Answers to the reviews of the paper "Entrainment and deposition of boulders in a gravel bed river" by Allemand et al.

Reply to the comments of Reviewer #1:

We thank you for your constructive comment: they helped us to clarify the manuscript and focus on the main message. Our objective is indeed to show that the export of boulders on a river bank is compatible with a time exponential decrease model.

R #1: "Although I find the technique to be interesting and simple and could thus provide simple measurements of bedload transport and flux, I also find the calculations to be filled with abundant assumptions, of which only a few are addressed, and no uncertainty calculations are presented."

As you pointed out, the quantification of the flux of boulders relies on so many assumptions that one may doubt of the accuracy of the numbers that we produce. As suggested by the second reviewer, the interest of this calculation lies ``more in the conceptual understanding than a number we should trust''. Accordingly, we removed section 4 of the manuscript ("Boulder Discharge"). Instead, we added a paragraph in the conclusion, in which we describe how the boulder discharge could be estimated based on our dataset. We hope that these modifications help to put the accent on the method, rather than on the result.

R#1: "First, all of the calculations for transport are made based parameters for the full channel, but sediment transport is only analyzed on the bar, which should have much lower transport potential then in the main channel, given a potentially greater depth in the thalweg. Furthermore, is there any data of how the bar's sediment size distribution compares with that of the main channel?"

As discussed above, we have removed section 4, dedicated to the quantification of bedload transport, from the manuscript. With this mind, we try to address your question based on a back to the envelope calculation, in the paragraph below.

We agree with you that the thalweg has a larger potential of transport than the bar: its depth (h) is around 0.5 m and its width (W1) is around 8 m. The width of bar (W2) is 25 m. Although no granulometric data are available for the channel, direct observation suggests that its grain size distribution is comparable to that of the bar. Assuming that this is indeed the case, we find that the flow discharge necessary to initiate the transport of boulders in the Thalweg ranges from 9 to 25 m^3s^{-1} (for a Shield number ranging from 0.02 to 0.04), whereas it ranges from 36 to 69 m^3s^{-1} above the bar. As a result, the duration of transport in the thalweg is 10 to 20 times that of the bank. As the bank is 3 times wider than the thalweg., the latter transports 3 to 6 times more boulders than the bank.

R #1: "Second, the parameters for the transport potential based on flow carry multiple assumptions, in particular based on the friction factor and the shield parameter (which seems far too low). I think it would be useful with an uncertainty analysis around these values rather than just picking two values and claiming that it fits the data". Following your comment, we changed the method to estimate the threshold Shields stress. Instead of choosing the threshold Shields stress from the Shields curve, we now estimate its value from a least square fit of equation 2 on our data set. The best fit is achieved for a Shields parameter of 0.032, that falls in the range of 0.02 to 0.1 given by Lamb et al. (2008). Of course, there is still room for uncertainty as our model does not account for the thalweg and assumes a friction coefficient C_f = 0.1. What matters to us is that this approach reproduces our data with a realistic range of parameters, and allows us to extrapolate the value of the threshold discharge to boulders of size between 0.5 and 0.75 m. (see chapt 3.3 from line 203 to line 232)

R #1: "Regarding the correlation for the transported boulder size and the discharge, this also carries quite a lot of assumptions that there is a relationship between transport size and discharge below ~80 cms. Perhaps it would be more advisable to carry out further calculations on boulder sediment flux with boulders >1 m so that you don't have to make assumptions regarding the relationship between boulder size transported and flow below max flows that you don't have data for."

Working with boulders larger than 1 meters would indeed spare us the trouble of having to estimate a threshold discharge. Unfortunately, the transport rate of such boulders is too low to achieve a reliable statistic during our 10 years' survey. This is why we chose to restrict our analysis to boulders of size between 0.5 and 0.75 m: this size range is large enough to allow for the tracking of boulders; yet, it is sufficiently small to achieve a significant transport rate.

R #1: "I also had a very hard time understanding the GIS methods. I think there was some kind of language issue in what is meant by 'GIS'. I couldn't figure out if the authors meant 'orthophotos' or a specific analysis when referring to 'GIS'. 'GIS' usually refers to the concept of geographic information systems or a software. Here they seem to use it as in referring to a specific data type of a map, perhaps?

We indeed use GIS to designate a specific data type, and we fear that this led to some confusion. We have therefore completely rewritten the description of the data and of their processing. We hope that this new version clarifies the points raised by the referee. (see from line 103 to line 145)

Furthermore, some kind of estimate of error in the size determination of boulders from the drone photos would be useful. How accurately could the boulders be digitized and thus quantified?"

We restricted our analysis to boulders of size greater than 0.5 m. The resolution of the images varies between 0.02 and 0.04 m, depending on the year of acquisition. The digitization is done with an uncertainty of one pixel. For a perfectly circular boulder visible on a 0.03m resolution image, the uncertainty on its diameter will be equal to twice the resolution, i.e. 0.06/0.5 or 12%. In some cases, boulders are leaning on each other and our measurement is then underestimated. We have added a sentence in the text to clarify these points.

R #1: "Lines 24-34 contain very general statements on bedload transport that shouldn't be necessary for readers of ESurf. Perhaps consider condensing this section to 1-2 sentences and move directly into measurement techniques since that is more relevant to this manuscript."

This paragraphs introduces the reader to the stochasticity of sediment transport, which forms the base of the interpretation of our data in terms of the probability of entrainment. This is why we prefer to keep these lines as they are.

R #1: "clarify that it is the bed of a river on a volcanic island, otherwise it sounds like it is the bed of the island."

We modified the sentence.

R #1: "How is a boulder defined? Is it using the Wentworth scale cut-off of 254 mm, or 1 m, or something based on the size distribution (e.g., D84)?"

We use the classification of Terry and Goff (2014), and have added the corresponding reference in the paper. The grains we follow, belong to the class "Boulders" — more specifically ``medium to coarse boulders" — that ranges from 0.256 to 4.096 m. (see line 120)

Terry, J.P., and Goff, J. (2014), Megaclasts: Proposed Revised Nomenclature at the Coarse End of the Udden-Wentworth Grain-Size Scale for Sedimentary Particles, Journal of Sedimentary Research (2014) 84 (3): 192–197. https://doi.org/10.2110/jsr.2014.19.

R #1: "Why is 50 m3/s worth mentioning? Why not 40 or 60 m3/s?"

We modified the sentences using the value of P90 that is 10 m^3s^{-1}. (see line 91)

R #1: "Please consider using the gender-neutral term 'uncrewed aerial vehicle'"

Done. (line 101)

Line 110

The corresponding section has been entirely rewritten.

R #1: "Perhaps I will be convinced later in the manuscript, but how do you know if a boulder has newly arrived in the reach or if it was a boulder that was transported and then deposited further downstream in the reach? Can the boulders be re-identified?"

We are not able to re-identify a boulder that was just displaced by few meters, unless this boulder be big or characteristic enough. Our method can only identify boulders that were deposited or entrained from their previous place.

R #1: "Do you have any data to show that transported boulders protruded higher above bed then immobile boulders?"

It seems indeed to be the case, but our DEM is not accurate enough to unambiguously demonstrate this fact.

R #1: "'significantly' in referring to change should only be used for statistically (in)significant changes. Please report the statistical test used and p-value to conclude that changes are significant."

The deviation of the data relative to the median value is less than 27 %. This why we consider that the total number of boulders on the bar is, at first order, at steady state. We have modified the text to clarify this point.

R #1: "Isn't this fairly obvious if there is the same number of boulders of each size?"

Yes. But the number of boulders in each bin is not the same. 0.5-0.75 m are dominant. We have modified Figure 4 which now indicates the number of boulders in each size range.

R #1: "Why is this unexpected?"

We removed this sentence.

R #1: "This sentence doesn't seem necessary. Isn't this the case for any sediment particle?"

We removed this sentence.

R #1: "Once again, it is unclear what is meant by 'GIS' here".

As discussed earlier, we have modified the description of the data acquisition and processing. We use now "dataset" instead of GIS, and have modified the corresponding sentence accordingly.

R #1: "I'm not sure I agree with the statement that they 'correlate well'. Boulders from ~0.5-1.5 m all move at the same discharge. So there seem to be quite a large variation in what moves at a particular discharge. Please provide a more nuanced evaluation of the correlation. Furthermore, please specify the type of correlation. It does not appear to be linear. Is it exponential? logarithmic? Etc...?"

Figure 5 indeed exhibits some significant scatter. We have therefore nuanced our evaluation of the correlation, and modified the sentence which now reads: `` we find that the size of these boulders increases with the maximum discharge.'' (Line 105)

Given the scatter of the data, we fear that it would be hazardous to try and deduce the type of correlation from figure 5. Instead, we prefer to check that our data are compatible with equation (2), as discussed below.

R #1: "Please justify the use of this value for Shields parameter. This seems quite low for a steep boulder-bed river. The common value for gravel-bed rivers is ~0.047 and steep boulder-bed channels have been found to have higher values ~0.1 (Lamb et al. 2008)."

Following this comment, we changed our method to estimate the threshold discharge. Instead of choosing a priori the value of the Threshold Shields stress, we now fit equation (2) to our data, with the Shields number as the fitting parameter. We find a value of 0.032, which falls in the range 0.02-0.1 commonly observed inn gravel bed rivers (Lamb et al. 2008, Buffington and Montgomery, 1997).

R #1: "Line 253: transport distance".

As discussed above, we removed section 4, and added a paragraph in the conclusion, in which we describe how the boulder discharge could be estimated based on our dataset. In this paragraph, we now use “transport distance” instead of “flight length”.

R #1: “Line 253: This is assuming they are moving straight downstream. Couldn't they have been moved into the thalweg of the main channel and not be visible because they are under the water surface?”

We cannot rule out this scenario. However, as we have no mean to evaluate its probability., we chose to assume that the boulders follow the flow and move downstream.

R #1: “Line 255: Why this density and not the more commonly used 2650 kg/m3? Please justify.”

We used this parameter in the part 4 that is now suppressed.

R #1: table 1: t seems like the surface density and mean grain volume values have quite a few too significant digits that does not seem reasonable (that it was measured at this level of precision).”
You are right. However, we have suppressed this table in the new version of the manuscript.

Reply to the comments of Reviewer #2:

Thank you for your constructive comments.

R #2 General Comments

Overall the paper appears technically sound and I have no major reservations with the work presented by the authors that would present it from being published. The methods are robust if perhaps still a touch manual to prevent them from being easily applied (as an example any sort of automated boulder detection algorithm might expedite the GIS work). The analysis of the data are fairly simple, and this is a major strength of the paper because it does not overinterpret the field data and connects well with laboratory derived results. The analysis, where perhaps oversimplified, is well qualified by the authors."

"The theory and description of how one would quantify a bed load flux of boulders is interesting, however it is not clear to me that we should really place much trust in the final numbers and I wonder if this thrust of the paper may need to be downplayed a bit. I don't think it is wrong, but that the accuracy of the result places it more in the conceptual understanding than a number we should trust. Whereas the model development and application to the residence times of the boulders (especially figure 7) is clear and a very nice result and important contribution as the concept of time is often underquantified in tracer studies."

The quantification of the flux of boulders relies on many assumptions, and you are right to doubt of the accuracy of the numbers that we produce. Accordingly, we removed section 4 of the manuscript ("Boulder Discharge"). Instead, we added a paragraph in the conclusion, in which we describe how the boulder discharge could be estimated based on our dataset. We hope that these modifications help to put the accent on the method, rather than on the result.

R #2: "One drawback of the manuscript, is that the connection to previous literature on some of the topics is missing. It is not as if something is wrong per se, but that some topics felt under explored and connections to the literature could be better explored/established. The boulder transport could certainly be framed within the active layer concept or within the work on partial transport (see the career of Peter Wilcock) but citations to those works are largely absent, alternatively I am sure the authors can inform or remark on the concepts of sorting or patchiness and how that might impact entrainment, but references to that literature are also absent. It would very much seem that the author results resoundingly confirm the concepts of partial transport between floods which would be a strength in the discussion."

Thank you for bringing these references to our attention. We now refer to the work of P. Wilcock (line 253), and have added a discussion about the connection between our observations and the active layer concept (line 160 - Church and Haschenburger 2006 is cited now).

R #2: "The paper would benefit from an English language editing service. There are 1 to 2 errors per page."

We apologize for this inconvenience. We have extensively reworked the new version of the manuscript and hope that the result is now well-written.

Specific Comments.

Ln. 29. Incomplete sentence after the ';'. DONE

Ln. 39. Seismic misspelled. DONE

Ln. 53. It looks like the wording of this sentence is a bit out of order. The tropical volcanic island aside should come at the end of the sentence. DONE

Ln. 71. '...located within the...' Missing word. DONE

Ln. 140. Here's a location where the references could reflect a broader geography (the idea of an immobile and active layer has been around for quite some time).

Thank you for bringing these references to our attention. We have added it to the text and use it to enrich our discussion.

Church, M., and Haschenburger, J.K.: What is the ''active layer''?, Water Resour. Res., doi:10.1002/2016WR019675. 53, 5–10, 2017

Ln. 145. It would be useful to me, to have the median grain size and standard deviation for the bar to be able to place the boulder sizes into context.

We don't have such granulometric measurement for the grains with a diameter smaller than 0.5 m.

Ln. 241. Definition wise I do not think 'assimilate' is incorrect, but it is not the common english usage of assimilate. I would suggest 'approximate'. Done

Ln. 250. You also might consider a minimum flight length estimate based on the experiments of Lajeunesse et al. (2010), Phillips and Jerolmack (2014) (cited by the authors) found it to provide a reasonable lower bound for tracer transport in a similar tropical boulder stream. Use of the largest boulders may not provide a lower bound. The roughness of the bed is relative to the size of the mobile particle; a larger particle is mobilized less but may move farther when entrained due to a lower relative roughness.

Thank you for this idea. We will consider the estimations you suggest in a future paper dedicated to sedimentary discharge.

Ln. 256-265. It is not clear to me that this paragraph is needed. It is fairly speculative and while it provides a number on the flux we can't constrain the error of the number or understand what to do with this number in context. That it is speculative is well qualified by the authors, it just may not be a needed paragraph.

As discussed above, we have removed section 4 of the manuscript.

Figures. The placement of the panel letters [a), b), c) etc.] feels a bit unfinished. The styling of the figures is a bit all over the place, from font sizes to line widths. This isn't the biggest issue but it is noticeable and can distract from the message of the figures.

We have redrawn the figures.

Figure 2b. Could you mark the points when field surveys were flown?

Figure 2b is meant to illustrate the frequency of floods. As a result, it presents a single year of data only, and we cannot use it to *mark the points when field surveys were flown.*

Figure 4. The vertical label in panel b is quite blurry.

Thank you. We have corrected this.

Figure 5. Y Label missing a 'k' in Block.

Thank you. We have corrected this.

Figure 6. I suggest that the ylabel be changed from duration to cumulative duration following the figure caption.

Done

Wording change suggestion - change 'The transport' to 'Transport is only possible for a few hours…'

Done*.*