

Author response:

Sediment storage and routing in bedrock canyons by Chloe B.A. Ross et al.

Submitted to Earth Surface Dynamics

Response to Editor

We are grateful to both referees for their thoughtful and constructive comments and suggestions. We appreciate their attention to detail, as well as their complimentary summaries of the work. Below we have done our best to address each suggestion, and outline the modifications made to the manuscript.

Response to Reviewer 1 (Stefanie Tofelde; numbering is ours)

In the study “Sediment Storage and Routing in Bedrock Canyons,” Ross et al. employ repeat high-resolution multibeam bathymetric surveys (2021–2023) to examine morphological changes across nine reaches of the Fraser Canyon, British Columbia, following a major sediment supply event in 2021. Based on four survey campaigns, they quantify spatial and temporal variations in sediment erosion and deposition, including changes in patch size, distribution, and volume. Their results highlight highly dynamic sediment behavior, with deposits exhibiting merging, splitting, and alternating phases of erosion and accumulation.

This contribution is based on a case study, and it successfully captures the highly dynamic behaviour characteristic of natural fluvial systems. The authors maintain a clear and well-structured presentation throughout, which is particularly commendable given the complexity of the dataset, including varying survey durations and differences among study reaches. Overall, the manuscript is very well organized and easy to follow.

The text is clearly written, and the figures are of high quality and effectively support the analysis. The study represents a valuable contribution to the field and provides a strong foundation for future model development (see specific comment below). Beyond one main point raised below and a number of minor technical corrections, I have no major concerns.

We thank the reviewer for their positive comments. We respond to the comments below.

Comments:

R1C1. It would strengthen the discussion to include a dedicated section—potentially at the end of the discussion or following lines 437–438, where this issue is briefly raised—addressing the broader implications of this case study for modeling sediment transport and long-profile evolution of bedrock rivers. The observations presented here underscore a clear mismatch between the complex, highly dynamic nature of sediment routing documented in the field and the simplified process representations commonly employed in current numerical models, which are often unable, or only partially able, to reproduce such behaviour. In particular, the observed patterns of transient storage, patch-scale dynamics, and episodic sediment release indicate that sediment transport is more spatially and temporally heterogeneous than is typically assumed. Explicitly acknowledging this discrepancy would provide valuable context for interpreting the results and help define key priorities for future model development, including improved representation of localized sediment storage, non-linear transport processes, and event-driven system responses to better capture river morphological evolution.

We appreciate Reviewer #1 raising this point. We agree that this is a key implication of our findings, and that explicitly addressing this will improve the impact of the work. We have added a section to the discussion to address implications for modeling bedrock river erosion:

“Our observations of sediment dynamics in the Fraser Canyon have important implications for modelling sediment transport and longitudinal profile evolution in bedrock rivers. In bedrock incision models that account for the effects of sediment cover, cover is commonly treated as a monotonic function of either sediment supply from upstream (Sklar and Dietrich, 2004; Turowski et al., 2007; Lamb et al., 2008) or sediment storage in a reach where sediment mass is conserved (Shobe et al., 2017; Guryan et al., 2024; Zhang et al., 2018). In contrast, here we observe large variations in net sediment transport and storage without meaningful changes in the areal footprint of transient sediment deposits. In most cases, nearly all changes in storage volume are accommodated by vertical changes in sediment thickness. Moreover, the magnitude of vertical changes we observe are generally much greater than likely heights of roughness elements in the underlying bedrock. Such roughness heights are used to scale cover with sediment storage in current mass conserving cover models. In the bedrock canyons of the Fraser River, lateral roughness, in the form of width variation, appears to be more important than vertical roughness in controlling the extent and persistence of sediment storage and alluvial cover. Morphologic variability also appears to drive spatial and temporal variability in sediment storage and release and thus sediment supply to downstream reaches.

Future model development could potentially reproduce some of these behaviours by explicitly incorporating variability in both local morphology and transport dynamics. For example, measured trends in bedrock channel width with drainage area commonly show that width varies locally by a factor of two or more (e.g. Wright et al., 2022; Venditti, 2026). Models that include stochastic variability in local width of this magnitude, or the systematic variation of width and depth characteristic of CPW morphologies, may be capable of reproducing the observed tendency for greater sediment storage in wider reaches. At the relatively short seasonal to interannual time scale of our observations, dynamic variation in sediment storage and release could be modelled with stochastic variation in the values of parameters that control the magnitude of sediment flux, entrainment or deposition (e.g. Turowski and Hodge, 2017), or by incorporating linkages between transport capacity and sediment storage as have been observed in gravel-bedded rivers (Lisle and Church, 2002; Reid et al., 2019). At the longer time scale of longitudinal profile evolution, width should coevolve with patterns of partial cover, due to the role of bed sediment in driving lateral erosion of bedrock banks by deflecting bedload (Fuller et al., 2016; Turowski, 2018; Li et al., 2020, 2023). Models that explicitly account for sediment in modulating both vertical and lateral rock erosion may ultimately be needed to reproduce the channel morphology and sediment dynamics of bedrock canyons like those in the Fraser River.”

R1C2: Figure 1: In (a) it might help to add a label of sideview and topview. In (b), (d), and (f) please add a scale bar for reference.

We have added the labels “top view” and “side view” to the panels associated with C.P.W. morphology as suggested. Approximate scale bars have been added to panels (b), (d), and (f).

R1C3: Figure 2: Please add an inset map indicating the study location within Canada. In panel (b), geographic coordinates are missing, which prevents subsequent georeferencing and should therefore be included. Additionally, the legend in panel (b) should clarify that the values represent upstream river kilometers; alternatively, the flow direction could be indicated with an arrow for clarity.

An inset map (what is now Figure 2b) has been added indicating the location of the Fraser Basin within Canada. Geographic coordinates have been added to what is now Figure 2c, as well as a flow direction arrow. The figure caption has been therefore updated accordingly to:

“Figure 2. Fraser River, British Columbia: (a) Fraser River Basin with locations of major towns as well as the Hope Gauging Station (Water Survey of Canada Gauge 08MF005); (b) outline of Canada (Statistics Canada, 2016) highlighting the location of the Fraser River Basin; (c) locations of canyons with repeat surveys as well as Anderson Creek and Zulu Creek tributary confluences.”

R1C4: *Figure 3 caption: Spelling mistake, should be ERA1 instead of ERA2 for the 2022 freshet.*

The spelling mistake has been corrected. Thank you for your attention to detail.

R1C5: *Figure 6a: Maybe add another number to the x-axis for better orientation. In the figure caption, add a comma before ‘(b) area...’.*

An additional number has been added to the x-axis in Figure 6a, and the comma has been added to the figure caption.

Response to Reviewer 2 (Anonymous; numbering is ours)

This paper uses a dataset of repeat bathymetric surveys along canyons of the Fraser River to explore variability of sediment erosion, deposition and storage and link this to canyon morphology and a sediment input event. I found this a very interesting paper – it is an amazing set of data! We do often make a lot of assumptions in models and calculations around bedload cover and storage, so it is really valuable to have data on this, particularly from a large river with variable morphology. The treatment and presentation of the data does a good job illustrating and synthesizing a large amount of complex change data. The interpretations are interesting and follow clearly from the data. I found the story on sediment staging particularly interesting. I don’t have any major concerns, just some very minor points below, although I do agree with the other reviewer that some discussion about implications for modeling would be a great addition.

We thank the reviewer for their supportive comments. We have added a discussion section on implications for modelling in response to Reviewer 1, comment 1 (R1C1).

Comments:

R2C1: *Line 125: Can you add the gauging station to the map in figure 2?*

The gauging station has been added to Figure 2a, labelled “Hope Gauging Station.”

R2C2: *Line 140: Lytton is also not on the map*

Lytton has been added to Figure 2a.

R2C3: *Line 170: 2022 is only April, not May?*

Yes, 2022 surveys were only in April. We have corrected the note at the bottom of Table 1 to reflect this (originally there was a typo that said “April/May 2022”, it now only says “April 2022”). Thank you for catching this.

R2C4: *Line 205: it would be good to specify here that you mean the minimum elevation at each pixel. I know you have this a few lines down, but the sentence as it is may give readers the wrong idea at first.*

We have adjusted this sentence to be clearer. It now reads:

“We calculated the dynamic sediment storage volume through surveyed reaches as the difference between survey bathymetry and the minimum elevation at each DEM pixel observed throughout all the surveys.”

R2C5: *Line 252: absolute value of the mean of each patch?*

We have adjusted this sentence to be clearer. It now reads:

“Yet, the absolute mean elevation change for each patch has a median of just ~0.7 m for all patches.”

R2C6: *Line 254: in line 204, it says that the smallest patch size considered was 2 m², and here it says 12 m², is that because no patches between 2-12 m² were observed?*

We have adjusted the statement at line 254 to clarify:

“We considered all patches greater than 2 m² when mapping, however the smallest patch we were able to discern from survey error with confidence was 12 m². The largest patch mapped was ~85,900 m².”

R2C7: *Line 272-3: this repeats what you already said in line 266*

We acknowledge that this is reiterative of the first sentence of the paragraph, but given the structure of the paragraph (going through each morphology one by one in sequence), we feel the need to leave this statement in the text. Additionally, here we state the magnitude of vertical change, and call Figure 7i.