

We thank Caroline Orchiston 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 suggestions made on the manuscript.

L62 - Visitors are described as being able to 'easily access and experience a glacier environment'. For day visitors (unlike more dedicated trampers/mountaineers) I would suggest the access is no longer easy, and that visitors are entering what could almost be described as a post-glacial environment in the lower reaches of the valleys. In the 1990s and early 2000s it was possible for day visitors to walk to the terminus and do a Glacier Walk on a paid tour. This is no longer possible because of the extent of glacial retreat, meaning that visitors have to take a tour via helicopter to fly above the glacier and do a glacial landing in order to get a full glacier experience. Thus the risk to tourists is not just downstream of the terminus, but on the glacier itself during landings. Was this factored into your analysis? It would also be useful to cite some data on the approx. proportion of visitors (pre-Covid) doing glacier flights compared to walking up to the viewing areas in the valleys. DOC would hold this data as concession manager.

We will amend our Study Site description to be clearer about the day visitors (see below). This risk analysis was only concerned with visitors walking DOC tracks in the valley up until a glacier viewpoint.

"The glaciers themselves can now only be accessed via helicopters, with visitors undertaking paid tours on the glacier, given the commercial sensitivities the risk from landslide hazards to visitors on commercial tours on the glacier have not been quantified in our risk analysis.

Due to commercial nature of these activities, quantifying risk to visitors on the glacier themselves was outside of the scope of this study and therefore we do not provide information with regards to the proportion of visitors walking the tracks versus partaking in commercial tours.

L71 - the sentence about the Alpine Fault as a major earthquake source needs a reference – the Howarth et al. 2021 Nature Geoscience paper is the best most recent.

We will make the suggested change.

Figure 1 – the text size on c) and d) is too small.

We will make the suggested changes to the figure.

Line 140 – can you provide some background context of the nature of the workforce in the glacial valleys? What types of jobs do they do, and how frequently are they undertaking these jobs? (Noting that this analysis is reported elsewhere in Massey 2018). Are they working in a limited area, or do they range across the valleys, and roughly how much time are they exposed to risk per day?

In Massey et al., 2018 we calculated the AIFR for the most exposed DOC worker. This was the person who walked and undertook daily checks of the main visitor tracks in each valley. This ranged from 2.2 hours to 2.8 hours a day depending on the valley. We will add this detail into Line 140 onwards, but more information is provided in Massey et al., 2018. This report will be made publicly available.

Line 175 – before you talk about risk exposure of tourists, you need to provide visitor data for the valleys (DOC and Stats NZ are the best sources), and also provide some context on the past two years of low visitor international visitation due to the pandemic. The pandemic hit following several years of strong tourism growth in NZ. The glaciers, alongside Aoraki/Mt Cook and Piopiotahi/Milford Sound were experiencing a million visitors per annum, causing significant pressure on tourism infrastructure and other social/community pressures. Glacier Country / South Westland had a heavy reliance on international visitors pre-Covid and has been one of the hardest hit regions of NZ in terms of reduced visitation when the international borders closed. Unlike other parts of NZ that moved to a domestic market quite effectively, South Westland is less accessible and can't attract e.g. weekend visitors because of its remoteness. This sort of context has implications for exposure and vulnerability (i.e. internationals are less likely to speak English and thus may not understand risk communication information).

We will add in information regarding pre-covid visitor data for the valleys to the Study site section, see below:

Prior to the Covid 19 pandemic and associated closure of New Zealand's border to international tourists, c.700,000 people per year walked the tracks in the Franz Josef Glacier Valley and c.400,000 people per year walked the tracks in Fox Glacier Valley. A maximum number of 6,000 people per day and 3,500 people per day walked the tracks in Franz Josef and Fox Glacier Valley respectively. Within this environment, visitors are exposed to a variety of landslide hazards”

Within the Time Variable Risk section of the discussion, we will include a point on the impact of Covid on exposure and vulnerability to emphasise its not only changes in hazard but the elements at risk that are also important (see italicised paragraph below). We suggest that a reduction in visitor numbers will reduce societal risk, which we define using f/N pairs where f represents the frequency of the event occurring and N represents the number of fatalities.

Alongside the impact of Covid, both main visitor tracks in the valley have been closed or partly closed due to geomorphic processes. In Fox Glacier from 2019 onwards the main visitor track on the north side of the valley has been closed due to the impact of the Alpine Gardens Landslide (access is now only provided on the south side of the valley). In Franz Josef from 2020 onwards the Waiho river has shifted towards the true left side of the valley resulting in the partial closure of main visitor track. This change in visitor tracks will also have knock on effects to both individual visitor risk and societal risk.

“Alongside changes in hazard behaviour, risk analysis should also account for dynamic changes in exposure and vulnerability. ... Since 2019 and 2020 the main visitor tracks in the Fox and Franz Josef Glacier valleys respectively have been closed or partially closed due to geomorphic processes. Until access is restored in both valleys, the exact location of the tracks in each valley and the number of people walking the tracks is unknown. In Fox Glacier Valley, the expansion of the Mill's Creek fan from debris flow activity has damaged access on the true-right side of the valley, while in Franz Josef Glacier Valley, the course of the Waiho River has restricted access on the true-left side of the valley. As such visitor exposure and therefore risk to landslide hazard is reduced. Alongside this, the Covid-19 pandemic and associated closure of New Zealand's border to international tourists has resulted in a reduction in visitor numbers to both glacier valleys. This reduction in visitor numbers will impact our societal risk metric, by reducing exposure of 1 or more people to an event that might result in fatalities.”

L225 – Southern Alps should be capitalised

We will make the suggested change.

Visitor exposure – walking speed isn't thoroughly explained and will be highly variable, e.g. family groups with young children are potentially more exposed due to frequent stopping, and slow pace.

We will add more detail to Section 3.6. Based on information provided by DOC, in Fox Glacier Valley, our average walker spent 1.5 hours walking to and from the glacier viewpoint and 0.2 hours driving to and from the car park (see Figure 1 c), while our slower walker spent 2 hours walking to and from the glacier viewpoint and 0.3 hours driving to and from the car park. In Franz Josef Glacier Valley, our average walker spent 2-hour walking to and from the glacier view point, and 0.3 hours driving to and from the car park (see Figure 1 d) while the slower walker spent 2.5 hours walking to and from the glacier viewpoint and 0.4 hours driving to and from the car park.

We also conducted our own field counts and checks on walking speed and approx. visitor numbers. This also revealed that not all visitors travelled the full length of the tracks and turned back at certain points. More detailed analysis and investigation of visitor behaviour and its impact on both exposure and vulnerability would be interesting to include but outside the scope of this study.

Figure 5a – the entirely blue colour gradient makes it very difficult to discern specific risk zones. Also 5c has a colour legend which is hard to match to the chart. Likewise with 6c.

We will make the suggested changes to the colour ramps and legends in both figures.

L420 – Fox River, capitalised

We will make the suggested change.

Use of the term societal risk – it is unclear. E.g Individual risk is clearly risk present to one person, but societal risk speaks to a much broader impact, while here you use it to describe risk to N or more people, i.e. multiple injuries or fatalities. Consider a different term.

We will define in Section 3.2 what we are defining as societal risk, which is the frequency of events resulting in 1 or more fatalities, as well as what we are excluding from societal risk (e.g. the broader impacts).

Throughout the document we will also make it clear when referring to societal risk that it is only the probability of multiple fatalities occurring.

Risk communication – Fig 10 is a useful way to attempt to convey comparative risks across commonly used activities. Effective communication of technical, complex risk scores with big numbers/exponents and uncertainties in order to support policy and practice is a huge challenge. While it is beyond the scope of this paper, the findings offer very interesting food for thought on how we can improve the translation of scenario-based risk data to maximise the societal benefits from a disaster risk reduction perspective. The use of qualitative measures/scales to translate risk into risk acceptability/tolerance data would be useful, but would require a detailed study of the local stakeholder and visitor perceptions of risk in order to generate appropriate risk tolerance outputs.

Thanks- this is an important point and comment, though outside the scope of this paper as noted. We have changed a sentence in Line 608 to highlight and provide a nod towards the role of risk perception (and the wider subject) in setting risk thresholds:

“The risk bands can be presented against risk comparator data to inform risk evaluation and risk tolerability processes in conjunction with an evaluation of how visitors and decision makers perceive risk (cf. Taig, 2022).”

The Taig 2022 reports contain more information on the risk comparator data and provide guidance to DOC for setting risk thresholds. It is our understanding that DOC intends to make these reports available on their website. The references for the reports 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.