Response to Comments for Chartrand et al – esurf_2022_040:

Coupling between downstream variations of channel width and local pool-riffle bed topography

Dear Associate Editor Sjöberg,

Thank you for the opportunity to provide a revised manuscript for further consideration with *Earth Surface Dynamics*. We appreciate the efforts of the referees in reviewing our work, and for providing thoughtful and helpful reactions to the presentation of our ideas. The revisions and responses below are based on careful consideration of their comments and recommendations. To aid the review process, we separate our responses and explanations based on the reviews provided Reviewer #1 and Reviewer #2. Before presenting our responses, we offer the following synopsis of the more substantive changes we provide with the revised manuscript. The reviews of our work are mostly focused on the need for clarification and additional details. This included:

- Development of three new Figures—Figures 2, 4 and 5 of the revised manuscript. **Figure 2** shows plan view maps of the two experimental width configurations, and a plot of how the width gradient differs between these configurations. This was requested by Reviewer 1. **Figure 4** shows detrended bed elevation profiles for the two steady-state conditions reported (t960 and t1752 min) and includes plotting of the zero crossing line to highlight elevation amplitudes above and below the zero crossing line. This was requested by Reviewer 1. **Figure 5** shows trended bed elevation profiles for 5 different observation times starting with the first steady-state condition at t960 min. The profiles after this time show how the profile changed and evolved. The profiles are shown with a DEM of Difference for the two steady-state times. This information was requested by Reviewer 2 and is the most detailed we can get in terms of showing profile dynamics based on our measurements.
- Development of a new Appendix A. **Appendix A** provides a detailed explanation of how the curves and stippled region of Figure 6 (Figure 3 in the reviewed submission) are calculated using Eq. 1 of the manuscript. In our explanation we make reference to the relevant parts of the Jupyter Notebook we prepared and have made available in the supporting online repository. This was requested by Reviewer 1.
- Clarification of width "variations" and width "changes". We have carefully edited the manuscript to be consistent in presentation. We refer to spatial differences of width as **width variations**, and temporal differences of width as **width changes**. We have also edited the manuscript for consistent reference to Delta w(x), which we refer to as the **width gradient** (we also provide a definition of width gradient on lines 43-45 of the revised manuscript; previously this definition was buried in a figure caption.). Use of width gradient is also consistent with one of our prior publications. These clarifications were requested by Reviewer 1.
- In addition to these more substantive changes, we have edited the manuscript throughout for clarity. The edits we made are relatively minor and do not introduce differences in any conclusions or findings.

Thanks in advance for your time and handling of our work.

Response to Reviewer 1 Comments:

This paper presents results from a flume experiment with downstream variations in width, which are used along with field and experimental data in the literature to assess the relationship between width changes and bed slope and consequently riffle-pool morphology. The data are presented in the context of a scaling relationship relating slope and width changes, and results show that local width changes are an important control in bed morphology development.

This is a thoughtful, well-written paper. It does a service in compiling data from dozens of prior studies and synthesizing them in the context of the paper's scaling relationship. Most of my comments are relatively minor and aimed at making the paper easier to understand and interpret.

Response: Thanks for your constructive and supportive feedback. We appreciate your time and energy in reviewing and thinking about our work. Your comments have helped us prepare a more clear and impactful communication and summary of our work.

Reviewer 1 Substantial comments:

The notion of 'changes in width' in the paper generally refers to downstream (spatial) changes in width, but there is some confusion with temporal changes in width (i.e., at-a-station widening or narrowing), in part because the flume experiment involved achieving quasi-steady-state, then changing the width of one section, and achieving a second quasi-steady state. So, there were places throughout the paper where as a reader I was not sure whether discussion of width changes meant spatial or temporal changes. One suggestion may be to refer to temporal width changes as 'changes', but spatial variations in width as 'variations' or 'gradients'. This would provide some consistency with the scaling model, where the delta_w variable is actually a gradient, not a dimensional change. Replacing 'Δw' with '∇xw' might help relieve some potential reader confusion, as would careful editing throughout the paper to ensure clarity about what type of width changes are at issue.

Response: Thanks for this important set of suggestions. We have addressed these comments by carefully editing the manuscript to be consistent in presentation. In general, we followed your suggestions:

1. At lines 44-47 we added: "...between the local dimensionless downstream width gradient $\Delta w(x)$ and bed slope $S_{local}(x)$ (Fig. 1)? The width gradient is calculated as the quotient of the downstream width difference between two points where the direction of width variation changes, divided by the downstream distance between these points. The bed slope is calculated as the quotient of the bed elevation difference between the same two points where the direction of width variation changes, also divided by the downstream distance between these points.
2. At lines 54-55 we added: "Throughout the text we refer to spatial differences of channel width as ``variations", and temporal differences of channel width at specific locations as ``changes".

We did not make changes based on your last suggestion and have left usage of $\Delta w(x)$. This keeps the current presentation consistent with our 2018 publication. We believe the text clarifications made in response to the comments should alleviate reader confusion.

It wasn't clear to me until about line 114 (the middle of section 3) that the paper would actually describe and present an experiments where the downstream pattern of width variation would be changed from one run to the next. That information should be explicitly described in the abstract, and potentially Introduction.

Response: We have added a phrase in the abstract at lines 7-8 to make this point clear: "...and following the imposed local width changes made during the experiment." We have also added a new **Figure 2** which shows the downstream width configurations for Phases 1 and 2 of the experiment, and a plot which shows differences of the downstream width gradient.

I like Figure 3, but it's not clear how the lines showing the predicted values of eq. 1 are generated from the equation alone. I looked at the python notebook in the repository which provided some clarification, but some additional information in the paper itself would be helpful.

Response: This is an important comment – thanks. We have added a new Appendix A which describes how the curves and stippled region of Figure 6 are calculated using Eq. 1. In our description we refer the reader to the appropriate points of the Jupyter Notebook in the online repository. We also note the major assumptions made to make the calculations—this provides new opportunities for future research.

The end of the Discussion (line 247 onward) provides some good context for how the scaling between width gradient and slope may be relevant for dam removal and sediment supply. I believe experiments have had difficulty replicating the field observations from the Elwha, however, where increased sediment supply led to a reversal in bed slope and temporarily filled in pools. Nelson et al. (2015) suggested that variable water discharge may have also played a role in that response, and the impact of time variations in flow may be worth including in the discussion here.

Response: Thanks for this comment. We agree with the idea that variable water discharge or differing flood hydrographs may have also played a role, and indicate this on lines 62-63 of the revised manuscript: "The timing and sequence of hydrograph events post dam removal may also play a role in downstream bed profile dynamics (Nelson et al., 2015, Morgan et al., 2021)." However, Morgan et al. (2021) used flume experiments to test for the specific possibility mentioned in the comment, and whether increased sediment supply, or variable water supply through a stepped symmetrical hydrograph is more important to understand temporal changes to bed elevation. Their results are clear—for their experimental set-up and procedure, enhanced sediment supply was found to be more important to help understand local changes to bar(riffle)-pool relief (see their Figs. 9, 10, 11 and 12, Sections 4.2 and 4.3 and their Conclusions)--a condition analogous to that discussed for the Elwha Dam removals. A key conclusion they report on page 882 is (and see a few sentences above the following sentence):

> "However, our results show the importance of also considering the sedimentologic regime as an increased sediment supply caused increased homogenization of the bed, both laterally and longitudinal."

As a result, we have left the Discussion basically as it was in the reviewed version. What is clear to us, and is consistent with the reviewers comment, more research is needed to disentangle effects related to hydrographs vs. sediment supply. One option is use of an experimental set-up and approach similar to Morgan et al, 2021, but with a wider grain size distribution. Their grain size distribution was somewhat narrow relative to gravel-bed rivers.

Additional comments by line number:

31: 'dynamic shifts' – does this refer to temporal or spatial changes?

Response: We have edited this and removed the use of "dynamic": "However, the specifics of how pool-riffle sequences respond to temporal changes of local width conditions and evolve to statistically steady-state bed topography are largely unexplored."

39: 'local adjustments of bank position' – same question – at-a-station change in width, or downstream (spatial) change in width? Please check throughout the paper these types of issues – I won't point them all out in the review.

Response: Thanks. We have carefully edited the manuscript for consistency and clarity around these issues you point out. At this specific instance, we revised the text as: "We address the question of how a pool-riffle channel segment responds to local temporal changes of channel width, and whether topographic adjustments conform to expectations of an inverse correlation between the local dimensionless downstream width gradient $\Delta w(x)$ and bed slope $S_{local}(x)$ (Fig. 1)?"

74: ΔUx^* is a dimensionless velocity change, not a dimensionless velocity.

Response: Thanks. Correction made.

Eq. 4: why use ~ instead of = in this equation? Does the dimensionless velocity just scale like a Froude number, or is this actually how it's calculated?

Response: Correction made. And yes, you are correct, this is how we calculate the dimensionless velocity,

Figure 2: I think the discussion would be easier to interpret if some data were added to this figure. Specifically, additional subplots showing (a) how width gradient changes in the downstream direction for both runs, (b) the downstream profile of the amplitude above/below the zero-crossing line for both runs, and (c) downstream profile of the local slope (Slocal(x)).

Response: See our summary of substantive changes made at the beginning of this response. We have added several new Figures which address these important comments, including Figures 2 and 4. We have not added a Figure which shows a plot of the local slope as this is shown in Figure 6 (Figure 3 in reviewed manuscript), and slope differences are clear in the profile plots. Slope data is calculated as a part of the plotting provided in the online repository.

Table 1: typo in footnote b: 'supple' should be 'supply'.

Response: Correction made.

128: My interpretation of Table 1 is that the times shown are when the flume was stopped, drained, and measurements were taken, but there is no information on this in the text. Please provide a bit more detail on the experimental procedure.

Response: Footnote 2 of Table 1 now clearly states that for the times shown, the flume was drained and measurements made. We have also added the following at lines 137-140 of the revised manuscript: "Measurements were made at several points during Phases 1 and 2 of the experiment: elapsed times 270, 480, 720, 960, 1200, 1440, 1680 and 1752 min (Table \ref{Table1}). To facilitate measurements the water and sediment supplies were stopped, and the flume drained at the indicated times."

Figure 3: I think the figure legend and figure caption have a mistake – I suspect phi (the porosity) ranged from 0.3 to 0.5, not epsilon. If that was in fact epsilon, the porosity would be up to 70%. Also, mysterious "?" in the fourth line of the figure caption.

Response: Great catch and thanks very much. Definitely a mistake on our part. This has been corrected and your thoughts are spot on. Phi indeed does vary between 0.3 and 0.5 in the calculations, not epsilon.

236: incomplete sentence ending in 'including .

Response: We have completed the sentence.

Fig A.4 caption states units are meters, but figure appears to have values in feet.

Response: Correction made.

<u>Response to Reviewer 2 Comments:</u>

In this paper, the authors study how established pool-riffle sequences respond to time-varying shifts in the channel width. For this, the authors conducted flume experiment with prescribed changes of channel width, and also applied a broad set of field, experimental, and numerical data from literatures. Their results show that local bed slope is inversely correlated with the spatial gradient of channel width, which could be well predicted by a scaling theory. The topic of this manuscript is of interest to the readers of Esurf. However, clarifications are still needed at several places in the methodology and results sections. I suggest that moderate revisions are needed before the manuscript can be accepted.

Response: Thanks for your helpful feedback and careful reading of the submitted manuscript. We appreciate your time and energy in reviewing and thinking about our work, and helping to catch several editorial related mistakes.

Main comments

1. In both the Abstract and the Introduction, you mentioned that the response of pool-riffle sequences to time-varying channel width is not well understood and thus is the object of this study. In the following sections of the manuscript, you showed the bed topography under two phases of channel width conditions. However, for both phases, the results you showed are for quasi-steady state. I agree that it is very good (and is a step forward) to learn the new steady state of pool-riffle system when the channel width varies. But to me, the quality of the manuscript would be greatly improved if the results of the transient process can also be presented (so that readers can know how the channel adjusts dynamically after the shift of channel width). For this, you can show the results between elapsed time 960 min and 1752 min during your experiment (if you have done the measurements).

Response: Thanks for this important comment. We are constrained on specifically speaking to dynamics during response, or transient periods because our measurement times were generally separated by intervals of 240 minutes. However, we have added Figure 5 in the revised manuscript in our attempt to address your comment as best we can with the data we collected. Figure 5 shows width-average profiles for three different times between the two steady-state periods, and we also show a DEM of Difference between the steady state periods. This is likely the best we can do to address the comment.

2. In Figure 3, you showed the calculational results of Equation 1 (as you explained in the caption). However, Equation 1 is actually not an equation, as there is no equal sign in it. How did you conduct the calculation?

Response: Eq. 1 is a scaling relationship. It is derived from the divergence form of the Exner equation through non-dimensionalization and identification of the "scales" of interest. This applied mathematical approach has been utilized in the physical sciences for many decades or longer, with roots in physics. The equation is calculated using the subsequent expressions Eq. 2-4. We refer the reviewer to our previous publication for more details, Chartrand et al., 2018, JGR-ES. Based on a comment by Reviewer 1, we have also added Appendix A as supporting explanation for how Eq. 1 is calculated. Hopefully this makes our work more transparent, in conjunction with the online repository of resources we have made available.

3. In Lines 183-186 and 254-258, you discussed the correlation between w(x) and Slocal. More specifically, when w(x) and Slocal have the same sign (both positive or both negative), you say they are direct correlated, otherwise you say they are inverse correlated.

However, by definition the correlation coefficient is calculated as Cov (X, Y)/(σσ), with Cov (X, Y) being covariance of X and Y, and σ (σ) being the standard deviation of X (Y). In this case, direct (positive) correlation means that large values of one variable are associated with large values of the other and small with small (with a correlation coefficient between 0 and 1); inverse (negative) correlation means that large ΔXYΔXY values of one variable are associated with small values of the other and small with large (with a correlation coefficient between 0 and -1).Therefore, I cannot understand how do you determine the correlation between Δ ΔSlocal)? Or do you mean the correlation between channel width w and bed elevation zb? (As you can tell whether w increases or decreases with the sign of w(x). The same is true for zb and Slocal.)

Response: We have used the phrases "inverse correlation" and "direct correlation" in a manner that is consistent with the most basic and general definitions applied to the sciences and social sciences. For example, when the downstream width gradient is "positive", Figure 6 shows the the local bed slope is commonly "negative". So, the two random variables are inversely correlated. A direct correlation describes conditions when both random variables are either positive, or negative. In applying this usage of terminology to individual points within Figure 6 it is important to keep in mind that the points represent specific locations at natural rivers, experimental flumes and within numerical spaces; the overall trend of the data plotted (the general basis for our usage of “inverse” and “direct” correlation) is a result of the collective points comprising the data.

We are not referring to correlation coefficients, nor relationships between local width and bed elevation. Our descriptions, analysis and figures are clear, and our usage of the phrases is reasonable. We recognize that the work of Brown and Pasternack (2017), and related publications from the same research group addresses the same, or a similar problem using an approach that is consistent with the gist of the reviewers comments. Either approach is valid and helpful in better understanding pool-riffles; however, in detail the approaches differ (we mention this in the manuscript). Yet, similar conclusions are reached. This strengthens the science.

Specific comments:

1. L49-56: This paragraph should belong to the Conclusions, not the Introduction.

   Response: Thanks for this suggestion. We have left the text unchanged and believe it is appropriate and helpful to offer a summary of results in the Introduction.

2. Figure 1: In the legend of the left panel, what do you mean by the “topographic profile”, bed elevation or bed slope?

   Response: We have changed the text to read: “Bed Elevation Profile”.

3. L77: What does Lc denote? Please explain.

   Response: Thanks for catching this oversight. We have indicated that L_c represents a characteristic length scale.

4. L81: Δqbx* is not defined in the manuscript.

   Response: The sentence containing the quantity indicates it represents the downstream bedload transport gradient. No changes made.

5. L81-83: What is the basis for these assumptions? Please clarify.

   Response: Exner (1925) assumed that the bed load transport q_b at any streamwise position in a river is proportional to the downstream flow velocity. So, differences of bedload transport are proportional to differences of downstream flow velocity. Exner’s assumption led to the divergence form of the Exner equation, and it provides a direct link between transport and flow velocity. We simply built from this view in a non-dimensional sense. We have not repeated this information in the present manuscript because the development of Eq. 1 has been previously published in Chartrand et al., 2018, JGR-ES, and in the present manuscript we have not changed or modified that development. No changes or additions made.

6. Caption of Figure 3: In the fourth line, it says “Result from ? comparable PRE4…”. Is there a typo?

   Response: Thanks for catching this mistake. We have corrected the issue with a corrected citation call.

7. Caption of Figure 3: In the 7th-9th line, the symbols are not consistent with those used in the plot. Please note the direction of the triangles.

   Response: Great catch. We have corrected the direction errors of the two symbols.

8. L168: Do you mean Δw(x), rather than Δ(x)?

Response: Yes, you are correct. Thanks. We have corrected this error.

9. L308 and 310: Do you mean Figures A1-A5 and Tables A1-A5?

   Response: Yes, you are correct. Thanks. We have corrected these errors.

10. Figure A3: How do you specify the four locations of open circles in this case? Any criteria? From the plot of bed elevation, it seems that you are not choosing the locations of pools or riffles.

    Response: In general, these are locations where the downstream width variation direction changes—i.e. widening to narrowing, or vice versa. This is how we remain consistent across data sets. We purposefully do not attempt to identify pool or riffle features because this is subject to bias and subjectiveness across individuals. We instead focus on locations where width variation changes direction because the regime diagram Figure 6 (of the revised manuscript) and our theory rests on downstream width gradients as a key driver of bed topography. This keeps our work and usage of literature derived data sets as objective as is realistically possible.