Author's response to the comments received for manuscript "esurf-2022-12"

As requested by the handling editor, the following pages contain a point-by-point reply to the comments provided by the referee that reviewed our first submission (esurf-2022-12).

Each of the referee's comment (**RC**) is numbered, and given in *black italics*. If a comment contained several points, we numbered them in *brown*, and address them individually in our author replies (**AR**, blue text). Where appropriate, the revised version of the text appears below in smaller font size and quotation marks (line numbers refer to the revised manuscript-version in which changes are tracked).

We are convinced that the constructive suggestions provided by both referees have improved our work, and thank the referees very much for the time invested in reviewing our submission.

Referee #2 (Jan-Christoph Otto):

General Comment

[RC 2.01] *The authors present a study on the future evolution of glacial lakes beneath glaciers in Switzerland. While this task has been previously performed for the same study area using a comparable approach, this study adds three significant new aspects to the procedure. The authors use an ice thickness model that is based on a large data set of GPR measurements for many glaciers (1). Even though the spatial assessment of the ice thickness is still based on models, the models used here have the potential to be more close to reality compared to the previous approaches that where based on glacier surface topographies only. Furthermore (2), the approach uses an established model to simulate the release of the potential overdeepenings by modelling glacier volume changes in relation to climate change for different climate scenarios. Finally, (3) the study for the first time accounts for the potential refilling of the exposed overdeepenings by generating a time- and space-dependent approximation of the sedimentation rate at various future stages of catchment and glacier evolution. This approach tackles the highly relevant uncertainty of the true lake evolution and potentially generates a more realistic picture of potential future lakes, despite other sources of uncertainty.*

The study is well laid out and the manuscript has been produced with great diligence and logic. The methods applied uses data and approaches based on various previous studies published in the recent past. Therefore, methods description is focusing on references to existing papers. Solely the approach to quantify the sediment infill rate adds a new methodological step in this study. This approach is clearly presented, even though some issues arise (see below). However, the procedure presented is convincing and represent a logical way of assessing this critical parameter of lake sedimentation, where very little data is available so far. All results are clearly presented and visualized at good quality. The discussion states the relevant and critical aspects and implications of the approach and topic in general. The authors compare their results to two previous similar studies considering a good agreement with the approach by Linsbauer et al. (2012) and larger discrepancies to the other previous study.

I consider the manuscript a valuable contribution to the issue of future evolution of glacial lakes. Especially the accounting for sediment refill adds an important new dimension and the results in relation to future glacier and sediment dynamics present highly valuable new insights into the future of glacial and proglacial sedimentary systems, despite the rather simple approximation of glacial erosion and lake sedimentation. It therefore represents a significant improvement compared to previous studies and is worth publishing. I have only few comments and minor issues to consider.

[AR 2.01] We thank the referee very much for both the time invested in reviewing our manuscript and the very positive assessment of our work. We are particularly pleased to read that the innovative aspects of our work are recognisable, that the contribution is deemed to be of relevance, and that our methods seem to have been presented in a clear manner. We are convinced that the constructive comments provided by the referee in the following have further strengthened our work and would like to thank the referee for that.

Specific Comment

[RC 2.02] *Section 3.3. – I have some concerns with the use of the variable α_{crit} in the estimation of the Sed_{in} components. For (1) abrasion, the variable makes sense as is. For (2), increase in deglaciarized area, and (3), glacial and periglacial erosion, I would suggest to reconsider your approach or the description of it. From my understanding α_{crit} represents the mean slope of all glaciers of the SGI2016 (L196 "α_{crit} are critical values for mean thickness and slope that correspond to an average Swiss glacier"). For parameter (1), it makes sense* *to me to use an overall mean for all glacier in the equation. Here you compare h and slope of individual glaciers with overall means across the SGI2016 dataset to generate an index of abrasion, which differs between glaciers due to size and topography. However, for parameter (2) and (3) I think it would make more sense to use α_{crit} as the mean slope of the individual glacier and not the overall mean. Since all other terms of the equation are referring to the individual glacier, I don't understand why slope does not. Maybe it's just a mistake in describing the equations. Please reconsider this issue.*

[AR 2.02] We perfectly understand the referee's concern and realize that we did not manage to properly convey our reasoning behind the individual terms featuring in the indices presented with the equations of Section 3.3. The main idea is to capture variations in sediment production rates (Sed_{in} in the referee's wording) by accounting for the morphological characteristics of individual glaciers and their surroundings. This is done by (1) ensuring that, on average over all glaciers, Sed_{in} matches an average sediment production rate as determined from literature values (former Lines 215-217), and (2) scaling this average rate on a glacier-by-glacier basis (this scaling is performed through the individual components of the indices) depending on how the morphology of a specific glacier compares to the average morphology of all glaciers. In this sense, α_{crit} is indeed meant to describes the average slope of all glaciers, and the terms $\alpha_{proglacial}/\alpha_{crit}$ (for proglacial erosion in Eq. 3) and $\alpha_{headwall}/\alpha_{crit}$ (for headwall erosion in Eq. 4) are meant to modulate the glacier's sediment production rate depending on the average slope of their specific proglacial area ($\alpha_{proglacial}$) or headwall ($\alpha_{headwall}$). What we realized thanks to the referee's comment, is that we failed to state that the α_{crit} values of the three parametrized processes (i.e. subglacial abrasion, proglacial erosion, and headwall erosion) can be different. We will both clarify this difference by explicitly introducing three values ($\alpha_{crit,1}$, $\alpha_{crit,2}$, and $\alpha_{crit,3}$) and better clarify the reasoning behind our procedure by adding the following information to the text:

Lines 194-198: "[…] The main idea behind our approach is to use a set of three dimensionless indices for scaling the rate of sediment input to each lake with the morphological characteristic of a given glacier. This scaling is thereby controlled by how a given morphological characteristic – such as the glacier surface slope or the size of the glacier proglacial area, for instance – compares to the average characteristic of all glaciers in the sample. […]"

Lines 207-209: "[…] $\alpha_{crit,2}$ is the average proglacial slope of all Swiss glaciers, and A_{basin} is the total area of the basin. Similarly to $i_{abrasion}$, the index is meant to capture relative variations between glaciers that are caused by differences in morphology, and indeed, a large, steep and recently deglacierized proglacial area will result in higher $c_{sed,in}$ than a small, flat, or long-established one. […]"

Lines 217-119: "[…] Similarly as for $i_{abrasion}$ and $i_{proglacial}$, the ratio $\alpha_{headwall}/\alpha_{crit,3}$ is meant to capture relative variations between glaciers, $\alpha_{crit,3}$ being the average headwall slope of all glaciers in the sample. The square for this equation term intends to qualitatively capture the exponential effect that […]"

Minor Comments

[RC 2.03] *L63 add Otto et al. (2022) to the list for completeness.*

[AR 2.03] This reference will be added.

[RC 2.04] *L147ff – Check the phrasing here with respect to the term "mean bedrock topography". Previously you generated the bedrock topography from the ice thickness models, now you go the other way…this does not make sense. I guess here you simply use the mean ice thickness model and not the bedrock topography. This would be in accordance to the Huss and Hock (2012) approach..*

[AR 2.04] The two formulations are equivalent but we agree that the wording might cause unnecessary confusion. We will reword into:

Lines xx-xx: "The current ice thickness distribution is taken from Grab et al. (2021), and GloGEM is applied to all glaciers of the SGI2016 with a glacier-specific calibration based on observed ice volume changes between 2000 and 2019 (Hugonnet et al., 2021)."

[RC 2.05] *L154 – replace or with for.*

[AR 2.05] Sure, this typo will be corrected.

[RC 2.06] *L188/189 – Erodibility is also affected by bedrock lithology. Sediment availability is equally important with respect to the tools required for abrasion. The former could probably not be accounted for here, while the latter is somehow represented by your consideration of headwall erosion. Please mentions these in the text.*

[AR 2.06] We perfectly agree and will mention bedrock lithology as an important, controlling mechanism. See also our reply to **RC 1.19**.

[RC 2.07] *L192 and L206ff – glacial and periglacial erosion….I would suggest to term this part solely periglacial or better headwall erosion (like you do in figure 5B), since you refer to the headwall area here only. Glacial erosion is represented by the approximation of abrasion in (1). Headwall erosion would include both processes, periglacial and feedbacks by glacial erosion.*

[AR 2.07] We agree and will only speak of "headwall erosion".

[RC 2.08] *L206 – consider adding some more recent references like: [Sanders et al. (2012) and/or Hartmeyer et al. (2020)]*

[AR 2.08] Both references are excellent suggestions and will be added.

[RC 2.09] *L386ff – In the methods section you described to quantify sediment infill rates in kg/m³ runoff. How do you relate these to erosion rates? (also relevant for figure 5B)*

[AR 2.09] Given the catchment-wide sediment infill rates (in kg/m^3, as described in the methods) and given the yearly runoff (in m^3/a, obtained from GloGEM), the total sediment yield (in kg/a) can be computed by simple multiplication. The specific erosion rates (in mm/a) are then obtained by assuming a given density for the eroded material (we assume $2800 kg/m^3$) and dividing by the total catchment area (which is known). We will add a short version of this explanation in the caption of Figure 5:

Fig. 5, caption: "[…] Numbers in the upper part of the panel show (i) sediment concentrations in the runoff […], and (ii) modelled catchment erosion rates. Both quantities are evaluated over 20-year time steps, and the latter quantity is obtained by assuming an average density for eroded materials of 2800 $kg\ m^{-3}$ and by dividing the catchment-wide sediment yield (now expressed as $m^3\ yr^{-1}$) by the catchment area."

[RC 2.10] *Figure 1 A: (1) rename the legend items...it seems like you depict the total deglaciated area and not the total lake area as described in the figure caption. (2) What does "1e6" represent at the upper left and lower right corners?*

[AR 2.10] (1) This was indeed a mistake and the legend will be corrected. (2) "1e6" was standing for "10^6", which was needed for the units of the coordinate system. We recognize that the information must have been confusing, and will amend that in the revised figure. The figure as it will appear in the revised manuscript is shown in our answer to **RC1.07**.