Answer to RC3: Comment on esurf-2021-91 from Saraswati Thapa

July 3, 2022

Dear reviewer,
Thank you very much for this detailed and constructive review which will be very useful to clarify and improve our article. Please find below the detailed answers. The reviewer's comments are shown in bold and some modifications of the manuscript are emphasized in blue.

Review of "Numerical modelling of the evolution of a river reach with a complex morphology to help define future sustainable restoration decisions", submitted to Earth Surface Dynamics, January 2022.

Dear editor and dear authors,

This review has been done jointly by Saraswati Thapa and Mikael Attal. We have read this manuscript with great interest: the research topic is very valuable in its content and we like that the paper highlights the importance of the numerical modelling approach for the evolution of a river reach in response to extreme flood events. We need more studies such as this one, that do combine high resolution pre and post surveys with numerical modelling, to test and calibrate models, and to assess their ability to replicate a range of features of importance to scientists and policy-makers, e.g., volumes eroded and deposited, changes in elevation and morphology, predicted response to anthropogenic changes (land use or risk management).

We enjoyed reading this manuscript that presents a very nice set of experiments using the TELEMAC-MASCARET model to reproduce the dramatic changes that occurred in a reach of the Gave the Pau. The results are enlightening, providing answers to a series of scientific questions and directions for future work. However, there are issues that need to be addressed before publication.

One of the main issues is the weak motivation for using this model in this particular example. We feel this could be better motivated, in particular when it appears, as we go through the results, that this model is not very good at reproducing braiding or suspended sediment transport (and this is a braided reach with 90% sediment transport in suspension!) There are many landscape evolution models considering many sediment transport equations and multiple grain sizes available. The model in this study used two bed load transport equations and neglected suspended load. The study area has very heterogeneous grain size, however, the model used single grain size D50 for the MPM formula and the D84 for the Recking formula rather than multiple grain size distribution (see for example Ramirez, J. A. et al. (2020) 'Modeling the geomorphic response to early river engineering works using CAESAR-Lisflood', Anthropocene, 32. doi:10.1016/j.ancene.2020.100266).

We made recommendations in the annotated manuscript, and one of the suggestions is that you could highlight the strengths and weaknesses of the model from the onset, highlight that the strengths make this model a good potential candidate to model the changes in the study area (it is one of a few models available that are

able to model morphodynamics (erosion and deposition) during large flood events), and that here you use this well constrained example to assess the model's ability to reproduce volumes and cross-sections, and assess its suitability as a tool to inform policy makers" (or something along these lines). Having a clear motivation for the use of the model and clear aims will strengthen the argument, as the reader will know what to expect as they progress through the paper. You can also build on these aims to justify the strategy for modelling, that is, which parameters you are planning to test (or not) and why. The information is there in the text, but we feel it would help if that were presented clearly at the onset. It is also important to build the argument on literature, and we have made suggestions throughout the text.

In general, the paper could do with more details in many sections: description of the model and parameters, description of how data were collected, description of results. There are also places where the outcomes of the model could be evaluated in a more quantitative way. This is particularly crucial for the last section where the impact of restoration scenarios is assessed through a couple of cross-sections, when the previous section demonstrated that the model was not very good at modelling cross-sections and better at modelling volumes.

Thank you very much for these helpful suggestions that we have all taken into account and will for sure improve the quality of our article.

A better description of the study site, including length and slopes, will be added to the text. We will also add a description of the data collection methods. A plot of the longitudinal profiles extracted from the LIDAR DEM of 2016 and 2019 will be added in the description part so that the reader better understands the characteristics of the study area. The figure that we intend to add to the last version of the article is presented below (Fig. 1).

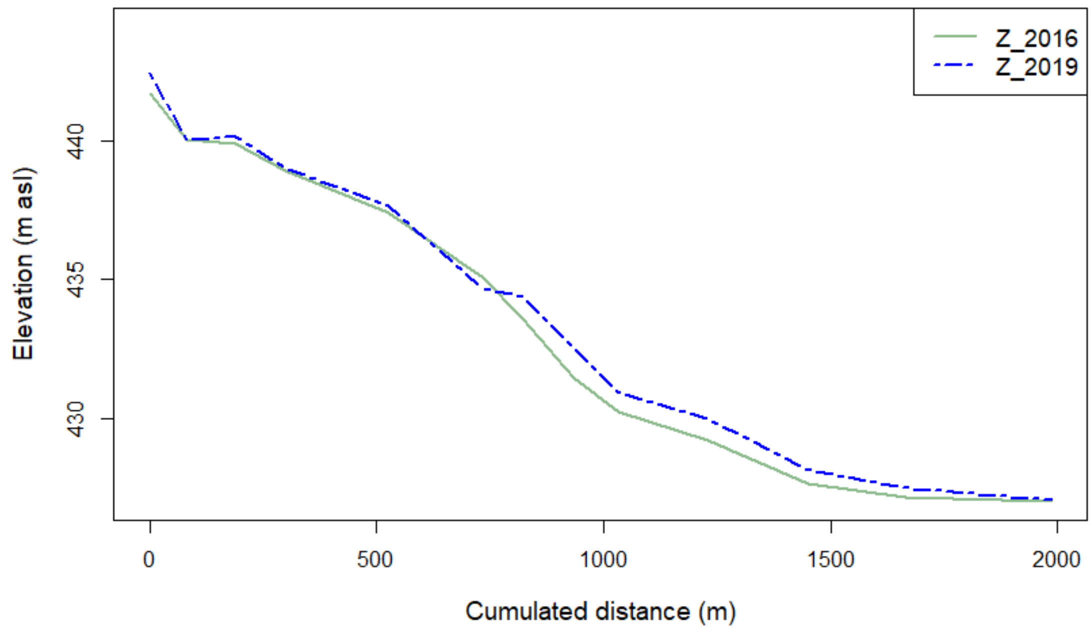

Figure 1: Longitudinal profile evolution following the flood of 2018.

Regarding the assessment of the restoration scenarios, we intended to show the riverbed elevation, which can increase flood risks, and not the exact braiding and morphological changes that are stochastic processes. We will, however add a volumetric analysis to be consistent with our discussion (section 5.4).

Finally, the writing can be improved. We have made suggestions in the attached annotated manuscript.
Thank you very much for these helpful suggestions that we have all taken into account. You will find below the details of the answers, except for the language corrections which were made directly in the manuscript without mention in this document.

This is an original study. Very few studies have attempted to apply numerical models to natural / real examples to model morphological changes on these space and time scales. We believe there is potential for a strong publication. We hope you find these suggestions useful and wish you all the best with your revisions.

Comments in the annotated manuscript:

L36: There have been a few publications with the CAESAR-Lisflood model as well in the past two years, which may be relevant? See for example: Ramirez, J. A. et al. (2020) 'Modeling the geomorphic response to early river engineering works using CAESAR-Lisflood', Anthropocene, 32. doi:10.1016/j.ancene.2020.100266.
Thank you for this relevant reference that has been studied and added to the last version of the article.

L63-64: How is this model considered to be suitable for this study as it has not been explored much? That is a very important point, in particular since one of the outcomes of the study is that the model may not be suitable due to not modelling suspended sediment. You may want to rephrase by describing the model, its strengths and weaknesses, and explaining that this study is a test of the model in a setting where it would be expected to perform well (i.e., it is developed to model sediment transport at the event timescale and is suited to areas with large sediment fluxes).
Clarifications will be added to the text.
Indeed, previous studies have shown that TELEMAC/Sisyphe was able to reproduce processes of erosion/deposition accurately in similar configurations (Reisenbüchler et al., 2020, 2019; Cordier et al., 2019). Sisyphe enables the use of different transport formulas (Meyer-Peter and Müller, 1948; van Rijn, 1984) and also take into account various factors influencing sediment transport, such as the effect of the bed slope (Koch and Flokstra, 1981; Soulsby, 1997) on the magnitude of the bedload transport (Riesterer et al., 2016). It also offers the possibility of programming other formulas, both for the parameterisation of friction and for solid transport, a possibility which has been used here to introduce formulations more adapted to the context of mountain rivers.

L182-188: What is Φ here? Is this K'/K or K/K' please double check. Also, it is not clear how D* should be grain size for grain class i. Can we correlate it with D50 or D90? Could you please add the referencing for this formula as well?
The definitions of Φ and $\tau*$ have been added in the manuscript.
The formula for the estimation of the grain roughness coefficient K' was also established by Meyer-Peter and Müller (1948) and involves the D_{90}, it has been clarified in the text.
Φ is the dimensionless solid transport, calculated as $\Phi = \frac{q_{sv}}{\sqrt{g(\rho_s/\rho-1)D^3}}$ with q_{sv} $[m^3/s/m]$ the unit solid volume transport: $q_{sv} = Q_{sv}/W$ with Q_{sv} $[m^3/s]$ the solid volume flow rate, W $[m]$ the river width, ρ_s $[kg/m^3]$ the density of the sediments, ρ $[kg/m^3]$ the density of water, g the

gravity acceleration and D $[m]$ the grain diameter. K/K' is the ratio between the flow Strickler coefficient K and the grain roughness coefficient K'. This term makes it possible to correct the total constraint in order to take into account only the grain shear stress. K is given by $K = \frac{U}{S^{1/2}R^{2/3}}$ and according to Meyer-Peter and Müller (1948) the grain roughness coefficient can be estimated as a function of the grain size distribution $K' = \frac{1}{n} = \frac{26}{D_{90}^{1/6}}$, with D_{90} the diameter at about 90% by weight of the grains [m]. $\tau*$ $[-]$ is the Shield number, calculated as $\tau* = \frac{\tau}{g(\rho_s - \rho)D}$ with τ $[N/m^2]$ the shear stress.

L190: What is that threshold value?

The threshold value characterize the incipent motion of sediment. Clarifications will be added to the text.

The Meyer-Peter-Müller equation is an excess shear relationship and its original formulation considers a critical Shields parameter equal to 0.047 as a threshold for characterizing the incipient motion of bed grains.

Eq. 6: What is q_b^*?

Clarifications will be added to the text.

q_b^* $[-]$ is a dimensionless bedload discharge.

Eq. 6: What is τ_{84}^*?

Clarifications will be added to the text.

τ_{84}^* $[-]$ is the Shield number, calculated from the diameter D_{84}: $\tau* = \frac{\tau}{g(\rho_s - \rho)D_{84}}$ with τ $[N/m^2]$ the shear stress.

L209: 'qsform.f': Make available?

Of course, fortran routines can be made available on request.

L231: Give more details. No spatial variability in grain size?

Only localized data have been collected over several sediment bars.

Figure 4: There are four sampling locations mentioned so what are those C4 and G3 locations for? Also, could you georeference the figure?

C4 and G3 are the grain size distributions on the Gave de Cauterets and the Gave de Gavarnie, upstream tributaries of the Gave de Pau. The figure will be georeferenced.

L235: Show data or cite source.

The data is presented in the figure below (Fig. 2). It has been communicated by the former hydropower company that was in charge of the exploitation of the two weirs before the flood of 2013.

L236-238: It means a very high suspended load. So you need strong justification why have you chosen this model, which does not consider suspended load?
L375-376: This location has high suspended load so you need to better justify the use of this model without suspended load.
L485-486: See earlier comments - need to justify the use of the model in this context, since it appears unable to model sediment in suspension.

In the Lac des Gaves, the deposit consists of an upper layer of coarse material over the first few centimeters, with finer sediment stored below and these fine sediments were mainly deposited downstream of the Lac des Gaves. The coarse sediments constituting the upper layer, it is the choice of a simulation of the bedload transport which was made.

Besides, bedload was the main concern of the river managers in the studied area since it is the fraction that controles the stability of the channel and is at the origin of the observed impacts such as erosions and depositions.

This will be better explained in the article.

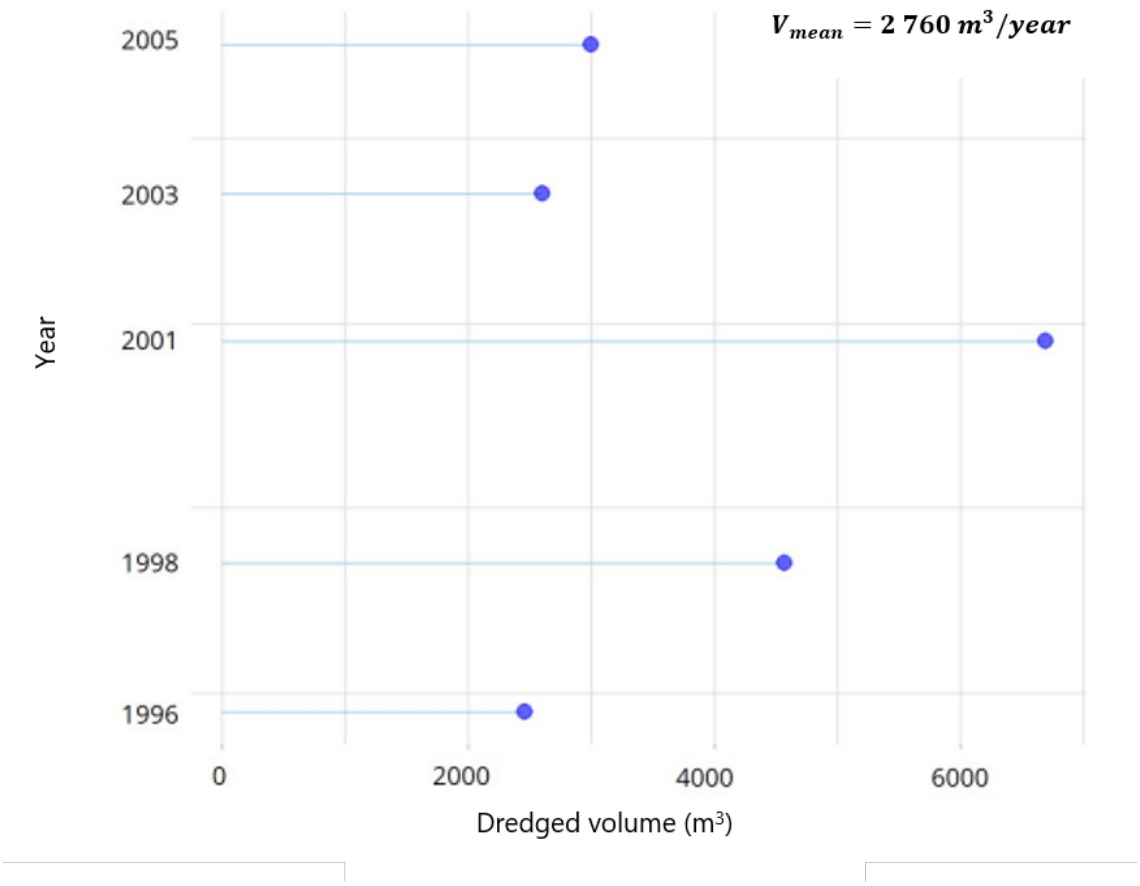

Figure 2: Longitudinal profile evolution following the flood of 2018.

L237: observation? Data?
This information comes from the available dredging data (5years).
This will be specified in the article.

L241-244: Which data are used to constrain the scenarios: discharge gauges? Rainfall gauges?
The hydrological model needs several input data, clarifications have been added in the text.
The data used for implementing MARINE model include rainfall (source: Météo France), topography (source: IGN), soil properties (source: INRA), land use (source: CORINE Land Cover) and event discharge (source: HydroEau France (DREAL) EDF).

L248-250: Could you also add the name of these tributaries on the figure as well?
Figure 5: I suggest adding the name of tributaries, georeferencing, and Scale bar.
This will be done.

The tenses are changing a lot from present to past to present (transition to next section). Please ensure consistency.
This will be done.

L260-261: A fine mesh should take more time to compute. How can it be less time consuming? Please double check.
Clarifications will be added to the text.
The finer mesh covers a much smaller area, so it is used to perform a less time consuming fine analysis of the sediment transport behaviour around the area of interest

L285: Did you measure the discharge yourself? If not, please mention the source.
No the discharge was measured by a public service in France named DREAL. This will be specified in the text.

L287-288: What is the significance of choosing this range of values?
This is a classical range of values for roughness in natural river.

Figure 6: Locate the weirs?
This will be done.

L295: Not entirely clear: what do you mean?
We meant that there are no other topographic campaigns between 2016 and 2019 that would allow the observation of the effects of the 2018 flood only. Clarifications will be added to the text.
Unfortunately, there have been no topographic campaigns between 2016 and 2019 that would account for the effects of the 2018 flood only.

L296-297: Show what you've got and your results before saying "more work is needed".
The sentence has been removed.

L325-328: Are they? Many models have been developed that do try to do that. They are not necessarily doing a great job, but there are numerical models of braided system, they exist. Are you referring to the fact that we cannot exactly model where a channel or a bar will be? That is certainly true. Scientists have been developing metrics to assess the goodness of a fit in such context without just using the ability to geographically match the location of features, see for example the work by HAjek and colleagues, and for example this paper that looks at clustering of sand bodies in stratigraphy (this is not for braided system but just to illustrate the point): https://pubs.geoscienceworld.org/gsa/geology/article/38/6/535/130307 See also https://www.sciencedirect.com/science/article/pii/S0037073811002260#section-cited-by
Yes, we were refering to the ability to geographically match the location of channels or bars. Thank you for the references, clarifications will be added to the text. On the suggestion of another reviewer, we have added another metric: the statistical distribution of erosion and disposition (Williams et al., 2016).
The statistical distribution of erosion/deposition has been analysed upstream the LDG (Fig. 3) and within the LDG (Fig. 4). We observe that the Strickler friction equation has a completely different dynamic and it tends to exaggerate sediment depositions compared to the Ferguson formula. These two figures will be added and commented in the last version of the article. it can be seen that some models reproduce the spatial distribution of deposited or eroded areas better than others, this will be further discussed in the article to improve the analysis.

Figure 7: Is that modelled? Measured? Say this is a DoD?
Yes, this is a DoD, Field erosion and deposition areas were estimated through topo-bathymetric differencing between two LiDAR DEMs surveyed in 2016 and 2019. Clarifications will be added to the legend.
Eroded (light blue) and deposited (dark green) areas in the LDG reach estimated through topo-bathymetric differencing between two LiDAR DEMs surveyed in 2016 and 2019

L346-348: I think figure 'a' is more matching with d and e rather than b and c? Is there a quantitative way of comparing? Can you compare the volume of erosion

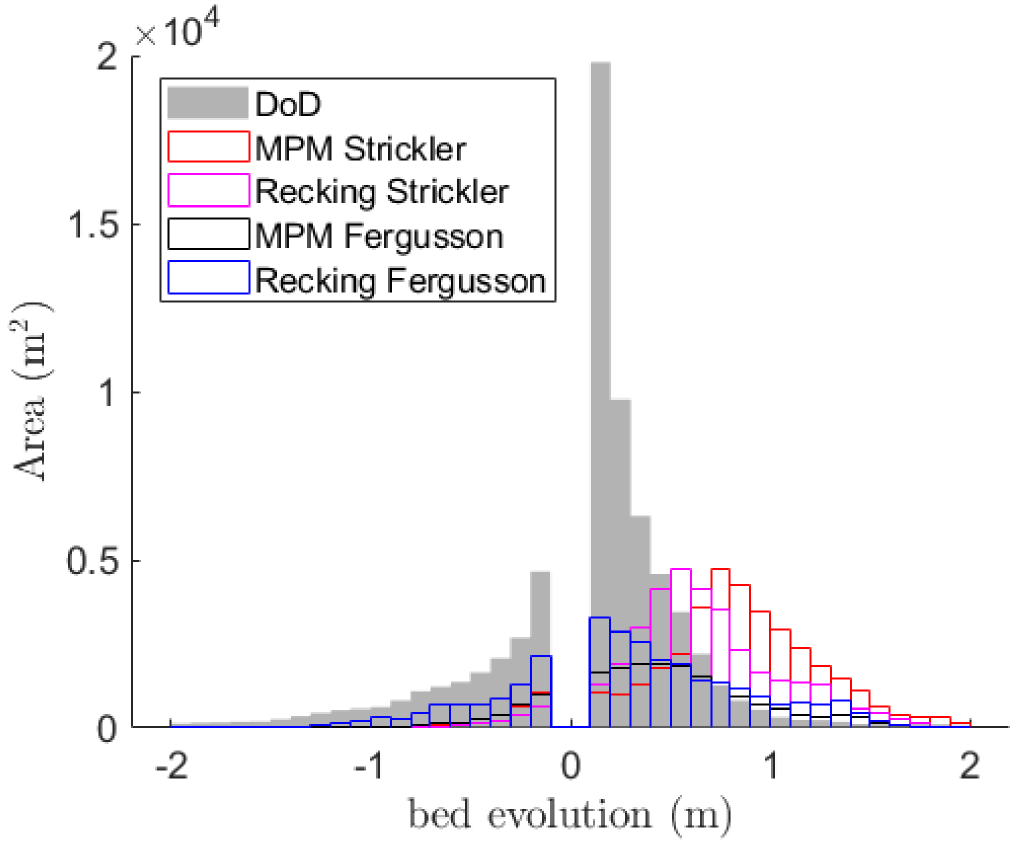

Figure 3: Statistical distribution of erosion/deposition observed with the DoD compared with the simulated evolution upstream the LDG

and deposition for all of these cases? I imagine you have used the same color level for the all figures? Regarding this statement, the magnitude of change seems to be greater in b and c than in d and e, whereas the extent of the deposition area is greater in d and e. Describe these results, similarities and differences in greater detail?
Figure 8: From these figures, I think figure a more matching with c and d rather than a nd b? I hope you have used the same color level for the all figures.
The same color levels have been used for all the figures, it's the one specified in the colorbar on the left.
Yes you're right figure 8(a) is more matching with d and e rather than b and c. It's probably due to the fact that the Strickler formula seems to overestimate erosion and deposition processes. Since the simulations only take into account bedload and the difference in DEMs obviously represents total load, it is therefore logical that the results of the formula overestimating the bedload seem closer to the observations of the total load. Of course this is only a qualitative way of comparison. The volume of erosion and deposition by bedload only for all these cases are compared later in the text (§5.3, table 2).
The similarities and differences will be more detailed in the last version of the article.

L351: Can you define the transition from low to high submergence? Would you consider the floods you model in the LDG as low or high submergence?
Low submergence corresponds to a water height of the same order of magnitude as the roughness. At the beginning of the flood, the submergence is low then it becomes high during the peak flood. Clarifications will be added to the text.
whereas the Ferguson friction law is known to have the best performance from low to high submergence (Rickenmann and Recking, 2011) which is probably more suited to our case study, for which the water height is of the same order of magnitude as the roughness at the beginning of

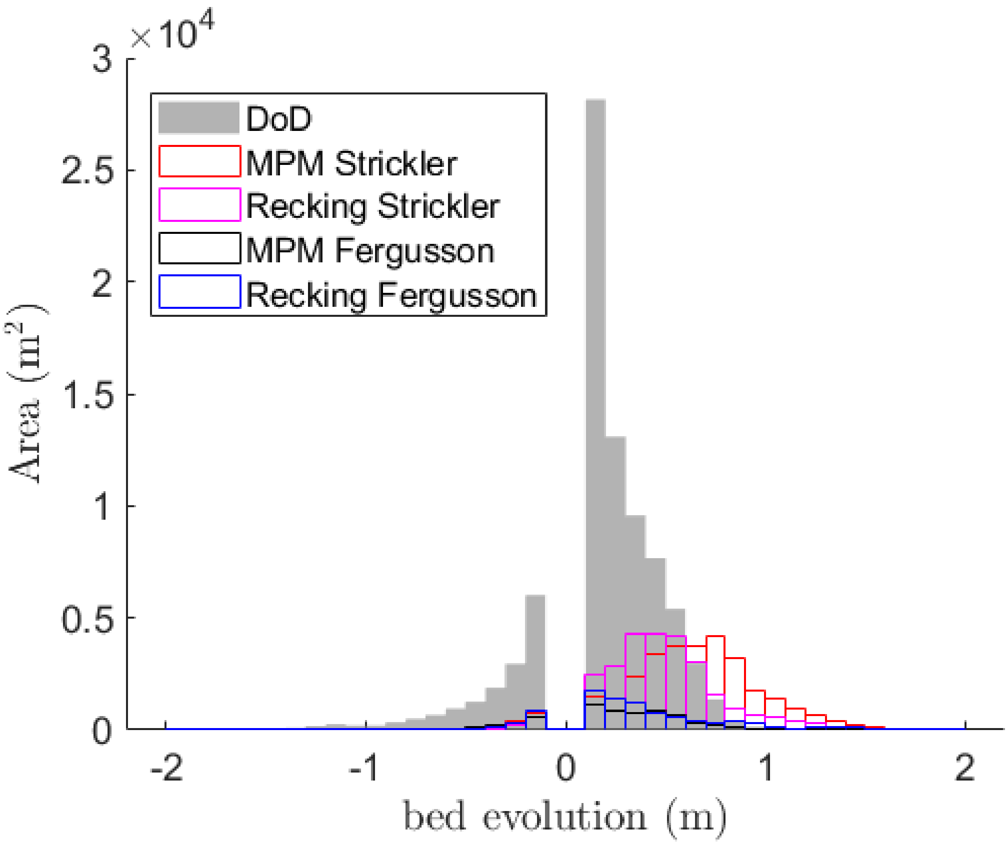

Figure 4: Statistical distribution of erosion/deposition observed with the DoD compared with the simulated evolution within the LDG

the flood. Then the submergence becomes high during the peak flood.

L357: Why should it overestimate?

MPM is a threshold formula. However, the simulation of the shear stress is subject to uncertainty, so around the threshold, if the simulated shear stress is underestimated there will be no sediment transport and if it is overestimated, there will be simulated sediment transport when there was none in reality. Therefore, the computational uncertainty around the shear stress threshold results in greater uncertainty in the sediment transport.

L373-374: Have you explored the multiple grain-size distribution option and is there any limitation to go with multiple grain size distribution?

The multiple grain-size distribution option option was not available in the solid transport module Sisyphe with the formulas used but work is underway to test its impact with the new solid transport module Gaia of the TELEMAC-MASCARET modelling system.

L378: How do you produce a longitudinal profile in a braided system?

The 1D plot is just an extraction of the longitudinal profile from the lowest bathymetric points of the 2D results. Clarification will be added in the text.

The 1D longitudinal profiles of the present paper are drawn from an extraction of the lowest bathymetric points of the 2D model.

Figure 8: Add labels next to b-e to facilitate the reading? e.g., MPM-Ferg, Reck-Ferg, MPM-Strick...

This will be done.

Figure 9: The results look quite different compared to Fig. 8b and c - the patterns don't exactly match. Why is this the case?
The results are the same on the common area located donwstream of the upstream weir but it's not the same color levels that have been used for figures 8 and 9.

L387-389: Do you think it would be possible to improve the performance with some additional simulations, for example by widening the input parameter like roughness? L389: Or the ability of the model to replicate the processes operating in this catchment.
We made several additional simulations that are not presented in the manuscript for the sake of simplicity. However the poor BSS values are mainly due to the fact that the model is not able to geographically match the location of channels or bars which is a known weakness of hydrosedimentary models. Clarifications will be added to the text.
This questions the relevance of the BSS criteria for complex morphologies such as the braided LDG reach as the hydrosedimentary model cannot simulate exactly where a channel or a bar will be.

L390-391: I don't understand: this looks pretty good to me! I can see across-channel relief that implies bars and multiple channels. What is so bad about this simulation?
The sentence will be reformulated as follows.
As mentionned above, Figure 13 shows that the model experiences difficulties to geographically match the location of channels and bars forming the braided morphology of the LDG reach.

L393: How much of this erosion is associated with the migration of bars, which would look like erosion next to deposition without a net change in sediment volume? Show the original 2016 profile for comparison on the figure?
This is a very interesting question. The sediment volume will be estimated in this area to verify if the observed erosion is associated with the migration of bars or if the mobilized materials were purged downstream.

L400: But this is not the only thing that matters, is it?
Of course mobilised sediment volumes are not the only important subject. However a knowledge of the mobilised volumes would already allow to progress in the elaboration of the knowledge of the site and the proposal of restoration project. It would already allow to estimate, for example, what volume of sediments could go downstream in a scenario of removal of the downstream weir.

Figure 10: It was said earlier in the text that the upstream condition was one where the elevation of the inlet does not change (line 277)
Yes, this is true, the upstream boundary condition imposes a constant elevation at the inlet. As it can be seen on the left part of the figure, the first measurement point is not located at the inlet, that's why the elevation changes. Clarification will be added in the legend of the figures.
Attention, the first point of the longitudinal profile is not located at the inlet.

L408-410: This is something that should have stated at the very beginning - this is something you can use to justify the study and use of the model. By making this statement from the onset, you can justify the adoption of a given modelling strategy.

The sentence has been added at the beginning, in §2.4 Restoration implications.
One of the processes on which the modeling efforts will focus is the deposition phenomenon within the LDG as it represents the potential volumes that might be mobilised if the weir lowering/removal restoration measure is considered.

L411-412: Can you give more details? Were the volumes estimated through DoD?
L413-414: Is the sediment deposition volume estimated from DEM of difference or any other approach, not mentioned here?
The total volume was estimated through DoD. The bedload fraction was estimated to represent 8 to 16% of the total observed deposited volume. This percentage value comes from the dredging data.

Table 2: Here, In the table, the simulated bedload volume score value in the lower limit is higher than the upper limit, could you explain it?
The lower limit represents 8% of the total observed deposited volume. The simulated bedload volumes are much higher than this lower limit, they are closer to 16% which is the upper limit. That's why the score is better for this upper limit (r closer to 1).

Figure 13: Could you use different color for showing cross-section in plan as you are showing the same green color for simulated bed level so just to avoid the confusion.
This will be done.

Figure 13: How were the cross-sections chosen? You may show a couple more to illustrate the variability as you move away from the weirs?
Many cross-sections were analysed during the post-processing of the results. However, to not overload the article, only the ones around the weirs (where most sediment transport processes occur) are presented.

L436-437: So, why was this model chosen? It would be good to develop a better justification at the onset of the paper ("the model is not developed to reproduce braiding or deal with suspended sediment; however it is one of a few models available that are able to model morphodynamics (erosion and deposition) during large flood events. Here we use this well constrained example to assess its ability to reproduce volumes and cross-sections, and assess its suitability as a tool to inform policy makers".
Thank you for this suggestion. The sentence has been added at the beginning, in §3 Model description.
The model is not developed to reproduce braiding or deal with suspended sediment; however it is one of a few models available that are able to model morphodynamics (erosion and deposition) during large flood events. Here we use this well constrained example to assess its ability to reproduce volumes and cross-sections, and assess its suitability as a tool to inform policy makers.

L441: How can you be sure?
The sentence will be rephrased.
Therefore another criterion adapted to braided rivers has also been considered: the statistical distribution of erosion and disposition (Williams et al., 2016). (see the answer at the beginning of this document).

L450: I do not understand: in the last few sections, you explained that the model was not very good at getting the sections right and that it was better at estimating

volumes. Can you also estimate volumes and show DoD so that the reader can better visualise the outcomes?
We understand the question which is relevant. The idea was just to have an idea of the morphodynamic processes (erosions and depositions) and have some orders of magnitude and not to have the exact location of the erosions/depositions. We will add a DoD to be consistent with the previous analysis.

L454: why this choice?
10-year return period-like flood events were chosen because they are both relatively large flood events with a rather low return period. Besides, this was also discussed with the river managers, who wanted to be prepared for such kinds of events that might occur more and more frequently. This will be explained in the article.

L468-470: Can you check? I imagine you can calculate the shear stress during the event? You should be able to answer to this question with your data.
Yes we are able to calculate the shear stress during the event. This will be checked and added to the last version of the article.

L494-497: Rephrase / be more specific.
The sentence will be rephrased.
One recommendation to decision makers is to not only consider the downstream weir but to consider both weirs in the restoration project.

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