On behalf of the authors we would like thank the third reviewer Daniel N. Scott for his additional profound and helpful comments regarding the revised version of the original manuscript. When incorporated, we are certain that his comments greatly improve our manuscript towards a finalized version.

In the following section we will reply to all comments of our third reviewer denoted with R1 (i.e. reviewer comment 1) and A1 (i.e. author response 1), respectively. As this review concerns the revised manuscript based on the review of both anonymous reviewers (available at https://www.hydrol-earth-syst-sci-discuss.net/hess-2019-35/hess-2019-35-AC2-supplement.pdf), we separate this author response from the previous and may only recapitulate comments and responses of both anonymous reviewers if necessary.

As major parts of the revised manuscript including introduction, discussion, conclusion and abstract are altered, we added the entire modified manuscript at the end of this response.

Reviewer #3 (Daniel N. Scott)

R1: 1,13: It strikes me as imprecise to say that wood can improve hydraulic and hydromorphological characteristics. Wood changes those things, but may or may not improve them, depending on one's valuation, although I certainly don't dispute that wood can "act positively on a river's ecology"! Consider rephrasing this statement to be less subjective.

A1: We agree, that this statement needs to be less subjective and modified it in the following way:

Original:

"The presence of large wood (LW) in river channels can improve the hydromorphological and hydraulic characteristics of rivers and streams and therefore act positively on a river's ecology."

Modification:

"Large wood (LW) can alter the hydromorphological and hydraulic characteristics of rivers and streams and may act positively on a river's ecology by i.e. leading to an increased habitat availability."

R2: 1,14: I'm really happy to see a shift from "large woody debris" to just "large wood"!

A2: We are glad that this modification is a consent between all reviewers.

R3: 1,23: What about the implementations are you testing? Answering that in a few words here will help guide readers through the rest of the abstract.

A3: We added a statement to the abstract. The modification is in accordance with the reviewer's suggestion and shown below:

Original:

"In this study, a two-dimensional hydraulic model is set up for a mountain creek to simulate the hydraulic effects of stable LW and to test different methods of LW implementation."

Modification:

"However, the work- and time-consumption varies between approaches of incorporating large wood in hydrodynamic models. In this study, a two-dimensional hydraulic model is set up for a mountain creek to simulate the hydraulic effects of stable LW and to compare multiple methods to account for large wood induced roughness. LW is implemented by changing in-channel roughness coefficients and by adding topographic elements to the model in order to determine which method most accurately simulates observed hydrographs and to provide guidance for future hydrodynamic modelling of stable large wood with two-dimensional models."

R4: 1,27: The writing here is unclear at times, and somewhat wordy. For instance, "Methodically, in-channel roughness coefficients are changed iteratively for retrieving the best fit between mean simulated and observed flood hydrographs with and without LW at the downstream reach outlet" Could instead be "We iterate in-channel roughness coefficients to best fit the mean simulated and observed flood hydrographs with and without LW at the downstream reach outlet" This is considerably shorter and easier to read, in my opinion. This is a style thing, but consider going through the manuscript (at least the abstract) and tightening up the wording to eliminate redundancy and imprecise verbiage. There are also some grammatical errors, likely stemming from the track changes, to watch out for (e.g., on line 1,29, there is a comma after an "and" that is out of place; there is a word missing on line 2,18). I won't comment on this further, as I'd rather focus on the scientific content and leave this to the authors and copyeditors. However, I suggest reading through the manuscript and editing for grammar and syntax.

A4: We are glad about this comment. The comma was removed and we changed the phrase according to the reviewer's suggestion:

Original:

"Methodically, in-channel roughness coefficients are changed iteratively for retrieving the best fit between mean simulated and observed flood hydrographs with and without LW at the downstream reach outlet and simplified discrete elements representing LW were incorporated into the calculation mesh."

Modification:

"We iterate in-channel roughness coefficients to best fit the mean simulated and observed flood hydrographs with and without LW at the downstream reach outlet. As an alternative approach of modelling LW induced effects, we use simplified discrete topographic elements representing individual LW elements in the channel."

R5: 1,31: Do you mean between the observed hydrographs and the model results? The statement as written implies a good fit between individual field observations.

A5: We agree. The sentence was modified in the following way:

Original:

"In general, the model results reveal a high goodness-of-fit of between the observed flood hydrographs of the field experiments without and with stable in-channel large wood. The best fit of simulation and mean observed hydrograph with in-channel LW can be obtained when increasing in-channel roughness through decreasing Strickler coefficients - in the entire reach instead of a reduction at LW positions only."

<u>Modification:</u>

"In general, the simulations reveal a high goodness-of-fit of between the observed flood hydrographs and the model results without and with stable in-channel large wood. The best fit of simulation and mean observed hydrograph with in-channel LW can be obtained when increasing in-channel roughness coefficients in the entire reach instead of an increase at LW positions only"

R6: 3,14: This statement is likely untrue. For a more nuanced discussion of piece and jam mobility, see Kramer and Wohl (2017, *Geomorphology*, DOI: 10.1016/j.geomorph.2016.08.026). It might be safe to say that pieces longer than channel width are more likely to be stable. Reading on, you seem to acknowledge this, so it would be good to eliminate this contradiction.

A6: We agree that mobile and stable large wood may not be to distinguished with such simple metrics. To avoid this section to be misleading, we modified it in the following way:

<u>Original:</u>

"Here, potentially mobile large wood and stable large wood have to be distinguished. Large wood assemblages and elements may be assumed stable when the median element length exceeds channel width (i.e. Gurnell et al., 2002), likely to occur in small first order streams and rivers, which in turn are the most abundant order of water courses on the planet (Downing et al., 2012). However, even in small but steep headwater streams, large wood may be transported during hydrogeomorphic events of high magnitude such as debris flows (Galia et al., 2018) or extreme floods. A conceptual model for a first estimate of large wood transport in water courses is given in Kramer and Wohl (2017) including hydrological as well as morphological variables. Further detailed information about large wood dynamics in river networks can be found in recent reviews of Ruiz-Villanueva et al. (2016a) and Wohl (2017). Potentially mobile large wood may drifts during floods, elements jam at bridges or other infrastructure and cause increased water levels, damage or completely destroy anthropogenic goods and structures (Schmocker and Hager, 2011). On the contrary, stable large wood remains in place, reduces water conveyance (Wenzel et al., 2014) and leads to increased water levels upstream and in turn, increased risk of flooding and water logging in surrounding areas. For these reasons, LW is removed from European rivers and streams for more than a century (Wohl, 2015) also to ensure navigability in larger rivers (Young, 1991)."

<u>Modification:</u>

"Large wood assemblages and elements are more likely to be stable when their length exceeds channel width (i.e. Gurnell et al., 2002), most likely to occur in small first order streams and rivers, which in turn are the most abundant order of water courses on the planet (Downing et al., 2012). However, even in small but steep headwater streams, large wood may be transported during hydrogeomorphic events of high magnitude such as debris flows (Galia et al., 2018) or extreme floods. A conceptual model for a first estimate of large wood transport in water courses is given in Kramer and Wohl (2017) including hydrological as well as morphological variables. Further detailed information about large wood dynamics in river networks can be found in recent reviews of Ruiz-Villanueva et al. (2016a) and Wohl (2017). Large wood may drift during floods, elements jam at bridges or other infrastructure and cause increased water levels, damage or completely destroy anthropogenic goods and structures (Schmocker and Hager, 2011). On the contrary, stable large wood reduces water conveyance (Wenzel et al., 2014) and leads to increased water levels upstream and in turn, increased risk of flooding and water logging in surrounding areas. For these reasons, LW is removed from European rivers and streams for more than a century (Wohl, 2015) also to ensure navigability in larger rivers (Young, 1991)."

R7: 4,4-4,17: This paper is about the hydraulic effects of wood, not wood mobilization. While all of this is interesting, I don't see how it has any bearing on this paper's objectives. Consider keeping the explanation of model dimensions (always a helpful thing to remind people of), but scrapping the review of wood transport modeling. The topic this paper addresses is plenty interesting, and doesn't really need this extraneous addition of wood mobility ideas to distract readers.

A7: Despite partly in contrast to comments of the anonymous reviewers, we agree that the focus of this paper should be on stable large wood and the simulation of its effects on water flow. However, to maintain a consent between all reviewers on the one hand and avoiding distraction of readers on the other, we keep the information that both, large wood transport and the hydraulic impact of stable large wood, can be simulated with hydrodynamic models but remove further information on LW transport modelling studies.

<u>Original:</u>

The mobility, transport and deposition of large wood (i.e. Ruiz-Villanueva et al., 2014; Ruiz-Villanueva et al., 2016b) as well as the resulting physical effects of stable in-channel LW (Smith et al. 2011) can be addressed using numerical hydrodynamic models. Numerical hydrodynamic models for the simulation of open-channel hydraulics can be classified by their dimension and solve the shallow water equations in their one-, two- or three-dimensional form for simulating channel flow in just one (x-)direction (1D), horizontally resolved (x- and y-direction) but depth-averaged (2D) or fully resolved in x-, y- and, z-direction (Liu, 2014). Due to i.e. the increasing effort of work and computational time with increasing dimension, the applicability of 1D, 2D or 3D models depends on the scale and phenomena of interest (Liu, 2014). For simulating the general hydraulic behaviour on reach-scale, 2D models are useful tools (Liu, 2014). A detailed description of the different model types and examples of application can be found in Liu (2014) or Tonina and Jorde (2013) with focus on ecohydraulics. For instance, Ruiz-Villanueva et al. (2014) and Ruiz-Villanueva et al. (2016b) simulate large wood transport and remobilization using a two-dimensional hydrodynamic model. Several studies also consider stable large wood in the scope of one- and two-dimensional hydrodynamic simulations for example for investigating its influence on flood hydrographs (Thomas and Nisbet, 2012), on floodplain connectivity (Keys et al., 2018) or are considered in research applications with an ecological focus by investigating the effect of stable LW on habitat availability or suitability (i.e. He et al., 2009; Hafs et al., 2014). In addition, Lange et al. (2015) simulate the effect of roughness elements including stable LW in the scope of stream restoration analyses.

Modification:

"The resulting physical effects of stable in-channel LW (Smith et al. 2011) as well as the mobility, transport and deposition of large wood (i.e. Ruiz-Villanueva et al., 2014; Ruiz-Villanueva et al., 2016b) can be addressed using numerical hydrodynamic models. Numerical hydrodynamic models for the simulation of open-channel hydraulics can be classified by their dimension and solve the shallow water equations (SWE) in their one-, two- or three-dimensional form for simulating channel flow in just one (x-)direction (1D), horizontally resolved (x- and y-direction) but depth-averaged (2D) or fully resolved in x-, y- and, z-direction (Liu, 2014). Due to i.e. the increasing effort of work and computational time with increasing dimension, the applicability of 1D, 2D or 3D models depends on the scale and phenomena of interest (Liu, 2014). For simulating the general hydraulic behaviour on reach-scale, 2D models are useful tools (Liu, 2014). A detailed description of the different model types and examples of application can be found in Liu (2014) or Tonina and Jorde (2013) with focus on ecohydraulics. Several studies consider stable large wood in the scope of one- and two-dimensional hydrodynamic simulations for example for investigating its influence on flood hydrographs (Thomas and Nisbet, 2012), on floodplain connectivity (Keys et al., 2018) or are considered in research applications with an ecological focus by investigating the effect of stable LW on habitat availability or suitability (i.e. He et al., 2009; Hafs et al., 2014). In addition, Lange et al. (2015) simulate the effect of roughness elements including stable LW in the scope of stream restoration analyses."

R8: 5,8-5,20: This addition is good, and seems to better explain your objectives. However, it is currently difficult to read, and a few sentences don't really fit with the overall purpose of the paragraph (to explain why you did this study). For instance, the last two sentences of this paragraph just says "Grabowski et al. (2019) highlight wood alternations of channel roughness and hydraulics as a knowledge gap in identifying local wood-induced risks." That sentence could be better placed at the beginning of this paragraph (or close to it) to motivate this study, as opposed at the end.

A8: We agree and reformulated the paragraph in the following way:

Original:

"Against this background, the aim of the present study is to simulate the physical effects of stable in-channel LW elements on flood hydrographs in a creek reach in low mountain ranges using a two-dimensional hydrodynamic model and previously conducted field experiments, explicitly described in Wenzel et al. (2014). The field data offer the rare opportunity to validate simulated large wood related hydraulic effects on hydrographs of small flood events. By conducting different hydrodynamic simulations, we aim (1) for the quantification of the change of channel roughness coefficients in the entire channel or at LW positions, necessary to obtain most accurate model results of flood hydrographs with stable large wood elements in the channel. As discrete LW elements are required for most accurate model results (Smith et al. 2011), we aim (2) for comparing previous model results with simulations with discrete large wood elements created through manipulating the calculation mesh. However, the integration of discrete elements into the calculation mesh can be highly time- and work-intensive (Lai and Bandrowski, 2014), which becomes especially true for larger scale applications. Hence, a comparison of the simulation accuracy between incorporating large wood through a rather quick change of channel roughness coefficients and as time-demanding simplified mesh elements can be provide beneficial information for future studies simulating stable large wood related effects on stream hydraulics and ecology. This is underlined by Grabowski et al. (2019) who identified remaining uncertainties for the use of large wood in river restoration and natural flood risk management in practice. Knowledge gaps remain for instance regarding the alteration of channel roughness and hydraulic impacts such as backwater effects for the identification of local risks (Grabowski et al., 2019) which can be addressed with hydrodynamic models."

<u>Modification:</u>

"The large wood induced alteration of channel roughness coefficients and overall hydraulic impacts such as backwater effects are crucial for the identification of local risks. Therefore, remaining knowledge gaps in these fields lead to uncertainties regarding the use large wood in river restoration and natural flood risk management in practice (Grabowski et al., 2019) and may hamper the its application. Against this background, the aim of the present study is to simulate the physical effects of stable in-channel LW elements on flood hydrographs in a creek reach in low mountain ranges using a two-dimensional hydrodynamic model and previously conducted field experiments, explicitly described in Wenzel et al. (2014). The field data offer the rare opportunity to validate simulated large wood related hydraulic effects on hydrographs of small flood events. By conducting different hydrodynamic simulations, we aim (1) for the quantification of the change of channel roughness coefficients in the entire channel or at LW positions, necessary to obtain most accurate model results of flood hydrographs with stable large wood elements in the channel. As discrete LW elements are required for most accurate model results (Smith et al. 2011), we aim (2) for comparing previous model results with simulations with discrete large wood elements created through manipulating the calculation mesh. However, the integration of discrete elements into the calculation mesh can be highly time- and work-intensive (Lai and Bandrowski, 2014), which becomes especially true for larger scale applications. Hence, a comparison of the simulation accuracy between incorporating large wood through a rather quick change of channel roughness coefficients and as time-demanding simplified mesh elements can be provide beneficial information for future studies simulating stable large wood related effects on stream hydraulics and ecology."

R9: 5,25: Instead of the vague "integration", consider "roughness modeling" or something similar.

A9: We changed the phrase accordingly:

Original:

"Although limited to smaller streams and rivers were large wood jams and elements can be assumed as stable or situations in which large wood elements are fastened, the present study can contribute to the ability of predicting hydraulic impacts of stable in-channel large wood within hydrodynamic simulations and can also provide beneficial practical information for conducting simulation-based impact assessments of stream restoration projects considering stable large wood by comparing different methods of large wood integration."

Modification:

"Although limited to smaller streams and rivers were large wood jams and elements can be assumed as stable or situations in which large wood elements are fastened, the present study can contribute to the ability of predicting hydraulic impacts of stable in-channel large wood within hydrodynamic simulations and can also provide beneficial practical information for conducting simulation-based impact assessments of stream restoration projects considering stable large wood by comparing different methods of large wood roughness modelling."

R10: Figure 6: It would be nice to show quantitative metrics of goodness-of-fit on these plots, to help with visual interpretation. One of these is best, and it would be nice if readers could quickly get that from this figure. Something in the caption might also work, but I just notice a lot of white space on the figure, so I feel that you could include this in the plots themselves. I know this information is in Table 2, but summarizing it in this figure would make this presentation more impactful.

A10: We agree. However, we only added the NSE as a widely used metric to the plot in order to avoid extensive redundancies with table 2 and to prevent subplots from becoming unclear.

Original:

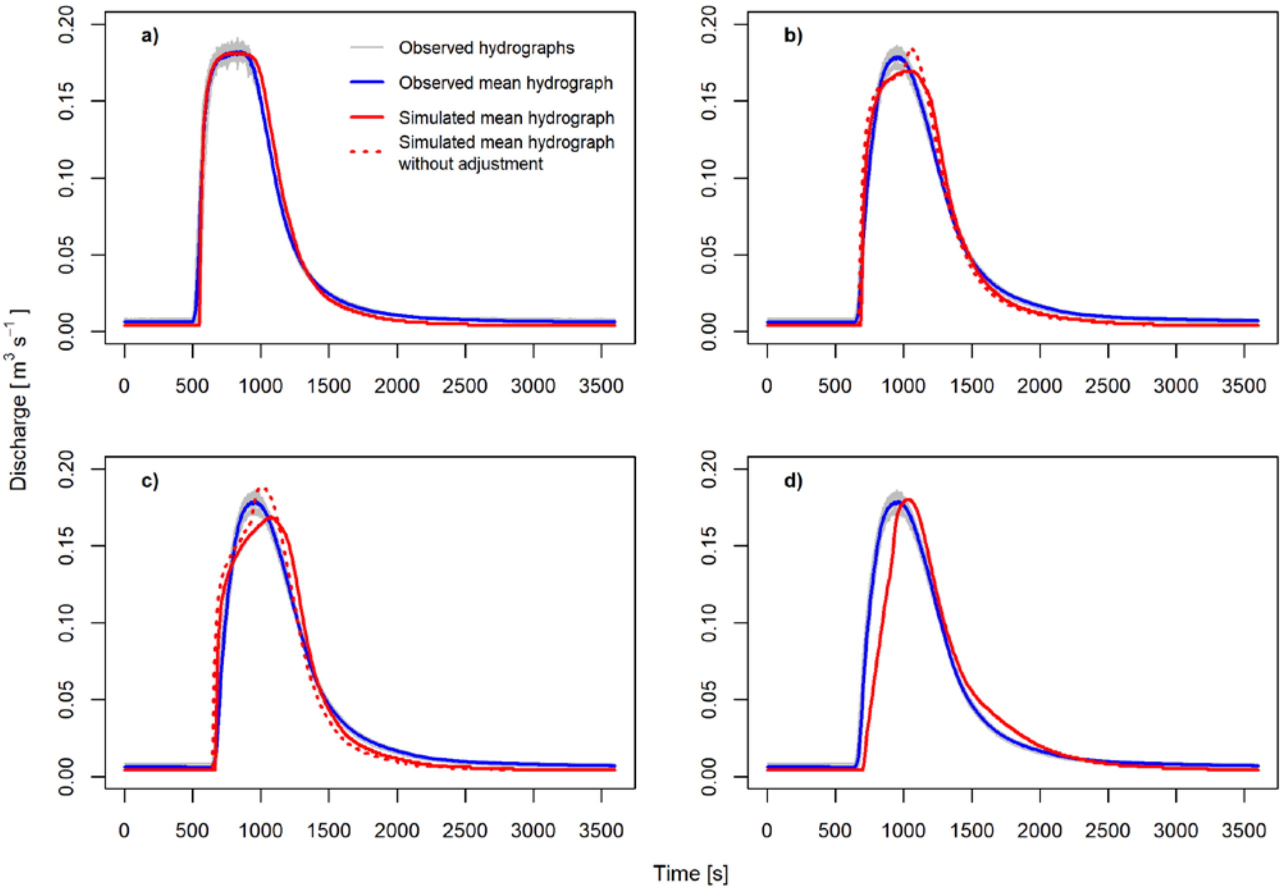

Figure 6: Best simulated mean flood hydrographs of all simulation variants with and without LW at Thomson-weir 2: a) results of the base variant BV without LW, b) variant V1 with stable LW as an increase of roughness in the entire channel, c) variant V2 with stable LW as an increase of roughness at element positions only and, d) variant V3 with LW as discrete topographic elements of the calculation mesh. For simulation variants V1 and V2 the best fit with and without subsequent adjustment of riparian Strickler coefficients is displayed.

Modification:

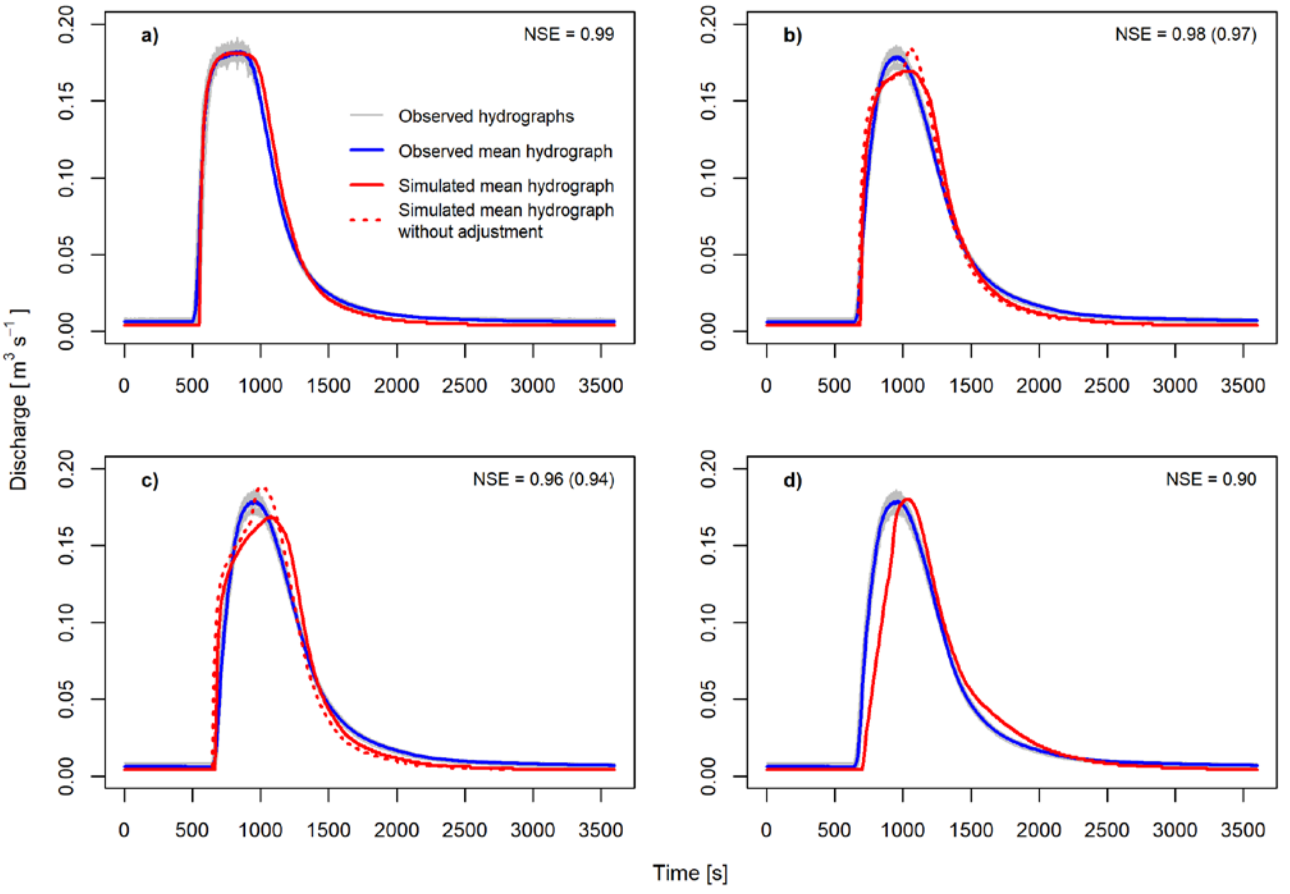

Figure 6: Best simulated mean flood hydrographs of all simulation variants with and without LW at Thomson-weir 2: a) results of the base variant BV without LW, b) variant V1 with stable LW as an increase of roughness in the entire channel, c) variant V2 with stable LW as an increase of roughness at element positions only and, d) variant V3 with LW as discrete topographic elements of the calculation mesh. For simulation variants V1 and V2 the best fit with and without subsequent adjustment of riparian Strickler coefficients is displayed. The Nash-Sutcliffe-Efficiency (NSE) is shown for each simulation variant. If displayed, values in brackets represent the NSE of simulations without adjustment of riparian roughness coefficients.

R11: 10,14: To help people who may be unfamiliar with these goodness-of-fit metrics, please briefly define then in terms of what values indicate high goodness-of-fit and what values indicate the opposite, either here (just before you present the values, or as you present them) or in the methods.

A11: We added brief information about this in the methods chapter:

Original:

"Simulation results are obtained at the location of Thomson-weir 2 in the calculation mesh represented by the lowermost cross-sectional nodestring in the channel of the study reach. Model performance is assessed by visual comparison of mean observed and simulated flood hydrographs without and with LW at Thomson-weir 2 as well as by calculating the statistical goodness-of-fit parameters Nash-Sutcliff-Efficiency (NSE), percent bias (PBIAS) and RSR (ratio of the root mean square error to the standard deviation of observed values) using the hydroGOF package by Zambrano-Bigiarini (2017) in R (R Core Team, 2017)."

Modification:

"Simulation results are obtained at the location of Thomson-weir 2 in the calculation mesh represented by the lowermost cross-sectional nodestring in the channel of the study reach. Model performance is assessed by visual comparison of mean observed and simulated flood hydrographs without and with LW at Thomson-weir 2 as well as by calculating the statistical goodness-of-fit parameters Nash-Sutcliffe-Efficiency (NSE), percent bias (PBIAS) and RSR (ratio of the root mean square error to the standard deviation of observed values) using the hydroGOF package by Zambrano-Bigiarini (2017) in R (R Core Team, 2017). For NSE a value of 1 indicates the highest model accuracy while the optimum value for RSR and PBIAS is 0 (Moriasi et al., 2007)."

R12: 11,2: I'm not sure I understand the justification for altering the previously-calibrated riparian-zone roughness coefficients. Wouldn't it be more rigorous to not alter these after calibration? Or, could you provide a process-based reason for altering them? Reading on, I see that you give this justification in the discussion. Consider alluding to that here to prevent readers from thinking the same thing I did.

A12: We added a note leading to the concerning section of the discussion.

Original:

"If the Strickler coefficients in the channel foreland (riparian area) were decreased from 3.5 to 2.4 $m^{1/3}$ s^{-1} in addition to the channel roughness, the break in the crest of the hydrograph disappears."

Modification:

"If the Strickler coefficients in the channel foreland (riparian area) were decreased from 3.5 to 2.4 $m^{1/3} s^{-1}$ in addition to the channel roughness, the break in the crest of the hydrograph disappears (see chapter 5.2)."

R13: 11,9: The titles/names you use for each variant should be very consistent throughout the manuscript. That is, if you want to use "spots", make that so everywhere you mention this variant. That consistency will really help readers keep track of your arguments. A summary table, like the one I suggest below, would also be helpful.

A13: We agree and replaced the word "spots" with LWD "sections" throughout the manuscript.

R14: 13,15-23: I don't understand why this riparian roughness coefficient adjustment is necessary with the variants with wood but not the variant without wood. Is this due to an increase in wetted area to cells that include more vegetation? This might just be my misunderstanding, but consider clearing this up a bit to justify why you adjusted riparian roughness in the wood-included models, but not the baseline model without wood.

A14: Yes, this is correct. The calibrated roughness coefficients from the simulation without wood are the baseline roughness for the simulations with wood. Thus, the riparian-zone roughness coefficients are calibrated to the flood extent (and hence, influence of riparian roughness elements such as vegetation) of the conditions without wood. However, in the field experiments and in the simulations with large wood the water level is higher, resulting in generally more water flowing through a larger riparian area. As pointed out in R14, a larger wetted area covered with vegetation and hence, different flow conditions between the variants with and without wood in the riparian zone could have led to the necessity of adjusting riparian Strickler coefficients.

We added more detailed information to the paragraph.

Original:

"For both simulation variants, subsequent adjustment of riparian roughness coefficients is necessary to improve the goodness-of-fit. Only increasing riparian roughness by decreasing Strickler coefficients results in a smooth crest as it can be originally observed in the field experiments. In the model, water flows too fast through adjacent riparian areas without subsequent adjustment of roughness. Emerged rigid elements such as riparian vegetation can lead to an increase of Manning's n and hence, a decrease of Strickler coefficients due to increasing friction exerted on flow (Shields et al., 2017). Therefore, generally low flow depths, a largely continuous cover of dense grassy vegetation as well as an uneven microtopography due to i.e. elevated grass root wads observed in adjacent riparian areas during field experiments could have led to the necessity of increasing local roughness in this study; especially due to the lack of such features in the model's calculation mesh."

Modification:

"For both simulation variants, subsequent adjustment of riparian roughness coefficients is necessary to improve the goodness-of-fit. Only increasing riparian roughness by decreasing Strickler coefficients results in a smooth crest as it can be originally observed in the field experiments. As the calibrated roughness coefficients from the simulation without large wood are the baseline roughness for the simulations with wood, the riparian-zone roughness coefficients are calibrated to the flood extent of the conditions without large wood. Due to generally higher water levels in the field experiments and in the simulations with large wood, more water flows through a larger riparian area covered with vegetation. In the model, water flows too fast through adjacent riparian areas without subsequent adjustment of roughness. Emerged rigid elements such as riparian vegetation can lead to an increase of Manning's n and hence, a decrease of Strickler coefficients due to increasing friction exerted on flow (Shields et al., 2017). Therefore, a larger wetted area with generally low flow depths, a largely continuous cover of dense grassy vegetation as well as an uneven microtopography due to i.e. elevated grass root wads observed in adjacent riparian areas during field experiments could have led to the necessity of increasing local roughness in this study; especially due to the lack of such features in the model's calculation mesh."

R15: 15,24: Is this redundant with your statement on line 15,11? Here is an example where the organization of paragraphs and ideas is not clear. Why contrast V1 and V2, then switch to discussing riparian roughness, then switch back to contrasting V1 and V2? A more logical flow (i.e., making sure that each new idea builds on the last, and relates to the paper's main message) could help shorten and clear up this presentation.

A15: Yes, this statement is rather redundant. We removed it and rearranged section 5.2:

Original:

"In simulation variants V1 and V2, roughness coefficients are used to represent large wood in the study reach. Both variants show a correct simulation of the time of rise of the flood hydrograph. Differences occur along the rising limb as well as the hydrograph's peak. Here, variant V1 produces a better fitting hydrograph. Compared to the simulation result of the mean observed hydrograph of the field experiments without in-channel LW, variants V1 and V2 produce less closely fitting simulated hydrographs, which is also indicated by the slightly lower values of statistical goodness-of-fit parameters. Nevertheless, these values still indicate a very high model accuracy.

For both simulation variants, subsequent adjustment of riparian roughness coefficients is necessary to improve the goodness-of-fit. Only increasing riparian roughness by decreasing Strickler coefficients results in a smooth crest as it can be originally observed in the field experiments. In the model, water flows too fast through adjacent riparian areas without subsequent adjustment of roughness. Emerged rigid elements such as riparian vegetation can lead to an increase of Manning's n and hence, a decrease of Strickler coefficients due to increasing friction exerted on flow (Shields et al., 2017). Therefore, generally low flow depths, a largely continuous cover of dense grassy vegetation as well as an uneven microtopography due to i.e. elevated grass root wads observed in adjacent riparian areas during field experiments could have led to the necessity of increasing local roughness in this study; especially due to the lack of such features in the model's calculation mesh.

Simulation variant V1 produces a better representation of the average observed hydrograph of field experiments with in-channel LW by increasing roughness in the entire channel of the study reach instead of increasing roughness at LW affected channel spots only (V2). In-channel LW elements decelerate flow beyond their own dimensions by generating upstream backwater areas and downstream wake fields of substantial length (i.e. Young, 1991; Bennett et al., 2015). Such features were also observed during field experiments (Wenzel et al., 2014). That means that LW affects flow upstream and downstream in an area which is larger than the wood piece itself, which can be one reason for the slightly better simulation results in V1 compared to V2.

Decreasing Strickler coefficients by 30 % in variant V1 compared to 55 % in LW affected spots only (V2) are in the range of previous studies. For instance, Gregory et al. (1985) detected an LW related increase in Manning's n by 48.5 % and Dudley et al. (1998) show an average increase of 36 %. Furthermore, MacFarlane and Wohl (2003) compare streams with and without LW and find Darcy-Weisbach's f on average 58 % higher in streams containing in-channel LW. However, it should be noted that boundary conditions, such as discharge, river size, LW volume, etc. as well as the methodological approaches greatly vary between studies. For example, MacFarlane and Wohl (2003) investigate high-gradient mountain streams while Shields and Gippel (1995) focus on lowland rivers. This illustrates the need of a common framework for better comparability of studies on large wood previously proposed by Wohl et al. (2010). This becomes especially true regarding the influence of stable in-channel LW on roughness coefficients."

Modification:

"In simulation variants V1 and V2, roughness coefficients are used to represent large wood in the study reach. Both variants show a correct simulation of the time of rise of the flood hydrograph. Differences occur along the rising limb as well as the hydrograph's peak. Here, variant V1 produces a better fitting hydrograph. Compared to the simulation result of the mean observed hydrograph of the field experiments without in-channel LW, variants V1 and V2 produce less closely fitting simulated hydrographs, which is also indicated by the slightly lower values of statistical goodness-of-fit parameters. Nevertheless, these values still indicate a very high model accuracy, suggesting that a less time-consuming adjustment of roughness coefficients allows an accurate simulation of stable large wood induced hydraulic effects.

In-channel LW elements decelerate flow beyond their own dimensions by generating upstream backwater areas and downstream wake fields of substantial length (i.e. Young, 1991; Bennett et al., 2015). Such features were also observed during field experiments (Wenzel et al., 2014). This means that LW affects flow upstream and downstream in an area which is larger than the wood piece itself, which can be one reason for the slightly better simulation results in V1 compared to V2.

For both simulation variants, subsequent adjustment of riparian roughness coefficients is necessary to improve the goodness-of-fit. Only increasing riparian roughness by decreasing Strickler coefficients results in a smooth crest as it can be originally observed in the field experiments. As the calibrated roughness coefficients from the simulation without large wood are the baseline roughness for the simulations with wood, the riparian-zone roughness coefficients are calibrated to the flood extent of the conditions without large wood. Due to generally higher water levels in the field experiments and in the simulations with large wood, more water flows through a larger riparian area covered with vegetation. In the model, water flows too fast through adjacent riparian areas without subsequent adjustment of roughness. Emerged rigid elements such as riparian vegetation can lead to an increase of Manning's n and hence, a decrease of Strickler coefficients due to increasing friction exerted on flow (Shields et al., 2017). Therefore, a larger wetted area with generally low flow depths, a largely continuous cover of dense grassy vegetation as well as an uneven microtopography due to i.e. elevated grass root wads observed in adjacent riparian areas during field experiments could have led to the necessity of increasing local roughness in this study; especially due to the lack of such features in the model's calculation mesh.

Decreasing Strickler coefficients by 30 % in variant V1 and 55 % in LW affected sections only (V2) are in the range of previous studies. For instance, Gregory et al. (1985) detected an LW related increase in Manning's n by 48.5 % and Dudley et al. (1998) show an average increase of 36 %. Furthermore, MacFarlane and Wohl (2003) compare streams with and without LW and find Darcy-Weisbach's f on average 58 % higher in streams containing in-channel LW. However, it should be noted that boundary conditions, such as discharge, river size, LW volume, etc. as well as the methodological approaches greatly vary between studies. For example, MacFarlane and Wohl (2003) investigate high-gradient mountain streams while Shields and Gippel (1995) focus on lowland rivers. This illustrates the need of a common framework for better comparability of studies on large wood previously proposed by Wohl et al. (2010). This becomes especially true regarding the influence of stable in-channel LW on roughness coefficients."

R16-18: 14,7-10: Is this entire paragraph necessary? This sort of thing is well-covered in the introduction, and doesn't seem to need repeating here.

14,11-19: In this paragraph, you lead with some ideas (that discrete elements are simplified in 2D models), then eventually get to a point (that this could cause the behavior seen in V3). Consider leading with the point, then explaining it. That can really help readers keep track of your arguments and get more from your presentation.

Section 5.3: All of these paragraphs begin with "nevertheless", which makes me think that that word might not be necessary here. This section in general is difficult to parse and would be a good candidate for revision. Consider exactly what your main message is here and try to cut out whatever doesn't relate to it. For instance, is the discussion on lines 14,24-33?
Reading it, I don't see how you clearly connect those papers to your work

A16-18: We agree that section 5.3 requires revision to make it easier to follow and that removal of unnecessary information is needed. We modified it in the following way:

Original:

"Although roughness coefficients are often used to account for the hydraulic influence of stable in-channel large wood, the implementation of LW as discrete elements in the calculation mesh may further improve simulation results (Smith et al., 2011). However, field data are an essential reference to compare the implementation of wood by altering in-channel roughness coefficients with the implementation of discrete elements in the calculation mesh.

Nevertheless, one problem of discrete LW elements in hydrodynamic models is that wood pieces have a complex shape, which strongly varies from piece to piece (and over time) concerning their geometry with twigs, branches, needles and floating debris caught up in the twigs. This complex shape as well as a permeability of LW elements and jams cannot be implemented in depth-averaged hydrodynamic models in detail and has to be simplified. The simplified implementation can be the reason, why variant V3 produces a temporal shift between mean simulated and observed flood hydrograph causing a slightly delayed rise and falling limb of the flood hydrograph and hence, a delayed passage of the flood wave at Thomson-weir 2. This indicates too strong flow alterations in the model resulting in higher amounts of water retained in the study reach. In this study, LW elements are implemented as discrete parts of the calculation not allowing water flowing through. Hence, they are designed with too extensive simplifications to account for the complexity of real LW elements.

Nevertheless, the variant V3 generates the best simulated hydrograph in regard to its overall shape compared to the mean observed hydrograph of field experiments with LW, indicating that discrete elements are an appropriate starting point for an advancement of model implementation and further studies on the hydrodynamics of in-channel LW. This is in accordance with previous studies using three-dimensional hydrodynamic models (computational fluid dynamics, CFD): For example, on the one hand, general flow patterns caused by large wood can be simulated using impermeable discrete elements, when an accurate simulation of flow near LW objects is neglectable (Xu and Liu, 2017). On the contrary, simplifications of LW objects made during the integration process into the calculation mesh may cause deviations and inaccuracies (Allen and Smith, 2012). Impermeability, dimensions and positions of elements result in too strong flow alterations and a temporal shift of the modelled hydrograph, while its general shape indicates the best simulation of flow processes in the study reach. Intense flow alterations may also account for the fact that a subsequent adjustment of riparian roughness coefficients is not required in variant V3, as too strong energy losses and flow declarations caused by discrete LW objects account for roughness originally caused by other roughness elements not represented in the calculation mesh such as riparian vegetation and microtopography.

Nevertheless, variant V3 still shows a very high goodness-of-fit. A similarly high Nash-Sutcliff-Efficiency was obtained in the study of Keys et al. (2018), who use discrete weirs to represent large wood objects for simulating their effects on floodplain connectivity. However, although variant V3 reveals the best simulation result, the temporal shift results in a lower goodness-of-fit and hence, model quality compared to simulation variants V1 and V2. Therefore, solely relying on statistical goodness-of-fit indicators on such high spatio-temporal scale may not be sufficient and visual interpretation should not be excluded when assessing model results."

<u>Modification:</u>

"Simulation variant V3 generates the best simulated hydrograph in regard to its overall shape compared to the mean observed hydrograph of field experiments with LW, indicating the best simulation of flow processes in the study reach. Therefore, the time-consuming incorporation of discrete elements is an appropriate starting point for an advancement of model implementation and further studies on the hydrodynamics of in-channel LW. However, variant V3 produces a temporal shift between mean simulated and observed flood hydrograph causing a slightly delayed rise and falling limb of the flood hydrograph and hence, a delayed passage of the flood wave at Thomson-weir 2. Natural discrete LW elements have a complex shape, which strongly varies from piece to piece (and over time) concerning their geometry with twigs, branches, needles and floating debris caught up in the twigs. This complex shape as well as a permeability of LW elements and jams cannot be implemented in depth-averaged hydrodynamic models in detail and has to be simplified. The simplified implementation in terms of element impermeability, dimensions and positions of wood pieces may result in too strong flow alterations, which in turn lead to higher amounts of water being retained in the study reach and thus, the temporal shift of the modelled hydrograph. Intense flow alterations may also account for the fact that a subsequent adjustment of riparian roughness coefficients is not required in variant V3, as too strong energy losses and flow declarations caused by discrete LW objects account for roughness originally caused by other roughness elements not represented in the calculation mesh such as riparian vegetation and microtopography.

Nevertheless, variant V3 still shows a very high goodness-of-fit. A similarly high Nash-Sutcliffe-Efficiency was obtained in the study of Keys et al. (2018), who use discrete weirs to represent large wood objects for simulating their effects on floodplain connectivity. However, although variant V3 reveals the best simulation result, the temporal shift results in a lower goodness-of-fit and hence, model quality compared to simulation variants V1 and V2. Therefore, solely relying on statistical goodness-of-fit indicators on such high spatio-temporal scale may not be sufficient and visual interpretation should not be excluded when assessing model results."

R19-22: 15, 8-16: By this point, it's clear that your results only apply to stable large wood. I don't think it's necessary to go through this explanation of how to evaluate wood stability. For starters, it's doubtful that the relationships given in Kramer and Wohl (2017) could even enable robust stability analysis, and hazard-focused wood stability analysis is better covered by other publications. Second, this paper isn't about wood mobility. You could clearly state in a single sentence that your results apply to small, single-thread, steep rivers with stable wood elements, and get the necessary idea across, without going into this level of detail that might derail a reader's attention.

15,26-31: This sentence is very long, and I'm unsure what you're trying to say. Consider cutting this down a bit and making the message clearer. For instance, as what "is the case"?

15,32: Is "SWE" defined anywhere else in the manuscript? I can't find it.

Section 5.4: In my opinion, these sections rarely are read, and often present information that is either obvious to the people who will actually be doing future work, or unnecessary for the people who won't be doing that work. Consider your audience here. Is it really necessary to explain all the ways this study could be improved? I could see a short paragraph stating what your results apply to (see comment on lines 26-31 of this page) being useful, but this reads as being unnecessary. Consider either shortening this section down to a few sentences, or integrating this information throughout the paper (where readers are more likely to actually read it). I know this section is in response to another reviewer's comment, but I suspect that this doesn't fully satisfy their comment either. It would be much more effective for readers to get this information throughout the paper, instead of the current presentation, which somewhat undermines the results.

A19-22: We agree to point 19-22 and completely removed section 5.4. We added important information from this section to the end of discussion sections 5.2 and 5.3. SWE was not defined yet, we defined it in the introduction chapter.

<u>Added to section 5.2:</u>

"The results presented may only be valid for small, single-thread and steep rivers with a defined amount of stable large wood elements indicating the narrow boundary conditions of this study. When modelling the potential impact of stable large wood as a change of in-channel roughness coefficients with different boundary conditions and without data of large wood-influenced discharge for calibration, the application of ensemble-simulations with literature-based values of large wood induced increase of roughness may be used for a first assessment. Here, estimation methods for large wood induced roughness increase in small, high-gradient streams and rivers as previously developed by Shields and Gippel (1995) for large lowland rivers would be useful. Additionally, reviews of recent advances in research on the hydraulics of LW in fluvial systems would be highly beneficial, similar to recent reviews and meta-analyses addressing ecological implications (i.e. Roni et al., 2015), large wood dynamics (i.e. Ruiz-Villanueva et al., 2016a; Kramer and Wohl, 2017), related risks for anthropogenic infrastructure (i.e. De Cicco et al., 2018) and large wood in fluvial systems in general (Wohl, 2017)."

<u>Added to section 5.3:</u>

"Although the roughness coefficient approach presented in this study is feasible with all models which are based on the SWE, only models enabling the simulation of two- and three-dimensional flow conditions can be used for the incorporation of simplified discrete large wood elements. In this study, only a single design of discrete large wood elements was incorporated as topographic features into the calculation mesh. Other designs may be also suitable such as discrete weirs (Keys et al., 2018) or arrays of pillars allowing water to flow through. Further research including a comparison of different designs of discrete large wood elements in 2D-simulations under equal boundary conditions could be beneficial. Furthermore, in the present study calibration is solely conducted using the hydrograph at Thomson-weir 2. As point measurements of flow depth, velocity and inundation extent in the field could improve model accuracy assessments, multi-criteria calibration approaches may be considered in future studies simulating the hydraulic effects of stable in-channel large wood."

R23: Section 6: Consider giving these conclusions in the discussion (throughout it) as well. Readers may get through the discussion wondering what the point of the analyses are, and then will need to get through the limitations sections before making it to the main point of the manuscript. I also suggest you clear up these points using something like a summary table. For instance, it could look something like the following:

Roughness method	Pros	Cons
V1 (reach-scale roughness adjustment)		
V2 (roughness increase near LW)		
V3 (discrete LW roughness elements)		

Such a table could give readers the essential information and recommendations from this modeling, put in context by a succinct discussion comparing the three modeling techniques you tested.

A23: We agree and added a concluding sentence to sections 5.2 and 5.3 to connect the results to the aims of our study. In addition, we slightly modified the conclusion and added a table summarizing the results and conclusions of our study in a relative way.

<u>Added to section 5.2:</u>

"Nevertheless, these values still indicate a very high model accuracy, suggesting that a less time-consuming adjustment of roughness coefficients allows an accurate simulation of stable large wood induced hydraulic effects."

<u>Added to section 5.3:</u>

"Simulation variant V3 generates the best simulated hydrograph in regard to its overall shape compared to the mean observed hydrograph of field experiments with LW indicating the best simulation of flow processes in the study reach. Therefore, the time-consuming incorporation of discrete elements is an appropriate starting point for an advancement of model implementation and further studies on the hydrodynamics of in-channel LW."

Original conclusion:

"The hydrodynamic simulations conducted in the present study show that average flood hydrographs of previously conducted field experiments without in-channel LW can be accurately simulated in the small and high-gradient study reach using HYDRO_AS-2D. Nevertheless, minor discrepancies need to be considered. The effect of stable in-channel LW was satisfactorily simulated using roughness coefficients. However, differences in model quality can be detected between increasing in-channel roughness in the entire reach or in LW affected spots only, where the latter results in a lower statistical goodness-of-fit. Visually, most accurate simulations of LW related impacts on flood hydrographs regarding its overall shape can be obtained using discrete large wood elements as proposed in previous studies (Smith et al., 2011) but comes with a temporal shift between observation and simulation due to the impermeability of the LW elements as well as a higher demand of effort and time for their incorporation into the model. Therefore, using channel roughness coefficients for simulating the impact of stable large wood elements on discharge time series suggests to be similarly accurate as the implementation of discrete elements on reach or larger (i.e. catchment) scale, where minor differences are smaller than the overall model uncertainty. Although constrained to limitations and uncertainties presented in chapter 5, the results of this study indicate that the impact of stable in-channel large wood may be simulated with a reduced amount of time and work required for model set-up and incorporation of discrete large wood elements through the use of roughness coefficients. Thus, model-based impact assessments of, for instance, stream restoration measures considering stable large wood, may become more feasible; especially on larger scale or in less critical channel-sections, where a fully resolved flow assessment with three-dimensional models is not required or practical. However, the present study is restricted to narrow boundary conditions, in turn illustrating the need of further research comparing methods of stable large wood incorporation in different models with varying model-dimensions and boundary conditions regarding channel morphology, large wood characteristics and water flow. Nevertheless, by comparing methods for simulating the impact of stable large wood on the reach scale, the present study can provide helpful information for practical applications in modelling stable large wood related effects in small, first order streams and rivers."

Modified conclusion:

"The hydrodynamic simulations conducted in the present study show that average flood hydrographs of previously conducted field experiments without in-channel LW can be accurately simulated in the small and high-gradient study reach using HYDRO_AS-2D. Nevertheless, minor discrepancies need to be considered. The effect of stable in-channel LW was satisfactorily simulated using roughness coefficients. However, differences in model quality can be detected between increasing in-channel roughness in the entire reach or in LW affected channel sections only, where the latter results in a lower statistical goodness-of-fit. Visually, most accurate simulations of LW related impacts on flood hydrographs regarding its overall shape can be obtained using discrete large wood elements as proposed in previous studies (Smith et al., 2011) but comes with a temporal shift between observation and simulation due to the impermeability of the LW elements as well as a higher demand of effort and time for their incorporation into the model (Table 3). Therefore, using channel roughness coefficients for simulating the impact of stable large wood elements on discharge time series suggests to be similarly accurate as the implementation of discrete elements on reach or larger (i.e. catchment) scale, where minor differences are smaller than the overall model uncertainty. Although constrained to the boundary conditions of this study, the simulation results indicate that the impact of stable in-channel large wood may be simulated with a reduced amount of time and work required for model set-up and incorporation of discrete large wood elements through the use of roughness coefficients. Thus, model-based impact assessments of, for instance, stream restoration measures considering stable large wood, may become more feasible; especially on larger scale or in less critical channel-sections, where a fully resolved flow assessment with three-dimensional models is not required or practical. However, the present study is restricted to narrow boundary conditions, in turn illustrating the need for further research comparing methods of stable large wood incorporation in different models with varying model-dimensions and boundary conditions regarding channel morphology, large wood characteristics and water flow. Nevertheless, by comparing methods for simulating the impact of stable large wood on the reach scale, the present study can provide helpful information for practical applications in modelling stable large wood related effects in small, first order streams and rivers."

Added table:

Table 3: Attributes of approaches for large wood implementation applied in this study relative to the base variant without large wood. Signs indicate an attribute being higher (+), lower (-) or equal (o) to the simulation without stable large wood.

Attribute	Variant V1 – reach-wise increase of roughness	Variant V2 – section-wise increase of roughness	Variant V3 – large wood as discrete elements
Work and time consumption	+	++	++++
Computational time	o	o	+
Statistical goodness-of-fit	-	--	---
Visual goodness-of-fit (hydrograph shape)	--	--	-

Complete reworked manuscript with all modifications shown (red figures were modified):