Response to Reviewer 1

We thank Nicolas Barth for the helpful suggestions and comments, as well as taking the time to read and evaluate our manuscript. Please find outlined below our response to the main suggestions made on the manuscript, as well as our line by line response.

(1) Figures. At least one figure panel is mislabeled. Changes/additions to labeling and color ramps could improve readability and understanding. I suggest one possible figure that could be added and the addition of another panel to an existing figure. Detailed suggestions are below.

Thanks for both this main comment and the associated line comments. We will do a thorough check and review for all figures, figure captions, and labels to make sure they are clear and readable. This includes changes to the colour map ramp in Figures 5,6 and 9 to make sure that the detail in the order of magnitude changes in risk values are more obvious. We will also include a new Figure 2 in the Study Site section to explain the different landslide types considered within our risk analysis. We include information on the types of infrastructure in our amendments to Figure 1.

(2) References. Some cited references appear missing, notably Taig 2021a&b. I thought the landslide risk assessment introduction was generally well referenced but that there could be more background references on the range of landslides (historic+prehistoric) documented in the western Southern Alps environment (Korup, Hancox, etc.) and as far as I could tell the landslide inventory used is not specifically referenced and undoubtedly must draw from or build upon existing compilations (Korup, QMAP, etc.). I also suggest Yosemite Valley references for the discussion- they might not have the same range of events as Franz/Fox but certainly lots of parallels with rockfall risk to tourists on trails.

The Taig reports have now been finalised, so the reference will be updated and included in the revised manuscript. It is our understanding that DOC intends to make these reports available on their website. The reports provide the background for risk comparison dataset and the risk threshold advice for DOC. The references are:

Taig T. 2022a. Risk comparisons for DOC visitors and staff. Cheshire (GB): TTAC Ltd. 131 p.

Taig T. 2022b. Guidelines for DOC on dealing with natural hazard risk. Cheshire (GB): TTAC Ltd. 91 p.

The references for our aseismic landslide inventory are included in the Appendices. We included in the landslide inventory only historic landslides where we knew the timing of failure (e.g. it was a single failure event with a well constrained volume). This detail was moved to the Appendices to provide a more concise methodology section; however, we are open to adding this back into the main text if it better supports our aseismic landslide magnitude – frequency relationship. We will include more information (and associated references) on the range of wider southern alps landslides within the Study Site (Section 2) to set the scene for the type and size of landslides that could occur.

Within the ‘Drivers of Risk’ Section 5.1 of the discussion, we can include a discussion on prehistoric landslides, our assumptions in the magnitude-frequency relationships, and the associated uncertainty of the aseismic landslides. This further emphasises the need for robust landslide inventories.

Thanks for highlighting the Yosemite rockfall risk references. Their risk analysis highlights how effective reduction in exposure can be to reduce the risk. We will add these references in to appropriate sections of the discussion. This also includes the note to crowd-sourcing the information on landslide occurrence. The QR code on signage sounds like a great idea to explore.

Line comments:

L 23: Since your study areas top out at 2000m and go down to 200m it might be more appropriate to point to "high relief mountain areas" rather than "high mountain areas" (most of the affected areas are closer to 200m).

We will make the suggested change.

L62-63: Surely you can get pre-COVID annual visitation estimates and typical daily number of workers in each valley from DOC? Similarly a peak tourist season daily count of tourists and workers? I think that would help a lot with the context.

Yes, we do have estimates of annual and peak visitor numbers, so will include these in the revised manuscript. For Fox Glacier Valley, the annual pre-COVID visitor numbers are approx. 400,000 per year with a maximum number of visitor's trips into the valley of approx. 3,500, while Franz Josef received approx. 700,000 per year with a maximum number of visitor's trips into the valley of approx. 6,000.

L70: I prefer capitalization of the formal fault name "Alpine Fault" as you use elsewhere.

We will make the suggested change.

L74-75: A reference or two would be good here if possible. And actually the next two sentences too.

We will add in the appropriate references.

L87-88: "respectively" not needed.

We will make the suggested change.

L 540: Taig 2021 (a&b?) is cited multiple times as a seemingly important reference but does not occur in the reference list.

We will update the reference list, as mentioned above.

L560-567: Not required if you think it breaks your narrative but there are several good references to rockfall risk in Yosemite Valley (4M visitors/yr) including their extensive rockfall database that visitor are encouraged to submit observations to (crowdsourced). A QR code to report a rockfall/etc could be placed on the signage suggested at L546.

https://www.nps.gov/yose/learn/nature/rockfall.htm

https://pubs.usgs.gov/ds/746/

I agree with you that better documentation of events will go the furthest for robust decision making.

The appendix was skimmed but appears to be appropriate.

To better acquaint your readers with the types of hazards and potential exposure, it might be helpful to have a multi-panel figure showing photographs (aerial and ground) of different hazards (rockfall, debris flow, rock avalanche, etc) and the style of infrastructure (trails, roads, etc.) within the valleys. I would suggest this could be a good Figure 2 (sliding current Figure 2 to the 3 spot). And relatedly some text in the Study Site section.

See our response above with regards to both the Yosemite references and new Figure 2 and related text.

L132: Just a general comment that I follow the life risk calculation approach and am fine with it. As you point out obviously a lot of unknowns that lead to orders of magnitude ranges of possibilities. I find the vulnerability factor particularly interesting. I wonder if later on in the discussion it is worth considering a 100% vulnerable scenario (i.e. approximate scenario that a trail closes because a large landslide is witnessed, near miss, or someone is struck by a rock but fine)- potentially important from an economic standpoint.

Agreed that there is more to explore with regards to different scenarios. We suggest that our risk model provides the base to explore these different scenarios using e.g. event trees. We will include such a point in our discussion section.

Figure 1: Nice figure overall. Some of the details are hard to see because of the resolution and jpg compression- I suggest the final version have a higher resolution. Maybe shade the glaciers in transparent blue polygons to improve context? Show Alpine Fault in Panel B? Maybe label bridge locations at outlets of the study areas? Clipped study area boundaries are a little arbitrary, especially Fox case study that crops the unnamed west-draining creek off Pt 1401, Serac Creek, and unnamed west draining creek from Mt Garnier (but whatever I guess).

We will make the suggested changes, including adding in the Alpine Fault to Panel B. Will include information on the infrastructure (road, tracks, bridges) on Panel C and D. We will update the Fox case study area boundary to better reflect the areas of our analysis, as we included and ran runout models from both the unnamed west -draining creek off Pt 1401 and the unnamed west draining creek from Mt Garnier.

Figure 2: Maybe add the PGA labels to the “Band 2”/etc in the legend so the figure stands alone better.

We will make the suggested change.

Figure 3: Slope angle legend is wrong in panel B (flipped). Specify how the local slope relief in panel C was created (typically a radius of a chosen width?). Provide citation for

data in panel A and panel D. What is the source and basis of the vegetation mapping in panel E? The bedrock ridge of Cone Rock (high probability in panel F) should be vegetated.

We will modify Panel B. We created the Local Slope Relief using a radius of 80 m based off the methodology in Massey et al., 2018. We used both Landcare's Land cover database and aerial photography collected in 2017 and 2018 DEM as the basis for the vegetation classification. We will add this information into the text and figure caption regarding this. With regards to Cone Rock, some of this area should have been classified as vegetated, though the high probabilities in Panel F aligned with either pre-existing rock slope failures or steeper with limited vegetation rock slopes, and as such we do not think that this will have a large impact on the results.

Figure 5&6: Pretty much same comments for both figures. The color ramp in panel A is so smooth (17 shades of blue) such that visually you can probably only determine color values to +/-1-2. It looks nice but a more variable color ramp would convey more information. In panel C it is hard to differentiate a lot of the colors chosen, particularly 10m3 and 10000m3. In panel D again I think helpful to have PGA ranges in legend.

We will make the suggested change to the colour ramp in both Panel A's. Will try and make the lines easier to differentiate in Panel C, as well as adding in the PGA range in the legend.

Figure 7: Is it worth scaling the two panels to the same LPR scale? Maybe some loss of detail but would help in comparing the two valley tracks directly.

We can make the suggested change – agreed that this will help with comparison between the two valleys.

Figure 8: Nice. Maybe mark the track positions on the different images? Was the Chalet Lookout Track marked on the LINZ topo abandoned due to this landslide?- dot that in to further illustrate the point?

Yes, the Chalet Lookout Track was abandoned fairly quickly after the landslide initiated, so will add the track positions onto the different panels.

Figure 9: Suggest a more variable color ramp again. Just a comment that it is interesting to see the SE of Cone Rock spillover in the LPR- a nice argument for the value of high res topo data in these analyses.

Will make the suggested change in colour ramp. Agreed with regards to the high-resolution topography, which is confirmed with a couple of debris flow events observed spilling over in the SE Cone Rock location.

Figure 10: I found this a really useful figure to help contextualize the results of your study, particularly in a way readers and policy makers can understand. While the per trip metric is helpful for evaluating tourist's risks, it is less helpful for evaluating the risk of workers who have prolonged and multiple exposures. It would be helpful to be able to evaluate the

risk of workers in the valley (trail maintenance, road worker, tour guide, etc.) compared to other places in New Zealand alongside this “one visit” risk. Presumably someone doing trail maintenance will linger in the more dangerous areas longer. Seems like you may have a lot of these data in Massey et al. 2018c? Wishful thinking perhaps but it would make a nice second panel to this figure.

There is companion figure in Massey et al., 2018c that shows the risk comparators for DOC workers (who walk the tracks daily) compared to other workplaces in NZ. Additionally, Taig (2022 a & b) provides guidance for DOC on determining risk to workers who are exposed to landslide hazards regularly versus workers that may only be temporarily exposed for short time frames.

To keep the focus of this paper on visitor risk and make sure that the length of this paper is appropriate, we are not likely to include a second panel on worker comparator risk. Though as with the Taig reports, it is our understanding that the Massey et al., 2018c report will be made available on the DOC website.