Westland District Council | Te Kahui o Poutini

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Westland District Council Submitter S181
Westland Distrct Council Further Submitter SF79

11th July 2023

West Coast Regional Council
PO Box 66
Greymouth

info@ttpp.nz

Westland District Council further submission on the Proposed Te Tai o Poutini Plan

Introduction

1. Westland District Council (the Council) thanks the West Coast Regional Council for the opportunity to make further submissions on the Proposed Te Tai o Poutini Plan.

2. This submission outlines the key matters that Westland District Council supports and raises some matters that Council would encourage further consideration of.

Submission

Specific submission points with recommended amendments/clarification are included in Appendix A.

Further submission points

1. Dark Sky provisions to include Okārito;
2. Include stormwater from building provisions in GRZ and RLZ;
3. Commercial Activity and Retail Activity definitions to include offsite hire of equipment for use on surface of water;
4. ECO rules to clarify how applicants can achieve ECO-R2(3);
5. Natural Hazards rules to reflect most recent report regarding Franz Josef;
6. Riparian Margin, Commercial Activity and Retail Activity interpretation.

Conclusion

In summary, thank you for the opportunity to provide this further submission. Council wishes to be heard in support of this submission.

For clarification on any points within this further submission please contact Olivia Anderson, Planning Manager, at olivia.anderson@westlanddc.govt.nz

Yours faithfully,

Simon Bastion
CEO Westland District Council

Appendix A – Specific further submission points and recommended amendments

Submission Point	Plan Section	Provision	Position on the further submission:	The reasons for our submission are:	The decision I would like the Council to make on this submission point is:
S275.016	Light	LIGHT	Support in Part	Council supports the consideration of greater protection for West Coast dark skies. Submission point 12 recommends that the requirements of Dark Skies Park designation under International Dark Skies be included for specific areas such as Punakaiki/Barrytown Flats for new builds and replacement works. The Okārito community is seeking Dark Sky Community accreditation through the International Dark Sky Association. This application is endorsed by the Okārito Community Association (OCA) meeting 27 November 2022 (see attached letter) and Glacier Country Tourism (see attached letter) and has the support of Council. To be consistent with the accreditation process currently underway within the Okārito community Dark sky provisions should be extended to Okārito township and Forks area. This measure will offer additional protection to nocturnal native fauna including unique West Coast species Okārito kiwi (*Apteryx rowi)*.	Allow in Part - Amend to include Dark Sky provisions at Punakaiki and Okārito.
S465.027	Settlement Zone	SETZ-R1.2 and R1.3	Support in Part	Council supports the inclusion of these provisions for the Settlement Zone but would like a provision similar to R1.3. included for the GRZ and RLZ as well. This measure has the intent of the current Westland District Plan provision 8.3 which requires	Allow in Part - Amend GRZ and RLZ rules to include stormwater provisions similar to SETZ-R1.2 (where relevant) and SETZ-R1.3.

				'Stormwater runoff from buildings shall be directed to the road channel, or to a watercourse within the property, or to an approved drain provided for that purpose.' Similar to MRZ-R1.7 and LLRZ R1.6 the intent is that stormwater runoff from all buildings (not just residential dwellings) should be managed on site not drain to a public road aside from secondary flow purposes.	
S536.032	Interpretation	COMMERCIAL ACTIVITY	Support in Part	Council supports amendment of the Commercial Activity definition. Definition should encompass ancillary activity to the commercial activity including hire where the financial exchange occurs offsite. The intent is that Commercial Activities on the Surface of Water involving hire of goods or services are a Discretionary Activity as per ASW-R7.	Allow in Part - Amend definition to read: *means any activity trading in goods, equipment or services. It includes any ancillary activity to the commercial activity (for example administrative or head offices)* and: a) The hire and use of goods, equipment and services for activities on the surface of water (ASW); b) The hire and use of goods, equipment and services in Open Space and Recreation Zones.
S538.013	Interpretation	RETAIL ACTIVITY	Support in Part	The current retail activity definition does not capture the offsite hire of equipment for use in the Open Space Zone. The intent is that Retail Activities within the OSZ are included within OSZ-R16.	Allow in Part - Amend definition of retail activity to include hire and use of goods, equipment and services.
S602.076	Ecosystems and Indigenous Biodiversity	ECO-R2	Support in Part	Council agrees that ECO – R2(3) and advice note requires amendment to remove ambiguity. Currently R2(3) requires *indigenous vegetation clearance does not disturb, damage or destroy nesting areas or habitat of protected species*. No	Allow in Part - Amend ECO – R2(3) to provide an advice note on how R2(3) can be achieved.

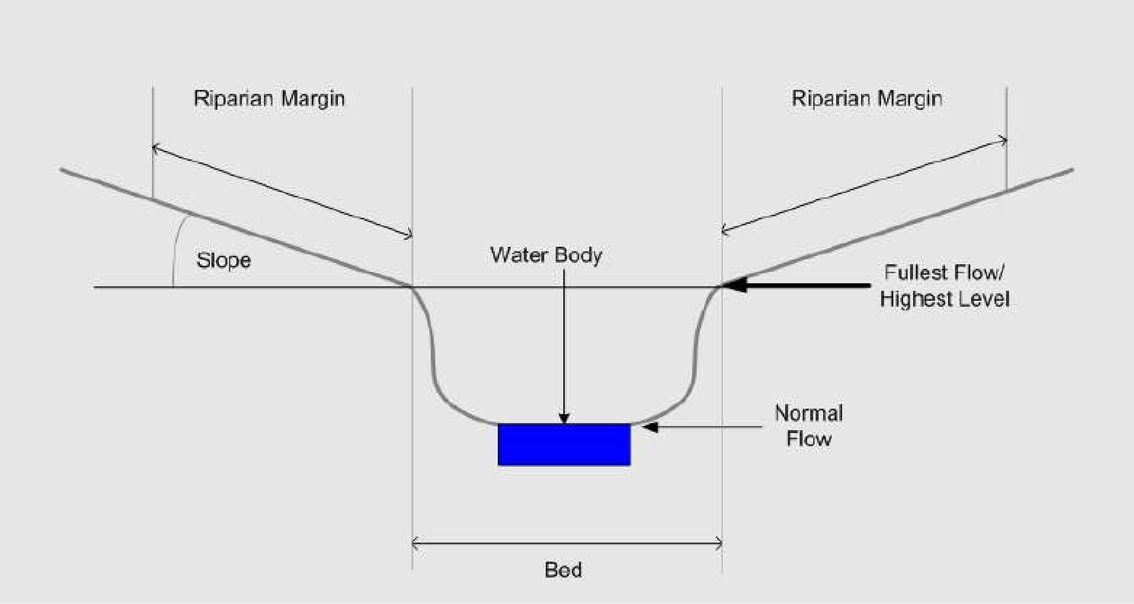
				information is provided as to where protected species habitat or nesting areas are or how applicants can provide evidence that they meet this requirement. If an ecological report is required to achieve this, then this is contrary to the intent of a Permitted Activity. An advice note should be added to confirm how R2(3) can be achieved.	
S617.011	Natural Hazards	NH- R1	Support	Council is in opposition to NH-R1 (1-5). Within the Westland District the proposed Rule will allow for rebuilding/replacement in an area of natural hazard risk within a 5 year period which is more lenient than the current RMA existing use right provisions. Council supports retaining the current RMA timeframe of 12 months (rather than extending to 5 years) as this will achieve the Objective to reduce risk to life, property and the environment from natural hazards as well as the Policy of precaution.	Allow - Delete rule NH-R1 (1-5) or modify rule to comply with current RMA existing use right timeframes.
S617.012	Natural Hazards	NH – R4	Support	This rule is contrary to existing national direction within the NZ Coastal Policy Statement. To allow for evaluation of matters raised in NZCPS Policy 25 and 27 Council agrees this rule should be subject to Discretionary Activity Status rather than Permitted Status. Council supports the change of status to Discretionary as it will allow Council and the community it represents to have a say in protection works which can compromise natural character and amenity.	Allow - NH-R4 to Discretionary Activity Status.
S617.013	Natural Hazards	HH – R7	Support	Council agrees with proposed amendment which is proposed to allow for the construction of small	Allow - Amend to state unoccupied buildings of no more than 50m$^{2.}$

				structures requiring minimum investment, reducing the risk to property and social effects on residents.	
S617.014	Natural Hazards	NH – R 10	Support	Council agrees that this rule is too permissive and agrees with the amendment to wording to require a 500mm minimum rather than standard. The rule should be Controlled rather than Permitted Activity status. The reason for this is that site specific engineer advice may recommend a raise floor level in excess of this requirement to provide protection of life and property.	Allow - Move NH-R10 to Controlled Activity Status.
S617.015	Natural Hazards	NH – R 38	Support	Council agrees this rule should be deleted. As discussed previously Council considers that the current RMA existing use provisions provide adequate provision for rebuilding within 12 months, the proposed rule is too lenient and may encourage development within the Coastal Hazard overlays which is not the intent of the NH Objectives and Policies which seek protection of lives and property.	Allow - Delete.
S617.018	Natural Hazards	NH	Support	Council supports the introduction of controls for areas subject to Tsunami or coastal erosion from storm surge. Measures similar to those provided for severe earthquake hazards may be appropriate in areas of the coastal environment subject to risk of tsunami. Areas affected by coastal erosion may also be vulnerable to storm surge and land loss and further development should be restricted in these areas to prevent potential loss of life and property.	Allow - Include rule to prohibit sensitive activities within the Coastal Severe Overlay.
S617.019	Natural Hazards	NH	Support	Include landslide risk to Franz Josef Township in hazard overlays and zoning. Council supports this measure in order to prevent loss of life. A copy of the final Franz Josef Hazard report is included with this further submission to support this request.	Allow - Include additional overlay and maps for landslide risk to Franz Josef Township.

S617.020	Natural Hazards	NH	Support	Council agrees that the final Franz Josef hazard report be utilised to inform landslide zoning overlays for Franz Josef. This measure is required to prevent potential loss of life and property.	Allow - Amend rule framework to prohibit development in landslide risk area of Franz Josef Township.
S620.041	Interpretation	RIPARIAN MARGIN	Support in part	Council supports amendment of the Riparian Margin definition. To provide for consistency of decisions the proposed plan definition should be consistent with the WCRC Land and Water Plan and include interpretation diagrams/tables. (See below)	Amend the definition of riparian margin: *Means all land within:* *a. 10m of any wetland;* *b. 20m of any lake; and* c. <u>A certain distance [as per attached table] from the usual and non-flood fullest flow/highest level [see diagram] of any river.</u>

Table of Riparian Margin widths

	River Width		
	1-3 metres wide	3-8 metres wide	>8 metres wide
Riparian Margin Width	5 metres	10 metres	20 metres



Deborah Patterson

From:	Okarito Chairperson <chairperson@okarito.org.nz>
Sent:	Wednesday, 3 May 2023 10:56 am
To:	Deborah Patterson
Cc:	darkskyokarito
Subject:	Fwd: Okarito Dark Sky Community
Follow Up Flag:	Follow up
Flag Status:	Flagged

Hi Deborah.
Just forwarding on the email from our association regarding support for the Okarito Dark Sky application process.

Nga mihi
Richard Saunders
Chairperson

Okarito Community Association
P.O Box 144, Franz Josef Glacier 7856

============ Forwarded message ============
From: Okarito Chairperson <chairperson@okarito.org.nz>
To: "simon.bastion"<simon.bastion@westlanddc.govt.nz>
Date: Tue, 28 Mar 2023 16:59:08 +1300
Subject: Okarito Dark Sky Community
============ Forwarded message ============

Kia Ora Simon.
Our community of Okarito has had several discussions regarding the proposal to apply for a Dark Sky Community designation through the International Dark Sky Association. The community has supported continuing the application process. There are rigorous standards for approval and one of the requirements for an application to be successful is the support of applicable government agencies such as Council.

The Okarito Community Association supports Council making a submission for the District Plan that would allow provisions for Dark Sky compliance language should the application be successful. Please let us know if you have any questions.

Nga mihi
Richard Saunders
Chairperson

Okarito Community Association
P.O Box 144, Franz Josef Glacier 7856

Forest & Bird
GIVING NATURE A VOICE

West Coast Branch

14/06/2023

The West Coast branch of Forest & Bird welcomes the initiative by the Okārito community to preserve and protect the dark skies of Okārito. We fully support the proposal for an accredited Dark Sky Community from the International Dark Sky Association. We also support that the dark sky provisions should be extended to the Okārito township. We look forward to seeing these provisions included in Te Tai o Poutini Plan for the Okārito area.

There are likely other communities across the West Coast that may be interested in dark sky accreditation and we trust TTPP will allow for such opportunities to be progressed going forward. With increasing levels of artificial light trespassing into the night across Aotearoa, we hope that West Coast councils will embrace the benefits to native species and to people's wellbeing by protecting the relatively pristine dark skies that exist in many parts of Tai Poutini.

Suzanne Hills on behalf of West Coast branch of Forest and Bird.

WestCoast.Branch@forestandbird.org.nz

GLACIER COUNTRY NEW ZEALAND
UNTAMED NATURAL WILDERNESS

Glacier Country Tourism Group Inc.
P O Box 78, Franz Josef Glacier 7856

11th April 2023

Okarito Dark Sky Community
darkskyokarito@gmail.com

Tēnā koutou

Glacier Country Tourism Group would like to express our support for the Okarito Dark Sky Community Project.

The project will provide many benefits for both the community and visitors to Glacier Country, adding to the visitor experience and enhancing the attractiveness of Glacier Country as a destination for both New Zealanders and International visitors.

The project will have a positive impact on the environment and will fit alongside other current conservation projects in the area such as Jobs for Nature and Predator Free South Westland / Zero Invasive Predators. The project will also provide opportunities for employment in nature tourism and give visitors a reason to stay longer in our area and enjoy all Glacier Country has to offer.

We are excited for the potential and give our full support to the Okarito Dark Sky Community Team in getting this initiative progressed.

Ngā mihi

Janelle Shaw Mike Nolan

Co-Chairpersons
Glacier Country Tourism Group

COMPARATIVE HAZARD AND RISK ASSESSMENT OF EXISTING AND PROPOSED FRANZ JOSEF TOWN SITES: REPORT FOR WESTLAND DISTRICT COUNCIL

February 2023

Tim Davies
School of Earth and Environment, University of Canterbury

EXECUTIVE SUMMARY

Franz Josef Glacier township is known to be subject to a number of natural hazards that threaten both assets and lives, including

1. river flooding from the Waiho-Callery river system and the Tatare River;
2. earthquake (surface rupture, ground shaking and liquefaction), predominantly from the Alpine fault;
3. failure (probably earthquake-triggered) of the steep hillslope immediately south-east of the existing township, causing a rock avalanche;
4. landslide dambreak flooding from the Callery and Tatare Rivers; and
5. debris-flows at Stoney Creek.

The threats from Waiho River flooding and an Alpine fault earthquake are widely-recognised, and official and societal concerns about them are such that it has been proposed to relocate the township to an alternative site in the same vicinity but more distant from both the Waiho and the Alpine fault.

New Zealand legislation requires that land-use decisions in respect of natural hazards are based on the concept of risk (defined as the annual probability of an event multiplied by its consequence), therefore it is necessary to assess the degree to which the proposed relocation will alter natural-hazard risks to assets and to life at Franz Josef.

This report estimates and compares the risks to the existing and proposed town sites that arise from these hazards. Due to the sparsity of data on individual hazards, estimates of absolute risk are subject to potentially large errors. The ratios of risks in the two sites, however, are more robust because errors will tend to be similar at both sites and may largely cancel each other out.

The main findings are that:

- Overall risks to life in the existing town are of the order of 10-20 times higher than those to the same population in the proposed town site.
- Risks to assets are of about the same order of magnitude over both existing and proposed sites, but somewhat greater over the former.
- In particular, the individual risk-to-life from rock avalanche hazard at the present town site (> 0.02 per year) appears to be about an order of magnitude higher than globally-accepted levels, but is much closer to acceptable levels in the relocated site.
- Societal risks-to-life due to rock avalanche, dambreak flood and debris flow appear to be unacceptably high by global standards across parts of the present and proposed town sites.

It is noted, however, that a number of assumptions underlie these results:

(a) That assets and people are uniformly spatially distributed across both existing and relocated town sites at equal spatial densities corresponding to pre-Covid population and tourist numbers. This means that the spatial distribution of hazards determines the risk distribution.
(b) That risks due to hazards 1, 3, 4 and 5 are only those that exist prior to the occurrence of a major earthquake. This is because hazards 1, 3, 4 and 5 are likely to be altered significantly following a major earthquake, but this alteration cannot be quantified realistically.
(c) That the rock avalanche hazard is real; it is emphasised that this is presently somewhat uncertain. A detailed geotechnical assessment is needed to assess this, because rock avalanche risk is the main cause of the much higher risk-to-life at the existing town site.
(d) That flood control banks are in place as planned in 2020 (Figs. 3 & 4), and these will not fail before 2040. This is because aggradation of the Waiho River is assumed to continue at the pre-2020 rate, and this will result in bank failure becoming much more likely after 2040.

Climate change has not been factored into present hazard and risk estimates, because the extent of its impacts on weather and river flows prior to 2040 have yet been defined sufficiently reliably. Climate change will affect both present and proposed town sites similarly, with the exception of increase in debris-flow frequency at Stoney Creek.

It follows from (b) and (d) above that the relative risks calculated herein are valid only until the next major earthquake or until 2040, whichever comes first; the probability of an Alpine fault earthquake occurring before 2040 is about 30-40%. A qualitative outline of risk changes after 2040 and/or after an earthquake is provided in Appendix C.

The risks to the proposed relocated town site can be reduced by concentrating assets and people in locations less vulnerable to hazards. The part of the proposed town site east of the Tatare River and north of State Highway 6 stands out as the least threatened area, excluding the Stoney Creek fan debris-flow area.

Further work is needed to

(i) reduce the uncertainty about the reality of the rock avalanche hazard;
(ii) assess how the relocated township layout will affect risks to lives and assets, and how these compare to risks to the present township layout;
(iii) assess how hazard frequency will change following the occurrence of a major earthquake; and
(iv) assess how flood frequency will change due to increased risk of stopbank overtopping after 2040.

When reliable estimates of the locations of assets and population of the proposed relocated township become available, further detailed work could be carried out to reassess the relative risks using the actual distribution of assets and people in the present town site. However the base data on hazard magnitude, frequency and spatial distribution are recognised to be approximate, and will limit the reliability of any precise risk estimates.

It is also important to note that no estimates of risk can predict the extent to which specific areas of land will be affected by hazards prior to 2040. Risk is a probabilistic concept that does not apply reliably to any small sample of events; only over a very long time period can outcomes be expected that correspond reliably to the present hazard and risk estimates.

CONTENTS

1. Introduction

On 20 December 2020 Westland District Council contracted University of Canterbury to provide a comparative hazard impact assessment of the existing and proposed Franz Josef town sites (Fig. 1, 2). This work is to be carried out by Dr Tim Davies and MSc thesis student Nandhini R.

Reported data required include

i. the approximate footprints of the identified hazards over a range of magnitudes and frequencies on both present and proposed town sites;
ii. a comparison of the average annual hazard impact on the present town site with that of the proposed new site, assuming the same degree of development at each site;
iii. identification of specific areas requiring more detailed investigation.

A Progress Report dated May 2022 dealt with the first of these.

The MSc thesis (R, 2022) was submitted at the end of June 2022, and provides an account of the project and a quantitative comparison of the hazard exposure of the sites. The main contribution of the thesis was to develop a GIS-based superposition of the hazard magnitude zones and to quantify their overlaps with the present and proposed town sites, and to find values for specific hazard mortality rates. The thesis was examined and passed by two external referees; the comments of the referees have been incorporated in the present report where appropriate.

This Final Report outlines the basis of, describes, and summarises the outcomes of, the MSc thesis and other work completed for this project.

2. Background

Franz Josef Glacier township in Westland (Fig. 1) was, pre-Covid, a rapidly-developing centre forming a key component of South Island tourism; in the future it is expected to resume that role. However it has for some time been of increasing concern that the township and its ca 400 permanent inhabitants, together with hundreds of seasonal workers and some thousands of daily tourists, are at serious risk from the natural hazards that threaten the area. The beauty of the natural landscape that attracts tourists to the area results from its extremely active tectonic setting, which gives rise to rapid landscape uplift and steep mountains, and from its intense hydrological regime with ca 10 000 mm of rain per year and active rivers. These same factors, however, also cause the occasional lethal earthquakes, landslides, floods and debris flows that can devastate Franz Josef with little or no warning. Although no such catastrophe has occurred in European recorded history, this only dates back to the mid-19th century, and landscape evidence suggests that many major events have occurred prehistorically; these will certainly be repeated in the future. No location on Earth is risk-free, however, and the Franz Josef community can continue to live more safely with its exciting environment if it acknowledges its predicament and plans to avoid the future events that can be foreseen.

New Zealand legislation requires that natural hazards threatening assets and lives are considered when locating developments, and that this consideration is framed in terms of risk. In this context, risk is defined as the annual probability that a specific natural event will occur, multiplied by its impact on society in terms of deaths and costs. Thus risk is a criterion that must be used in decision-making about where to locate societal assets and, hence, people.

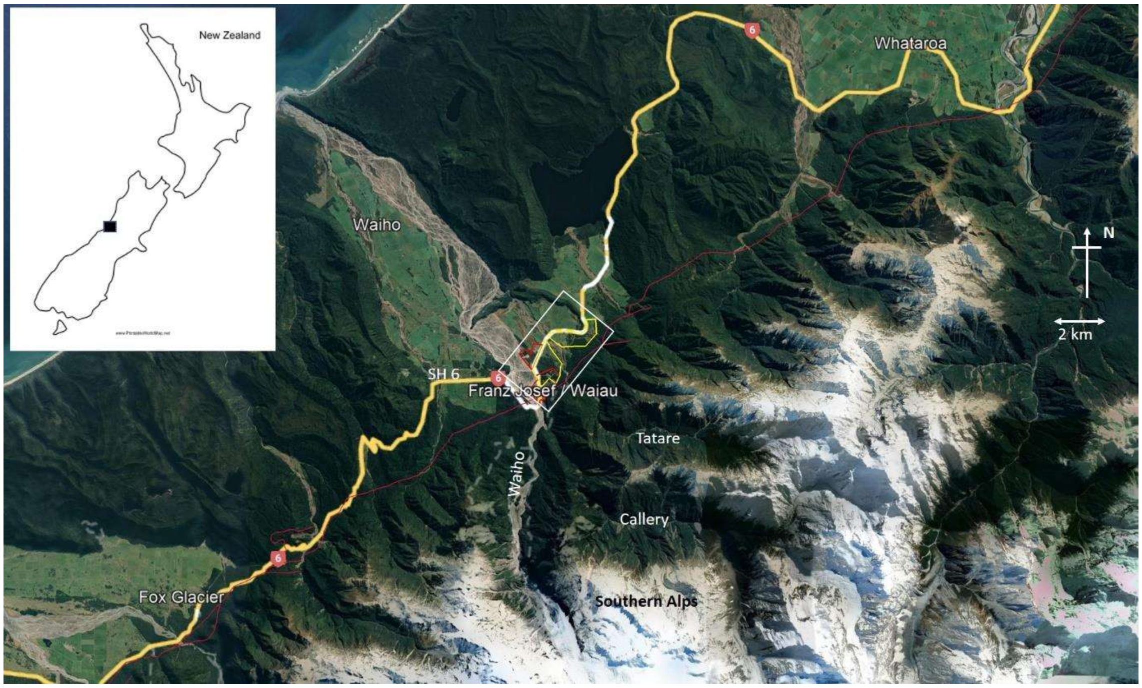


Fig. 1 Franz Josef area, Westland showing Alpine fault (red line), SH 6 (yellow line), Southern Alps and major rivers. White square is area of Fig. 2. Modified Google Earth image.

It has been proposed that Franz Josef township can reduce its hazard exposure, and hence risks, if its assets and population are relocated to a different site in the same general area. The purpose of the present work is to estimate and compare the risks from natural hazards to both the present town site and to the proposed relocation site. The existing (OT1 and OT2) and proposed (NT1 and NT2) town sites, each comprising two distinct areas, are shown in Fig. 2.

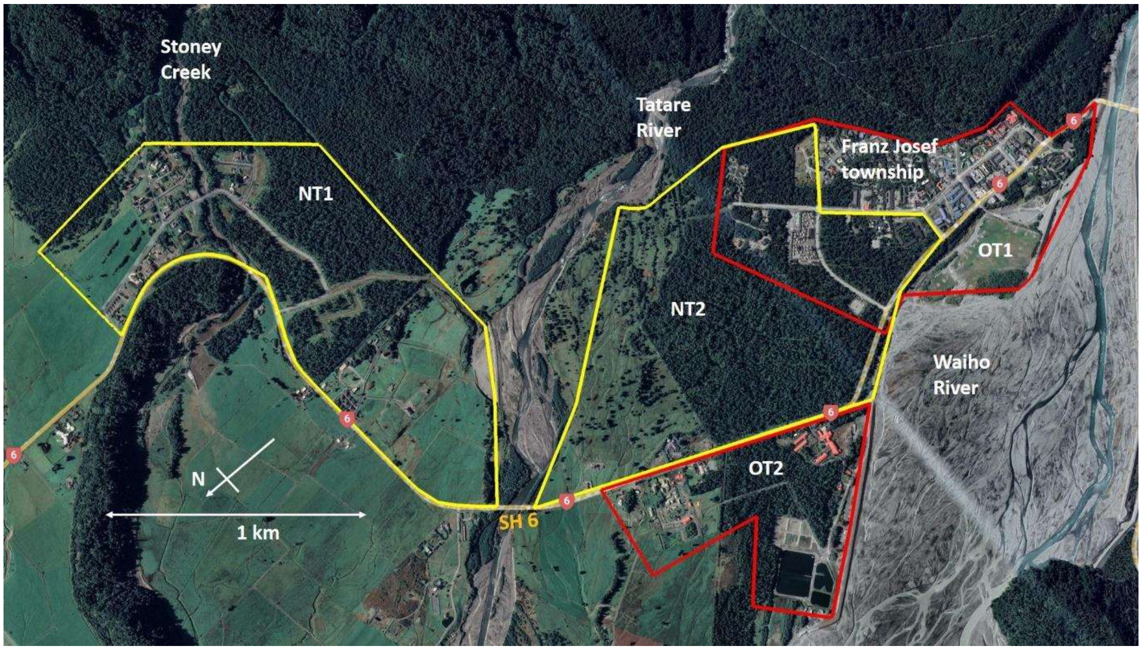


Fig. 2 Close-up of Franz Josef township area showing present town sites (red lines: OT1 and OT2) and proposed town sites (yellow lines: NT1 and NT2). Modified Google Earth image.

3. Previous hazard and risk assessments

This is the first hazard assessment that specifically considers the proposed new town sites.

McSaveney and Davies (1998) carried out the first natural hazard assessment for Franz Josef Glacier township and its environs, which however considered only the flood hazard due to the Waiho River and the earthquake hazard due to the Alpine fault. At that time the latter hazard had only recently been generally acknowledged, prior controversy over whether the Alpine was indeed seismogenic or moved by slow slip having been resolved in the mid-1990s. Since then considerable progress has been made in understanding seismic hazard in Westland and its likely impacts (e.g. Robinson et al., 2016; Howarth et al., 2021; Blagen et al., 2022). The 1998 hazard assessment focussed mainly on Waiho River flooding, using a geomorphic approach because of the lack of flow and sediment transport data.

Langridge et al. (2016) incorporated post-1998 work on the Alpine fault (Langridge et al., 2011; Howarth et al., 2014) and the Waiho River (Land River Sea Ltd, 2014), and considered in addition threats due to alluvial fan flooding; to landslide-dambreak flooding from the Callery River, which had caused relocation of a holiday park in 2003 following research by Davies (2002) and OptimX (2002); to coseismic and aseismic landsliding based on work by Hovius et al. (1997), Stark and Hovius (2001) and Robinson et al. (2016); and to rock avalanche based on work by Barth (2013) and Davies (2014). Areas susceptible to ground rupture, seismic shaking, Waiho flooding and liquefaction were delineated but without associated probabilities. Hazards due to debris flows at Stoney Creek and to landslide dambreak floods from the Tatare River were not mentioned, despite their prior consideration by Welsh and Davies (2011) and Davies and Korup (2007) respectively.

Tonkin and Taylor (2017) summarised hazard knowledge and presented options for risk management. Davies and Loew (2019) and Davies and Moretti (2021) estimated the likely size and annual probability of rock avalanche hazard at Franz Josef, and Dunant et al. (2021) derived a magnitude-frequency relationship for landslide-dambreak floods from the Callery River. In addition, R (2021) carried out a magnitude-frequency analysis of landslide dambreak floods from the Tatare River.

4. Methodology

The present report draws on the previous work centred on the Alpine fault for estimating earthquake-related hazards and risks. Waiho River flood hazard and risks assessments utilise data from the most recent modelling by Land River Sea (Gardner, 2021) and the aggradation analysis of Beagley et al. (2020). The areas affected by landslide dambreak floods from the Callery and Tatare Rivers are delineated for a range of return periods by modelling carried out specifically for this project by GNS Science Ltd under their Endeavour programme, while the areas affected by rock avalanches of a range of return periods are delineated using the empirical relationships of Davies (1982) and Korup and Clague (2009). To generate an impact-frequency relationship for debris flows at Stoney Creek, empirical relationships from the literature were assumed to apply, together with the assumption that debris flows result from aseismic landslides in the catchment. These analyses and the resulting impact-frequency data are outlined in Appendix A.

Using GIS, R (2022) has calculated the overlap of each hazard type and frequency with the old and new town sites. Assuming that both assets and people are uniformly and equally spatially distributed across each town site, at the pre-Covid permanent and tourist populations, the asset risks and risks-to-life for each hazard, and the total for all hazards, are calculated.

5. Main assumptions and implications

All hazard assessments rely on a suite of assumptions. Here the main, overarching assumptions are set out and their implications made clear. The estimations of the individual hazards also involve their own specific assumptions, which are set out when these are considered.
It is assumed that:

5.1 The spatial distribution of assets within the town sites is uniform. Thus the impact of each hazard event is characterised only by the spatial distribution of the hazard event itself, not by the location of any specific asset. The hazard spatial distribution, however, provides information that may be useful in deciding where to locate assets across the relocation sites in order to reduce impacts. Similarly, risk-to-life estimates are based on assumed uniform distributions of people across the two sites at pre-Covid permanent, itinerant and tourist populations. Asset and population distributions are assumed uniform in time.

5.2 Stopbanks are present as planned in 2020 (Figs 3, 4), including raising of existing banks and installation of a bank to prevent the Waiho avulsing into the Tatare downstream of the oxidation ponds. These stopbanks are also assumed to operate as designed (i.e. not fail).

5.3 The Waiho River continues aggrading. Beagley et al. (2020) showed that if the Waiho behaves over the next century as it has during the last 50 years, its bed will aggrade by about 17 m at the SH6 bridge by 2120, assuming that it remains confined in its present bed by raising stopbanks. To address this situation, the West Coast Regional Council medium-term strategy is to relax/remove the western stopbanks (on the true left of the Waiho River) so that the flood threat to the east bank (true right) land is greatly reduced (Gardner, 2021). Thus the eastern stopbanks only need to function until this strategy is implemented; they have been designed to cope with about 20 years of aggradation (Gardner, 2021), so this is the corresponding time-scale over which the present work applies. Note also that the probability of a major earthquake in the next 20 years is about 30-40%; this event will drastically alter (increase) the subsequent flood risk due to large coseismic landslide sediment input to the river (Robinson et al., 2016; Briggs et al., 2018; Appendix C). The present work therefore only applies until that event occurs.

5.4 The rock avalanche hazard exists as described. As outlined by Davies and Loew (2019) there remains some doubt about this, to resolve which needs detailed geotechnical investigation.

Earthquake hazard at Franz Josef is dominated by the expectation of a major earthquake on the Alpine fault. This probability of this event is about 75% in the next 50 years, according to Howarth et al. (2021). Following this earthquake, or one on a different fault within the Southern Alps, the hazard probabilities at Franz Josef over the following decades to century will change significantly, because of the large volume of earthquake-generated landslide sediment that will be deposited in rivers and the severe aggradation and increased flooding this will cause (Blagen et al., 2022; Orchiston et al., 2018). It is not presently feasible to anticipate quantitatively how the hazardscape will be affected by the next major earthquake. The present work therefore considers only the current, pre-earthquake hazard distribution (which however includes the immediate impacts of the earthquake itself) in comparing the hazard exposures of the two town sites.

The present risk calculations thus apply only until the planned stopbanks become unreliable due to river aggradation in about 2040, or until the next major earthquake, whichever comes sooner.

Future hazards at Franz Josef are expected to alter with time due to climate change. Climate change has however been ignored in the present work because, first, it is a relatively slow process whose impacts will take many years to become fully apparent and in the meantime it is sufficiently accurate to predict future climate-related hazards based on past experience of these; and, second, climate change impacts are likely to be similar for both present and proposed town sites and so will not significantly affect the relative hazard vulnerability of the sites. When consideration extends to longer-term timeframes climate change will be a much more serious factor (Appendix C).

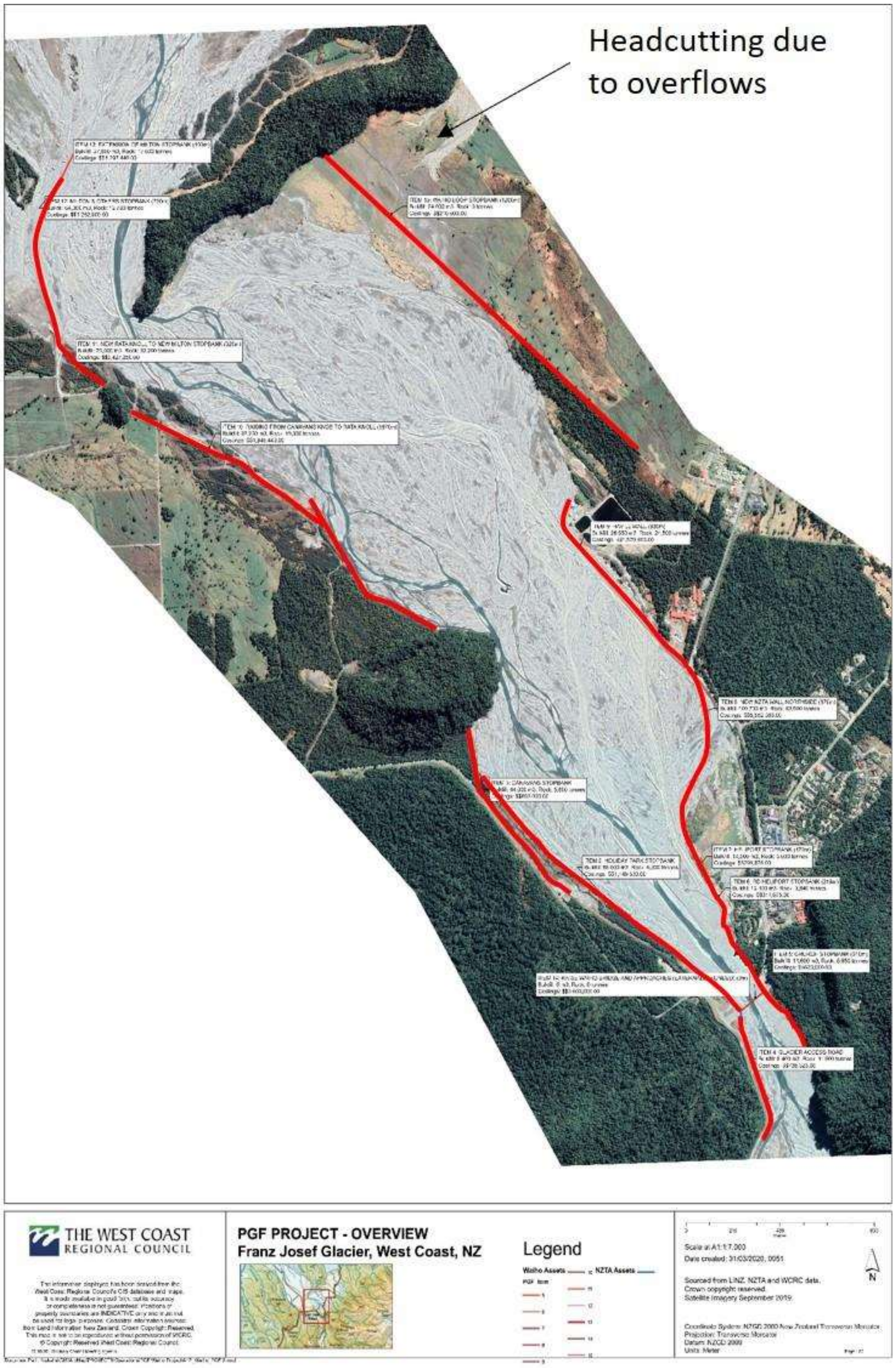
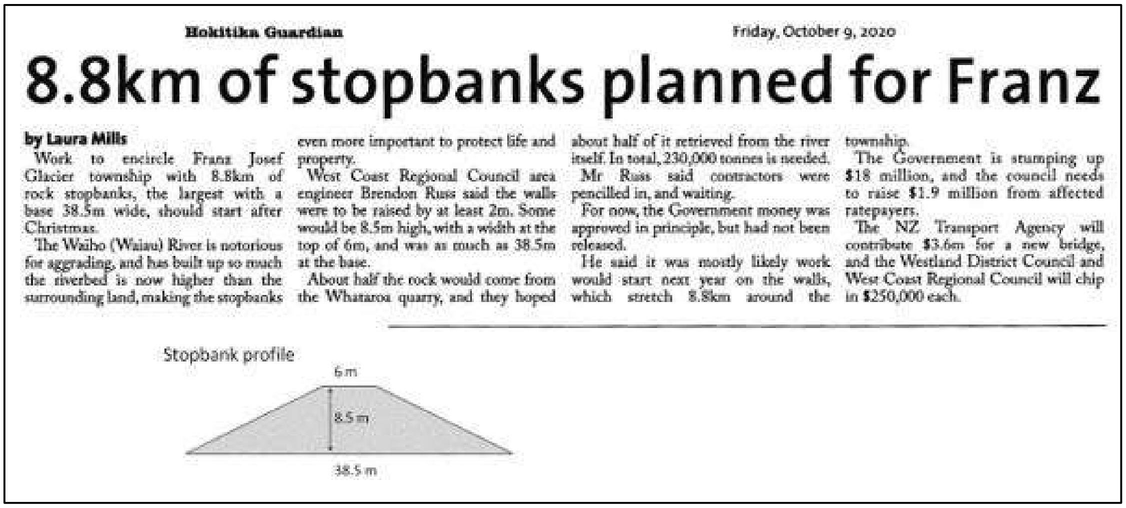


Fig. 3 Existing and planned stopbanks at Franz Josef (West Coast Regional Council).



Hokitika Guardian Friday, October 9, 2020

8.8km of stopbanks planned for Franz

by Laura Mills

Work to encircle Franz Josef Glacier township with 8.8km of rock stopbanks, the largest with a base 38.5m wide, should start after Christmas.

The Waiho (Waiau) River is notorious for aggrading, and has built up so much the riverbed is now higher than the surrounding land, making the stopbanks even more important to protect life and property.

West Coast Regional Council area engineer Brendon Russ said the walls were to be raised by at least 2m. Some would be 8.5m high, with a width at the top of 6m, and was as much as 38.5m at the base.

About half the rock would come from the Whataroa quarry, and they hoped about half of it retrieved from the river itself. In total, 230,000 tonnes is needed.

Mr Russ said contractors were pencilled in, and waiting.

For now, the Government money was approved in principle, but had not been released.

He said it was mostly likely work would start next year on the walls, which stretch 8.8km around the township.

The Government is stumping up $18 million, and the council needs to raise $1.9 million from affected ratepayers.

The NZ Transport Agency will contribute $3.6m for a new bridge, and the Westland District Council and West Coast Regional Council will chip in $250,000 each.

Fig. 4 Information and cross-section of planned stopbanks (Hokitika Guardian, 2020)

6. Hazards affecting town sites

Outlined herein are the estimated spatial extents and recurrence intervals for the known hazards whose areas of impact overlap with either or both the present and proposed town sites:

1. rainstorm-generated flooding from the Waiho-Callery river system and the Tatare River;
2. earthquake (surface rupture, ground shaking and liquefaction), predominantly from the Alpine fault;
3. earthquake-triggered landslide (rock avalanche) from the steep hillslope south-east of the existing township;
4. landslide dambreak flooding from the Callery and Tatare Rivers; and
5. debris-flows at Stoney Creek.

A number of natural hazards that can affect Franz Josef Glacier township, but are either insufficiently localised in impact or localisation of their impacts cannot be predicted, are not considered because they are likely to affect both present and proposed town sites equally. These include windstorms, hailstorms, snowstorms, surface flooding from rainfall, lightning strikes and wildfire.

Because few reliable data exist describing the magnitude-frequency relationships of the considered hazard events the quantities used and derived in the following analyses are necessarily approximations. Hence the areas delineated as affected by events of specific return periods, though as realistic as possible, are also approximations and must be acknowledged as such in any use of this report. Even if these delineations were ideally accurate, however, they could not reliably predict the areas affected by any specific future events because they are statistical descriptions of what can occur over very long time periods. Nevertheless, they are useful for comparing the hazard exposures and risk levels in the existing and proposed township areas.

The areas delineated as affected by events of different return periods are in some cases the result of state-of-the-art numerical simulations (Waiho River flooding; landslide dambreak flooding from the Callery and Tatare), while others (rock avalanche, debris flow, earthquake) are based on empirical data from within New Zealand and from overseas. The data sources and analyses underlying the hazard assessments are detailed in Appendix A.

The ranges of return periods considered vary between hazards. Thus, for example, the area affected by a 100,000-year return period rock avalanche is delineated because, although it has a very low probability (10^{-5}) of occurring in any given year, it poses a significant risk to life because it can kill a large proportion of the exposed population (80% of people in the present town site, 35% of those in the proposed new town site). Note that the fact that the occurrence of a rock avalanche probably requires an earthquake does not mean that every earthquake will cause a rock avalanche, so it is necessary to treat these risks separately, although they are related; the direct earthquake-related risks are due only to ground rupture and shaking. The occurrence of earthquakes is dominated by the Alpine fault earthquake which currently is a 50 – 100-year return interval event and is also the maximum conceivable event for the area, and is expected to kill only a small proportion of those present. Thus the ways in which earthquakes and landslides contribute to risk are very different, because they have very different magnitude-frequency-impact distributions.

6.1 River flooding:

(a) Waiho River

The area of land threatened by flooding from the Waiho River has been modelled by Gardner (2021), based on the stopbanks planned in 2020, but omitting consideration of the new bank planned to extend from the vicinity of the oxidation ponds to the Waiho Loop (Fig. 3); this is designed not to overtop at flows below 2500 m^3s^{-1}. These stopbanks are designed on the basis of current bed levels plus 20 years' ongoing aggradation at about 0.18 m/year (Gardner, 2021). The flooded areas have been modelled for discharges of 500 to 3500 m^3s^{-1}, and Fig. 5 indicates the flooding extent for 2500 m^3s^{-1}, which is about a 200-year flood; it is notable that there is no substantial threat to either town site as long as the stopbanks remain functional.

Table 1 Flood magnitude and frequency, Waiho River (derived from Gardner, 2014)

Return period, years	Discharge, m^3s^{-1}
20	1857
50	2128
100	2330
400	2735
500	2800
1000	3000
5000	3300
10000	3500

(b) Tatare River

Flooding of the Tatare River has not been an issue historically because its river bed is incised well below the general land surface from the SH6 bridge downstream, with the depth of incision increasing to over 10 m at the Waiho Loop. However parts of the western new town site (NT2) adjacent to the Tatare upstream of the SH6 bridge are close to the river-bed elevation and likely to be prone to flooding in severe rainstorms, especially if there are substantial sediment inputs from the Tatare catchment. In the absence of detailed rainstorm-generated flood modelling for the Tatare River the return period of this extent of inundation is arbitrarily assigned as 100 years for risk estimation purposes.

As pointed out by Davies et al. (2013), overflows from the Waiho into the Tatare immediately upstream of the Waiho Loop are increasing during high flows as the Waiho bed aggrades, and the ca 10 m lower elevation of the Tatare bed causes headward erosion that causes these flows to increase over time (indicated in Fig. 2). If a large proportion of Waiho floods in due course enters the Tatare then substantial aggradation of the Tatare is to be expected, which can then progressively cause its upstream bed level to increase. Modelling by Davies et al. (2013) indicated that flooding from the Tatare upstream of the SH6 bridge may eventually be exacerbated due to this aggradation. To prevent this scenario the planned stopbank upgrades include a bank extending from the oxidation ponds to the Waiho Loop (Fig. 3) designed to contain Waiho flows of 2500 m^3s^{-1} (Gardner, 2021) which is about a 200-year event (Table 1). We assume that this bank will prevent such overflows as designed.

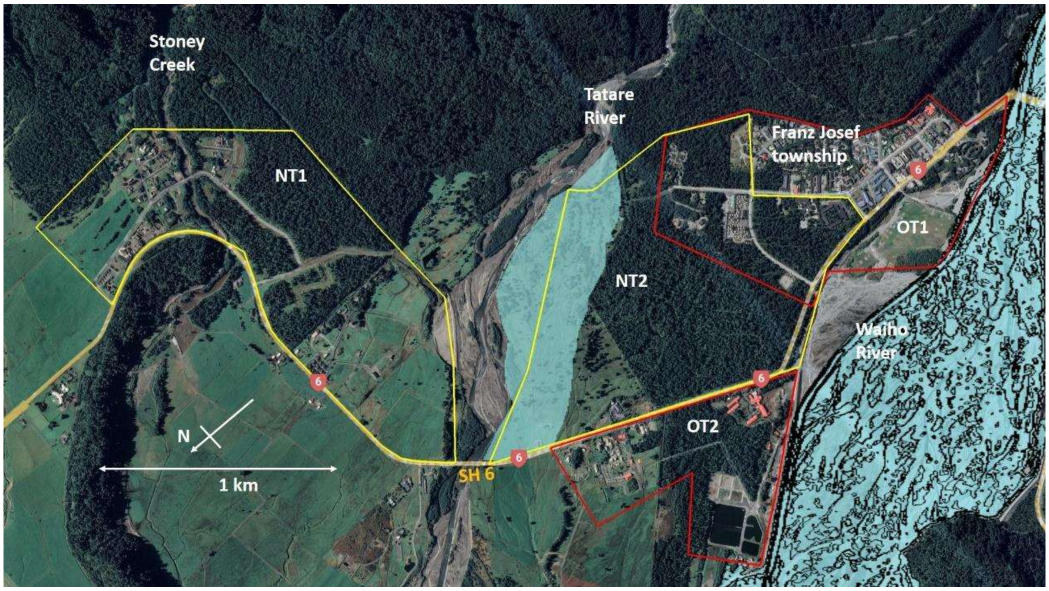


Fig. 5 Flood hazards (blue) at Franz Josef from Tatare (left) and Waiho (right) Rivers, ca 100-200-year return interval. Modified Google Earth image.

With the planned stopbanks in place, only minor flooding of any of the town sites from the Waiho is anticipated over the next 20 years. After that (Appendix C), ongoing river aggradation will increase the probability of stopbank failures; however it is not feasible to model that situation because the flooding location, intensity and extent will depend on the location and nature of the stopbank failures, which are not predictable.

6.2. Earthquake: Alpine fault

The Alpine fault marks the boundary between the Pacific and Australasian tectonic plates and delineates the western rangefront of the Southern Alps (Fig. 1). It is known to have ruptured several times per millennium with earthquakes of M_w 8 or greater over the past 8000 years (Berryman et al., 2012); Howarth et al. (2021) estimated that the next such earthquake has a 75% probability of occurring in the next 50 years, with a current annual probability of 1-2%.

The surface trace of the last (1717 AD) rupture of the Alpine fault passes through the present township site and is encompassed by the Fault Rupture Avoidance Zone (FRAZ; Langridge et al., 2011; Toy et al., 2020; brown area in Fig. 6) that was designated by WDC in 2010 but rescinded in 2016. In this zone severe ground rupture is expected to occur during the earthquake, with consequent destruction of assets and corresponding risk to life. This affects only the present town site OT1 (Fig. 6). Note that our risk analysis assumes severe impacts throughout the 100 m wide fault avoidance zone, although in reality catastrophic damage is likely to be limited to a few metres from the actual rupture.

The other major consequence of the earthquake is ground shaking. This is shown by Langridge et al. (2016) to be essentially uniform across all of the town sites, with a peak ground acceleration of greater than 0.75g (7.5 ms^{-2}, corresponding to Modified Mercalli Scale 10+, which means severe damage to buildings and possible loss of life). This aspect of earthquake hazard is thus identical across both present and proposed town sites.

While earthquakes on other smaller faults in the region can undoubtedly cause shaking at Franz Josef, the risks due to Alpine fault rupture far outweigh these and so they are not considered herein.

6.3 Liquefaction and lateral spreading

Earthquake shaking may also cause liquefaction to occur at one location (white area in Fig. 6) identified by Langridge et al. (2016). This location is within both the present and the proposed town sites, so its impact is identical to both. Given the relatively coarse gravels that make up the alluvial sediments in the area, however, liquefaction seems unlikely to contribute significant additional shaking-derived damage in Franz Josef. Because of this and its very localised distribution, liquefaction is not considered in the comparison of hazards and risks between the town sites. If liquefaction is most likely during Alpine fault earthquakes then the return period is the same as that of ground rupture, or about 50-100 years

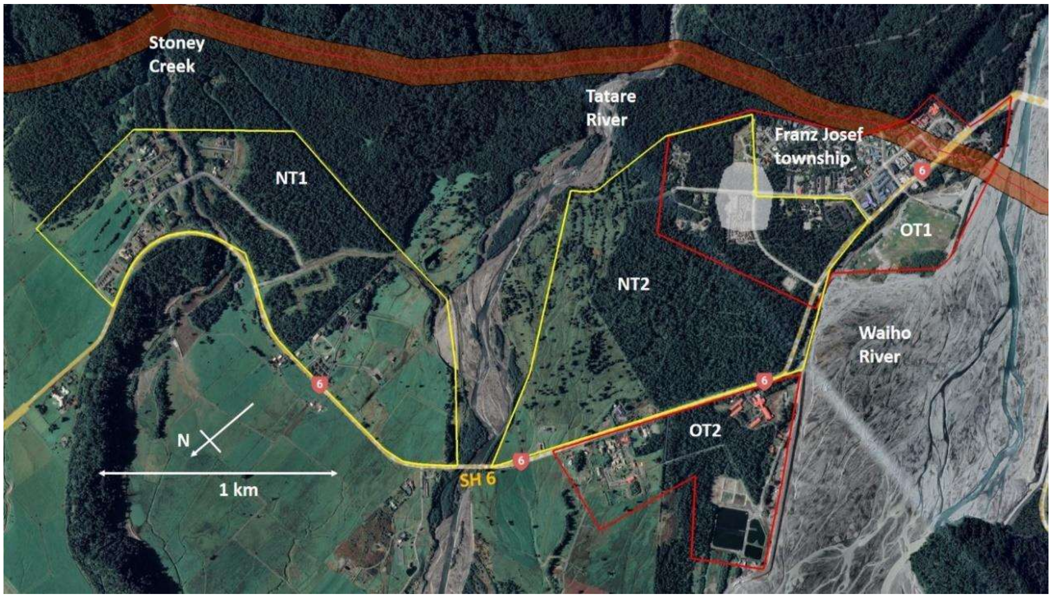


Fig. 6 Earthquake-related hazard at Franz Josef. Brown = surface rupture zone; white area = risk of liquefaction. The whole area shown is expected to be affected by shaking > 0.75g. Return period for rupture and shaking ca 50-100 years. Modified Google Earth image.

Lateral spreading due to severe shaking will affect earth structures, especially all river stopbanks which will subside and spread thus reducing their crest level and ability to contain floods. While this will not cause immediate damage to other assets or loss of life, it will severely impact on flood risk and river behaviour post-earthquake (Appendix C).

6.4 Earthquake-triggered landslide (rock avalanche)

Following its earlier identification by Barth (2014), Langridge et al. (2016) describe a potential major landslide (rock avalanche) that could fall from the hillslope overlooking Franz Josef, most likely during an earthquake on the Alpine fault that crosses the foot of the slope. Davies and Loew (2019) and Davies and Moretti (2021) estimated a potential failure volume of the order of 10^7 m^3 for this event, and an annual probability of the order of 10^{-5}, or 1 in 100,000. We have derived a relationship between landslide volume and probability from New Zealand data (Korup and Clague, 2009), and the corresponding runouts (Table 2) from an empirical volume-runout relationship (Davies, 1982); these are shown in Fig. 7. A 10^8 m^3 rock avalanche would affect all of the town sites except the northern half of NT2, but the ability of the source slope to yield such a large event is doubtful, and it would have a return period of about 4 million years, so is not included in the hazard analysis.

It is worth noting that Davies and Moretti (2021) estimated the societal risk-to-life presented to the present town site OT1 by the 10^7 m^3 event (with an assumed 100,000-year return interval) to be about 10^{-2} per year, which is about 100-1000 times higher than internationally-used levels of acceptable risk. The present, more detailed, work confirms these orders of magnitude.

Table 2 Rock avalanche volume, runout distance and return period

Volume, m^3	**Probability, a^{-1}***	**Runout, km****	**Return period, (yr)**
10^5	1.6×10^{-2}	0.5	60
10^6	4×10^{-4}	1.0	2,500
10^7	1×10^{-5}	2.1	100,000

*Korup and Clague (2009) based on $p(10^7 m^3) = 10^{-5} a^{-1}$.
**Davies, 1982; runout = $10(\text{volume})^{1/3}$.

It is important to note that Davies and Moretti (2021) raised the possibility that this slope could also fail catastrophically without an earthquake trigger, most likely (but not necessarily) during a severe rainstorm. The probability of such failure is unknown but likely to be low.

6.5 Landslide dambreak flooding

Landslides in the mountains east of the Alpine fault take place in steep terrain through which run deeply-incised rivers. A major landslide in this terrain has a high probability of blocking a river by forming a temporary "landslide dam". The lake formed behind this will overtop the dam and can cause it to fail, either immediately or some time later; the release of the impounded lake water will cause a severe but short-lived flood to move through the downstream river system, carrying large quantities of sediment and woody debris. Such an event in the Poerua River in 1999 took place several days after the landslide occurred and caused extensive damage to farmland downstream. This ten million cubic metre landslide was neither earthquake- nor rainfall-triggered. Dambreak flood peaks are usually much higher than those of normal floods (though durations are much shorter), and correspondingly affect larger areas; an event of this type affecting Franz Josef township would cause severe damage and threaten lives (Davies, 2002).

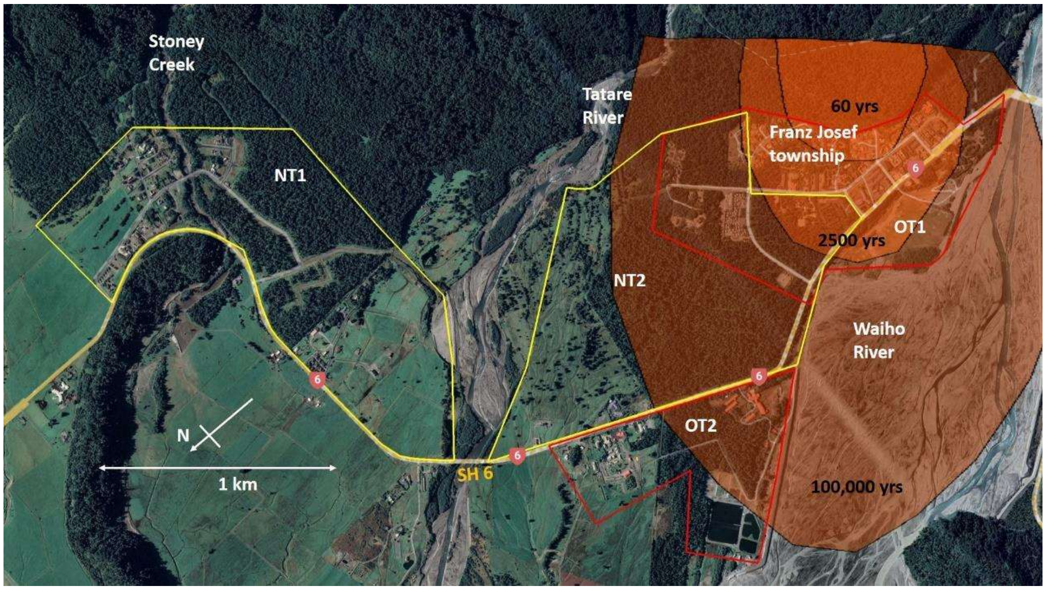


Fig. 7 Landslide (rock avalanche) hazard at Franz Josef. Modified Google Earth image.

Franz Josef is vulnerable to landslide dambreak floods from the Callery and Tatare Rivers, both of which flow between steep, high slopes for much of their catchment lengths. The Callery is a major tributary of the Waiho with its confluence about 1 km upstream of the township (Fig. 1). Ollett (2001), Davies (2002) and OptimX (2002) quantified the risk-to-life due to landslide dambreak flooding in the Callery River (Table 3), as a result of which the Franz Josef Holiday Park was relocated from its riverside site in 2003; Dunant et al. (2021) subsequently refined this analysis. R (2021) quantified the landslide-dambreak flood hazard from the Tatare River (Table 4), which had not been investigated previously. GNS Science, through its Endeavour research programme (Massey, C.I., GNS Science Ltd, PO Box 30368 Lower Hutt, *pers. comm.* 2022), used a numerical model ("RAMMS") to simulate dambreak flood flows of a range of return intervals from the Callery and Tatare Rivers, together with the areas these events would impact (Figs 8 - 10). Note that these dambreak discharges assume only minor background flows; in the unlikely event that they coincide with substantial rainstorm-flood flows the total discharges could be correspondingly higher.

Table 3 Callery-Waiho landslide dambreak flood magnitude-frequency (Dunant et al., 2021).

Peak discharge m^3s^{-1}	1000	2000	3000	4000	5000	6000	7000	8000	9000
Return period years	5	15	25	45	75	100	175	300	2000

Table 4 Tatare landslide dambreak flood magnitude-frequency (R, 2021)

Peak discharge m^3s^{-1}	1000	2000	3000	4000	5000	6000	7000	8000	9000
Return period years	40	75	100	330	500	700	950	2100	4000

These simulations used the unmodified 2016 digital elevation model for the area, and thus the 2016 stopbank levels. Therefore the areas shown flooded by the dambreak flows (Figs 8 & 9) are not constrained by the planned stopbanks (Fig. 3). This is a realistically conservative scenario because a landslide dambreak flood differs considerably from a normal rainstorm flood, in particular because it assumes some of the characteristics of a debris flow surge with a high, tree-and-boulder laden main surge that may overtop stopbanks designed to contain normal floods. The simulations accounted for the higher mean sediment concentration of a dambreak flood, but not for its rapidly-varied flow. The highest return period events would in any case overtop the planned stopbanks.

Note that Davies and Korup (2007) found evidence of intense sedimentation close to the liquefaction site (white polygon, Fig. 8) which they interpreted as caused by a prehistoric dambreak flood from the Tatare.

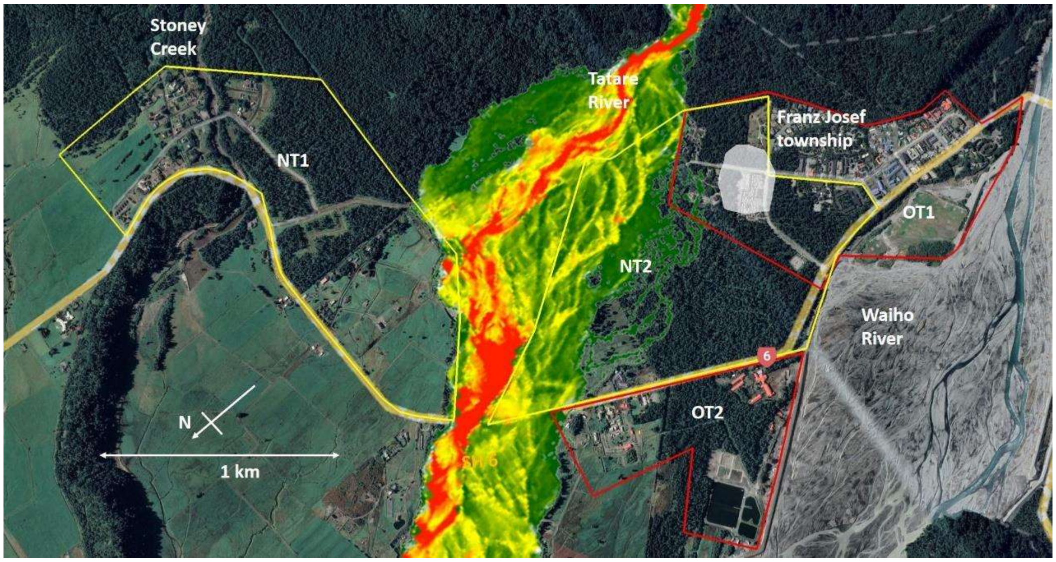


Fig. 8 Extent of ca 500-year return interval landslide dambreak flooding from the Tatare River (5000 m^3s^{-1}). Modified Google Earth image. Colour code: Green = shallow, yellow = moderate, red = deep.

6.6 Debris flows

Debris flows are sudden, severe sediment-flood events that occur occasionally in small, steep catchments, and are capable of causing devastating damage to assets as demonstrated by the 2005 event at Matatā, Bay of Plenty; they also pose a serious threat to life. The catchment of Stoney Creek has been identified as prone to debris flows (Welsh and Davies, 2011), but no data are available to quantify the debris-flow magnitude-frequency relationship at this site. We have therefore adopted published international empirical relationships based on catchment area to assess the likely magnitudes and deposit areas of debris flows from Stoney Creek (Appendix A).

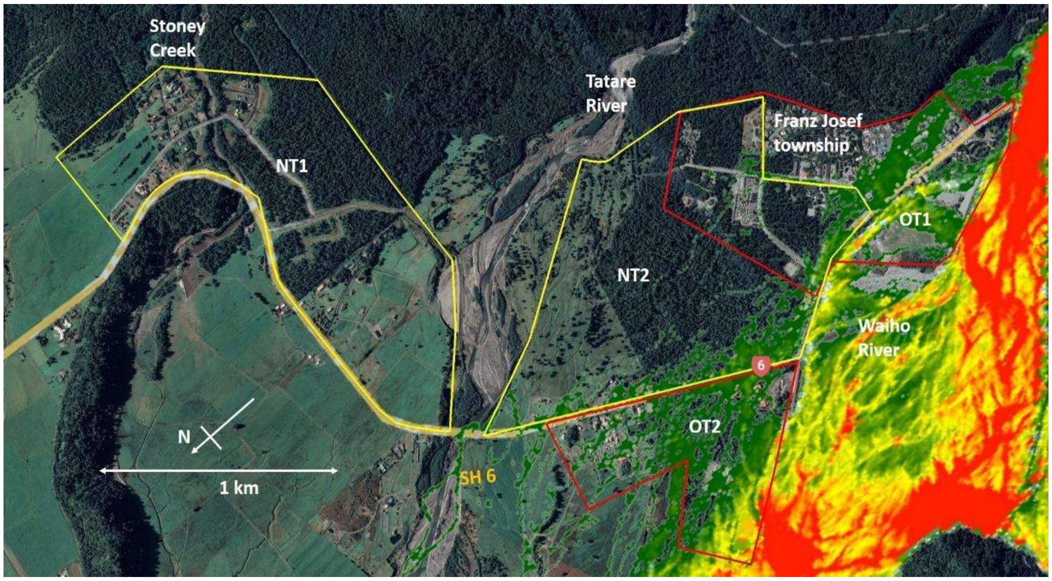


Fig. 9 Extent of ca 350-year return interval landslide dambreak flooding from the Callery River (8600 m^3s^{-1}). Modified Google Earth image. Colour code: Green = shallow, yellow = moderate, red = deep.

We also assume that such flows would result from rainfall-induced landslides in the Stoney Creek catchment, and that these would follow the magnitude-frequency relationship established for such events in the western Southern Alps by Hovius et al. (1997); see Table 5. It is acknowledged that this assumption ignores the potential for debris flows to mobilise streambed sediments in the catchment and on the fan, so estimates of volume are likely to be on the low side; however the catchment is short and very steep so this error is unlikely to be large. The areas affected by these flows are shown in Fig. 10. Note that this is the pre-earthquake debris-flow hazard, since the Hovius et al. (1997) data refer to non-seismic conditions. Following a major earthquake there is likely to be a large volume of available coseismic landslide sediment in the catchment, so the occurrence of debris flows in subsequent intense rainstorms will have a higher probability (Appendix C).

Table 5 Stoney Creek debris-flow magnitude-frequency

Debris flow volume m^3	Return period years
1000	500*
5000	100
10000	100
20000	150
50000	500
100000	1000
200000	2500

* Probability density rollover at low volume causes higher return period; see Hovius et al. (1997).

6.7. All hazards

Combining all the above hazards shows the hazardscape of the present and proposed town sites (Fig. 10). Note these are for various return periods: debris flows (blue) 500, 1000 and 2500 years; rock avalanche (brown) 100, 2500 and 100,000 years; landslide-dambreak flood

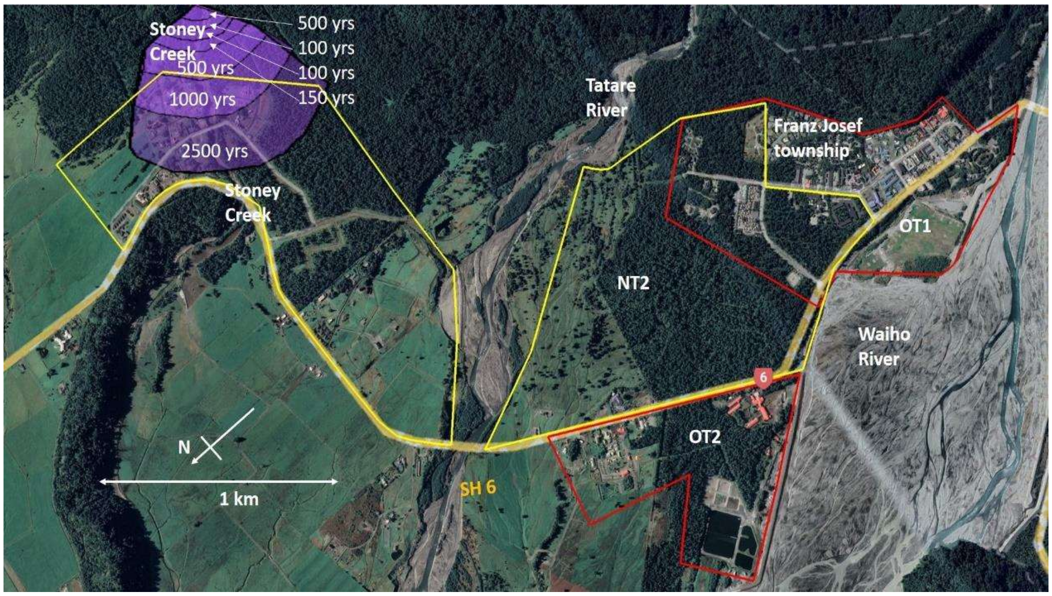


Fig. 10 Debris-flow hazards at Franz Josef. Modified Google Earth image.

(green/yellow/red) 300 years (Callery) and 500 years (Tatare); ground rupture (brown) and liquefaction (white), 50-100 years; and river flooding (light grey), 100 years. While the mix of return periods precludes detailed conclusions at this stage, some trends are clear:

- Much of the current township (OT1 and OT2) and most of the present NT2 site are hazard-affected, as is the Stoney Creek area in NT1
- About 80% of NT1 is free of *known* hazards except for ground shaking

A risk analysis allows these preliminary indications to be refined.

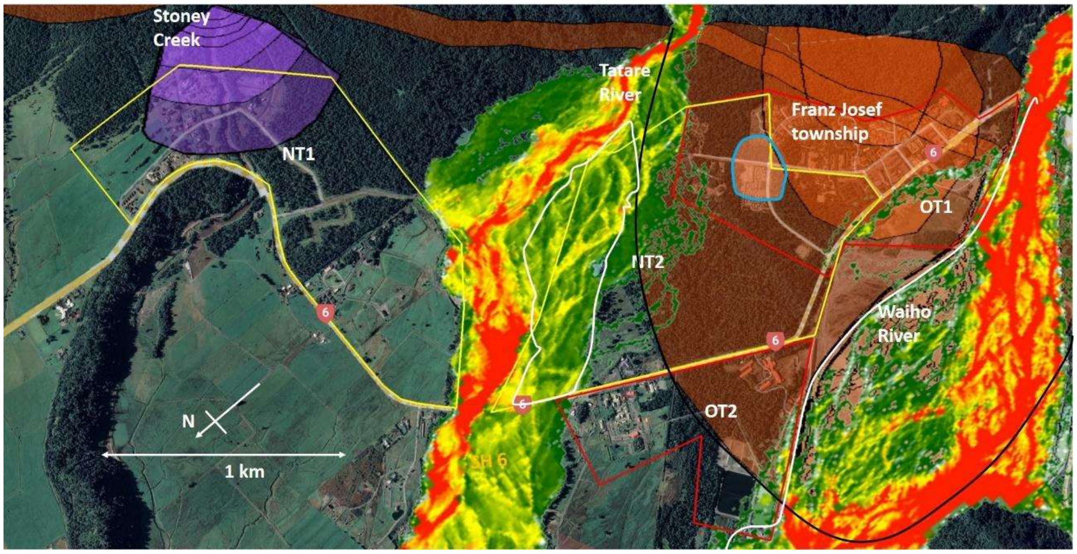


Fig. 11 All hazards affecting present and proposed town sites. Modified Google Earth image. White lines outline Waiho and Callery rainstorm flooding; blue line delineates liquefaction hazard; brown shade indicates rock-avalanche hazard; purple shade indicates debris-flow hazard. Dambreak flooding colour code: Green = shallow, yellow = moderate, red = deep.

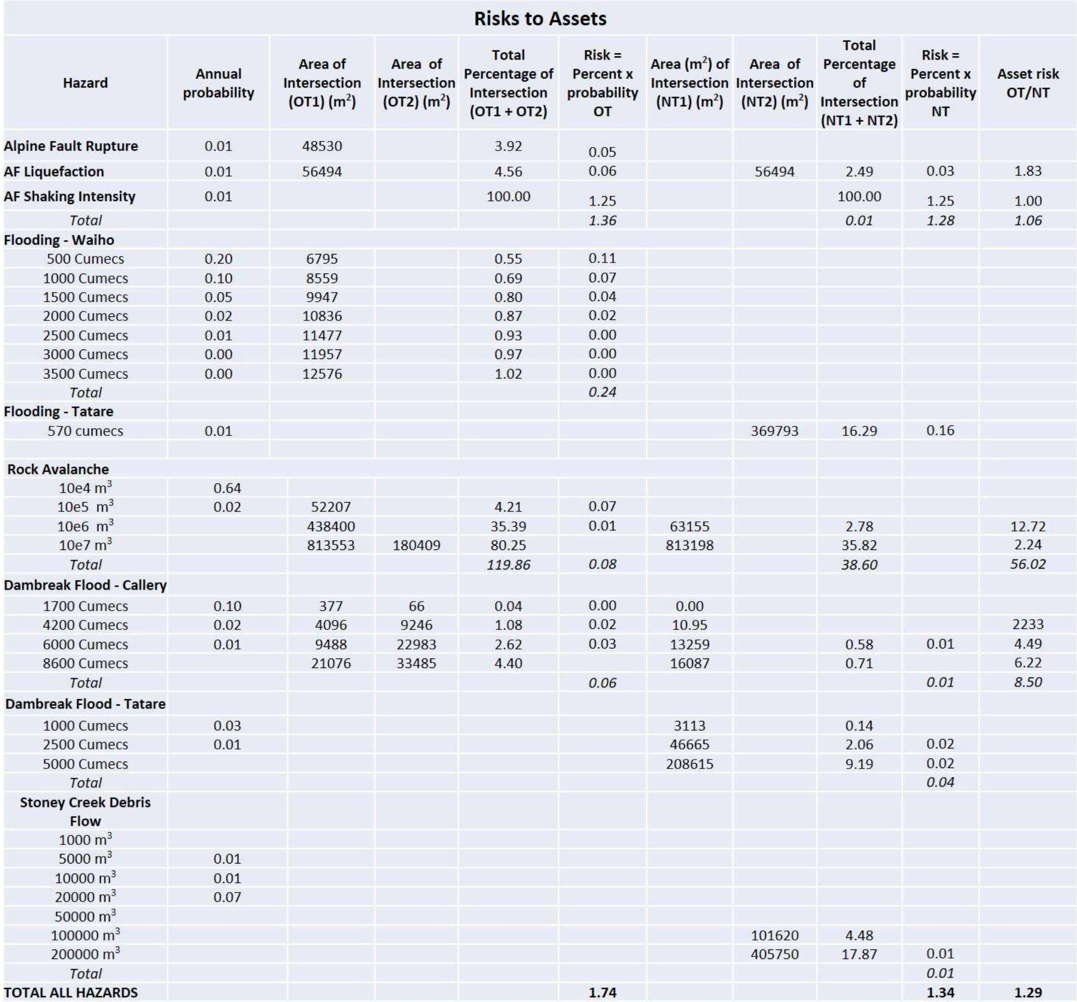
7. Risks

In order to quantify the risks to Franz Josef resulting from the hazards delineated above, it is necessary to quantify the assets and lives that could be damaged by hazard events. Since there is no information available about the spatial distribution of assets and population across the proposed relocation sites NT1 and NT2, we assume that both are uniformly distributed across the full area of NT1 and NT2. In order to compare the risks between the NT and OT sites, we therefore make the same assumption about the distribution of assets and population across existing town sites OT1 and OT2, rather than using the actual distributions.

7.1 Risks to assets

On the above basis, the risks to assets can be compared simply by comparing the proportion of each site exposed to specified hazards; thus, assuming that any asset is equally affected by any hazard to which it is exposed, asset risks are proportional to asset exposures. Table 7.1 shows that the risks to assets in the present town sites OT1 and OT2 is about 30% greater than that in the proposed town sites NT1 and NT2. Considering the possible errors in the data and analysis, however, this not necessarily a significant difference.

Table 7.1 Risks to assets in present (OT1 & OT2) and proposed (NT1 & NT2) town sites (R, 2022)



Risks to Assets

Hazard	Annual probability	Area of Intersection (OT1) (m^2)	Area of Intersection (OT2) (m^2)	Total Percentage of Intersection (OT1 + OT2)	Risk = Percent x probability OT	Area (m^2) of Intersection (NT1) (m^2)	Area of Intersection (NT2) (m^2)	Total Percentage of Intersection (NT1 + NT2)	Risk = Percent x probability NT	Asset risk OT/NT
Alpine Fault Rupture	0.01	48530		3.92	0.05					
AF Liquefaction	0.01	56494		4.56	0.06		56494	2.49	0.03	1.83
AF Shaking Intensity	0.01			100.00	1.25			100.00	1.25	1.00
Total					*1.36*			*0.01*	*1.28*	*1.06*
Flooding - Waiho										
500 Cumecs	0.20	6795		0.55	0.11					
1000 Cumecs	0.10	8559		0.69	0.07					
1500 Cumecs	0.05	9947		0.80	0.04					
2000 Cumecs	0.02	10836		0.87	0.02					
2500 Cumecs	0.01	11477		0.93	0.00					
3000 Cumecs	0.00	11957		0.97	0.00					
3500 Cumecs	0.00	12576		1.02	0.00					
Total					*0.24*					
Flooding - Tatare										
570 cumecs	0.01						369793	16.29	0.16	
Rock Avalanche										
10e4 m^3	0.64									
10e5 m^3	0.02	52207		4.21	0.07					
10e6 m^3		438400		35.39	0.01	63155		2.78		12.72
10e7 m^3		813553	180409	80.25		813198		35.82		2.24
Total				*119.86*	*0.08*			*38.60*		*56.02*
Dambreak Flood - Callery										
1700 Cumecs	0.10	377	66	0.04	0.00	0.00				
4200 Cumecs	0.02	4096	9246	1.08	0.02	10.95				2233
6000 Cumecs	0.01	9488	22983	2.62	0.03	13259		0.58	0.01	4.49
8600 Cumecs		21076	33485	4.40		16087		0.71		6.22
Total					*0.06*				*0.01*	*8.50*
Dambreak Flood - Tatare										
1000 Cumecs	0.03					3113		0.14		
2500 Cumecs	0.01					46665		2.06	0.02	
5000 Cumecs						208615		9.19	0.02	
Total									*0.04*	
Stoney Creek Debris Flow										
1000 m^3										
5000 m^3	0.01									
10000 m^3	0.01									
20000 m^3	0.07									
50000 m^3										
100000 m^3							101620	4.48		
200000 m^3							405750	17.87	0.01	
Total									*0.01*	
TOTAL ALL HAZARDS					**1.74**				**1.34**	**1.29**

7.2 Risks to life - Individual

The individual risk to life is the annual probability of being killed by a specific hazard event, related to the individual with the highest risk. As with assets, we assume that the population is distributed equally across the areas of both the existing and the proposed town sites, so that the probability of an individual being in any specific location is equal everywhere. Then the risk of an individual being affected by a hazard event in any of the four sites is equal to the percentage of that site which is overlapped by the event multiplied by the probability of occurrence of that hazard.

However, not all hazards present an equal threat to life, and the probability of death requires the probability of impact to be multiplied by the probability that the impact will be fatal, which varies between hazards. Data on this factor are sparse, however; the factors used herein (Table 7.2) are explained in Appendix B, and Table 7.3 shows the resulting individual risks-to-life for the township sites. It is notable that individual risks-to-life are about 15 times higher in the present town sites than in the proposed town sites; even considering the potential errors in the analysis, this is a significant difference.

Table 7.2 Mortality rates (% of population exposed) for various hazards

Earthquake	0.3%
Flood	0.59%
Rock avalanche	100%
Dambreak flood	2%
Debris flow	27%

While these mortality rates are obviously very approximate, they are adequate for use to compare risks between the present and proposed sites.

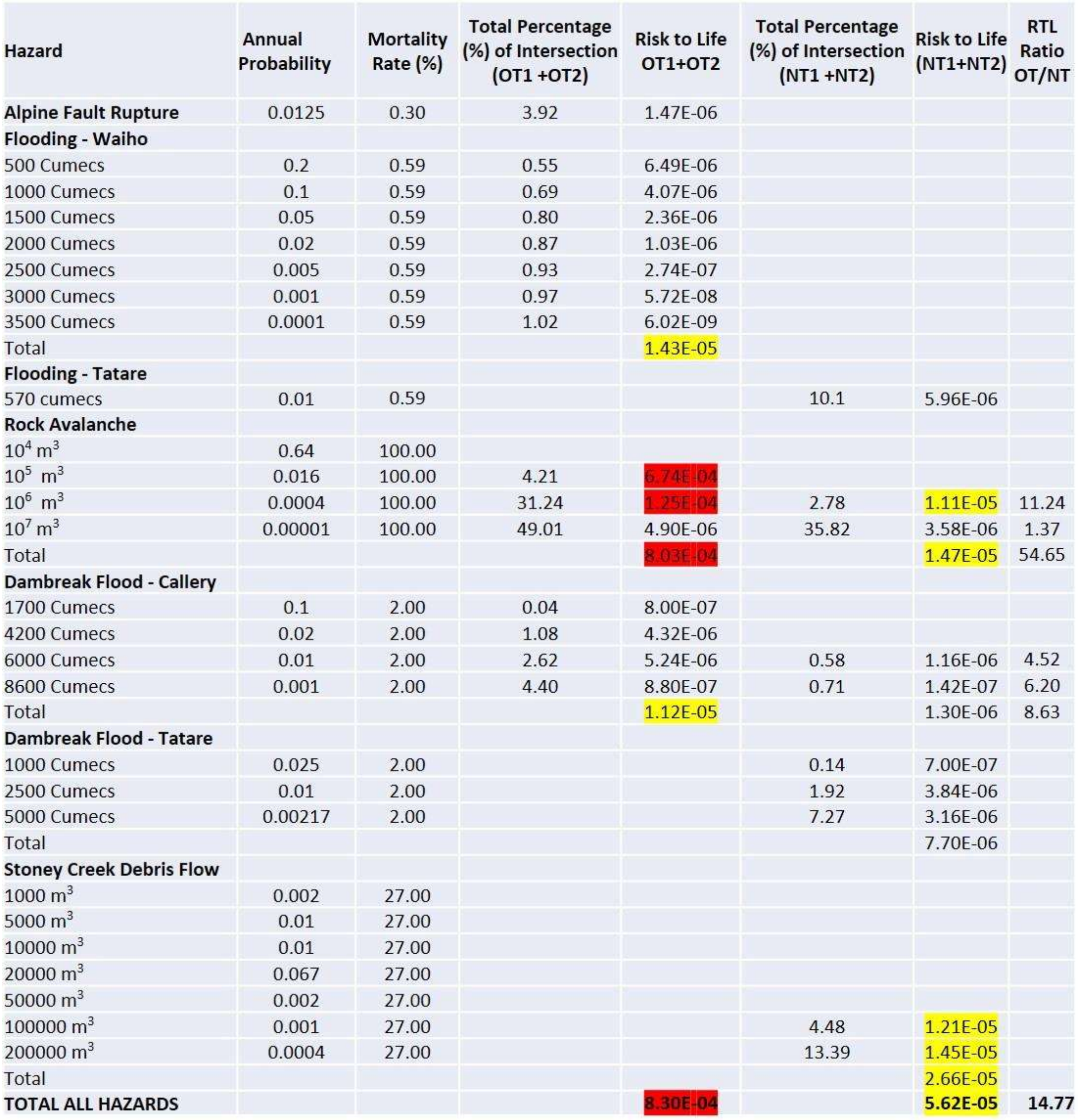
The upper limit of acceptable individual risk-to-life in New Zealand is about 10^{-4} per year (e.g. Taig et al., 2012), so in Table 7.3 risks greater than 10^{-4} are highlighted in red while risks between 10^{-5} and 10^{-4} are highlighted in yellow.

7.2 Risks to life – Societal

A further factor determining the societal acceptability of risk-to-life is the number of people at risk of death. Not surprisingly, society has less tolerance for events that cause many deaths than for those that cause few. Fig. 13 shows generally accepted tolerance limits for landslide deaths in Canada (Porter and Morgenstern, 2013), and similar diagrams are commonly used globally as indicators of orders of acceptable risk limits for a variety of hazards (Mona, 2014).

In order to estimate the societal risk-to-life at Franz Josef we need to know the population at risk. The permanent population is about 400; in addition, thousands of tourists visit the town in the season between about October and April, and these are serviced by a considerable number of temporary or itinerant workers. Hence to approximate the societal risk-to-life we assume a year-round population of 1000 as being of the correct order of magnitude, and again this is assumed uniformly distributed across both town sites. In this case Fig. 13 gives a bound on unacceptable risk as 10^{-6}; and Table 7.4 indicates that much of both the present and the proposed sites pose unacceptable societal risks-to-life. While the very approximate nature of the hazard mortality rates (Table 7.2) makes this deduction questionable, it suggests that even the relocated town site may not be acceptably safe, even though it is about 15 times less risky than the present site.

Table 7.3 Individual risks-to-life for existing (OT1 and OT2) and proposed (NT1 and NT2) town sites. Red highlight indicates risk > 10^{-4} per year, yellow indicates risk > 10^{-5} per year. Modified from R, 2022.



Hazard	**Annual Probability**	**Mortality Rate (%)**	**Total Percentage (%) of Intersection (OT1 +OT2)**	**Risk to Life OT1+OT2**	**Total Percentage (%) of Intersection (NT1 +NT2)**	**Risk to Life (NT1+NT2)**	**RTL Ratio OT/NT**
Alpine Fault Rupture	0.0125	0.30	3.92	1.47E-06			
Flooding - Waiho							
500 Cumecs	0.2	0.59	0.55	6.49E-06			
1000 Cumecs	0.1	0.59	0.69	4.07E-06			
1500 Cumecs	0.05	0.59	0.80	2.36E-06			
2000 Cumecs	0.02	0.59	0.87	1.03E-06			
2500 Cumecs	0.005	0.59	0.93	2.74E-07			
3000 Cumecs	0.001	0.59	0.97	5.72E-08			
3500 Cumecs	0.0001	0.59	1.02	6.02E-09			
Total				1.43E-05			
Flooding - Tatare							
570 cumecs	0.01	0.59			10.1	5.96E-06	
Rock Avalanche							
10^4 m^3	0.64	100.00					
10^5 m^3	0.016	100.00	4.21	6.74E-04			
10^6 m^3	0.0004	100.00	31.24	1.25E-04	2.78	1.11E-05	11.24
10^7 m^3	0.00001	100.00	49.01	4.90E-06	35.82	3.58E-06	1.37
Total				8.03E-04		1.47E-05	54.65
Dambreak Flood - Callery							
1700 Cumecs	0.1	2.00	0.04	8.00E-07			
4200 Cumecs	0.02	2.00	1.08	4.32E-06			
6000 Cumecs	0.01	2.00	2.62	5.24E-06	0.58	1.16E-06	4.52
8600 Cumecs	0.001	2.00	4.40	8.80E-07	0.71	1.42E-07	6.20
Total				1.12E-05		1.30E-06	8.63
Dambreak Flood - Tatare							
1000 Cumecs	0.025	2.00			0.14	7.00E-07	
2500 Cumecs	0.01	2.00			1.92	3.84E-06	
5000 Cumecs	0.00217	2.00			7.27	3.16E-06	
Total						7.70E-06	
Stoney Creek Debris Flow							
1000 m^3	0.002	27.00					
5000 m^3	0.01	27.00					
10000 m^3	0.01	27.00					
20000 m^3	0.067	27.00					
50000 m^3	0.002	27.00					
100000 m^3	0.001	27.00			4.48	1.21E-05	
200000 m^3	0.0004	27.00			13.39	1.45E-05	
Total						2.66E-05	
TOTAL ALL HAZARDS				**8.30E-04**		**5.62E-05**	**14.77**

Note: the risk columns in Tables 7.3 and 7.4 use scientific notation in which for example 8.30E-4 means 8.30 x 10^{-4}, or 0.000830.

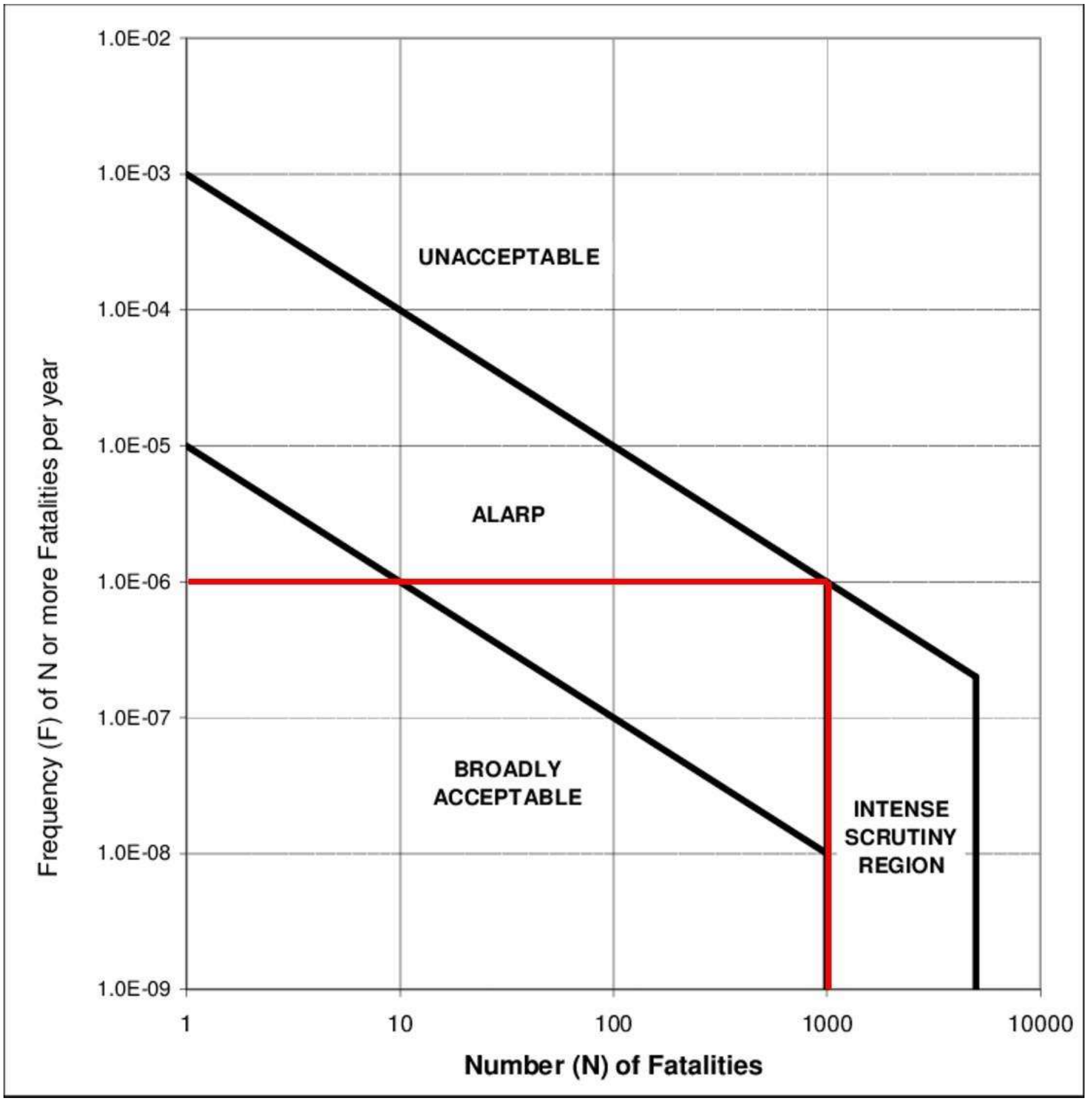
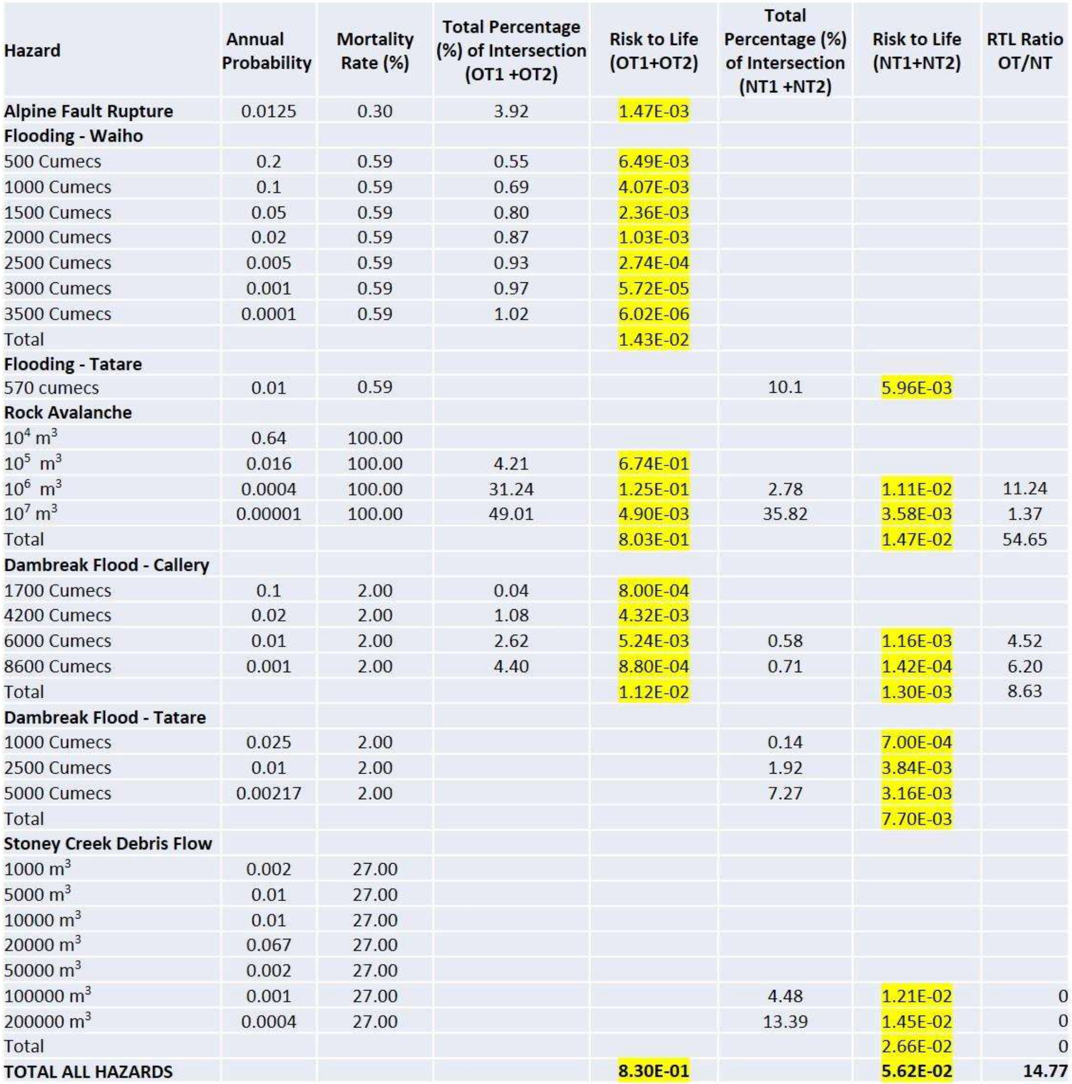


Fig. 13 Ranges of acceptable risks for multiple fatalities (Porter and Morgenstern, 2013). Red lines indicate that unacceptable risk for 1000 deaths is 10^{-6} per year. Note that this figure accepts a higher limit to individual risk (10^{-3} per year) than that commonly used in New Zealand (10^{-4} per year; Taig et al, 2012)

Table 7.4 Societal risks-to-life for existing (OT1 and OT2) and proposed (NT1 and NT2) town sites. Yellow indicates risk > 10^{-6} per year. Modified from R, 2022.



Hazard	Annual Probability	Mortality Rate (%)	Total Percentage (%) of Intersection (OT1 +OT2)	Risk to Life (OT1+OT2)	Total Percentage (%) of Intersection (NT1 +NT2)	Risk to Life (NT1+NT2)	RTL Ratio OT/NT
Alpine Fault Rupture	0.0125	0.30	3.92	1.47E-03			
Flooding - Waiho							
500 Cumecs	0.2	0.59	0.55	6.49E-03			
1000 Cumecs	0.1	0.59	0.69	4.07E-03			
1500 Cumecs	0.05	0.59	0.80	2.36E-03			
2000 Cumecs	0.02	0.59	0.87	1.03E-03			
2500 Cumecs	0.005	0.59	0.93	2.74E-04			
3000 Cumecs	0.001	0.59	0.97	5.72E-05			
3500 Cumecs	0.0001	0.59	1.02	6.02E-06			
Total				1.43E-02			
Flooding - Tatare							
570 cumecs	0.01	0.59			10.1	5.96E-03	
Rock Avalanche							
10^4 m^3	0.64	100.00					
10^5 m^3	0.016	100.00	4.21	6.74E-01			
10^6 m^3	0.0004	100.00	31.24	1.25E-01	2.78	1.11E-02	11.24
10^7 m^3	0.00001	100.00	49.01	4.90E-03	35.82	3.58E-03	1.37
Total				8.03E-01		1.47E-02	54.65
Dambreak Flood - Callery							
1700 Cumecs	0.1	2.00	0.04	8.00E-04			
4200 Cumecs	0.02	2.00	1.08	4.32E-03			
6000 Cumecs	0.01	2.00	2.62	5.24E-03	0.58	1.16E-03	4.52
8600 Cumecs	0.001	2.00	4.40	8.80E-04	0.71	1.42E-04	6.20
Total				1.12E-02		1.30E-03	8.63
Dambreak Flood - Tatare							
1000 Cumecs	0.025	2.00			0.14	7.00E-04	
2500 Cumecs	0.01	2.00			1.92	3.84E-03	
5000 Cumecs	0.00217	2.00			7.27	3.16E-03	
Total						7.70E-03	
Stoney Creek Debris Flow							
1000 m^3	0.002	27.00					
5000 m^3	0.01	27.00					
10000 m^3	0.01	27.00					
20000 m^3	0.067	27.00					
50000 m^3	0.002	27.00					
100000 m^3	0.001	27.00			4.48	1.21E-02	0
200000 m^3	0.0004	27.00			13.39	1.45E-02	0
Total						2.66E-02	0
TOTAL ALL HAZARDS				**8.30E-01**		**5.62E-02**	**14.77**

As expected, societal risk is directly proportional to individual risk using the assumptions herein, so the ratio of societal risk between the present and proposed town sites is again about 15; or, acknowledging the approximations involved, particularly in hazard mortality, about 10-20.

The contribution of the rock avalanche component to the total risk-to-life profiles is very high. If rock avalanche risk is assumed to be zero, the 10-20-fold reduction (14.77 in Tables 7.3 and 7.4) in risk-to-life achieved by relocating to the proposed sites NT1 and NT2 effectively disappears (becoming 0.65). Ignoring rock avalanche risk however has no significant effect on asset risk. This demonstrates the need for a geotechnical assessment of the reality of the rock avalanche hazard to assess the reality of the risk-to-life basis for relocation from the OT sites to the NT sites.

8. Risk reduction

8.1 Land use zoning

It is clear that the risks to assets and lives are lower – in the case of risks to life, much lower - if the township is relocated to the proposed new sites NT1 and NT2, if the rock avalanche hazard is real. This assumes that assets and people are distributed uniformly across both present and proposed sites. While this assumption is necessary until information is available about asset and population distribution across relocated sites NT1 and NT2, it is clear from the hazard distributions outlined in section 5 above that risks to both lives and assets can be further reduced if assets and population across the relocated sites are distributed so as to avoid the high-hazard areas identified herein. In particular, the Stoney Creek fan area is exposed to debris-flow hazard in NT1, while eastern parts of NT2 are exposed to rock avalanche and to flood and dambreak flood hazard from the Tatare River (Fig. 12); western parts of NT2 are exposed to rock avalanche hazard. By contrast, all of NT1 except for the Stoney Creek fan appears to be hazard-free except for earthquake shaking.

8.2 Event warning and evacuation

The only hazard for which prior warning is readily feasible is rainstorm-generated flooding; weather forecasting and/or rain radar could conceivably provide perhaps hours of warning that might allow evacuation to save lives. However this hazard is the least intense of those affecting Franz Josef, and warning and evacuation have not been utilised hitherto for this common hazard on the West Coast.

When a landslide dam has formed, and does not fail immediately, the option exists to immediately evacuate areas that could be affected by a dambreak flood. However many landslide dams fail immediately on first overtopping, which can occur before the threatened populace is aware of the dam emplacement if this occurs during a severe storm (Davies, 2002), so this strategy cannot be completely reliable. Nevertheless it would be useful to install flow recorders at the Tatare and Callery[1] valley mouths, so that the unusually low flows that accompany filling of a landslide dam could be detected even during severe floods.

Warning and evacuation are not feasible for earthquake, debris flow or rock avalanche hazard events.

8.3. Event modification

Risk can be reduced if the impact of hazard events on assets and people can be reduced by altering the behaviour of the hazard processes.

Flooding is commonly reduced by stopbanking, and this has been done extensively on the Waiho River at Franz Josef (Fig. 2). There is the possibility of using stopbanks to reduce the flood hazard from the Tatare River (Fig. 5) to the eastern part of NT2, but this may not be desirable because (i) there is evidence that stopbanking is not a permanent solution to flood hazards because it causes or exacerbates aggradation (Davies and McSaveney, 2006), as on the Waiho (Beagley et al., 2020); and (ii) it tends to increase flood hazard on the other side of the river.

Earthquake: there is no known way to modify the occurrence or severity of an earthquake. The impact of ground shaking on buildings can be reduced by strengthening the structure, but not to

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[1] A depth recorder was present at the mouth of the Callery Gorge for this express purpose for some years prior to its destruction in 2011.

the extent that damage can be prevented in MM10+ shaking. While strengthening may reduce the impact of ground rupture on a building there is no way to guarantee this.

Rock avalanche: A rock avalanche comprises a mass of rock debris from boulder- to dust-size, metres or tens of metres deep, moving across the land surface at some tens of metres per second. It is inconceivable that any structure could be designed to realistically resist or modify such an event, nor is it feasible to engineer the slope to reduce the probability that it will fail during an earthquake.

Landslide-dambreak flood: A landslide-dambreak flood usually has a much shorter and much higher peak than a rainstorm flood, and is also likely to be transporting much larger quantities of rock and tree debris. It is therefore much less feasible to attempt to modify a dambreak flood than a rainstorm flood; while stopbanks may retain part of the flow, overtopping and failure of stopbanks is much more likely during a dambreak flood, and design of stopbanks to contain a dambreak flood would be extremely difficult and unreliable.

Debris flow: While structural countermeasures for debris flows are common in Europe and Japan, they have only rarely been used in New Zealand. The data developed herein for the Stoney Creek risk analysis could be used to derive dimensions for debris-flow structures (detention basins, stopbanks or check-dams) but the reliability of the resultant design would be open to question, mainly because debris-flow behaviour is poorly known and models have large imprecisions (e.g. Davies, 1997; Farrell and Davies, 2019). Avoidance is by far the best way to reduce debris-flow risk.

9 Comments

9.1. Precision and realism

This report provides a comparative analysis of the relative hazards and risks affecting the existing and proposed town sites at Franz Josef. In quantifying the hazards and risks a difficult balance has had to be struck between precision and realism, acknowledging that much of the data on which the analysis is based is of low reliability because of poor understanding of the hazard phenomena involved. Hence the hazard zones delineated, and the frequencies they are assigned, are both acknowledged approximations.

While it would be possible, with considerably more effort, to develop more precise values for hazard magnitude-frequency relationships and for corresponding hazard zones, it is doubtful whether the effort would be worthwhile in terms of the usefulness of these outputs for decision-making. In my opinion it is not realistic to expect better than order-of-magnitude reliability for hazard frequency (recalling in any case that frequency cannot be measured accurately without data encompassing several tens of events; Davies and Davies, 2018). The same restriction therefore applies to quantification of risk, and this is made clear in the highlighting of the risk tables herein.

The work above, and the conclusions below, are aligned with the need for risk quantification to be explicit in land-use decision-making as a result of New Zealand becoming a signatory to the 2015 Sendai Framework for Disaster Risk Reduction. To this end the present work attempts to balance precision with realism in risk quantification – noting again, however, that the comparative nature of this work greatly enhances the robustness of the outcomes.

9.2 Need for further research

The most serious hazard to the present town site, and to parts of the proposed relocated town site, is that of rock avalanche. However, Davies and Loew (2019) point out that, depending on the rock structure in the hillslope source of the event, it is possible that a coseismic failure of this particular slope might not result in a long-runout rock avalanche. If this were the case, and a rock avalanche were not a realistic prospect, the total risk-to-life across both existing and proposed relocated sites would be of the same order of magnitude. In order to settle what is therefore a crucial matter, detailed geotechnical investigation of the slope is required as outlined by Davies and Loew (2019). Although the existence of rock avalanche deposits in similar locations elsewhere on the West Coast (Round Top, Dufresne et al., 2010; Wanganui, Chevalier et al., 2009; Cascade, Barth 2014) suggests that the hazard at Franz Josef is indeed real, the possibility that it is not, because of local geology, warrants investigation because of its dominant influence on risk-to-life.

As has been made clear, the ongoing aggradation of the Waiho River limits the conclusions herein to a time-frame from the present until about 2040, at which time the flood protection from proposed upgrading of the Waiho stopbanks is likely to be decreasing rapidly. In addition, the occurrence of a major earthquake in the region (whether on the Alpine fault or on a different fault within the mountains) is likely to significantly alter the hazard frequencies used herein; the probability of such an event before 2040 is about 20-40%. In order to plan the medium- to long-term future of Franz Josef, further information is needed on how stopbank failure and earthquake occurrence will affect subsequent hazards and risks at Franz Josef. In addition, because of the longer future time-scale, the likely impacts of climate change will be more significant and require deeper investigation.

10 Conclusions

Assuming that population and assets are uniformly and equally distributed among the present and proposed town sites at Franz Josef, then in the period up to about 2040, or until the occurrence of the next major West Coast earthquake, whichever is the sooner:

10.1 The total exposure of assets to all hazards is of similar order of magnitude in both existing and proposed relocated town sites.

10.2 The total risk-to-life, both individual and societal, from all hazards in the proposed relocated town site is about one order of magnitude (10-20 times) lower than that in the existing town site. This difference is caused mainly by the greater rock avalanche hazard to the latter.

10.3 While the individual risk-to-life appears to be close to acceptable across much of the proposed relocated sites, it is at unacceptable levels in much of the present town site due to rock avalanche hazard. However the societal risk-to-life appears to be unacceptable across parts of both town sites.

10.4 Judicious siting of assets and population across the proposed relocated town site could reduce the risks to both assets and life below the levels shown herein; for example, avoiding development in the debris-flow-susceptible area of NT1.

10.5 The most serious hazard to both present and proposed relocated town sites is from a major rock avalanche overrunning much of the OT sites and less of the NT sites. In effect, the rock avalanche hazard is the main risk-to-life justification for the proposed relocation. Because there is some doubt as to the reality of this threat, detailed geotechnical investigations are needed to confirm or deny its existence.

10.6 In order for the risks in the proposed relocated townsite to be known in the medium-to-long term (after a major earthquake or 2040, whichever comes sooner), more information is needed on the likely alteration of hazard distributions and frequencies that will result from aggradation-triggered Waiho River stopbank failures, and from an Alpine fault earthquake. Better information on climate-change impacts will also be needed for this longer time-frame.

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Matthew Gardner of Land, River, Sea Consulting Ltd kindly provided flooding data for the Waiho River. Chris Massey of GNS Science Ltd carried out simulations and made available data for landslide dambreak flooding from the Waiho and Tatare rivers. Tom Robinson of University of Canterbury provided constructive comments throughout and peer-reviewed the draft report; this final version incorporates his review suggestions.

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APPENDIX A - HAZARD ANALYSES

A1 Flood hazard: Waiho River

Gardner (2021) carried out numerical modelling using MIKE 21 software and land surface elevation data from 2016 and 2019 Lidar together with 2021 satellite data. The modelling was used to develop designs for stopbank upgrading. Maps of water depths derived from this modelling were used to delineate flood extents for flows from 500 to 3500 m^3s^{-1} (Fig. A1)

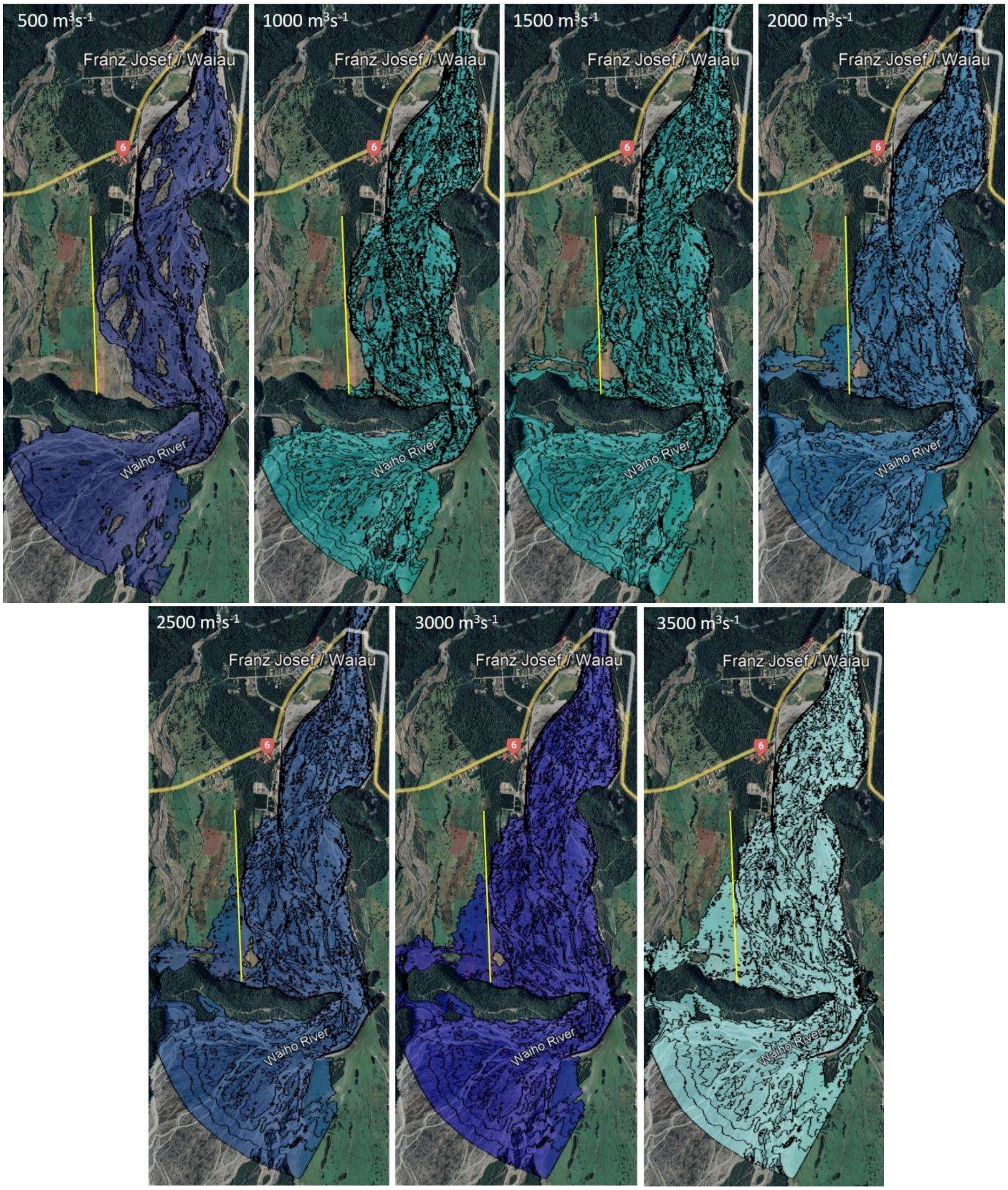


Fig. A1.1 Extents of Waiho River floods modelled by Gardner (2021). Yellow line is new stopbank effective up to 2500 m^3s^{-1}.

A2 Debris-flow hazard

The only known location in either town site potentially affected by debris flows is the settlement on Stoney Creek fan in NT1; this was first identified by Welsh and Davies (2011). The catchment area A_c of Stoney Creek is 2.1 km^2 and the catchment relief Δh above the fanhead is 1200 m, so

$$\text{Melton ratio } R = \Delta h/A_c^{0.5} = 1200/(2.1*10^6)^{0.5} = 0.82$$

It is well-known that catchments with $R \geq 0.5$ are susceptible to debris-flow occurrence so it is reasonable to assume that this is the case with Stoney Creek. No records exist of debris flows in Stoney Creek, but Welsh and Davies (2011) reported that large boulders were unearthed from below the fan surface during excavation of building platforms, confirming the occurrence of past debris-flow events. The Alpine fault also runs through the catchment, so the presence of fault-shattered rock will contribute to the high fine-sediment loads that cause debris flows.

To establish a magnitude-frequency relationship for debris flows in Stoney Creek we first approximate debris-flow volume. ENGEO (2021) developed Fig. A2.1 from data in Bergmeister et al. (2009), Rickenmann & Zimmermann (1993) and d'Agostino and Marchi (2001); this suggests a debris-flow volume between 10 000 and 50 000 m^3 in a 2.1 km^2 catchment

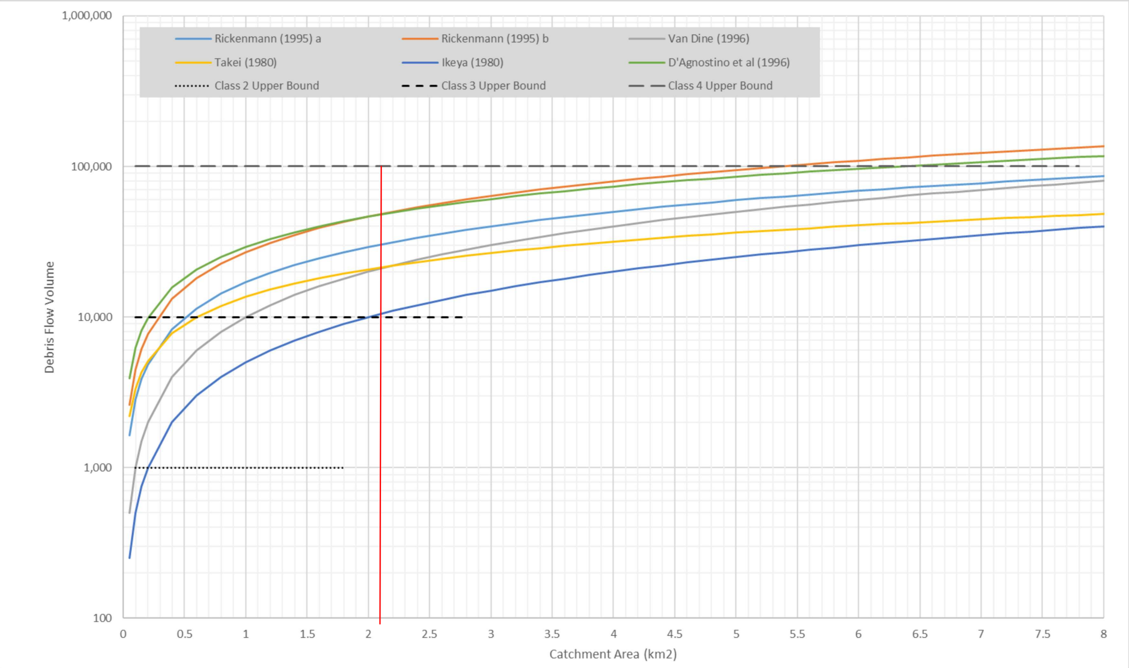


Fig. A2.1 Relationships between catchment area (km^2) and debris-flow volume (m^3) (ENGEO, 2021)

Alternatively, De Haas and Densmore (2019) and Marchi et al. (2019) show a maximum volume of 200,000 m^3 for a 2.1 km^2 catchment (Fig. A2.2).

Next we estimate the frequencies of debris flows of various volumes:

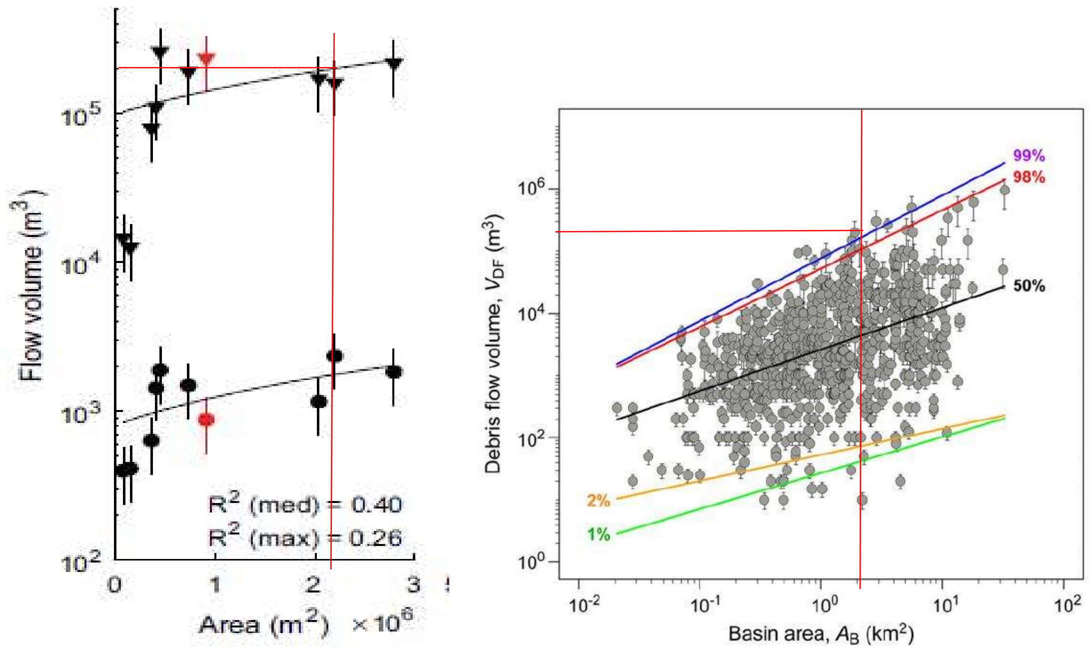


Fig. A2.2 Area-volume plots from De Haas and Densmore (2019) (left) and Marchi et al. (2019) (right)

If we use the higher of the volume estimates ($V = 2*10^5$ m^3), and assume that the debris-flow volume results from occurrence of a landslide of the same volume, then landslide surface area x mean depth = $2*10^5$. If we further assume that the landslide surface trace is an ellipse with eccentricity = 2 (i.e. length l = 2 x width w), then $lw = l^2/2$ and landslide surface area = $0.5\pi l^2$. Hovius et al. (1997, eq. 3), in their study of aseismic landslide frequency in Westland, use landslide depth d = 0.5l for aseismic landslides in Westland, which for a volume of $2*10^5$ m^2 gives a surface area of 40 000 m^2.

For the median debris-flow, Marchi et al. (2019) (Fig. A2.2) give a volume of 2000 m^3 which, using the same calculation as above, gives an area of 1800 m^2. Fig. A2.3 (Hovius et al., 1997) give the

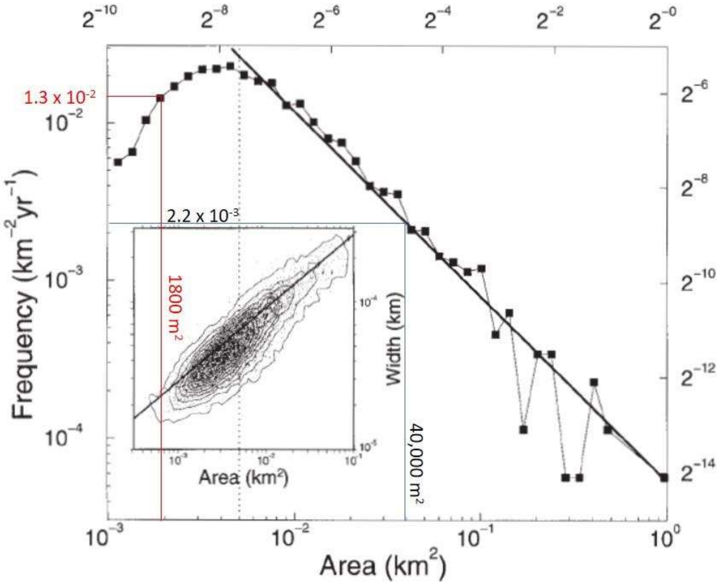


Fig. A2.3: frequency of maximum and median aseismic landslides in Westland (Hovius et al. (1997) Fig. 3); assumed to apply also to debris flows in Stoney Creek frequencies of these events as $2.2*10^{-3}$ and $1.3*10^{-2}$ respectively. Fig. A2.4 shows the frequency-magnitude relationship of Hovius et al. (1997) as the basis for debris flows at Stoney Creek.

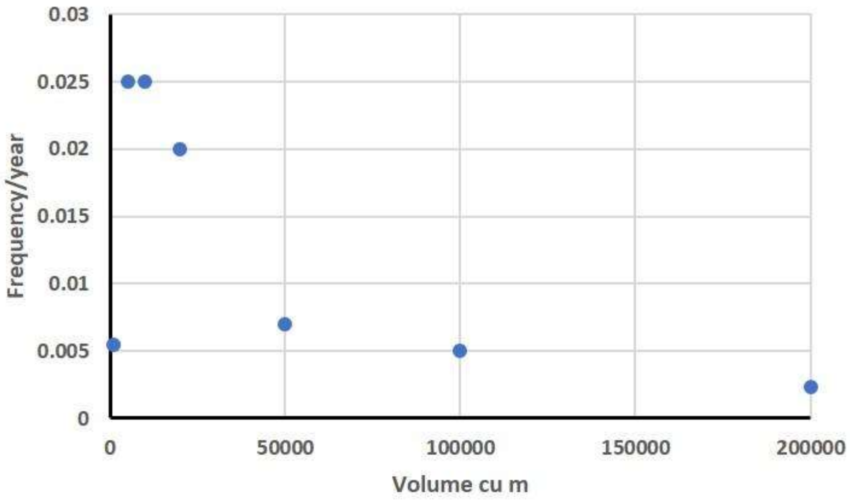


Fig. A2.4 Magnitude-frequency relationship for debris flows at Stoney Creek

The area inundated by a debris flow A_i, which is also the hazard area, is given by Jakob (2005) as $A_i = 20V^{2/3}$. No information is available to estimate the width and extent of a debris-flow deposit, so at Stoney creek the deposit areas were assumed to start at the fan head, and to widen to approximately 100 m within 150 m downstream; thereafter the deposit areas were assumed to remain constant at ~ 100 m. Given the inundation areas this allowed the downstream extent of the deposit area to be estimated.

Since any given debris flow could run in a path anywhere on the fan, the probability of any particular fan location being impacted by a debris flow in any given year is equal to the annual frequency of a flow large enough to reach the location divided by the ratio of impacted area/whole fan area affected by that flow magnitude (Table A2.1), and the resultant hazard distribution is shown in Fig. A2.5.

Table A2.1: Volume-frequency data for Stoney Creek debris flows

Debris-flow volume cu m	**Event frequency /yr (Hovius)**	**Inundation area sq m**	**Total fan area vulnerable sq m**	**Whole-width impact frequency /yr**
1000	0.0055	2000	6000	0.0018
5000	0.025	5850	15000	0.0097
10000	0.025	9286	26000	0.0089
20000	0.02	14741	43000	0.0069
50000	0.007	27154	100000	0.0019
100000	0.005	43105	200000	0.0011
200000	0.0023	68427	400000	0.0004

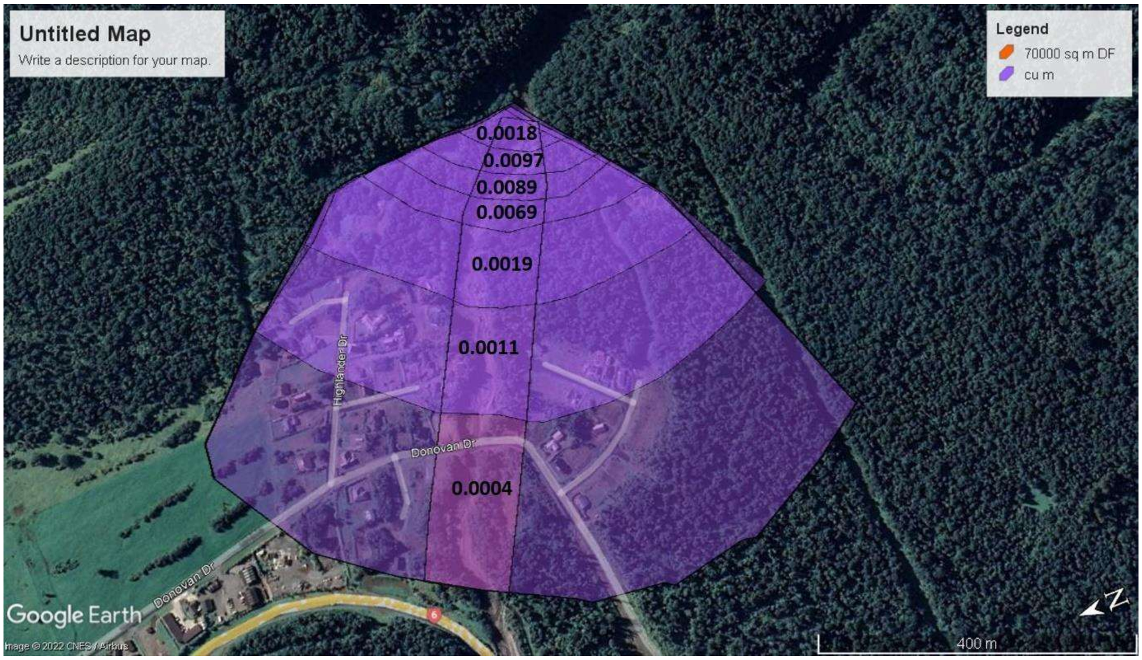


Fig. A2.5 Outlines of Stoney Creek debris-flow deposit areas with annual probabilities. Modified Google Earth image.

A3 Rock avalanche hazard (adapted from Davies & Moretti, 2021):

Immediately south-east of the present town site, a very steep hillslope rises about 750 m to a minor summit (Fig. A3.1). Davies and Loew (2019) and Davies and Moretti (2021) considered the morphology and likely origin of this slope, concluding that during successive earthquakes on the Alpine fault (which runs at its foot) it may be deforming in such a way that it could fail catastrophically in a future earthquake, causing rocky debris to run out across, and bury, the township.

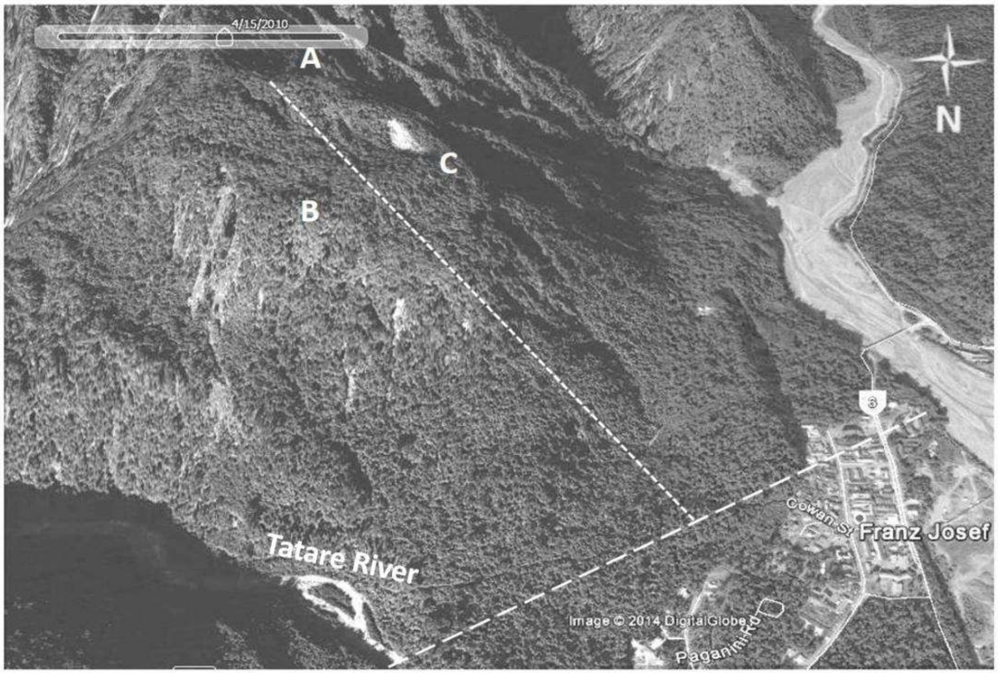


Fig. A3.1. Slope overlooking Franz Josef Glacier, Westland, New Zealand. BC indicates the outer edge of the slope-top bench; B to C is about 400 m. Dashed line indicates trace of the Alpine fault; dotted line is location of section (Fig. A3.3).

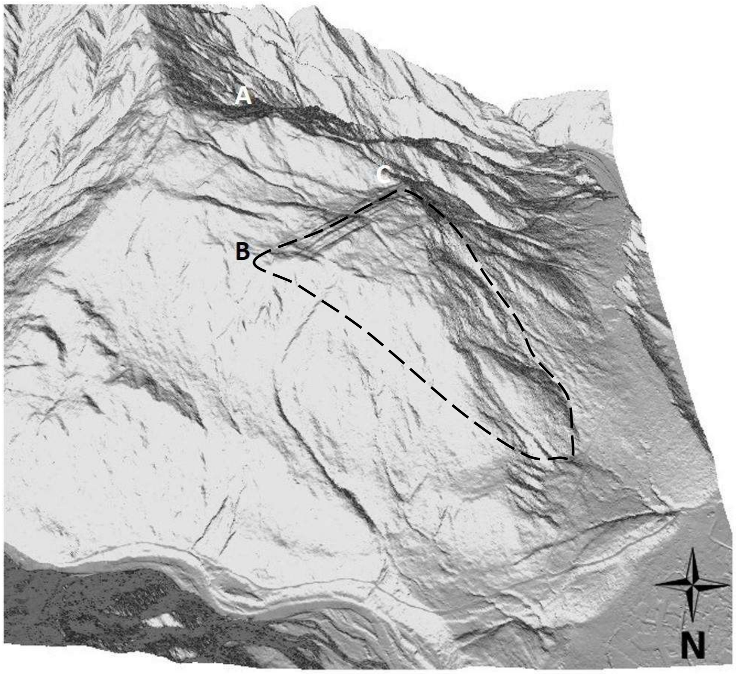


Fig. A3.2. Oblique LIDAR image of identical view to Fig. A3.1 with vegetation removed; A, B and C are corresponding locations. (Source: Danilo Moretti). Chain-dashed line indicated approximate potential failure area.

Fig. A3.2 is a Lidar image from which vegetation has been removed, showing the rock surface of the hillslope, in particular the prominent ridges that run across the slope-top bench, which Davies and Moretti (2021) show to be characteristic of slopes that are deforming prior to coseismic failure.

Volume: Davies & Moretti, 2021, state:
"If a potential failure surface is sketched on the Franz Josef slope profile (Fig. A3.3), the long-sectional area of the failure would be about 50 000 m^2. If the average width of the failure were say 200 m … then the failure volume would be of the order of 10^7 m^3.

A3.1 Rock avalanche

If a large-scale failure of the slope overlooking Franz Josef were to occur, debris comprising rocks of all sizes from powder up to boulders would slide and flow down the slope achieving velocities of many tens of metres per second and would run out across, and deposit on, the township. The forest and bush on the terrace at the base of the slope would offer little protection from a several-million-cubic-metre rock avalanche. The simple empirical relationship of Davies (1982):

$$L^* = 10\ V^{1/3}$$

where L is the end-to-end deposit length in m and V the volume in m^3, reasonably matches the deposit extents of the Cascade, Round Top and Toppenish Ridge landslides. It suggests that if the Franz Josef debris volume were 10^7 m^3 the debris deposit would be of the order of 2000 m long – thus extending over and then well beyond the township. If this were to occur buildings would be destroyed and many lives lost; the chances of survival in the runout zone, even if in a building, would be negligible. If the volume is only 10^6 m^3 the runout is ~ 1 km, and so still sufficient to cover the township.*

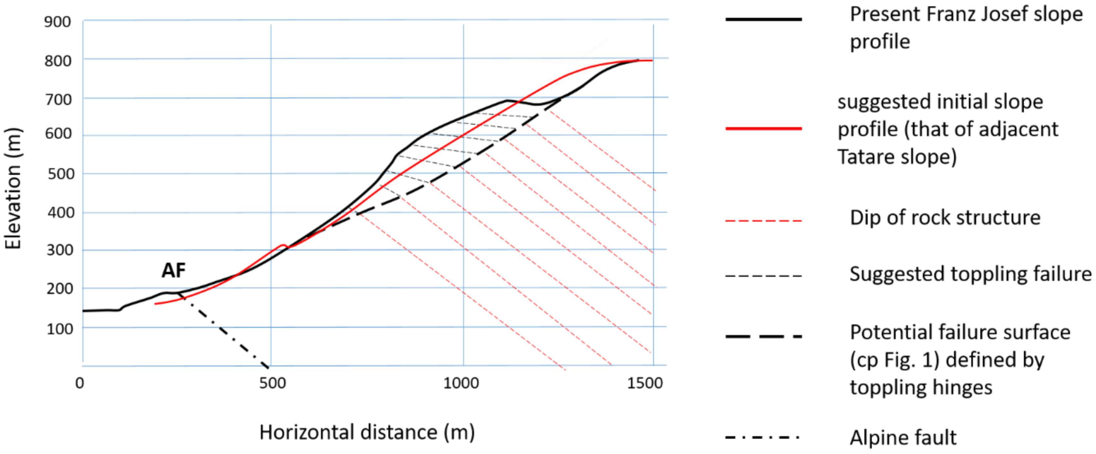


Fig. A3.3 Franz Josef slope profile (black full line) with suggested original profile (red full line, taken from adjacent Tatare slope to the north). Also sketched are Alpine fault (AF), and eastward dipping rock structure (light red dashed lines) with potential slip and toppling along failure surface defined by the toppling hinge envelope (light blue dashed lines).

The conclusion is that the Franz Josef slope has characteristics that may indicate its potential for future large-volume catastrophic failure, and that, given the presence of a town at the foot of the slope, there is a need to consider the consequences of such a failure. It is also possible that the origin of the slope-top bench, and of the parallel ridges on the bench, do not imply current instability and failure potential of the slope. As we now demonstrate, however, the consequences of a large-scale failure of this slope would be extremely serious, therefore it is a matter of urgency that the origin of the Franz Josef hillslope morphology, and its current and future stability, are investigated as soon as possible.

A3.2 Failure Probability

Because there is no evidence that a major landslide has occurred previously from this slope, there are no local empirical data to estimate its future probability. Nevertheless, similar events have occurred elsewhere on the western range-front of the Southern Alps, at Round Top (4 x 10^7 m^3*; ca 930 AD; Dufresne at al., 2010), Wanganui-Wilberg (4 x* 10^7 m^3*; ca 1300 AD; Chevalier et al., 2009) and Cascade (7 x* 10^8 m^3*; ca 660 AD; Barth, 2014). These have all occurred since about 660 A.D., giving a frequency of about 1 event every 500 years or 2 x* 10^{-3} a^{-1} *somewhere along the range-front. The length of the (Alpine fault-bounded) range-front is about 400 km; approximately half of this is occupied by valleys so the probability of a major slope failure per susceptible km is about* 10^{-5} $a^{-1}km^{-1}$*. Given that the hillslope at Franz Josef extends about 1 km along the range-front, the probability of large-scale failure of this specific hillslope is about* 10^{-5} a^{-1}*. It is important to note that because of the extremely dynamic geomorphology of the region (tectonic uplift ~ 5 mma*$^{-1}$*; annual rainfall ~ 10 000 mma*$^{-1}$*) deposits of even very large landslides can be rapidly removed by river erosion; for example Chevalier et al. (2009) estimated that 75% of the Wanganui-Wilberg deposit has been eroded by the Wanganui River in the 700 years since its emplacement. Thus the frequency of large landslides may be higher than the present estimate, but is unlikely to be lower.*

There is no evidence of failure of the Franz Josef slope in the ca 18 000 years since it became ice-free, so the annual probability of its failure – if assumed unchanging with time - is likely to be less than 1 in 18 000, or about 5 x 10^{-5}*. However, the morphological characteristics of the Franz Josef hillslope suggest that it is more likely to fail than the many hillslopes that do not exhibit these characteristics, so its failure probability, though unknown, is again likely to be greater than* 10^{-5} a^{-1}*.”* (Davies & Moretti, 2021)

Fig. A3.4 below shows the volume-probability trend of Southern Alps rock avalanches (Korup & Clague 2009). If the Franz Josef event has a volume of 10^7 m^3 and an annual probability of 10^{-5}, then the probabilities of landslides of greater and smaller volumes are as shown in Table A3.1, assuming the volume-probability line slope is that given by Korup & Clague (2009).

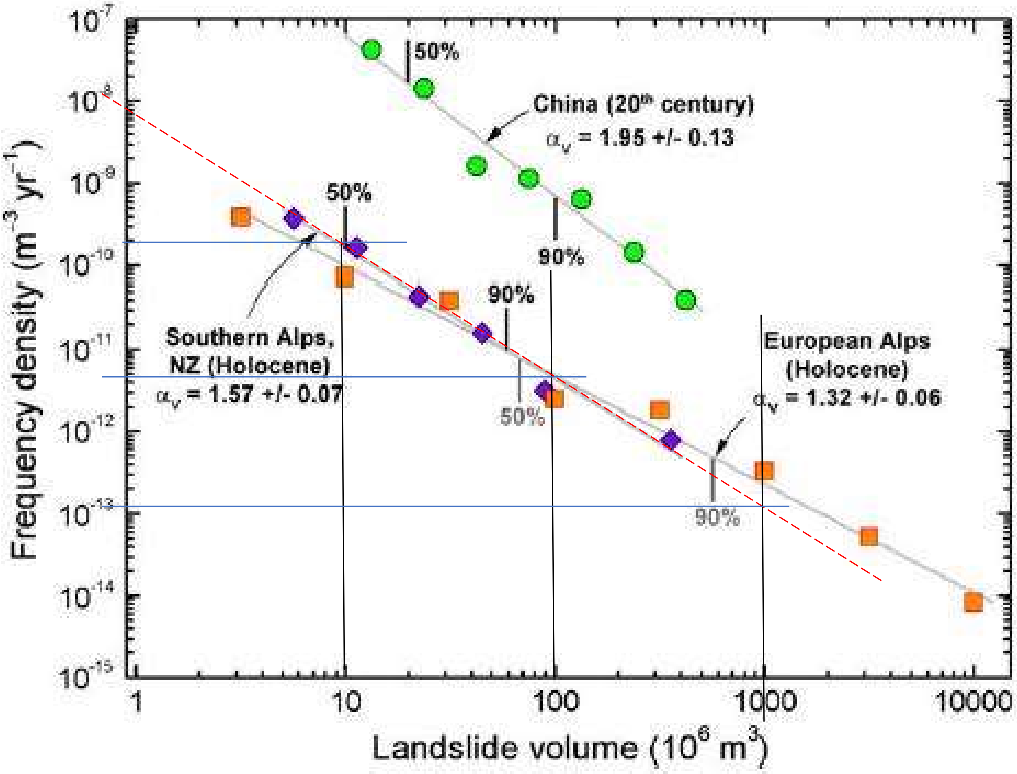


Fig. A3.4 Probability trend of Southern Alps rock avalanches (blue diamonds, red dashed line); after Korup and Clague, 2009.

Fig. A3.5 shows the approximate areas affected by the rock avalanches in Table A3.1.

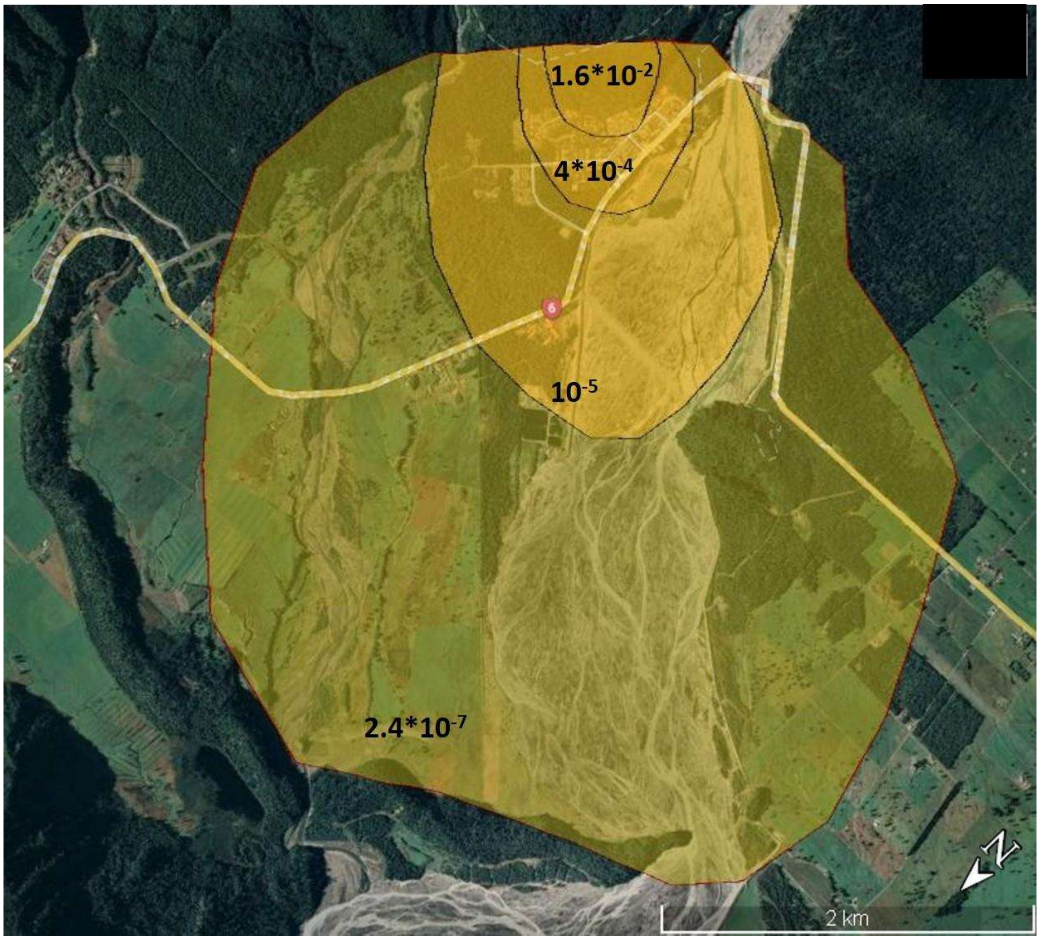
Table A3.1 Rock avalanche volume, probability and runout distance

Volume, m^3	**Probability, a^{-1}***	**Runout, km****	**Return period (yr)**
10^8	2.4 x 10^{-7}	4.6	4,000,000
10^7	1 x 10^{-5}	2.1	100,000
10^6	4 x 10^{-4}	1.0	2,500
10^5	1.6 x 10^{-2}	0.5	60

*Korup and Clague, 2009 based on p(10^7 m^3) = 10^{-5} a^{-1}.

**Davies, 1982; runout = 10*(volume)$^{1/3}$.

Note that in reality the hillslope source of these rock avalanches can almost certainly not generate an event of 10^8 m^3 because it is not big enough. Hence this volume is not used in risk analyses.



[redacted]

Fig. A3.5 Approximate areas covered by rock avalanche debris deposits of various annual frequencies. Modified Google Earth image.

A3.4 Can the slope in fact fail catastrophically?

Davies and Loew (2019) commented as follows on the question of whether the slope can fail in such a way as to cause a rock avalanche: "While this appears to be a possibility, it is also possible that the slope characteristics have arisen due to a geological process or slope deformation mechanism that does not lead to large-scale catastrophic failure of the slope. Whether or not this slope can fail catastrophically can only be determined by knowledge of the internal geological structure and activity of the slope. *In particular, if the slope has the potential to develop sliding along steeply dipping sliding planes (as indicated for the Cascade landslide in Fig. 9) then the situation is critical and calls for urgent mitigation measures.* The purpose of the present study is to point out the potential risk and to recommend investigations to resolve these fundamental questions."

A4. Landslide dambreak floods: Tatare and Callery Rivers

The MDRR dissertation of R (2021) generated a magnitude-frequency relationship for landslide dambreak floods from the Tatare River, while Dunant (2019) derived a corresponding relationship for the Callery River (Fig. A4.1, upper and lower respectively).

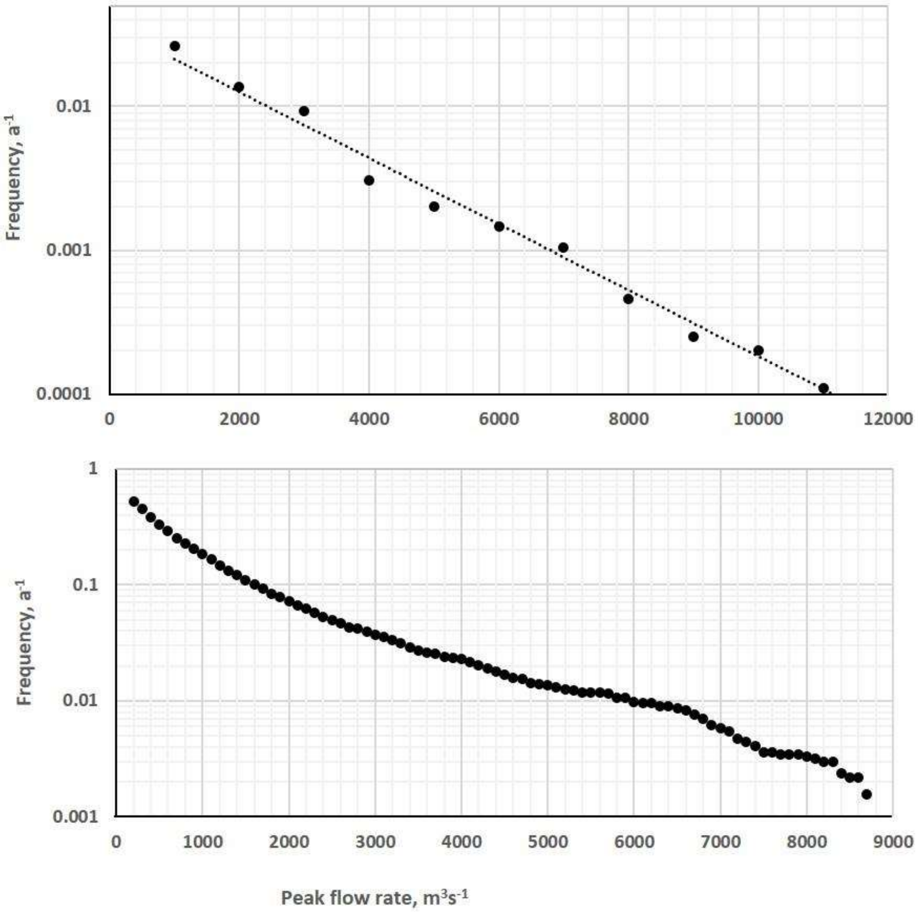


Fig. A4.1 Landslide-dambreak flood magnitude-frequency in the Tatare (upper; R, 2020) and Callery (lower; Dunant, 2019) Rivers.

In order to assess the land areas affected by landslide dambreak floods GNS Science Ltd (C.I. Massey, *pers. Comm*. 2022) undertook numerical modelling using RAMMS software as outlined in Morgenstern et al. (2021) for selected flood peak flows as in Table A4.1 (this information was supplied as part of the Endeavour Research Programme "Kaikoura earthquake-induced landscape dynamics"):

Table A4.1 Peak flows and frequencies for modelled landslide dambreak floods

Tatare River				
Peak flow m^{3}s^{-1}	1000	2500	5000	
Frequency a^{-1}	0.03	0.009	0.002	
Callery River				
Peak flow m^{3}s^{-1}	1600	4200	6000	8600
Frequency a^{-1}	0.10	0.02	0.01	0.002

Note that these models were run with 2016 LIDAR data so do not account for planned stopbank improvements. However the ability of stopbanks to contain dambreak floods is significantly lower than their ability to contain normal floods because of the very large volumes of sediment associated with the former and the consequent severe bed aggradation.

Figs A4.2 – A4.4 below show the areas modelled as flooded by Tatare River landslide dambreak floods (modified Google Earth images).

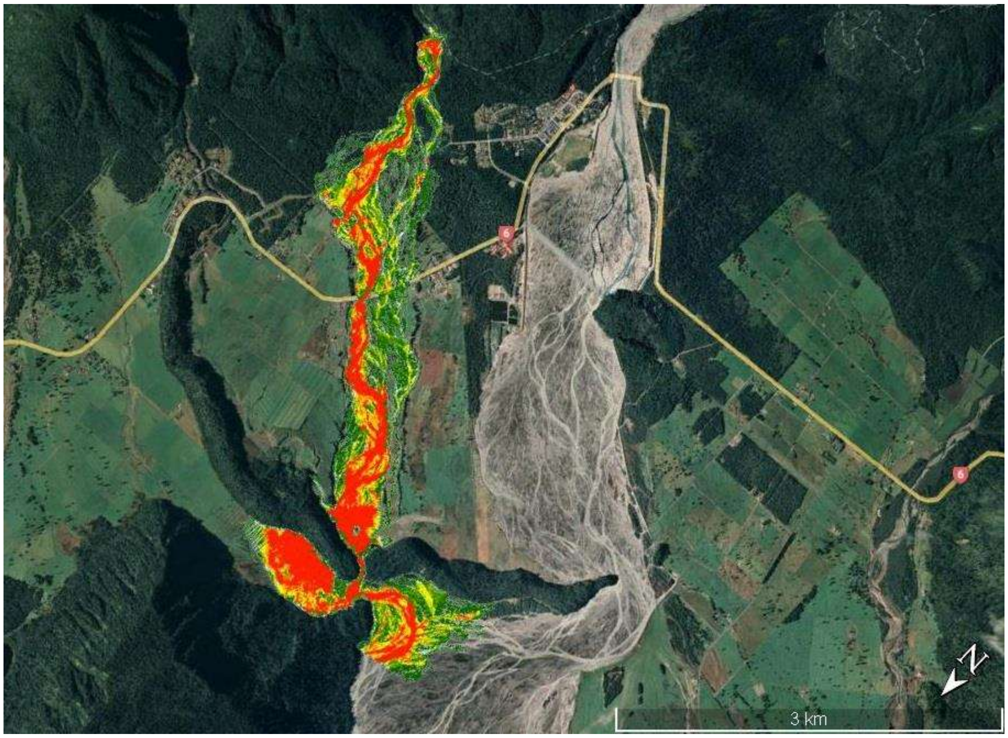


Fig. A4.2 Tatare River landslide dambreak flooding peak flow = 1000 m^3s^{-1}. Colour code: Green = shallow, yellow = moderate, red = deep.

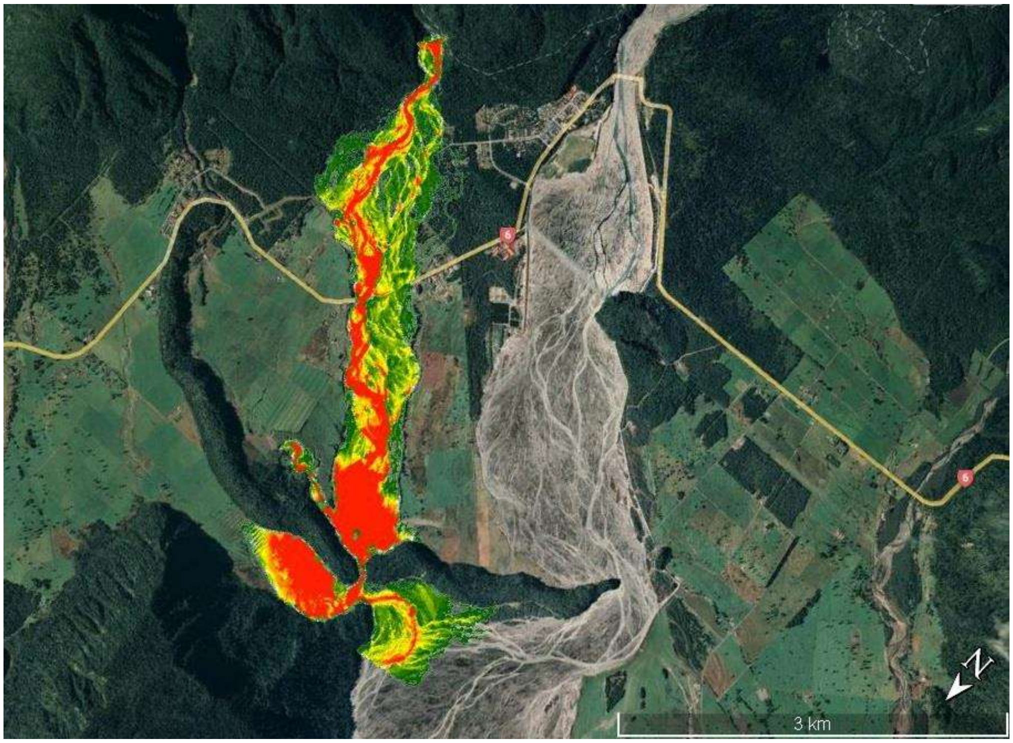


Fig. A4.3 Tatare River landslide dambreak flooding peak flow = 2500 m^3s^{-1}. Colour code: Green = shallow, yellow = moderate, red = deep.

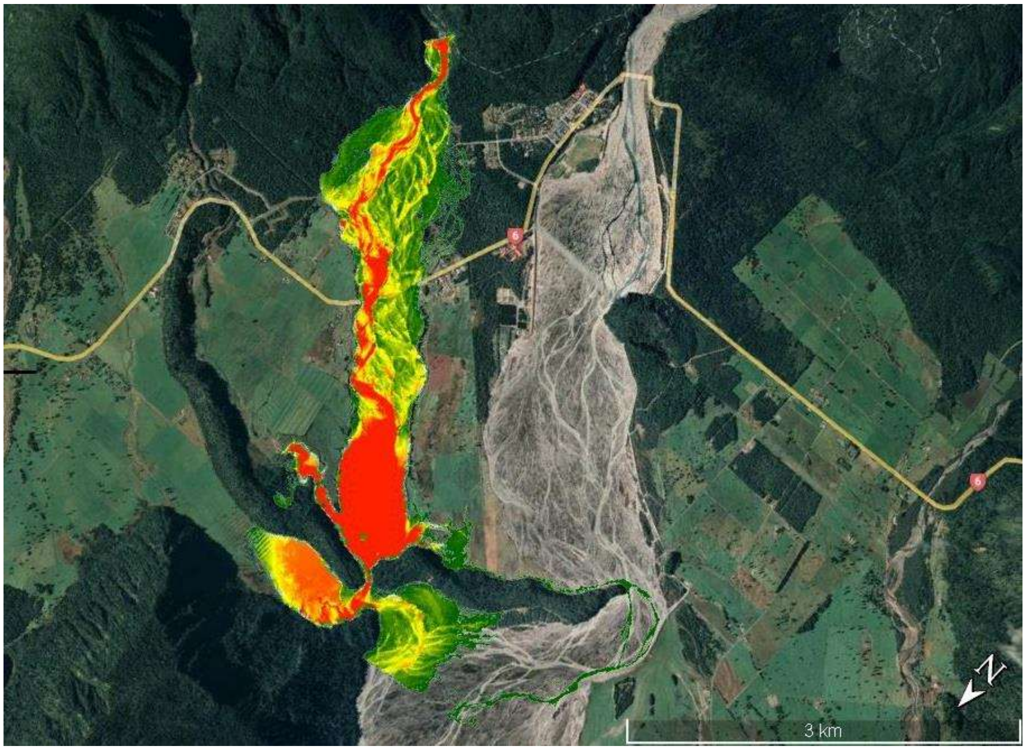


Fig. A4.4 Tatare River landslide dambreak flooding peak flow = 5000 m^3s^{-1}. Colour code: Green = shallow, yellow = moderate, red = deep.

Figs A4.5 – A4.8 below show the areas modelled as flooded by Callery landslide dambreak floods.

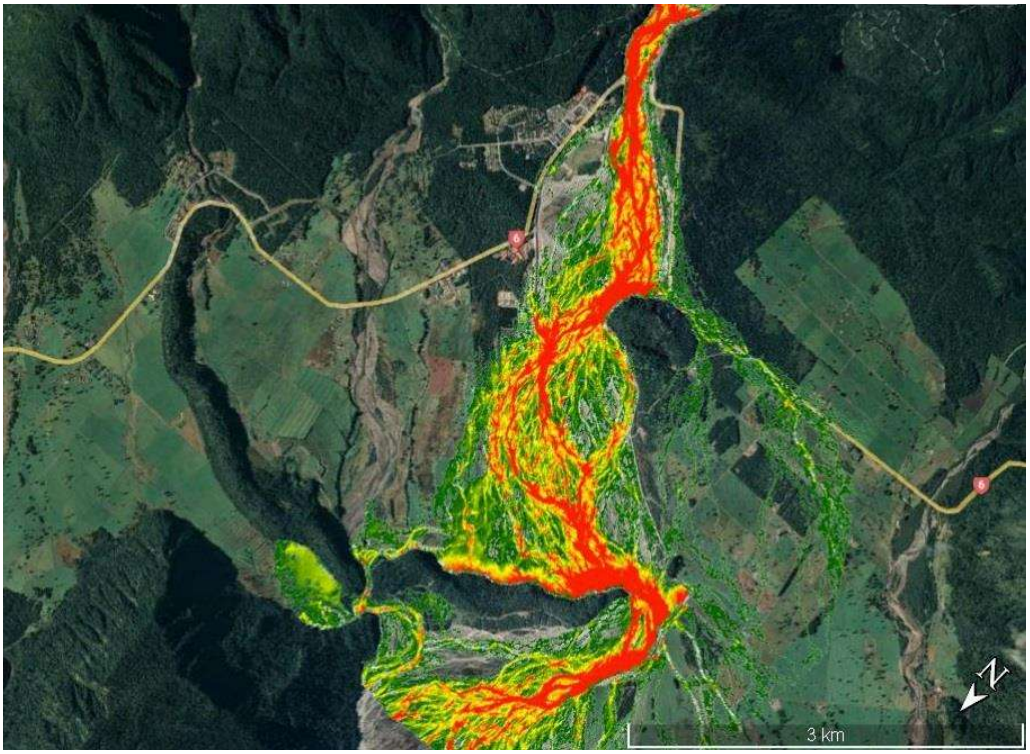


Fig. A4.5 Callery River landslide dambreak flooding peak flow = 1600 m^3s^{-1}. Colour code: Green = shallow, yellow = moderate, red = deep.

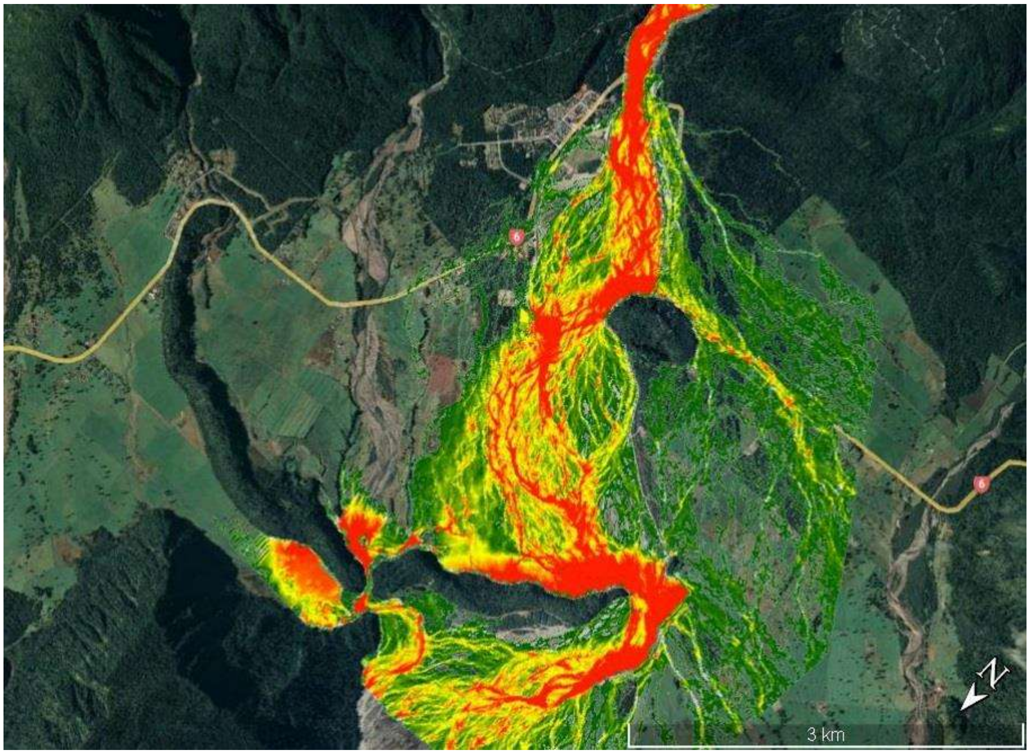


Fig. A4.6 Callery River landslide dambreak flooding peak flow = 4600 m^{3}s^{-1}. Colour code: Green = shallow, yellow = moderate, red = deep.

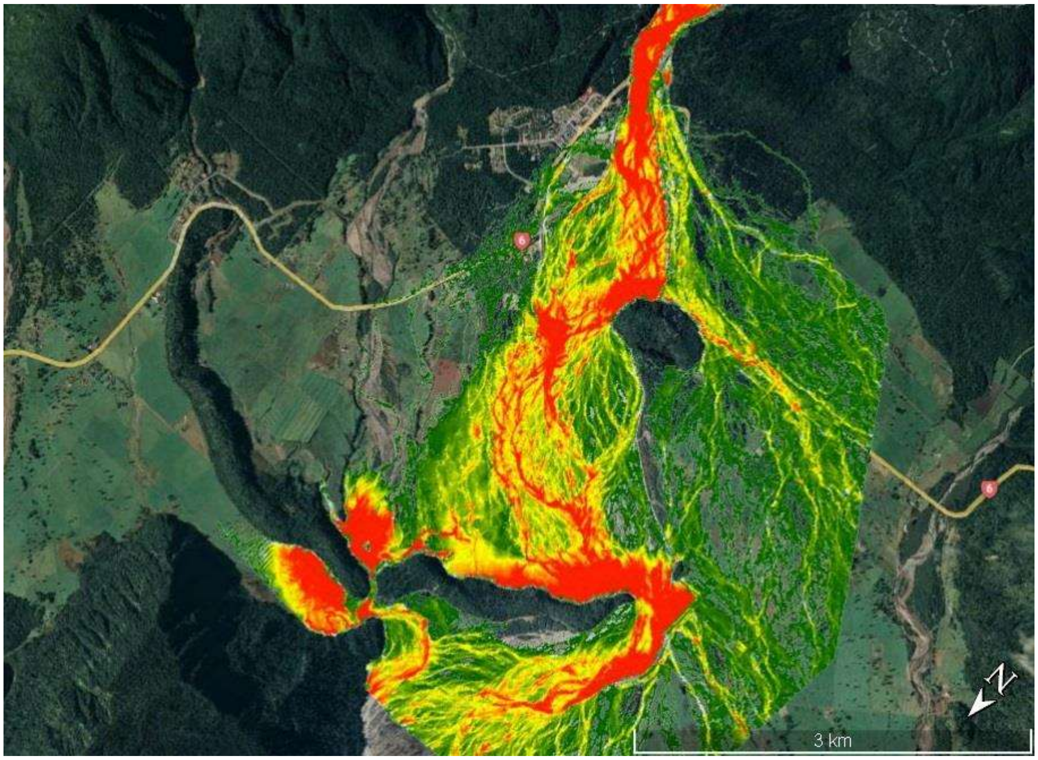


Fig. A4.7 Callery River landslide dambreak flooding peak flow = 6000 m^{3}s^{-1}. Colour code: Green = shallow, yellow = moderate, red = deep.

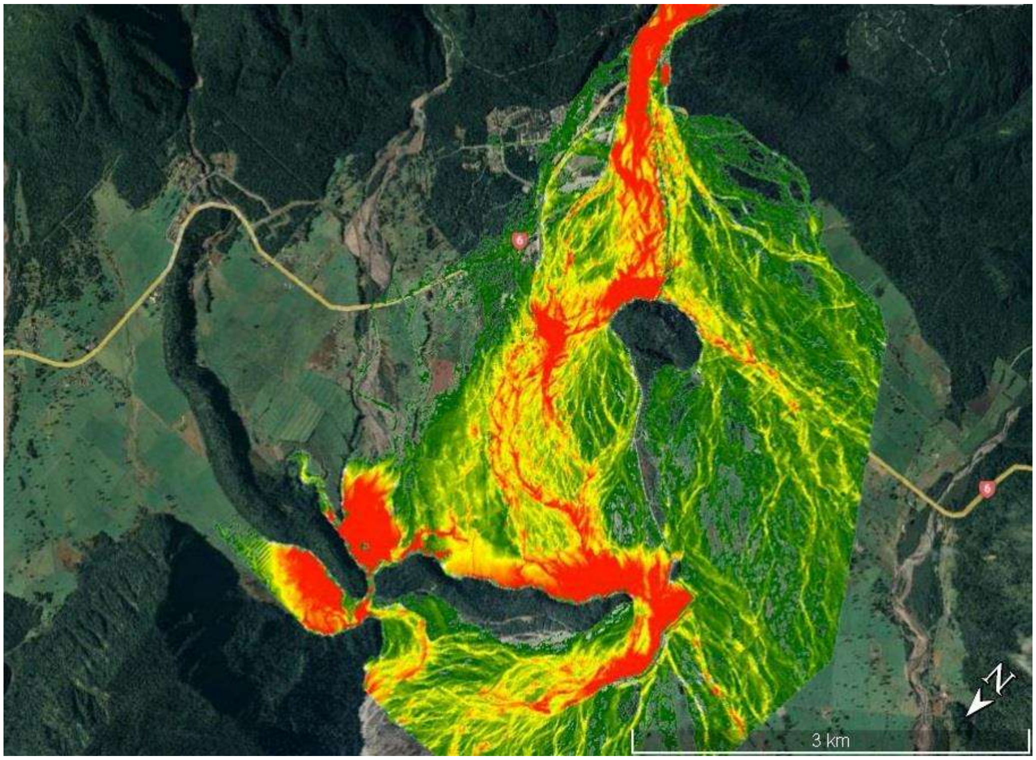


Fig. A4.8 Callery River landslide dambreak flooding peak flow = 8600 m^3s^{-1}. Colour code: Green = shallow, yellow = moderate, red = deep.

APPENDIX B – PROBABILITY OF DEATH RESULTING FROM IMPACT OF A HAZARD WITH A PERSON (MORTALITY RATES)

(Adapted from unpublished MSc thesis of R, 2022)

B1 Earthquake Mortality Rate

Casualty estimations or realistic fatality rates for earthquakes are generally complicated and hard to derive due to inconsistencies and lack of quality of data (So, 2016). When compared with other areas with similar seismicity, New Zealand has had a relatively low number of earthquake-related deaths (Nichols et al., 2000). There have been several methods and criteria used to calculate the mortality rates for earthquakes. For the purpose of this study, an earthquake-related death was defined as one that occurred directly or indirectly as a result of ground shaking and only considered earthquakes that have occurred in New Zealand. Abeling et al. (2017) examined patterns and mortality rates in New Zealand between the years 1840-2017, during which approximately 21 earthquakes with MMIs VII or greater occurred. The main factor of consideration for Franz Josef was the magnitude and intensity of any given earthquake. Fig. 3.9 by Abeling et al. (2017) illustrates the mortality rates by MMI.

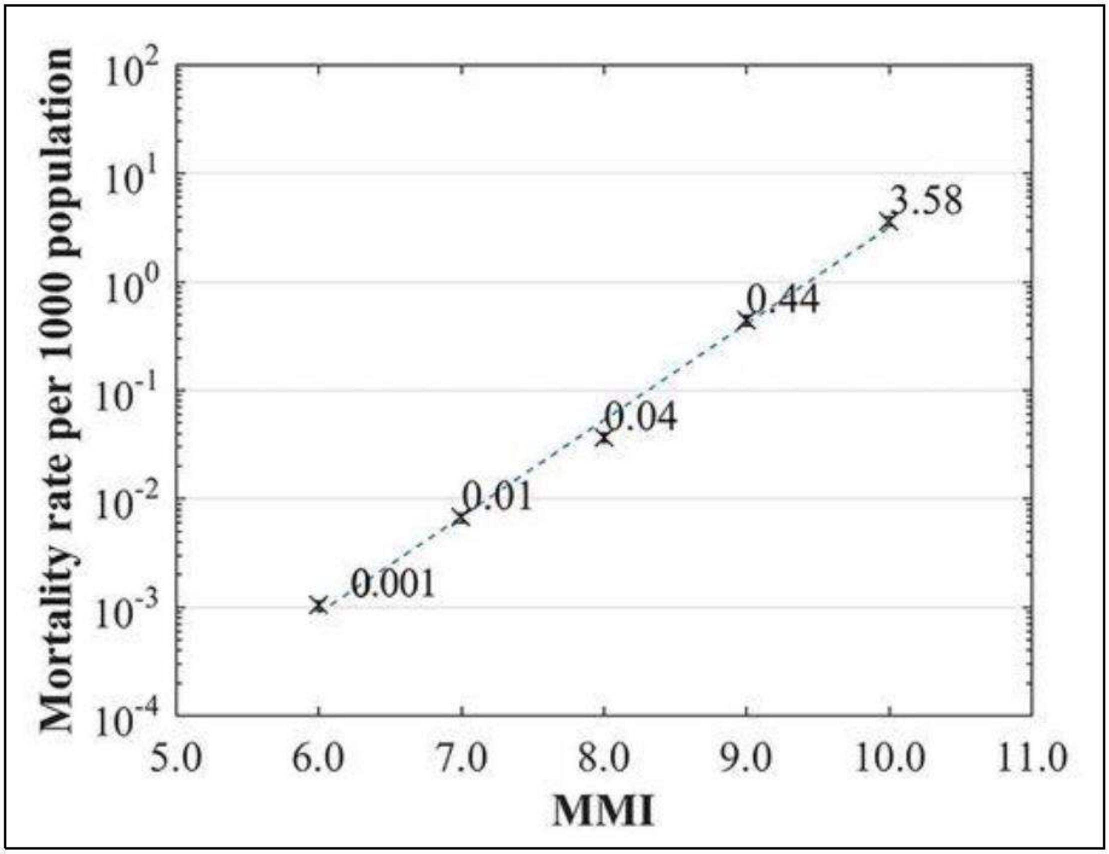


Figure B1.1: Mortality rate by MMI per 1000 population exposed to a severe New Zealand earthquake (Abeling et al., 2017)

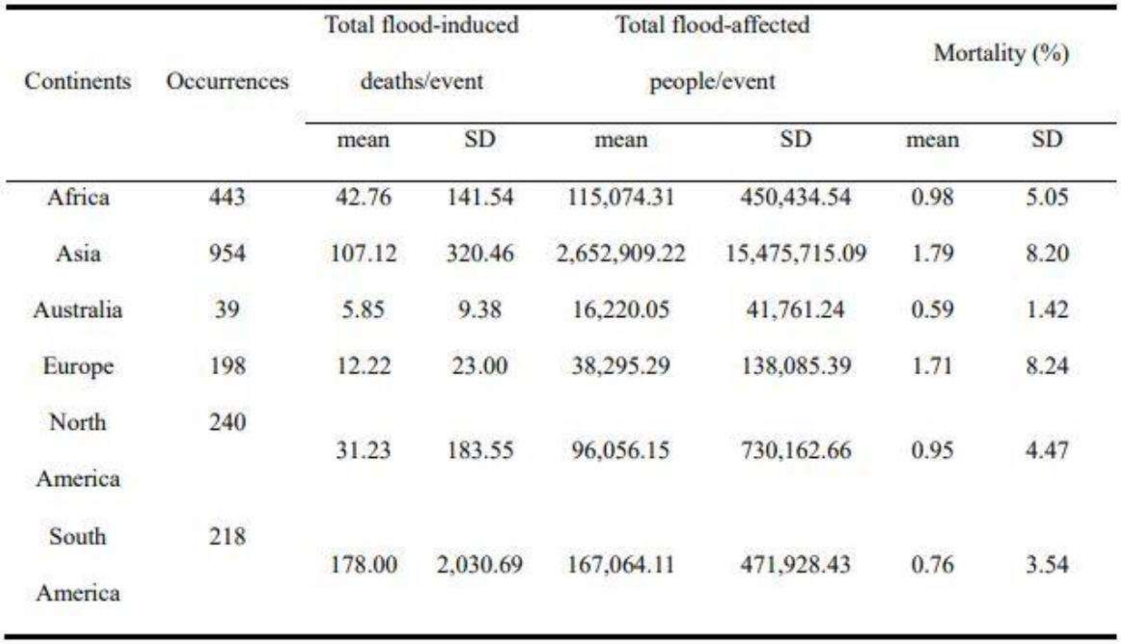
Given that shaking from the Alpine fault earthquake is expected to be MM10 or greater across all of the town areas, an earthquake mortality rate of 3 per 1000 (0.3%) was used for the purposes of this study.

B2 Rock Avalanche Mortality Rate

Landslide vulnerability and the underlying causes of landslide fatality are widely understudied (Pollock & Wartman, 2020). There are several key factors that determine human vulnerability and probability of death during a landslide event. Of the various situational risk factors, distance from slope was deemed the most critical factor. According to Pollock and Wartman (2020), the odds of death increase with decreasing distance, whereby individuals closer to the slope (less than 100m) have 1.6x more likely to be killed. Due to the nature and fast velocity of a rock avalanche, the modelled runout distance, and the distance between buildings and individuals to the hillslope above the current townsite, a mortality rate of 100% was used.

B3 Flooding Mortality Rate

Flood-induced mortality rate was derived from (Hu et al., 2018), who calculated mortality rates for flood-induced deaths within different continents (Fig. B2). Given that past occurrence rates of floods, flood-affected population as well as other underlying factors such as GDP per unit area, income and other variabilities in New Zealand is comparable to that for the Australian continent, the flood mortality rate of 0.59% was used.

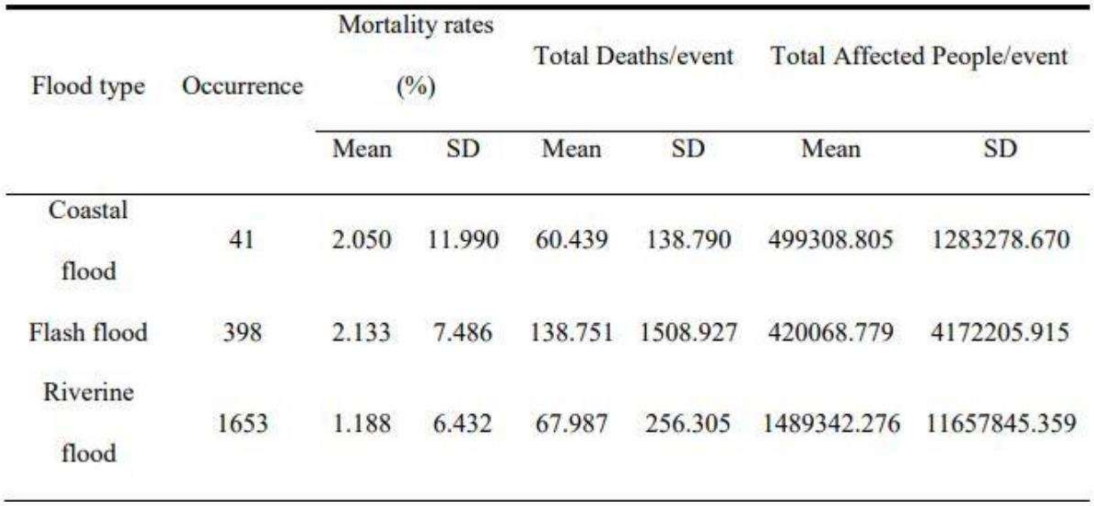


Continents	Occurrences	Total flood-induced deaths/event		Total flood-affected people/event		Mortality (%)	
		mean	SD	mean	SD	mean	SD
Africa	443	42.76	141.54	115,074.31	450,434.54	0.98	5.05
Asia	954	107.12	320.46	2,652,909.22	15,475,715.09	1.79	8.20
Australia	39	5.85	9.38	16,220.05	41,761.24	0.59	1.42
Europe	198	12.22	23.00	38,295.29	138,085.39	1.71	8.24
North America	240	31.23	183.55	96,056.15	730,162.66	0.95	4.47
South America	218	178.00	2,030.69	167,064.11	471,928.43	0.76	3.54

Figure B3.2: Flood induced mortality rate across the different continents (Hu et al., 2018).

B4 Landslide Dambreak Flood Mortality Rate

Flood-induced mortality rates for other flood disaster categories was also adopted from Hu et al. (2018). Figure B4.1 shows the mortality rates for different flood types. However, a category for



Flood type	Occurrence	Mortality rates (%)		Total Deaths/event		Total Affected People/event	
		Mean	SD	Mean	SD	Mean	SD
Coastal flood	41	2.050	11.990	60.439	138.790	499308.805	1283278.670
Flash flood	398	2.133	7.486	138.751	1508.927	420068.779	4172205.915
Riverine flood	1653	1.188	6.432	67.987	256.305	1489342.276	11657845.359

Figure B4.1: Mortality rates for the various flood types (Hu et al., 2018).

floods from a landslide-induced dambreak was not present. Therefore, the mortality rate for the most comparable flood type; flash flood (2.1%) was considered. The 1999 Mount Adams dambreak flood remained largely confined to the river channel and thus, caused no deaths and little damage (Becker et al., 2007). Given that floods caused by landslide dambreak events often occur quickly and carry more debris than normal floods, and are similarly detrimental to flash floods, a value of 2% mortality rate was used.

B5 Debris Flow Mortality Rate

The vulnerability values assigned by Wei et al. (2021) were used to calculate the mortality rate for a debris flow from Stoney Creek whereby vulnerability was defined as the "degree of loss of any given element exposed to a debris flow of a given magnitude". According to Wei et al. (2021), most injuries and deaths resulting from debris flows in China occur in buildings due to damage caused to the buildings. As such, only the risk to the lives of people in buildings was considered. Given that there are ongoing developments within the region next to Stoney Creek, it was safe to assume a similar scenario for a Stoney Creek debris flow, whereby only the risk to life of people within buildings was considered and the risk to life of people outside of buildings in the event of an occurrence was omitted. Therefore, the vulnerability of the people was calculated as vulnerability of person x building vulnerability. Wei et al. (2021), assigned the maximum vulnerability of people as 0.9 and the maximum building vulnerability as 0.315. Therefore, the mortality rate for debris flow was calculated to be 27%.

APPENDIX C – QUALITATIVE PICTURE OF RISK TRENDS POST-2040 AND/OR POST-EARTHQUAKE

It is worth exploring quantitatively the possible longer-term (post-2040/post-earthquake) changes in risks to the town sites, to provide a context for shorter-term decision-making. The main factors affecting longer-term risks are whether or not a major earthquake has occurred on the Alpine fault, and whether or not the Waiho River stopbanks on the true left (west) bank have been removed as suggested by Gardner (2021).

As noted in the Report, climate change will be a more significant factor in longer-term risk assessments. Collins (2021) has addressed this issue in preliminary fashion, suggesting for example that under the most extreme climate-change scenarios, winter river flows in Westland may exhibit detectable increases at multi-decadal time-scales. However, more useable inferences await further research. Debris-flow frequencies also seem likely to increase; for example, the 2005 debris flow at Matatā was triggered by a 200-500-year return interval rainstorm, but by the end of this century such an event would have a 40-50-year return interval under the RCP 8.5 climate change scenario.

We consider three longer-term scenarios:

1. Pre-earthquake, stopbanks still in place as per 2020 plan
2. Pre-earthquake, west bank Waiho stopbanks removed
3. Post-earthquake

C1 Pre-earthquake, stopbanks still in place as per 2020 plan

By 2040, assuming aggradation of the Waiho continues and no major earthquake has occurred, the river bed level will have risen so that the overtopping risk has become significantly higher. This will have the effect of increasing the flooding risk to much of the old town sites OT1 and OT2 and to part of NT2 (Fig. C1.1)

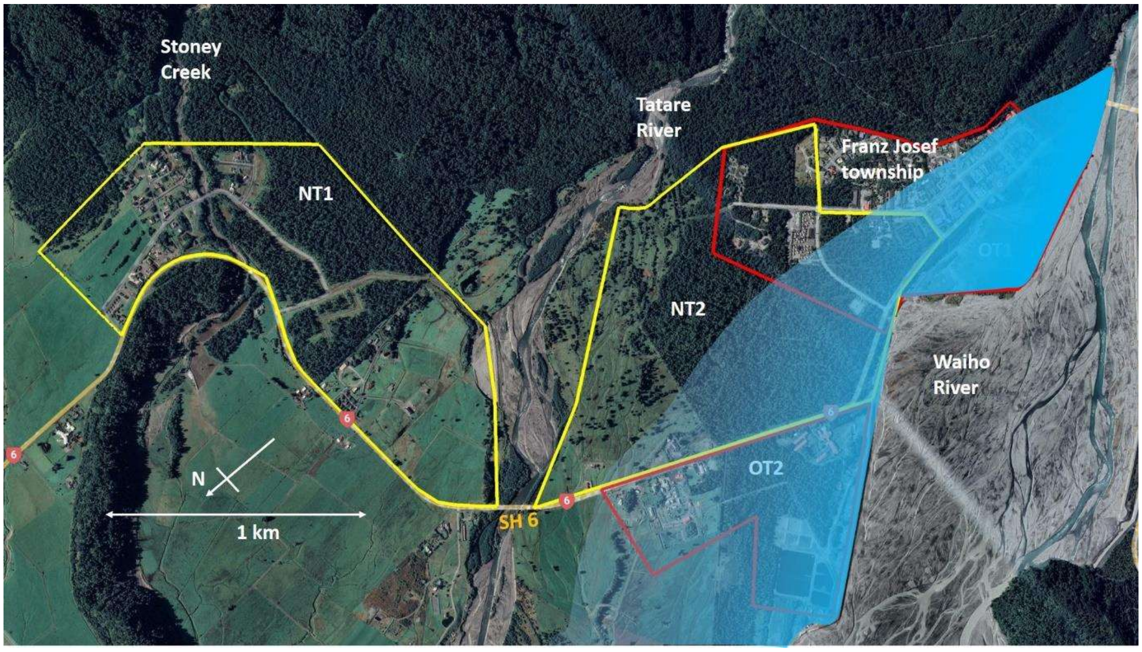


Fig. C1.1. Approximate higher-risk post-2040 and pre-earthquake Waiho River flood zone (blue).

C2 Pre-earthquake, west bank Waiho stopbanks removed

If the western stopbanks have been removed, the flood risk to the east side of the Waiho River will be very much reduced, effectively to zero as in the pre-2040 case (Fig. 5).

C3 Post-earthquake

The severe and widespread shaking accompanying a major earthquake will cause many slope failures in the mountains, some of them large. As noted in the Report, stopbanks will also be severely damaged and become less effective. All river catchments may receive substantial quantities of landslide sediments during the mainshock and in some of the aftershocks, resulting in a major pulse of river-bed aggradation affecting the Waiho, Callery and Tatare Rivers soon after the earthquake. This pulse will begin during the first rainstorm following the earthquake, and will increase over several years or perhaps a decade to a peak depth of several or many metres at the range-front (aggradation following the 1999 Mt Adams landslide peaked at 5 m or so about 6 years after the event; Croissant et al., 2017); thereafter the aggradation wave will move down the river affecting floodplains over further decades, constraining land use over much of the West Coast (Blagen et al., 2022). Flood risks will also be increased adjacent to the Tatare River affecting township sites NT2 and possibly NT1 (Fig. 5)

During the seismic period of the mainshock and significant aftershocks (which is likely to last several years to a decade), landslide dambreak flood risks from the Callery and Tatare Rivers may increase significantly (Tables 3 and 4, Figs 8 and 9).

Debris flow risk on Stoney Creek fan (Fig. 10) will increase following the earthquake mainshock and large aftershocks, because of the likely increase in the volume of landslide sediment available in the catchment, through which the Alpine fault runs. The 1999 Chi Chi earthquake in Taiwan caused the number of rainfall-triggered landslides to increase fourfold during the two following years (Lin et al., 2004), while experience following the 2008 Wenchuan earthquake shows debris-flow occurrence in the affected area reducing fourfold from its post-earthquake peak by 2016 (Li et al., 2018), so debris-flow risk at Stoney Creek may follow a similar pattern of rapid increase and more gradual decrease.

> ***C3(i)*** If an earthquake were to occur with the Waiho River western stopbanks still in place, the coseismic shaking would probably severely damage all the stopbanks, reducing their crest height significantly. This, together with the accelerated aggradation due to coseismic sediment input to the Callery and Waiho, means that flood risk will be greatly increased in the area shown in Fig. C.1.1, and probably even more widely.
> ***C3(ii)*** However, if the western stopbanks are no longer in place when the earthquake occurs, much of the sedimentation may be expected to occur on the true left (western) side of the Waiho, with correspondingly less on the town side.

Appendices: References

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