is far beyond the scope of this study). Therefore, we changed the wording (mainly in the introduction) to avoid the expectation that our concept is based on a dynamic (time-variable) approach. We hope that this matches the concerns raised by the reviewer
- The section of the three methods applied to quantify the scale-breaks of suspended sediment is a bit unclear. I am convinced that better explaining the three distinct methods, eventually doing a bit more math, would improve the manuscript. For example, I cannot see how the authors defined the subsets used in the second method, i.e. how do the authors construct the "sequences" of discharge Qi? I am also curious why the authors did not use a change-point detection algorithm and applied a piecewise regression to a lower and higher flow regime. I am not saying that the approach chosen by the authors is "wrong", yet I was just interested in more details on the methods chosen.
  - ⇒ Basically, we did a piecewise regression as suggested by the reviewer to detect the change-point between the low and high flow. We hope that the strongly rephrased paragraph avoids any potential confusion.
- The authors considered the geometric mean in their study. Later in the manuscript, they state, however, that the simple average is ~0.8 x the geometric mean (L 269). I am wondering why the authors did not chose a simple average from the very beginning?
  - ⇒ If the steepness of the regression line in a scatter plot changes without a change in the mean of the y-values (e.g. the SSC-values), then the lines circulate around the geometric mean of the x-values (see Warrick, 2015). That is the reason why we used the geometric mean to normalize the values and therefore to achieve independence of the regression coefficients a and b. However, we related the Q_gm to the Q_median and Q_avg later on, since these are much more familiar to most geoscientists and hydrologists. Additionally, the median allows to refer to the time the river systems spend in the high flow and low flow regime (50/50).

- Regarding the sampling routine, I was wondering if the same sampling protocol has been applied for both the daily and weekly measurements? Did the sampling involve also depth-integration?
  - ⇒ We added some more information regarding the water sampling to clarify the questions of reviewer. We clearly state now, that water sampling was limited to the top 50cm of the water surface. Thus, no depth-integrated sampling was applied.
- The authors explain possible interpretations of the coefficients. Yet, the part around line 159 (MTb L-(1+3b) is not clearly written. Maybe the authors can provide some better explanation to follow their reasoning. → We gave additional information and explanation regarding the units.
- L 178: Therefore, Q values were classified into equally spaced classes at a log-scale. How many classes exactly? → the number of classes was variable (depending on the Q-range); however the width of the classes was constant, we added this info in the text.
- L 150: “Chla was used as a proxy … for biomass dynamics” What do the authors refer to here exactly when mentioning dynamics? Better to use simply load? → we removed the word dynamics and simply state that chla is as proxy of phytoplankton biomass!
- L8: major relevance for sustainable sediment management. What is that exactly and maybe I missed it, but where do the authors consider this in their manuscript? → Indeed, we did not discuss the implications of our results for sustainable sediment management. This introductory sentence aims to motivate the reader to show the general implications why a good understanding of the processes of suspended sediment transport are needed, without aiming to discuss these implications in detail.
- L 44: “Water flow velocities regulate the water residence times, which in turn affect the time for phytoplankton growth in river systems. Low flow conditions with increased residence times provide favorable conditions for phytoplankton growth or even blooms. In contrast, short residence times can strongly reduce the share of autochthonous biomass in suspended sediments, even if light availability, temperature and nutrient levels are not limited (Fischer, 2015; Quiel et al., 2011).” This argument is not completely clear to me. I see the time restrictions for phytoplankton growth given a fast draining river. However, it depends on where you sample, I guess, too. Given high flow velocities, I assume that the concentration of phytoplankton is indeed relatively low in the water column. However, as load is the product of concentration times discharge, the overall phytoplankton load may be high, too. I am not a biologist. Maybe the authors can better explain their thoughts on that and how this may affect the results and findings they present here. → Here we consider mainly the control of (mineral and organic) suspended sediment concentrations and highlight the fact that autochthonous organic matter has a contrasting relationship to discharge compare to allochthonous susp. matter. The effect on the load is discussed in chapter 4.3. We added a sentence to highlight this difference and to show that the focus here is rather on concentration than on load.
- The authors used coffee filter and stated that the pore diameters of 0.7 to 1 µm. How was this number determined? → This was done in an earlier study of our sediment lab (published in German only). This study compared grain size analysis of suspended sediment before and after filtering. We rephrased the relevant sentence to hint to this approach, but we do not intend to show the results here.
- L 109: Specific discharge. I assume that this is well known to most of the readers. Regardless, I think it would be good to define it here. The same is true for “long-term discharge weighted averages of SSC”. Please define this, too. → specific discharge is not

defined. We added a line in chapter 2.2. to inform about the calculation of discharge weighted SSC.

- L 143 ff. The way LOI is explained here is not completely clear. Based on the context, LOI is here defined as the fraction of the total load, i.e. 0-1. However, the authors also write that “The organic component was combusted at 500◦C for 1 hour to estimate the LOI of the suspended matter.” This sentence implies a mass involved and, thus, units. Please clarify. See also L 291: “Here we use LOI as a measure of the organic fraction of the total suspended solids.” Maybe the latter sentence can be moved into the methods section? → we added a sentence that clearly defines that LOI is give as a fraction of the total SSC: ‘In our study LOI is give as the ratio of organic suspended matter to the total SSC.‘
- The authors applied the t-test to test the rating coefficients. Are the samples normally distributed and all other requirements met? If not, the t-test is not applicable. → we check for normal distributions. We added some information to the boostrapping, stating that distributions were normal distributed.
- L 194: “For 52 out of 62 stations, SSC - Q rating curves show a distinct break in scaling relation (for examples see Fig. 3) with similar values for Qb estimated from three different approaches (Tab. 2).” Is there any spatial pattern in terms of signal propagation along nested catchments? This would be an interesting finding. → We did not check for the spatial pattern pf the break point. Given the rather narrow distributions of Q_br and the uncertainty related to the estimation of Q_br, we doubt that the differences between stations along a single river channel provides meaningful information. This could however be part of a future paper ;-)
- L 310: “At stations where the organic fraction of the SSC adds a substantial share to the total SSC,. . .” What is substantial? → we added some more information regarding the Moselle where this share is roughly 60% at low flows.
- L 207: “This control is highlighted in Fig. 7, which plots bh with respect to the fraction of the contributing catchment area that is steeper than 10% slope gradient. Catchments with a higher fraction of steep slopes are characterized be higher bh -values.” While this finding is somehow expected, I was wondering how the authors decided to choose the 10% value? Why didn’t the authors consider all percentiles, i.e. involving the entire topography? 10% sounds a bit arbitrary to me. → The reviewer is correct. 10 % is arbitrarily chosen. However, the result would not change much if another threshold is chosen.
- L 220: “However, the lower number of measurements at the LOI-stations (approx. 1000 at both stations) resulted in a larger uncertainty of the parameter estimation (Δbl and Δbh) from the bootstrap regression”. Can the authors somehow quantify the involved uncertainties? → the larger uncertainty results from the larger standard deviation of the distributions of the estimated parameters, as denoted by the terms in the brackets. To clarify this, we changed the word ‘uncertainty’ with ‘standard deviation’
- L 226: “resulting in rating exponents b of −0.51 ± 0.03 and −0.47 ± 0.01 , and a -coefficients of 0.202±0.003 and 0.319±0.006 for the Rhine and the Moselle, respectively”. Please include b here; It makes the reading a lot easier. → we included b here as suggested
- L 261: “The dry continental climate in the Elbe and Oder catchments likely reduces the reactivity of the river systems, requiring larger increases of rain and discharge to increase the specific sediment supply in these basins compared to basins with higher/more frequent precipitation in the western part of Germany.” This is a reason- able interpretation. Yet, can the authors provide a reference? Or can the authors estimate

catchment-averaged rainfall and relate this to the sediment fluxes observed? → Due to the suggestions of Kristin Bunte, we revised this discussion with a stronger focus on soil moisture. Thus, we are not sure if simply annual rainfalls will provide much more information. Certainly, we are not able to give numbers for (antecedent) soil moisture; this is far beyond the scope of the paper.

- L 274: "Thus, the transition from bl to bh is likely to be a result of a change of controlling factors of the suspended sediment from intrinsic (within the river system) to extrinsic (outside the river channel but within the catchment) factors." Well, this is just a personal suggestion: I suggest do avoid intrinsic and extrinsic in this case here: It is a hydrological system, though. Given the catchment scale used here, intrinsic suggest within the catchment and extrinsic from outside the catchment. However, I leave this up to the authors and editors. → The reviewer is correct if we would analyze the holistic sediment budget of a river catchment. However, our main focus here is the river channel. To avoid the complications due to the potentially different views regarding these terms, we defined the meaning of intrinsic and extrinsic within the brackets. We have the feeling that this should avoid any confusion.
- L 353: "In the case of substantial share of the organic SSC to the total SSC, our results suggest that the common practice using a continuous sediment rating results in large errors that can be reduced applying rating relationship including scale breaks." Well, does this really matter if organic transport shares are only important during low flows? I would assume that temporal changes in the sediment rating (hysteresis) might be equally important or even more important. In fact, this study shows that larger fraction of organic matter remains unconsidered during low flows only. → Again, we focus our discussion on the suspended sediment concentration. Indeed, geomorphologist are more concerned about loads and fluxes and the effect of the uncertainty of loads is much smaller than that on concentrations. However, from a biologist point of view, concentrations of organic matter are of great importance for biological processes. Finally, increased suspended concentrations (due to the high organic matter content) at low flow effect the global regression, leading to underestimates of the regressed SSC compared to measured values). We explained these effects on loads by adding an additional sentence at the end of this paragraph.

Scale-breaks of suspended sediment rating in large rivers in Germany induced by organic matter

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Abstract. Understanding the transport of suspended sediment and associated nutrients is of major relevance for sustainable sediment management aiming to achieve healthy river systems. Sediment rating curves are frequently used to analyze the suspended sediments and their potential sources and sinks. Here we are using more than 750 000 measurements of suspended sediment concentrations (*SSC*) and discharge collected at 62 gauging stations along 19 waterways in Germany based on the suspended sediment monitoring network of the German water and shipping authority, which started in the 1960ties. Furthermore, we analyse more than 2000 measurements of the loss on ignition (*LOI*) of suspended matter at two stations along the rivers Moselle and Rhine to assess the mineral and organic fraction of the suspended matter. SSC and LOI are analysed in terms of the power law rating to identify discharge depended controls of suspended matter.

Our results indicate that for most studied gauging stations, rating coefficients are not constant over the full discharge range, but there is a distinct break in the sediment rating curve, with specific SSC-Q domains above and below this break. The transition of the rating exponent is likely results from a change of factors controlling suspension of intrinsic organic matter at low flows to extrinsic sediment supply (including mineral and organic fractions) due to hillslope erosion at high flows. Based on these findings we developed a conceptual rating model separating the mineral and organic fraction of the suspended matter in the Germany waterways. This model allows evaluating the sources of the mineral and organic fraction of the suspended matter and facilitates new insights into the first order control of discharge on the quality and quantity of suspended sediments.

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1 Introduction

Suspended sediment dominates sediment transport of almost all lowland rivers of the world (Naden, 2010; Walling, 1996), and represents 90-95% of the global riverine sediment load to the coastal oceans (Syvitski et al., 2005). Silt and clay particles, which comprise the dominant grain size fraction of the suspended sediments, form an important transport medium for nutrients, pollutants and contaminants. Sustainable sediment management aiming to achieve healthy river systems therefore requires a sound understanding of the sources and sink of suspended sediment along the riverine flow paths.

Transport of the suspended sediment is strongly conditioned by sediment characteristics (Owens et al., 2005; van Rijn, 1984; Walling et al., 2000). Size and density of the sediment particles control their propensity to settle within the turbulent flow of

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the river, counteracting the gravitational settling (Naden, 2010; Partheniades, 2009). Size and density of the fine suspended particles in turn affects their affinity to form aggregates and flocs, due to strong cohesive forces between fine grain particles (Winterwerp and Van Kesteren, 2004). Depending on sediment sources, suspended particles are either mineral, organic, or a combination of both. Erosion of (organic-rich) topsoil from either hillslopes or floodplains represents an important source of suspended sediment (mainly silt and clay) and supplies large amounts of (allochthonous) organic matter with site-characteristic carbon contents (Hoffmann et al., 2009). Sediment supply generated by surface runoff in response to intensive and/or long-lasting rainfall events typically results in increased levels of suspended sediment concentration (SSC) in river channels during higher discharges (e.g. Asselmann, 2000; Gray, 2018).

In addition to the allochthonous suspended matter, phytoplankton is an important source of organic suspended matter that is autochthonously produced within rivers. Especially during summer months, when phytoplankton growth is supported by high water temperatures, sufficient light and high nutrient levels, autochthonous organic matter may dominate the total suspended load in many large lowland rivers and those with intense agricultural land use within the river catchment (Cloern, 1999; Hillebrand et al., 2018; Thorp and Delong, 2002). Water flow velocities regulate the water residence times, which in turn affect the time for phytoplankton growth in river systems. Low flow conditions with increased residence times provide favourable conditions for phytoplankton growth or even blooms with high organic SSC. In contrast, short residence times can strongly reduce the share of autochthonous biomass in suspended sediments because phytoplankton growth rates cannot compensate higher discharges, even if temperature, light availability, and nutrient levels are not limiting phytoplankton growth (Fischer, 2015; Quiel et al., 2011). Thus, a negative relationship between autochthones organic SSC and discharge is expected, in contrast to allochthonous suspended matter.

Besides physical factors controlling the abundance of phytoplankton in river systems, several studies stress the importance of biological controls. For instance, Hardenbicker et al. (2016) suggest that low phytoplankton concentrations in the Rhine are at least partly the result of losses due to grazing by the invasive bivalve mollusk *Corbicula fluminea*, which increased in density since the early 1990ies, while phytoplankton declined during the same time. Furthermore, predicting the characteristics of the suspended matter is confounded by the heterogeneous and composite structure of flocs and aggregates that are composed of mineral particles as well as living and dead organic matter (Winterwerp et al., 2006). The size of the flocs is a function of the turbulence-induced collision of suspended particles and the cohesive and adhesive forces between the flocs. The latter is strongly controlled by the grain size and the organic matter of the suspended particles. Their size and density, in turn, affect the transport conditions, with large and dense flocs being predominantly deposited, while flocs with a high organic matter content and a low density are transported over long distances (Winterwerp et al., 2006).

Sediment rating curves are frequently used to analyse the transport conditions of suspended sediments and their potential sources and sinks (Asselmann, 2000; Cohn et al., 1992) or to predict suspended sediment yields at ungauged or unfrequently gauged stations (Ferguson, 1986; Horowitz, 2003; Morehead et al., 2003; Syvitski et al., 2000). Rating curves plot SSC as a function of water discharge Q, while the temporal aggregation (or resolution) depends on the approach and available data and

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ranges from 15 minutes to annual averages. In many cases, there is a close link between both variables that is mostly described by a power law:

$$SSC = aQ^{b}, \tag{1}$$

where a and b are coefficients that depend on the characteristics of the river system. a represents the SSC at unit discharge and the exponent b has been discussed in terms of sediment availability and the erosivity of the stream (Asselmann, 2000; Syvitski et al., 2000). While a varies over several orders of magnitude, depending on the river system characteristics, values of b are typically more confined and range between 0.2 and 2.0 (Syvitski et al., 2000), with lower values in arid environments (i.e., 0.2 to 0.7) and higher values in humid, temperate river systems (i.e., 1.4-2.5, as proposed by Reid and Frostick, 1987). However, small changes in the rating exponent b can cause strong changes in SSC, which are in the same order of magnitude as the changes imposed by the (large) variability in a (Syvitski et al., 2000). Using Eq. 1, many studies found a strong negative relationship of a and b (Asselmann, 2000), which is however not a matter of the natural balance between the two rating parameters (as proposed by Syvitski et al., 2000) but an artefact of the statistical analysis as the units of a are depending on b. Warrick (2015) suggests using normalized Q and SSC values to avoid this confusion and provide a statistically sound rating analysis (see also method section).

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In most cases, observed Q and SSC scatter strongly around the regression line from Eq.1. Deviations from the simple power law haven been shown to result from i) hysteresis effects during single flood events (Aich et al., 2014; Zuecco et al., 2016), ii) seasonal changes of water and sediment sources or flow hydraulics (Asselmann, 2000; Morehead et al., 2003) or iii) long-term trends of changing sediment supply (Warrick, 2015). Event-based deviations are associated to: i) clock-wise hysteresis (i.e. the SSC-peak precedes the Q-peak) with a rapid SSC-increase, due to within-channel mobilization of suspended sediment and subsequent sediment exhaustion, or ii) anti-clock-wise hysteresis (i.e. maximum Q precedes the SSC-peak), due to the long transport distance of sediment sources that are located within the catchment (e.g. arable land on inclined hillslopes with increased soil erosion rates) (Asselmann, 2000), as well as combinations of both within one event (leading to a complex hysteresis pattern). While the general processes affecting a rating relation in specific cases are well known, it is difficult to predict the rating behaviour as a result of the many confounding processes and linkages.

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Recently, we have learned more about the controlling factors of sediment rating, but so far the effect of organic material on SSC rating is not sufficiently understood. Most monitoring studies focus on total suspended sediment without fractionation into mineral and organic components. In this respect suspended sediment is equivalent to *seston*, a term used in ecological sciences to describe the total particulate matter including living organisms, organic detritus and inorganic particles (Naden, 2010; Wetzel, 2001). Consequently, most sediment rating studies, which focus on prediction of total SSC levels in river systems based on water discharge or on hysteresis effects of total SSC during single flood events, lump organic and inorganic

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particles into sediment rating curves. To the authors' knowledge, there is no study that rigorously investigates the influence of the variable mineral and organic fractions in river systems on the rating of sediment.

Here we hypothesize that the mineral and organic fractions of SSC in large German rivers are controlled by different and independent processes reflected in specific rating coefficients. We test this hypothesis by i) analysing the scaling of total suspended sediment with discharge, before we ii) differentiate between the scaling behaviour of the mineral and organic fractions of the suspended sediment against discharge. Furthermore, we develop a conceptional sediment rating model considering the mineral and organic fraction of the suspended sediment transport. To perform this study, we used a rich dataset on suspended sediment in the German waterways and analysed more than 750 000 suspended sediment measurements.

Gelöscht: show distinctly different scaling behaviours that are related to independent processes

2 Method

2.1 Study sites

In this study we explore discharge and suspended sediment measurements at 62 gauging stations along 19 waterways in Germany. The studied rivers comprise the Danube, Rhine, Ems, Weser, Elbe and Oder, including some larger tributaries (Tab. 1 for details and Fig. 1 for location). The gauging stations cover contributing areas from 2,076 to 159,555 km², with a median of 24,424 km². The topography of the river catchments includes the steep high mountain terrain of the European Alps (e.g. Alpine Rhine and Danube) as well as the mountainous regions with various geological settings in Central Europe and the flat terrain of Northern Germany, which is mainly composed of glacial and fluvial Quaternary deposits. The long-term average discharge of all stations ranges from 9 to 2289 m³/s (Tab. 1). The strong control of contributing area on discharge is clearly reflected by the higher specific discharges (i.e., discharge per contributing catchment area) of the rivers Rhine and Danube (Jochenstein station), which are characterized by strong discharge contributions from the Alps (Fig. 2). In contrast, stations in the Elbe and Oder catchments show much lower (specific) discharges at a given catchment area, due to lower rainfalls in the more continental climate, compared to the rivers in West and Central Germany, which are fed by elevated precipitation of the more maritime climate.

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2.2 Suspended sediment monitoring in German waterways

Suspended sediment in German waterways is monitored daily using instantaneous water samples taken manually by the Federal Waterways and Shipping Administration (Wasserstraßen- und Schifffahrtsverwaltung des Bundes, WSV) at ~70 sampling locations. SSC monitoring started in 1965 and has accumulated long-term records that cover >30 years for many stations. Here, we selected only those stations from the monitoring network that are not located at artificial channels (with different flow regimes) and that cover periods longer than 10 years (Tab. 1 and Fig. 1), resulting in a total of 62 stations. Periods with more than 10 years were chosen to have sufficient data for the statistical analysis. Data from Maxau station at the river Rhine and from some tributaries haven been formerly presented by Asselmann (2000) and Horowitz (2003) in terms of a rating analysis and by Frings et al. (2014) and Frings et al. (2019) in terms of sediment budget calculations.

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At each monitoring site, 5-liter bucket water samples were taken once each work day (excluding weekends and legal holidays) roughly in the top 30 cm of the water surface. During floods, the sampling frequency was increased up to 3 samples per day, unless sampling was stopped due to safety reasons. If more than one sample per day was taken, we used the mean SSC of all samples of that day. Limiting the water sampling to the top 30 cm slightly underestimates the average SSC in a channel cross-section (and thus the suspended sediment load). However, we argue that the rating behaviour does not significantly changes compared to depth integrated measurements.

Water samples were filtered using commercial coffee filters, which were weighed before and after filtering (under constant climatic conditions in the lab with 20°C air temperature und 50% air moisture) to calculate the daily SSC [kg/m³] (Hillebrand 2013). The use of coffee filters is cost-efficient and facilitates measuring SSC at a large number (i.e. 70 samples per day at the national scale) and of sufficient quality. Using grain size analysis of filtered and non-filtered sediments (not presented here), we estimated an average pore diameter of the coffee filters in the range of 0.7 to 1 µm. We therefore miss the smallest particles of the suspended sediments (e.g. clays < 0.7 µm), which represent a minor fraction of the total suspended solids. In general, suspended sediment mainly contains silt (approx. 75%) and only a small fraction of clay (mostly 10-20 %) and fine sand (mostly below 10%) (for a detailed particle size analysis of the suspended sediment of the river Rhine see Hillebrand and Frings, 2017). Thus, fine clay < 1µm are expected to be below 10% of the suspended sediment. For each SSC monitoring station, discharge is either measured at the station or nearby, without major tributaries entering the river between the SSC station and the discharge station. Water level is typically measured each 15 min and discharge is calculated using a rating curve. In this study, we used daily average discharge, which is then related to the daily SSC samples.

As shown in Tab.1, long-term averages SSC of all stations range between 10.7 and 51.6 mg/l, with an average of 25 mg/l. Long-term discharge weighted averages of SSC are somewhat higher ranging between 11.8 and 84.4 mg/l with a mean of 36 mg/l. Higher discharge weighted SSC reflect higher SSC at high discharge, which result in higher weights of increased SSC. In agreement with other national monitoring systems (e.g. Diplas et al., 2008; Habersack and Haimann, 2010; Spreafico et al., 2005; Thollet et al., 2018), SSC values for most stations used in this study include both the mineral and organic material of suspended sediment. Loss on ignition (*LOI*) and chlorophyll a (*Chla*), are monitored since 1997 at two sampling locations, located immediately upstream of the confluence of the rivers Moselle and Rhine in Koblenz. At both stations, water samples of 2 to 5 litters were taken at a weekly interval (in contrast to the daily sampling of the stations of the suspended sediment monitoring), resulting in a total of 1033 and 1056 samples from the Rhine and the Moselle, respectively (until end of 2017). Similar to SSC water samples, sampling for *LOI* was limited to the upper 50cm of the water surface using a bucket water sampler.

To estimate the *LOI* at both stations, the water samples were filtered using a glass fiber filter with a pore size of about 1 µm (Whatman GF 6, GE Healthcare, Germany). The filter was weighted empty (after heating at 500°C for 1 hour to combust organic remains on the filter) and after filtration. Between filtration and weighting the full filter was dried at 105°C for 24 hours, to obtain the total suspended sediment SSC_{tot} (including the mineral and organic components). The organic component was combusted at 500°C for 1 hour to estimate the *LOI* of the suspended matter. In our study LOI is give as the ratio of organic

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suspended matter to the total SSC. Based on the *LOI*, we segregated the mineral (SSC_{mrl}) and organic (SSC_{org}) fraction of the SSC: $SSC_{org} = LOI \times SSC_{tot}$ and $SSC_{mrl} = (1 - LOI) \times SSC_{tot}$.

For both stations, *Chla* was analysed parallel to the *LOI* samples. *Chla* was used as a proxy of phytoplankton biomass in the rivers Rhine and Moselle. *Chla* concentrations were determined using German Standard Methods (DEW, 2007). Briefly, phytoplankton was filtered on glass-fiber filters and pigments were extracted with hot ethanol. Chlorophyll concentrations were determined photometrically (DR 2800, Hach Lange, Germany). *Chla* concentration (given in µg/l) was transferred to living phytoplankton biomass using a C:Chla-ratio of 40 and a particulate organic matter (POM) to particulate organic carbon (POC) ratio of 0.42 (Geider, 1987; Hardenbicker et al., 2014; Hillebrand et al., 2018).

2.3 Rating analysis

To analyse suspended sediment as a function of discharge, we calculate sediment rating curves following Eq. 1. The interpretation of the coefficients a and b in Eq. 1 is impeded by their interdependence as illustrated by units of a that depend on the exponent b: with SSC having the dimension M/L^3 (M and L represent the dimension mass and length, and L^3 is equal to volume) and Q^b having dimension of L^{3b}/T^b (were T represent the dimension of time), the units of a are given by $MT^bL^{-(1+3b)}$ (note the direct dependency on the exponent b). To avoid this complication and to facilitate the comparison of rating curves between various stations, SSC and Q values are normalized by the geometric means (SSC_{GM} and Q_{GM}, respectively) computed for each station according to Warrick (2015):

$$SSC/SSC_{GM} = a\,(Q/Q_{GM})^b \qquad (2)$$

In Eq. (2) a and b are dimensionless. The exponent b can be linked to the response of SSC to changing discharge and a represents the normalized *SSC* at Q_{GM}. The normalization using Eq. 2 does not have any effect on the exponent b (i.e. the slope of the regression line does not change), but changes the absolute value of a.

For most studied gauging stations included in this study, a and b are not constant over the full discharge range, but there is a distinct break in the sediment rating curve, with specific SSC-Q_w domains above and below this break. To estimate the discharge at which this break occurs (Q_{br}), we used three approaches. The first approach is based on the locally weighted scatter smoothing (lowess) regression curve (compare red dotted line in Fig. 3), which was calculated using the gplot-package in R according to Cleveland (1981). We defined Q_{br} to be located at the maximum curvature of the lowess regression curve. In the second approach, we used a sequence of n equally log-spaced discharges (Q_i/Q_{GM}, with 1<i<n and constant width of $\Delta Q = 10^{0.025}$) between Q_{min}/Q_{GM} and Q_{max}/Q_{GM} and extracted for each Q_i/Q_{GM} the corresponding SSC_i/SSC_{GM} value of the lowess regression curve. For each i $(1 < i < n)$ we build two subsets i) the low flow subset with data pairs smaller than or equal to Q_i/Q_{GM} and the high flow subset with discharge larger than Q_i/Q_{GM}. We than applied a piecewise non-linear least

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square (NLS) regression to both subsets, which were both forced through the data pair (Q_i/Q_{GM}, SSC_i/SSC_{GM}). As i increases (from Q_1/Q_{GM} to Q_n/Q_{GM}), the mean absolute error (MAE) of the NLS regression of the low flow subset increases (first slowly while the break-point is approached and then more rapidly as the breakpoint is exceeded) and the MAE of the high flow decreases in a similar fashion (first rapidly and then slowly). As Q_i/Q_{GM} approaches the break-point Q_{br}, the MAEs of both NLS regressions are small and their sum is at minimum. Thus, Q_{br} was set to the Q_i/Q_{GM} with the minimum of the sum of the MAE. The third approach is similar to the dual regression of the low and high flow subsets as applied in the 2nd approach. However, the third approach does not use the SSC-values of the lowess curve but uses log-binned median SSC/SSC_{GM} of equally spaced discharge bins at the log scale (compare yellow points in Fig. 3). The median SSC/SSC_{GM} values and the mid-point of each Q-class was split into low flow and high flow subsets and used for the piecewise regression analysis to identify Q_{br} at which the sum of the MAE of both subsets was minimized.

At extreme discharges, rating relationships tend to be strongly scattered due to the low density of $SSC - Q$ data pairs. To estimate the Q_{br}, we thus excluded measurements with Q smaller than the 1% and larger than the 99% discharge percentile of each station.

After the identification of Q_{br} for each station, the coefficients in Eq. 2 were estimated for the low flow regime (i.e. all measured SSC-Q data pairs with $Q < Q_{br}$) and the high flow regime (i.e. all measured SSC-Q data pairs with $Q > Q_{br}$) using log-linear and non-linear least square regression (see. Tab. 2). Coefficients for the low flow regime are denoted by a_l and b_l and for the high flow regime by a_h and b_h. To estimate the confidence intervals and thus to test for significant differences between rating exponents for the low-flow and high-flow regimes, we used a bootstrapping approach with 1000 replications (resulting in normal distributions of b_l and b_h with 1000 estimates) and compared the distributions of b_l and b_h () using a t-test with a 95% confidence level.

The rating relations for LOI, SSC_{org} and SSC_{min} of the two stations at the rivers Moselle and Rhine in Koblenz was analysed the same way (similar to Eq. 2) as the SSC at the 62 stations from the suspended sediment monitoring network.

3 Results

3.1 Rating of the total suspended sediment

For 52 out of 62 stations, $SSC - Q$ rating curves show a distinct break in scaling relation (for examples see Fig. 3) with similar values for Q_{br} estimated from three different approaches (Tab. 2). For the remaining 10 stations, no distinct breakpoint is detectable (Fig. 3). After visual inspection and removal of non-plausible break-points of each station, we calculated the average Q_{br} for each station. In general, breakpoints of the $SSC - Q$ relation range between $0.8 < Q_{br} < 1.9$, with 50% of all values ranging between 0.9 and 1.3 (Fig. 4) (the mean Q_{br} over all stations is 1.2), indicating that the breakpoints of many stations are slightly larger than the geometric mean discharge.

Gelöscht: was used for each Q_i and for both subsets (below and above each Q_i). First a and b were estimated for the high-flow subset ($Q > Q_i$). Subsequently, a and b were estimated for the low-flow subset ($Q < Q_i$), while the regression curve was forced to intersect the high-flow regression line at Q_i. For each Q_i the sum of the mean absolute error (MAE) of both regressions was calculated.

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Gelöscht: Therefore, Q values were classified into equally spaced classes at a log-scale. For each class, the median *SSC* was calculated. Subsequently, t

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Gelöscht: (i.e. subset $Q > Q_{br}$)

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Rating exponents for the low flow regime (b_l) range between -0.75 and 1.15 and for the high flow regime (b_h) between -0.6 and 2.45. In general, the distribution of b_l peaks close to the median b_l = 0.14 (see Fig. 5). SSC decreases as a function of Q (i.e. $b_l < 0$) at 19 stations and increasing SSC at 33 stations. b_h is < 0 at 11 stations and > 0 at 51 stations, with a median b_h = 0.83 (Fig. 5). 23 stations are characterized by strong increases of SSC with Q (i.e. b_h > 1).

Patterns of spatial distribution become apparent (Fig. 6) for the rating coefficients b_l and b_h. Highest b_h-values (positive rating in the high flow regime) are found along the Rhine and its tributaries, Danube and Upper Weser, while the rivers in northern lowland Germany (mainly the Ems, Elbe and Oder rivers) show low b_h-values. This control is highlighted in Fig. 7b, which plots b_h with respect to the fraction of hillslopes steeper than 10% in the contributing catchment area. Catchments with a higher fraction of steep slopes generate higher b_h-values compared to the lowland rivers, indicating higher sediment supply in catchment with more extensive hillslope with slope gradients > 10%. Furthermore, the majority of the stations at the rivers Elbe and Oder, which are characterized by low annual rainfall in the contributing catchment, plot below the regression line. In contrast to b_h, b_l does not show a clear spatial pattern nor any relationship to the fractions of steep catchment areas (Fig. 7a).

3.2 Rating of the mineral and organic fraction

As noted above, *LOI* and *Chla* were measured at the Moselle and the Rhine just upstream from their confluence in Koblenz based on weekly sampling from 1997-2017. Despite the lower sampling frequency (samples at the suspended sediment stations were taken on each working day), the shorter monitoring period (SSC-monitoring started in 1964; Tab. 1), and a slightly different lab protocol, the rating behaviour of total SSC of both stations is similar to the rating of the other SSC stations along the rivers Rhine and Moselle (Fig. 8a-d and Tab. 2): i) rating breaks occur at 0.96 and 0.91 of the normalized discharge (Q/Q_{GM}) for the Rhine and the Moselle, respectively, and ii) the rating exponents b_l (0.29 ± 0.20 and -0.03 ± 0.07 for the rivers Rhine and Moselle, respectively) and b_h (2.26 ± 0.18 and 1.54 ± 0.14 for the Rhine and Moselle, respectively) are similar to the other stations along the Rhine and the Moselle. However, the lower number of measurements at the LOI-stations (approx. 1000 at each of the two stations) resulted in a larger standard deviations of the parameter estimates (Δb_l and Δb_h) based on the bootstrap regression.

Results from the LOI measurements of both stations show a higher organic matter contents in the Moselle (mean *LOI* = 0.385) compared to the Rhine (mean 0.237). *LOI* negatively correlates with discharge at both stations (Fig. 8e+f). However, the relationship for the Moselle is much better constrained. High *LOI* values cluster during the summer months (April – September), while low *LOI* values are more prominent during winter months (Fig. 8e+f and Fig. 9). Based on the bootstrap regression, a single power-law ($LOI = a \times (Q/Q_{GM})^b$) was fitted to the *LOI* data, resulting in rating exponents b of -0.51 ± 0.03 and -0.47 ± 0.01, and a-coefficients of 0.202 ± 0.003 and 0.319 ± 0.006 for the Rhine and the Moselle, respectively. Based on the total SSC and LOI, the mineral fraction of the suspended sediment ($SSC_{mrl} = (1 - LOI) * SSC_{tot}$) was calculated. SSC_{mrl} increases with discharge for both stations (Fig. 8c+d). Yet the variability for any given discharge is large (ranging approximately an order of magnitude) and increases at lower discharges.

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Gelöscht: Fig. 6 shows the spatial distribution of the rating coefficients

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Gelöscht: Thus differences between the rivers located in the steeper terrain of S and SW Germany and the flat northern lowland rivers are likely controlled by topography.

Gelöscht: the fraction of the contributing catchment area that is steeper than 10% slope gradient

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In contrast to the *LOI*, *Chla* does not show significant changes with discharge. Fig. 8g+h shows dominantly low Chla values for the Rhine and Moselle. Increased Chla-values are mainly limited to lower discharges ($Q/Q_{GM} < 1$). Higher *Chla* values occur only during moderate flows in spring and summer. *Chla* values in the Rhine peak in April, and in May at the Moselle (Figs. 8 and 9).

4 Discussion

4.1 Controls on rating behaviour of suspended sediment

The sediment rating concept, which expresses suspended sediment concentration (*SSC*) or suspended sediment load (Q_s) as a function of discharge (Q), is based on the assumption that factors controlling the generation of runoff in the catchment are closely linked with factors controlling the sediment supply to the river channel (Gray, 2018). This is certainly the case if rainfall produces erosive surface runoff, which in turn results in sheet, rill and/or gully erosion (e.g.Poesen, 2018) and the presence of this process chain is supported by the majority of the rating curves presented in this study: 51 of 62 stations show a clear increasing trend with a positive rating exponent in the high flow regime, which is attributed to the production of surface runoff and strong sediment supply through sheet and rill erosion. A positive rating exponent of the SSC-Q relation implies that the sediment load increases "faster" than the discharge (e.g. sediment load increases more than twofold if discharge doubles). This follows from the following equation:

$$Q_s = SSC \times Q = (aQ^b) \times Q = aQ^{b+1} \qquad (3)$$

which indicates a rating exponent > 1 of the Q_s-Q relation for $b > 0$, as shown for most stations. However, if sediment load increases "faster" than the discharge, additional sediment sources (either external or internal) must be mobilized as discharge increases. Rivers showing rapid increases of SSC (and thus Q_s) are termed "reactive" rivers by Syvitski et al. (2000). The (re-)activation of sediment sources can be mainly explained by the extension of areas of water-saturated soils, which contribute to surface runoff and discharge and thus increases the connectivity during rainstorm events (Bracken et al., 2013; Fryirs, 2013). Since topography (esp. hillslope gradient, path lengths and surface roughness) exert a dominant control on hydrological and sediment connectivity (Baartman et al., 2013; Heckmann et al., 2018; Hoffmann, 2015), a strong relationship between the rating exponent and the topographic characteristics of the catchments can be anticipated (Gray, 2018; Syvitski et al., 2000). Our results show a clear trend of increasing b_h as the fraction of steep hillslope (i.e. slope gradients > 10%) increases, thus confirming the expectation. Thus high b_h values are observed at gauging stations with discharge contributions from the European Alps (e.g. the Danube below Jochenstein and the Rhine) and from tributaries with mountainous catchment topography (e.g. the Neckar and Moselle catchments). The strong control of the slope gradient of the contributing catchments indicate that additional sediment sources, which are mobilized during increasing discharges, are primarily located at hillslopes (i.e. external sediment sources) and sediment sources within the river play a minor role. Furthermore, our results that show

Gelöscht: A more pronounced seasonal pattern with maximum *Chla* values typically in April for the Rhine and May for the River Mosel is shown in Fig. 8 and 9).

Gelöscht: characterized by

Gelöscht: is associated with a rating exponent > 1 of the Q_s-Q relation:

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Gelöscht: (e.g. sediment load increases more than twofold if discharge doubles) and that

Gelöscht: increasing connectivity during rainstorm events that leads to an

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Gelöscht: confirm this expectation (Fig. 7b),

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Gelöscht: with increasing ratios of inclined hillslopes steeper rating curves for the Rhine tributaries than the Rhine itself is confirmed by the results by Asselmann (2000), which were obtained by a limited number of stations, with tributaries showing steeper rating curves than the larger river Rhine.

While b_h is dominantly controlled by topography, Fig. 7b indicates also a climatic control on the rating exponent in the high flow regime. Interestingly, most stations from the Elbe and Oder catchments plot below the regression line in Fig. 7b. This indicates that the Elbe and Oder show lower b_h values for a similar fraction of slopes steeper than 10% compared to the general trend. Assuming similar catchment topographies for a specified percentage of catchment area steeper 10%, the lower b_h values are mainly explained by climatic differences. The dry continental climate in the Elbe and the Oder catchments likely reduces the reactivity of the river systems, requiring larger increases of rain and discharge to increase the specific sediment supply in these basins compared to basins with higher/more frequent precipitation in the western part of Germany. The lower reactivity may be explained by the general tendency of lower antecedent soil moisture in more continental climates, and thus a slower increase of water-saturated soils, that increase the sediment connectivity during rainstorm events (Bracken et al., 2013; Fryirs, 2013). Furthermore, sandstone in the Thuringia Forest in the Elbe headwater and extensive glacio-fluvial deposits along the Elbe and the Oder may be more porous and generate less runoff than the schists in mountains and highlands along the Rhine and in central west Germany.

The break of the rating behaviour, which is observed for 52 of the 62 suspended sediment stations along the German waterways, implies a change of processes and/or factors controlling suspended sediment in river channels at the transition from low to high flow regimes. A similar scale break has been shown along the Rhone river in France by Poulier et al. (2019). Interestingly, the break for most stations present in this study occurs at $Q/Q_{GM} \sim 1.1$, which is roughly equivalent to $Q/Q_{avg} \sim 0.9$ or $Q/Q_{median} \sim 1.0$. Given that the break is close to the median discharge implies that river discharge is 50% of the time in the low flow rating regime and 50% in the high flow rating regime.

In contrast to b_h, there is no simple relation of the low-flow rating exponent b_l to the topographic characteristics of the contributing catchment (Fig. 7a). This result is not unexpected, given the fact that hillslopes during low flow conditions do not contribute significantly to runoff and suspended sediment in the river channel, but discharge mainly results from ground water supply. Thus, the transition from b_l to b_h likely reflects a change of factors controlling suspended sediment from intrinsic (within the river system) to extrinsic (outside the river channel but within the catchment) factors.

Many of the tributary waterways of the Rhine, and the Upper Rhine itself, are controlled by barrages to support navigation during low flow and to supply energy. Thus, the operation of barrages and management of water flow is a potential factor controlling the rating break. Reservoirs upstream of the barrages act as sediment sinks for cohesive fines during low flow conditions (Hoffmann et al., 2017). During high flows, weir shutters are opened to prevent damage of the barrages and to control floods. Significant amounts of fine cohesive sediments can be potentially remobilized during high flows if critical shear stresses at the reservoir bed can exceed shear strength of the cohesive fines. However, in most cases weir shutters are only opened during floods, implying resuspension of cohesive sediments only at discharges much higher than Q_{avg}. Furthermore, preliminary evidences indicate that reservoirs upstream of weirs act as sediment sinks esp. during high flows when large

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Gelöscht: the ratio of the geometric mean to the average discharge (Q_{avg}) is close to 0.8 for most stations, the rating break and thus the change of processes or controlling factor occurs most likely close to $\sim 0.9 \times Q_{avg}$

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amounts of sediment are transported (Hoffmann et al., 2017). Given that the prominent rating break occurs at lower discharges (i.e. at Q/Q_{GM} ~ 1.1 or Q/Q_{avg} ~ 0.9) than those discharges which potentially resuspend cohesive sediments in the upstream reservoirs, barrage operation does not seem to control the rating break. Furthermore, the rating break is also observed in free-flowing waterways (without barrages), pointing to controlling factors not related to the management of the weirs or reservoirs. Therefore, the question remains which factors control the rating exponent at low flows and the transition of the rating behaviour at average discharge? Our data show that the contribution of organic suspended matter to total SSC may play a crucial role of the SCC rating at low flows.

Gelöscht: It is therefore unlikely that the prominent break at

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4.2 Controls of the mineral vs. organic fraction of the suspended sediment

Here we use *LOI* as a measure of the organic fraction of the total suspended solids. Results from the *LOI* measurements at the two stations in Koblenz show generally higher *LOI* values at the Moselle (where LOI > 0.5 is frequently observed) compared to the Rhine, where *LOI* rarely exceed 0.5 (less than 1% of all measurements). Both stations reveal a significant control of discharge on *LOI*. Negative rating exponents of -0.51 ± 0.03 and -0.47 ± 0.01, for the rivers Rhine and Moselle, respectively, indicate declining organic matter concentrations with increasing discharge. At the Moselle, declining trends are partially explained by seasonal effects, with low discharges and high *LOI* dominating in summer and high discharges and low *LOI* dominating in winter months (Fig. 8 and Fig. 9). However, along the Rhine, seasonal trends are much less pronounced, and *LOI*-values scatter much stronger around the regression line in Fig. 8e+f compared to those of the River Moselle.

Negative rating exponents of *LOI* indicate that suspended matter at low flow is enriched in organic carbon, highlighting the primary control of low flow dynamics with increased water and plankton residence time on *LOI*. In addition to the controlling flow dynamics, higher *LOI* during spring and summer months show the positive effect of water temperature and light availability on plankton growth (Cloern, 1999), which may dominate the total suspended organic matter in the river Moselle at Koblenz especially during April and May (Fig. 9) (Hardenbicker et al., 2014). Under warm low flow conditions, increasing discharges rapidly dilute high concentrations of autochthonous carbon causing a decline of total suspended sediment (which is dominated by the organic fraction under warm low-flow conditions) as evidenced in early summer 2011, which was characterized by exceptionally low discharge of the Rhine in May and June (Hardenbicker et al., 2016). While a positive correlation between SSC_{tot} and Q was observed for most of the year in 2011 in the Rhine at Koblenz, SSC_{tot} relates negatively with discharge during these low-flow months, indicating a shift in the SSC regime as phytoplankton dominates the organic suspended fraction.

At stations where the organic fraction of SSC generally adds a substantial share to the total SSC (e.g. as in the case of the Moselle, where LOI reaches 60% at low flows), the rating exponent b_l is negative. For instance, Hardenbicker et al. (2016) reported for the Elbe that LOI and $Chla$ contributions to SSC increased with distance downstream that is associated with a downstream decrease of b_l (Fig. 6a). Furthermore, low *LOI*-levels in the upper and middle Rhine are characterized by higher b_l-values (~0.5). Thus our results indicate that the suspended sediment rating at low flows is strongly controlled by intrinsic

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(within-channel) processes that govern the formation of organic matter within the river channel: organic rich stream flows are generally characterized by b_l-values close to 0 or < 0, while organic poor channels show typically b_l>0.5.

Gelöscht: channels

4.3 Modelling of the total suspended sediment

The presented data indicate that the observed rating break of total suspended sediment concentration is mainly controlled by the transition from autochthonous production of organic suspended matter at low flows to the allochthones supply of (dominantly mineral) suspended matter during high flows. Our results suggest that SSC_{mrl} and LOI can be modelled separately using a power law rating. If the rating behaviour of $SSC_{mrl} = f(Q/Q_{GM})$ and $LOI = f(Q/Q_{GM})$ is known, the organic and total suspended sediment concentration can be estimated:

$$SSC_{org} = \frac{LOI}{1-LOI} SSC_{mrl}, \qquad SSC_{tot} = \left(\frac{LOI}{1-LOI}+1\right) SSC_{mrl} \qquad (4)$$

Using the bootstrap regression of the LOI-station at the River Moselle, with $SSC_{mrl} = (5.27 \pm 0.14) \times (Q/Q_{gm})^{(1.37\pm0.03)}$ and $LOI = (0.32 \pm 0.004) \times (Q/Q_{gm})^{(-0.47\pm0.01)}$, the modelled SSC_{tot} (Fig. 10) shows the following features: i) at very low discharges ($\sim Q/Q_{gm} < 0.2$), SSC_{tot} typically declines with increasing Q , ii) at higher discharges SSC_{tot} increases with discharge, iii) the gradient of the modelled SSC_{tot}-lines continuously increases with Q and approaches the rating exponent of the mineral SSC-fraction at high Q/Q_{gm}. This model result generally agrees with the measured SSC_{tot}-values. The decrease of the modelled SSC_{org}-values at very low discharges supports the notion that the organic fraction of the suspended matter is affected by dilution effects. The dilution effect of the autochthonous organic matter is outpaced by increased (allochthones) supply of organic matter, which leads to increasing SSC_{org} at higher discharges as a result of strong supply of organic rich top soils through surface runoff and soil erosion.

Empirical sediment rating curves show distinct rating breaks slightly above Q/Q_{gm}~ 1 for most stations. In contrast, suspended sediment rating of the modelled SSC_{tot} based on Eq. 4 changes more gradually i) from negative relations at very low discharges, ii) to slight increases of SSC_{tot} at low to medium (average) discharge and iii) to strong increases of SSC_{tot} with Q/Q_{gm} at high discharges. The gradient of the modelled SSC_{tot} at high discharges approaches the rating exponent of SSC_{mrl}, which is similar to the rating exponent b_h in the high flow domain above the rating break. Assuming that a_h and b_h are mainly controlled by the mineral fraction of the suspended sediment, we argue that the rating of the high flow regime can be used as a first order approximation of the SSC_{mrl} at low flow conditions and that the excess of SSC_{tot} compared to the modelled SSC_{mrl} is primarily explained by the organic fraction of the suspended sediment (compare Fig. 10 and 11). Differences between b_h (i.e. the rating at high discharge) and the rating of SSC_{mrl} may be partially explained by the organic fraction of suspended sediment that is not derived from *in situ* (autochthonous) organic matter, but is supplied from hillslope through the erosion of organic rich top soils.

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In case of the river Moselle, our results indicate that SSC_{tot} exceeds SSC_{mrl} by a factor of ~1.5 to 2 at discharges smaller than Q_{GM}. Thus, monitored suspended sediment yields, which are mostly based on estimates of the total SSC, overestimate the mineral fraction of the SSC at low to moderate flows. The frequency analysis of the long-term suspended monitoring data at the Rhine station at Koblenz, which integrates the organic and mineral fraction of the suspended matter, shows roughly 50 % of the total annual suspended load is transported in 10% of the time during floods. Due to the inclusion of the organic matter and the resulting overestimate of the (mineral) suspended sediment at low to medium flows, floods are likely to be more important in the transport of the mineral fraction of the suspended load. In the case of a clear rating break, our conceptual model separating the rating at low and high flows due to the shift of the process regime can be used to separate the organic and mineral fraction and give a first order estimate of the autochthonous organic fraction of the total SSC.

Gelöscht: overestimation

In the case of substantial contribution of the organic SSC to the total SSC, our results suggest that the common practice of using a continuous sediment rating results in large errors that can be reduced. These errors potentially influence regression results at high SSCs, generally leading to an underestimate of SSC based on continuous rating curves. Much better results for the prediction of SSC and hence sediment load can be achieved by applying rating relationships that include rating breaks.

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5. Conclusion

Using more than 750 000 suspended sediment and discharge measurements at 62 gauging stations along 19 waterways in Germany and more than 2000 measurements of the loss on ignition of suspended matter at two stations along the rivers Moselle and Rhine, we performed a detailed rating analysis of suspended matter and its organic content. Our main findings may be summarized as follow:

1. For most studied gauging stations, rating coefficients are not constant over the full discharge range, but show a distinct break in the sediment rating curve, with specific $SSC - Q$ domains above and below this break. Typically, the rating break occurs slightly above the geometric mean discharge.
2. The transition of the rating exponent (from b_l to b_h) is likely a result of a change in controlling factors of suspended sediment from intrinsic (within the river system) to extrinsic (outside the river channel but within the catchment) sources. Our results suggest that the formation of organic matter within the river channel is an important control of the rating behaviour at low discharges, while the extrinsic control is related to the supply of suspended sediment due to hillslope erosion, as supported by the relationship between the rating exponent and the fraction of hillslopes steeper than 10% within the contributing catchment area.
3. Based on these findings we developed a conceptual rating model separating the mineral and organic fraction of the suspended matter in the Germany waterways. The model assumes a positive power law rating of the mineral fraction of the SSC with Q and a negative power law rating of the LOI with Q and can be used to model the rating behaviour of the total SSC as frequently measured by suspended monitoring networks. An evaluation of this model using data from other river systems in Europe is in progress.

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Author contributions. HF provided OC data from both stations in Koblenz and provided feedback on data anlysis and discussion of results. YB provided SSC data and analysed the spatial distribution of the rating coefficients. JB contributed to the rating analysis and supported discussion on the results. TH performed rating analysis of all stations and prepared the manuscript with the cooperation of all co-authors.

Competing interests. The authors declare that they have no conflict of interest.

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Formatiert: Schriftart: Kursiv

Gelöscht: are taken from the

Gelöscht: water

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References

Aich, V., Zimmermann, A., and Elsenbeer, H.: Quantification and interpretation of suspended-sediment discharge hysteresis patterns: How much data do we need?, Catena, 122, 120-129, 2014.

Asselmann, N.: Fitting and interpretation of sediment rating curves, Journal of Hydrology, 234, 228-248, 2000.

Baartman, J. E. M., Masselink, R., Keesstra, S. D., and Temme, A. J. A. M.: Linking landscape morphological complexity and sediment connectivity, Earth Surface Processes and Landforms, 38, 1457-1471, 2013.

Bracken, L. J., Wainwright, J., Ali, G. A., Tetzlaff, D., Smith, M. W., Reaney, S. M., and Roy, A. G.: Concepts of hydrological connectivity: Research approaches, pathways and future agendas, Earth-Science Reviews, 119, 17-34, 2013.

Cleveland, W. S.: LOWESS: A program for smoothing scatterplots by robust locally weighted regression, The American Statistician, 35, 54, 1981.

Cloern, J. E.: The relative importance of light and nutrient limitation of phytoplankton growth: a simple index of coastal ecosystem sensitivity to nutrient enrichment, Aquatic Ecology, 33, 3-16, 1999.

Cohn, T. A., Caulder, D. L., Gilroy, E. J., Zynjuk, L. D., and Summers, R. M.: The validity of a simple statistical model for estimating fluvial constituent loads: An Empirical study involving nutrient loads entering Chesapeake Bay, Water Resources Research, 28, 2353-2363, 1992.

Diplas, P., Kuhnle, R., Gray, J., Glysson, D., and Edwards, T.: Sediment transport measurements. In: Sedimentation engineering: processes, measurements, modeling, and practice, Marcelo, H. G. (Ed.), American Society of Civil Engineers, 2008.

Ferguson, R. I.: River Loads Underestimated by Rating Curves, Water Resources Research, 22, 74-76, 1986.

Fischer, H.: Zur Steuerung der Trophie großer Flüsse, Korrespondenz Wasserwirtschaft, 8, 225-230, 2015.

Frings, R. M., Gehres, N., Promny, M., Middelkoop, H., Schüttrumpf, H., and Vollmer, S.: Today's sediment budget of the Rhine River channel, focusing on the Upper Rhine Graben and Rhenish Massif, Geomorphology, 204, 573-587, 2014.

Frings, R. M., Hillebrand, G., Gehres, N., Banhold, K., Schriever, S., and Hoffmann, T.: From source to mouth: Basin-scale morphodynamics of the Rhine River, Earth-Science Reviews, 196, 2019.

Fryirs, K.: (Dis)Connectivity in catchment sediment cascades: a fresh look at the sediment delivery problem, Earth Surface Processes and Landforms, 38, 30-46, 2013.

Geider, R. J.: Light and Temperature Dependence of the Carbon to Chlorophyll a Ratio in Microalgae and Cyanobacteria: Implications for Physiology and Growth of Phytoplankton, New Phytologist, 106, 1-34, 1987.

Gray, A. B.: The impact of persistent dynamics on suspended sediment load estimation, Geomorphology, 322, 132-147, 2018.

Habersack, H. and Haimann, M.: Schwebstoffmessungen in Österreich ADCP-Messung - Bericht, 2010.

Hardenbicker, P., Rolinski, S., Weitere, M., and Fischer, H.: Contrasting long-term trends and shifts in phytoplankton dynamics in two large rivers, International Review of Hydrobiology, 99, 287-299, 2014.

Hardenbicker, P., Weitere, M., Ritz, S., Schöll, F., and Fischer, H.: Longitudinal Plankton Dynamics in the Rivers Rhine and Elbe, River Research and Applications, 32, 1264-1278, 2016.

Heckmann, T., Cavalli, M., Cerdan, O., Foerster, S., Javaux, M., Lode, E., Smetanová, A., Vericat, D., and Brardinoni, F.: Indices of sediment connectivity: opportunities, challenges and limitations, Earth-Science Reviews, 187, 77-108, 2018.

Hillebrand, G. and Frings, R.: Von der Quelle zur Mündung: Die Sedimentbilanz des Rheins im Zeitraum 1991 – 2010, Bericht KHR/CHR II-22. Internationale Kommission für die Hydrologie des Rheingebietes, Lelystad. ISBN: 978-90-70980-39- 9, DOI: 10.5675/KHR_22.2017., 2017.

Hillebrand, G., Hardenbicker, P., Fischer, H., Otto, W., and Vollmer, S.: Dynamics of total suspended matter and phytoplankton loads in the river Elbe, Journal of Soils and Sediments, 18, 3104-3113, 2018.

Hoffmann, T.: Sediment residence time and connectivity in non-equilibrium and transient geomorphic systems, Earth-Science Reviews, 150, 609-627, 2015.

Hoffmann, T., Glatzel, S., and Dikau, R.: A carbon storage perspective on alluvial sediment storage in the Rhine catchment, Geomorphology, 108, 127-137, 2009.

Hoffmann, T., Hillebrand, G., and Noack, M.: Uncertainty analysis of settling, consolidation and resuspension of cohesive sediments in the Upper Rhine, International Journal of River Basin Management, 15, 401-411, 2017.

Horowitz, A. J.: An evaluation of sediment rating curves for estimating suspended sediment concentrations for subsequent flux calculations, Hydrological Processes, 17, 3387-3409, 2003.

Morehead, M. D., Syvitski, J. P., Hutton, E. W. H., and Peckham, S. D.: Modeling the temporal variability in the flux of sediment from ungauged river basins, Global and Planetary Change, 39, 95-110, 2003.

Naden, P. S.: The Fine-Sediment Cascade. In: Sediment cascades: an integrated approach, Burt, T. and Allison, R. (Eds.), Wiley-Blackwell, 2010.

Owens, P. N., Batalla, R. J., Collins, A. J., Gomez, B., Hicks, D. M., Horowitz, A. J., Kondolf, G. M., Marden, M., Page, M. J., Peacock, D. H., Petticrew, E. L., Salomons, W., and Trustrum, N. A.: Fine-grained sediment in river systems: environmental significance and management issues, River Research and Applications, 21, 693-717, 2005.

Partheniades, E.: Chapter 4 - The Hydrodynamic Transport Processes of Cohesive Sediments and Governing Equations. In: Cohesive Sediments in Open Channels, Partheniades, E. (Ed.), Butterworth-Heinemann, Boston, 2009.

Poesen, J.: Soil erosion in the Anthropocene: Research needs, Earth Surface Processes and Landforms, 43, 64-84, 2018.

Poulier, G., Launay, M., Le Bescond, C., Thollet, F., Coquery, M., and Le Coz, J.: Combining flux monitoring and data reconstruction to establish annual budgets of suspended particulate matter, mercury and PCB in the Rhône River from Lake Geneva to the Mediterranean Sea, Science of The Total Environment, 658, 457-473, 2019.

Quiel, K., Becker, A., Kirchesch, V., Schöl, A., and Fischer, H.: Influence of global change on phytoplankton and nutrient cycling in the Elbe River., Regional Environmental Change, 11, 405-421, 2011.

Reid, I. and Frostick, L. E.: Discussion of conceptual models of sediment transport in streams. In: Sediment Transport in Gravel-Bed Rivers, Thorne, C. R., Bathurst, J. C., and Hey, R. D. (Eds.), John Wiley, New York, 1987.

Spreafico, M., Lehmann, C., Jakob, A., and Grasso, A.: Feststoffbeobachtung in der Schweiz. Ein Tätigkeitsgebiet der Landeshydrologie, Bundesamt für Wasser und Geologie, Bern, 2005.

Syvitski, J. P., Morehead, M. D., Bahr, D. B., and Mulder, T.: Estimating fluvial sediment transport: The rating parameters, Water Resources Research, 36, 2747-2760, 2000.

Syvitski, J. P., Vörösmarty, C., Kettner, A., and Green, P.: Impact of Humans on the Flux of Terrestrial Sediment to the Global Coastal Ocean, Science, 308, 376-380, 2005.

Thollet, F., Le Bescond, C., Lagouy, M., Gruat, A., Grisot, G., Le Coz, J., Coquery, M., Lepage, H., Gairoard, S., Gattacceca, J. C., Ambrosi, J.-P., and Radakovitch, O.: Observatoire des Sédiments du Rhône. IRSTEA (Ed.), 2018.

Thorp, J. H. and Delong, M. D.: Dominance of autochthonous autotrophic carbon in food webs of heterotrophic rivers., Oikos, 96, 543-550, 2002.

van Rijn, L.: Sediment Transport, Part II: Suspended load transport, Journal of Hydraulic Engineering, ASCE, no 11., Journal of Hydraulic Engineering, 11, 1613-1641, 1984.

Walling, D. E.: Erosion and sediment yield: a global overview, IAHS Publ., 236, 3-19, 1996.

Walling, D. E., Owens, P. N., Waterfall, B. D., Leeks, G. J. L., and Wass, P. D.: The particle size characteristics of fluvial suspended sediment in the Humber and Tweed catchments, UK, Science of The Total Environment, 251, 205-222, 2000.

Warrick, J. A.: Trend analyses with river sediment rating curves, Hydrological Processes, 29, 936-949, 2015.

Wetzel, R.: Limnology. Lake and River Ecosystems, Elsevier, 2001.

Winterwerp, J. and Van Kesteren, W. G. M.: Introduction to the physics of cohesive sediment in the marine environment, Elsevier, Amsterdam, 2004.

Winterwerp, J. C., Manning, A. J., Martens, C., de Mulder, T., and Vanlede, J.: A heuristic formula for turbulence-induced flocculation of cohesive sediment, Estuarine, Coastal and Shelf Science, 68, 195-207, 2006.

Zuecco, G., Penna, D., Borga, M., and van Meerveld, H. J.: A versatile index to characterize hysteresis between hydrological variables at the runoff event timescale, Hydrological Processes, 30, 1449-1466, 2016.

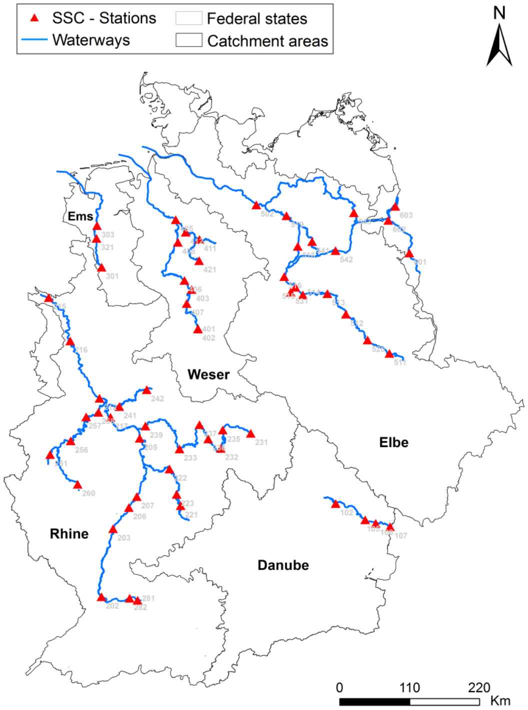


Figure 1: Selected sampling locations of the WSV-suspended monitoring network used in this study. Labels refer to the station codes given in Tab. 1.

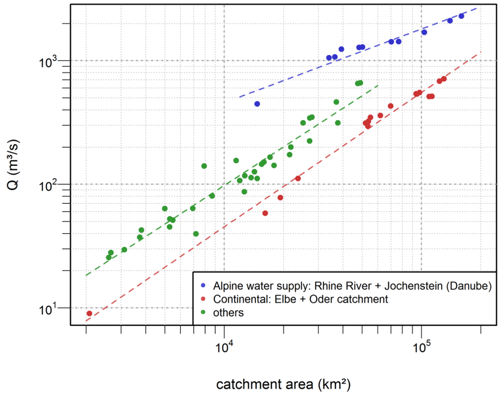


Figure 2: Discharge as a function of catchment area for 62 gauging stations that are used as reference stations of the suspended sediment monitoring network.

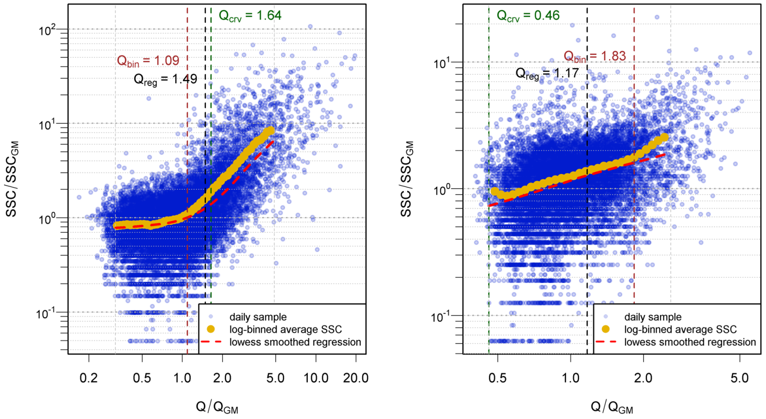
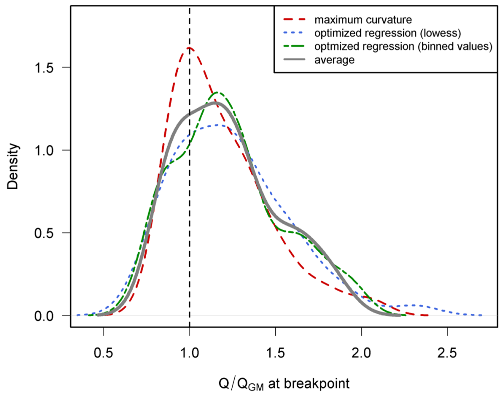


Figure 3: Rating curves of the stations at Rockenau (river Neckar, ID 222) and Kachlet (river Danube, ID 103). For locations see Fig. 1.



Kommentiert [TH5]: Figure updated considering the comments of referee #1

Figure 4: Density distribution of rating breaks (Q_{br}) derived from the scaling analysis of the suspended sediment concentration. For detailed results see also Tab. 2.

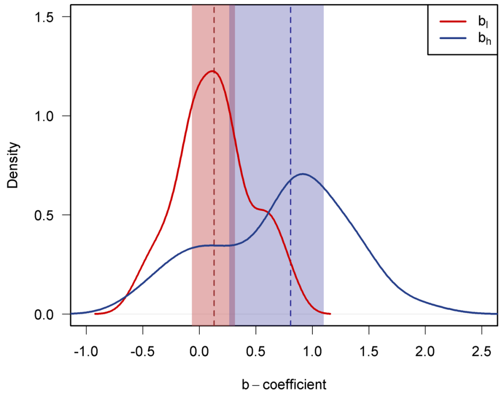


Figure 5: Density distribution of rating exponents (following Eq.2) for the low flow (b_l) and high flow (b_h) regime. The blue and red vertical dashed lines indicate the median values, the blue and red shaded areas indicate the 25% and 75% percentile of both rating coefficients.

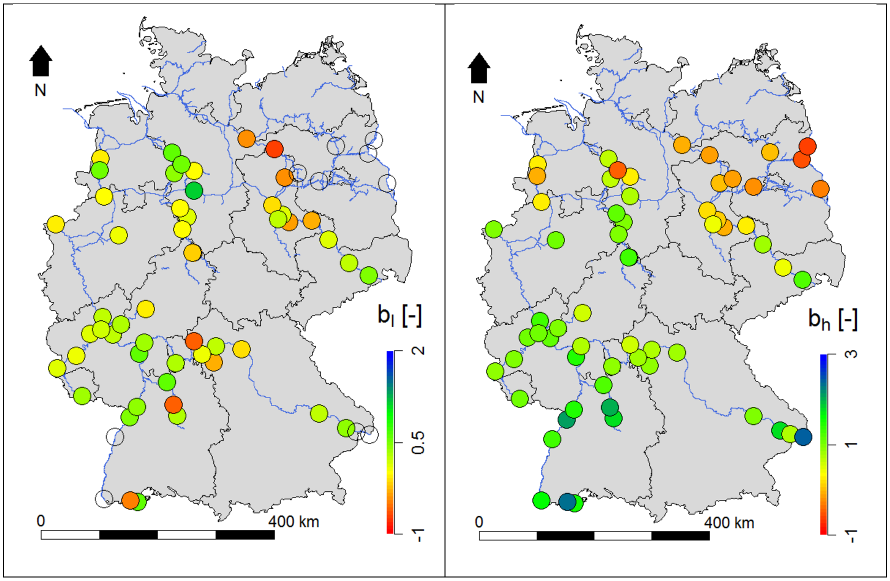


Figure 6: Maps representing the spatial distribution of the rating exponents. Left map indicates b_l and right map indicates b_h. Empty circles in the left graph denote stations without a significant rating break.

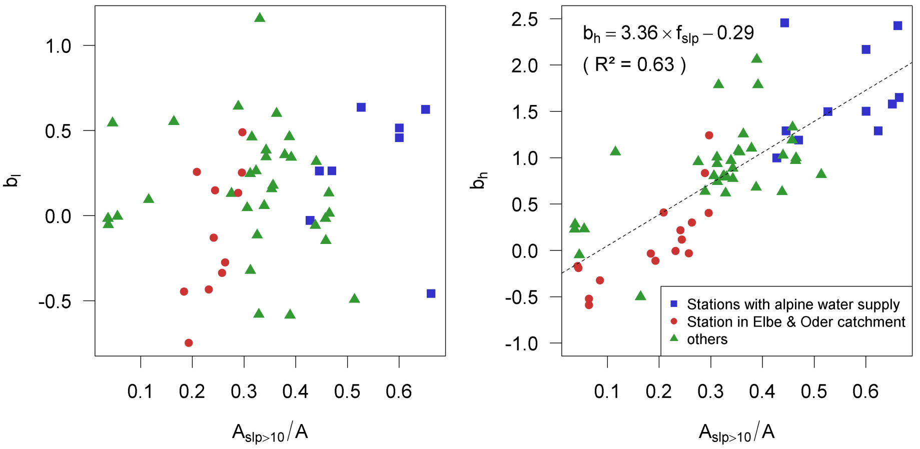


Figure 7: Relation of rating coefficients (b_l left and b_h right) and the ratio of the catchment area with hillslopes steeper than 10% ($A_{slp>10}$) vs. total catchment area (A).

Kommentiert [TH6]: Figure updated, considering comments of referee #1

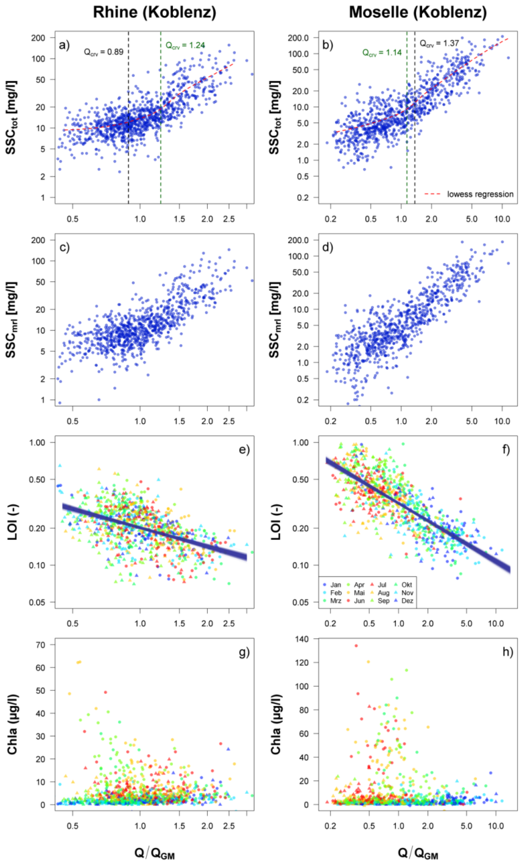


Figure 8: Rating of total SSC (1st row), mineral SSC (2nd row), loss on ignition (LOI, 3rd row) and chlorophyll a (Chla, 4th row) for the station Koblenz-Rhine (left) and Koblenz-Moselle (right). Blue lines on LOI-scatter plots show regression results using 1000 bootstrap-replicates.

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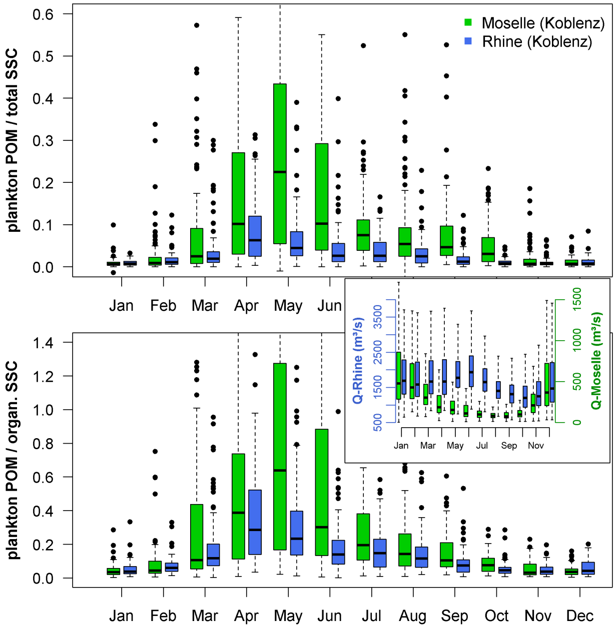

Figure 9: Boxplot of seasonal variation of plankton POM with respect to total *SSC* (top) and organic *SSC* (bottom) for the stations Koblenz Rhine (blue) and Koblenz Moselle (green) from 1990-2017. Organic *SSC* is derived from *LOI* measurements and plankton *POM* is calculated from *Chla*-measurements using a *POC/Chla*-ratio of 40 and a *POC/POM*-ratio of 0.42. Plankton POM/organic SSC ratios > 1 are due to measurement errors of *Chla* and *LOI* and due to simplified conversion ratios. The inset shows the boxplot of seasonal discharge variations at both stations.

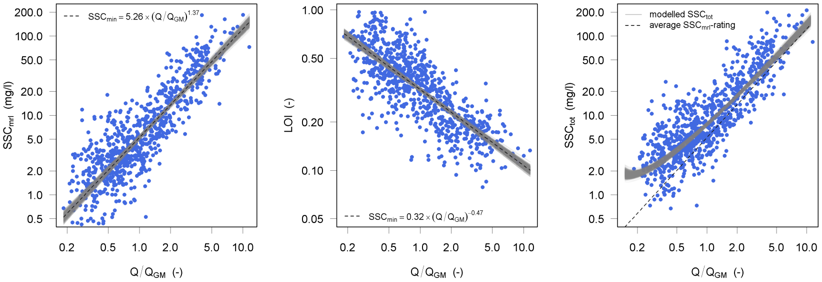

Figure 10: Statistical modelling of the total suspended sediment concentration (*SSC_{tot}*, right) based on the positive and negative power law rating of the mineral fraction of the SSC (*SSC_{mrl}*, left) and the loss on ignition (*LOI*, middle), respectively.

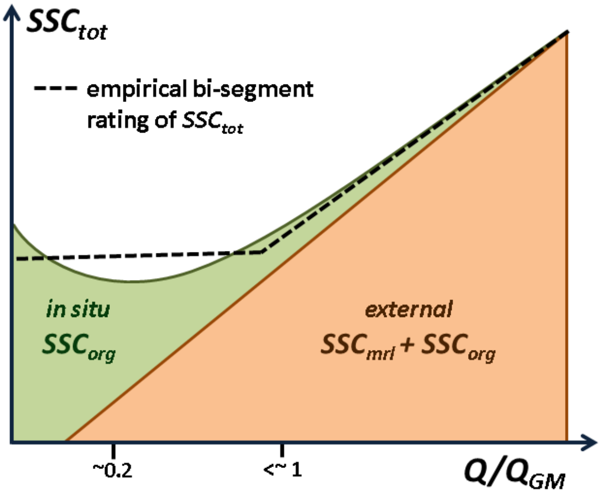

Figure 11: Conceptual model of suspended sediment rating in the German waterways.

Table 1: Overview of sampling locations, contributing catchment size, monitoring period, number of samples (n) and average (avg), median (med) and geometric mean (GM) of discharge Q and suspended sediment concentration (SSC). The map index refers to the numbers in the map (Figure 1).

Map index	Station name	River	Location (river-km)	Catchment (km²)	Monitoring period	n	Q (mg/l)			SSC (mg/l)		
							avg	med	GM	avg	med	GM
102	Straubing	Donau	2321,3	37026	1982	7197	462	395	414	16,9	14	13,5
105	Vilshofen	Donau	2249,5	47609	1966	11282	651	573	597	20,0	16	15,3
106	Kachlet	Donau	2230,7	49045	1975	9214	661	578	606	20,4	17	16,1
107	Jochenstein	Donau	2203,1	76653	1974	9174	1425	1292	1319	47,9	23	25,2
281	Reckingen	Rhein	90,2	14718	1972	10038	446	411	416	13,9	10	10,6
282	Albbruck Dogern	Rhein	108,9	33987	1972	10601	1053	969	974	19,7	13	13,0
202	Weil	Rhein	173	36472	1970	10104	1070	984	985	27,5	17	17,0
203	Kehl	Rhein	294	39330	1970-2013	11201	1237	1134	1145	16,4	11	11,4
206	Plittersdorf	Rhein	339,8	48276	1977-2013	9281	1278	1170	1187	18,3	14	14,2
207	Maxau	Rhein	362,3	50196	1964	13203	1285	1175	1189	22,9	18	16,8
205	Nierstein	Rhein	480,6	70387	1983	7228	1419	1283	1315	21,1	17	17,1
217	Sankt Goar	Rhein	557	103488	1970	11398	1694	1520	1557	26,3	21	20,3
215	Emmerich	Rhein	851,9	159555	1982	8710	2289	1950	2072	27,2	25	22,7
212	Weißenthurm	Rhein	608,2	139549	1971	9919	2102	1830	1893	32,9	25	25,9
221	Poppenweiler	Neckar	164,9	5005	1965-2014	11609	64	45	49	30,7	18	17,5
222	Rockenau	Neckar	61,3	7916	1971	10364	140	104	109	34,7	19	20,3
223	Lauffen	Neckar	125,1	12676	1987	6209	87	65	69	22,0	15	14,8
231	Viereth	Main	380,8	12010	1972-2005	8455	107	78	86	18,6	16	15,2
235	Garstadt	Main	323,7	12722	1986-2005	4949	117	82	93	23,4	19	18,7
232	Marktbreit	Main	275,7	13693	1965-2012	11801	113	83	91	25,8	21	19,5
236	Erlabrunn	Main	241,2	14244	1986-2005	4941	126	90	101	25,3	21	20,9
237	Steinbach	Main	210	17914	1987	6121	142	103	114	20,3	17	16,2
233	Kleinheubach	Main	121,7	21505	1973-2014	9702	173	124	136	27,6	22	21,0
239	Eddersheim	Main	15,6	27100	1986-2012	6506	223	161	177	28,9	23	22,8
242	Wetzlar	Lahn	125,3	2669	1986-2007	4843	28	16	18	20,9	17	15,9
241	Kalkofen	Lahn	31,6	5303	1970	10240	45	26	30	22,2	14	13,4
277	Hamm. Wehr	Lippe	120,1	2607	1976	8737	26	19	20	15,6	12	11,7
260	Güdingen	Saar	91,7	3811	1973	10314	42	26	29	18,3	11	10,7
251	Wincheringen	Mosel	221,9	11522	1974	9558	155	91	99	31,7	22	23,2
256	Detzem	Mosel	166,8	25130	1981-2002	5320	314	183	205	31,7	21	22,3
257	Cochem	Mosel	50,2	27165	1981-2011	7387	343	211	231	29,4	19	21,5
258	Brodenbach	Mosel	27,2	27872	1981-2009	6672	349	214	235	31,9	21	22,4
321	Meppen	Hase	1	3126	1974-1996	5740	29	22	24	21,9	21	19,4

301	Rheine	Ems	153	3740	1964	13506	37	23	25	27,4	18	17,4
303	Lathen	Ems	253,3	8696	1966	12951	80	57	61	18,6	16	14,6
421	Herrenhausen	Leine	87,1	5304	1965-2006	10448	52	38	41	40,0	24	23,8
411	Marklendorf	Aller	75,9	7209	1971	11563	40	30	32	14,9	14	12,5
412	Rethem	Aller	34,2	14730	1973	10601	111	85	91	21,4	19	17,6
401	Hann.-Münden.W.	Werra	0,5	5497	1965	12639	51	38	40	51,6	39	39,0
402	Hann.-Münden.F.	Fulda	1	6947	1965	12639	64	43	51	23,3	18	16,0
407	Höxter	Weser	69,4	15501	1983	8224	145	103	118	30,4	23	23,0
403	Bodenwerder	Weser	110,7	15924	1964	12875	151	109	123	32,3	24	23,7
406	Hameln	Weser	135,2	17077	1979	9333	166	118	134	32,0	24	23,6
408	Nienburg	Weser	268,1	21815	1985	7862	199	143	163	29,5	23	22,7
405	Intschede	Weser	329,5	37720	1969	11270	313	234	256	35,1	28	27,3
543	Zehdenick	Havel	15,1	2076	1991	4290	9	7,5	7,1	10,7	9	8,7
542	Ketzin	Havel	34,1	16173	1991-2016	6310	58	54	45	12,9	11	9,8
541	Rathenow	Havel	103,6	19288	1991-2016	6498	78	72	64	14,9	13	11,8
531	Calbe	Saale	20	23719	1991	6740	111	84	93	26,8	20	21,7
511	Pirna	Elbe	34,7	52080	1991	6120	313	234	257	22,7	18	16,8
520	Meissen	Elbe	83,4	53885	1994	5310	323	239	264	25,1	19	19,8
512	Torgau	Elbe	154	55211	1993	5790	346	253	282	32,1	27	26,1
513	Wittenberg	Elbe	216,3	61879	1991	6339	360	272	295	28,0	24	23,8
514	Aken	Elbe	274,8	69849	1991	5887	429	326	353	25,3	23	21,8
515	Barby	Elbe	294,8	94060	1991	6431	538	401	447	33,1	28	27,9
516	Magdeburg Strombr.	Elbe	326,6	94942	1992	6395	537	397	447	26,0	21	20,8
518	Tangermünde	Elbe	389,1	97780	1991	6397	552	422	462	31,2	27	26,3
519	Wittenberge	Elbe	454,6	123532	1993	5907	681	526	576	32,0	25	26,1
502	Hitzacker	Elbe	522,6	129877	1963	13703	712	571	605	34,0	30	28,4
601	Frankfurt / Oder	Oder	585,8	53590	1991	4822	294	246	252	24,8	21	20,6
602	Hohensaaten	Oder	662,3	109564	1991	4943	512	440	453	21,7	18	17,6
603	Schwedt	Oder	690,6	112950	1991	5022	513	442	454	23,8	20	19,4

Table 2: Results from rating-break analysis and and log-linear and non-linear least square regression of rating exponent (Eq. 2) above (b_h) and below (b_l) rating break (Q_{br}/Q_{gm}).

Map index	name	Q_{br}/Q_{gm}				log-linear regression				non-linear LS regression			
		loess-regression	loess-curvature	binned regression	mean	b_l	Δb_l	b_h	Δb_h	b_l	Δb_l	b_h	Δb_h
102	Straubing	1,03	1,09	1,09	1,07	0,28	0,04	0,97	0,04	0,25	0,08	1,01	0,08
105	Vilshofen	1,55	1,55	1,54	1,55	0,65	0,03	1,50	0,07	0,46	0,07	1,79	0,11
106	Kachlet	-	-	-	-	-	-	0,68	0,02	-	-	0,74	0,03
107	Jochenstein	-	-	-	-	-	-	2,01	0,02	-	-	2,45	0,15
202	Weil	-	-	-	-	-	-	1,23	0,02	-	-	1,65	0,22
203	Kehl	-	-	-	-	-	-	0,85	0,02	-	-	1,29	0,08
205	Nierstein	1,09	1,05	1,15	1,1	0,65	0,04	1,44	0,04	0,64	0,07	1,50	0,09
206	Plittersdorf	1,31	1,29	1,37	1,32	0,69	0,04	1,80	0,07	0,52	0,09	2,17	0,15
207	Maxau	0,95	0,97	0,87	0,93	0,60	0,04	1,41	0,03	0,46	0,06	1,50	0,05
212	Weißenthurm	0,95	0,99	0,87	0,94	0,36	0,03	1,18	0,03	0,26	0,07	1,29	0,05
215	Emmerich	1,08	1,11	1,15	1,11	-0,02	0,04	0,93	0,04	-0,03	0,05	1,00	0,05
217	Sankt Goar	1,01	1,01	1,03	1,02	0,21	0,04	1,22	0,03	0,26	0,06	1,19	0,06
221	Poppenweiler	1,61	1,72	1,83	1,72	0,23	0,02	1,52	0,05	0,34	0,12	1,79	0,08
222	Rocke-u	-	-	1,09	1,09	0,15	0,02	1,37	0,03	0,60	0,09	1,26	0,05
223	Lauffen	1,33	1,39	1,63	1,45	0,12	0,03	1,31	0,06	-0,59	0,19	2,06	0,13
231	Viereth	1,28	1,15	1,09	1,17	-0,01	0,03	0,70	0,03	-0,11	0,10	0,80	0,09
232	Marktbreit	1,01	1,02	1,09	1,04	-0,26	0,03	0,87	0,03	-0,32	0,05	0,94	0,05
233	Kleinheubach	1,17	1,12	1,3	1,2	0,25	0,03	0,92	0,03	0,35	0,04	0,89	0,04
235	Garstadt	1,27	-	1,3	1,29	0,25	0,04	0,74	0,04	0,26	0,06	0,79	0,06
236	Erlabrunn	1,19	-	1,3	1,25	0,13	0,03	0,70	0,04	0,05	0,06	0,80	0,06
237	Steinbach	0,79	0,84	0,82	0,82	-0,43	0,05	0,50	0,03	-0,58	0,08	0,62	0,06
239	Eddersheim	1,44	1,41	1,15	1,33	0,34	0,03	0,77	0,04	0,39	0,05	0,77	0,05
241	Kalkofen	1,94	1,83	1,54	1,77	-0,11	0,03	1,34	0,04	0,32	0,05	1,03	0,05
242	Wetzlar	1,64	1,19	1,37	1,4	-0,25	0,03	0,72	0,03	-0,06	0,04	0,63	0,04
251	Wincheringen	1,35	-	1,3	1,33	0,01	0,01	1,05	0,02	0,13	0,03	0,96	0,02
256	Detzem	1,19	-	1,03	1,11	-0,08	0,02	0,98	0,03	0,06	0,05	0,97	0,04
257	Cochem	1,19	1,31	1,22	1,24	0,18	0,02	1,01	0,02	0,16	0,05	1,08	0,04
258	Brodenbach	1,27	1,37	1,22	1,29	0,17	0,02	1,00	0,03	0,18	0,05	1,06	0,05
260	Güdingen	2,31	2,05	1,15	1,84	0,29	0,03	0,74	0,06	0,36	0,24	1,10	0,21
277	Hamm. Wehr	1,33	1,32	1,37	1,34	0,07	0,02	1,07	0,03	0,09	0,04	1,06	0,05
281	Reckingen	1,15	-	-	1,15	0,81	0,04	0,96	0,06	0,62	0,12	1,58	0,18
282	Albbruck Dogern	-	-	0,87	0,87	0,80	0,05	1,40	0,04	-0,46	0,39	2,42	0,27
301	Rheine	1,3	1,05	1,15	1,17	-0,05	0,02	0,26	0,03	-0,02	0,04	0,23	0,03

303	Lathen	0,8	0,91	0,87	0,86	-0,11	0,03	0,27	0,02	-0,05	0,02	0,28	0,02
321	Meppen	1,14	-	1,15	1,15	0,61	0,02	-0,11	0,03	0,54	0,03	-0,05	0,03
401	Hann.-Münden.W.	1,18	1,18	1,09	1,15	-0,46	0,02	0,77	0,03	-0,49	0,06	0,82	0,06
402	Hann.-Münden.F.	1,54	1,29	1,94	1,59	-0,06	0,03	1,11	0,05	-0,15	0,09	1,33	0,11
403	Bodenwerder	1,61	-	1,63	1,62	0,08	0,03	0,83	0,05	0,13	0,06	0,97	0,08
405	Intschede	-	-	1,22	1,22	0,49	0,02	0,70	0,03	0,64	0,03	0,64	0,03
406	Hameln	1,84	1,56	1,73	1,71	-0,07	0,03	1,17	0,05	-0,02	0,06	1,19	0,08
407	Höxter	1,33	1,28	1,3	1,3	-0,06	0,03	0,95	0,04	0,01	0,07	1,00	0,07
408	Nienburg	1,62	1,52	1,73	1,62	0,31	0,03	0,79	0,05	0,46	0,04	0,68	0,05
411	Marklendorf	0,76	0,99	0,73	0,83	0,00	0,03	0,31	0,02	0,00	0,03	0,23	0,01
412	Rethem	1,51	-	1,63	1,57	0,52	0,02	-0,44	0,03	0,55	0,03	-0,50	0,04
421	Herrenhausen	0,92	1,21	0,77	0,97	0,54	0,03	0,88	0,03	1,16	0,06	0,79	0,03
502	Hitzacker	1,26	1,08	1,3	1,21	-0,41	0,02	-0,06	0,03	-0,45	0,02	-0,03	0,03
511	Pir-	1,8	-	1,94	1,87	0,40	0,03	1,39	0,07	0,49	0,06	1,24	0,11
512	Torgau	1,46	-	1,45	1,46	0,15	0,03	0,86	0,04	0,13	0,04	0,83	0,05
513	Wittenberg	0,87	0,91	0,87	0,88	-0,16	0,04	0,26	0,02	-0,28	0,04	0,30	0,02
514	Aken	0,92	0,93	0,82	0,89	-0,25	0,04	-0,04	0,03	-0,34	0,04	-0,03	0,03
515	Barby	0,92	0,88	0,87	0,89	0,13	0,04	0,08	0,03	0,15	0,05	0,12	0,02
516	Magdeburg Strombr.	0,97	0,97	-	0,97	-0,04	0,05	0,19	0,03	-0,13	0,04	0,22	0,03
518	Tangermünde	0,93	0,91	0,92	0,92	-0,28	0,04	-0,06	0,02	-0,43	0,04	-0,01	0,03
519	Wittenberge	1,04	0,94	1,03	1	-0,57	0,04	-0,14	0,03	-0,75	0,04	-0,11	0,03
520	Meissen	0,78	0,86	-	0,82	0,21	0,05	0,36	0,03	0,25	0,06	0,40	0,04
531	Calbe	0,87	0,92	-	0,9	0,11	0,04	0,32	0,03	0,26	0,06	0,41	0,04
541	Rathenow	-	-	-	-	-	-	-0,22	0,01	-	-	-0,17	0,01
542	Ketzin	-	-	-	-	-	-	-0,22	0,01	-	-	-0,19	0,01
543	Zehdenick	-	-	-	-	-	-	0,04	0,01	-	-	0,04	0,02
601	Frankfurt / Oder	-	-	-	-	-	-	-0,24	0,02	-	-	-0,33	0,02
602	Hohensaaten	-	-	-	-	-	-	-0,49	0,02	-	-	-0,52	0,02
603	Schwedt	-	-	-	-	-	-	-0,53	0,02	-	-	-0,59	0,02
999	Koblenz (Rhein)	0.96	0.97		0.96					0,29	0,20	2,26	0,18
998	Koblenz (Mosel)	0.87	0.94		0.91					-0,03	0,07	1,54	0,14

Seite 8: [1] Gelöscht **Thomas Hoffmann** **07.04.20 21:28:00**