Author‘s response to referee #1 comments on “How do modeling choices impact the representation of structural connectivity and the dynamics of suspended sediment fluxes in distributed soil erosion models?” by Uber et al.

In the following, the reviewer comments appear in black italic and our answers are provided in blue. When there are quotations from the text of the article, they appear in quotation marks.

We wish to thank the anonymous referee #1 for this very detailed and constructive review of our study and acknowledge the time spent and effort made. His/her comments helped us to substantially improve the paper and we hope that the changes made accordingly will contribute to an easier understanding of the text.

As a general response, we would like to point out that, upon reading many of the reviewer's comments or questions, we realized that the second objective of the article was mis-explained and therefore misunderstood. While the first objective is achieved by performing a sensitivity analysis of the choices made during the construction of the models (modelling scenarios 1, 2 and 3 in Table 2), the second objective corresponds to an opening towards the understanding of the temporal dynamics of fine sediment fluxes as a function of the geomorphological characteristics of two different catchments, in particular due to the location of the sources and their structural connectivity. Thus, the scenarios 4 described in Table 2 allow a better visualization and interpretation of the contributions of the different subcategories of sedimentary sources to the outlets.

In the revised version of the manuscript, we added, as proposed by referee #1, a study design section that links the different modeling scenarios in Table 2 to the two objectives reformulated in the table to be more explicitly linked to those announced in the introduction, also slightly reformulated.

After reading the comments of referee #1 we also became aware that the title of the manuscript only referred to our first objective while it did not refer to the second one. Thus we changed the title to the manuscript to “How do modeling choices and erosion zone locations impact the representation of connectivity and the dynamics of suspended sediments in a multi-source soil erosion model?”

1 Summary

Uber et al. present a numerical modeling study that explores how modeling choices related to computational mesh generation, parameterization, and source-classification grouping influences a variety of output metrics describing hydrograph and sedigraph characteristics. […]

Thank you for your general acknowledgement and positive feedback on our work.

Below I describe comments and recommendations first in narrative form and then as line-level comments. My most substantial concern is that the paper lacks an overarching introduction to the study design—a section in which the authors set up the specific questions or hypothesis that they seek to address and connect them with a conceptual description of their numerical experiment design. A related comment is that I found the explanation of the modeling choices difficult to follow. Both of these issues meant that it was difficult to connect the study design and methods with the results and discussion.

We addressed your concerns by including a short section "study design" as you proposed and made changes in the description of the modeling scenarios to better understand the modeling choices (see the further points).

I recommend acceptance after major revisions and look forward to seeing this paper published.

Thanks again for the constructive proposals and the recommendation for publication.

2 Narrative Comments

2.1 Addition of an "Study Design" Section

The experimental design employed by the authors is valid and appropriate for the questions that they seek to pose. However, I found description clearly connecting the big picture questions ("what controls sediment flux from mesoscale watersheds") to the scenario design currently introduced by Section 3.4 and Table 2 was missing, or spread across too many sections of the paper.

I recommend that a new section be placed immediately after the introduction. In this section you would describe your experimental design and connect it to the big picture you have laid out in your introduction. Such a section would include the specific questions and hypotheses each scenario's experiment seeks to answer and an explanation of why this question was targeted.

While the reader may not know the details of the two sites or the model, your introduction should provide enough information such that this section can come before the more detailed methods section. Such a section will introduce to the reader the concrete questions your scenarios were designed to address.

Such as section should a description of the type of model analysis method used (e.g., a series of one-at-a-time sensitivity studies) and explain why this sort of method is appropriate to address the study objectives. Pianosi et al. (2016) is a good place to start for background on this topic. This will help the reader understand the type of results you will obtain.

In such a section, I would also like to see an introduction to why two catchments are used and why calculating whole-catchment connectivity metrics (described in Section 3.1); e.g., doing the same set of simulations across two catchments with different geology/land use/etc allows you to isolate how transferable your results are to catchments with different properties. This would also allow you to set up why you calculate a variety of catchment connectivity metrics (presented in Table 1) and explicitly state that you will eventually work to connect those connectivity metrics with the variability identified by the sensitivity analysis (a start at this is done at L461).

We introduced a section "study design" as you proposed. However, we introduced it as an introduction of the modeling scenarios section, as it is directly linked to the description of the scenarios. The new section is now entitled "3.4 Study design and modeling scenarios". While this section is short we hope that the changes made in further sections will also help to improve the understanding of the study design. Thank you also for the recommendation of introducing our approach with the paper by Pianosi et al. and the hints to be more precise on the type of sensitivity analysis conducted.

2.2 Improve explanation of modeling choices

The core of the study hinges on connecting the modeling set up described in Section 3.3 to the scenarios described in Section 3.4. However, I found it difficult to connect these two sections, mostly because I found it hard to follow exactly what the authors varied in their modeling set up.

The most constructive form of feedback I think I can provide here is a summary of what I understood after reading the paper four times, as well as what I would recommend so that I might have understood this after the first reading.

Thank you for your summary from an outside perspective which helped us to be more precise on some parts, see comments below.

Based on my reading, what I understand is that there Iber requires a computational mesh, and the mesh size can vary in space. Each mesh cell has a value for Manning's n and a value for α.

This is correct. We try to be more precise by changing the first sentence in section 3.3 that now reads "As a distributed model, Iber requires a computational mesh which is made up by three main modeling units with different spatial discretizations and roughness coefficients, i.e. the river network, the hillslopes and the badlands."

Choice 1: The considered area is divided up into three conceptual domains which influence the grid cell size and Manning's n value based on the CDA (hillslope, channel, badlands). Based on the delineation of these domains the mesh is discretized.
Next the mesh is parameterized with a spatially variable for Manning's n value. You might have chosen to let Manning's n vary smoothly, or something else, but you have chosen that the domain will get two Manning's values (channel and hillslope).

This is correct. Again, we try to be more precise by adding "Values for Manning's and erodibility were assigned to each mesh element." in line 219 of the initially submitted version of the manuscript. We also added the following sentence in line 221: "It was chosen that the domain would get two Manning's values (channel vs hillslope), i.e a value for the modeling unit "river network" and another value for the modeling units "hillslopes" and "badlands".

Choice2 focuses on those values. While water can fall on and run across the entire computational mesh, sediment can only be sourced from the bare bedrock areas. In these areas, the propensity to produce sediment is parameterized by α.

We reformulated the sentence starting in line 222 which now reads "While runoff is generated and routed in the entire catchment, the production of sediment was limited to the potential erosion zones. The latter include all the mesh elements in the modeling unit "badland" and the mesh elements of the "hillslopes" modeling unit that belonged to the diffuse agricultural sources in the Claduègne catchment. The erosion zones were classified according to ..."

I don't think the following was ever stated, but in order to produce the source proportion sedigraphs, I believe that some method of source tracking can be chosen in order to elucidate the dynamics of the basin.

To be more precise about that, we reformulated the sentence starting in line 225 which now reads "Sediment production (Drdd,s) was calculated in each mesh element of the potential erosion zones for each source class separately. Sediment transfer (Eq. 2) was then routed over the entire catchment.

Thus, separate sedigraphs for each source class were obtained at the outlet of the catchment and the contribution of each source class to total sediment flux could be calculated for every time step."

Furthermore, we thoroughly revised the description of the model in section 3.2 to be precise about this aspect. In Eq. 2 we added the subscript s to be more explicit about the fact that it was solved for each sediment class separately.

Different classification of these tracked sources is represented by Choice 3 (I think). Thus Scenarios 2a–2d focus on Choice 1, Scenarios 3a–f focus on Choice 2, and I think that different delineations of source tracking (Choice 3), along with different choices for Manning's n yield Scenario 4.

As mentioned in the general answer, the last set of scenarios (Sc. 4) were designed to answer the second objective written at the end of the introduction. The aim of Sc. 4 is to better interpret the modelled temporal dynamics of sediment fluxes for various groups of sediments depending on their geology and also on their distance to the outlet or to the river network. Thus, Sc. 4a and 4b do not really correspond to choices during modeling set up as the overall sedigraphs are not modified. They just allow a better visualization of the sediment origin (in subgroups) in order to facilitate the comparison with the connectivity indicators. To go further in the discussion and the interpretation of the impact of the location of sources within the catchment, and particularly to assess to which extent the conclusions derived from Sc. 4a and 4b were dependent on changes in roughness parameters, Sc. 4c and 4d were added, but they were initially not designed to be part of the sensitivity analysis conducted for objective 1.

I would recommend the following to the authors:
Revise section 3.3 to describe more clearly what the modeling choices are such that they set the reader up to understand the details of scenario design discussed in the following section.
• In Section 3.3 or in the new "study design" section proposed above, explain why these choices are important to focus on. Are they the only choices? Are they the only ones which carry uncertainty? There are many things you might have focused on (e.g., assess the sensitivity to the channel grid cell size), but you chose these elements, why? To be clear, I think the elements you've chosen are great, I just want more description of why they were chosen.

This suggestion was accepted and included in the new section "3.4 Study design and modeling scenarios" where it reads "Based on preliminary studies that are not reported here, these factors were found to be the most important ones in determining sediment flux dynamics. While other factors (erodibility, rainfall intensity) crucially influence absolute values of erosion and suspended sediment concentration, their values are less important to determine arrival times and temporal dynamics of source contributions."

• Clarify how the source classification is represented in model specification. Does this choice not influence the model physics, but just the model output that permits a different view on the dynamics?

Yes, this is the case. E.g. the sedigraphs of the sources "Limestone 1" (close to the outlet) and "Limestone 2" (further) in scenario 4a sum up to the sedigraph of the source "Limestone" (which includes close and distant subsources) in the basic scenario. Thank you for pointing out that this was not clear. The following sentence was added at the end of section 3.4 "It should be stressed that this source classification does not influence model physics, i.e. total sediment yield from a source (close + distant sources) remains the same as in the basic scenario where they are not differentiated."

• *Explain why sediment is only sourced from the bare bedrock.*

We changed the sentence starting in line 126 to "The land use is dominated by forests and scrublands, which are permanently covered by vegetation and are thus assumed to be negligible as sediment sources. Agricultural zones are barely present in the catchment."

2.3 Improve connection between study design and discussion

The structure of the discussion roughly follows the three non-base case scenarios and presents the most salient aspects of the results. However, within each of the major discussion sections, I found the text difficult to follow. I suspect that by being more explicit about the target questions and hypotheses earlier in the text the authors will be able to very lightly restructure the discussion such that the reader is easily able to connect the discussion with the study intent and numerical experiments.
In addition, the end of the discussion starts to tie together the basin-scale metrics presented in Table 1 and the numerical modeling results. It would be beneficial to introduce earlier on that you will do this and describe in more detail how this is accomplished (e.g., regression, rank correlation). Knowing that this sort of analysis is coming will help explain why all of the basin-scale metric are calculated and discussed starting
at L136.

Thank you for that remark. We included this idea in the new section "3.4 Study design and modeling scenarios" by adding "[…] indicators of structural connectivity of the two catchments are used to describe the configuration of sediment sources in the catchment. They are compared to the modeled hydro-sedimentary fluxes both qualitatively by visual analyses and quantitatively by means of the calculation of characteristic times of the hydrographs and sedigraphs (e.g. time of concentration, lag time)"
We prefer not to use a specific term like regression or rank correlation because we are comparing only 5 data points at a maximum (4 sources in the Galabre catchment + liquid discharge)

2.4 Figures
The interactive figures provided by Uber et al. (2020) are a fantastic complement to the paper. I might consider adding catchment as a facet (e.g., facet grid with scenario catchment) because this would facilitate comparison between catchments.

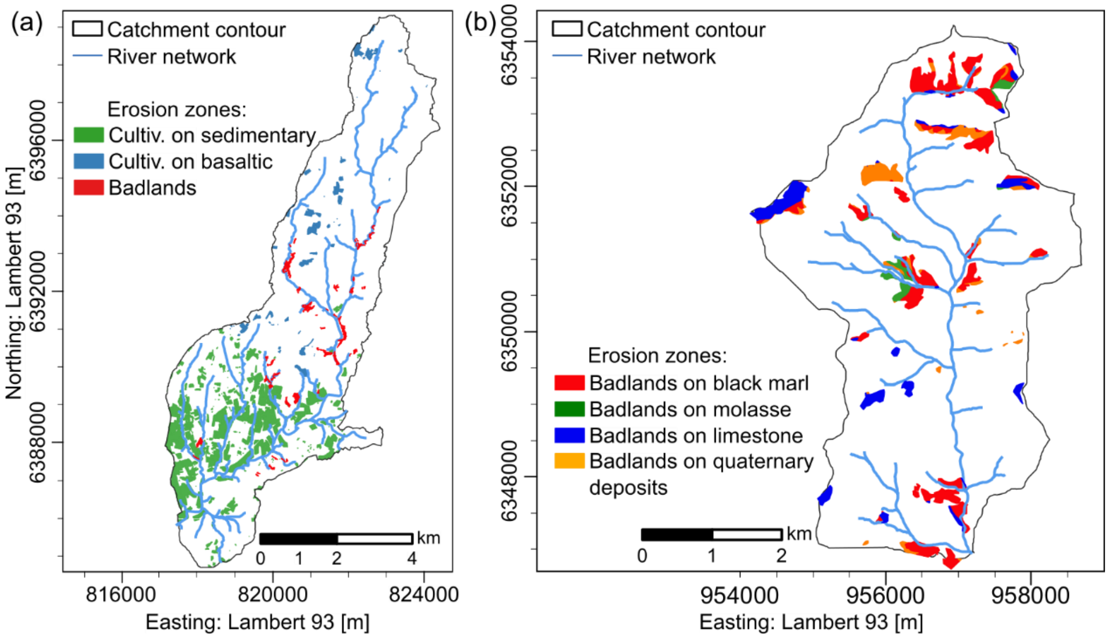
This is a nice idea, but it is not easy to implement. We prefer to keep the interactive figures as they are.

I'd also like to applaud your consistency in the use of color to denote geological unit across figures. This should be a standard expectation, but it isn't, and it makes comprehension much better.

Thank you very much for the positive feedback on the (interactive) figures.

My primary concern with figures relates to the maps presented in Figure 1. This figure shows us inconsistent information across the two catchments (e.g., badlands only shown in 1a)

We revised figure 1 in a way that consistent information is shown for the two catchments. The land use information in fig 1b was omitted as it is indeed essential for this study and it is presented by Esteves et al. (2019). Now the figure shows the erosion zones that were considered in the two catchments as colored patches.



and does not show us all of the information used in the modeling study that is the focus of the work. I recommend that Figure 1 be redrafted into a series of rows that shows the reader the main elements used in model initialization for each catchment. For example, row one might show a shaded relief map with the river system and badlands areas, row 2 would show the considered geologic units used, row 3 might show the weighting factor W presented by Borselli et al. (2008), while row 4 would show the roughness based weighting factor of Cavalli et al. (2013).

We prefer to keep figure 1 simple as the paper already has several figures that are composed of different subfigures. The information you request is contained in Magdalena Uber's PhD thesis available at https://tel.archives-ouvertes.fr/tel-02926078 and a reference was added at the end of the caption of figure 1: "Further maps of the study sites can be found in Uber (2020)".

2.5 Code availability

For the purposes of computational reproducibility, state the version of Iber used.

We changed the introduction of the model at the beginning of the section "3.2 Model description" to be clearer about the fact that we worked with a version of the model that is in development: "Surface runoff, soil erosion and sediment transport in the study catchments were modelled with an ad-hoc version of the software Iber (Bladé et al., 2014) developed in a previous study by the authors (Cea et al. 2016)". While the hydraulic model can be downloaded from the iberaula website, the erosion and sediment transport module is still a research version developed initially by Cea et al. (2016) which cannot be downloaded yet.

No statement has been made about model input file availability. Such files should be digitally archived for the purpose of reproducibility.

Given that the erosion and transport part of the model cannot be downloaded yet, we do not think there is any interest in dropping the input files on a repository.

3 Line Level Comments

Bullet points in this Section indicate "<LineNumber>", "F<Figure Number>", or "T<Table Number>".

36 The term "Mediterranean and mountainous" is used a few times, first here. Mediterranean could be interpreted a few ways: e.g., places with a Mediterranean climate, places near the Mediterranean. Recommend being more specific about what is meant.

Thank you for pointing that out. We meant the terms as "having a Mediterranean and mountainous climate". However, this is not the case in the study by Vanmaercke et al. that was cited in line 36, so we prefer to clarify it in line 42 where we replace "Mediterranean and mountainous watersheds" with "watersheds with a Mediterranean or mountainous climate".

56 Recommend giving an example of your objectives and thus how structural connectivity is represented to anchor this abstract concept on a concrete example or two.

We replaced the sentence ending in this line by the sentence "In the context of soil erosion and sediment transfer studies it is of interest how active erosion zones are linked to the catchments outlet." to be more precise about the use of the concept of structural connectivity in this study.

76 I suspect the sentence that ends in this line needs a reference.

We added the reference "(Merrit et al., 2003)"

87 Be more specific about which models and provide examples with associated references.

The half-sentence "such as WEPP (Laflen et al., 1991)), Kineros (Woolhiser et al., 1990)) and Mike 11 (Hanley et al., 1998)" was added.

100 Additional subsubsection headers would have helped me understand this section more easily. For example Section 3.1 discusses both a description of the catchments and connectivity metrics calculated, and Section 3.3 discusses many different aspects of the model set up. I would split each of these subsections into multiple subsubsections.

We agree with the reviewer for section 3.1. Thus we split it in a first subsection labelled "Catchment descriptions" and a second one labelled "Connectivity indicators". However, we decided to keep section 3.3 unchanged.

129 A few lines or a paragraph summarizing the similarities and differences of the two catchments would benefit the reader here.

We agree to sum up the main differences at the end of the paragraph, by adding the sentences "In comparison, the Galabre catchment is smaller and steeper than the Claduègne catchment. The distribution of the erosion zones differs in the two catchments, with the ones in the Galabre catchment being more dispersed over the entire catchment but smaller in size due to the absence of diffuse agricultural sources." Their main similarity is the fact that they are both mesoscale catchments in a mountainous and Mediterranean context. As this is stated several times before we prefer not to repeat it again here.

136 Some statements about why these connectivity metrics were chosen would benefit the reader.

This was explained in lines 140-142 "The distance to the outlet and the distance to the stream of a given position in the catchment serve as proxies of longitudinal (upstream-downstream) and lateral (hillslope-channel) connectivity in the sense of Fryirs (2013)" and in lines 144 – 146 "However, neither of these measures takes into account surface roughness and slope. Thus, two of the most widely used indicators of connectivity, i.e. the IC proposed by Borselli et al. (2008) and the adjusted version of IC proposed by Cavalli et al. (2013), were calculated." We hope that adding the precisions in the brackets helps to better understand the explanations to the reader who might not be familiar with the work by Fryirs (2013).

In addition, explain (here or in something like the proposed "Study Design" section) what you expect to learn from these metrics and how they are used.

Ok, we included that explanation in the section "3.4 Study design and modeling scenarios" as you proposed.

137 The distance to the outlet metric has been called the "width function" by the landscape evolution modeling community Hancock et al. (2010, 2002). Work by this community has shown that it is not a particularly good metric for comparing catchment topography, but is a does provide a good assessment of hydrology. It may be useful to connect with this literature.

Thank you for the hint and the recommendation of the reference. We added the sentence "The distance to the outlet metric refers to the width function applied as a measure of network structure and catchment shape by Hancock et al. (2010).".

138 Mathematically represent the connectivity indices of Borselli et al. (2008) and Cavalli et al. (2013) here so that the reader can more clearly understand what they represent.

We prefer to refer the reader to the original publication here and not go into too much detail. The two indices are not the most important metrics used in this paper. It is already a bit unusual to describe the calculations of these metrics in the study sites section but we took that decision in order to keep it short. Thus, going into further detail would be beyond the scope of this short description of the metrics.

171–173 This detail of model set up should be located elsewhere. Probably is a subsubsection of Subsection 3.3 (see also the comment at L237 and 289.

We agree and relocated the sentence in line 237.

211 Being able to connect this discussion of badlands in model set up to a consistent picture of where badlands are located is why I mentioned earlier that Figure 1 should be revised to include consistent information about each catchment.

Ok, see our response to your comment on figure 1.

215 Connect and justify the choice of a 5 m minimum grid size with relevant field observations and the numerics of the Iber model? E.g., how does this compare with the range of values for channel width in each catchment? Do the numerics of Iber benefit from a relationship between minimum grid cell size and channel width (e.g., smallest grid cell = channel width, 10 grid cells = channel width).

Given that the same surface water and sediment routing equations are applied in all three units (the river network, the hillslopes and the badlands), the model presents a continuous representation of hillslopes and the river network. In order that the river flow strictly follows the slope of the topography, we had to choose a cell size that is in the order of magnitude of the resolution of the DEM (1 m). A smaller mesh size of 1 m for example would strongly increase the number of mesh elements and thus computation time without increasing the accuracy of the results so this value is a compromise between exact representation of the topography, computational efficiency and accuracy of results. Thus, the minimum grid size of 5 m was chosen as a compromise between the representation of the flow structure in the river, computation time and accuracy of results.

217 20 m seems like a rather large grid cell size for gullied areas. Explain and/or justify this value.

You are right that the topography on the steep badlands is not exactly reproduced by this value. Again, it presents a compromise between detail, computational efficiency and accuracy of results. We did preliminary analyses that are not reported in this paper on the impact of the mesh size (only for hydrology and on a subcatchment) by conducting a convergence-of-the-mesh experiment: starting at a coarse mesh size and then gradually decreasing it. At some point the results converged, i.e. a smaller mesh size did not lead to significantly different results. This is how the optimal mesh size was determined. The resulting optimal mesh size of 20 m for badlands is related to the fact that erosion is represented only by the detachment of rainfall which is modelled in a simple way as a function of the rainfall amount. This optimal mesh size would have been different if detachment by overland flow had been implemented as the topography controls the water heights and velocities.

222 The erosion source locations should be shown in Figure 1 in addition to the subplots shown in later figures.

We revised figure 1 so that it now shows the erosion zones clearly.

222 If I'm interpreting this correctly, I believe you are saying that sediment production can only occur in the areas of bare bedrock. This should be explained further and justified. In addition, discuss how this model set up decision impacts the implications of this study for overall soil erosion (as these bare bedrock patches only make up a small portion of the study watershed).

Thank you for the remark. We remind that the erosion zones were previously defined in the sediment fingerprinting studies by Legout et al. (2013) and Uber et al. (2019) for the Galabre and Claduègne catchment respectively. In line 126 we noted that in the Galabre catchment the land use classes other than the badlands are "permanently covered by vegetation and are thus assumed to be negligible as sediment sources". Badlands are therefore the only sources of erosion. In the Claduègne catchment, apart from badlands, some diffuse, agricultural sources have to be considered. In the new version of the manuscript, we have stressed such a difference between the two catchments following your comment on line 129 by adding the sentence "The distribution of the erosion zones differs in the two catchments, with the ones in the Galabre catchment being more dispersed over the entire catchment but smaller in size due to the absence of diffuse agricultural sources". Also, we hope that with changes made to figure 1 it is now easier to see the extent and location of the erosion zones.

227–236 It is difficult to understand if this section of text is summarizing the work of Uber et al. (2019) or if it is presenting an analysis of modeling results. Revise to clarify this point.

We rephrased the two sentences ending in line 235: "SSYs,ev is the contribution of source s to SSYev and was calculated based on the mean source contributions. They were estimated with sediment fingerprinting in the Claduègne catchment by Uber et al., 2019 and in the Galabre catchment by Legout et al., 2013." We hope that in this way it gets clear that the reference Uber et al., 2019 refers only to the sediment fingerprinting in the Claduègne catchment. The rest of the section explains the calculations made for this study.

227 Introduce the units of α when the variable is first presented.

Thank you for pointing it out. We state the unit in line 230 where the formula is given now.

237 No discussion of time discretization, model run duration, or external forcing (e.g., rain) is present in the prior subsection. These elements of model set and running should be discussed.

Based on your comment above we move the description of the hyetograph (rainfall forcing) here. Further we added "The simulated time is 24 h, including 12 h of rain and 12 h for the fluxes to reach the outlet" (line 295) to be precise about the model run duration here. The description of the model (section 3.2) was revised thoroughly and now states the method of time discretization: "The solver is explicit in time, meaning that the maximum time step that can be used to evolve the equations in time is limited by the Courant-Friedrichs-Lewy (CFL) condition (Courant et al. 1967). This implies that the time step in typical applications is of the order of one second or less. The CFL condition is implemented in the solver and thus, the computational time step is automatically evaluated from the grid size, water velocity and water depth"

237 Based on the results presented, it appears that Iber has the capability of tracking the source of water/sediment as it moves through the catchment and that how these source regions are grouped is what is meant by the "source classification" column of Table 2. This aspect of the model should be discussed. As best as I can tell this is a critical aspect of interpreting Scenario 4.
In addition, it is not clear whether this choice of model set up impacts the dynamics of water and sediment (or if it just impacts how they are analyzed). E.g., are simulation 1 and 4a and 4b the same simulation just analyzed/post processed differently?

We hope that this gets evident after our general answer at the beginning of this document and the changes we made following your earlier comments in narrative form.
In line 278 it now says: “It should be stressed that this source classification does not influence model physics, i.e. total sediment yield from a source (close + distant sources) remains the same as in the basic scenario where they are not differentiated.” Further in line 225, it now says “Sediment production ($D_{rdd,s}$) was calculated in each mesh element of the potential erosion zones for each source class separately. Sediment transfer (Eq. 2) was then routed over the entire catchment. Thus, separate sedigraphs for each source class were obtained at the outlet of the catchment and the contribution of each source class to total sediment flux could be calculated for every time step.” Eq. 2 was also changed to be more explicit that it was solved for each class separately.

260 The simulations of Scenario 3 represent two one-at-a-time sensitivity studies (Sc. 3a–3c for sensitivity to hillslope Manning’s n and Sc. 3d–3f for channel). Recommend using more formal language to describe the numerical experiments as it will help the reader anticipate the type of results presented.

We stated that in the new section “3.4 Study design and modeling scenarios” you proposed earlier and repeat it in line 256 by adding one-factor-at-a-time sensitivity analysis in brackets: “We tested the impact of varying the CDA threshold on the modeled hydro-sedimentary response while keeping all other parameters unchanged compared to the basic scenario (one-factor-at-a-time sensitivity analysis)”.

268 It is not clear to me how the different options for source classification of Scenario 4 relate to changes in the parameterization of the model. Were different values of α used? Something else? Clarify.

There are no changes in the parameterization of the model. We hope our general answer and specific response to your comment on line 278 allow a better understanding about the aims of Sc. 4. For example, in the Claduègne catchment, the difference is that instead of having three source classes in the basic scenario (badland, basaltic, sedimentary), there are 6 source classes (badlands-close, badlands-distant, basaltic-close, basaltic-distant, sedimentary-close, sedimentary-distant) in scenario 4b and 4d. This is visualized in figures 10 and 11. We hope the changes made as explained in our response to your narrative comments and the one on line 278 make this source classification and its implication easier to understand.

In addition, these scenarios include two options for the Manning’s n value, the base case and one in which the hillslope value is low and the channel value is high. The results of Scenarios 4c and d are discussed at L454. Formally introduce what the purpose of this sub-scenario is.

Thank you for pointing that out. We added at the end of section 3.4 the sentences “Besides the values for Manning's n used in the basic scenario, in Sc. 4c and 4d we used values for Manning's n that were less contrasted between the hillslopes and the river network. This was done to assess whether the interpretation of Sc. 4a and 4b (i.e. the discussion on how the location of the sources in terms of their distance to stream or outlet, impacts the temporal dynamics of SS fluxes at the outlet) depended on the values of n.”.

272–274 This sentence, in which you link the changes to the model set up with a hypothesis is exactly the sort of text that a "Study Design" section would benefit from. Recommend that similar sentences for each scenario exist and be present in such a section.

Following this comment, we made sure that for every Scenario a sentence like this explain why this scenario was created. For scenario 2 we added line 258: "Thus, it can be assumed that modeled sediment dynamics are sensitive to this parameter.". For scenario 3 we think the explanation is already in the text l.261: "As the first objective of this study is to assess the impact of choices made during model set-up on the simulated sediment flux dynamics, the model was run with different values of Manning's n in the river network modeling unit on one hand and in the hillslopes and badlands modeling units on the other hand".
In the section "3.4 Study design and modeling scenarios", it is now stated: "The underlying hypothesis is that both modeling choices (notably CDA threshold and Manning's n) and catchment characteristics (structural connectivity of the sources) determine travel times from the sources to the outlet. With the presented study design, it could be assessed whether modeling choices or actual catchment configurations were more important in generating output variability".

280 This section clearly describes what model output metrics were used, however it does not explain why these output metrics were chosen or justify why they are appropriate given the overall goals of the study. This section should be expanded to include this information.

Thanks for pointing that out. We added the following sentence at the end of Section 3.5: "We use these metrics to quantitatively assess differences in model output between the scenarios described above."

289 This sentence describing model run details should go elsewhere in the text. Probably in a section on external forcing, along with the text currently located at L171–173 (see comment at L237).

We have completed the information on the duration of the simulations at the end of section 3.3 but we have left this sentence in this section as we have not found a better place.

296 Be more specific about which aspects of the model. Some aspects are sensitive and some are not.

We changed "the model was sensitive" to "modeled hydrographs and sedigraphs were sensitive".

307 Connect this statement with new text earlier in the paper describing why two catchments are used. Set the reader up for this sort of discussion by explaining why two catchments are used, and comparing/contrasting them.

We hope that the introduction of the modeling scenarios with the new section "3.4 Study design and modeling scenarios" allows to better understand the interest of studying two catchments. Particularly the following sentence was added to: "With the presented study design, it could be assessed whether modeling choices or actual catchment configurations were more important in generating output variability."

313 Justify why this is a reasonable interpretation and connect with literature.

We do not have found any relevant study to cite for this purpose. However, analyzing all the characteristics of both catchments leads to a clear contrast of their slopes. Whatever the compartments (hillslopes, intermittent streams and main stream) the slopes are on average two to three times higher in the Galabre than in the Claduègne catchments, leading to modelled hydrological response times smaller in the Galabre than in the Claduègne catchment in accordance with measurements.

337 This statement presents a different conclusion than Table 3 and the text near L296 which states that different CDA values result in output metric variability. These three elements of results and discussion should be consistent.

The emphasis here is on "in this range". We rephrased it so that it becomes more evident: "Overall, our results showed that the thresholds of 15, 35 and 50 ha produced very similar results. Thus, in this range, the model was not very sensitive to the CDA threshold."

344-350 The purpose and reasoning of the argument you advance here is not clear. As you highlight it in the conclusion (L487) I believe you think it is an important point. Recommend this text be revised.

Thank you for pointing out that the paragraph was not clear, we rephrased it: "This result showed that it is important to use a CDA threshold that is in the same order of magnitude as the value that produces a realistic river network. Field observations or detailed maps (i.e. topographic map at scale 1:25000) can be valuable sources of information for this purpose. The sensitivity of model output to variations of the CDA threshold was also observed by other authors (Pradhanang and Briggs, 2014). For our modeling set-up it is reassuring that model results converged when the CDA threshold used is derived from field observations."

352 The section of Table 2 that shows the results of Scenario 3 indicates that changing Manning's n in the hillslope has a larger impact on the results than changing the channel value. This should be discussed.

It is true that generally changing n on the hillslopes has a larger impact than changing n in the river network. But this might not be true universally. Thus, we prefer to keep the formulation as it is ("Interestingly, in the Claduègne catchment liquid discharge was more sensitive to changes in $n_{hillsl.}$ than to n_{river} while solid discharge was more sensitive to n_{river}. This was not the case in the Galabre where both liquid and solid discharges were more sensitive to $n_{hillsl.}$", line 360). Actually, changing n on the hillslopes had less impact on the sedigraphs than what could be expected. We discuss that in the paragraph l.378-381 where we have added information in brackets in the new version of the manuscript: "Our results showed that even though modeled liquid discharges were sensitive to $n_{hillsl.}$(e.g. maximum liquid discharge changed by 24% in the Claduègne catchment and 12% in the Galabre catchment), the sedigraphs of the main sources and thus of total suspended solid discharge were much less sensitive to this parameter (maximum solid discharge changed by 3% in the Claduègne catchment and by 1% in the Galabre catchment, Figure 8). This was due to the fact that in both catchments the main sediment sources were located close to the river (Table 1, Figure 2). Thus, only a small fraction of the trajectory of particles was located on the hillslopes."

372 What is meant by "more stable"?

We added "more stable in time" to be more precise.

379 Here and elsewhere, sensitivity should be presented as a relative measure. E.g., this output was more sensitive to choice/parameter A than to choice/parameter B. Without the comparison the statement is uninterpretable.

We added the percent change with respect to the basic scenario as a quantitative measure of sensitivity (information in brackets): "Our results showed that even though modeled liquid discharges were sensitive to $n_{hillsl.}$,(e.g. maximum liquid discharge changed by 24% in the Claduègne catchment and 12% in the Galabre catchment), the sedigraphs of the main sources and thus of total suspended solid discharge were much less sensitive to this parameter (maximum solid discharge changed by 3% in the Claduègne catchment and by 1% in the Galabre catchment , Figure 8)"

392 Here you discuss both a contrast between the two catchments, the analysis of Scenario 4, and connecting basin-wide metrics of IC with the sensitivity results. Recommend structuring the section to help the reader anticipate this.

We hope that the clarification made on objective 2 help the reader to better anticipate what is compared and discussed in this section.

393 Introduce this idea in the study design.

As you recommended, we announced the comparison of the two catchments in the new section "3.4 Study design and modeling scenarios": "With the presented study design, it could be assessed whether modeling choices or actual catchment configurations were more important in generating output variability."

397–399 This has already been stated.

Thank you for pointing that out. We propose to delete the sentence "The rising limb of the hydrograph was also steeper in the Galabre than in the Claduègne catchment (shorter Tlag and Tc, Figure 5, Table 3)." However we prefer to keep the second sentence. The steeper slopes of the Galabre catchment are assumed to be the reason for several findings: the faster reaction of the catchment, the steeper hydrograph and sedigraph, the lower sensitivity to Manning's n in the river.

402 Add a figure reference.

The figure reference is given 3 lines above: "From Figures 7 and 9 a general pattern of the contribution of the different geological sources to total solid discharge can be derived: In the Claduègne catchment […]" To make it more evident that this paragraph refers to figures 7 and 9 we propose to replace the full stop with a colon in line 400.

407 More specific. E.g., close = first, or something different?

We added a complement to the sentence (the last part of the sentence after the last comma): “In the Galabre catchment at the onset of the event (“1”), suspended sediment originated almost entirely from the black marls, i.e. the source closest to the outlet.”

421 It is not clear if Scenario 4 represents a different approach to tracking something else? Because the description of how Sc. 4 was constructed is incomplete it is nearly impossible to understand the results of Sc. 4.

Thank you for pointing out that the description of Sc. 4 was insufficient to understand it from an external perspective. We hope that this gets clearer after the changes we made in the methods section according to your comments above. However, as it seems to be an important point, we added a further explanation on how results were obtained l.422: “In this way, model output consisted of separate sedigraphs for the close and distant subsources of a given source class. The sum of these sedigraphs is the same as the sedigraph of that source class in the basic scenario.”

423–425 Give the reader a little more context about “typical interpretations of discharge sediment flux hysteresis” and provide a description of what a clockwise vs counterclockwise loop means.

We expanded the paragraph by giving a short description of the interpretations of Q-SSC flux hysteresis: “Figures 10 and 11 showed for the Galabre catchment that the limestone sources that were close to the river and the ones that were close to the outlet exhibited a clockwise discharge-sediment flux hysteresis pattern while the distant ones exhibited an anticlockwise pattern. These results confirmed typical interpretations of hysteresis loops, i.e. the assumption that clockwise loops indicate a dominance of close sources because maximum sediment flux occurs before peak discharge while anticlockwise hysteresis patterns indicate a dominance of more distant sources (Bača, 2008; Misset et al., 2019). The results further highlighted that the sedigraphs of the different sediment sources were strongly related to their location in the catchments and their structural connectivity.”

431 Not sure what is meant by this sentence.

We are not sur which sentence is referred to. We rephrased the two sentences which now say “Thus, the mean distance to the outlet was not sufficient to determine travel times of the sources to the outlet. Additionally, the triangular rain applied to both catchments lasted had a rather long periodduration, much longer than the times of concentration of both catchments.”

448 Unclear if distance to the outlet (or stream) being considered is related to the parameterization or the analysis of the results.

The latter is the case. The sentence was rephrased accordingly: “When the results were analyzed in terms of the distance to the outlet, it was remarkable that […]”

461 This sentence starts a new line of inquiry: which basin-wide metrics (Table 1) best predict the sensitivities documented by the numerical experiments. A more explicit discussion of the methods used here (e.g., comparing basin wide metrics to sensitivity ranking) should be added to the methods. In addition, the description of this analysis should be expanded.

We understood that this comment is related to the comment above that the reviewer wished to have a more explicit statement of the method used to "correlate" basin metrics to the metrics of the sedigraph. However, as stated earlier, we wish to refrain using statistical terms such as correlation or rank analysis for the comparison of only 5 data points.

465 This sentence is not clear.

Thank you for pointing that out. The idea behind this sentence is explained in the following sentences so we deleted this unclear sentence.

468 It is not clear that your study design supports this type of analysis. To my ability to tell you have not varied the location and/or erodibility of the sediment sources within the catchment. As such, your study design does not permit assessment of how variability in location of sediment sources influences the output metrics.

Indeed we cannot prove this statement with quantitative metrics of sensitivity. Nonetheless, we think that the analysis is justified. We did not vary locations of the sources but we compared different sources with different locations. Concerning erodibility, it is true that we don't report on how changes made in the erodibility coefficient impacts model output. This is due to the fact that detachment rate is linearly related to erodibility in our model. Thus, changing the values of alpha changes absolute values of detachment rate but not the temporal dynamics of sediment fluxes. We stressed that following your earlier comments by adding "While other factors that were not considered here (erodibility, rainfall intensity) crucially influence absolute values of erosion and suspended sediment concentration, their values are less important to determine arrival times and temporal dynamics of source contributions" in the new section "3.4 Study design and modeling scenarios".

469 The point you are making here is not clear, mostly because the text introduced at L344-350 is not clear.

Thank you again for noticing that this point was not clear. We hope that the changes we made in the results section (former L344-350) make it easier to follow this conclusion.

478 Unclear how the study is about source soils when the only erodible material is the exposed bedrock. This should be addressed here and earlier in the text.

We changed "source soils" to "sources" here. We also revised the description of what was considered a source in section 3.3: "[…] the potential erosion zones. The latter include all the mesh elements in the modeling unit "badland" and the mesh elements of the "hillslopes" modeling unit that belonged to the diffuse agricultural sources in the Claduègne catchment". Furthermore, Figure 1 now shows clearly what was considered as a source in the two catchments (Badlands in the Galabre catchment, Badlands as well as cultivated soils in the Claduègne catchment).

Most Figures In the many multi-panel plots I recommend use of consistent x and y axis limits and/or explicit notation of inconsistent axis limits in Figure captions.

Whenever this was possible we used consistent x and y limits. However, whenever two erosion zones were compared, it was not possible because then the dynamics in the graphs of the less erosive zone would not be visible because of the very different erodibility of the sources (e.g. the y-axis of fig. 6). Furthermore, we focus on temporal dynamics and not on absolute values in this study. Thus, we did not state this explicitly in the figure legends.

F10–13 The panel (f) is the sort of information that would be great to have in a revised Figure 1. The background color scheme for the inset maps (distance to outlet, distance to stream) should be represented by a legend.

As noted above, we prefer to keep figure 1 simple to stress the most important information on the location of the erosion sources and wish to keep the panel (f) in these figures where the focus is on the distance to the outlet and distance to the stream metrics.

T2 The layout of the table makes it difficult to see the difference between the scenario 4 options.

We revised the column "Aim" in Table 2 to better relate this table to the 2 objectives of the study. In the text we better explained why two sets of values for n were used in Sc. 4 following your comment above.

T3 1. Why are the simulations used for Scenario 4 not in the table?

As the classification of the sources was different in Sc. 4 than in the other scenarios we would have to give all 3 metrics (T_lag, T_c, T_spr) for each one of 31 subsources so this would add nearly 100 lines to the table which is already quite long.

2. Recommend adding some vertical lines to help guide the viewer in separating Sc. 1, Sc. 2, and the two halves of Sc. 3.

We prefer to keep the classic table layout without vertical lines.

3. Overlaying the table text on top of a tile plot is a great addition. However, the darkest blue values make reading the text impossible.

We changed the text color to white so that it is easier to read the text on the darkest blue shades.

4. Not clear why some values have NA, explain.

Following your comment, we explained this in the caption of the table: "NA values indicate that the hydrograph or sedigraph did not recede to 0.1 Qmax within the simulated time."

Author‘s response to Editor G. Hancock comments on “How do modeling choices impact the representation of structural connectivity and the dynamics of suspended sediment fluxes in distributed soil erosion models?” by Uber et al.

In the following, the reviewer comments appear in black italic and our answers are provided in blue. When there are quotations from the text of the article, they appear in quotation marks.

We wish to thank you for your comments that helped us to substantially improve the paper and we hope that the changes made accordingly will contribute to an easier understanding of the text.

Review of ‘How do modelling choices impact the representation of structural connectivity and the dynamics of suspended sediment fluxes in distributed soil erosion models’ by Uber et al. This is a timely paper. Given the number of hydrology and sediment transport models available understanding the sensitivity of parameters is extremely important. Therefore, the topic is of high interest. The paper reports on an assessment of model sensitivity in two catchment in France. The field data and numerical experiment is nicely done. However, there a few comments that need to be addressed that can make the paper stronger.

Thank you very much for the review of our manuscript and for the recognition of our work.

The Abstract summarises the paper nicely. However, the Introduction needs some attention. At the end of the Introduction, I largely agree and understand all the you have described, but I am not sure where the paper is really going. I have read the Introduction several times and it is not clear what you are really going to do. This leads to a comment about Section 3.4 (and its logic) which is somewhat difficult to rationalise in terms of the various model runs and setup. The Introduction needs to be refocussed with a much stronger and defined aim particularly at the end of the section. The sentence on lines 72-74 seems to summarise the overall intent of the paper. While the sentences on lines 92-94 are quite vague.

Thank you for pointing out that the introduction was not clear and that the objectives were not easily understandable. This flaw also got evident from some of the comments of the anonymous referee #1 and to some misunderstandings of the referee despite considerable effort made and multiple readings of the paper.

Following your comment and the comments by referee #1 we reformulated the sentence in line 92-94 you refer to: “This paper contributes to improve our understanding of the hydrosedimentary processes in the catchment that lead to sediment flux variability at the outlet”. We also slightly reformulated the objectives “Since model outputs are supposed to be highly sensitive to the choices made during model set-up, the first objective is to assess the impact of the choices made during model discretization and parameterization on modeled suspended sediment flux dynamics. A second objective is to assess how structural connectivity, particularly the location of the sediment sources, impacts modeled suspended sediment flux dynamics for both catchments.”

Moreover, we propose to change the title to better reflect these two objectives: “How do modeling choices and erosion zone locations impact the representation of connectivity and the dynamics of suspended sediments in a multi-source soil erosion model?”

We further revised the column “Aim” in table 2 to better relate this table to the two objectives of the study.

Line 174- Soil erosion module I have no problem with using a single layer in an instance like this. However, the model used here only models erosion? No deposition? I realise that the inclusion of deposition adds complexity and would likely slow model run time but what is the effect of neglecting this on the findings? Landscape Evolution Models have demonstrated that including deposition has a significant influence on erosion particularly gullying. I say this as you mention gullies in the Badlands in Section 3.3.

It is true that we don't include deposition in our model and we agree that it could be considered as a strong simplification of reality. However, in both catchments, the slopes of the stream are high (>2.5%) and mainly incised into the bedrock. Contrary to what can happen downstream of the measuring stations where the slopes of the river decrease considerably, the temporary storage of fine sediments and their resuspension are not dominant processes compared to the fluxes of fine sediments coming from the primary sources of the catchments. For further studies we plan to include deposition and resuspension to assess to which extent these temporary storages are important processes to consider in such catchment configuration. Nonetheless, in this first step, we wished to keep the model as simple as possible and to focus on the processes that we believed were the most important ones in our catchments (i.e. rainfall detachment and transport via surface runoff). Both of our study sites are prone to heavy rainfalls and flash floods that lead to high sediment exports during these events. We focus on these events where we believe that the sources are highly connected to the river network.

A further issue is that you are only modelling suspended sediment? Is this the case? What about bedload? Is the quantity of bedload significant? Should you be examining total load? Line 420-424. Here you talk about total solids. Does this include bedload? Or is it suspended load?

You are right, we are only modeling suspended sediments. When we wrote "total solid discharge" we meant the sum of solid discharge from the different sources. It is true that this is ambiguous, so we changed it to "total suspended load" or to "total suspended solid discharge" in line 421 and elsewhere.

Conclusion. Can this be rewritten to summarise succinctly the interesting work here. A Conclusion should summarise and largely be standalone with data presented. I suggest that lines 489-492 have been discussed elsewhere. As presented it reads like an extension of the Discussion and does not do the paper justice.

As suggested we have reorganized and shortened the conclusion to highlight the main findings of this study. We therefore propose the following conclusion in the revised version of the article that will be submitted.

"This study aimed to improve our understanding of hydrosedimentary processes leading to temporal variability in the contribution of potential sources to suspended sediments at the outlet of two mesoscale catchments using a distributed, physically based numerical model. As a first objective, we analyzed to which extent the choices made during model discretization and parameterization impacted the modeled suspended sediment flux dynamics. The shape and the magnitude of the modeled hydrographs and sedigraphs were sensitive to the contributing drainage area threshold to define the river network and to Manning's roughness parameter n in the river network and on hillslopes. However, the model was less sensitive to all three values once the parameters varied only in a restricted, reasonable range. The pattern of modeled source contributions remained relatively similar when the CDA threshold was restricted to the range of 15 to 50 ha, n on the hillslopes to the range 0.4-0.8 and to 0.025-0.075 in the river.

Then, the second objective was to assess how the location of geological sources in the catchment impacted the modelled temporal dynamics of suspended sediments at the outlets. The classification of the geological sources in subgroups showed that the hydrosedimentary responses differed in the two studied catchments due to the combined effects of the distance from the sources to the point of entry of sediments in the river network, the distance of the sources to the outlet as well as the slopes of hillslopes and rivers. Among the various structural connectivity indicators tested to describe the geological sources, the mean distance to the stream was found to be the most relevant proxy of the temporal characteristics of the modeled sedigraphs."

Other issues:

Line 128. What is 'molasses'?

It is a geological classification of sedimentary rocks. This was given in line 123 "The catchment is entirely located on sedimentary rocks comprising limestones (34%), marls and marly limestones (30%), gypsum (9%), molasses (9%) and Quaternary deposits (18%)."

I really liked the interactive figures

Thank you for the positive feedback on the interactive figures.

How do modeling choices and erosion zone locations impact the representation of connectivity and the dynamics of suspended sediments in a multi-source soil erosion model?

~~How do modeling choices impact the representation of structural connectivity and the dynamics of suspended sediment fluxes in distributed soil erosion models?~~

Magdalena Uber[1], Guillaume Nord[1], Cédric Legout[1], Luis Cea.[2]

[1]Univ. Grenoble Alpes, CNRS, IRD, Grenoble INP, IGE, 38000 Grenoble, France

[2]Environmental and Water Engineering Group, Department of Civil Engineering, Universidade da Coruña, A Coruña,

Correspondence to: Cédric Legout (cedric.legout@univ-grenoble-alpes.fr) France

Code de champ modifié

1.Abstract

Soil erosion and suspended sediment transport understanding is an important issue in terms of soil and water resources management in the critical zone. In mesoscale watersheds (>10km²) the spatial distribution of potential sediment sources within the catchment associated to the rainfall dynamics are considered as the main factors of the observed suspended sediment flux variability within and between runoff events. Given the high spatial heterogeneity that can exist for such scales of interest, distributed physically based models of soil erosion and sediment transport are powerful tools to distinguish the specific effect of structural and functional connectivity on suspended sediment flux dynamics. As the spatial discretization of a model and its parameterization can crucially influence how structural connectivity of the catchment is represented in the model, this study analyzed the impact of modeling choices in terms of contributing drainage area (*CDA*) threshold to define the river network and of Manning's roughness parameter (*n)* on the sediment flux variability at the outlet of two geomorphological distinct watersheds. While the model~~l~~ed liquid and solid discharges were found to be sensitive to these choices, the patterns of the modeled source contributions remained relatively similar when the CDA threshold was restricted to the range of 15 to 50 ha, *n* on the hillslopes to the range 0.4-0.8 and to 0.025-0.075 in the river. The comparison of both catchments showed that the actual location of sediment sources was more important than the choices made during discretization and parameterization of the model. Among the various structural connectivity indicators used to describe the geological sources, the mean distance to the stream was the most relevant proxy of the temporal characteristics of the mode~~l~~led sedigraphs.

Mis en forme : Normal

2.Introduction

Soil erosion and suspended sediment transport are natural processes that can be exacerbated by human activities and are thus a major concern for soils and water resources management. They cause on- and off-site effects such as the loss of fertile top soil, muddy flooding, freshwater pollution due to the preferential transport of adsorbed nutrients and contaminants, increased costs for drinking water treatment, reservoir siltation and aggression of fish respiratory systems (Owens et al., 2005; Brils, 2008; Boardman et al., 2019). Although these problems are already important in the Mediterranean and mountainous context (Vanmaercke et al., 2011), questions arise about the future evolution of suspended sediment yields due to the expected increase on the intensity and frequency of severe precipitation events in the following decades in these areas (Alpert et al., 2002; Tramblay et al., 2012; Blanchet et al., 2018).

In mesoscale catchments (<100 km²), which correspond to a relevant scale for decision makers, correct modeling of the hydrosedimentary responses requires a good understanding of the interactions between the spatiotemporal dynamics of the rainfall with the spatial distribution of the catchment geomorphological characteristics. Several studies have shown that the contributions of potential sediment sources can differ considerably from one flood event to another and at different times of sampling within a flood event (Brosinsky et al., 2014 ; Gourdin et al., 2014; Cooper et al., 2015; Gellis and Gorman Sanisaca, 2018; Vercruysse and Grabowski, 2019), particularly in watersheds with a Mediterranean or mountainous climate ~~Mediterranean and mountainous watersheds~~ (Evrard et al., 2011 ; Navratil et al., 2012; Poulenard et al., 2012; Legout et al., 2013; Uber et al., 2019). Possible reasons for the observed variability of suspended sediment fluxes from one event to another include seasonal variations of the climatic drivers of soil erosion and sediment transport, variability of the spatial distribution of rainfall, land cover changes and human interventions (Vercruysse et al., 2017). At the event scale, the distribution of sources within the catchment and thus different travel times of sediment from sources to the outlet as well as rainfall dynamics are assumed to be the dominant reason for the observed suspended sediment flux variability (Legout et al., 2013). Thus, the dynamics of suspended sediment fluxes during one event are hypothesized to result from the interplay of structural and functional connectivity of the sources in the catchment. Wainwright et al. (2011) define structural connectivity as the "extent to which landscape units are contiguous or physically linked to one another". ~~. What makes up these landscape units depends on the scale and the study objectives~~ In the context of soil erosion and sediment transfer studies it is of interest how active erosion zones are linked to the catchments outlet. ~~.~~ Structural connectivity can be measured using indices of contiguity (Heckmann et al., 2018). It is an intrinsic property of the landscape, that usually does not consider interactions, directionality and feedbacks. Functional connectivity on the other hand, specifically describes the linkage of landscape units by processes that depend e.g. on the characteristics of rain events. While some recent studies have shown the benefits of using the concepts of structural and functional connectivity to understand the spatial and temporal variability of sediment fluxes (Cossart et al., 2018; Lopez-Vicente and Ben-Salem, 2019), distinguishing both concepts remains challenging (Wainwright et al., 2011).

Distributed physically based models of soil erosion and sediment transport are powerful tools to distinguish the specific effect of structural and functional connectivity on suspended sediment flux dynamics. Some recent studies have already combined erosion and sediment transport modeling with sediment fingerprinting data (Theuring et al., 2013; Wilkinson et al., 2013; Palazón et al., 2014, 2016; Mukundan et al., 2010a, 2010b). However, all of these studies focused on long term mean source contributions, without working at high temporal resolution to understand the dynamics of suspended sediment fluxes within and between flood events. Yet, numerical models can help to understand the effect of the distribution of sources within the catchment, their linkage to the outlet, their travel times and the characteristics of the rain events on the variability of suspended sediment source contributions observed at the outlet.

The fact is that modeling soil erosion and sediment transport remains a challenge as there is no optimal model to represent all erosion and hydrological processes in the catchment and there is no standard protocol for the choice and set-up of the model (Merrit et al., 2003; Wainwright et al., 2008). Indeed, the outputs of hydro-sedimentary models are very sensitive to choices made by the modeler in the way that processes are selected and spatially implemented, as well as during model discretization, parametrization, forcing and initialization (Merrit et al., 2003). We consider especially that the spatial structure and the discretization of the model, as well as its parameterization can crucially influence how structural connectivity of the catchment is represented in the model. In mesoscale catchments, the connectivity of sources to the outlet depends a lot on the distance to the stream. In many cases, however, the definition of the stream is not unambiguous (Tarboton et al., 1991, Turcotte et al., 2001). In most cases, the river network is based on topographic analysis in GIS software, where a stream is made up of all the cells of the digital elevation model (DEM) that exceed a threshold of contributing drainage area (CDA, Tarboton et al., 1991; Colombo et al., 2007). The CDA of a DEM cell is the cumulative size of all cells that are located upstream of the given cell and that drain into that cell. Thus, the definition of the stream and in consequence the connectivity of active erosion sources to the outlet is highly dependent on the choice of the CDA threshold (Colombo et al., 2007). Concerning parameterization, travel times of the sources to the outlet and thus structural connectivity also depend on how surface water and sediment fluxes are calculated and parameterized. Many distributed models such as WEPP (Laflen et al., ~~(~~1991~~)~~), Kineros (Woolhiser et al., ~~(~~1990~~)~~) and Mike 11 (Hanley et al., 1998) use the depth-integrated shallow water equations (St. Venant equations) or different approximations of them, as the kinematic or the diffusive wave approximations, for routing surface water to the outlet of the catchment (Pendey et al., 2016). These equations are highly sensitive to the roughness parameter, which values depend whether shallow water with partial inundation on hillslopes or concentrated flow in rivers are model~~l~~ed (Baffaut et al., 1997; Tiemeyer et al., 2007; Fraga et al., 2013, Cea et al., 2016). This paper contributes to improve our understanding of the hydrosedimentary processes in the catchment that lead~~ing~~ to sediment flux variability at the outlet. We focus on the role of structural connectivity using a distributed physical based model, applied to two mesoscale Mediterranean catchments. Since model outputs are supposed to be highly sensitive to the choices made during model set-up~~discretization and parameterization~~, the first objective is to assess the impact of ~~these~~ the choices made during model discretization and parameterization on modeled suspended sediment flux dynamics~~the representation of structural connectivity~~. A second objective is to assess how structural connectivity, particularly ~~structural connectivity in turn~~the location of the sediment sources, impacts modeled suspended sediment flux dynamics for both catchments.

3.Methods

3.1.Characteristics of the modeled study sites

3.1.1 Catchment description

Both study sites are long term research observatories belonging to the French network of critical zone observatories (OZCAR, Gaillardet et al., 2018).

The 42 km^2 Claduègne catchment is a tributary of the Auzon river in Southeastern France. Being part of the Cévennes-Vivarais Mediterranean Hydrometeorological Observatory (OHMCV, Boudevillain et al., 2011), the catchment is a research site dedicated to the investigation of meteorological and hydrosedimentary processes during heavy rain events and flash floods (Braud et al., 2014; Nord et al., 2017). The climate is dominated by

Mis en forme : Normal, Justifié, Interligne : 1.5 ligne

Mediterranean and oceanic influences with heavy rain events occurring mostly in autumn and to a lesser extent in spring, and localized thunderstorms occurring more rarely in summer. These intense rain events can cause flash floods and high sediment export. Average annual precipitation is 1050 mm (Huza et al., 2014). The geology of the catchment is composed of basalts in the northern part and sedimentary rocks in the southern part. Uber et al. (2019) identified three sources of suspended sediment: i) marly calcareous badlands are the major source of suspended sediments due to their erodibility and connectivity to the river network, ii) diffuse sources on basaltic geology comprising cultivated fields (mainly cereals) that are temporarily bare and iii) diffuse sources on sedimentary geology equally comprise cultivated fields (mainly cereals) and vineyards where bare soil is found in between the rows of the vine plants (Figure 1a). Table 1 gives the surface and the slopes of the catchment and the erosion zones. The 20 km^2 Galabre catchment is a headwater catchment of the Bléone river located in the southern French alps (Figure 1b). It is part of the Draix-Bléone Observatory dedicated to the study of hydrology and erosive processes in a mountainous context with extensive badlands. The climate of the Galabre catchment, whose altitude varies between 735 and 1909 m, is impacted by Mediterranean and mountainous influences with a mean annual precipitation of around 1000 mm. There is a high seasonality with most precipitation occurring in spring and autumn, although thunderstorms with high rain intensity also occur in summer (Esteves et al., 2019). The catchment is entirely located on sedimentary rocks comprising limestones (34%), marls and marly limestones (30%), gypsum (9%), molasses (9%) and Quaternary deposits (18%). A prominent feature of the catchment are the badlands, that are found on all five types of rock and cover about 9.5% of the surface of the catchment (Esteves et al., 2019). The land use is dominated by forests and scrublands, - which are permanently covered by vegetation and are thus assumed to be negligible as sediment sources. Agricultural~~while agricultural~~ zones are barely present in the catchment. Suspended sediment fingerprinting studies revealed that most of the sediments originate from the badlands of molasses and marls (Poulenard et al., 2012; Legout et al., 2013). Table 1 gives the characteristics of the catchment. In comparison, the Galabre catchment is smaller and steeper than the Claduègne catchment. The distribution of the erosion zones differs in the two catchments, with the ones in the Galabre catchment being more dispersed over the entire catchment but smaller in size due to the absence of diffuse agricultural sources.

Liquid and solid fluxes are continuously monitored at the outlets of both catchments with the same sensors and protocols, from which suspended sediment yields are calculated (Table 1). Water level is measured with an H-radar and converted to discharge with a stage discharge rating curve. Suspended sediment concentrations are monitored with turbidimeters and suspended sediment samples are automatically taken every 40 min once a threshold of turbidity and water level is exceeded. These samples are dried and weighed and are used to establish a rating between turbidity and suspended sediment concentrations.

3.1.2 Connectivity indicators

In order to quantify the structural connectivity of the sources in the catchments, four indicators were calculated, i.e. the distance to the outlet, distance to the stream and the two indices of connectivity (IC) proposed by Borselli et al. (2008) and Cavalli et al. (2013). The distance to the outlet metric refers to the width function and is applied as a measure of network structure and catchment shape by Hancock et al. (2010). Maps of the distance to the outlet along the flowlines (i.e. the distance that water and sediments travel following the gradient of the terrain elevation) and the distance to the stream were created. For the latter, the stream network obtained with a CDA threshold of

Mis en forme : Titre 3, Gauche

50 ha was used. The distance to the outlet and the distance to the stream of a given position in the catchment serve as proxies of longitudinal (upstream-downstream) and lateral (hillslope-channel) ~~and lateral~~ connectivity in the sense of Fryirs (2013). Both maps were created using TauDEM (Tarboton, 2010) and a digital elevation model at a resolution of 1m (Claduègne: bare earth Lidar DEM, Nord et al., 2017; Galabre: RGE ALTI product of IGN, 2018). However, neither of these measures takes into account surface roughness and slope. Thus, two of the most widely used indicators of connectivity, i.e. the IC proposed by Borselli et al. (2008) and the adjusted version of IC proposed by Cavalli et al. (2013), were calculated. Both indicators were calculated for each pixel of the DEM and take into account the CDA of that pixel and the distance to the stream along the flow lines. They also both include a weighting factor for the mean slope in the CDA and along the downstream path as well as a second weighting factor *W*. Borselli et al. (2008) weight the index with land use, thus the factor *W* was derived from the values proposed by Panagos et al. (2015) for the land use data that was obtained from Inglada et al. (2017). Cavalli et al (2013) on the other hand propose a roughness index as the weighting factor *W* that represents a local measure of topographic surface roughness that is calculated for a 5 x 5 cell moving window. Both indicators were calculated using the program SedInConnect (Crema and Cavalli, 2017). All these four indicators were calculated for each pixel within the catchments and their values on the erosion zones were extracted. Mean values and standard deviations are given in Table 1, while the distributions of the distance to the outlet and to the stream are shown in Figure 2. These characteristics of the catchments indicate that not only erodibility but also structural connectivity differs strongly between the two catchments and between sources.

3.2.Model description

~~Equations describing the hydraulic routing of water, soil erosion and sediment transport are implemented in the 2D software Iber (Cea and Bladé, 2015):~~ Surface runoff, ~~sediment transport and~~ soil erosion and sediment transport in the study catchments were modeled with an ad-hoc version of the software Iber (Bladé et al., 2014) developed in a previous study~~ies~~ by the authors (Cea et al. 2016). A detailed description of the model and numerical schemes is beyond the scope of this paper and can be found in previous publications. Thus, just a brief description of the model equations is presented in the following.

Hydrodynamic module

Water depth and velocity fields are ~~derived~~ computed from the solution of the 2D depth-averaged shallow water ~~full St. Venant~~ equations applied to the whole catchment domain (including ~~the~~ hillslopes and ~~the river network~~channel)~~both on the hillslopes and in the river network~~. Including rainfall and infiltration terms as well as Manning's formula for bed friction the hydrodynamic equations solved by the model ~~they~~ can be written as:

$$\frac{\partial h}{\partial t}+\frac{\partial q_x}{\partial x}+\frac{\partial q_y}{\partial y}=R-I$$

$$\frac{\partial q_x}{\partial t}+\frac{\partial}{\partial x}\left(\frac{q_x^2}{h}\right)+\frac{\partial}{\partial y}\left(\frac{q_x q_y}{h}\right)=-gh\frac{\partial z_s}{\partial x}-g\frac{n^2}{h^{7/3}}|q|q_x \qquad (1)$$

$$\frac{\partial q_y}{\partial t}+\frac{\partial}{\partial x}\left(\frac{q_x q_y}{h}\right)+\frac{\partial}{\partial y}\left(\frac{q_y^2}{h}\right)+=-gh\frac{\partial z_s}{\partial y}-g\frac{n^2}{h^{7/3}}|q|q_y$$

where h is the water depth, t is time, q_x and q_y are the components of the unit discharge in the two horizontal directions, R is the rainfall intensity, I is the infiltration rate, g is gravity acceleration, z_s is the elevation of the free surface and n is Manning's roughness parameter. The shallow water equations are solved with an unstructured finite volume solver developed in Cea and Bladé (2015) for rainfall runoff applications at the catchment scale.

The solver is explicit in time, meaning that the maximum time step that can be used to evolve the equations in time is limited by the Courant-Friedrichs-Lewy (CFL) condition (Courant et al. 1967). This implies that the time step in typical applications is of the order of one second or less. The CFL condition is implemented in the solver and thus, the computational time step is automatically evaluated from the grid size, water velocity and water depth.As the focus of this study is on choices made during model set-up and how structural connectivity is represented, a synthetic triangular hyetograph (duration of 12 h, maximum intensity of 5 mm h^{-1}) representing effective precipitation (i.e. *R-I*) is applied spatially homogeneous over the entire catchment.

Soil erosion module

The A full description of the soil erosion model can be found in Cea et al. (2016) and a summary is given here. The complete soil erosion model uses a two-layer soil structure that consists of one layer of eroded material over a layer of non-eroded cohesive soil. Different sediment classes, each one with its own physical properties, can be considered and routed with the model.

Given the results of Cea et al. (2016) that the two-layer structure of the model increases its complexity without significantly improving its predictive capacity in real applications, we only use a single-layer structure with vertically uniform erodibility. We assume that the single-layer structure is adequate for the badlands where there usually is a thick regolith layer, and erosion from the underneath cohesive layer is negligible compared to the one of the regolith layer. In the complete model, two particle detachment processes are considered, i.e. rainfall-driven detachment and flow-driven entrainment. In our case, we assume that rainfall-driven detachment is the most significant of both processes and thus, it is the only detachment mechanism considered in our simulations. We further assume that all eroded particles are transported in suspension to the outlet and that deposition is negligible. This wash load hypothesis leads to a further simplification of the erosion module compared to the original one proposed by Cea et al. (2016), i.e. the omission of the deposition term. Given the previous assumptions, the soil erosion model used in this work solves the following mass conservation equation for each sediment class considered:Thus, the suspended sediment concentration at every time step and location is calculated from Eq. 2, which is a simplified version of the equation given in Cea et al. (2016) for the case where a single-layer structure, only rainfall-driven detachment and no deposition are assumed:

$$\frac{\partial h C C_s}{\partial t} + \frac{\partial q_x C_s C}{\partial x} + \frac{\partial q_y C_s C}{\partial y} = D_{rdd,s} \qquad s = 1, N_c$$

(2)

where N_c is the number of sediment classes, C_s C [kg m^{-3}] is the depth-averaged sediment concentration of the sediment class *s* in the water column and $D_{rdd,s}$ [kg m^{-2} s^{-1}] is the rainfall-driven detachment rate for the sediment class *s*. The rainfall-driven detachment that is calculated assuming a linear relationship between the detachment rate and the rain intensity, i.e. $D_{rdd,s} = \alpha_s R$, where α_s [kg mm^{-1} m^{-23}] is the rainfall erodibility coefficient for the sediment class *s* and that represents the flux of sediment mass flux detached per unit area by a unit rainfall intensity. Thus, the suspended sediment concentration at every time step and location is calculated from Eq. 2, which is a simplified version of the equation given in Cea et al. (2016) for the case where a single-layer structure, only rainfall-driven detachment and no deposition are assumed.: Eq. 2 is solved with an unstructured finite volume solver using the same spatial discretisation as for the hydrodynamic equations. For a detailed description of the numerical schemes used to solve Eq. 2 coupled to the shallow water equations the reader is referred to Cea and Vázquez-Cendón (2012). The solution of Eq. 2 allows us to compute the concentration, and thus the mass fluxes (as the product of the concentration times the unit discharge)~~,~~ of each sediment class at any time and location in the catchment, and in particular, the contribution of each sediment class to the total sedigraph computed at the basin outlet.

~~*Solution schemes*. The model equations are solved with a finite volume solver, using an explicit temporal discretisation. A detailed description of the numerical schemes is beyond the scope of this paper. The reader is referred to Cea and Bladé (2015) and Cea and Vázquez-Cendón (2012) for details on the numerical methods.~~

3.3.Model discretization and input data

~~The geometry of the catchments is divided in~~ As a distributed model, Iber requires a computational mesh which is made up by three main modeling units with different spatial discretization and roughness coefficients, i.e. the river network, the hillslopes and the badlands. The river bed was delineated by i) identifying the river network using TauDEM (Tarboton, 2010) and ii) creating a polygon by "buffering" the line feature of the river. In order to take into account that the width of the river varies from upstream to downstream, we introduced a distinction between the perennial river network defined using a CDA of 500 ha and the intermittent river network obtained using a CDA of 15 ha. ~~-~~While the highest value of 500 ha is often used for cartography and large scale modeling studies (e. g. Colombo et al., 2007; Vogt et al., 2007; Bhowmik et al., 2015), the smallest value of 15 ha was found to create a river network that includes the intermittent streams observed in the catchment. For the former a buffer of 10 m to both sides of the river was applied. For the latter, composed of small tributaries and in good agreement with field observations of the whole extension of the hydrographic network during floods, a buffer of 5 m was applied. The badlands were delineated based on orthophotos and verified during field trips, while the hillslopes cover the rest of the catchments. While the badlands are a part of the hillslopes in terms of geomorphology and hydraulics, we differentiated them here to be able to apply a different parameterization and discretization.

These principal modeling units were discretized as a finite volume mesh. In our study, we used an unstructured triangular mesh with variable mesh size in the different units. The smallest mesh size was required in the modeling unit "river network", where water and sediment fluxes are concentrated, so it was set to 5 m. ~~On~~ In the modeling unit "hillslopes" a coarser mesh size of 100 m was chosen in order to reduce the number of elements and thus computation time. In the modeling unit "badlands", where the fluxes are concentrated in the steep gullies, an intermediate mesh size of 20 m was used. At the border between two ~~landscape~~ modeling units the mesh size evolves gradually. With this discretization the model of the Claduègne consists of roughly 173.000 mesh elements, while the one of the Galabre catchment of 75.000 elements. Values for Manning's ~~n~~ and erodibility were assigned ~~element~~to each mesh element. The Manning's roughness ~~coefficients~~ parameter was~~ere~~ ~~spatially~~ uniform in each modeling unit but could vary from one scenario to another with values ranging from 0.025 to 0.1 in the "river network" and from 0.2 to 0.8 in ~~the two other units~~"hillslopes" and "badlands". It was chosen that the domain would get two Manning's values (channel vs hillslope), i.e a value for the modeling unit "river network" and another value for the modeling units"hillslopes" and "badlands".~~.~~

While runoff is generated and routed in the entire catchment, the production of sediment was limited to the potential erosion zones. The latter include all the mesh elements in the modeling unit "badlands" and the mesh elements ~~on the~~of the "hillslopes"~~s~~ modeling unit that belonged to the diffuse agricultural sources in the Claduègne catchment. The erosion zones were classified according to ~~While equations 1 and 2 are solved on the entire catchment, the production of sediments was restricted to the potential erosion sources that were classified~~

~~according to~~ i) their geology, i.e. in three classes for the Claduègne and four for the Galabre catchment (Figure 1), ii) their geology and their distance to the outlet (Figure 2a,c) and iii) their geology and their distance to the stream network (Figure 2b,d). ~~Separate sedigraphs were calculated for each source class, solving equation 2 in each mesh element for each source class separately.~~ Sediment production ($D_{rdd,s}$~~Eq. 2~~) was calculated in each mesh element of the potential erosion zones for each source class separately. Sediment transfer (Eq. 2) ~~i~~was then routed over the entire catchment. Thus, separate sedigraphs for each source class were obtained at the outlet of the catchment and the contribution of each source class to total sediment flux could be calculated for every time step. The rain erodibility coefficient α of each geological class was estimated from the available observed time series of suspended sediment concentrations (SSC), discharge and rainfall. Using the discharge and SSC, the suspended sediment flux was calculated and integrated over time for each recorded event to obtain event suspended sediment yield SSYev [g]. The value of α [g mm^{-1} m^{-2}] was estimated separately for every event and every source as:

$$\alpha_{s,ev} = \frac{SSY_{s,ev}}{R_{ev} \cdot A_s} \qquad (3)$$

where A_s is the erodible surface of the respective source and R_{ev} [mm] is the amount of effective rainfall during the respective event. $SSY_{s,ev}$ is the contribution of source *s* to SSY_{ev} and was calculated based on the mean source contributions. They were estimated with sediment fingerprinting in the Claduègne catchment by Uber et al.~~,~~ (2019) and in the Galabre catchment by Legout et al.~~,~~ (2013). ~~mean source contributions obtained from sediment fingerprinting studies in the Claduègne (Uber et al. 2019) and the Galabre (Legout et al., 2013).~~ An average value of α_s ~~[g mm^{-1} m^{-2}]~~ was calculated by averaging over all the available observed events (Table 1). As the focus of this study is on choices made during model set-up and how structural connectivity is represented, a synthetic triangular hyetograph (duration of 12 h, maximum intensity of 5 mm h-1) representing effective precipitation (i.e. R-I) is applied spatially homogeneous over the entire catchment. ~~-~~The simulated time is 24 h, including 12 h of rain and 12 h for the fluxes to reach the outlet.

3.4. Study design and ~~Modeling~~ modeling scenarios

To achieve the first objective dealing with the impact of modeling choices on the temporal dynamics of modeled hydro-sedimentary fluxes, a one-factor-at-a-time sensitivity analysis (Pianosi et al., 2016) was conducted. The model was set-up and parameterized in a basic scenario (Table 2, Sc.1) and then subsequently two different input factors were varied~~-~~: the CDA threshold to define the river network (Sc. 2) and Manning's roughness parameter n (Sc. 3). Based on preliminary studies that are not reported here, these two factors were found to be the most important ones in determining sediment flux dynamics. While other factors~~ that were not considered here~~ (erodibility, rainfall intensity) crucially influence absolute values of erosion and suspended sediment concentration, their values are less important to determine arrival times and temporal dynamics of source contributions. For the second objective dealing with the impact of the location of erosion zones, indicators of structural connectivity of the two catchments are used to describe the configuration of each sediment sources in the catchments. They are compared to the modeled hydro-sedimentary fluxes both qualitatively by visual analyses and quantitatively by means of the calculation of characteristic times~~-scales~~ of the hydrographs and sedigraphs (e.g. time of concentration, lag time). To this end, another ~~third~~ set of scenarios w~~as~~ere generated where the sediment sources were subdivided into more or less connected zones (Table 2, Sc. 4).

The underlying hypothesis is that both modeling choices (notably CDA threshold and Manning’s n) and catchment characteristics (structural connectivity of the sources) determine travel times from the sources to the outlet. With the presented study design, it could be assessed whether modeling choices or actual catchment configurations were more important in generating temporal variability in sediment outputs.

Sc.1: Basic scenario

In the basic scenario the threshold to define the river network was set to 15 ha and the sources were classified according to their geology as in the sediment fingerprinting studies. In the “river network” modeling units, Manning’s *n* was set to 0.05 and in the “hillslopes” and “badlands” modeling units it was set to 0.8. The value in the river network corresponds to what can be expected from values reported in the literature for streams comparable to the Claduègne and the Galabre (Te Chow, 1959; Barnes, 1967; Limerinos, 1970). For the values on the hillslopes there are fewer recommendations from the literature as the use of the St. Venant equations for the calculation of fluxes on hillslopes is much less common. Existing studies indicate that the values have to be considerably higher than those used commonly in river flow models (Engman et al., 1986; Hessel et al., 2003; Fraga et al., 2013; Hallema et al., 2013). As these values are uncertain, the impact of this parameterization was assessed in further scenarios. The basic scenario was used as the main reference to compare the other scenarios to and for the comparison between the two catchments.

Sc. 2: Impact of the CDA threshold

We tested the impact of varying the CDA threshold on the modeled hydro-sedimentary response while keeping all other parameters unchanged compared to the basic scenario (one-factor-at-a-time sensitivity analysis). As different values for Manning’s n were applied in the “river network” modeling unit~~s~~ on one hand and in the “hillslopes” and “badlands” modeling units on the other hand, the travel times of the sediments from source to sink vary depending on the length of the river network in the model. Thus, it can be assumed that modeled sediment dynamics are sensitive to this parameter. Five values of the CDA threshold were used: 15, 35, 50, 150 and 500 ha.

Sc. 3: Impact of the parameterization of Manning's n

As ~~one of~~ the first objective~~s~~ of this study is to assess the impact of choices made during model set-up on the simulated sediment flux dynamics, the model was run with different values of Manning’s *n* in the “river network” modeling unit~~s~~ on one hand and in the “hillslopes” and “badlands” modeling units on the other hand. In the river network units, values were varied spanning a range from 0.025 to 0.100. This corresponds to the full range of plausible values (Te Chow, 1959; Barnes, 1969; Limerinos, 1970). In the “hillslopes” and “badlands” modeling units, the value of 0.8 used in the basic scenario is already at the upper end of values reported in the literature (e.g. Te Chow, 1959; Engman, 1986; Hessel et al., 2003; Hallema et al., 2013). Thus, values in the range of 0.2 to 0.8 were tested.

Sc. 4: Source classification based on connectivity

In order to test how the spatial distribution of the sources in the two distinct catchments contribute to the modeled sedigraph at the outlet, the geological sources were classified into subclasses based on their distance to the outlet (Sc 4a,c) and distance to the stream (Sc 4b,d). These two measures serve as a proxy for the structural connectivity of the sources. The underlying hypothesis is that depending on their connectivity, several patches of the same source have different travel times to the outlet and can therefore lead to several peaks in the sedigraph of the source. In Sc 4b and 4d , the geological sources were classified in two groups based on their distance to the stream. The badland sources in both catchments were classified as being directly adjacent to the stream network or not. The diffuse sources in the Claduègne catchment, i.e. cultivated soils on basaltic and sedimentary geology, were classified using a threshold of distance to the stream of 150 m. In Sc 4a and 4c, the geological sources were classified in one to four groups depending on their distribution to the outlet (Figures 2a and 2c). Besides the values for Manning's n used in the basic scenario, in Sc. 4c and 4d we used values for Manning's n that were less contrasted between the hillslopes and the river network. This was done to assess whether the interpretation of Sc.4a and 4b depended on the values of n. It should be stressed that this source classification does not influence model physics, i.e. total sediment yield from a source (close + distant sources) remains the same as in the basic scenario where they are not differentiated.

3.5.Comparison of scenarios

Modelled outputs for each scenario can be accessed and visualized through Uber et al. (2020). To assess the impact of the changes done in each scenario with respect to the basic scenario, several characteristics of the modeled hydrograph and sedigraphs of all sources were calculated. The lag time of liquid discharge $T_{lag,Ql}$ is calculated as the time between the barycenter of the hyetograph and the barycenter of the hydrograph. The time of concentration of liquid discharge $T_{c,Ql}$ is defined as the time between the end of effective precipitation and the end of the outlet hydrograph. A third characteristic time, $T_{spr;Ql}$, was defined to assess the spread of the hydrograph and thus, a characteristic duration of the flood event (Figure 3). All of these measures were also calculated for solid discharge ($T_{lag,Qs}$, $T_{c,Qs}$, $T_{spr,Qs}$) and for each source separately. Further, maximum liquid discharge $Q_{l,max}$ and solid discharge $Q_{s,max}$ were determined for each scenario. Our simulations were truncated 12 h after the end of precipitation and in some cases fluxes did not recede to zero, so a threshold of 0.1 Q_{max} was used to calculate T_{lag}, T_c and T_{spr} for solid and liquid discharges. We use these metrics to quantitatively assess differences in model output between the scenarios described above.

4.Results and discussion

4.1.Impact of modeling choices on modeled sediment dynamics

Varying the contributing drainage area threshold

Results show that the modelmodeled hydrographs and sedigraphs were was sensitive to the choice of the CDA threshold used to define the river network. Figure 4 shows the modeled hydrographs that were obtained when the CDA threshold was varied from 15 to 500 ha. For both catchments, higher values led to a less steep rising limb of the hydrograph, lower and later peak flow, slower recession and a flatter hydrograph (Figure 4a,c). Thus, the lag time T_{Lag}, time of concentration T_c and time of spread T_{spr} of liquid discharge increased with increasing CDA threshold (Figure 5a,b,c; Table 3). In both catchments, the hydrographs obtained with thresholds of 15, 35 and 50 ha were relatively similar, but the results obtained with 150 and 500 ha differed considerably. In the Claduègne catchment peak flow was reduced by approximately a factor 2 when the threshold was increased from 15 to 500 ha, while in the Galabre catchment it decreased by about 20% (Table 3). In the Claduègne catchment the hydrograph obtained with the threshold of 500 ha was much flatter than the one in the Galabre catchment and the recession was very slow, so that even 12 h after the end of precipitation, discharge at the outlet persisted. This was not the case in the Galabre catchment.

The different hydrological response could not be attributed to the difference in size of the catchments alone, because a subcatchment of the Claduègne that has the same size as the Galabre catchment and a similar mean slope than the entire Claduègne catchment (mean +/- sd: 25 +/- 32 %) also had a less steep rising limb of the hydrograph than the Galabre (Figure 4b). The T_{Lag} of 3.2 h (basic scenario) was smaller than the one of the Claduègne catchment at the outlet (4 h) but also considerably larger than the one of the Galabre catchment (2.3 h). Thus, we assume that the fast rise and recession of the hydrograph in the Galabre catchment were mainly due to the steeper slopes in this catchment (Table 1) given that the lengths of the river networks are similar. This is coherent with the presumption that catchment response times are negatively correlated with catchment slopes (Gericke and Smithers, 2014).

The modeled response of the sedigraphs were also very sensitive to the CDA threshold. T_{lag}, T_c and T_{spr} of solid discharge increased generally with increasing CDA threshold, in particular from 150 to 500 ha (Figure 5a,b,c; Table 3). Nevertheless, the changes of CDA did not affect the sedigraphs similarly for each sediment source. In the Claduègne catchment, the sedigraphs obtained with CDA thresholds of 15, 35 and 50 ha were similar to each other, but when larger values were used, they varied substantially for each sediment source (Figure 6a,b,c,d). In particular, the sedigraphs of the basaltic and sedimentary sources were considerably delayed when the 500 ha threshold was used. In the Galabre catchment the sedigraphs of all sources were highly sensitive to significant changes of the CDA threshold with changes in $T_{lag,Qs}$ and $T_{c,Qs}$ of more than 100% for the CDA threshold of 500ha (Table 3). When the threshold of 500 ha was used, the shape of the sedigraph of some sources differed. Indeed, for the badlands in the Claduègne catchment and the black marls and the molasses in the Galabre catchment, the single peak sedigraph turned into a multi peak sedigraph (Figure 6).

The differences in the modeled sedigraphs when different values for the CDA threshold were used were also obvious when the simulated contributions of the sources to total suspended sediment load were regarded (Figure 7 and interactive figures at https://shiny.osug.fr/app/EROSION_MODEL.2020). Increasing the CDA threshold from 15 to 500 ha notably prolonged the first flush of black marl dominated sediment in the Galabre catchment (marked as “1” in Figure 7c,d). During the rising limb of the hydrograph and peak flow (marked “2”), the source contributions were variable while they remained relatively constant during the recession period (“3”) when the CDA threshold of 500 ha was used. This was not the case when the threshold was set to 15 ha. In this case, the contribution of molasses decreased steadily throughout the event while the one of limestone and quaternary deposits increased (“2”,”3”, and “4” in Figure 7c). In the Claduègne catchment notably the arrival of the basaltic sources at the outlet was much delayed when the CDA threshold of 500 ha was used compared to when the one of 15 ha was used. The shape of the sedigraph with multiple peaks that was modeled with a threshold of 500 ha resulted in a slower and less steady recession of the badland sources (Figure 7b).

Overall, our results showed that the thresholds of 15, 35 and 50 ha produced very similar results. Thus, in this range, the model was~~, i.e. the catchments were~~ not very sensitive to the CDA threshold~~ in this range~~. The parameters given in Table 3 changed by a maximum of 37% compared to the basic scenario. Other authors have shown that the CDA thresholds can vary spatially (i.e different values are found in different subcatchments) and temporally (CDA thresholds vary between seasons or between events; Montgomery et al., 1993; Bischetti et al., 1998; Colombo et al., 2007). In the studied catchments, variability in this range seemed not to be of prime importance. However, the larger thresholds of 150 and 500 ha changed the modeled sediment dynamics considerably (changes of up to 280% with respect to the basic scenario and several parameters changed > 150%,

Code de champ modifié

Table 3). This result showed that it is important to use a CDA threshold that is in the right same order of magnitude as the value that produces a realistic river network.. compared to fField observations or detailed maps (i.e. topographic map at scale 1:25000) can be valuable sources of this information for this purpose. The sensitivity of model output to variations of the CDA threshold was also observed by other authors (Pradhanang and Briggs, 2014). For our modeling set-up it is reassuring that model results converged when the CDA threshold used is derived from in the "right" order of magnitude that can be expected from field observations. Pradhanang and Briggs (2014) also tested the effect of CDA threshold on annual sediment yield and streamflow modeled with the AnnAGNPS model. In their study, they observed a high sensitivity of the model output to variations of the CDA threshold from 0.5 to 20% of catchment area (5-25 km²). Differently to our study, they did not observe a convergence of the results in the "right" order of magnitude of the CDA threshold but results differed strongly between the 6 considered catchments.

Mis en forme : Normal

Varying Manning's n

Changing Manning's *n* influenced the timing, the peak and the spread of both liquid discharge and total solid suspended sediment loaddischarge (Figure 8, Table 3). In general, increasing n_{river} *and* $n_{hillsl.}$ led to a later time of rise of the hydrograph, a later time of peak and to slower recession with longer $T_{lag,Ql}$ and $T_{c,Ql}$ (Figure 5, Table 3). Nevertheless Q_{lmax}, $T_{lag,Ql}$, $T_{c,Ql}$ and $T_{spr,Ql}$ were less sensitive to changes of n_{river} and $n_{hillsl.}$ in the Galabre than in the Claduègne catchment (Figure 5, Table 3). While increasing *n* also led to less maximum liquid discharge, this was not the case for solid discharge. Peak solid discharge even increased with increasing n_{river} in the Claduègne catchment and to a lesser degree also in the Galabre catchment (Table 3). Interestingly, in the Claduègne catchment liquid discharge was more sensitive to changes in $n_{hillsl.}$ than to n_{river} while solid discharge was more sensitive to n_{river}. This was not the case in the Galabre where both liquid and solid discharges were more sensitive to $n_{hillsl.}$.

Changing Manning's n also influenced the temporal dynamics of source contributions. A low $n_{hillsl.}$ of 0.2 led to a multi-peaked sedigraph in the Claduègne catchment (Figure 8b). This difference in the shape of the sedigraph also led to a difference in the modeled temporal dynamics of the percentage of source contributions (Figure 9a). When $n_{hillsl.}$ was set to 0.2, the decrease of the contribution of the badland sources to total suspended sediment load in the Claduègne catchment was slower during the main part of the event (marked "2" in Fig 9a) and the break point between phase 2 and 3 in the decrease of the badland source was more pronounced than in the basic scenario where $n_{hillsl.}$ was set to 0.8 (Figure 7a). In fact, for several hours during phase 2, the contributions of the three sources were nearly constant. This was not the case for the scenarios 3b and 3c where $n_{hillsl.}$ was set to 0.4 and 0.6. These scenarios hardly differed from the basic scenario (see interactive figures). In the Galabre catchment the scenarios 3b and 3c also hardly differed from the basic scenario. When $n_{hillsl.}$ was set to 0.2, the contributions during the main part of the event ("2" in Figure 9b) remained more stable in time than in the basic scenario (Figure 7c).

Code de champ modifié

Changing n_{river} hardly changes the dynamics of the modeled source contributions in both catchments (see interactive figures). In the Claduègne catchment, increasing n_{river} from 0.025 to 0.1 generally increased $T_{lag,Qs}$ and $T_{c,Qs}$ (Figure 5, Table 3) and led to a slight prolongation of the first flush of sediments from the sedimentary source. In the Galabre this was also the case for the first flush of sediments originating from black marl, as it was the case for the changes in the CDA threshold shown in figure 7d.

Code de champ modifié

Our results showed that even though modeled liquid discharges were sensitive to $n_{hillsl.}$, (e.g. maximum liquid discharge changed by 24% in the Claduègne catchment and 12% in the Galabre catchment), the sedigraphs of the main sources and thus of total suspended solid discharge were much less sensitive to this parameter (maximum solid discharge changed by 3% in the Claduègne catchment and by 1% in the Galabre catchment , Figure 8). This was due to the fact that in both catchments the main sediment sources were located close to the river (Table 1, Figure 2). Thus, only a small fraction of the trajectory of particles was located on the hillslopes. This was also represented in the modeled dynamics of the source contribution which barely changed unless the most extreme value of 0.2 was applied. This result suggests that it is sufficient to have a rough idea of the value of Manning's n to study the dynamics of sediment fluxes. In the Claduègne catchment the modeled sedigraph was affected by variations of n_{river} which was less true for the Galabre catchment. This might be related to the difference of slopes of the river network in both catchments. Indeed, the mean slope in the river network is 2-3 times higher in the Galabre than in the Claduègne catchment (Table 1), suggesting that the model was more sensitive to changes in Manning's n when slopes were low. However, also in the Claduègne catchment, changes in n_{river} did not change the modeled dynamics of the source contributions, which was again encouraging for the use of this type of model to understand hydro-sedimentary dynamics.

4.2.The role of structural connectivity on the dynamics of suspended sediment fluxes at the outlet

The application of the same rainfall event with a similar spatial discretization and parameterization to the two studied catchments (i.e. basic scenario) allowed to provide a more detailed analysis on how their respective characteristics influenced their hydrosedimentary response. A first result was that the Galabre catchment reacted faster than the Claduègne catchment. The hydrographs and the sedigraphs rose earlier than in the Claduègne catchment.~~ The rising limb of the hydrograph was also steeper in the Galabre than in the Claduègne catchment (shorter T_{lag} and T_c, Figure 5, Table 3)~~. We assume that this was mainly due to the steeper slopes of the Galabre catchment (Table 1). From Figures 7 and 9 a general pattern of the contribution of the different geological sources to total ~~solid discharge~~suspended sediment load can be derived:~~.~~ In the Claduègne catchment at the onset of the event ("1"), the sediments originated from the sedimentary source and the badlands. During the phases 2 and 3 of the event, the main source (i.e. the badlands, Table 1) clearly dominated total ~~solid discharge~~suspended sediment load. The contribution of this source decreased gradually while the percentage of contribution of the two others increased. In the Galabre catchment at the onset of the event ("1"), suspended sediment originated almost entirely from the black marls, i.e. the source closest to the outlet. In the second phase of the event, the main source (i.e. molasse) arrived and clearly dominated total ~~solid discharge~~suspended sediment load. Thereafter, the contribution of the molasses decreased while the one of the limestones and the quaternary deposits increased (phases 3 and 4). These general patterns were broadly consistent with the location of the different geological sources in the two catchments. However, some discrepancies appear when comparing the timings of arrivals of the various geological sources to the ranking of the various connectivity indicators (i.e. distance to stream, to outlet, *IC* Borselli and *IC* Cavalli). The lag times of the sources in the Claduègne catchment could generally be ranked as $T_{lag,Qs}$ *bad* < $T_{lag,Qs}$ *sed* < $T_{lag,Qs}$ *bas* (Table 3, Figure 5). This was also true for $T_{c,Qs}$ and $T_{spr,Qs}$ and consistent with the ranking of the mean distance to the stream as well as with both mean IC values but not with the mean distance to the outlet, as the sedimentary sources were the closest from the outlet (Table 1). In the Galabre catchment $T_{lag,Qs}$, $T_{c,Qs}$ and $T_{spr,Qs}$ of the molasses and marls were always smaller than the ones of quaternary deposits and limestones (basic scenario, Table 3). This was coherent with the ranking of mean distances to the stream but not with the ranking of mean distances to the outlet nor with the one of mean IC values (Table 1). Actually, the mean IC values in the Galabre were very similar for each of the four geological sources of sediments and could not really be used to discriminate the sources in terms of the timing of arrivals of the sedigraphs at the outlet.

To further address the respective roles of the distance to the outlet and the distance to the stream on the pattern of source contributions to total ~~solid discharge~~suspended sediment load throughout events, the geological sources were subdivided based on these measures in the scenarios 4a to 4b (Table 2). In this way, model output consisted of separate sedigraphs for the close and distant subsources of a given source class. The sum of these sedigraphs is the same as the sedigraph of that source class in the basic scenario. Figures 10 and 11 showed for the Galabre catchment that the limestone sources that were close to the river and the ones that were close to the outlet exhibited a clockwise discharge-sediment flux hysteresis pattern while the distant ones exhibited an anticlockwise pattern. These results confirmed typical interpretations of ~~discharge-sediment flux~~ hysteresis loops, i.e. the assumption that clockwise loops indicate a dominance of close sources because maximum sediment flux occurs before peak discharge while anticlockwise hysteresis patterns indicate a dominance of more distant sources (Bača, 2008; Misset et al., 2019). The results further ~~and~~ highlighted that the sedigraphs of the different sediment sources were strongly related to their location in the catchments and their structural connectivity. The absence of coherent trends of the ranking of the $T_{lag,Qs}$ with the one of the mean distances of the sources to the outlet could be related to the distribution of the distances to the outlet of all sediment sources that were generally more scattered than the distribution of the distances to the stream, particularly for the Galabre catchments (Figures 2c,d). Thus, the mean distance to the outlet was not sufficient to determine travel times of the sources to the outlet ~~could not be fully representative of a given geological source~~. Additionally, the triangular rain applied to both catchments ~~lasted~~ had a rather long ~~period~~duration, much longer than the times of concentration of both catchments. Thus, the sedigraphs of all subsources were stretched over a time span that was comparable to the time span of the rain event. The distant sources arrived at the outlet long before the flux of the close sources ceased. Consequently, the sedigraphs of the different subsources of both catchments were superposed and did not lead to separate peaks.

Even though different patches of closer and more distant subsources did not lead to multipeak sedigraphs and thus to a very high flux variability, the classification into close and distant subsources from the outlet allowed to explain the dynamics of source contributions. The first peak of black marls that arrived at the outlet of the Galabre during the onset of the event, originated entirely from the subsources that were close to the outlet and adjacent to the river network (marked “1” in Figures 10e and 11e). For the molasses and quaternary deposits, the distance to the river or the outlet hardly impacted the variability of the predicted source contributions. The first molassic sediments that arrived at the outlet during the rise of the hydrograph (“2”), originated almost entirely from the molassic patch that was directly adjacent to the river network. However, the decrease of the contribution of the adjacent sources during peak flow (“3”) occurred simultaneously with the arrival of the further sources.

A similar dynamic was observed in the Claduègne catchment. The first flush of sediments with a high contribution from the sedimentary source, originated entirely from sedimentary sources that were directly adjacent to the stream and from the badlands that were closest to the outlet (marked “1” in Figures 12e and 13e). When the results were analyzed in terms of the distance to the outlet ~~was considered~~, it was remarkable that sediments which originated from the class badland 3 (corresponding to a distance to the outlet of 7.5-10 km; $T_{lag,Ql}$ = 2.17 h) arrived during the rising limb of the hydrograph (“2“) before the ones that originated from badland 2 (distance to the outlet of 5-7.5 km, $T_{lag,Ql}$ = 2.67 h) even though they were further away from the outlet. This was coherent with the distance to the stream. While all patches belonging to the class badland 3 were directly adjacent to the river network, the ones belonging to the class badland 2 were further away from the river. It should however be stressed that this finding was related to the parameterization of the model and the choice of using contrasted roughness coefficients in hillslopes and in the river. In the results of scenario 4c where n_{river} was set to 0.1 and $n_{hillsl.}$ was set to 0.2 (i.e. less difference between n_{river} and $n_{hillsl.}$) this was not observed.

The fact that in both catchments different hysteresis loops were observed for subsources of different connectivity showed that the subsources exhibited different hydrosedimentary behavior. It also showed that even a simple classification based on the distributions of the geological sources of sediments according to their distance to the stream or the outlet could help to understand the sediment flux dynamics at the outlet of mesoscale catchments. Among the various connectivity indicators (i.e. distance to stream, to the outlet, IC Borselli, IC Cavalli) tested in both studied catchments, the mean distances of the various geological sources to the stream were the most robust proxies of the rankings of the three temporal characteristics of sedigraphs (i.e. T_{lag}, T_c and T_{spr}). Overall, our results showed that the location of the sources in the catchment highly influenced the temporal dynamics of suspended solid discharges at the outlet. ~~The main characteristics of the sediment flux dynamics were observed for all the modeling scenarios.~~ While the two studied mesoscale catchments and also the subsources of sediments within the same catchment exhibited different sensitivities to model discretization and parametrization, one main result of this study was that the actual location of sediment sources and their structural connectivity were more important than the modeling choices. Indeed, as soon as appropriate CDA thresholds (typically 15 to 30ha) and Manning's *n* (in streams typically between 0.03 and 0.06 and on hillslopes between 0.4 and 0.8) were used, the temporal dynamics of the modeled contributions of the different sources were relatively independent of the modeling choices. Values could be varied in quite a high range without significantly changing these flux dynamics. As this finding could be different for different types of rain events, notably shorter events, further studies should focus on the influence of rainfall dynamics on modell~~l~~ed sediment fluxes in mesoscale catchments as was done recently by Battista et al. (2020).

Mis en forme : Normal

5.Conclusion

This study aimed to improve our understanding of hydrosedimentary processes leading to temporal variability in the contribution of potential sources~~ soils~~ to suspended sediments at the outlet of two mesoscale catchments using a distributed, physically based numerical model. As a first objective, we analyzed to which extent the choices made during model discretization and parameterization impacted the~~ ~~ modeled suspended sediment flux dynamics~~representation of the structural connectivity in the model~~. The shape and the magnitude of the modeled hydrographs and sedigraphs ~~was~~ere sensitive to the contributing drainage area threshold to define the river network and to Manning's roughness parameter *n* in the river network and on hillslopes. However, the model was less sensitive to all three values once the parameters varied only in a restricted, reasonable range. ~~In our study sites, t~~The pattern of modeled source contributions remained relatively similar when the CDA threshold was restricted to the range of 15 to 50 ha, *n* on the hillslopes to the range 0.4-0.8 and to 0.025-0.075 in the river.

~~Therefore~~Then, the second objective was to assess how the location of geological sources in the catchment impacted the modelled temporal dynamics of suspended sediments at the outlets. ~~In both studied catchments the actual location of sediment sources and their structural connectivity was found to be more important than the choices made during discretization and parameterization of the model.~~ The classification of the geological sources in subgroups

Comparing the two studied catchments showed that their hydrosedimentary responses differed in the two studied catchments due to the combined effects of the distance from the sources to the point of entry of sediments in the river network, the distance of the sources to the outlet as well as the slopes of hillslopes and rivers.different locations of the sources in the catchments and the slopes of the river network and hillslopes. Among the various structural connectivity indicators ustested to describe the geological sources, the mean distance to the stream was found to be the most relevant proxy of the temporal characteristics of the modeled sedigraphs. Nevertheless, the classification of the geological sources in subgroups according to the distance to the outlet and to the stream allowed a better assessment of the timings of suspended sediments at the outlets.

It allowed to assess how structural connectivity in the catchments governs hydrosedimentary fluxs at the outlet. On the one hand,to which extent the modeling choices made during model discretization and parameterization could impacted the representation of the structural connectivity in the model two mesoscale catchments and thus determines travel times and modeled hydrographs and sedigraphs. On the other hand, structural connectivity is governed by the location of the sources in the catchment, the distance from the sources to their point of entry in the river network, their distance to the outlet as well as slopes on the hillslopes.As structural connectivity represents the way sediment sources are topologically connected to the catchment outlet we considered that the main elements to be considered were the location of the sources with respect to the river network, the length between the point of entry of the source into the river network and the outlet of the catchment, and the friction parameters that will interact with the slope to explain the temporal distribution of sediment flows at the outlet.

We observed that the model was sensitive to the contributing drainage area threshold to define the river network and to Manning's roughness parameter *n* in the river network and on hillslopes. However, the model was less sensitive to all three values once the parameters varied only in a restricted, reasonable range. In our study sites, the pattern of modeled source contributions remained relatively similar when the CDA threshold was restricted to the range of 15 to 50 ha, *n* on the hillslopes to the range 0.4-0.8 and to 0.025-0.075 in the river. In both studied catchments the actual location of sediment sources and their structural connectivity was found to be more important than the choices made during discretization and parameterization of the model.

Comparing the two studied catchments showed that their hydrosedimentary responses differed due to the different locations of the sources in the catchments and the slopes of the river network and hillslopes. Among the various structural connectivity indicators used to describe the geological sources, the mean distance to the stream was found to be the most relevant proxy of the temporal characteristics of the sedigraphs. Nevertheless, the classification of the geological sources in subgroups according to the distance to the outlet and to the stream allowed a better assessment of the timings of suspended sediments at the outlets.

6.Acknowledgements

The authors would like to acknowledge the Ciment platform of the Université Grenoble Alps for access to calculation clusters, the Draix Bléone and OHMCV long term observatories funded by the National Institute of Science of the Universe for access to data sets and the OZCAR research infrastructure. The authors are grateful to Laurent Bourgès, Rémi Cailletaud and OSUG for the publication of the DOI of dataset and the deployment of shinyproxy on the OSUG servers to host the interactive application that enables to visualize the dataset.

Mis en forme : Normal

7.References

Alpert, P., Ben-Gai, T., Baharad, A., Benjamini, Y., Yekutieli, D., Colacino, M., Diodato, L., Ramis, C., Homar, V., Romero, R., et al. (2002). The paradoxical increase of Mediterranean extreme daily rainfall in spite of decrease in total values. Geophysical research letters, 29(11):31-1.

Bača, P. (2008). Hysteresis effect in suspended sediment concentration in the Rybàrik basin, Slovakia. Hydrological Sciences Journal, 53(1):224-235.

Baffaut, C., Nearing, M., Ascough II, J., and Liu, B. (1997). The WEPP watershed model: II. sensitivity analysis and discretization on small watersheds. Transactions of the ASAE, 40(4):935-943.

Barnes, H. H. (1967). Roughness characteristics of natural channels. Number 1849. US Government Printing O_ce.

Battista, G., Molnar, P., and Burlando, P. (2020). Modelling impacts of spatially variable erosion drivers on suspended sediment dynamics. Earth Surface Dynamics, 8, 619–635.

Bhowmik, A. K., Metz, M., and Schäfer, R. B. (2015). An automated, objective and open source tool for stream threshold selection and upstream riparian corridor delineation. Environmental Modelling & Software, 63:240-250.

Bischetti, G., Gandolfi, C., and Whelan, M. (1998). The definition of stream channel head location using digital elevation data. IAHS Publications-Series of Proceedings and Reports-Intern Assoc Hydrological Sciences, 248:545-552.

Bladé, E., Cea, L., Corestein, G., Escolano, E., Puertas, J., Vázquez-Cendón, M.E., Dolz, J. and Coll, A. (2014). Iber: herramienta de simulación numérica del flujo en ríos. Revista Internacional de Métodos Numéricos para Cálculo y Diseño en Ingeniería, 30(1), 1-10.

Blanchet, J., Molinié, G., and Touati, J. (2018). Spatial analysis of trend in extreme daily rainfall in southern France. Climate Dynamics, 51(3):799-812.

Boardman, J., Vandaele, K., Evans, R., and Foster, I. D. (2019). Off-site impacts of soil erosion and runoff: why connectivity is more important than erosion rates. Soil Use and Management.

Borselli, L., Cassi, P., and Torri, D. (2008). Prolegomena to sediment and ow connectivity in the landscape: A GIS and field numerical assessment. Catena, 75(3):268-277.

Boudevillain, B., Delrieu, G., Galabertier, B., Bonnifait, L., Bouilloud, L., Kirstetter, P.-E., and Mosini, M.-L. (2011). The Cévennes-Vivarais Mediterranean Hydrometeorological Observatory database. Water Resources Research, 47(7): W07701.

Braud, I., Ayral, P.-A., Bouvier, C., Branger, F., Delrieu, G., Le Coz, J., Nord, G., Vandervaere, J.-P., Anquetin, S., Adamovic, M., Andrieu, J., Batiot, C., Boudevillain, B., Brunet, P., Carreau, J., Confoland, A., Didon-Lescot, J.-F., Domergue, J.-M., Douvinet, J., Dramais, G., Freydier, R., Gérard, S., Huza, J., Leblois, E., Le Bourgeois, O., Le Boursicaud, R., Marchand, P., Martin, P., Nottale, L., Patris, N., Renard, B., Seidel, J.-L., Taupin, J.-D., Vannier, O., Vincendon, B., and Wijbrans, A. (2014). Multi-scale hydrometeorological observation and modelling for flash flood understanding. Hydrology and Earth System Sciences, 18(9):3733-3761.

Brils, J. (2008). Sediment monitoring and the European Water Framework Directive. Annali dell'Istituto Superiore di Sanita, 44(3):218.

Mis en forme : Français (France)

~~Brosinsky, A., Foerster, S., Segl, K., and Kaufmann, H. (2014). Spectral fingerprinting: sediment source discrimination and contribution modelling of artificial mixtures based on VNIR-SWIR spectral properties. Journal of Soils and Sediments, 14(12):1949-1964.~~

Brosinsky, A., Foerster, S., Segl, K., López-Tarazón, J. A., Piqué, G., and Bronstert, A. (2014). Spectral fingerprinting: characterizing suspended sediment sources by the use of VNIR-SWIR spectral information. Journal of Soils and Sediments, 14(12):1965 - 1981.

Cavalli, M., Trevisani, S., Comiti, F., and Marchi, L. (2013). Geomorphometric assessment of spatial sediment connectivity in small alpine catchments. Geomorphology, 188:31-41.

Cea, L. and Bladé, E. (2015). A simple and efficient unstructured finite volume scheme for solving the shallow water equations in overland ow applications. Water Resources Research, 51(7):5464-5486.

Cea, L., Legout, C., Grangeon, T., and Nord, G. (2016). Impact of model simplifications on soil erosion predictions: application of the GLUE methodology to a distributed event-based model at the hillslope scale. Hydrological Processes, 30(7):1096-1113.

Cea, L. and Vàzquez-Cendon, M. E. (2012). Unstructured finite volume discretization of bed friction and convective flux in solute transport models linked to the shallow water equations. Journal of Computational Physics, 231(8):3317-3339.

Colombo, R., Vogt, J. V., Soille, P., Paracchini, M. L., and de Jager, A. (2007). Deriving river networks and catchments at the European scale from medium resolution digital elevation data. Catena, 70(3):296-305.

Cooper, R. J., Krueger, T., Hiscock, K. M., and Rawlins, B. G. (2015). High-temporal resolution fluvial sediment source fingerprinting with uncertainty: a Bayesian approach. Earth Surface Processes and Landforms, 40(1):78-92.

Cossart, E., Viel, V., Lissak, C., Reulier, R., Fressard, M., and Delahaye, D. (2018). How might sediment connectivity change in space and time? Land Degradation & Development, 29(8):2595-2613.

Crema, S. and Cavalli, M. (2017). SedInConnect: A stand-alone, free and open source tool for the assessment of sediment connectivity. Computers & Geosciences.

Courant R, Friedrichs K and Lewy H. (1967). On the partial difference equations of mathematical physics. IBM journal of Research and Development. 11(2):215-234

Engman, E. T. (1986). Roughness coefficients for routing surface runoff. Journal of Irrigation and Drainage Engineering, 112(1):39-53.

Esteves, M., Legout, C., Navratil, O., and Evrard, O. (2019). Medium term high frequency observation of discharges and suspended sediment in a Mediterranean mountainous catchment. Journal of Hydrology, 568:562-574.

Evrard, O., Navratil, O., Ayrault, S., Ahmadi, M., Némery, J., Legout, C., Lefèvre, I., Poirel, A., Bonté, P., and Esteves, M. (2011). Combining suspended sediment monitoring and fingerprinting to determine the spatial origin of fine sediment in a mountainous river catchment. Earth Surface Processes and Landforms, 36(8):1072-1089.

Fraga, I., Cea, L., and Puertas, J. (2013). Experimental study of the water depth and rainfall intensity effects on the bed roughness coefficient used in distributed urban drainage models. Journal of Hydrology, 505:266-275.

Fryirs, K. (2013). (dis)connectivity in catchment sediment cascades: a fresh look at the sediment delivery problem. Earth Surface Processes and Landforms, 38(1):30-46.

Mis en forme : Anglais (États-Unis)

Gaillardet, J., Braud, I., Hankard, F., Anquetin, S., Bour, O., Doriger, N., De Dreuzy, J.-R., Galle, S., Galy, C., Gogo, S., Gourcy, L., Habets, F., Laggoun, F., Longuevergne, L., Le Borgne, T., Naaim-Bouvet, F., Nord, G., Simonneaux, V., Six, D., Tallec, T., Valentin, C., et al. (2018). OZCAR: the French network of critical zone observatories. Vadose Zone Journal, 17(1).

Gellis, A. and Gorman Sanisaca, L. (2018). Sediment fingerprinting to delineate sources of sediment in the agricultural and forested Smith Creek watershed, Virginia, USA. JAWRA Journal of the American Water Resources Association.

Gericke, O. and Smithers, J. (2014). Review of methods used to estimate catchment response time for the purpose of peak discharge estimation. Hydrological Sciences Journal, 58(11):1935-1971.

Gourdin, E., Evrard, O., Huon, S., Lefèvre, I., Ribolzi, O., Reyss, J.-L., Sengtaheuanghoung, O., and Ayrault, S. (2014). Suspended sediment dynamics in a Southeast Asian mountainous catchment: Combining river monitoring and fallout radionuclide tracers. Journal of Hydrology, 519:1811-1823.

Hallema, D. W., Moussa, R., Andrieux, P., and Voltz, M. (2013). Parameterization and multi-criteria calibration of a distributed storm flow model applied to a Mediterranean agricultural catchment. Hydrological Processes, 27(10):1379-1398.

Hancock, G., Lowry, J., Coulthard, T., Evans, K., and Moliere, D. (2010). A catchment scale evaluation of the SIBERIA and CAESAR landscape evolution models. Earth Surface Processes and Landforms, 35:863–875.

Hanley, N., Faichney, R., Munro, A. and Shortle, J.S. (1998). Economic and environmental modelling for pollution control in an estuary. Journal of Environmental Management, 52(3):211–225.

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

Hessel, R., Jetten, V., and Guanghui, Z. (2003). Estimating manning's n for steep slopes. Catena, 54(1-2):77-91.

Huza, J., Teuling, A. J., Braud, I., Grazioli, J., Melsen, L. a., Nord, G., Raupach, T. H., and Uijlenhoet, R. (2014). Precipitation, soil moisture and runoff variability in a small river catchment (Ardèche, France) during HyMeX Special Observation Period 1. Journal of Hydrology, 516:330-342.

Inglada, J., Vincent, A., and Thierion, V. (2017). Theia OSO land cover map 2106. https://www.theia-land.fr/en/product/land-cover-map/ [access: 26-03-2020].

Laflen, J. M., Lane, L. J., and Foster, G. R. (1991). WEPP: a new generation of erosion prediction technology. Journal of Soil and Water Conservation, 46(1):34-38.

Legout, C., Poulenard, J., Nemery, J., Navratil, O., Grangeon, T., Evrard, O., and Esteves, M. (2013). Quantifying suspended sediment sources during runoff events in headwater catchments using spectrocolorimetry. Journal of Soils and Sediments, 13(8):1478-1492.

Limerinos, J. T. (1970). Determination of the manning coefficient from measured bed roughness in natural channels. US Geological Survey Water Supply Papers, 1898(B):47.

Lopez-Vicente, M. and Ben-Salem, N. (2019). Computing structural and functional flow and sediment connectivity with a new aggregated index: A case study in a large Mediterranean catchment. Science of The Total Environment, 651:179-191.

Merritt, W., Letcher, R., and Jakeman, A. (2003). A review of erosion and sediment transport models. Environmental Modelling & Software, 18(8-9):761-799.

Mis en forme : Allemand (Allemagne)

Misset, C., Recking, A., Legout, C., Poirel, A., Cazihlac, M., Esteves, M., and Bertrand, M. (2019). An attempt to link suspended load hysteresis patterns and sediment sources configuration in alpine catchments. Journal of Hydrology.

Montgomery, D. R. and Foufoula-Georgiou, E. (1993). Channel network source representation using digital elevation models. Water Resources Research, 29(12):3925-3934.

Mukundan, R., Radclie, D., and Risse, L. (2010a). Spatial resolution of soil data and channel erosion effects on swat model predictions of ow and sediment. Journal of Soil and Water Conservation, 65(2):92-104.

Mukundan, R., Radclie, D. E., Ritchie, J. C., Risse, L. M., and McKinley, R. A. (2010b). Sediment fingerprinting to determine the source of suspended sediment in a southern piedmont stream. Journal of Environment Quality, 39(4):1328.

Navratil, O., Evrard, O., Esteves, M., Ayrault, S., Lefèvre, I., Legout, C., Reyss, J.-L., Gratiot, N., Nemery, J., Mathys, N., Poirel, A., and Bonté, P. (2012). Core-derived historical records of suspended sediment origin in a mesoscale mountainous catchment: the River Bléone, French Alps. Journal of Soils and Sediments, 12(9):1463-1478.

Nord, G., Boudevillain, B., Berne, A., Branger, F., Braud, I., Dramais, G., G_erard, S., Le Coz, J., Legout, C., Molinie, G., Van Baelen, J., Vandervaere, J.-P., Andrieu, J., Aubert, C., Calianno, M., Delrieu, G., Grazioli, J., Hachani, S., Horner, I., Huza, J., Le Boursicaud, R., Raupach, T. H., Teuling, A. J., Uber, M., Vincendon, B., and Wijbrans, A. (2017). A high space-time resolution dataset linking meteorological forcing and hydro-sedimentary response in a mesoscale Mediterranean catchment (Auzon) of the Ardèche region, France. Earth System Science Data, 9(1):221-249.

Owens, P., Batalla, R., Collins, A., Gomez, B., Hicks, D., Horowitz, A., Kondolf, G., Marden, M., Page, M., Peacock, D., Petticrew, E., Salomons, W., and Trustrum, N. (2005). Fine-grained sediment in river systems: environmental significance and management issues. River research and applications, 21(7):693-717.

Palazon, L., Latorre, B., Gaspar, L., Blake, W. H., Smith, H. G., and Navas, A. (2016). Combining catchment modelling and sediment fingerprinting to assess sediment dynamics in a Spanish Pyrenean river system. Science of The Total Environment, 569-570:1136-1148.

Palazon, L., Gaspar, L., Latorre, B., Blake, W., and Navas, A. (2014). Evaluating the importance of surface soil contributions to reservoir sediment in alpine environments: a combined modelling and fingerprinting approach in the posets-maladeta natural park. Solid Earth, 5(2):963-978.

Panagos, P., Meusburger, K., Van Liedekerke, M., Alewell, C., Hiederer, R., and Montanarella, L. (2014). Assessing soil erosion in Europe based on data collected through a European network. Soil science and plant nutrition, 60(1):15-29.

Pandey, A., Himanshu, S. K., Mishra, S., and Singh, V. P. (2016). Physically based soil erosion and sediment yield models revisited. Catena, 147:595-620.

Pianosi, F., Beven, K., Freer, J., Hall, J. W., Rougier, J., Stephenson, D. B., and Wagener, T. (2016). Sensitivity analysis of environmental models: A systematic review with practical workflow. Environmental Modelling & Software, 79:214–232.

Poulenard, J., Legout, C., Némery, J., Bramorski, J., Navratil, O., Douchin, A., Fanget, B., Perrette, Y., Evrard, O., and Esteves, M. (2012). Tracing sediment sources during floods using Diffuse Reflectance Infrared Fourier

Transform Spectrometry (DRIFTS): A case study in a highly erosive mountainous catchment (Southern French Alps). Journal of Hydrology, 414-415:452-462.

Pradhanang, S. M. and Briggs, R. D. (2014). Effects of critical source area on sediment yield and streamflow. Water and environment journal, 28(2):222-232.

Tarboton, D. (2010). TauDEM (Terrain Analysis Using Digital Elevation Models). http: //hydrology.usu.edu/taudem/taudem5/ [access: 26-03-2020].

Tarboton, D. G., Bras, R. L., and Rodriguez-Iturbe, I. (1991). On the extraction of channel networks from digital elevation data. Hydrological Processes, 5(1):81-100.

Te Chow, V. (1959). Open-channel hydraulics, volume 1. McGraw-Hill New York.

Theuring, P., Rode, M., Behrens, S., Kirchner, G., and Jha, A. (2013). Identification of fluvial sediment sources in the Kharaa River catchment, northern Mongolia. Hydrological Processes, 27(6):845-856.

Tiemeyer, B., Moussa, R., Lennartz, B., and Voltz, M. (2007). MHYDAS-DRAIN: A spatially distributed model for small, arti_cially drained lowland catchments. Ecological modelling, 209(1):2-20.

Tramblay, Y., Neppel, L., Carreau, J., and Sanchez-Gomez, E. (2012). Extreme value modelling of daily areal rainfall over mediterranean catchments in a changing climate. Hydrological Processes, 26(25):3934-3944.

Turcotte, R., Fortin, J.-P., Rousseau, A., Massicotte, S., and Villeneuve, J.-P. (2001). Determination of the drainage structure of a watershed using a digital elevation model and a digital river and lake network. Journal of Hydrology, 240(3-4):225-242.

Uber, M., Legout, C., Nord, G., Crouzet, C., Demory, F., and Poulenard, J. (2019). Comparing alternative tracing measurements and mixing models to fingerprint suspended sediment sources in a mesoscale Mediterranean catchment. Journal of Soils and Sediments, pages 1-19.

Uber, M. (2020). Suspended sediment production and transfer in mesoscale catchments: a new approach combining flux monitoring, fingerprinting and distributed numerical modeling. PhD Thesis, Université Grenoble Alpes, 249 p. http://theses.fr/2020GRALU011 [access: 24-11-2020]

Uber, M., Nord, G., Legout, C., Cea, L., (2020). Modeled contributions of sediment sources to total suspended sediment flux in two mesoscale catchments. UGA. http://dx.doi.org/10.17178/EROSION_MODEL.2020.

Vanmaercke, M., Poesen, J., Verstraeten, G., de Vente, J., and Ocakoglu, F. (2011). Sediment yield in Europe: spatial patterns and scale dependency. Geomorphology, 130(3-4):142-161.

Vercruysse, K. and Grabowski, R. C. (2019). Temporal variation in suspended sediment transport: linking sediment sources and hydro-meteorological drivers. Earth Surface Processes and Landforms.

Vercruysse, K., Grabowski, R. C., and Rickson, R. (2017). Suspended sediment transport dynamics in rivers: Multi-scale drivers of temporal variation. Earth-Science Reviews, 166:38-52.

Vogt, J., Soille, P., Colombo, R., Paracchini, M. L., and de Jager, A. (2007). Development of a pan-European river and catchment database. In Digital terrain modelling, pages 121-144. Springer.

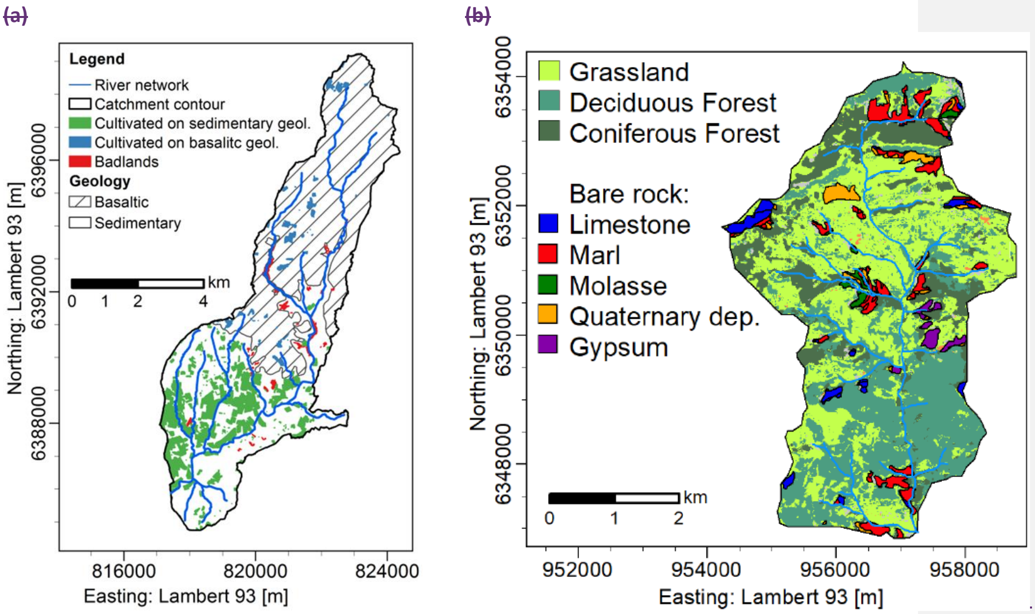
Wainwright, J., Parsons, A. J., Muller, E. N., Brazier, R. E., Powell, D. M., and Fenti, B. (2008). A transport-distance approach to scaling erosion rates: 1. background and model development. Earth Surface Processes and Landforms, 33(5):813-826.

Wainwright, J., Turnbull, L., Ibrahim, T. G., Lexartza-Artza, I., Thornton, S. F., and Brazier, R. E. (2011). Linking environmental regimes, space and time: Interpretations of structural and functional connectivity. Geomorphology, 126(3-4):387-404.

Mis en forme : Allemand (Allemagne)

Mis en forme : Allemand (Allemagne)

Wilkinson, S. N., Hancock, G. J., Bartley, R., Hawdon, A. A., and Keen, R. J. (2013). Using sediment tracing to assess processes and spatial patterns of erosion in grazed rangelands, Burdekin River basin, Australia. Agriculture, Ecosystems & Environment, 180:90-102.
Woolhiser, D.A., Smith, R.E. and Goodrich, D.C. (1990). KINEROS—A Kinematic Runoff and Erosion Model: Documentation and User Manual. Rep. No. ARS-77. USDA, Washington, D.C.



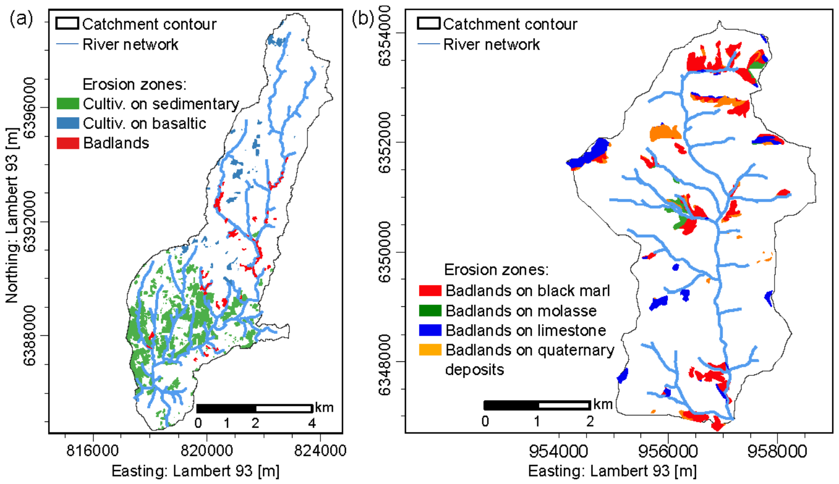


Figure 1: Maps of the (a) Claduègne and (b) Galabre catchments. Note that gypsum badlands are not considered in this study as this material is highly soluble and do not contribute to sediment fluxes. Further maps of the study sites can be found in Uber (2020).

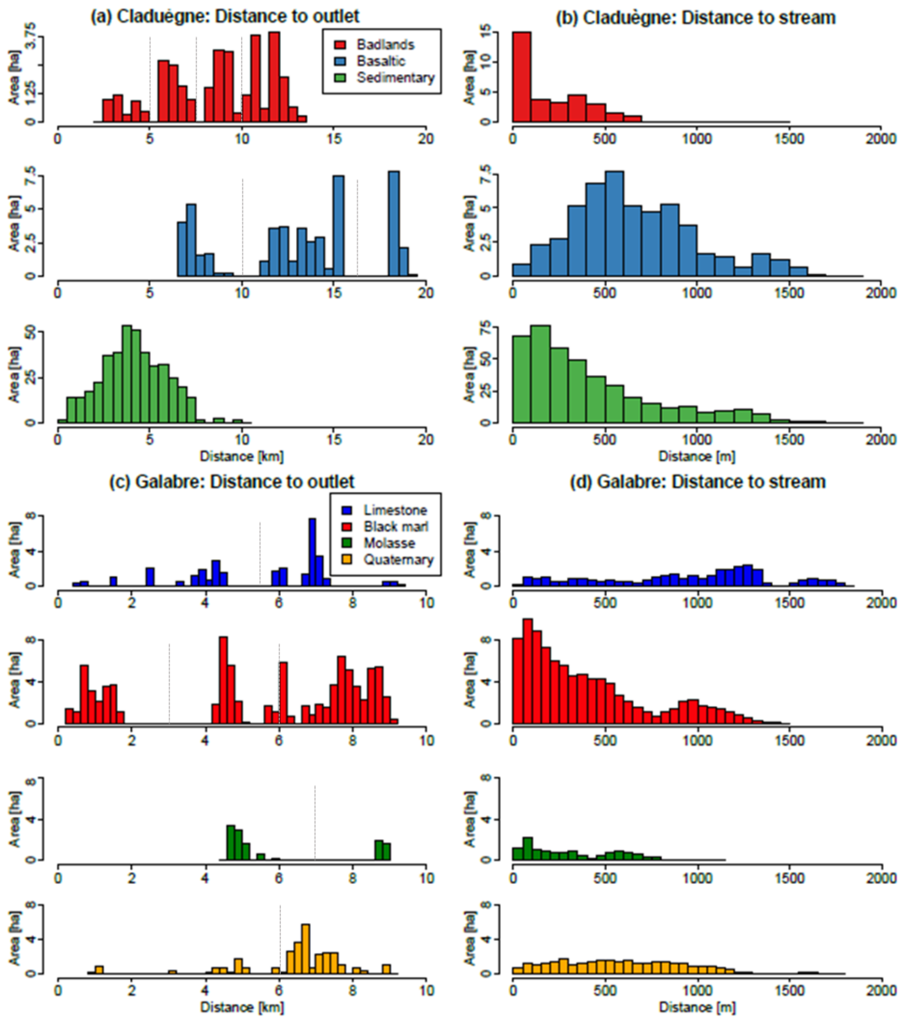


Figure 2: Distribution of the distance of the sources to the outlet (a for the Claduègne, c for the Galabre) and the stream (b for the Claduègne, d for the Galabre). The stream was defined with a threshold of contributing drainage area of 50 ha. The values represent distances along the flowlines that water and sediments travel following the gradient of the relief. Dashed grey lines correspond to the limits of subgroups of geological sources based on their distance to the outlet modelled in Sc 4b and 4d.

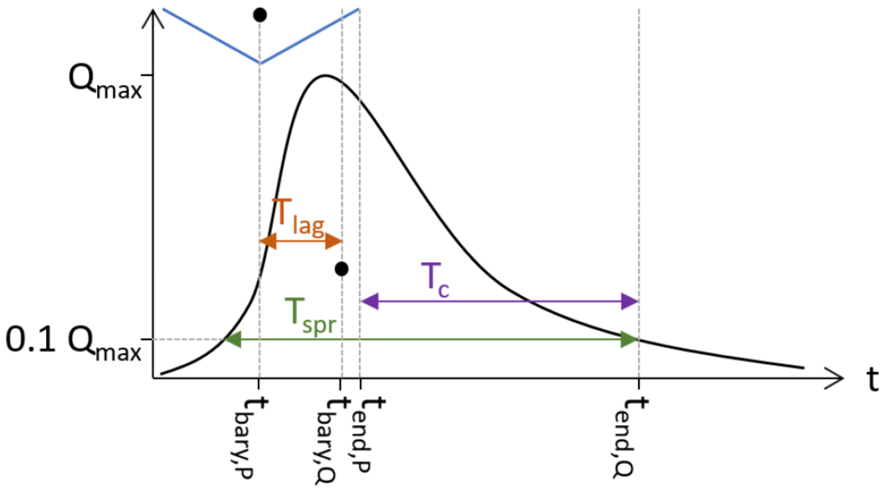


Figure 3: Scheme of the calculation of characteristic times T_{lag}, T_c and T_{spr} that were calculated using the simulated liquid and solid discharges. The points represent the barycenter of the hyetograph (blue curve) and of the fraction of discharge above the threshold of $0.1Q_{max}$ (black curve).

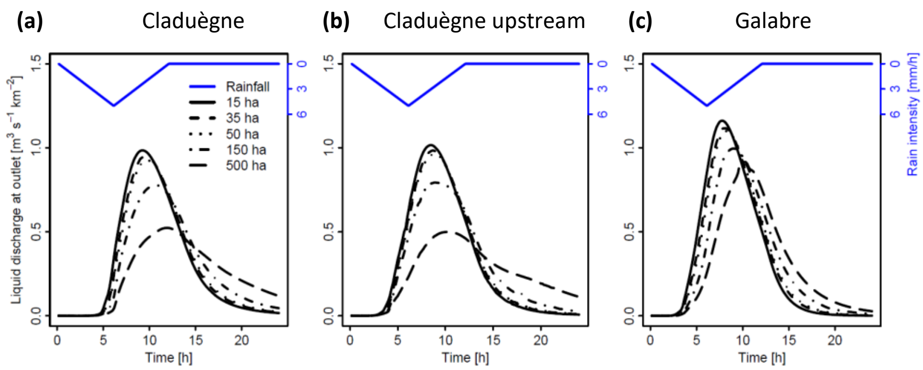


Figure 4: Simulated specific discharge obtained with different scenarios of model discretization at the outlet of (a) the 42km² Claduègne catchment, (b) the 20km² upstream outlet of the Claduègne where the size of the subcatchment is the same as the one of (c) the Galabre catchment. The threshold for defining the river network is varied from 15 ha to 500 ha.

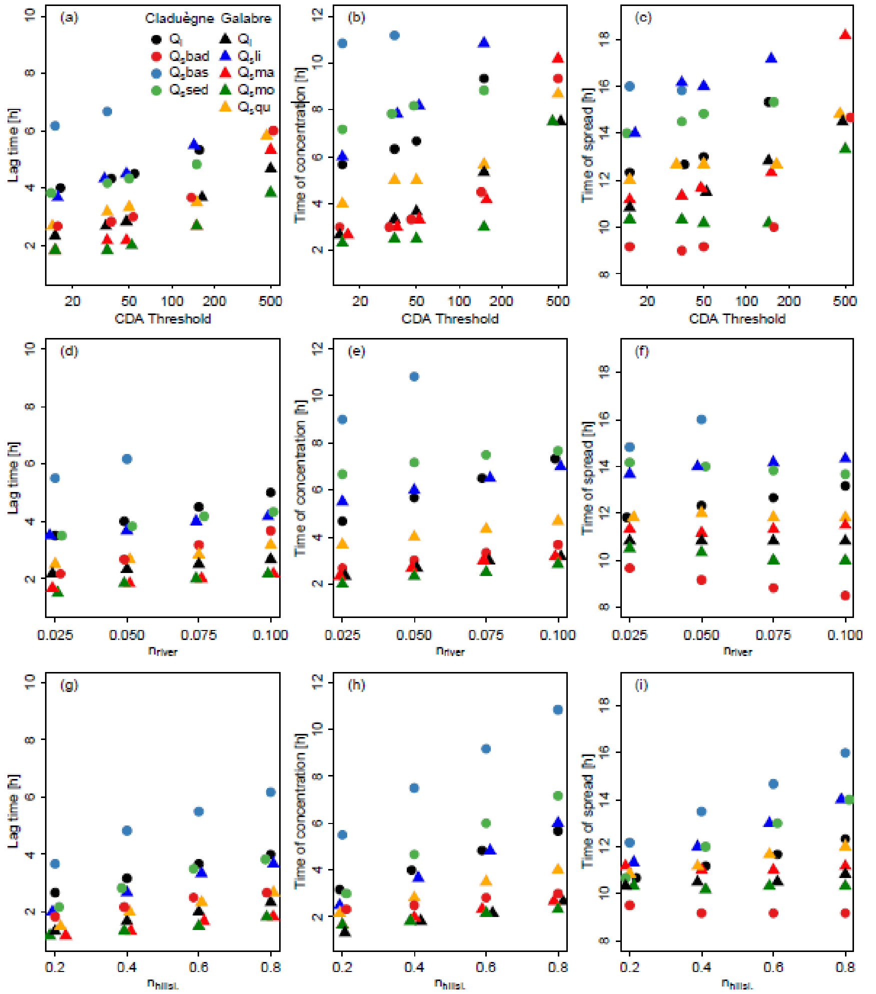


Figure 5: Sensitivity of lag times, times of concentration and time of spread to changing the CDA threshold (top row), Manning's *n* in the river network (middle row) and on the hillslopes (bottom row). For each catchment the characteristic times are given for liquid discharge (Ql) and for solid discharge (Qs) of the different source classes. Some symbols were slightly shifted on the x-axis if they were hard to see or overlapped by other symbols.

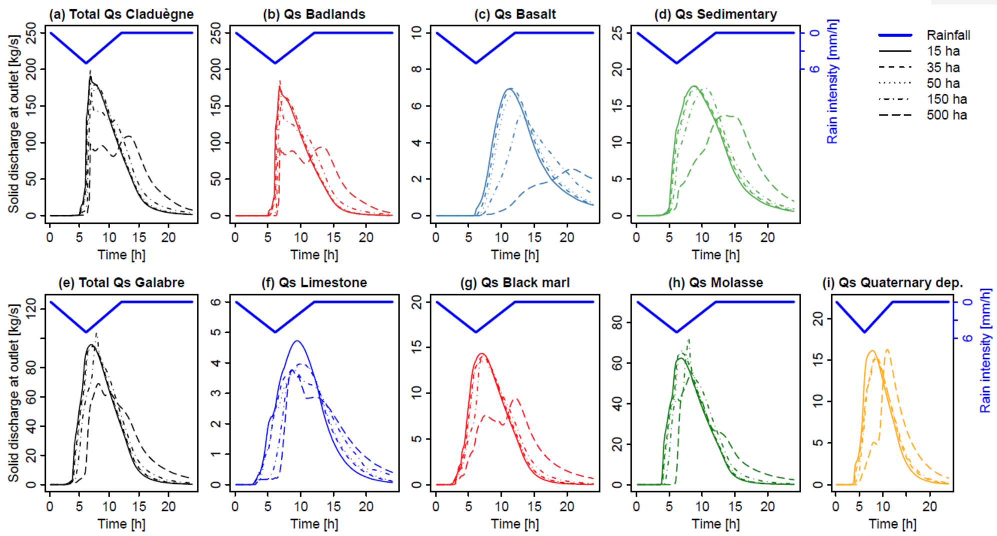


Figure 6: Simulated sedigraphs for total suspended solid discharge (Qs) and for each source in the two catchments when different values are used for the threshold of contributing drainage area (CDA) to define the river network.

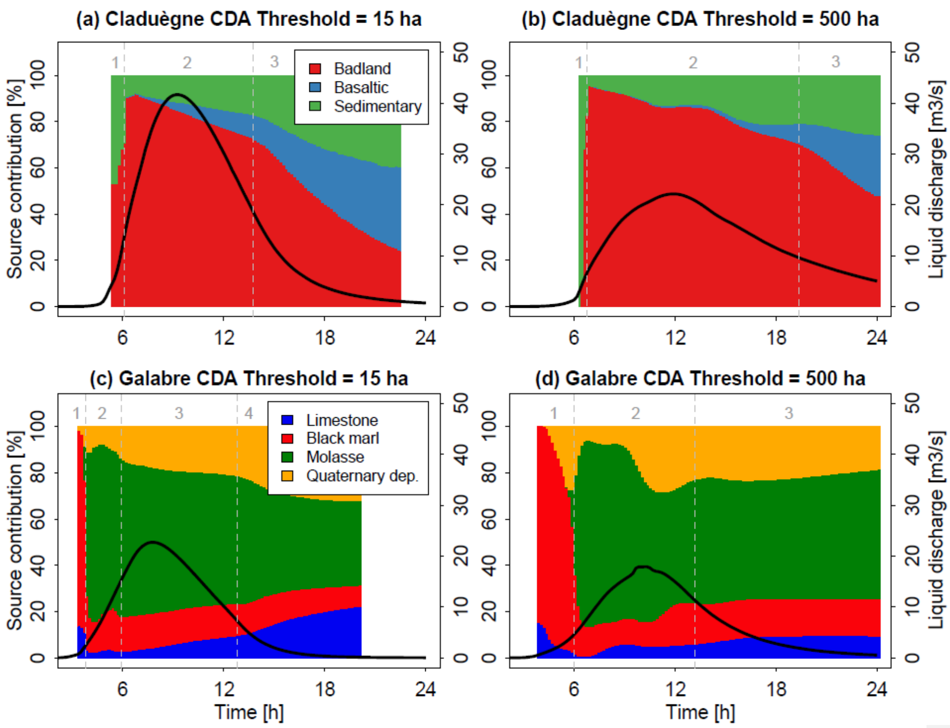


Figure 7: Modeled source contributions of the sediment sources in the Claduègne and Galabre catchments when the threshold of contributing drainage area (CDA) is set to 15 ha (left, Sc. 1) or to 500 ha (right, Sc. 2d). The color shows the contribution of the different sources to total suspended sediment load in percent. The hydrograph is additionally shown to represent the timing of the event. The results obtained with all five CDA thresholds (15, 35, 50, 150 and 500 ha) for both catchments can be visualized in interactive figures at https://shiny.osug.fr/app/EROSION_MODEL.2020

Code de champ modifié

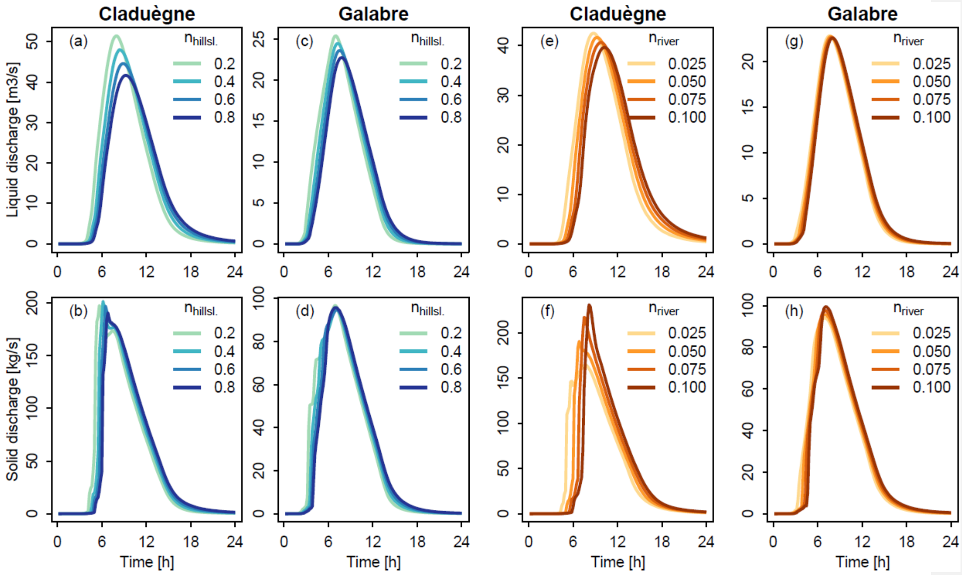


Figure 8: Sensitivity of modeled hydrographs (top row) and sedigraphs (bottom row) to changing Manning's roughness parameter on the hillslopes (a to d) and in the river network (e to h). For subfigures a to d n_{river} was fixed to 0.05. For subfigures e to h n_{hillsl} was fixed to 0.8.

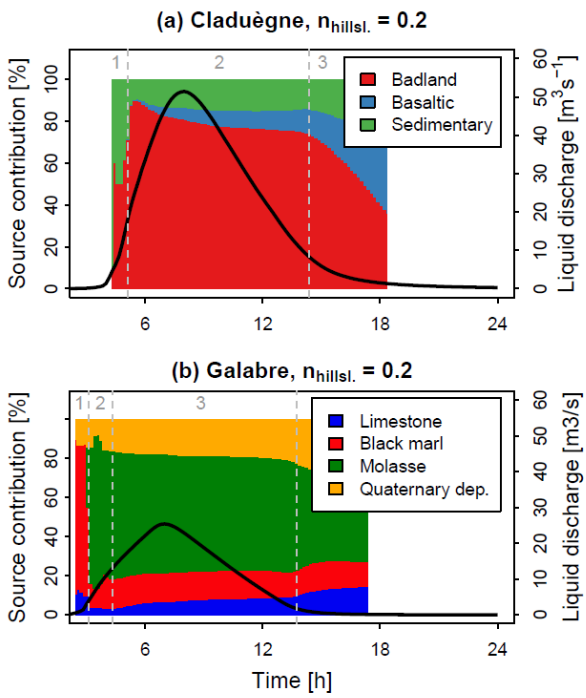


Figure 9: Modeled contributions of the sediment sources in the two catchments when Manning's *n* on the hillslopes was set to 0.2 (Sc. 3a). The color shows the contribution of the different sources to total suspended sediment load in percent. The hydrograph is additionally shown to represent the timing of the event. The results obtained with all roughness values for both catchments can be visualized in interactive figures at https://shiny.osug.fr/app/EROSION_MODEL.2020

Code de champ modifié

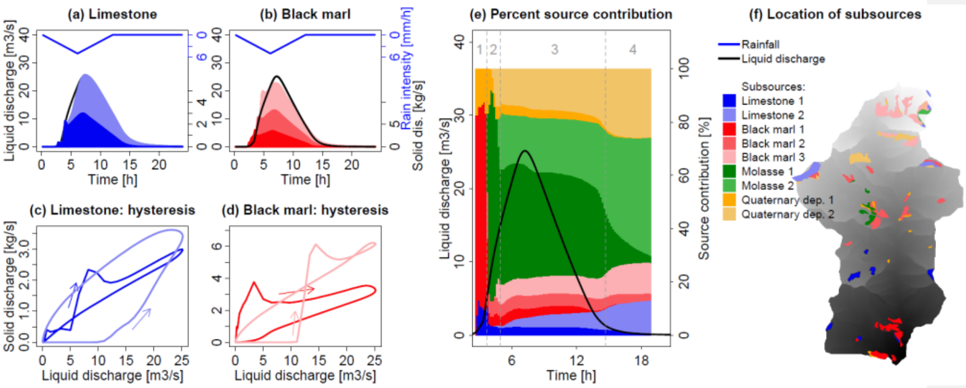


Figure 10: (a,b) Contribution of subsources of Limestone and Black marl that are classified according to their distance to the outlet (Sc. 4a). The colored areas show the contribution of sources close to the outlet (darker colors) and more distant sources (lighter colors) to the sedigraph. (c,d) shows the hysteresis loops of the subsources. (e) shows the contribution of each subsource to total suspended solid discharge in percent. The dashed lines and the grey numbers above the figure distinguish different periods of the event as referred to in the text. (f) Location of the subsources in the Galabre catchment.

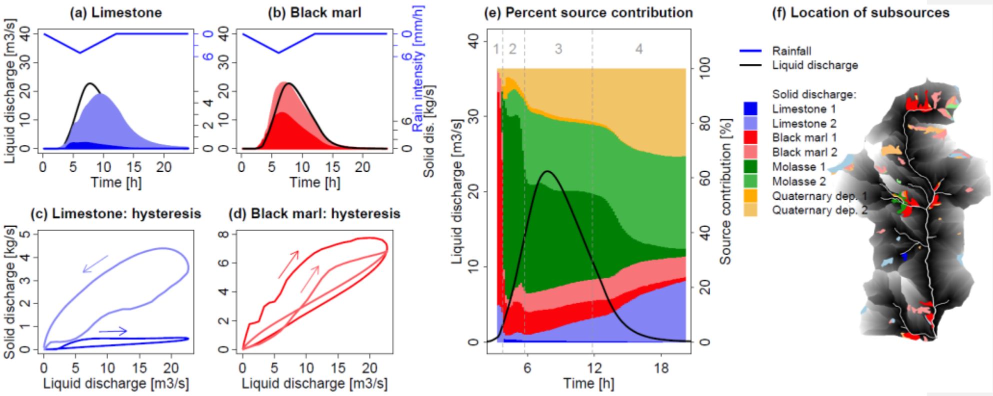


Figure 11: Contribution of subsources that are classified according to their distance to the stream in the Galabre catchment (Sc. 4b). For the description of the subfigures, see the caption of Figure 10.

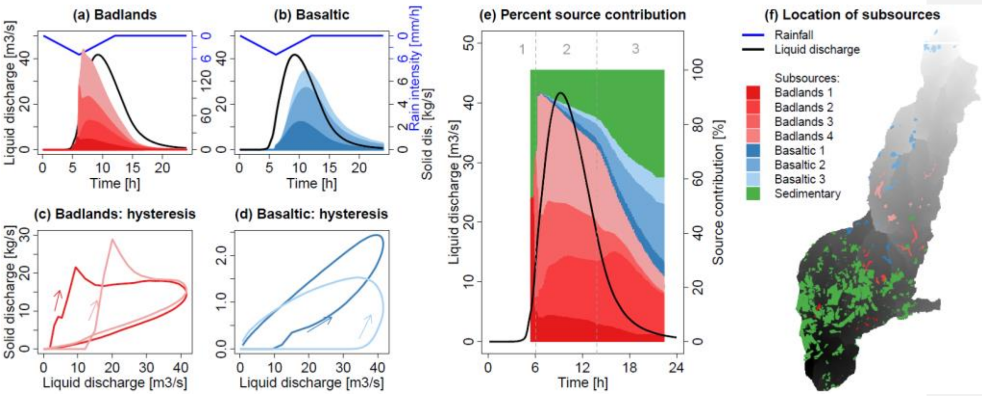


Figure 12: (a-b) Contribution of subsources of badlands and basaltic sources that are classified according to their distance to the outlet (Sc. 4a). The colored areas show the contribution of sources close to the outlet (darker colors) and more distant sources (lighter colors) to the sedigraph. (c-d) show the hysteresis loops of the subsources. Subfigure (e) shows the contribution of each subsource to total solid discharge in percent. The dashed lines and the grey numbers above the figure distinguish different periods of the event as referred to in the text. (f) Location of the subsources in the Claduègne catchment.

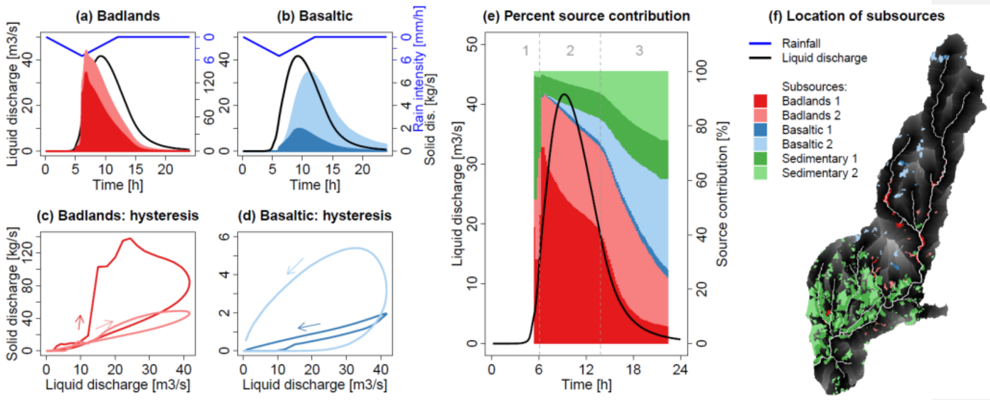


Figure 13: Contribution of subsources that are classified according to their distance to the stream in the Claduègne catchment (Sc. 4b). For the description of the subfigures see the caption of Figure 12.

	Claduègne				Galabre				
	Entire catchment	Badland	Basaltic	Sedimentary	Entire catchment	Limestone	Marl	Molasse	Quaternary deposits
Catchment morphology									
Area [km^2]	42.24	0.32	0.52	4.19	19.55	0.34	0.93	0.13	0.33
K_G [-]	1.87	-	-	-	1.47	-	-	-	-
Slope, hillslopes	24 ± 30	82 ± 68	11 ± 21	12 ± 13	54 ± 40	101 ± 127	67 ± 38	56 ± 30	54 ± 33
Slope, river network									
Intermittent streams	6.78	-	$9.22^{a)}$	$6.06^{a)}$	19.17	-	-	-	-
Main stream	2.72	-	$4.93^{a)}$	$2.50^{a)}$	5.71	-	-	-	-
Connectivity									
Distance to outlet [km]	9.18 ± 5.10	8.59 ± 2.82	12.91 ± 3.92	4.15 ± 1.73	4.75 ± 2.17	5.49 ± 1.99	5.28 ± 2.91	6.03 ± 1.72	6.25 ± 1.65
Distance to stream [km]	0.44 ± 0.35	0.21 ± 0.19	0.67 ± 0.34	0.42 ± 0.36	0.53 ± 0.37	0.89 ± 0.47	0.39 ± 0.35	0.34 ± 0.24	0.57 ± 0.35
IC (Borselli et al., 2008)	-9.18 ± 0.61	-8.35 ± 0.43	-9.30 ± 0.37	-8.75 ± 0.66	-8.84 ± 0.75	-7.94 ± 0.39	-7.95 ± 0.60	-8.19 ± 0.36	-8.03 ± -0.42
IC (Cavalli et al., 2013)	-5.85 ± 0.53	-5.50 ± 0.34	-6.34 ± 0.50	-5.73 ± 0.50	-4.56 ± 0.50	-4.52 ± 0.33	-4.57 ± 0.55	-4.81 ± 0.35	-4.56 ± 0.40
Erodibility									
Suspended sediment yield [$t\,y^{-1}$]	15947	12394	1084	2469	12856	953	1956	7474	2473
Specific yield [$t\,km^{-2}y^{-1}$]	380	38623	2087	589	666	2780	2113	57075	7418
Rain erodibility $\alpha^{b)}$ [$g\,mm^{-1}m^{-2}$]	3.1	37.5	2.0	0.6	7.4	2.8	2.1	57.1	7.4

Table 1: Characteristics of the two catchments and the erosion zones. KG is Gravelius' compactness indicator defined as the ratio between the catchment perimeter (P) and the one of a circle with equal surface. The values given for the slopes on the hillslopes, the distance to the outlet, the distance to the streams and the two connectivity indicators (IC) represent the mean +/- standard deviation. The mean slopes in the river network are given for the entire network including intermittent streams (defined with a threshold of CDA of 15 ha) and for the main, perennial network (CDA of 500 ha). a) The values correspond to the slope in the river network on the basaltic plateau and on sedimentary geology and are not limited to the erosion zones. b) Rainfall erodibility corresponds to the mass of sediment detached on 1m² by 1mm of rain (Cea et al., 2015).

Sc.	*Th$_{CDA}$ [ha]*	*Source classification*	*n$_{river}$ [-]*	*n$_{hillsl.}$ [-]*	*Aim*
1	15	Geology	0.050	0.8	Basic scenario
2a	35	Geology	0.050	0.8	Impact of modeling choice ~~for the river network threshold~~(spatial discretization) on the temporal dynamics of SS fluxes
2b	50	Geology	0.050	0.8	
2c	150	Geology	0.050	0.8	
2d	500	Geology	0.050	0.8	
3a	15	Geology	0.050	0.2	Impact of modeling ~~choice for the~~ parameterization ~~of~~ (~~Manning's n~~roughness) on the temporal dynamics of SS fluxes
3b	15	Geology	0.050	0.4	
3c	15	Geology	0.050	0.6	
3d	15	Geology	0.025	0.8	
3e	15	Geology	0.075	0.8	
3f	15	Geology	0.100	0.8	
4a	15	Geology and distance to the outlet	0.050	0.8	Impact of the location of erosion zones within the catchments on the temporal dynamics of SS fluxes~~Dynamics between more and less connected sources~~
4b	15	Geology and distance to the stream	0.050	0.8	
4c	15	Geology and distance to the outlet	0.100	0.2	
4d	15	Geology and distance to the stream	0.100	0.2	

Table 2: Model scenarios (Sc) detailed according to the value of the contributing drainage area threshold to define the river network (ThCDA), the approach to classify the sources, the values for Manning's roughness parameter (n) in the river network and on the hillslopes and the aim of the respective scenario.

	1 Basic Scenario	2a $Th_{CDA} = 35\,ha$	2b $Th_{CDA} = 50\,ha$	2c $Th_{CDA} = 150\,ha$	2d $Th_{CDA} = 500\,ha$	3a $n_{hillsl.} = 0.2$	3b $n_{hillsl.} = 0.4$	3c $n_{hillsl.} = 0.6$	3d $n_{river} = 0.025$	3e $n_{river} = 0.075$	3f $n_{river} = 0.100$
Claduègne											
T_{lag,Q_l} [h]	4.00	4.33	4.50	5.33	NA	2.67	3.17	3.67	3.50	4.50	5.00
T_{c,Q_l} [h]	5.67	6.33	6.67	9.33	NA	3.17	4.00	4.83	4.67	6.50	7.33
T_{spr,Q_l} [h]	12.33	12.67	13.00	15.33	NA	10.67	11.17	11.67	11.83	12.67	13.17
$Q_{l,max}$ [$m^3 s^{-1}$]	41.65	40.16	39.14	32.91	22.14	51.44	48.00	44.57	42.51	40.67	39.64
$Q_{s,max}$ [$kg\,s^{-1}$]	191.04	198.67	183.24	169.41	108.65	197.45	201.52	196.98	163.88	217.06	230.97
T_{lag,Q_s} bad [h]	2.67	2.83	3.00	3.67	6.00	1.83	2.17	2.50	2.17	3.17	3.67
T_{c,Q_s} bad [h]	3.00	3.00	3.33	4.50	9.33	2.33	2.50	2.83	2.67	3.33	3.67
T_{spr,Q_s} bad [h]	9.17	9.00	9.17	10.00	14.67	9.50	9.17	9.17	9.67	8.83	8.50
T_{lag,Q_s} bas [h]	6.17	6.67	NA	NA	NA	3.67	4.83	5.50	5.50	NA	NA
T_{c,Q_s} bas [h]	10.83	11.17	NA	NA	NA	5.50	7.50	9.17	9.00	NA	NA
T_{spr,Q_s} bas [h]	16.00	15.83	NA	NA	NA	12.17	13.50	14.67	14.83	NA	NA
T_{lag,Q_s} sed [h]	3.83	4.17	4.33	4.83	NA	2.17	2.83	3.50	3.50	4.17	4.33
T_{c,Q_s} sed [h]	7.17	7.83	8.17	8.83	NA	3.00	4.67	6.00	6.67	7.50	7.67
T_{spr,Q_s} sed [h]	14.00	14.50	14.83	15.33	NA	10.67	12.00	13.00	14.17	13.83	13.67
Galabre											
T_{lag,Q_l} [h]	2.33	2.67	2.83	3.67	4.67	1.33	1.67	2.00	2.17	2.50	2.67
T_{c,Q_l} [h]	2.67	3.33	3.67	5.33	7.50	1.33	1.83	2.17	2.33	3.00	3.17
T_{spr,Q_l} [h]	10.83	11.33	11.50	12.83	14.50	10.33	10.50	10.50	10.83	10.83	10.83
$Q_{l,max}$ [$m^3 s^{-1}$]	22.71	21.83	21.50	19.47	17.89	25.38	24.43	23.58	22.79	22.61	22.54
$Q_{s,max}$ [$kg\,s^{-1}$]	95.70	94.73	94.29	103.65	69.15	96.64	95.15	94.54	94.08	97.66	99.52
T_{lag,Q_s} li [h]	3.67	4.33	4.50	5.50	NA	2.00	2.67	3.33	3.50	4.00	4.17
T_{c,Q_s} li [h]	6.00	7.83	8.17	10.83	NA	2.50	3.67	4.83	5.50	6.50	7.00
T_{spr,Q_s} li [h]	14.00	16.17	16.00	17.17	NA	11.33	12.00	13.00	13.67	14.17	14.33
T_{lag,Q_s} ma [h]	1.83	2.17	2.17	2.67	5.33	1.17	1.33	1.67	1.67	2.00	2.17
T_{c,Q_s} ma [h]	2.67	3.00	3.33	4.17	10.17	1.67	2.00	2.33	2.33	3.00	3.17
T_{spr,Q_s} ma [h]	11.17	11.33	11.67	12.33	18.17	11.17	11.00	11.00	11.33	11.33	11.50
T_{lag,Q_s} mo [h]	1.83	1.83	2.00	2.67	3.83	1.17	1.33	1.50	1.50	2.00	2.17
T_{c,Q_s} mo [h]	2.33	2.50	2.50	3.00	7.50	1.67	1.83	2.17	2.00	2.50	2.83
T_{spr,Q_s} mo [h]	10.33	10.33	10.17	10.17	13.33	10.33	10.17	10.33	10.50	10.00	10.00
T_{lag,Q_s} qu [h]	2.67	3.17	3.33	3.50	5.83	1.50	2.00	2.33	2.50	2.83	3.17
T_{c,Q_s} qu [h]	4.00	5.00	5.00	5.67	8.67	2.17	2.83	3.50	3.67	4.33	4.67
T_{spr,Q_s} qu [h]	12.00	12.67	12.67	12.67	14.83	10.83	11.17	11.67	11.83	11.83	11.83

Change [%]	0-9	10 - 19	20 - 29	30 - 49	50 - 69	70 - 89	90 - 119	120 - 149	150 - 179	≥ 180

Table 3: Calculated characteristics of modeled hydrographs and sedigraphs for the different scenarios. Abbreviations: $T_{lag;Ql}$: lag time of liquid discharge, $T_{c;Ql}$: time of concentration of liquid discharge, $T_{spr;Ql}$: spread of the hydrograph, $Q_{l;max}$: peak of liquid discharge. *Qs* refers to solid discharge and the characteristic times are calculated for each source separately (i.e. badlands, basaltic and sedimentary in the Claduègne catchment; limestone, black marl, molasses and quaternary deposits in the Galabre catchment). The background color of the cells represents the percent change of each value with respect to the basic scenario. NA values indicate that the hydrograph or sedigraph did not recede to 0.1 Q_{max} within the simulated time.