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.

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. We have added a sentence in the manuscript that clarifies this point.

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.

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.

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 P99 that is 10 m^3s^{-1}.

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

Done.

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 displaced from their previous place. We have added a sentence that clarifies this point.

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: ``Despite a significant scatter, we observe that the maximum discharge recorded at the gauge station increases with the size of the largest transported boulders.''

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.