Dear Editor,

We have now completed the revision of our manuscript and responded to the three reviews provided. Enclosed are the salient points raised by the reviewers and our general answers. A detailed response is provided to each review separately.

1. All reviewers point to the interest of the dataset we acquired and its usefulness.
2. All reviewers agree with the technique we develop in order to compare the geometry of individual threads from braided and meandering rivers.
3. All reviewers agree with our main conclusions.
4. Two reviewers ask for a thorough clarification of the terms used in the article (river, channel, thread). We do this by adding a figure that defines these terms, and strive to provide a consistant use of these terms throughout the revised manuscript.
5. Two reviewers ask us to be more specific in the method sections and to justify the usage of "meandering" and "braided" for the rivers we studied. Concerning the former comment, we now specify the data acquisition procedure in more detail. Concerning the latter comment, we report values for the sinuosities and braiding indexes that legitimate the use of the terms.
6. Two reviewers question the representativeness of the baseline dataset. They wonder why we did not include data from well known studies on meandering and braided rivers. In our answers to the reviewers, we recall the necessity for datasets to be available in order for them to be included. P. Ashmore, upon reading the submitted manuscript, provided us with a supplementary dataset on individual braided threads of the Sunwapta river, Canada. This set is now added to the baseline dataset and strengthens our conclusions. P. Ashmore is now co-author of the revised version of the manuscript.

We hope that you will now find the revised version of our manuscript suitable for publication in *ESurf*.

Respectfully,
The authors

Answer to Pr. Voller

February 4, 2016

Note: Bold text indicates the reviewer's comments.

This paper statistically compares the morphologies of channel threads in braided gravel bed river systems with the morphologies of isolated meandering gravel bed channels. In keeping with previous findings related to sand bed channels, the analysis shows that, when braided and meaning gravel bed streams coexist in the same climatic and geological environments, the morphologies, in particular the width and depth, of the channels are statistically indistinguishable.

This is an excellent paper. Adding significantly to the data base on morphologies of gravel bed rivers and providing a sound statistical analysis techniques for comparing stream morphologies.

Further strong points in the paper include:

A very informative comparison of the current data with data from previous gravel river studies, see (Fig 4) and Table 2.

Repeating the analysis with both d50 and d90 adds robustness to the findings.

The work provides a nice example of how the threshold theory can be effectively used to detrend stream morphology data.

The conclusions do a very good job of explaining the possible consequences of the findings for ongoing laboratory and modeling studies. We greatfully acknowledge the encouraging comments of the referee. Below are our answers to the specific points.

I note some very small points that the authors may like to correct:

For total clarity in the 2nd line of 1292 it might be a good idea to provide the definition of the aspect ratio (W/H). This is done in the corrected version.

In the first line of 1293 is the adjective "gently" required since the slope $S \sim 0.01$ is given. We have removed the adjective from the corrected version.

It appears to me that the ordering of the figures and tables do not follow their citation in the text (e.g., see placement of Fig 5). We have changed the labelling accordingly.

Perhaps the sentence Various species of grass dominate the vegetation over the entire basins, and their influence on the morphology of the streams is certainly only mild could be reworded, I would suggest something like Although a variety of grass species make up the basins vegetation their relative influence on the channel morphology can be assumed to be small. Thank you for this sugestion that we endorse.

In the last line of 1299, would the word "segmented" work better than "rumpled" Yes indeed.

Answer to reviewer 2

February 5, 2016

Note: Bold text indicates the reviewer's comments.

1 General comments

The manuscript by Metivier and co-workers reports on channel geometry, discharge and grain size data collected from the Bayanbulak Grassland, China, during two field campaigns. The manuscript is generally well written and contains valuable data on gravel-bed rivers, complementing currently existing data. The data is presented in a smart format allowing for comparison to other datasets and systems of all sizes.

The manuscript could be significantly improved by defining key terms used throughout the manuscript. This includes the terms 'meandering' and 'braiding', which are distinguished throughout the manuscript, in the graphs, and also a conclusion hinges on this distinction, while it remains unclear to the reader how a meandering and braiding river is defined in this study. Other improvements may arise from a more detailed explanation of the measurement strategy and protocol, and the inclusion of a discussion section to better develop the ideas the authors may have on the key findings of this study. We wish to thank reviewer 2 for his/her positive comments. We hereafter provide detailed answers.

The manuscript would benefit from a definition of the different terms used to describe channel forms throughout the manuscript. A plethora of terms describing channels forms such as 'rivers', 'streams', 'channels', 'reaches' and 'threads'. A clear definition of all terms will help the reader understand what is meant exactly, how the terms link different hierarchical morphological forms (i.e. rivers and threads within rivers), and will ensure consistency throughout the manuscript. A graph with a visual representation of all the mentioned channel forms and their terms as used in the manuscript would be highly insightful for this purpose. This graph would be well placed in the beginning of the introduction where many terms are already mentioned, or could be placed in the Method section. We have added a figure in our introduction to clarify the definition of the terms used. To summerize, "rivers" and "streams" correspond to the same definition, they include the channel and its floodplain. We now use "river" only. The channel corresponds to the flow that is enclosed between its banks. The threads correspond to the places where the flow occurs. In a meandering river there is only one channel and one thread. In a braided river there is usually one channel composed of many threads separated by bars or islands. As much as possible we try to be coherent with previous work from Métivier and Barrier (2012) and (Gaurav et al., 2015).

A crucial element missing from the current manuscript is a definition of meandering and braided rivers. What definition was used to determine whether a river was meandering or braiding? It seems likely to use the sinuosity to quantify the degree of meandering and a braiding index to quantify the degree of braiding. And how was this measured? For example, along what kind of basin length was the sinuosity measured? Was this done consistently for all

reaches reported on? Also, how many transects were used to quantify the braiding index, and was this done consistently for all reported reaches? Such quantification of river pattern will be helpful to substantiate qualitative statements like 'highly meandering' on p. 1293, line 9. In addition, formal quantification of the reported river patterns may also provide additional understanding on the reported similarities between the termed meandering and braided rivers. For example, are only the statistical distributions for lower sinuous meandering rivers similar to braided ones, and maybe not the highly sinuous (sinuosity ¿ 1.5) meandering rivers? This latter analysis allows for a more sophisticated analysis of the collected data and would also allow the authors to align their work with previous work on this topic where distinctions between river patterns could be made based on the degree of sinuosity, see for example Kleinhans and Van den Berg (2011). Meandering rivers are single-thread rivers whose sinuosity is higher than some arbitrary value. On average the sinuosity of single-thread channels is 1.5 ± 0.2 near the measurement sites (measurements were performed on 1 km-long stretches). Hence most of our rivers are highly meandering if one refers to the classification of Schumm (1977).

The differenciation between braided and meandering rivers was very clear on the field, as quoted by the reviewer below. All the braided rivers we surveyed had a large number of threads flowing in a large, non-vegetated, channel enclosed within natural banks. In all cases the total braiding index would be more than 3.

Finally, given the small number of mildly sinuous channels we did not try the split the dataset into subsets. We now explicitely state these points in the revised manuscript

A more detailed explanation of the measurement strategy and protocol would help the reader better understand the collected channel geometry, discharge and grain size data. A number of questions that a revised manuscript should answer at minimum are: The answers below are included in the revised version of the manuscript.

How many cross-sections were measured to represent a specific river? Each thread was measured at one to six locations.

What were the criteria to choose a cross-section, knowing that channel width variations along a river can be substantial. Were cross-sections always made at a similar location (e.g. middle of bend) in the river? Please motivate. The reaches were chosen according to their accessibility and the sections were chosen at random. Our purpose here is not to study one particular river at any particular given position, but rather to sample as many possible section types on as many streams as possible to test whether a consistent picture emerges

How were the reported average values on flow velocity, water depth and grain size calculated? Is this a stream cross-sectional average, or does it represent a single (maximum?) flow velocity in the middle of the stream? Please specify this for the two methods used (ADCP profiles and manual measurements). We try to be more explicit in the revised version.

When we used an ADCP, we mounted the instrument on a raft and performed cross-sections from which we extracted both the geometry and the discharge of the thread. For manual measurements, we used rulers and ropes to level the topography of the section. We then calculated the average width and depth. We measured the average surface velocity using floats. The average velocity was derived from the surface velocity using a classical correction factor (Sanders, 1998)

How many counts of grain size were used to calculate a D50 and D90 for each crosssection? We used the Wolman's counting method and procedure (Wolman, 1954; Bunte and Abt, 2001). Depending on the surface exposure of gravels, the count number ranged from 200 to 500.

Along which length were the long profiles and slopes of the streams measured? Does this align with the length across which an assessment of the degree of meandering and braiding was made? The length of topographic profiles varies from 100 m for braided threads to more then 3 km for one meandering channel. We measured the sinuosity of meandering channels using topographic profiles, when available, or Google images. In the latter case, we obtained the sinuosity from 1 km long profiles centered on the measurement sites. We now mention this explicitely.

The manuscript is currently lacking a discussion. The conclusion is currently partly functioning as a discussion, which is rather confusing and which also hampers a detailed reflection of the authors on how their results fit into earlier work. Such a discussion would allow the authors to expand on key findings of the study such as the observed geometrical similarities between meandering and braided rivers and the resultant lack of a transition from braided to meandering channels as reported in other work, and the extension of their findings from gravel-bed to sand-bed environments. Therefore, I encourage the authors to include a dedicated Discussion section in the revised manuscript in which they expand upon the aforementioned key findings. Other findings that may be expanded upon are the notion of the relationship between sediment load and channel aspect ratio, and how flume experiments and numerical models can be used specifically to further this work. Adding such a discussion will also involve a rewrite of the current conclusion section, which is highly speculative in nature as it stands. We understand the reviewer's concern and have accordingly expanded the conclusion. We acknowledge that the conclusion on the influence of the sediment flux on the aspect ratio is still speculative at this point, and we have made it clear.

2 Technical corrections

p. 1291, line 21: Much more work has been done on this topic and should be referenced here in addition to Schumm 2005. For example, Leopold and Wolman (1957), Ferguson (1987) and Kleinhans and Van den Berg (2011) to name a few. Following the comment we added the suggested references.

p. 1291, line 21: 'supported by laboratory experiments' seems inappropriate here and is not supported by the listed references, which all focus on theoretical rivers or field data. Thank you for this quote. In fact Fredsøe (1978) includes a comparison with experimental data, but we added a reference to the experimental work of Fujita and Muramoto (1985) for alternate bars, and Ashmore (1991) for the development of braid bars.

p. 1291, line 23: developed Done.

p. 1291, line 23: pattern Done.

p. 1292, line 2: What do the authors mean with 'sediment discharge'? Sediment load, sediment type, sediment concentration, or a combination of these? Please expand. By the sediment discharge we mean the total sediment flux (or load as quoted by the referee).

p. 1292, line 5: The authors may also want to refer to Braudrick et al (2009) and Van Dijk et al (2013) to cover recent work on the interaction between coarse-bedded rivers and vegetation. We included these references.

p. 1292, lines 12-14: 'In sandy. . ..same environment'. This sentence requires a reference. This statement corresponds to the work of Gaurav et al. (2015) that is cited elsewhere. We now cite it here.

p. 1293, line 8: I suggest changing Figure 5 to Figure 2 as it is introduced here as the second graph. Done.

p. 1293, line 9: Please define 'highly meandering'. Is this a sinuosity above 1.5? Same holds for a braided pattern: how is it defined? What kind of braiding index is typical? As mentioned earlier, the notion of high sinuosity is arbitrary. The reviewer seems to place it above 1.5 whereas it has traditionally been placed around 1.3 by others (Schumm, 1977). The meandering streams of Bayanbulak have a sinuosity of 1.5 on average, so they can safely be considered as highly meandering. We now mention this explicitely in the text

p. 1293, line 10: Figs 2 and 3 show examples of a meandering pattern and braided stream, but not a transition from one to the other. I suggest to place the reference to the figures after the first part of the sentence. We place the figures at the end of the sentence in order not to cut the latter with references to figures, tables or bibliography. We believe the reader can safely find his/her way.

p. 1293, line 13: 'is certainly only mild'. Please change to 'is only mild'. Done.

p. 1293, line 14: Why is referred to Hey and Thorne (1986) here? Hey and Thorne (1986) do not specifically look at the influence of vegetation on the river morphology in the studied basin, and the reference therefore seems out of place. Please remove or expand to motivate why Hey and Thorne (1986) should be referenced here. We cite Hey and Thorne (1986) because they disclose data on the riparian vegetation that has been widely used in fluvial geomorphology studies. (Metivier and Barrier, 2012), for example, use this data to discuss the influence of vegetation on the aspect ratio of gravel-bed rivers. We added references to our earlier work and to the well known work of Andrews (1984).

p. 1294, lines 21-22: The maximum reported channel widths and discharges do not correspond with the data reported in Table 3 and Table 4. In these tables, the maximum channel width is only 35 m (not 77 m) and the maximum discharge is only 51 m3/s (not 100 m3/s). This is a mistake. The reviewer is right and the values correspond to those in the table. The Kaidu river when it leaves Bayanbulak has a width of 77m and a discharge of 100 m^3/s but the d_{50} of its bed is sandy so it was not included in the study. The figures are unaffected.

p. 1294, line 23: please change 'average' to 'median'. Done.

p. 1295, line 2: 'morphology' should be changed to 'geometry'. Done.

p. 1295, lines 2-3: Please clarify that this statement is derived from the threshold theory lines as depicted in Figure 6. This statement is not derived from the threshold theory. It is awaited since single-thread channels all exhibit a power law relationship with discharge.

p. 1295, lines 3-4: Please clarify where this can be seen and what is meant with 'isolated' here. Looking at Figure 6, I am assuming that 'isolated' refers to meandering but I am not sure. We changed "isolated" to "meandering" in the text.

p. 1295, line 7: Please remove '(Sect. 4)'. Done.

p. 1295, lines 8-9: This statement is true for the width and depth data, but not so much for slope where a lot of scatter is present and 'gathering around a straight line' seems an inadequate description of the presented data. This is confirmed later on when calculating fitting coefficient in Table 1. We agree with the refereee. Based on the sole dataset we acquired, the gathering is not obvious. There the GBR dataset is useful as it shows that there is indeed a trend and that the Bayanbulak dataset accords with it. We have clarified this point in the revised version.

p. 1295, line 19: wider with respect to the grain size. Not wider in terms of absolute values. This could be made more explicit. We added this explicitely in the text

p. 1297, line 12: The dashed lines on Fig. 6 represent Eqs. (2) – (4). Done.

p. 1298, line 18: supports. Done.

p. 1298, line 14: please change 'morphology' to 'geometry'. Done

p. 1299, line 1: Which mean are the authors referring to? We are referring to the means of the distributions of rescaled variables. We have clarified this point in the text.

p. 1299, lines 7 - 8: This statement needs more clarification and motivation. At a minimum, it should be explained to the reader how 'meandering' and 'braiding' are defined and measured. Also, the term 'morphologically' may need to be changed to 'geometrically' because channel width, depth and are geometrical properties. In contrast, the morphological pattern of the provided examples of meandering and braided rivers from satellite images seem qualitatively very different. We have modified the text at several places to clarify the distinction between meandering and braiding. The measurement methods are now described in more details. We changed "morphologically" to "geometrically" and added a sentence to clarify this.

p. 1299, lines 11 - 12: There are no correlation coefficients reported in Table 2, in contrasted to what is suggested here. The correlation coefficients are indeed not reported in Table 2. They are all smaller then 0.01, not 0.1. We mention this in the text.

p. 1299, line 19: please change morphologically to geometrically. Done

p. 1299, lines 23 - 25: This sentence signals a large extension of the results from gravel-bed systems to sand-bed systems and should be expanded to better develop the authors' reasoning here. The reference to the sand-bed systems is based on work on the Kosi megafan, so does it only apply to these fan environments or do the authors see application in other sand-bed systems as well? I believe that this sentence is not suited for the conclusion but would be well placed in a Discussion section, which is currently lacking. This may also provide a better place to the develop the authors' ideas on the similarity between the geometry of meandering and braiding channels, rather than making it part of the conclusion. The extension to sand-bed rivers is based on previously published results (Gaurav et al., 2015). We have modified the conclusion to clarify our claims.

p. 1299, lines 26 – p 1300 line 2: it would be very helpful to know what the authors mean exactly with the terms 'a braid', 'individual threads', and 'isolated channels' in this sentence. The aforementioned definition graph of channel forms may be useful. We have clarified the text to avoid confusions and added a figure to specify the terms used.

p 1300 line 18: Bertoldi and Tubino (2007) is not mentioned in the main text. p 1300 line 20: Bolla Pittaluga et al (2003) is not mentioned in the main text. p 1301 line 6: Devauchelle et al (2011) is not mentioned in the main text. p 1301 line 28: Mackin (1948) is not mentioned in the main text. p 1302 line 3: Paola (2001) is not mentioned in the main text. p 1303 line 9: Zolezzi et al (2006) is not mentioned in the main text. We removed all non-cited references.

Figure 1: Could the writing in the white rectangles be enlarged to aid the reader? Also, the smaller rectangles are hard to see, a larger contrast or different colour may be needed. Done

Figure 2: Could the corresponding meander bend in the satellite image be indicated? Also, what is the location of the braided stream picture within the satellite image? The pictures were not georeferenced. This is why we did not try to point at the precise position on the stream were the image was taken. Furthermore, the Google images were not from the same year as the field images.

Figure 4: Please change 'normed' to 'normalised'. Tables 1-4: I suggest introducing Tables 3 and 4 before Tables 1 and 2, mainly because Tables 3 and 4 contain the actual data while Tables 1 and 2 contain variables derived from the data reported in Tables 3 and 4. Done

References

Andrews, E. D. (1984). Bed-material entrainment and hydraulic geometry of gravel-bed rivers in Colorado. *Geol. Soc. of Am. Bull*, 95:371–378.

Ashmore, P. E. (1991). How do gravel-bed rivers braid? *Canadian Journal of Earth Sciences*, 28(3):326–341.

Bunte, K. and Abt, S. (2001). Sampling surface and subsurface particle-size distributions in wadable gravel- and cobble-bed streams for analyses in sediment transport, hydraulics, and streambed monitoring. Technical report.

Fredsøe, J. (1978). Meandering and braiding of rivers. *Journal of Fluid Mechanics*, 84(04):609–624.

Fujita, Y. and Muramoto, Y. (1985). Studies on the process of development of alternate bars.

Gaurav, K., Métivier, F., Devauchelle, O., Sinha, R., Chauvet, H., Houssais, M., and Bouquerel, H. (2015). Morphology of the kosi megafan channels. *Earth Surface Dynamics*, 3(3):321–331.

Hey, R. D. and Thorne, C. R. (1986). Stable channels with mobile gravel beds. *Journal of Hydraulic Engineering*, 112(8):671–689.

Metivier, F. and Barrier, L. (2012). Alluvial landscape evolution: what do we know about metamorphosis of gravel bed meandering and braided streams. In Church, M., Biron, P., and Roy, A., editors, *Gravel-bed Rivers: processes, tools, environments.*, chapter 34, pages 474–501. Wiley & Sons, Chichester.

Métivier, F. and Barrier, L. (2012). Gravel-bed rivers. processes, tools, environments, chapter 34, alluvial landscape evolution: What do we know about metamorphosis of gravel-bed meandering and braided streams. *Wiley–Blackwell*, 1(2.1):2–3.

Sanders, L. (1998). A manual of field hydrogeology. *Prentice-Hall, Inc., 113 Sylvan Ave. Englewood Cliffs NJ 07632 USA. 381*, page 1998.

Schumm, S. A. (1977). *The fluvial system.* John Wiley & Sons Inc.

Wolman, M. G. (1954). A method for sampling coarse river bed material. *EOS Trans. AGU*, 36:655–663.

Answer to reviewer 3

February 5, 2016

Note: Bold text indicates the reviewer's comments.

This paper focuses upon associations between channel morphology and discharge for 92 sites along single-thread meandering and braided gravel-bed channels in the Bayanbulak grassland, China. There are well established associations published in the literature between morphology (width, depth, slope) and discharge, that identify thresholds between the two morphological states. For example Leopold and Wolman (1957) identify a threshold condition between meandering and braided channels in the relationship between slope and discharge. The authors in this study compare their data with Parker et al. (2007), Church and Rood (1983) and King et al. (2004). Comparison could be made with a wider selection of studies, including Leopold and Wolman's (1957) original work on the topic. We are aware of all these studies (Metivier and Barrier, 2012). We would be happy to include all datasets used from previous work, but the data used by Leopold and Wolman (1957), for instance, is not available.

Overall the numerical formulation and statistical treatment of the data look fine, however the methodology needs more detail, some clarification, and possibly some further justification. It appears that the authors were analyzing the morphological and discharge characteristics of threads (anabranches) from the braided channel and comparing these with single-thread meandering reaches. Surely the main conclusions concerning morphology are therefore unsurprising e.g. no major width differences in channel width. Why did the authors not survey the full active width of the braided channel; including multiple channels and bar tops? The authors need to present further rationale for concentrating on discrete threads of channel. As discussed here and in Gaurav et al. (2015), most studies to date focus on what is called the "active width" of braided rivers, whereas we propose to focus on individual threads. There are several reasons for this.

w_i is the width of the i^{th} thread of a braided channel (N threads in total). As shown here the hydraulic geometry of braided threads is identical for each individual thread:

$$w_i = \alpha Q_i^{\beta} \tag{1}$$

where α, β are to constants and $\beta < 1$. Summing the threads together leads to

$$W = \sum_{i=1}^{i=N} w_i = \alpha \sum_{i=1}^{i=N} Q_i^{\beta} \neq \alpha \left(\sum_{i=1}^{i=N} Q_i \right)^{\beta} . \tag{2}$$

The original hydraulic geometry of the threads is therefore lost through the scale integration process.

The study of active widths of braided streams is inherited from stability analyses that consider an originally wide channel, destabilized by growing bars (Engelund, 1970; Parker, 1976; Devauchelle et al., 2010; Zolezzi et al., 2012). In contrast, we propose that the physics of individual threads is of specific interest. It is a step towards understanding their collective behavior.

From inspection of the aerial images in Fig 3, it appears that meandering, wandering and braided channels may all exist within the study area, yet there is no mention of wandering. Why are the authors just working on braided and meandering channels? Are some of the sites sampled actually wandering in nature? The authors must offer a correct classification of their channel types. We agree but the purpose of this work is not to establish a detailed classification. Wandering channels are an intermediate planform between braided and meandering rivers. Their definition is somewhat arbitrary (Church, 1983; Brierley, 1989). Here we propose to compare threads of single and multi-thread rivers. It turns out that the single-thread rivers of the Bayanbulak grassland are mostly meandering rivers (average sinuosity of 1.5) whereas multi-thread rivers are mostly braided (total braiding index larger than 3.3).

Why are the morphological characteristics of braided and meandering rivers worthy of study; bearing in mind the immense volume of research already conducted in these channel types? The key finding of this study appears to be the lack of morphological differences between braided and meandering streams. The authors must make it clear what the significance of these conclusions are. The lack of significant difference between meandering and braided threads suggests that a fully-developped braided river can be considered as a collection of individual threads. The physics of single-thread rivers thus probably applies to braided rivers. We also show that the scaling relationships of braided and meandering threads is, to leading order, controlled by the threshold of motion. Our observations show that the aspect ratio of a thread, because it does not depend on discharge, is an important quantity to understand the influence of variables such as the sediment discharge on the geometry of threads.

Page 1291: Line 18, simply splitting alluvial channel types into two end members is far to simplistic, and not very helpful for future understanding. What of the wide variety of other channel typologies e.g. Montgomery and Buffington (1997), or Rosgen (1994)? In this paper we are interested in the comparison of threads of single-thread and multi-thread rivers. Because of their high sinuosity, the single-thread rivers we study are meandering but this point is not critical to our analysis.

Line 22, 23, there are two spelling errors; 'developed' and 'pattern'. Please can the authors check spelling throughout the manuscript Done.

Line 23, should Ashmore's (1991) fundamental laboratory work on braiding mechanisms be cited here? Yes we have included this reference earlier in the introduction.

Line 25, define 'aspect ratio' This is now done in the text.

Page 1292: Line 7, do braided rivers have banks? Yes indeed at least in the case of the Bayanbulak rivers. These banks limit the active channel from the braid plain and they are well defined. The picture below shows an example of such a bank. As this discussion is open and online we propose not to include this picture in the revised paper in order to keep terse.

Line 10, when the authors discuss single threads – are they referring to anabranches within the braided channel? Surely if morphological comparison are to be made between braided and meandering then it is the full channel (which may comprise multiple threads, and bar tops, along a braided reach), that needs to be considered rather than isolated threads. If isolated threads from braided reaches are being compared against single-thread meandering reaches, then it is unsurprising that their morphology is similar. Yes, we are indeed referring to anabranches and have answered this point in our answer to general comments.

Page 1294: Line 8, what were the length of the profiles used for channel slope measurement? Where these taken along the thalweg of the channels, and anabranches? Yes, the profiles where taken along the thalwegs and they are on average 1 km-long. We specify this point in the corrected manuscript.

Line 11, How many clasts were measured at each site? It is customary to use the 84th percentile of the cumulative grain size distribution in many bedload transport studies. Why is the 90th percentile used here? Between 200 and 500 clasts were measured depending on the exposure. We added this precision in the text. The 90th percentile is as common as the 84th percentile (see for example Garcia, 2008, for a review).

Line 19, why are only these three sources used for comparison? What of other fundamental work (e.g. Leopold and Wolman, 1957)? We agree that adding some other datasets would be useful. But in order to establish comparisons the data must be available (see Metivier and Barrier, 2012, for a discussion). The data of Leopold and Wolman (1957), like many other benchmark papers, are not available and can therefore not be used for comparison purposes.

Line 26, Individual threads suggests that dry bar tops are not included in the braided channel cross-section - however surely they are part of the active channel, and should be included in the analysis ? See the general discussion above.

Page 1295: Line 22, Could the others clarify their argument here, concerning the role of coarse particles in controlling morphology. It could equally be argued that very fine-grained cohesive sediments also strongly control morphology We agree that the representative grain-size of a gravel-bed river has always been the subject of debates, yet the influence of coarse particles on the channel geometry has been discussed by many authors and seems well established. See for example Parker (1978) and Parker et al. (2008).

Page 1296: Line 2, Do the authors mean isolated 'meandering' threads? Please clarify We have modified the text to clarify this point.

Page 1299: Line 1, The 'means' of what? Please could the authors clarify. The means of the statistical distribution. We have clarified this in the text.

Page 1300: Line 1, surely the behavior between single-thread meandering (with well defined banks and more cohesive sediments), should be expected to differ to that of true braided with unrestricted movement? Could the authors clarify the statement here. We do not intend to claim that threads from meandering and braided rivers are equivalent. Our data show that if meandering threads are expected to differ from braided threads, this difference does not express itself in the variables studied in this paper (width, depth and slope).

Line 5, 10, There are a number of statements concerning the role of sediment transport/supply in controlling channel morphology made in the conclusions. Undoubtedly sediment supply plays an important role in controlling channel morphology, however the authors present no data on this. Rather than make comments concerning sediment transport, the authors should concentrate on the conclusions they can make from the data presented in the paper, and highlight the significance of these findings. We agree that this point, in our conclusions, on the influence of sediment transport is speculative. We have changed the text to make it clear.

Tables 3 and 4, There appears to be very little difference in some of the grain size metrics (D50 and D90 values) and slopes between some of the sites. In fact many are identical. However the channel dimension and hydraulic data differ markedly between the same sites. The two do not stack up! - Surely there must be differences between sites? Could the authors make some comments on this? This means that the channel dimensions are influenced by another parameter. We hypothethise that the sediment discharge may be at the origin of these differences.

References

Brauderick, C. A., Dietrich, W. E., Leverich, G. T., and Sklar, L. S. (2009). Experimental evidence for the conditions necessary to sustain meandering in coarse-bedded rivers. *Proc. Nat. Acad. Sci.*

Brierley, G. J. (1989). River planform facies models: The sedimentology of braided, wandering and meandering reaches of the Squamish River, British Columbia. *Sedimentary Geology*, 61:17–35.

Church, M. (1983). Pattern of instability in a wandering gravel bed channel. *Modern and ancient fluvial systems. International Association of Sedimentologists, Special Publication*, 6:169–180.

Devauchelle, O., Malverti, L., Lajeunesse, E., Lagree, P.-Y., Josserand, C., and Thu-Lam, K.-D. N. (2010). Stability of bedforms in laminar flows with free surface: from bars to ripples. *Journal of Fluid Mechanics*, 642:329–348.

Dijk, W., Lageweg, W., and Kleinhans, M. (2012). Experimental meandering river with chute cutoffs. *Journal of Geophysical Research: Earth Surface (2003–2012)*, 117(F3).

Engelund, F. (1970). Instability of erodible beds. *jfm*, 42:225–244.

Garcia, M. H., editor (2008). *Sedimentation engineering: processes, management, modeling, and practice.* ASCE.

Gaurav, K., Métivier, F., Devauchelle, O., Sinha, R., Chauvet, H., Houssais, M., and Bouquerel, H. (2015). Morphology of the kosi megafan channels. *Earth Surface Dynamics*, 3(3):321–331.

Leopold, L. B. and Wolman, M. G. (1957). River Channel Patterns. Technical Report 282-B.

Metivier, F. and Barrier, L. (2012). Alluvial landscape evolution: what do we know about metamorphosis of gravel bed meandering and braided streams. In Church, M., Biron, P., and Roy, A., editors, *Gravel-bed Rivers: processes, tools, environments.*, chapter 34, pages 474–501. Wiley & Sons, Chichester.

Parker, C., Simon, A., and Thorne, C. R. (2008). The effects of variability in bank material properties on riverbank stability: Goodwin Creek, Mississippi. *Geomorphology*, 101(4):533–543.

Parker, G. (1976). On the cause and characteristic scales of meandering and braiding in rivers. *Journal of Fluid Mechanics*, 76(3):457–480.

Parker, G. (1978). Self-formed straight rivers with equilibrium banks and mobile bed. part 2. the gravel river. *Journal of Fluid Mechanics*, 89(01):127–146.

Zolezzi, G., Bertoldi, W., and Tubino, M. (2012). Morphodynamics of bars in gravel-bed rivers: Bridging analytical models and field observations. *Gravel-Bed Rivers: Processes, Tools, Environments*, pages 69–89.

~~Morphology~~ Geometry of meandering and braided gravel-bed ~~streams~~ threads from the Bayanbulak Grassland, Tianshan, P.R. China.

February 15, 2016

Abstract

The Bayanbulak Grassland, Tianshan, P.R. China is located in an intramountane sedimentary basin where meandering and braided gravel-bed ~~streams~~ rivers coexist under the same climatic and geological settings. We report ~~on measurements of their~~ and compare measurements of the discharge, width, depth, slope and grain size ~~. Based on this data set, we compare the morphology~~ of individual threads from these braided and meandering ~~streams~~rivers. Both types of threads share statistically indistinguishable regime relations. Their depths and slopes compare well with the threshold theory, but they are wider than predicted by this theory. These findings are reminiscent of previous observations from similar gravel-bed ~~streams~~rivers. Using the scaling laws of the threshold theory, we detrend our data with respect to discharge to produce a homogeneous statistical ensemble of width, depth and slope measurements. The statistical distributions of these dimensionless quantities are similar for braided and meandering ~~streams~~threads. This suggests that a braided river is a collection of intertwined ~~channels~~threads, which individually resemble ~~isolated streams~~those of meandering rivers. Given the environmental conditions in Bayanbulak, we furthermore hypothesize that bedload transport causes the ~~channels~~ threads to be wider than predicted by the threshold theory.

1 Introduction

The morphology of alluvial rivers extends between two ~~end members~~end-members: in meandering rivers, the flow of water and sediments is confined in a single ~~channel~~thread, whereas in braided rivers the flow is distributed into intertwined threads separated by bars ~~.~~(Figure 1; Leopold and Wolman, 1957; Ferguson, 1987; Ashmore, 1991; Schumm, 2005; Kleinhans and van den Berg, 2011)

Linear stability analyses, supported by laboratory experiments, explain how bedload transport generates bars, ~~which in turn can grow into a fully developped braided parttern~~ and favors the formation of meandering or braided patterns. (Parker, 1976; Fredsøe, 1978; Fujita and Muramoto, 1985; Devauchelle et al., 2007; Ashmore, 1991; Zolezzi et al., 2012). This mechanism proves more efficient in wide and shallow channels. Field measurements indicate that the bankfull aspect ratio (ratio of width to depth) of braided rivers is usually much larger ~~that~~ than that of meandering ones, thus suggesting that the bar instability is indeed responsible for braiding (Parker, 1976; Fredsøe, 1978; Fujita and Muramoto, 1985; Devauchelle et al., 2007; Ashmore, 1991; Zolezzi et al., 2012). What exactly controls the aspect ratio of an alluvial river remains an open question, although sediment discharge and riparian vegetation ~~are~~ seem significant in this respect: high sediment load and weak vegetation both favour wider and shallower channels, and often induce braiding (Smith and Smith, 1984; Gran and Paola, 2001; Tal and Paola, 2007; Brauderick et al., 2009; Tal and Paola, 2010; Dijk et al., 2012; Metivier and Barrier, 2012).

In a ~~fully developed braided river~~fully-developed braided channel, emerged bars separate the threads from each other (Figure 1), and the very definition of bankfull conditions becomes ambiguous. Most authors treat the ~~river~~ channel as a whole by defining lumped quantities, such as the total ~~river~~ channel width or the average water depth (Metivier and Barrier, 2012). Conversely, ~~a few studies consider~~ few studies focus on the morphology of ~~individual threads, and compare it to isolated channels . In sandy braided~~ braided and meandering channels at the level of individual threads (Church and Gilbert, 1975; Mosley, 1983; Ashmore, 2013; Gaurav et al., 2015). In sand-bed rivers, the ~~morphology of individual~~ geometry of braided threads appears to be indistinguishable from that of ~~isolated streams from the same environment~~meandering ones. This observation accords with recent laboratory experiments (Seizilles et al., 2013; Reitz et al., 2014). To our knowledge, this similarity has not been fully investigated in gravel-bed ~~braided~~ rivers.

Here, we report on measurements in the Bayanbulak Grassland, Tianshan Mountains, P.R. China, where tens of meandering and braided gravel-bed rivers develop in the same environment. After comparison with other datasets from the literature, we compare the morphology of braided and meandering threads in our dataset. Finally, we rescale our measurements based on the threshold theory to generate and analyse a single statistical ensemble from ~~streams~~ rivers highly dispersed in size (Glover and Florey, 1951; Henderson, 1963; Seizilles et al., 2013; Gaurav et al., 2015).

2 Field site

The Bayanbulak ~~grassland~~ Grassland is an intramontane sedimentary basin standing at an elevation of about 2500 m in the Tianshan Mountains (Figure 2). Two main wetlands, the Qong Yulduz basin (known as the Swan Lake in Chinese), and the Kizik Yulduz basin, are distributed around the main Kaidu River. They are immediately surrounded by ~~gently~~ sloping meadows (slope $S \sim 0.01$), themselves enclosed with the Tianshan Mountains which provide water to the Kaidu River (Zhang et al., 2002). The hydrology of the basins is controlled by snowmelt and summer orographic precipitations (Zhang et al., 2002; Yang and Cui, 2005). Snow accumulates from November to March, and starts melting in April, inducing the water discharge to rise in all ~~streams~~ rivers (Zhang et al., 2007). Orographic precipitation takes over in summer (between 260 and 290 mm), and the discharge continues to rise until August (Figure 3).

The morphology of the Bayanbulak ~~streams~~ rivers varies between highly meandering (sinuosity above 1.3 to 1.5), and braided, and the same river often switches from one to the other along its course (Figures 4 and 5). The ~~streams~~ rivers span about four orders of magnitude in discharge, and about two in width (Figure 6). ~~Various species of grass dominate the vegetation over the entire basins, and~~ Although a variety of grass species grow in the basin, their influence on the ~~morphology of the streams is certainly only mild~~ channel morphology is probably moderate (Zhang et al., 2002; Andrews, 1984; Metivier and Barrier, 2012). Finally, most ~~streams~~ rivers flow over gravel, which size distribution does not vary significantly over the ~~basins~~ basin (Figure 6). All these features combine to make the Bayanbulak ~~grassland~~ Grassland an ideal field site to investigate the morphology of gravel-bed rivers.

3 Method

~~To compare the morphology of braided and meandering threads, we~~ We carried out two field campaigns in July 2012 and July 2013, during the high-flow season to compare the geometry of braided and meandering threads (Figure 3). We treated the threads of braided rivers ~~as individual channels~~individually, based on the wetted area at the time of measurement (Figure 1). We measured the cross-section geometry, the discharge, the grain-size distribution and the slope of ~~as many streams~~the threads from as many rivers, spanning as broad a range in discharge, as possible.

We chose the sections at random, according to their accessibility, our purpose being to collect a statistically significant dataset.

To measure the cross section and the water discharge of large ~~streams~~rivers, we used a ~~2Mhz~~ 2Mhz acoustic Doppler current profiler (ADCP, Teledyne-RDI StreamPro). ~~In shallower streams~~The instrument was mounted on a raft and cross-sections where performed from which we extracted both the geometry and the discharge of the threads.

In shallower rivers, we used wading rods ~~, rulers and floats~~ and rulers to measure the ~~surface velocity, and estimated the vertically averaged velocity from it~~ thread geometry. The mean surface velocity was measured using floats. The average velocity was obtained from the surface velocity using a correction factor of 0.6 (Sanders, 1998; Gaurav et al., 2015). The discharge was obtained by the product of the average velocity with the wetted area.

Repeated ADCP profiles across the same section show that discharge, width and depth measurements are all reproducible within less than ~~15~~15 %. Manual measurements ~~yields~~ yield an uncertainty of about ~~2~~2 % for width, ~~12~~12 % for depth and ~~25~~25 % for velocity. The resulting uncertainty on discharge is less than ~~40~~40 % for both methods.

We used a Topcon theodolite with a laser rangefinder to measure the long profile of the ~~streams~~threads, and estimate their slope. The length of topographic profiles varies from 100 m for small braided threads to more than 3 km for one meandering thread. Uncertainties on the location of the ~~total station~~ theodolite and atmospheric inhomogeneities curtail the precision of long-distance profiles. For our measurements, we expect the uncertainty on ~~angle~~ angles to reach $90''$. The corresponding absolute uncertainty on the slope of a river is about $5 \cdot 10^{-4}$.

~~Finally, we~~ We measured the grain-size distribution from surface counts~~, and~~ . Depending on the size of exposed surfaces, the number of counts ranged from 200 to 500 (Wolman, 1954; Bunte and Abt, 2001). We extracted the median grain size d_{50} and the size of the ~~90th~~ 90th percentile d_{90} from these ~~distribution~~distributions.

Finally, the sinuosity of the threads was measured using the topographic profiles when available. When these were not available, we used Google images and calculated the sinuosity from 1 km-long stretches centered on the measurement site. The Bayanbulak rivers we surveyed exhibit two very distinct planforms. Single-thread rivers are, on average, highly meandering with a sinuosity of 1.5 ± 0.2 (Schumm, 2005). The braided rivers we surveyed have a total braiding index ranging from 3.3 to almost 11.2. As our objective is to compare these two end-members, we ignored rivers with intermediate wandering morphology (Church, 1983). Overall, our dataset is composed of 92 measurements of width, depth, average velocity, discharge, slope and grain size, among which 53 correspond to braided-river threads (Table 1), and 39 to ~~meandering~~ meandering-river threads (Table 2).

4 Regime equations

Figure 6 compares our measurements to ~~three sources:~~ four other sources. Three of them, the compendiums of Parker et al. (2007), Church and Rood (1983) and King et al. (2004) ~~,~~ include measurements from single-thread rivers. The fourth one corresponds to measurements on individual threads of the braided Sunwapta River (Ashmore, 2013). These sources are hereafter referred to as ~~GBR. All streams from~~ the GBR dataset~~are isolated (non braided) threads~~.

The Bayanbulak ~~streams~~ threads are widely dispersed in size (~~$0.6 \leq W \leq 77$ m~~$0.6 \leq W \leq 35$ m), and discharge (~~$0.002 \leq Q \leq 100$ m^{3}s^{-1}~~$0.002 \leq Q \leq 51$ m^{3}s^{-1}). On average, they are smaller than the GBR ~~streams. Similarly, their average grain size~~ threads. The median grain size of the Bayanbulak threads $d_{50} \simeq 0.013$ m is finer (the standard deviation of the d_{50} is $\sigma_{d_{50}} \sim 0.008$ m). Our dataset therefore extend the GBR ~~one towards smaller channels~~ones towards smaller threads with finer sediments.

We now consider the empirical regime equations of individual threads (Figure 7). To facilitate the comparison between the GBR ~~streams~~ dataset and our own, we use dimensionless quantities, namely W/d_{50}, H/d_{50}, S and $Q_* = Q/\sqrt{g d_{50}^5}$, where g is the acceleration of gravity. Not surprisingly, the ~~morphology~~ geometry of a thread is strongly correlated with its water discharge: its width and depth increase with discharge, while its slope decreases. At first sight, these trends are similar for ~~isolated~~ meandering and braided threads. They also compare well to the GBR data set, although the Bayanbulak ~~streams~~ threads are slightly wider than the GBR ones on average. The measurement uncertainty, although significant, is less than the variability of our data, except for slopes smaller than about $5 \cdot 10^{-3}$~~(section 4)~~.

Despite considerable scatter, ~~our measurements~~ both our measurements and the GBR datasets gather around straight lines in the log-log plots of Figure 7, suggesting power-law regime equations:

$$\frac{W}{d_{50}} = \alpha_w Q_*^{\beta_w} \ ; \quad \frac{H}{d_{50}} = \alpha_h Q_*^{\beta_h} \ ; \quad S = \alpha_s Q_*^{\beta_s} \tag{1}$$

where α_w, α_h, α_s, β_w, β_h and β_s are dimensionless parameters. To evaluate them, we use reduced major axis regression (RMA) instead of least square regression because the variability of our data is comparable along both ~~axis~~ axes (Sokal and Rohlf, 1995; Scherrer, 1984). The resulting fitted coefficients are reported in Table 3. The scatter in the slope measurement is too large to provide significant estimates of the slope coefficients α_s and β_s. At the 95% confidence level, the regime relationships of meandering and braided threads cannot be distinguished. Similarly, the depth of the Bayanbulak ~~streams~~ threads cannot be distinguished from those of the GBR ~~ones~~threads. Conversely, the Bayanbulak ~~streams~~ threads are significantly wider than the GBR ~~ones~~threads with respect to their median grain size.

So far we have made the width, depth and discharge dimensionless using d_{50} as the characteristic grain size of the sediment. This choice, however, is arbitrary (Parker et al., 2007; Parker, 2008). Large grains are arguably more likely to control the ~~morphology of the river~~ geometry of the threads than smaller ones, and a larger quantile might be a better approximation of the characteristic grain size. For comparison, we rescaled our measurements using d_{90} instead of d_{50}, and repeated the above analysis. Our conclusions are not altered significantly by this choice of ~~a~~ characteristic grain size (Table 3).

5 Detrending

So far, we have found that the empirical regime equations of ~~isolated~~ meandering and braided threads are statistically similar. To proceed further with this comparison, we would like to convert our measurements into a single statistical ensemble. We thus need to detrend our dataset with respect to water discharge, based on analytical regime equations. Following Gaurav et al. (2015), we propose to use the threshold theory to do so.

The threshold theory assumes that a river transports its sediment load slowly enough for ~~is~~ its bed to be near the threshold of motion (Glover and Florey, 1951; Henderson, 1963; Yalin and Ferreira da Silva, 2001; Seizilles, 2013). Momentum and mass balances then ~~yields~~ yield power-law regime equations, the original formulation of which reads (Glover and Florey, 1951)

$$\frac{W}{d_s} = \left[\frac{\pi}{\sqrt{\mu}} \left(\frac{\theta_t (\rho_s - \rho)}{\rho} \right)^{-1/4} \sqrt{\frac{3 C_f}{2^{3/2} \mathcal{K}\left[1/2\right]}} \right] Q_*^{1/2}, \tag{2}$$

$$\frac{H}{d_s} = \left[\frac{\sqrt{\mu}}{\pi} \left(\frac{\theta_t (\rho_s - \rho)}{\rho} \right)^{-1/4} \sqrt{\frac{3\sqrt{2} C_f}{\mathcal{K}\left[1/2\right]}} \right] Q_*^{1/2}, \tag{3}$$

$$S = \left[\left(\mu^{1/2} \frac{\theta_t (\rho_s - \rho)}{\rho} \right)^{5/4} \sqrt{\frac{\mathcal{K}\left[1/2\right] 2^{3/2}}{3 C_f}} \right] Q_*^{-1/2}, \tag{4}$$

where

$$Q_* = \frac{Q}{\sqrt{g d_s^5}}, \tag{5}$$

is the dimensionless discharge. $\rho = 1000\,\mathrm{kg/m^3}$ and $\rho_s = 2650\,\mathrm{kg/m^3}$ are the densities of water and sediment, $C_f \approx 0.1$ is the turbulent friction coefficient, Q the water discharge, $\theta_t \sim 0.04$ the threshold Shields parameter, $\mu \sim 0.7$ the friction angle for gravel, and $\mathcal{K}[1/2] \approx 1.85$ a transcendental integral (Glover and Florey, 1951; Henderson, 1963; Seizilles et al., 2013).

This formulation is similar to the one proposed by Parker et al. (2007), but for two points. First, equations (2) to (4) represent a threshold channel, whereas Parker et al. (2007) extend the theory to active channels.

Second, the formulation of Glover and Florey (1951) uses a constant friction coefficient in the momentum balance, whereas Parker et al. (2007) use a more elaborate friction law. Here we use the simplest formulation, as the variability of our data overshadows these differences (Metivier and Barrier, 2012).

The dashed ~~line~~ lines on Figure 7 ~~represents~~ represent equations (2) to (4). On average, the Bayanbulak ~~streams~~ threads are wider, shallower and steeper than the corresponding threshold ~~channel~~thread. However, the theory predicts reasonably their dependence with respect to discharge, thus supporting its use to detrend our data. Accordingly, we define a set of rescaled quantities as follows:

$$W_* = \frac{W}{d_s C_W \sqrt{Q_*}} = \frac{W (g d_s)^{1/4}}{C_W \sqrt{Q}}, \tag{6}$$

$$H_* = \frac{H}{d_s C_H \sqrt{Q_*}} = \frac{H (g d_s)^{1/4}}{C_H \sqrt{Q}}, \tag{7}$$

$$S_* = S \frac{\sqrt{Q_*}}{C_S} = \frac{S \sqrt{Q}}{g^{1/4} d_s^{5/4} C_S}. \tag{8}$$

Here the coefficients C_W, C_H, C_S correspond to the prefactors in square brackets of equations (2) ~~,(3), and~~ to (4). We used the typical values reported above for the coefficients that do not vary in our dataset.

Figure 8 shows the relationship between the rescaled ~~stream morphology~~ thread geometry and its dimensionless discharge, using d_{50} to approximate the characteristic grain size d_s. The new quantities W_*, H_* and S_* appear far less dependent on the water discharge than their original counterpart, although a residual trend remains for all of them. Using ordinary least squares, we fit power laws to our rescaled data to evaluate this residual trend. We find $W_* \propto Q_*^{-0.19\pm0.03}$ and $H_* \propto Q_*^{-0.10\pm0.05}$ for the Bayanbulak ~~streams, and $W_* \propto Q_*^{-0.01\pm0.04}$ and $H_* \propto Q_*^{-0.16\pm0.04}$~~ threads, and $W_* \propto Q_*^{-0.1\pm0.02}$ and $H_* \propto Q_*^{-0.05\pm0.02}$ for the GBR ~~streams~~threads. The width of the Bayanbulak ~~streams~~ threads shows the strongest correlation, yet even this correlation is mild. Finally, slopes are more strongly correlated with discharge than width and depth both for the GBR ~~streams~~ threads ($S_* \propto Q_*^{0.21\pm0.05}$), and the Bayanbulak ~~streams~~ threads ($S_* \propto Q_*^{0.39\pm0.11}$). However, most of the difference between the Bayanbulak and GBR ~~streams~~ threads is due to slopes well below the measurement precision. In all cases, the scatter is large, and all correlations fall within the standard deviation of the dataset.

6 Thread ~~morphology~~geometry

We now analyze our rescaled measurements as a homogeneous statistical ensemble (Figure 8). The means of the rescaled distributions of width, depth and slope all fall about one order of magnitude away from one, and their dispersion around this mean is also about one order of magnitude (table 4). This observation ~~support~~ supports the use of the threshold theory to scale the morphology of the Bayanbulak ~~streams~~rivers.

The dispersion of the rescaled slope is more significant than that of width and depth. We believe that, in addition to the technical difficulties associated to the measurement of slope in the field (section 3), the dispersion of the grain size explains this scatter. Indeed, gravels are broadly distributed in size, and unevenly distributed over the river bed (Guerit et al., 2014). Since the rescaling for slope involves the grain size d_s to the power of 5/4, whereas this exponent is only 1/4 for width and depth (equations (6) to (8)), we believe the grain-size dispersion impacts more strongly the rescaled slope than the rescaled width and depth.

The means of the distributions for braided threads and meandering threads differ by less than a factor of two, much smaller than the standard deviation. Fitting lognormal distributions to our data, we find that the meandering and braided ~~channels~~ threads from Bayanbulak cannot be distinguished from each other, at the 95% level of confidence. The depth and slope of the ~~Balyanbulak streams~~ Bayanbulak threads are also not significantly different from the GBR ~~ones. Only~~ threads. Finally, the width of the Bayanbulak ~~streams is significantly~~ threads is larger than that of the GBR ~~streams~~ones. We therefore conclude that, within the natural variability of our observation, the sections of meandering and braided ~~streams are morphologically similar~~ threads are geometrically similar although the morphology of the braided and meandering rivers looks qualitatively different (Figures 2 and 4). Again, the use of d_{90} instead of d_{50} as a characteristic grain size does not alter this conclusion.

According to the rescaling equations (6) to (8) the aspect ratio of a ~~stream~~ river W/H should be naturally detrended (Figure 9). Indeed, the correlation coefficient of aspect ratio and discharge is less than ~~0.1~~ 0.01 for all datasets~~(table 4)~~. As expected, the aspect ratio of braided and meandering threads cannot be distinguished at the 95% level of confidence. Finally, the difference between the width of the Bayanbulak ~~streams~~ threads and that of the GBR ~~streams~~ threads also appears in the distribution of aspect ~~ratio~~ratios: the Bayanbulak ~~streams are significantly wider~~ aspect ratios are larger than the GBR ones.

7 Conclusion

Our measurements on gravel-bed ~~streams~~ rivers in the Bayanbulak ~~grassland~~ Grassland reveal that braided threads are ~~morphologically~~ geometrically similar to meandering ones. Their size can be virtually detrended with respect to water discharge using the threshold theory. As a result, their aspect ratio is naturally detrended. These findings accord with recent observations in sand-bed ~~streams~~ rivers of the Kosi Megafan (Gaurav et al., 2015). They also accord with recent results from rivers of the Ganges-Brahmaputra plain (Gaurav, 2016).

The striking similarity between braided and meandering threads in gravel-bed and sand-bed rivers supports the view that fully-developed braided rivers are essentially a collection of threads interacting with each other, rather than a single wide channel ~~rumpled~~ segmented by sediment bars. If confirmed, this would suggest that a braid results from the collective behavior of individual threads, the property and dynamics of which would be close to that of ~~isolated channels~~meandering threads (Sinha and Friend, 1994; Ashmore, 2013; Reitz et al., 2014).

Our observations, like those of Gaurav et al. (2015) ~~and~~ or the GBR dataset, are much dispersed around their average value, which points at the influence of hidden parameters on their morphology. Among those, the intensity of sediment transport is likely to play a prominent role~~.~~, at least in the case of the Bayanbulak rivers where both vegetation and grain-size distributions are relatively uniform over the grassland.

More specifically, field observations suggest that a heavier sediment load tends to increase the aspect ratio of a ~~stream~~thread, other things being equal (Smith and Smith, 1984; Tal and Paola, 2010; Metivier and Barrier, 2012). This proposition remains speculative though, and needs to be thoroughly tested against dedicated field measurements, which we believe should include both braided and meandering threads. Finally, if the sediment discharge is indeed the most prominent parameter after water discharge, its influence on the ~~morphology~~ geometry of a channel should also manifest itself in laboratory experiments.

References

Andrews, E. D. (1984). Bed-material entrainment and hydraulic geometry of gravel-bed rivers in Colorado. *Geol. Soc. of Am. Bull*, 95:371–378.

Ashmore, P. (2013). *Fluvial Geomorphology*, volume 9 of *Treatise on Geomorphology*, chapter Morphology and dynamics of braided rivers, pages 289–312. Academic Press, San Diego, CA.

Ashmore, P. E. (1991). How do gravel-bed rivers braid? *Canadian Journal of Earth Sciences*, 28(3):326–341.

Brauderick, C. A., Dietrich, W. E., Leverich, G. T., and Sklar, L. S. (2009). Experimental evidence for the conditions necessary to sustain meandering in coarse-bedded rivers. *Proc. Nat. Acad. Sci.*

Bunte, K. and Abt, S. (2001). Sampling surface and subsurface particle-size distributions in wadable gravel- and cobble-bed streams for analyses in sediment transport, hydraulics, and streambed monitoring. Technical report.

Church, M. (1983). Pattern of instability in a wandering gravel bed channel. *Modern and ancient fluvial systems. International Association of Sedimentologists, Special Publication*, 6:169–180.

Church, M. and Gilbert, R. (1975). *Glaciofluvial and glaciolacustrine sedimentation*, volume 23 of *Special Publication*, chapter Proglacial Fluvial and Lacustrine Environments, pages 22–100. SEPM.

Church, M. and Rood, K. (1983). Catalogue of Alluvial River Channel Regime Data. *Univ. British Columbia, Department of Geography, Vancouver.*

Devauchelle, O., Josserand, C., Lagrée, P., and Zaleski, S. (2007). Morphodynamic modeling of erodible laminar channels. *Physical Review E*, 76(5):056318.

Dijk, W., Lageweg, W., and Kleinhans, M. (2012). Experimental meandering river with chute cutoffs. *Journal of Geophysical Research: Earth Surface (2003–2012)*, 117(F3).

Ferguson, R. (1987). *Hydraulic and sedimentary controls of channel pattern*. Blackwell Oxford, UK.

Fredsøe, J. (1978). Meandering and braiding of rivers. *Journal of Fluid Mechanics*, 84(04):609–624.

Fujita, Y. and Muramoto, Y. (1985). Studies on the process of development of alternate bars.

Gaurav, K. (2016). *Morphology of alluvial rivers*. PhD thesis, IPGP.

Gaurav, K., Métivier, F., Devauchelle, O., Sinha, R., Chauvet, H., Houssais, M., and Bouquerel, H. (2015). Morphology of the kosi megafan channels. *Earth Surface Dynamics*, 3(3):321–331.

Glover, R. E. and Florey, Q. (1951). *Stable channel profiles*. US Department of the Interior, Bureau of Reclamation, Design and Construction Division.

Gran, K. and Paola, C. (2001). Riparian vegetation controls on braided stream dynamics. *Water Resources Research*, 37(12):3275–3283.

Guerit, L., Barrier, L., Narteau, C., Métivier, F., Liu, Y., Lajeunesse, E., Gayer, E., Meunier, P., Malverti, L., and Ye, B. (2014). The grain-size patchiness of braided gravel-bed streams – example of the urumqi river (northeast tian shan, china). *Advances in Geosciences*, 37:27–39.

Henderson, F. M. (1963). Stability of alluvial channels. *Transactions of the American Society of Civil Engineers*, 128(1):657–686.

King, J. G., Emmett, W. W., Whiting, P. J., Kenworthy, R. P., and Barry, J. J. (2004). Sediment transport data and related information for selected coarse-bed streams and rivers in Idaho. Gen. Tech. Rep. RMRS-GTR-131. Fort Collins, CO RMRS-GTR-131, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO.

Kleinhans, M. G. and van den Berg, J. H. (2011). River channel and bar patterns explained and predicted by an empirical and a physics-based method. *Earth Surface Processes and Landforms*, 36(6):721–738.

Leopold, L. B. and Wolman, M. G. (1957). River Channel Patterns. Technical Report 282-B.

Metivier, F. and Barrier, L. (2012). Alluvial landscape evolution: what do we know about metamorphosis of gravel bed meandering and braided streams. In Church, M., Biron, P., and Roy, A., editors, *Gravel-bed Rivers: processes, tools, environments.*, chapter 34, pages 474–501. Wiley & Sons, Chichester.

Mosley, M. (1983). Response of braided rivers to changing discharge. *Journal of hydrology. New Zealand*, 22(1):18–67.

Parker, G. (1976). On the cause and characteristic scales of meandering and braiding in rivers. *Journal of Fluid Mechanics*, 76(3):457–480.

Parker, G. (2008). Transport of gravel and sand mixtures. In Garcia, M. H., editor, *Sedimentation engineering: processes, management, modeling, and practice*, volume 110, chapter 3, pages 165–251. ASCE.

Parker, G., Wilcock, P., Paola, C., Dietrich, W. E., and Pitlick, J. (2007). Quasi-universal relations for bankfull hydraulic geometry of single-thread gravel-bed rivers. *Journal of Geophysical Research–Earth Surface*, 112:1–21.

Reitz, M. D., Jerolmack, D. J., Lajeunesse, E., Limare, A., Devauchelle, O., and Métivier, F. (2014). Diffusive evolution of experimental braided rivers. *Phys. Rev. E*, 89:052809.

Sanders, L. (1998). A manual of field hydrogeology. *Prentice-Hall, Inc., 113 Sylvan Ave. Englewood Cliffs NJ 07632 USA. 381*, page 1998.

Scherrer, B. (1984). *Biostatistique*. Chicoutimi, Québec: G. Morin.

Schumm, S. A. (2005). *River variability and complexity*. Cambridge Univ Pr.

Seizilles, G. (2013). *Forme d'équilibre d'une rivière*. PhD thesis, Université Paris Diderot.

Seizilles, G., Devauchelle, O., Lajeunesse, E., and Métivier, F. (2013). Width of laminar laboratory rivers. *Phys. Rev. E*, 87:052204.

Sinha, R. and Friend, P. (1994). River systems and their sediment flux, indo-gangetic plains, northern bihar, india. *Sedimentology*, 41(4):825–845.

Smith, N. D. and Smith, D. G. (1984). William River: An outstanding example of channel widening and braiding caused by bed-load addition. *Geology*, 12(2):78.

Sokal, R. and Rohlf, F. (1995). *Biometry*.

Tal, M. and Paola, C. (2007). Dynamic single-thread channels maintained by the interaction of flow and vegetation. *Geology*, 35(4):347.

Tal, M. and Paola, C. (2010). Effects of vegetation on channel morphodynamics: results and insights from laboratory experiments. *Earth Surf. Proc. Landf.*, 35(9):1014–1028.

Wolman, M. G. (1954). A method for sampling coarse river bed material. *EOS Trans. AGU*, 36:655–663.

Yalin, M. S. and Ferreira da Silva, A. M. (2001). *Fluvial Processes*. International Association of Hydraulic Engineering and Research Monograph.

Yang, Q. and Cui, C. (2005). Impact of climate change on the surface water of kaidu river basin. *Journal of Geographical Sciences*, 15(1):20–28.

Zhang, B., Yao, Y.-h., Cheng, W.-m., Zhou, C., Lu, Z., Chen, X., Alshir, K., ErDowlet, I., Zhang, L., and Shi, Q. (2002). Human-induced changes to biodiversity and alpine pastureland in the bayanbulak region of the east tienshan mountains. *Mountain research and development*, 22(4):383–389.

Zhang, Y., Li, B., Bao, A., Zhou, C., Chen, X., and Zhang, X. (2007). Study on snowmelt runoff simulation in the kaidu river basin. *Science in China Series D: Earth Sciences*, 50(1):26–35.

Zolezzi, G., Bertoldi, W., and Tubino, M. (2012). Morphodynamics of bars in gravel-bed rivers: Bridging analytical models and field observations. *Gravel-Bed Rivers: Processes, Tools, Environments*, pages 69–89.