MILFORD OPPORTUNITIES

MILFORD OPPORTUNITIES PROJECT

Hazards and Visitor Risk Review Report

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Stantec

Stantec NZ Limited

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CONTENTS

EXECUTIVE SUMMARY 1

1 PROJECT BACKGROUND / DEFINITION 4

PURPOSE OF PROJECT 4

PROJECT AMBITION 4

PROJECT PILLARS 4

PROJECT OBJECTIVES 5

WORKSTREAM OBJECTIVES 6

NATURAL DISASTERS AND COVID-19 IMPACTS 7

2 SCOPE OF WORK: HAZARDS & VISITOR RISK REVIEW 8

3 BASELINE: CURRENT STATE / EXISTING CONDITIONS 9

CONTEXT 9

INTRODUCTION TO ORGANISATIONAL ARRANGEMENTS 10

INFRASTRUCTURE AND LIFELINES 13

MILFORD SOUND PIOPIOTAHI 13

TE ANAU AND MANAPOURI 20

DOUBTFUL SOUND PATEA 22

INTRODUCTION TO EXISTING VISITOR DISTRIBUTION 22

MILFORD SOUND PIOPIOTAHI 22

TE ANAU AND MANAPOURI 25

AVERAGE DAY LOWER IMPACT HAZARDS 26

MILFORD SOUND PIOPIOTAHI 27

TE ANAU AND MANAPOURI 35

MODERATE IMPACT SEASONAL AND PERIODIC HAZARDS 35

MILFORD SOUND PIOPIOTAHI 35

TE ANAU AND MANAPOURI 40

RARE SEVERE HAZARD SCENARIO 40

MILFORD SOUND PIOPIOTAHI 44

TE ANAU AND MANAPOURI 56

4 LONG LIST OPTIONS FOR DISCIPLINE 59

ORGANISATIONAL ARRANGEMENTS 59

READINESS AND RESPONSE CAPACITY 60

KEY MITIGATION MEASURES BY HAZARD TYPE 60

AF8 AND LANDSLIDE-INDUCED TSUNAMI 60

AVALANCHE 65

ROCKFALL / LANDSLIDE 66

FLOOD AND DEBRIS FLOWS 67

COASTAL TSUNAMI AND STORM SURGE WITH SEA LEVEL RISE 68

TRAVEL RELATED AND 'BUSINESS AS USUAL' 68

COMMENTS ON SPECIFIC LONG LIST ITEMS 69

MAIN IDEA 1: COMPELLING SUITE OF EXPERIENCES IN PIOPIOTAHI69

MAIN IDEA 2: REDESIGN MILFORD VILLAGE 69

MAIN IDEA 3: ENHANCE THE MILFORD CORRIDOR EXPERIENCE 69

MAIN IDEA 4: DEVELOP TE ANAU AS A SUB-REGIONAL VISITOR HUB70

MAIN IDEA 5: EXPAND THE VISITOR OFFERING AROUND TE ANAU70

MAIN IDEA 6: OVERARCHING SUB-REGION COMPETITIVE ADVANTAGE 70

MAIN IDEA 7: NEW TRANSPORT MODEL 70

MAIN IDEA 8: USE TOURISM TO IMPROVE CONSERVATION 70

MAIN IDEA 9: NEW GOVERNANCE AND MANAGEMENT STRUCTURES 71

5 RECOMMENDED OPTION 72

GENERAL / ORGANISATIONAL 72

MILFORD SOUND PIOPIOTAHI 72

SH94 CORRIDOR 79

TE ANAU AND MANAPOURI 80

SUMMARY MATRIX 81

6 SUMMARY AND CONCLUSION 82

RECOMMENDATIONS FOR URGENT FURTHER ASSESSMENT 82

7 REFERENCES 84

APPENDICES

APPENDIX 1: LANDSLIDE-INDUCED TSUNAMI

APPENDIX 2: OCEAN-SOURCE TSUNAMI

APPENDIX 3: RISK OVERVIEW MATRIX

FIGURES

Figure 1: Milford Sound Piopiotahi main study area of interest and regional context ... 9
Figure 2: Milford Sound Piopiotahi overview ... 14
Figure 3: As-built infrastructure networks within Milford Village ... 14
Figure 4: As-built infrastructure networks within Cleddau Village ... 15
Figure 5: Chorus radio link to Milford Sound Piopiotahi (Source: Chorus) ... 17
Figure 6: Milford Aerodrome location ... 18
Figure 7: Damage to Routeburn Flats Bridge, Routeburn Track (Image credit: DoC) ... 20
Figure 8: Te Anau 3 Waters Network. (Source: Southland District Council GIS) ... 20
Figure 9: Manapouri 3 Waters Network (Source Southland District Council GIS) ... 21
Figure 10: Relationship between vehicles and total visitors ... 23
Figure 11: Homer Tunnel monthly in-bound vehicle movements in 2019 ... 23
Figure 12: Homer Tunnel vehicle counts on a peak day in 2019 ... 24
Figure 13: Approximate land-based spatial peak visitor concentrations ... 25
Figure 14: Illustration of rock and tree slips to north of ferry terminal (left), and indicative path of the May 2019 slip (right) ... 28
Figure 15: Damage to storagebuilding in Milford Sound Piopiotahi 2016 (photo credit Tim Holland) ... 28
Figure 16: May 2019 slip initiation site and trapped debris (from Baddiley and Bond (WSP 2019) ... 29
Figure 17: Slip at Monkey Creek on Milford Road (2022) looking east30
Figure 18: Landslide damage at Howden Hut on the Routeburn Track (4 February 2020) Photo: Grace Houpapa ... 30
Figure 19: Stirling Falls, Milford Sound Piopiotahi ... 31
Figure 20: Car fire in the Homer Tunnel (2019) ... 32
Figure 21: Rescue of walker who fell into the chasm after climbing over the barrier to take a photograph (2015) ... 33
Figure 22: Large cruise liner in Milford Sound Piopiotahi ... 34
Figure 23: Homer Saddle above the western portal (both photographs) ... 36
Figure 24: Homer Tunnel eastern portal (photo Waka Kotahi NZ Transport Agency) ... 36
Figure 25: Known avalanche paths and the MRA avalanche zone on SH94 (Source: LINZ / Waka Kotahi) ... 37

Figure 26: Damage at Forks Bridge (1.5km from Homer Tunnel, Hollyford side) due to February 2020 flood event. Photo: Waka Kotahi 39

Figure 27: Giants Gate swing bridge on Milford Track following Feb 2020 storms........ 39

Figure 28: Location of known active fault lines in the region............ 41

Figure 29:Earthquakes since 1900 (from Dykstra 2012, referencing Turnbull et al 2010)........ 42

Figure 30: Cascade of effects from a major seismic event (from Figure 6 of the AF8 scenario report, Orchiston et al, 2016) 44

Figure 31: Aerial of the ~200,000 m3 rock fall in Gold Arm of Charles Sound which caused a ~4-5 m high tsunami during the 2003 Fiordland earthquake New Zealand. The wave travelled ~800 m across the fiord and stripped vegetation and soil 4–5 m above high tide level........ 45

Figure 32: Large historic landslides in Fiordland area (from Dykstra, 2012)........ 46

Figure 33: Wave probability assessment from Taig et al, 2015 (simplified donor attenuation models)........ 47

Figure 34: Historic landslide deposits (from Dykstra, 2012) 48

Figure 35: A geologist stands in front of a 5m diameter boulder moved by the Taan Fiord tsunami near where it reached its highest elevation (193m). Photo courtesy of Ground Truth Trekking 49

Figure 36: Illustrative simple hazard zone sketch (not yet based on computational modelling)........ 50

Figure 37: Liquefaction risk. Source: Environment Southland/GNS 55

Figure 38: Liquefaction Te Anau / Manapouri (Source: Environment Southland/GNS)........ 57

Figure 39: Wilmot Pass road near Deep Cove (possible tsunami refuge above the 40m contour – highlighted) 58

Figure 40: Illustrations of possible elements of visitor hub building forms to blend into the visual landscape (left) and keep a lower vertical aspect area to reduce extreme wave loading (right)........ 61

Figure 41: Illustrations of possible elements of low profile bunkder refuge / shelter 62

Figure 42: Potential tsunami evacuation muster points (pink arrow at existing lookout ~30m, and white arrow on 80m contour). 63

Figure 43: Large boat tackling a large storm wave illustrating the importance of pilot wave training (Photo: Scott Reid) 64

Figure 44: Wilmot Pass road near Deep Cove (possible tsunami refuge, above the 40m contour - highlighted)........ 65

Figure 45: Homer Tunnel eastern portal........ 66

Figure 46: Homber Tunnel western portal with temporary rockfall protection 66
Figure 47: Chart of potential fatalities from landslide induced tsunami at Piopiotahi 76
Figure 48: International risk evaluation examples (from Macciotta and Lefsrud, 2018) 76
Figure 49: Example of a modern heliport layout in South Africa 78
Figure 50: Lituya Bay Alaska, July 9, 1958, M7.7, landslide ~ 30x10^6 m3, largest wave ever recorded. There was also a 1936 event with run-up of 150m without associated earthquake. 89
Figure 51: Taan Fiord landslide and tsunami, Alaska, 2015. (adapted from Higman et al. 2018.) 90
Figure 52: A geologist stands in front of a 5m diameter boulder moved by the Taan Fiord tsunami near where it reached its highest elevation (193m). Photo courtesy of Ground Truth Trekking. 91
Figure 53: Lake Te Anau and Manapouri - Locations of interest and tsunami runup results (from Hancox 2012) 91
Figure 54: Ocean-source Tsunami 93

TABLES

Table 1: Application of Stage 2 Objectives 6
Table 2: Organisations key safety responsibilities........ 10
Table 3: List of underwater landslide deposits identified by Dykstra (2012), with estimates of wave heights by Taig, et al (2015) and additional comments on specific entries of interest. . 48
Table 4: Potential evacuation pathways (illustrative) 52
Table 5: Rough estimate of probabilities and potential fatalities from landslide-induced tsunami at Piopiotahi. 75
Table 6: Tsunamis with runup of 50 m or greater in the past century. (Table from Higman et al. 2018) 88

EXECUTIVE SUMMARY

Milford Sound Piopiotahi is a global iconic visitor attraction that (prior to Covid-19) drew nearly 1 million visitors in 2018/19, peaking at around 6,000 visitors on the busiest day. However, it is also rugged and isolated, and visitors are exposed to a range of hazards. Not all of these hazards are easy for staff or visitors to see, predict or manage.

In this report, the baseline chapter briefly reviews the organisational arrangements currently in place to identify and manage risks from individual, local, regional and national bodies. Then key existing infrastructure from a lifeline's perspective is discussed, notably safe refuge, emergency supplies of water, fuel/power, communication and access/egress (road, air, sea) for evacuation. Visitor distribution is outlined to understand spatial and temporal patterns, especially at peak times when over 3,000 people (2018/19 data) can be on the Milford Sound Piopiotahi side of the Homer Tunnel.

With that background, the three levels of hazard exposure scenarios are discussed. Due to the focus of the project, slightly more emphasis is placed on Milford Sound Piopiotahi and sites within the SH94 corridor to Te Anau that were identified as key components of visitor risk and/or sites considered through the option development process. Manapouri and Doubtful Sound Patea are mentioned briefly where information allows. The three hazard scenarios discussed in this report are:

- Average day. Lower impact hazards range from 'normal' risks, such as driving, flying, slips, trips or wasps to tree falls, smaller landslides or rock falls. These hazards are actively mitigated by standard procedures within the Department of Conservation (DOC), concession holders / operators, Waka Kotahi NZ Transport Agency, Milford Road Alliance, Airways NZ, etc. Some of these hazards may be triggered by rainfall or minor earthquakes but can also happen at any time without an 'obvious' trigger. Therefore, there is no guaranteed safe day in Milford Sound Piopiotahi, even in fine weather.

- Moderate impact, seasonal and periodic hazards. These include strong seasonal hazards such as snow, ice and avalanche risk in winter and spring, which, together with road safety, is proactively managed by the Milford Road Alliance and the Avalanche Control Programme. This also includes periodic flooding from moderate events, such as the February 2020 flood event that made the road impassable and damaged (requiring considerable repairs), through to tidal events (high astronomical tides and/or storm surge). These events may have some warning hours before the event, but are still costly to manage, respond, rescue and recover from. There is currently little information on the precise frequency of these events, which are expected to get worse in the future due to climate change and are also subject to changes in landscape due to landslides or debris flows that can change the course of rivers. Weather conditions can hinder evacuation by air or sea, therefore safe refuge on site is important.

- Rare severe hazard scenario. This includes multiple impacts of a major seismic event associated with the Alpine Fault, such as the potential for large co-seismic landslides and avalanches (especially in winter/spring) and landslide-induced tsunami, among other impacts. The Alpine Fault Magnitude 8 (AF8) project has been investing in considerable research into this large and complex challenge. A large landslide-induced tsunami has the potential to be very destructive with little or no warning. The risk assessment of a landslide-induced tsunami in Fiordland has been declared a hazard of national significance[1]. There is an estimated 16 percent probability over the next 50 years (approximately 0.3 percent or 1:300 probability per year) of a catastrophic event comprising over 100 fatalities (extending >2000 fatalities in the case of a large wave on a busy day). Effort is needed to mitigate the risks associated with this event and increase the probability of survival if and/or when such an event occurs. Failure to apply reasonable effort to mitigate this risk could result in significant reputational risk to the

[1] Southland Civil Defence: Emergency Management Group Plan (2017)

responsible organisations, including Emergency Management Southland, DOC, Southland District Council (SDC), tourism organisations/industry and NZ Inc.

After this discussion on hazards, the long list of options are addressed and then the Recommended Option is put forth from a hazard and visitor risk perspective. The following key changes were considered when determining the Recommended Option:

- Layout of the proposed Milford Sound Village referenced in the masterplan report is influenced by the need to provide quick access to robust buildings that are resilient to an Alpine Fault earthquake and large waves from landslide-induced tsunami. There are short lead times from severe ground shaking to wave impact (1-7 minutes depending on landslide location in the fiord), which severely limits refuge or evacuation options. Although the risk of a large rockfall from Barren Peak is relatively low, it is still best to minimise time spent in the area between the bluff and the ferry terminal where rockfall runout is more likely. This drives a significant move toward a low number of earthquake-resilient buildings that can withstand wave overtopping. The proposed village layout is influenced by this central philosophy. One requirement is for a multi-function land-based visitor hub where visitors can arrive, refresh, orient and group by ticket for events. Whether integrated with the visitor hub or standalone, the staff accommodation and hotel should also be built to withstand this scenario, along with smaller satellite bunkers or shelters, to improve land-based survival for staff or visitors who are further from the main building(s) when an event occurs. These shelters would serve tourism functions at other times (information, interpretation, experience, etc). Further probabilistic modelling is recommended to improve understanding of all stages of the tsunami.

- Adapting boats with lifejackets and/or flotation aids with more immediate access (e.g., lifejackets under each seat or flotation aids that can be deployed by staff within seconds rather than minutes). Training pilots in heavy wave conditions to improve survival prospects, as the wave pattern may be complex. Creating high hazard exclusion zones in shallower water and 150m or more from valley sides where boat traffic should be minimised. These will help to avoid direct hits from rockfall or landslides and allow space for better manoeuvring through waves. Further modelling of wave behaviour may aid in refining the proposed mitigation for boats.

- Visitors currently congregate and wait at the ferry terminal, however any queuing and ticketing should take place at the resilient hub as mentioned above, with shuttles taking passengers to the ferry terminal to load and depart as quickly as possible, minimising exposure in high hazard areas. Bunker and shelter provisions should be considered to provide some level of protection at these remote locations, considering peak number of visitors at any time.

- An idea has been proposed by other workstreams for a Bowen Falls Cable Car (or funicular). At a concept level, it has been suggested to follow adjacent to the existing hydropower pipeline to the top of the hill, with a pathway from the top station to a viewing platform near the top of Bowen Falls. Analysis by Dykstra (2012) suggests the Bowen hanging valley near the falls has been subject to a major landslide deposit of Barren Peak material in the order of 9,000 years ago and indicates that another similar large failure in similar location with sufficient runout distance and volume to overlap the proposed route is unlikely. Smaller rockfalls from Barren Peak such as occurred in 2019 tend to follow a route further south from the pipeline, although may also divert into the small watercourse that flows westwards as it approaches ground level. The design of the base station and early elevation profile for the new feature would need to consider this watercourse in addition to rock and debris falls. The proximity to the hydropower pipeline may present some benefit for future inspection and maintenance of the pipeline but would also need to be designed so as not to undermine the structural integrity of the pipeline or the hydropower building at ground level.

- Other masterplan ideas for Milford Sound Piopiotahi include additional walkways, changes to aerodrome and helicopter landing areas, parking, etc. From a hazard and visitor risk perspective, these changes have been influenced by the baseline hazard profile to maintain or reduce risk where possible. Execution of these enhancements would require further site-specific risk assessments and mitigation design through consenting and ongoing risk management processes.

- Homer Tunnel entrance risks could be partly reduced or managed whilst still offering viewing opportunities (outside high avalanche times) by creating a low profile rockfall shelter at Loop 2 just below the western entrance and a better protected parking area with rockfall shelter outside the eastern portal. The structure would need to be able to withstand regular avalanche and moderate rockfall. This could be achieved by a strong roof structure, optionally semi-circular in shape and partly sunken into the terrain, protected on the landward side with gabion walls. Structure options would be considered in detailed design.

- Whakatipu / Hinepipiwai Lake Marian carpark 'super track head' is proposed for additional short and longer walks, which would be notified as closed in the winter and/or during high avalanche periods. A site-specific risk assessment will be required to optimise the routes and risk exposure and set the criteria for track closures. Similar will apply to other proposed developments on the corridor, such as additional walking or cycling tracks.

- Cascade Creek and Knobs Flat both have some risk from flooding. Both sites would require some upgraded flood protection infrastructure, landscaping and scour protection, although given the high debris loads regular maintenance is likely to be required which should be factored into consents and costs. An upgraded walking track is proposed from Cascade Creek to a new tramping hut in Mistake Creek, not far from U-pass. Site specific assessment will be required to balance investment in upgrade and maintenance costs against residual risk tolerance for the target user groups (e.g. Back Country Adventurers and Remoteness Seekers), being clear on the associated branding and messaging.

- Te Anau developments will support the visitor hub, park and ride, bus facilities, etc. Although these are not yet fully developed, the draft options do not hold major risks or differentiators. All sites will require more detailed road safety assessments and additional road safety improvements on the existing network. Risks from natural hazards are considered low and would be managed by SDC/EMS following existing standard procedures.

In summary, for the highest potential impact of an AF8 event with landslide-induced tsunami at Milford Sound Piopiotahi, the collective mitigation measures in the Recommended Option are intended to transform probable outcomes from say an estimated 10 percent baseline survival rate in a large event to an aspirational target in the order of 90 percent survival rate (possibly higher, subject to further modelling, detailed design, mitigation planning and revised probabilistic risk assessment). Once further wave and risk modelling has been done, it is also advised to confirm the risk tolerability thresholds for extreme and/or societal risks, through consultation with various visitor sectors, staff, responder agencies and government bodies. The Recommended Option achieves one of the core requirements of the project to provide resilience to risk and change. It is not reasonably practicable to remove all risk, but the provision of mitigation through the Recommended Option, plus carefully balanced information for visitors and staff, will allow people to accept the residual risk and respond in the best way to promote their survival.

The Recommended Option represents a worthwhile investment in protecting lives and livelihoods. Even if the anticipated AF8 event does not trigger an immediate co-seismic landslide-induced tsunami, it is likely that Milford Sound Piopiotahi and Milford Road would close for a substantial period of time due to the heightened risk of aftershocks triggering further avalanches, rockfalls and landslides onto the road and/or into the Fiord (with associated tsunami). Such a closure to tourism could last a year or longer, depending on the effectiveness of mitigation and level of damage requiring re-build once aftershocks reduce to an acceptable level. Being aware of the risks and providing robust infrastructure will help to lessen the social shock and help to shorten the recovery period.

1 PROJECT BACKGROUND / DEFINITION

PURPOSE OF PROJECT

1.1 The purpose of the Milford Opportunities Project (MOP is to develop a collaborative Master Plan for the Milford corridor and Milford Sound Piopiotahi sub-regional area to ensure:

that Milford Sound Piopiotahi maintains its status as a key New Zealand visitor 'icon' and provides a 'world class' visitor experience that is accessible, upholds the World Heritage status, national park and conservation values and adds value to Southland and New Zealand Inc."

PROJECT AMBITION

1.2 The Milford Opportunities Project Master Plan must be world class, ambitious and creative. It should not be constrained simply by what can be done now within the current rules, instead it must consider what needs to be done and what the most appropriate outcome will be. The project is about making a substantive change and creative 'outside the box' thinking is needed before it is filtered by practical operation realities. The outcome must be:

- Consistent with the project's purpose and objectives.
- Consider a time frame of at least 50 years.
- Able to significantly enhance both conservation and tourism.

The Master Plan must give effect to the seven pillars (or values) identified in Stage One of the project and be supported by robust assessment and analysis.

PROJECT PILLARS

1) **MANA WHENUA VALUES WOVEN THROUGH**

Iwi's place in the landscape and guardianship of mātauranga Māori me te taiao (Māori knowledge and the environment) are recognised. Authentic mana whenua stories inform and contribute to a unique visitor experience.

2) **A MOVING EXPERIENCE**

Visitors experience the true essence, beauty and wonder of Milford Sound Piopiotahi and Murihiku / Southland through curated storytelling, sympathetic infrastructure and wide choices suited to a multi-day experience

3) **TOURISM FUNDS CONSERVATION AND COMMUNITY**

The visitor experience will become an engine for funding conservation growth and community prosperity.

4) **EFFECTIVE VISITOR MANAGEMENT**

Visitor are offered a world class visitor experience that fits with the unique natural environment and rich cultural values of the region.

5) **RESILIENT TO CHANGE AND RISK**

Activities and infrastructure are adaptive and resilient to change and risk, for instance avalanche and flood risks, changing visitor trends, demographics and other external drivers.

6) **CONSERVATION**

Manage Fiordland National Park to ensure ongoing protection of pristine conservation areas, while enabling restoration of natural ecological values in less pristine areas.

7) **HARNESS INNOVATION AND TECHNOLOGY**

Leading technology and innovation is employed to ensure a world class visitor experience now and into the future.

PROJECT OBJECTIVES

1.3 The objective for the MOP are:

a) Protect and conserve the place now and into the future.

b) Recognise iwi's place in the landscape, guardianship and values.

c) Increase the effectiveness, efficiency and resilience of infrastructure.

d) The visitor experience funds conservation growth and community prosperity.

e) Reduce visitor exposure and risk to natural hazards.

f) Increase the connection of people with nature and the landscape.

g) Offer a world class visitor experience that is unique and authentically New Zealand.

h) Identify sustainable access opportunities into Milford Sound Piopiotahi.

i) Identify parts of the built environment that are surplus to requirements or could be shifted to improve visitor function and resilience.

j) Identify opportunities to create additional economic benefit for the communities of Southland and Otago including Queenstown via the pulling power of Milford Sound Piopiotahi.

k) Develop a Master Plan that:

   i. Creates and encapsulates a unique experience.

   ii. Is culturally, environmentally and physically appropriate and sustainable.

   iii. Clearly articulates what is acceptable and what is not acceptable visitor management and development within the identified value framework.

   iv. Considers the impacts of climate change at place.

   v. Supports the economic stability of Te Anau, Queenstown, Southland and NZ Inc.

   vi. Portrays a clear future for investment.

   vii. Informs the review processes for Fiordland National Park Plan and Southland Coastal Plan.

   viii. Sets out the ideal governance and management structure to ensure successful delivery on the objectives.

WORKSTREAM OBJECTIVES

1.4 These Objectives were refined from Stage 1 and were agreed with the Governance Group during Stage 2. The application of the Objectives within this Workstream is shown in the table below.

Table 1: Application of Stage 2 Objectives

#	Stage Two Objective	Application to Hazards and Visitor Risk Review
1	Ngāi Tahu's role as mana whenua and Treaty partner is acknowledged and Te ao Māori values are embedded throughout.	Iwi to influence risk tolerability refinements, and mana whenua role within wider CDEM arrangements.
2	Milford Sound Piopiotahi is protected and conserved as required by its World Heritage status.	Resilient infrastructure that enhances visitor experience and tolerable risk/safety will support revenue generation to help fund all aspects of conservation (ecological, place and culture, including mitigation, maintenance and CDEM)
3	The visitor experience is world class and enhances conservation of natural and cultural heitage values and community.	Resilient infrastructure that enhances visitor experience and tolerable risk/safety will support revenue generation to help fund all aspects of conservation (ecological, place and culture, including mitigation, maintenance and CDEM)
4	Infrastructure is effective, efficient, resilient, and sustainable (including access methods).	Resilient infrastructure that enhances visitor experience and tolerable risk/safety will support revenue generation to help fund all aspects of conservation (ecological, place and culture, including mitigation, maintenance and CDEM)
5	Visitors benefit communities, including Ngāi Tahu, communities of Te Anau, Southland, and Otago.	Visitors generate revenue and enable jobs, resilient infrastructure and sustainable

#	Stage Two Objective	Application to Hazards and Visitor Risk Review
		access to the corridor and Milford Sound Piopiotahi with tolerable risk/safety

NATURAL DISASTERS AND COVID-19 IMPACTS

1.5 MOP stage 2 approach was impacted significantly by the 2020 Fiordland floods and then the COVID-19 pandemic.

1.6 Strategically, the consultant project team were required to be flexible in our approach and creative in our delivery. As a response to changing conditions we proposed methodologies to make allowance for factors such as lack of visitors, an initial inability to undertake site visits and at times a restricted or reduced availability of staff from external organisations.

2 SCOPE OF WORK: HAZARDS & VISITOR RISK REVIEW

2.1 The area is subject to a number of hazards and a clear understanding of the hazard risks throughout the project area will inform development the Master Plan and be used to assess the 'strategic options' against. This project will create a baseline of natural and human hazard risk and assessment for that assessment.

2.2 Hazards include but are not limited to climate change (eg. changing weather patterns, sea level, rise, etc), wind, slips, tree slides, rock fall, avalanche, flooding, alpine fault, tsunami, risks to personnel of getting to and from work/living in Milford, potential for marine and land-based oil spill, Homer tunnel, vehicle crashes, sinking vessels, etc.

2.3 The key outcomes of this project are to:

a) Produce a report that includes:

- An assessment of hazard risks (natural and human) for Milford Sound Piopiotahi and the national park road corridor to, and including, Te Anau Basin.
- Maps identifying hazards where appropriate.
- An evaluation and summary of existing information to inform Master Plan development and outcomes.
- A specific evaluation of locations through the project area linked to the 'strategic options' included in the Master Plan and other workstreams including Land Capability Analysis, and Infrastructure Assessment.
- Comment on the level of hazard risks to visitor safety and experience and infrastructure development.

b) Contribute information to the Master Plan that enables the identification and development of strategic options.

3 BASELINE: CURRENT STATE / EXISTING CONDITIONS

CONTEXT

3.1 Visitor risk is a function of hazard probability, exposure (presence or concentration of visitors in relation to hazards, including visitor vulnerability) and the impact (direct and indirect threat to life, health, property, etc). This chapter will first look at the infrastructure that enables access and lifelines to visitors, and at some current patterns of visitor movements as an influencing factor on risk exposure. With that background, the three levels of hazard exposure scenarios are used to discuss baseline risks to visitors during increasingly rare but potentially damaging types of events.

3.2 Due to the focus of the project, slightly more emphasis is placed on Milford Sound Piopiotahi and sites within the Eglinton Valley and Te Anau corridor that are identified as key components of visitor risk and/or sites considered through the option development process. Manapouri and Doubtful Sound Patea are mentioned briefly where information allows.

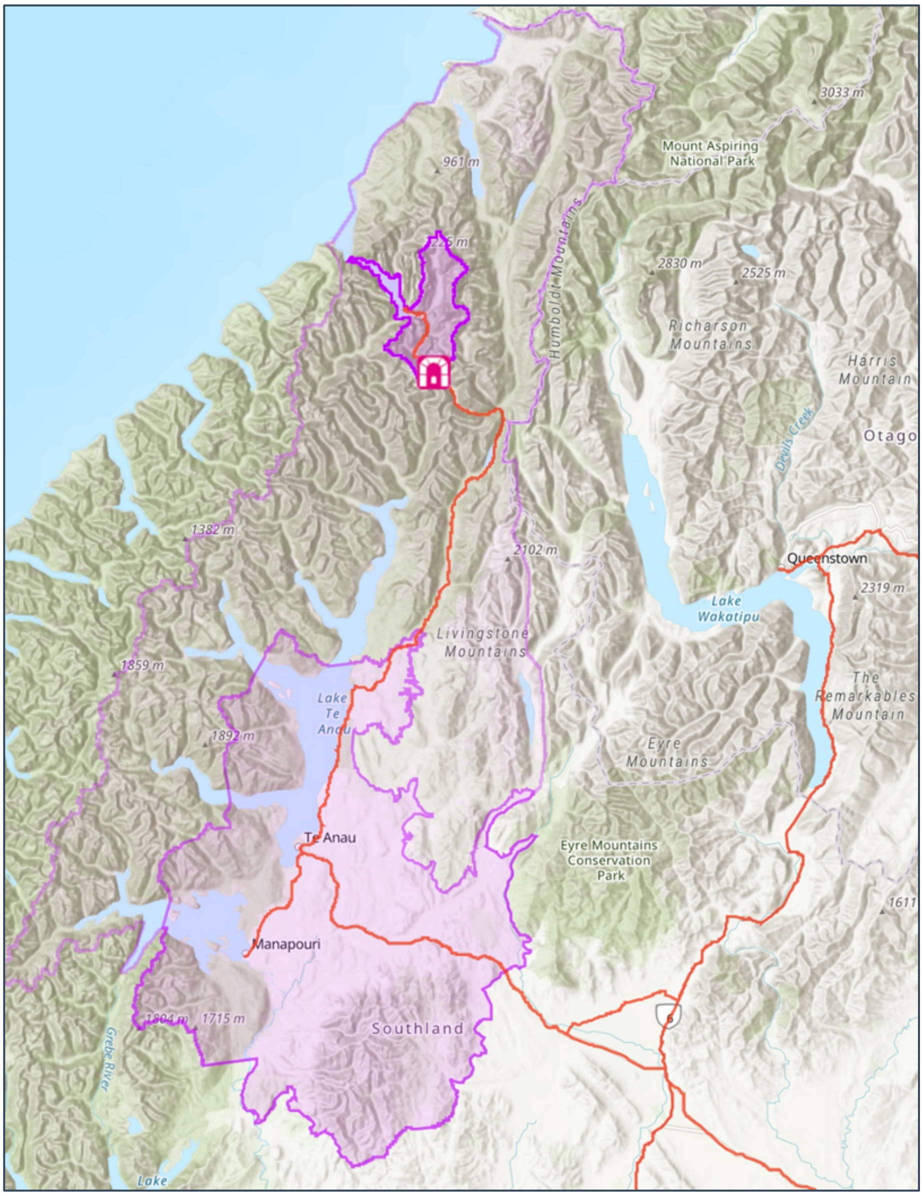


Figure 1: Milford Sound Piopiotahi main study area of interest and regional context

INTRODUCTION TO ORGANISATIONAL ARRANGEMENTS

3.3 Individuals and organisations both have a role in enabling visits to the area to be undertaken with tolerable risk, that is reasonably aligned with visitor expectation, understanding and acceptance of risk.

3.4 Individuals, for example, can seek to be informed and pay attention to information or notices regarding risks, safe driving (including realistic journey times), understanding safe boundaries (especially when taking photographs) and being aware of weather (hiking/ tramping or driving).

3.5 Many organisations, however, have specific legal responsibilities or opportunities to identity and reduce risks, provide safe infrastructure, help influence or promote safe public behaviour (through developing and/or implementing guidance, providing online information, signage, and staff) and to help deal with accidents or incidents at various scales (response and recovery). These organisations may include voluntary groups, operators or regional/national authorities. Table 2 provides a summary of organisations, key roles to visitor safety or incident management and spatial coverage across the four geographical areas.

Table 2: Organisations key safety responsibilities

Organisation	Key role in visitor risk management	Milford Sound Piopiotahi	Corridor	Te Anau and Manapouri	Doubtful Sound Patea
Operators and Concession holders	This 'group' covers scenic cruise boat operators (Real Journeys, Go Orange, Jucy, Southern Discoveries, Mitre Peak Cruises), tour bus operators, guided hike operators (e.g. Ultimate Hikes), Milford Sound Piopiotahi Underwater Observatory (Southern Discoveries), kayak tour operators, etc. They each have responsibility to identify, minimise and mitigate risks to clients under their supervision/care, by following their own plus regional / national safe operating practices, and are often the local first line of response in any emergency. In a larger scale emergency, these groups would liaise with regional coordinators where communication allows, and helicopter and/or boat operators are likely to be involved in evacuating people to Te Anau, Queenstown or Bluff (by boat) if the need arises.	Yes	Yes	Yes	Yes
Clubs and groups	Groups and/or clubs for hunters, fishing, hiking/tramping, plus local volunteer organisations or charities. This includes local/regional search and rescue teams (such as those in Te Anau and the Milford Sound Piopiotahi Emergency Response Team) who are largely voluntary in addition to their employed day-jobs.	Yes	Yes	Yes	Yes
Milford Sound Piopiotahi Infrastructure	Provision of safe drinking water and electricity, plus communication infrastructure, etc (refer to section on infrastructure)	Yes	No	No	No
Milford Sound Tourism	Provision of tourism infrastructure in Milford Sound Piopiotahi. They own and operate the harbour, wharves, visitor's terminal and parking in Milford Sound Piopiotahi, and run the wastewater plant and the rubbish and recycling systems.	Yes		No	No

Organisation	Key role in visitor risk management	Milford Sound Piopiotahi	Corridor	Te Anau and Manapouri	Doubtful Sound Patea
Milford Road Alliance	A partnership between Waka Kotahi NZ Transport Agency and Downer NZ, to ensure the safe and efficient management of activities on State highway 94 between Te Anau and Milford Sound Piopiotahi. These include active avalanche control, incident response, managing the Homer Tunnel and general maintenance for the route.	Yes	Yes	No	No
Department of Conservation	DOC is the government agency charged with conserving New Zealand's natural and historic heritage, under the National Parks Act and a variety of other legislation (refer to Task 7 report "Governance, Management and Legislation"). This includes duties to assess, manage and provide information on risks at DOC visitor destinations.	Yes	Yes		Yes
Iwi / Ngāi Tahu	Te Rūnanga o Ngāi Tahu have an important role in Iwi and Mana Whenua risk awareness and response within their own networks of Whanua and to the wider community as demonstrated by their tremendous support following the Christchurch 2011 and Kaikoura 2016 earthquakes, and the appointment of Robyn Wallace as General Manager Emergency Preparedness and Climate Response to ensure this capacity is maintained and developed.	Yes	Yes	Yes	Yes
Southland District Council	SDC's role not only encompasses the management and improvement or regulation of some physical assets such as buildings, 3-waters, roads and bridges, but also the Southland communities' social, economic, cultural and environmental wellbeing. *Area office in Te Anau, main office Invercargill.	Yes*	Yes*	Yes*	Yes*
Environment Southland	As the regional council, Environment Southland is responsible for the sustainable management of Southland's natural resources - land, water, air and coast - in partnership with the community. Key member of Emergency Management Southland and responsible for flood protection.	Yes*	Yes*	Yes*	Yes*

Organisation	Key role in visitor risk management	Milford Sound Piopiotahi	Corridor	Te Anau and Manapouri	Doubtful Sound Patea
Emergency Management Southland	Emergency Management Southland (formerly Southland Civil Defence Emergency Management Group) was stablished by the four Southland Councils (Environment Southland, Invercargill City Council, Gore District Council, Southland District Council), and is responsible for the delivery of Civil Defence and Emergency Management responses throughout the region. The Emergency Coordination Centre helps to manage the linkage between local organisations providing support on the ground to regional and national resources where appropriate. This is clearly an important role given the number of organisations in this table. They also have responsibilities under Section 17 of the CDEM Act 2002 to assess future risk scenarios to inform management readiness and response. They work with scientific community (e.g. GNS and universities) to understand seismic and tsunami risks, as discussed extensively through this report.	Yes*	Yes*	Yes*	Yes*
Waka Kotahi, NZ Transport Agency	Lead member of Milford Road Alliance, plus wider responsibilities for provision of an efficient, effective and safe land transport system.	Yes	Yes	Yes*	Yes*
Ministry of Transport	The Ministry of Transport is the government's principal transport advisor, setting policy in relation to land transport (NZ Transport Agency) and air (Civil Aviation Authority and Airways NZ)	Yes*	Yes*	Yes*	Yes*
NZ Police	Supports public safety and law enforcement and collaborates with other organisations for emergency management at all scales. *Nearest police station is in Te Anau.	Yes*	Yes*	Yes*	Yes*
Fire and Emergency NZ	The Fire and Emergency New Zealand Act 2017 combined urban and rural fire services into a single, integrated fire and emergency services organisation. Their principal objectives include reduction of unwanted fires and protecting and preserving life, and preventing or limiting injury, damage to property, land and the environment. The Act includes response to natural hazards and disasters subject to capability, capacity and provided this does not affect their ability to carry out main functions. There are voluntary fire brigade points of presence in Milford Sound Piopiotahi, Te Anau and Manapouri.	Yes	Yes*	Yes	Yes*
NZ Defence Force	The Defence Act 1990 also allows the Armed Forces to be made available for the performance of public services and assistance to the civil power in time of emergency.	Yes*	Yes*	Yes*	Yes*

**Remote organisation with local responsibilities*

3.6 Many of these organisations have been involved in the response to major incidents in recent years, such as earthquakes in Christchurch (2011), Kaikoura (2016), 2020 floods and COVID-19 response. These events have stimulated development of knowledge, skills, communication pathways, relationships and capacity of the emergency response mechanisms. However, there are policy-level challenges that need to consider hazards such as AF8 and landslide-induced tsunami concerning tourism and the White Island 2019 incident. The 2020 floods and Covid-19 impacts are also placing considerable financial pressure on the tourism industry, which has the potential to reduce knowledge and capability in front-line safety and emergency response.

3.7 Te Anau and Manapouri are more urban towns with conventional treatment and management of risks, with SDC leading that responsibility (but not exclusively). Doubtful Sound Patea is more similar to Milford Sound Piopiotahi, as it is in the Fiordland National Park under DOC-led jurisdiction but is even more remote to access than Milford Sound Piopiotahi.

INFRASTRUCTURE AND LIFELINES

3.8 Despite its remote location, there is considerable amount of infrastructure in the Milford Sound Piopiotahi corridor and village. Much of this infrastructure is tourism focussed and seeks to provide reasonably safe access for visitors, but also carries important additional functions. Where it is designed and managed well, infrastructure can serve to reduce exposure to hazards or mitigate risks and forms important lifelines for safety during or evacuation from a hazardous scenario. Therefore, need to consider not only the vulnerability of visitors, but also of lifeline infrastructure and organisation arrangements. This concept will be expanded throughout this baseline chapter and will be part of the lens when looking at future options for Milford Sound Piopiotahi.

3.9 The Task 5 report on Infrastructure (Baseline Section) includes details of existing infrastructure for the communities and visitors of Milford Sound Piopiotahi, Te Anau, and Manapouri. The following sections summarise pertinent information particularly where it relates to visitor risk and/or mitigation.

3.10 The lifelines are commonly designed/constructed and operated by different organisations. This makes it more difficult to assess system-wide resilience. For example, the water supply may have additional redundancy / resilience options, but if these are all fully reliant on a single electricity supply, this could reduce system resilience. It was not within the masterplan scope to perform a system-wide resilience assessment, but relevant vulnerabilities are highlighted below where information allows. There may be additional components not reflected in this report.

MILFORD SOUND PIOPIOTAHI

3.11 Milford Sound Piopiotahi is very isolated with a high probability of the road being blocked in a major event, such as a large earthquake or flood event. Therefore, it is important to understand lifeline infrastructure locally within the village to sustain life, especially for a few days until people can be evacuated by air or boat, which could be subject to delays from bad weather. It is anticipated that after a major event, it will take a long time to repair infrastructure, and for a major earthquake the risk of aftershocks (causing further landslides, rock falls, debris flows and heightened possibility of landslide-induced tsunami) means that Milford Sound Piopiotahi may be closed to residents and tourists for 1-2 years. This influences the drivers for system-wide infrastructure resilience differently from a large city with many people living there permanently.

3.12 A high-level overview of Milford Sound Piopiotahi is provided in Figure 2, with key locations annotated. This is followed by drawings illustrating existing infrastructure networks. Some of these are owned and operated by different organisations and may have components that are reliant on one another, e.g., water pumps reliant on power. Whilst there appears to be some measures taken toward resilience, e.g., some operators storing additional water on site. However, having systems reliant on each other belonging to multiple owners makes it difficult to perform a system-wide resilience assessment. Further discussion on elements of the network are provided in the subsections below.

Figure 2: Milford Sound Piopiotahi overview

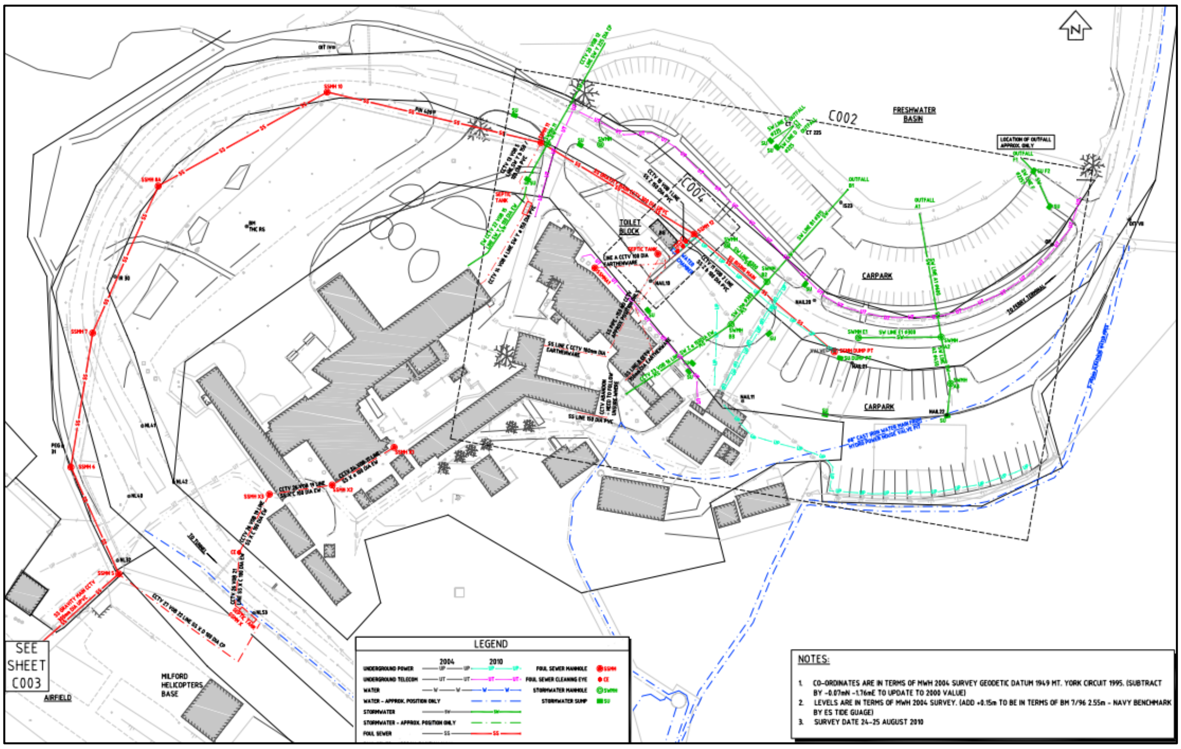


Figure 3: As-built infrastructure networks within Milford Village

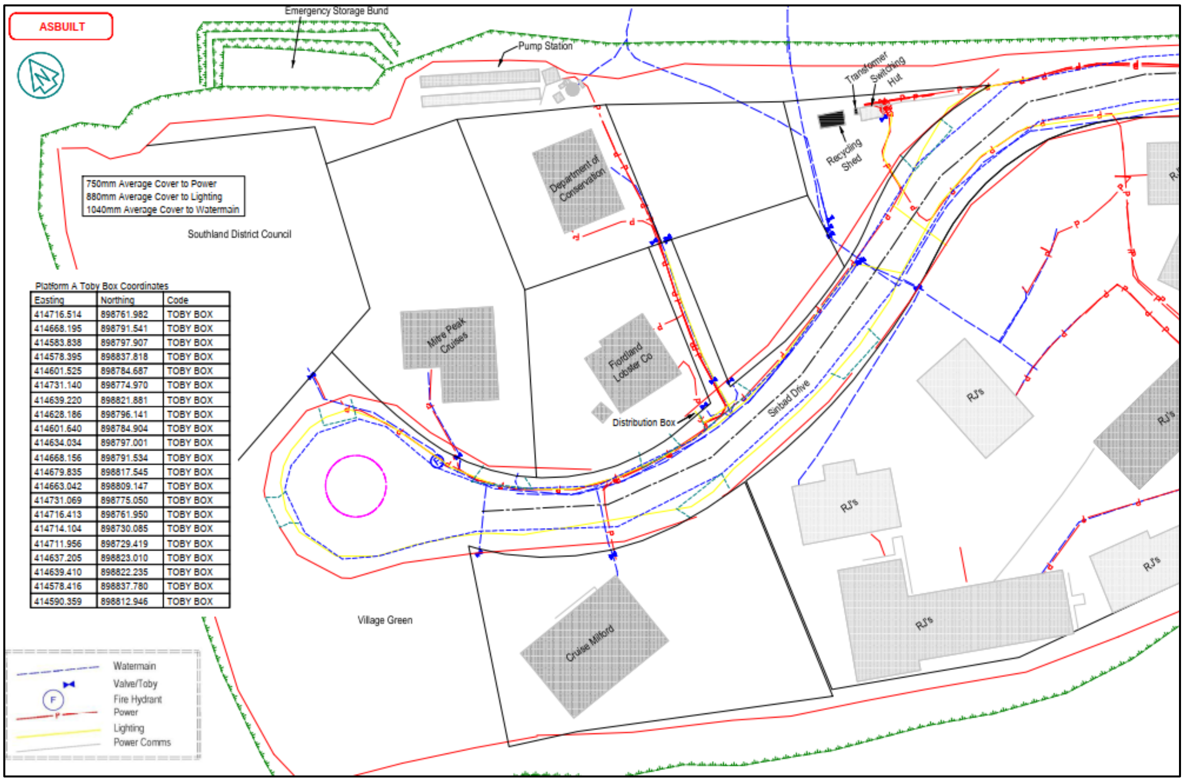


Figure 4: As-built infrastructure networks within Cleddau Village

WATER SUPPLY

3.13 Milford Sound Piopiotahi's water supply is owned and operated by Milford Sound Infrastructure, and primarily sourced from the hydro scheme penstock at Bowen River. The water is treated by filtration and ultraviolet (UV) disinfection and stored in two storage tanks of 85m^3 and 45m^3 capacity (providing approximately 12 hours of storage at peak flow). Several of the operators who maintain staff accommodation in Milford Sound Piopiotahi have water storage tanks that act as a backup when the main water supply is unsuitable. This can occur if high turbidity is measured, or a boil water advisory is issued.

3.14 A bore (5L/s) has recently been installed by Milford Sound Infrastructure Ltd to provide a supplementary water source in the event of damage to the hydro scheme penstock.

3.15 Most of the reticulation network has been replaced over the past 20 years and is assumed to be in good condition.

3.16 The water supply from the Milford Sound Piopiotahi hydro scheme is vulnerable to both flood and earthquake damage, as is the reticulation network. Less catastrophic but more frequent disruption occurs due to high turbidity of the water supply in flood events. As there is limited storage within the network, the water supply system is relatively vulnerable to disruption from a large natural hazard event, especially when considering the potential for large numbers of people on site during peak times.

WASTEWATER

3.17 The wastewater network and wastewater treatment plant (WWTP) in Milford Sound Piopiotahi is owned and maintained by Milford Sound Tourism Ltd. Some properties have private septic tank systems and are not connected to the wastewater network.

3.18 The Milford Sound Piopiotahi WWTP is an older plant that is currently undergoing upgrades, though historically this plant has been compliant with all discharge consent conditions.

3.19 The WWTP is located on the Cleddau delta adjacent to the airport, and discharges treated effluent to Deepwater Basin. The plant is potentially vulnerable to seismic damage in a sufficiently large earthquake, which could also lead to soil liquefaction damage. The plant also sustained some damage in the February 2020 flooding event.

STORMWATER

3.20 There is limited stormwater infrastructure within Milford Village. The system may require upgrades to meet more stringent discharge quality requirements in the future, such as the addition of stormwater treatment facilities for road and carparking systems.

3.21 Given the high rainfall in this area, overland stormwater flow can occur posing risk to buildings, such as occurred in the February 2020 flood event. After rockfalls or landslides, the spatial distribution of debris may cause overland flow paths to change.

POWER

3.22 Electricity is generated at Milford Sound Piopiotahi from a run-of-river hydroelectric scheme on the Bowen River, with backup diesel generation. The scheme is operated by Milford Power Holdings (a company affiliated with Milford Sound Infrastructure).

3.23 Power is distributed through a 3.3kV backbone network feeding 240v 3-phase cables. The whole network is underground. The network is a star configuration with no duplication but is considered reliable with most cables being installed within the past 20 years. Fault conditions can be mitigated by back feeding or utilising generation located around Milford Sound Piopiotahi.

3.24 There is a back-up diesel generator to provide power if the hydro fails. There are a few days of diesel supply available at the generator site, and in longer outages, operation of the diesel generator is dependent on either diesel supply by road or alternative supply of diesel from the boat fuel stocks.

3.25 Milford Sound Piopiotahi's electricity supply is vulnerable to flood and seismic hazard. The hydropower plant requires maintenance following floods and other events and is not considered highly robust.

TELECOMMUNICATIONS

3.26 Telecommunications are a key factor in rapid emergency response, whether a medic needing to be flown to the site of a vehicle accident or coordinated regional response to a major disaster.

3.27 There is currently no cell phone coverage at Milford Sound Piopiotahi , and only limited coverage on Milford Road. Telephone services are currently available at Knobs Flat (card-phone), from Homer Tunnel (satellite phone for emergency use only) and Milford Sound Piopiotahi (card-phone). Under the Mobile Blackspot Program operated by Crown Infrastructure Partners, coverage will be rolled out to Milford Sound Piopiotahi , Doubtful Sound, Knobs Flat and key visitor locations along Milford Road (among others) in 2021.

3.28 The telephone system into Milford Sound Piopiotahi is owned and operated by Chorus. Currently, the system operates on a microwave link with multiple repeaters at high alpine locations, plus a fibre cable from Mt Prospect to Te Anau (see Figure 5). The radio link has limited band width of 2Mb/s total supporting up to 30 simultaneous phone calls for the 76 customers and does not provide an internet connection. Plans are in development to extend the fibre connection from Te Anau to Milford Sound Piopiotahi in the future.

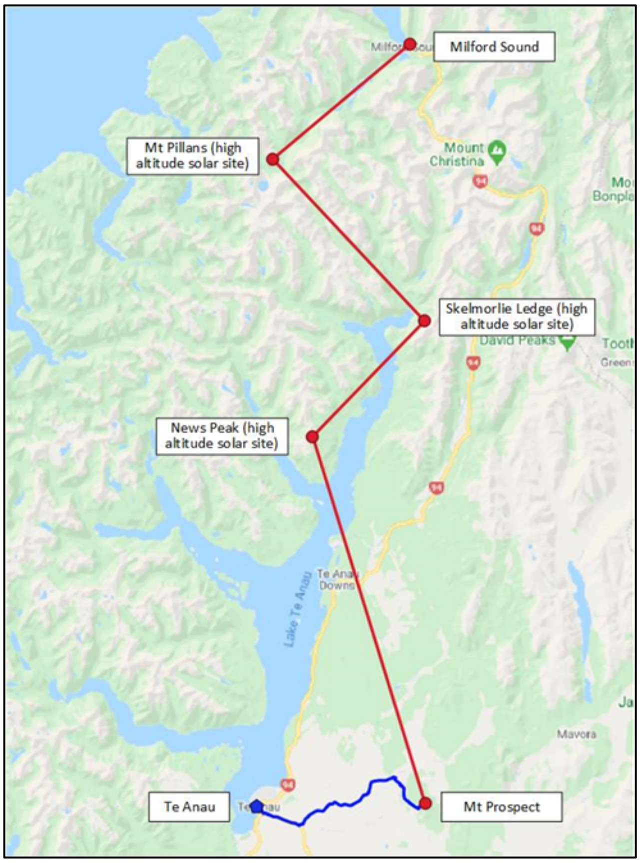


Figure 5: Chorus radio link to Milford Sound Piopiotahi (Source: Chorus)

3.29 The high-altitude repeaters can only be serviced using helicopter access. This system is built reasonably well but relies on solar panels with batteries for approximately 10 days backup. The microwave system is vulnerable to wind, snow, lightning and earthquake damage to the infrastructure, with outages thought to occur every 1-2 years. Currently, provision is planned for future fibre optic cable to be laid along the road from Te Anau, with a number of junctions / break-out points near key visitor locations. Works in the Homer Tunnel have included ducting for this proposed cable. The robustness of a cable vs. the microwave link remains to be proved, as the road is subject to rockfall and avalanche hazard from above and flooding which can trigger scour and damage of road shoulder and culverts and slip failures below. This may have been assessed as part of the roll out plan, but there is no current information on its anticipated reliability to natural hazards.

3.30 There are multiple communication radio systems into Milford Sound Piopiotahi. These include the DOC's radio repeater system; Ultimate Hikes VHF radio system with multiple repeaters back to base at Queenstown; Marine Radio (multiple channels); airways (multiple channels) and the system used by the Milford Road Alliance.

3.31 The Milford Road Alliance operate the most extensive radio system in the area. This involves multiple analogue and digital repeaters into Milford Sound Piopiotahi and provides coverage along the road. This has significant bandwidth and handles eight live feed cameras from along the road and the tunnel to Te Anau. The live feed cameras are only useful when weather conditions allow.

3.32 There are multiple private satellite telephones in the area, including Real Journeys and Ultimate Hikes. Satellite communication is dependent on a satellite being available within line of sight. The topography can make line of sight to the limited number of satellites difficult. Satellite connections provide limited internet access for staff and guests at Milford Sound Lodge.

TRANSPORTATION (AIR, ROAD AND SEA)

3.33 Transport routes are essential for getting emergency support into site and/or for evacuation. This can cover air, road or sea (generally in that order of preference in an emergency due to speed / travel time). Further information on transport infrastructure and access is provided in the Task 4 (Transport and Access) report. Pertinent details are captured here, with a high-level assessment of vulnerabilities in relation to hazards and visitor risk. A detailed computational probability or engineering impact assessment of any infrastructure is beyond the scope of the master-planning project.

3.34 Milford aerodrome is located on the Cleddau delta (Figure 6).

Figure 6: Milford Aerodrome location

3.35 The capacity of the aerodrome is limited by the runway length and geographical constraints. The aerodrome is surrounded by water on three sides and steep mountains on the remaining side. At present, the aerodrome is suitable for light to small aircraft and helicopters only.

3.36 The Milford aerodrome runway is vulnerable to flooding (fluvial, tidal), especially at the north-western end where the pavement elevations are the lowest. The delta has liquefiable soils and may be vulnerable to damage in a seismic event, which may limit its reliability for fixed-wing aircraft for emergency evacuation post-earthquake.

3.37 Flights can be restricted due to adverse weather, which can delay access to emergency support and/or evacuation.

3.38 From Milford Sound Piopiotahi , it is approximately a 40-45 minute flight to Te Anau or Queenstown.

3.39 A key feature on SH94 between Te Anau and Milford Sound Piopiotahi is the Homer Tunnel. It was constructed between 1934 and 1953, is 1.27km long, has a 10 percent gradient and varies in width from 6.5 to 7.5m. Whilst capable of two-way operation, it is normally traffic-signal controlled for one-way operation, which requires vehicles to queue on approach from either the east or west.

3.40 The Milford Road and Homer Tunnel are vulnerable to closures due to avalanche, flooding, rockfall and other hazards described in this report. This poses risks not only at the sites of hazard, but also renders the road unreliable as an access/egress route for lifeline services.

3.41 Carparking and corridor assessment for vehicle traffic and road safety concerns is reported in the Task 4 (Transport and Access) report.

3.42 The main terminal for transferring passengers on to boat trips out to Milford Sound Piopiotahi is in Freshwater Basin. This building is owned and managed by Milford Sound Tourism (formerly the Milford Sound Development Authority). A $6.2 million upgrade of the terminal facilities was completed in 2012, including relocation of the existing breakwater, dredging to enlarge the harbour, replacement and realignment of floating wharves and extension of the visitor terminal deck.

3.43 On the southern side of the delta at Deepwater Bain are berthing facilities and landward infrastructure for the Fiordland cray-fishing fleet, sea kayaking and ecotourism ventures. Private boat owners can use the Milford Sound Piopiotahi boat ramp (a concrete dual access ramp, with parking available) at Deepwater Basin Road. The current boat ramp requires repair, and investigations are underway.

3.44 Berthing facilities and landward infrastructure, including terminal facilities, may function as an evacuation route if the road is blocked and flying is restricted.

3.45 In the February 2020 flooding event, the visitor centre and parking areas, as well as accommodation within Cleddau Village were flooded. Over 360 people were stranded by the flooding, with some moved to Mitre Peak Lodge or staying on boatts until they could be airlifted out.

DOC HUTS AND TRACKS

3.46 Huts can form an important refuge for hikers, particularly during adverse weather or other incidents.

3.47 Huts on the Milford Track are in the ‘Great Walk’ category and have cooking facilities (including gas), heating, lighting (solar power), water supply and flush toilets (serviced by septic tanks).

3.48 Homer Hut is a 30-bunk hut located just off Milford Road before Homer Tunnel and owned by the NZ Alpine Club. The hut has gas cooking facilities, water from a roof collection system, solar lighting, a radio and long-drop toilets.

3.49 There are numerous other huts located within the Fiordland region, which are typically ‘standard’ huts with fireplaces, long-drop toilets and basic water supplies (typically from roof rainwater collection).

3.50 Tracks are inspected periodically and require regular maintenance to keep a moderately safe route through boulder fields and debris falls, especially after minor quakes or moderate floods. Many tracks are within mountainous environments with mobile geology and are subject to damage through erosion or material deposition in storm events. For example, the February 2020 floods caused damage to over 78 tracks on public conservation land in Southland and Westland.

Figure 7: Damage to Routeburn Flats Bridge, Routeburn Track (Image credit: DoC)

TE ANAU AND MANAPOURI

3.51 The figures below provide an overview of three waters infrastructure in Te Anau and Manapouri. The network services are managed by SDC, working in line with national drinking water standards. Further discussion is provided in the sub-sections below.

Figure 8: Te Anau 3 Waters Network. (Source: Southland District Council GIS)

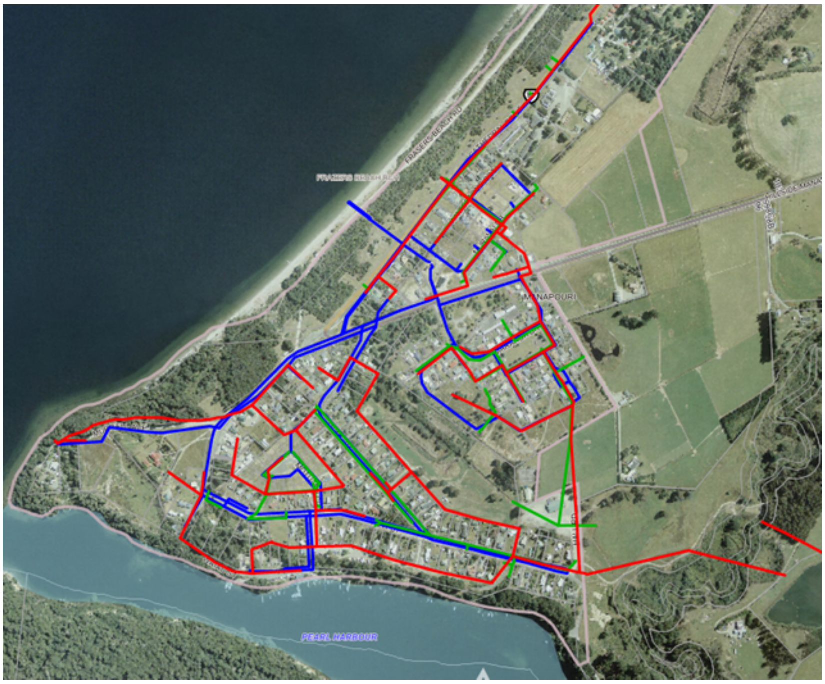


Figure 9: Manapouri 3 Waters Network (Source Southland District Council GIS)

WATER SUPPLY

3.52 Te Anau's water supply is sourced from groundwater via shallow bores adjacent to Lake Te Anau, and Manapouri's from Lake Manapouri. Both reticulation networks require staged renewals, particularly for ageing 1960's Asbestos Cement (AC) pipes. Firefighting water supply capacity is poor in Manapouri, and the potable water system includes limited storage. Water loss is relatively high (estimated at 46 percent in Te Anau and 20 percent in Manapouri).

3.53 Upgrades are scheduled for the both the Te Anau ($8.4M) and Manapouri ($1M) water treatment plants (WTPs). However, the Manapouri WTP is at risk of non-compliance against drinking water standards due to high turbidity. Resolution of this issue is part of current planned upgrades. Both plants are likely to need process upgrades to meet increasingly strict drinking water quality requirements under Taumata Arowai in conjunction with future growth.

WASTEWATER

3.54 Both Te Anau and Manapouri are serviced by reticulated wastewater networks with modern WWTPs.

3.55 The Te Anau and Manapouri wastewater networks are in fair to good condition. Upgrades are scheduled or underway for both Te Anau and Manapouri WWTPs. The upgrades will include some allowance for population growth and process improvements, but further investment is likely to be required in the future to meet increasingly strict discharge standards and population or visitor growth associated with the recommended tourism options.

STORMWATER

3.56 Both Te Anau and Manapouri are served by reticulated stormwater networks, with little to no stormwater treatment. With regulation changes pending for stormwater discharges and increasingly stringent water quality standards, it may be necessary to retrofit both stormwater networks with improved treatment in the future.

3.57 Some of the stormwater systems are at risk from natural hazards. For example, the discharge into the Upukerora River in Te Anau is affected by gravel aggradation, causing pipe blockage and backup within the network.

POWER

3.58 The Power Company Limited have a zone substation to supply Te Anau, Manapouri and surrounding rural areas. The substation is a 66kV structure with two 66kV circuit breakers, supplying two 66/11kV 9/12MVA transformers. The system is part of the northern 66kV ring supplied from Heddon Bush. The substation has AAA security classification, the highest rating.

3.59 The SDC wastewater pipeline route from Te Anau to Manapouri is immediately adjacent to an existing 11kV cable. The cable will be relocated and upgraded to provide additional capacity, as part of the Te Anau wastewater upgrade project.

TELECOMMUNICATIONS

3.60 Spark and Vodafone mobile coverage is available in Manapouri and Te Anau. Resilience of the local network is important to enable effective emergency response into Milford Sound Piopiotahi and Milford Road. Regional response would also require communication with other resources in Queenstown and Invercargill.

TRANSPORTATION

3.61 Refer to the Task 4 (Transport and Access) report for comments on the road network into the area and corridor.

DOUBTFUL SOUND PATEA

3.62 Very little asset information was found or readily available for Doubtful Sound Patea in the initial information collection and screening. The Doubtful Sound Patea hazards are discussed briefly in the relevant hazards' sections, where sufficient baseline information was found in the initial screening. The Master Plan option development did not highlight major development shifts in Doubtful Sound Patea, so the investigation into the baseline infrastructure and risks was not as comprehensive as Milford Sound Piopiotahi or the SH94 Corridor.

INTRODUCTION TO EXISTING VISITOR DISTRIBUTION

MILFORD SOUND PIOPIOTAHI

3.63 To understand the exposure of visitors to various hazards, visitor numbers and journey types must be identified, including indicative spatial and temporal distributions (visitor concentrations, time of day and seasonal patterns).

3.64 Excluding cruise-liner visitors (as they do not disembark in Milford Sound Piopiotahi), over 80 percent are international visitors (2019 data). Most of these international visitors, and a sizable proportion of the domestic visitors, go into the DOC visitor category of Short Stop Traveller. This category generally has a low level of risk tolerance and may not have the awareness, experience, fitness or skills to understand and manage risk exposure in a remote location. As the dominant visitor group, DOC policy[2] (and common sense) dictate managing risks to cater at least for the dominant visitor category. There may be additional considerations for more vulnerable visitors that can be managed by advising only short excursions from vehicles or buildings on high quality wheelchair-friendly pathways as opposed to longer excursions on variable grade paths.

3.65 Additional insights on visitor movements are available in the baseline chapter of the Tourism Workstreams Report.

3.66 Discussions to date suggest the data is not available to gain an accurate spatial or temporal idea at sub-daily interval other than vehicle counts through the Homer Tunnel. The vehicle counts include buses and multi-person vehicles, so individual count is significantly higher than these numbers, estimated at an average of about 4.4 persons per vehicle (Figure 10). The 2019 seasonal distribution is provided in Figure 11, which shows the strong seasonal pattern in vehicle numbers. This is also evident in the monthly scenic cruise data, with monthly passenger totals of ~113,000 in January 2019 (averaging approximately 3,650 daily) and ~27,000 in August 2019 (averaging approximately 870 daily).

[2] DOC Visitor Risk Management Policy, 2017

3.67 The majority of the large cruise ship passengers (222,000 in 2019) who also pass through the region are normally in the summer.

3.68 Use of the Milford Track is not supported by DOC, along with the other Great Walks out of season from late April to late October. Experienced climbers who use the track in Winter do so at their own risk and require understanding and skills in Alpine/avalanche risk management and river crossings (since some bridges are removed to reduce damage). The tracks can expose unsuspecting hikers to rapid changes in conditions at any time of year, but particularly in winter or the shoulder seasons (autumn and spring).

3.69 Whilst not a complete picture of all visitors to Milford Sound Piopiotahi, the above illustrates a significant reduction in visitor presence and hazard exposure during the winter months. However, the seasonal avalanche hazard, snow on the road, and increase in tunnel closures, will increase the hazard exposure of those who do visit. This is discussed further in subsequent sections of this report.

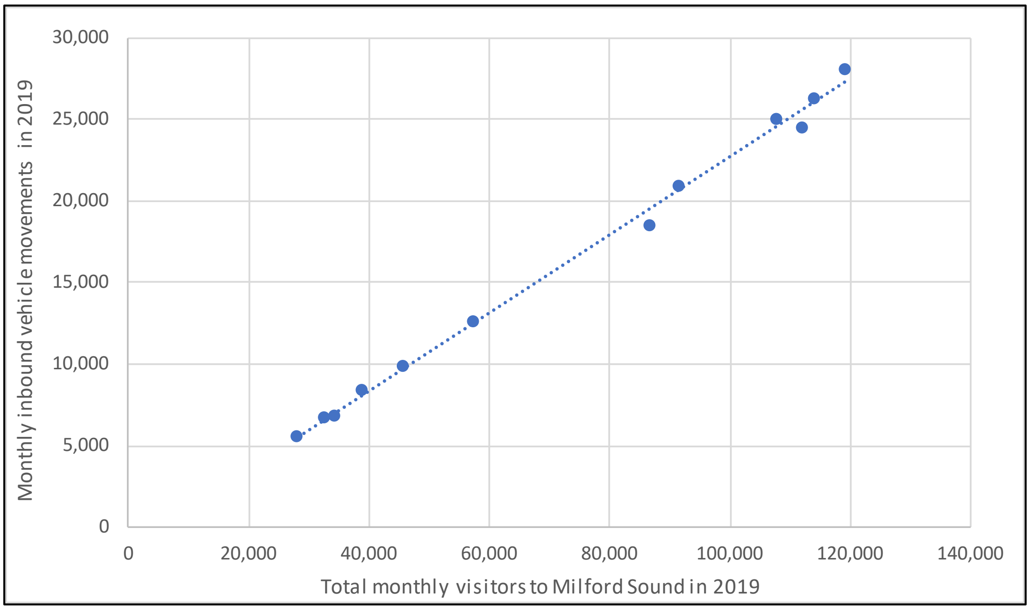


Figure 10: Relationship between vehicles and total visitors

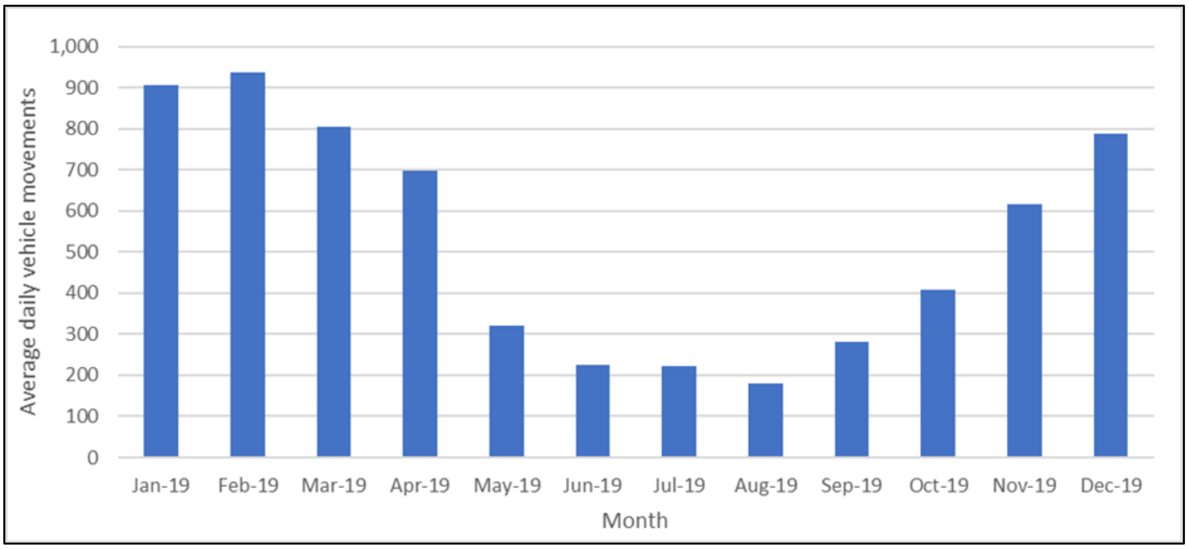


Figure 11: Homer Tunnel monthly in-bound vehicle movements in 2019

3.70 The Homer Tunnel inbound and outbound vehicle counts are shown in Figure 12, including a cumulative calculation of vehicles on the Milford Sound Piopiotahi side of the tunnel. These numbers include buses and high occupancy vehicles, and exclude additional visitors arriving by cruise ship or on foot. They also exclude those arriving by air travel (around 5 percent) and may be influenced by local overnight stays (staff and hotel accommodation, plus campers), so the estimated maximum number of people on the Milford Sound Piopiotahi side of the tunnel during peak times is estimated to be over 3,000. This is confirmed by the number of scenic cruise boat participants, which was 5,771 on the busiest day (Chinese New Year 2018); approximately 5 percent did not take a scenic cruise, therefore this puts the total number of visitors on the day over 6,000, of which more than half are present in the middle of the day. The daily total is currently less than 1,000 in winter. The peak occupancy of over 3,000 represents a large number of people exposed to a major event, such as a large earthquake or catastrophic landslide-induced tsunami. In winter, when the road is not closed due to weather, this number is likely to be less than 1,000. Additional insights on visitor movements are available in the baseline chapter of the Tourism Workstreams Report.

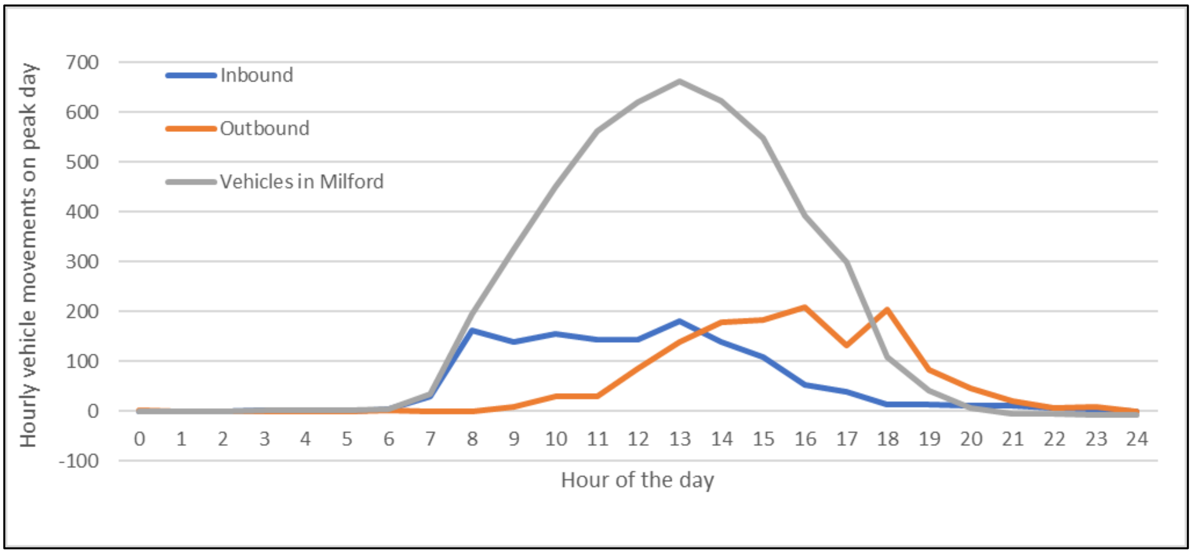


Figure 12: Homer Tunnel vehicle counts on a peak day in 2019

3.71 Although there is not accurate spatial data on peak occupancy, a rough estimate of land-based peak occupancy is provided in Figure 13. The total is well below 3,000, partly due to a large number of people on scenic cruise boats at peak times (potentially 1,000 people, excluding major cruise liners), and some between the tunnel and Milford Sound Piopiotahi , or vice versa. This highlights the potentially large number of fatalities in a major earthquake and/or landslide-induced tsunami, as there is very little time or space to seek refuge.

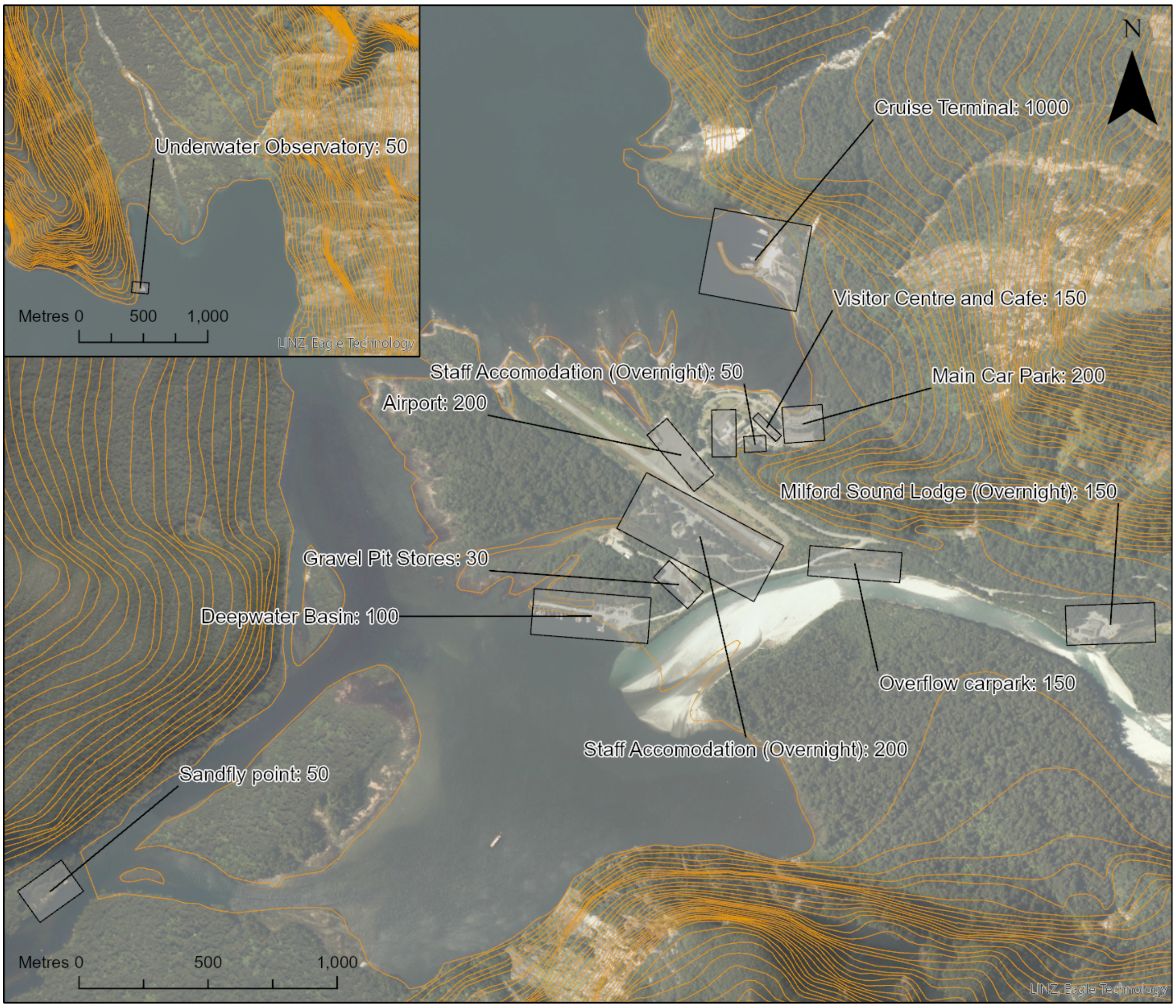


Figure 13: Approximate land-based spatial peak visitor concentrations

TE ANAU AND MANAPOURI

3.72 Te Anau has many pass-through visitors traveling to Milford Sound Piopiotahi. Some make Te Anau their destination for overnight stops, either side of the Milford Sound Piopiotahi visit, whilst others pass through from Queenstown or further. There is also some local tourism or recreational activities in Te Anau, including walks and boat tours, etc. The hazard profile for Te Anau is not as high as Milford Sound Piopiotahi , so the spatial and temporal distribution of hazard exposure is managed under 'business as usual' by SDC and other organisations. Further insights into visitor distributions and local population and activities in Te Anau are available in the Task 6 (Te Anau Basin) report.

3.73 Manapouri is not on SH94's direct route from Queenstown or Invercargill, and therefore has a lower number of pass-through visitors going to Milford Sound Piopiotahi. Some visitors may stop in Manapouri overnight either side of a Milford Sound Piopiotahi and/or Doubtful Sound Patea visit, whilst others may be on a multi-stop journey within the region. There are also some local tourism or recreational activities in Manapouri, including walks and boat tours, etc. The hazard profile for Manapouri is not as high as Milford Sound Piopiotahi, so the spatial and temporal distribution of hazard exposure managed under 'business as usual' by SDC and other organisations. Further insights into visitor distributions and local population and activities in Manapouri are available in the Task 6 (Te Anau Basin) report.

3.74 Doubtful Sound Patea has a similar natural hazard profile, but much less infrastructure and much lower visitor numbers than Milford Sound Piopiotahi. Hazards are discussed in the following sections, where information allows.

AVERAGE DAY LOWER IMPACT HAZARDS

3.75 The hazards covered by this category are typically inherent to routine operations in the region and cover a wide range of human and natural sources. Whilst there may occasionally be risk to life from these hazards, such occurrences are generally seldom and localised.

3.76 Operators and local authorities have responsibilities and legal frameworks to lead the management and mitigation of these risks, although visitor awareness and behaviour can also be an influencing factor.

Approximately 831,000 of the 850,000 visitors to Milford Sound Piopiotahi in 2018 were passengers on one of the scenic cruise vessels, indicating the high proportion of visitors that utilise one of the tourism operators, although this does not necessarily include the journey. A requirement of the Fiordland National Park Management Plan (DOC 2007) is that tourism operators are to take primary responsibility for the safety of their clients. Management of these hazards should be governed by the standard operating procedures of tourism operators, who also have first aiders and safety duty officers. These operators may also be required to have additional plans developed around their services, and where relevant, register under the Health and Safety at Work (Adventure Activities) Regulations 2016. A large proportion of visitors will take a scenic cruise, guided sea kayaking trip or a transfer from Sandfly Point after finishing the Milford Track. These operators would also be required to register a Marine Transport Operator Plan with Maritime NZ. Many of these host organisations also have responsibilities for overnight staff and/or guests, whether at the lodges or camper facilities.

DOC have published a Best Practice Guideline “Managing risks to visitors on public conservation land and waters”. The guide provides best practice treatment for a wide variety of hazards, including inter alia, adverse weather, carparks, drinking water quality, fire (in facilities and wildfire), hunters, poisonous and stinging plants, wasps, caves/tomos/sinkholes, seals, falls, ropes and climbing, treefall, waves and water-based activities. Additional care is also required to cater for more vulnerable visitors. Routine maintenance of trails and huts by DOC has an influence on safety of walkers, along with guided hike operators such as Ultimate Hikes.

The Milford Road Alliance (MRA) have responsibilities and procedures to manage or improve road safety, including vehicle breakdowns and management of congestion, tunnel safety, proactive management of and/or repairs following rockfalls or other hazards. The MRA also provide road safety information at key points along the roads, combined with regular patrols to facilitate incident response and general maintenance. The speed limits on the state highway have been through a consultation process with a view to reducing speed limits. Refer to Task 4 (Transport and Access) report and the Waka Kotahi website[3].

The local district authorities and national authorities (SDC, Waka Kotahi and the Civil Aviation Authority) have responsibilities to monitor and improve public safety on roads and in the air.

Self-drive visitors will be exposed to hazards they may be less aware of or familiar with, and where they are not under direct care of operators, there is a reduced potential for direct management or mitigation of risks.

Some hazards may be partly mitigated by educating visitors through online information channels and signage indicating estimates for drive time, trail walking time and trail user suitability, etc.

Visitor awareness and behaviours can be a key factor in increasing or decreasing exposure to hazards, and part risk mitigation. Survey data from Waka Kotahi indicates the information least sought before travelling to Milford Sound Piopiotahi included safety information.

[3] https://www.nzta.govt.nz/projects/sh94-homer-tunnel-to-milford-sound-speed-consultation/

3.77 The hazards are discussed further in the subsequent sections, under the following themes:

- Tree, debris and rock falls.
- Driving and road safety.
- Backcountry and trail users.
- Water activities.
- Air travel.
- Environment.
- Human activity.

MILFORD SOUND PIOPIOTAHI

3.78 Tree, debris and rock falls

Debris falls, rock falls and minor landslides occur quite frequently due to the very steep slopes. Triggers can include small earthquakes (which are quite frequent given proximity to fault lines and seismic activity in the area), heavy rainfall or even changes in temperature, humidity, vegetation (growth / die-back) and therefore the trigger may not always be obvious or readily predictable.

The cliff closest to the northern side of the terminal is a little less than 200m high. Several small rockfalls and tree slides ('regolith' containing earth and trees) have occurred in recent years, including a slip in 2016 that damaged a store shed in the parking area. Due to the limited height, the probability of wide-scale destruction from this source is relatively low. However, a small rockfall in May 2019 was initiated at around 950m up Barren Peak, which caused debris and boulders to careen down the mountain and block a culvert near the terminal. Fortunately, much of the debris and boulders were caught in a bend in the streambed it was following, which reduced the impact downstream. Large boulders from this height can project a considerable distance and cause substantial damage and risk to life. This event was a close call and initiated without an earthquake. An AF8 event could have more severe outcomes in this location. A storage building in the terminal area was badly damaged by a small landslide of trees, mud and debris in 2016, and a debris flow blocked a culvert in 2019 flooding the ferry terminal area. There have also been a variety of previous slips on the steep face near the ferry terminal, as shown below.

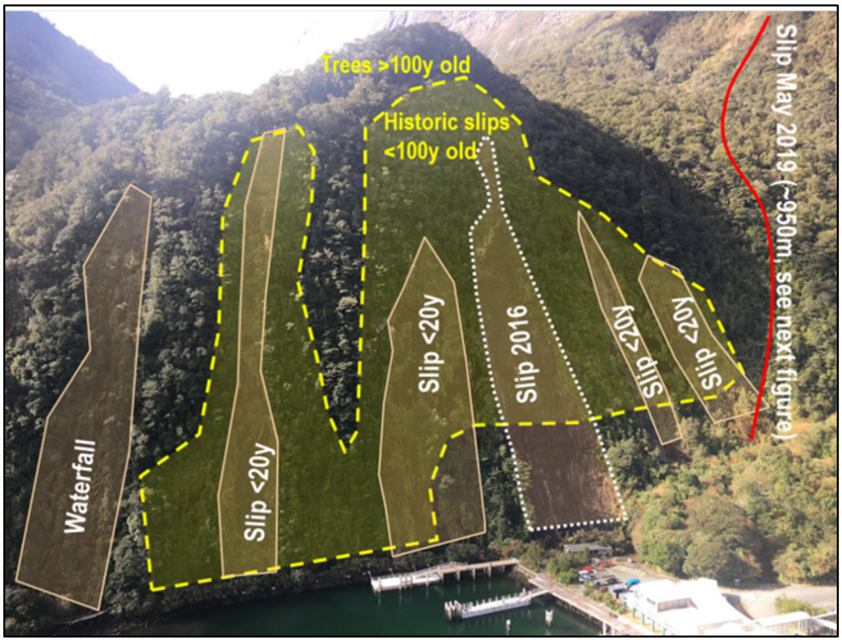


Figure 14: Illustration of rock and tree slips to north of ferry terminal (left), and indicative path of the May 2019 slip (right)

Figure 15: Damage to storagebuilding in Milford Sound Piopiotahi 2016 (photo credit Tim Holland)

Figure 16: May 2019 slip initiation site and trapped debris (from Baddiley and Bond (WSP 2019)

Debris fall and landslide hazards present visitor exposure along many sections of the SH94, including but not limited to, the avalanche zone between Hollyford Road turn and the Chasm. They may be triggered by minor earthquakes, freeze-thaw weathering and rainfall events. Exposure is further increased in queuing traffic at the Homer Tunnel entrances, especially at peak times of day. Several landslides have resulted in road closures over the past 10 years (see Figure 17). Sometimes a risk location is identified, and the road closed to allow the rockfall to be triggered by MRA.

A magnitude 5.5 earthquake triggered small debris falls in the area on 12 August 2019. However, as discussed later in this report, a large earthquake will trigger many slides all over the region.


Figure 17: Slip at Monkey Creek on Milford Road (2022) looking east

A landslide hit Howden Hut on the Routeburn Track during the February 2020 extreme rainfall event. There were only minor injuries, but as landslides hit overnight and the hut was full (about 30 people), this represents a significant potential hazard (see Figure 18).


Figure 18: Landslide damage at Howden Hut on the Routeburn Track (4 February 2020) Photo: Grace Houpapa

There is an early warning system alarm on the Cleddau, intended to identify a landslide or avalanche dam in the river by detecting a drop in river levels. This could later be followed by breaking of the dam and associated flooding.

Small rockfalls frequently occur in the fiord. Visitors are exposed to this hazard on scenic cruises and sea kayaking trips that venture close to the walls of the fiord. A highlight of many trips is dipping the bow of the boat in Stirling Falls (Figure 19) and other smaller waterfalls.

Figure 19: Stirling Falls, Milford Sound Piopiotahi

Tall trees can fall onto the roads or paths, posing risk to drivers and hikers. In 2016, a double fatality occurred with a tree landing on a car driving at open road speed. Given much of the highway is in tree cover, MRA manage this risk through periodic inspections of nearly 3,500 trees in a database. Similarly, DOC do periodic inspections of tree fall risk around its sites, huts and tracks to proactively reduce this risk where possible.

3.79 Driving and road safety

The Milford Road Alliance manage the 120km of SH94 from Te Anau and Milford Sound Piopiotahi. The road becomes progressively more winding north of Te Anau Downs, without a formal gateway that alerts the driver to the gradual change in driving conditions. Many visitors to Milford Sound Piopiotahi are international visitors driving hired cars. They may have different expectations of a state highway route as a safer high-speed environment, although it does not have potential safety features that would be incorporated in modern design. Even if they do some research about driving times, they may underestimate additional time associated with slow winding roads, slow moving traffic, stopping to take photographs and queues at the Homer Tunnel and other congested locations (e.g., Mirror lakes, the Divide, Falls Creek, Gertrude Saddle, and the Chasm).

This could worsen pressure to reach Milford Sound Piopiotahi by a specific time for a booked cruise, contributing to unsafe driving and/or lack of concentration. The proximity of pedestrians (often distracted by views and taking photographs) could contribute to accidents in some areas.

Traffic in Homer Tunnel is managed (one way during the hours of 8am to 6pm) from the Traffic Operation Centre (TOC), which is operated by the Milford Alliance from the Alpine Operations Centre (AOC), close to the Homer Tunnel. The TOC has over 40 video cameras on the road and high Alpine sites. Some of the cameras in the tunnel include thermal imaging to facilitate monitoring of vehicles on the route. The technology in the AOC helps reduce incidents and allows for quicker response in the event of an incident.

Between 2009 and 2018, there were 76 crashes on SH94 between the eastern entrance of the Homer Tunnel and Milford Sound Piopiotahi ; three people died and eight seriously injured. Just over 40 percent of the 76 crashes were between 2016 to 2018. The personal risk is considered high, among the top five sections of rural state highway in New Zealand. Further details are provided in the Task 4 (Transport and Access) report.

Tunnel closures have occurred due to vehicle fires, e.g. 2002 bus fire, 2009 bus fire, 2019 car fire (Figure 20). These can result in the tunnel being closed for longer than one day, which can result in many visitors being trapped on the Milford Sound Piopiotahi side. Waka Kotahi received $25M funding in 2020 to investigate options and improve fire systems and other structural and safety improvements in the area.

Driving and road safety is covered in more detail in the Task 4 (Transport and Access) report.

Figure 20: Car fire in the Homer Tunnel (2019)

3.80 Backcountry and trail users

Management and maintenance of trails is carried out by DOC and supported by track operators such as Ultimate Hikes. Bridge load limits are posted at suspension bridge crossings. DOC guidance contains best practice for treatment of river hazards, fires in huts, tree-fall hazards and significant falls, although these do occasionally still occur (see Figure 21). DOC monitors its own sites and requires operators or concessionaires to have their safety plans audited by an approved auditor. The DOC website contains a variety of safety information, including reference to the New Zealand Avalanche Advisory and Fiordland National Park Weather Forecasts.

There is currently no mountain biking allowed on the main tracks in Fiordland National Park.

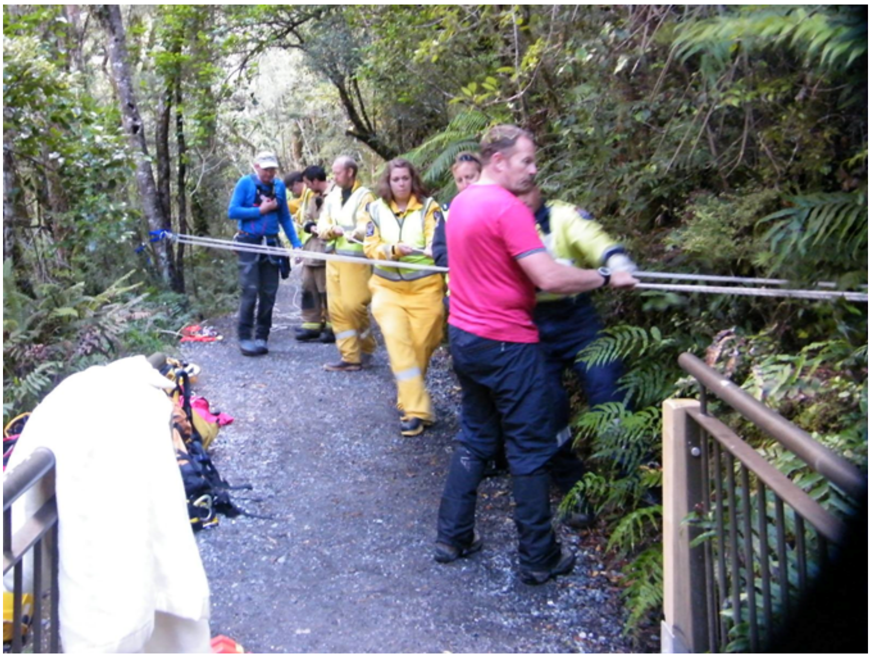


Figure 21: Rescue of walker who fell into the chasm after climbing over the barrier to take a photograph (2015)

3.81 Water activities

These hazards include risk falling overboard on scenic cruises or kayaking accidents. DOC guidance, operator safety plans (regulated by the Adventure Activities Regulations where applicable) and Maritime NZ regulations all help to provide a framework for managing these hazards. Safe practices must be followed and monitored (audited) by operators.

3.82 Air travel

There were 7,773 landings of helicopters and small fixed wing aircraft in 2019, carrying 61,312 passengers. A DOC concession is required for landing, and pilots who have not operated in Milford Sound Piopiotahi in the last six months must have received an in-person briefing from an experienced pilot familiar with operations. Several factors may combine to significantly increase hazards, including the difficult terrain, tight turns compounded by localised variations in wind, turbulence downdrafts, rapid changes in weather, reliance on visual flight rules and congestion.

There have been fatal accidents recorded in the area, including:

- A mid-air collision occurred on December 30, 1989 with seven fatalities. Two Cessna 207 light aircraft collided over Milford Sound Piopiotahi in good weather conditions resulting in one aircraft crashing into the sea, the other landing.
- A Cessna 207 bound for Milford Sound Piopiotahi collided with the Gertrude Saddle on January 19, 2002 resulting in six fatalities. The aircraft failed to reach sufficient height to clear the saddle, weather conditions were suitable for the flight.
- A helicopter was lost between Howden Hutt and Milford Sound Piopiotahi January 3, 2004 in difficult weather conditions, resulting in two fatalities. The wreckage was found nine years later in 2012, despite an extensive search at the time.

Airways NZ operate an aerodrome flight information service (AFIS) providing air traffic information to improve safety (although not issuing instructions to pilots). It was recently considered for withdrawal, which could increase risks of flying accidents, although the withdrawal is currently pending further review.

3.83 Environment

Fuelling of scenic cruise vessels, handling of boat sullage, and sewage treatment represents a risk to the environment, as outlined in the Workstream 2 (Conservation Impact Analysis) report. In 2004, approximately 13,000 litres of diesel were deliberately spilled into the harbour in an apparent act of sabotage.

Approximately 222,000 tourists visited Milford Sound Piopiotahi in 2019 on large cruise liners. Although relatively few of these passengers will disembark, the presence of these large vessels is an environmental risk and source of pollution. Despite pilotage being required, a cruise liner experienced a minor grounding in 2017.

Refer to Workstream 2 (Conservation Impact Analysis) report for more detailed discussion on environmental risks and impacts.

Figure 22: Large cruise liner in Milford Sound Piopiotahi

3.84 Human activity

Operators and DOC have plans for antisocial human activity such as terrorism, crime/vandalism, illegal hunting or other activities and pandemics, although these plans are likely to be under review and updates following COVID-19.

3.85 Summary

Although typical daily hazards covered in this section are mostly managed by operator-maintained standard operating procedures, incidents can and do occur due to the hazardous surroundings and unaware or occasionally reckless human behaviour. These systems also remain vulnerable to cascading hazards or cumulative effects, such as reliance on road/air transport for evacuation or urgent medical attention when road or flying conditions may not allow this. Even in summer, search and rescue efforts can be hampered by heavy rainfall and/or poor visibility, including associated restrictions on flying. There is also the underlying ever-present risk of the higher impact hazard scenarios, which cannot always be predicted as outlined in later sections.

TE ANAU AND MANAPOURI

3.86 Te Anau and Manapouri built-up areas fall just outside the Fiordland National Park and therefore DOC jurisdiction. Day to day public risks are managed predominantly by SDC through regulatory functions and through their shared emergency readiness and response arrangements with Emergency Management Southland. Both Te Anau and Manapouri are on lower, flatter ground and have less immediate risk with rock falls, for example.

3.87 Lake Te Anau and Lake Manapouri are within the National Park, as are the mountain trails and Doubtful Sound Patea, which have a similar organisational setup and general hazard profile associated with steep sided mountains, water, rockfalls and isolation. Many of the tracks at Doubtful Sound Patea are only accessible by boat or on foot, and the lack of road contributes to the isolation and require helicopter for emergency evacuation or access to medical help. Whilst aerial support by sea plane and helicopters may be feasible subject to weather conditions, there are fewer landing spaces, which may lengthen the time taken to effect an evacuation.

3.88 Refer later in this report for higher impact hazards in these areas.

MODERATE IMPACT SEASONAL AND PERIODIC HAZARDS

3.89 This group represents two main hazard categories with more significant impacts and/or management challenges.

3.90 The first category has a strong seasonal pattern: avalanches, snow and winter driving. As detailed in section “Introduction to existing visitor distribution”, there is a strong seasonal control on visitor density and distribution, which will also influence hazard exposure. Management of these seasonal and moderate impact periodic hazards is more complex with multiple stakeholders involved.

3.91 The second category is moderate probability periodic hazards, such as flooding events from either fluvial or tidal sources. More severe or regionally significant events may trigger an overall management response by Emergency Management Southland (Civil Defence), as occurred during the February 2020 flood event.

MILFORD SOUND PIOPIOTAHI

SEASONAL HAZARDS: AVALANCHE AND SNOW

3.92 Avalanche hazard on Milford Road SH94 is managed as part of the MRA Avalanche Control Programme.

3.93 Avalanches present a significant hazard during winter and spring, with the main season between June and October. Visitor exposure occurs in the SH94 avalanche zone marked for 17km between Falls Creek and the Chasm. There are 54 identified avalanche paths in this area, some up to 1.6km wide. Management of this hazard on SH94 is the responsibility of the MRA with a specialist avalanche control team monitoring conditions at road and mountain level, managing traffic flow and triggering controlled avalanches. This team assess avalanche conditions based on a low, moderate, high scale that is communicated to road users using road information signs. Where necessary, no stopping signs are used, with snow gates available for road closures.

3.94 This hazard is most evident close to the Homer Tunnel where each portal is surrounded by near vertical 800m walls. Visitor exposure is greatly increased during peak travel times when there will likely be congestion and queues near the tunnel. Figure 23 and Figure 24 illustrate the steep slopes and avalanche risk from the Homer Saddle above the western portal and eastern portal, respectively.

3.95 Avalanches can also be triggered by earthquakes at times when the ‘predicted’ avalanche risk is not necessarily high (based on snowpack and weather conditions), making it impossible to guarantee complete avoidance of this risk.

3.96 The MRA also help to manage necessary road closures when heavy snow makes winter driving particularly hazardous. Sometimes snowy or icy conditions may be passable for experienced drivers with snow chains, but generally the decision is taken to close the road as many visitors are unfamiliar with fitting or driving with chains and may pose risk to themselves and other road users.

Figure 23: Homer Saddle above the western portal (both photographs)

Figure 24: Homer Tunnel eastern portal (photo Waka Kotahi NZ Transport Agency)

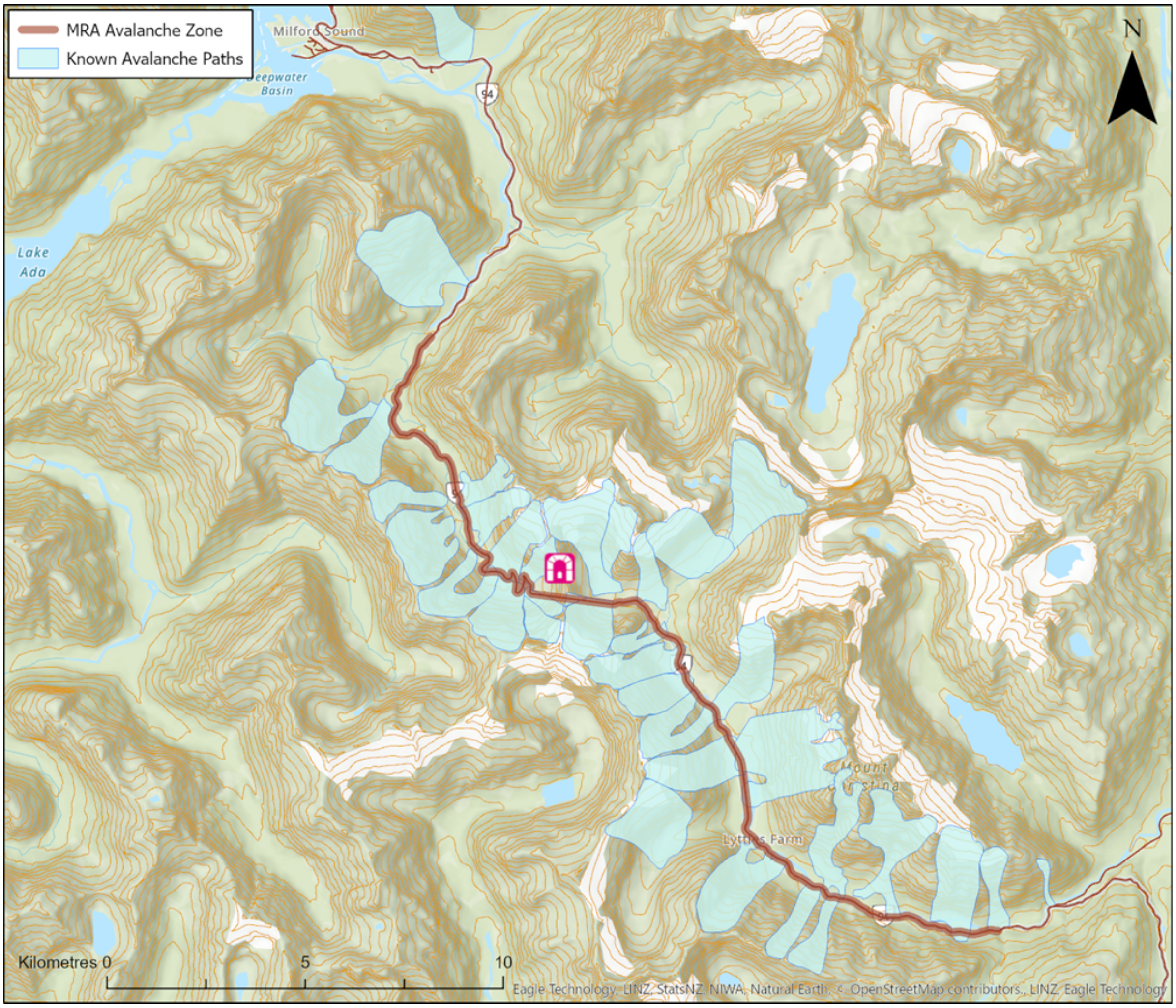


Figure 25: Known avalanche paths and the MRA avalanche zone on SH94 (Source: LINZ / Waka Kotahi)

3.97 Black ice can occur frequently in the winter, especially at high altitudes, and is usually included in forecasts from the Met Service and Waka Kotahi. MRA operates an ice patrol every winter morning from Te Anau to Milford Sound Piopiotahi, looking for icy sites and proactively using chemical and grit to reduce the risk where possible.

3.98 Milford Road is closed for an average of eight days per year, mainly as a result of snow or avalanche hazard. In 2020, an exception was due to the flooding damage.

3.99 Whilst visitor numbers are lower in winter and therefore constitute lower statistical exposure, the hazards are higher, and search and rescue efforts can be hampered by cold weather, poor visibility, poor flying or hiking conditions, etc. The cold also shortens the survival window.

3.100 It is anticipated that climate change may result in higher total precipitation in future, resulting deeper snowpack. In addition, slightly warmer temperatures may change the density of the snowpack and result in greater avalanche activity.

PERIODIC HAZARDS: FLUVIAL FLOODING WITH DEBRIS FLOWS

3.101 The strong orographic gradient typical of the South Island's west coast results in exceptionally high precipitation. A mean annual rainfall of 6,716mm is recorded at Milford Sound Piopiotahi AWS (NIWA, 2014), with even higher accumulations likely along ridges and at peaks. Mean annual rainfall and extreme rainfall depths are both predicted to increase as a result of climate change. Rainfall on the west coast could increase as much as 70 percent by 2100 in the higher climate change estimates (Carey-Smith et al, 2018, Te Rūnanga o Ngāi Tahu, 2018). Due to the steep catchment gradients and large amount of exposed bedrock, this rainfall results in rapid runoff and large volume river discharge. The high energy rivers can move substantial material, causing erosion in some places and aggradation in others. Flooding and erosion damage are common on some sections of roads, and tracks are also vulnerable to morphological changes.

3.102 There has been significant investment in infrastructure to mitigate flooding hazard both along SH94 and in the Milford Sound Piopiotahi Village area.

3.103 A flood mitigation project completed in 2011[4] consisted of upgraded stop banks along the northern bank of the Cleddau River as it flows into the delta area and raising of the staff accommodation and storage area by up to 4m. A river level sensor and warning system was also installed to provide early warning of rising river levels. The scheme is reported to provide a 100-year ARI level of protection with some allowance for climate change, comprising the simultaneous occurrence of:

- 1% AEP + 16% flood in the Cleddau River (2,088 m3/s).
- 1% AEP + 16% flood in the Arthur River (3,330 m3/s).
- 1% AEP combined tide and storm surge sea level increase.
- 0.5 m increase in sea level due to possible climate change.

The recommended climate change allowances have since been revised upwards (MfE 2018, NIWA 2018). When updating the climate change allowances, it would be advisable to look at the fluvial/tidal combined probability, since the assumption of co-incidental 1 percent AEP probabilities is overly conservative (resulting in a combined risk that is much less than 1 percent AEP). Further alluvial deposition in the river channel and on the delta may result in further increases in water levels over time. Depending on the masterplan outcomes, further analysis may be required in the future to refine the basis for design or adaptation of resilient infrastructure.

3.104 Movement of material due to landslides or major floods can cause rivers to change or flood unexpectedly. For example, in 2019, a slip blocked a culvert and caused flooding in the Freshwater Basin area of Milford Sound Piopiotahi.

3.105 Flooding in February 2020 caused damage at multiple locations along SH94. Milford Sound Piopiotahi airport recorded approximately 600mm of rainfall in 24 hours, and nearly 1,000mm in 60 hours, which is estimated at approximately 1:200 annual exceedance probability. Accurate spatial understanding of rainfall on the mountains is difficult due to the lack of rain gauges and steep topography, which hinders accurate radar rainfall estimates. Some of the most severe damage was about 1.5km to the Hollyford side of the Homer Tunnel (see Figure 26).

[4] https://www.odt.co.nz/regions/queenstown-lakes/flood-protection-project-opened

Figure 26: Damage at Forks Bridge (1.5km from Homer Tunnel, Hollyford side) due to February 2020 flood event. Photo: Waka Kotahi

3.106 Milford Sound Piopiotahi, and also airlift of several groups stranded along the road and tracks. Access for four-wheel drive emergency vehicles was restored in nine days, and limited convoy access for businesses was available from February 16, 2020. This period would have increased hazard exposure due to limited availability for emergency access and hazard mitigation, in addition to potential remobilisation of unstable material.

3.107 Flooding is also a significant source of hazard exposure on trails developed in the area. Figure 27 shows the washed-out Giants Gate footbridge on the Milford Track after the February 2020 flood event.

Figure 27: Giants Gate swing bridge on Milford Track following Feb 2020 storms

3.108 Another location prone to frequent flooding is the Cascade Creek camp site.

3.109 The frequency and severity of flooding is expected to increase with climate change, with associated erosion or aggradation continuing to cause damage and requiring maintenance.

PERIODIC HAZARDS: TIDAL FLOODING

3.110 Tidal flooding currently occurs due to high astronomical tides and/or storm surge events. Limited information was provided on coastal flood frequency or extreme water level analysis. One of the existing assets at low elevation is the runway, which dips as low as 1.5m above mean sea level at the north-western end. The last roughly 300m of runway would need to be raised up to around 2.5m above mean sea level (depending on design life, climate change scenario/epoch, structural resilience to shallow groundwater, etc). Depending on design decisions, further analysis may be required to provide refined water levels to inform design, including updated climate change allowances and fluvial, groundwater and tidal / surge combined probabilities.

3.111 Tidal flooding is expected to occur more frequently as climate change causes rising sea levels.

TE ANAU AND MANAPOURI

3.112 Te Anau and Manapouri are on lower, flatter ground and not subject to avalanche risk in the winter. Usual winter driving precautions with snow and occasional ice are to be expected given the location.

3.113 Fluvial flooding presents some risk to Te Anau and to a lesser extent also Manapouri, but only during very extreme events. Environment Southland is responsible for mapping and managing fluvial flood risk, including extreme events.

3.114 Doubtful Sound Patea is subject to similar risks to Milford Sound Piopiotahi regarding tidal flooding.

RARE SEVERE HAZARD SCENARIO

3.115 Given the scale of this scenario, additional background is given at regional level, before describing location-specific impacts.

3.116 Milford Sound Piopiotahi is situated close to the Alpine Fault, which extends through much of the South Island Alps and then continues approximately 1km offshore of the mouth of Milford Sound Piopiotahi in a south-westerly direction into the Fiordland Subduction Zone and Puysegur Trench (see Figure 28).

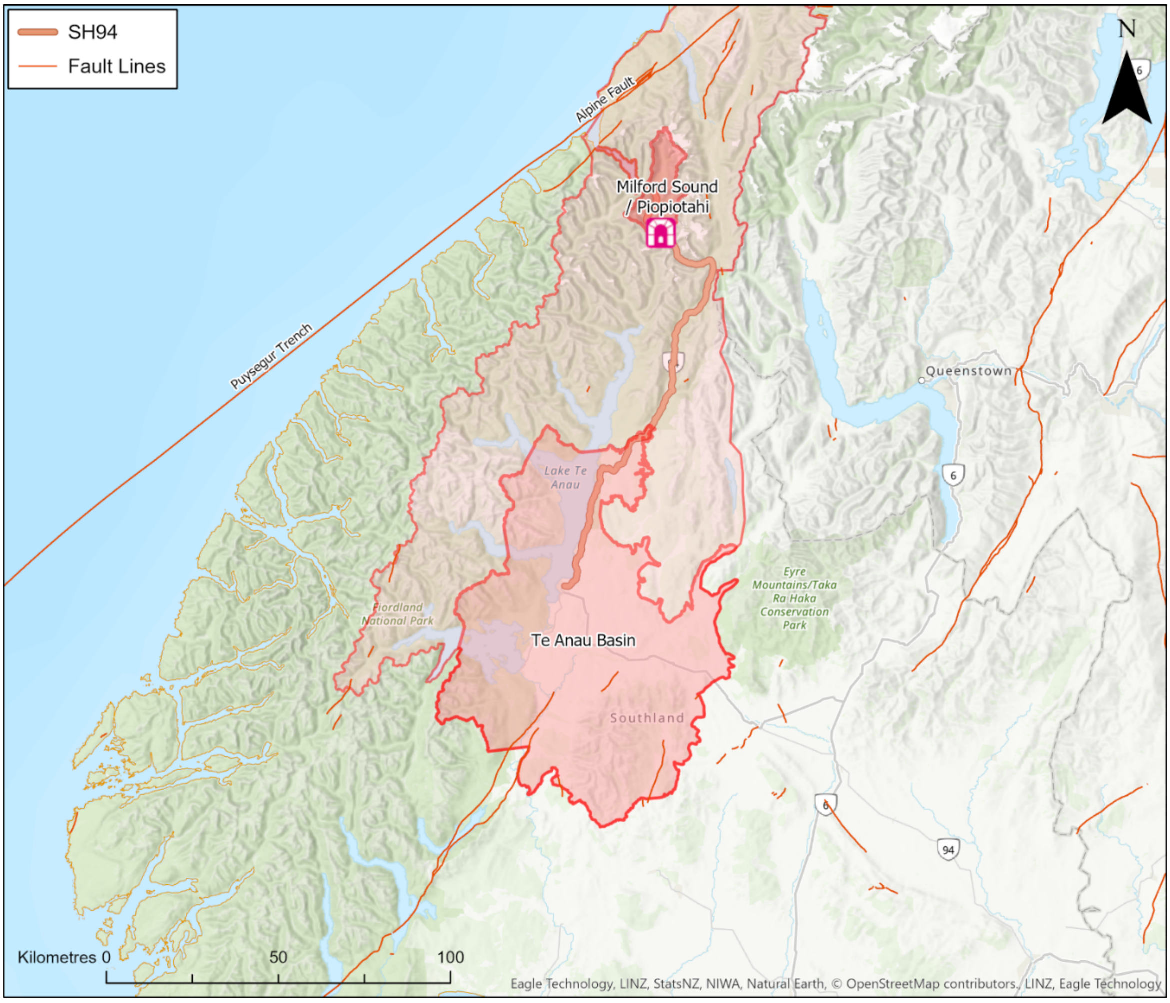


Figure 28: Location of known active fault lines in the region

3.117 The Alpine Fault Magnitude 8 (AF8) project is a collaboration between the six South Island Civil Defence Emergency Management (CDEM) groups and science, including research from six universities and Crown Research Institutes, emergency services, lifelines, iwi, health authorities and many other partner agencies. The programme is managed by Emergency Management Southland, to better understand and communicate the impacts and response requirements to this credible worst-case scenario.

3.118 Earthquakes of various magnitudes occur frequently in the area. Figure 29 illustrates spatial distribution of earthquake epicentres with their magnitudes, since 1900 (from Dykstra 2012, referencing Turnbull et al 2010).

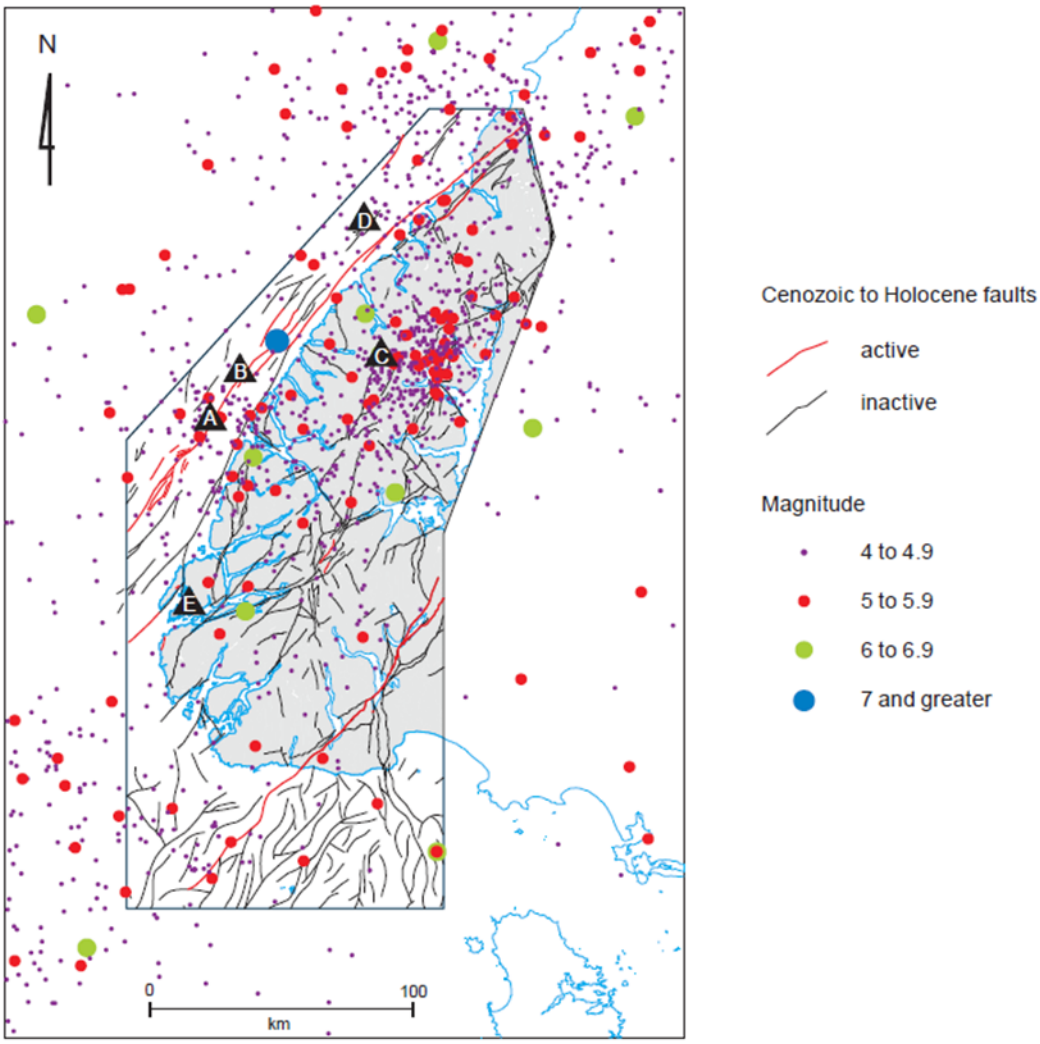


Figure 1.10: Earthquakes since 1900 in and around Fiordland, plotted by magnitude, with known major Cenozoic faults shown. Major earthquake epicentres, marked by black triangles, are: A. Secretary 1993, M_w 6.8; B. Fiordland 2003, M_w 7.2; C. Te Anau 1988, M_w 6.7; D. Milford 1976, M_w 6.5; E. Dusky Sound 2009, M_w 7.8. The blue circle marks the 1938, M_w 7 earthquake off Charles Sound. Most large earthquakes in Fiordland are relatively deep and not obviously associated with major fault surface traces, as they are related to the subduction interface. After Turnbull et al. (2010), figure 73.

Figure 29:Earthquakes since 1900 (from Dykstra 2012, referencing Turnbull et al 2010)

3.119 In contrast to the above earthquakes which are mostly smaller (<7) and relatively localised, historical analysis (Berryman et al, 2012, Orchiston et al, 2016) suggests that a major rupture along the strike-slip of the Alpine Fault with long displacements (and multiple aftershocks) occurs roughly every 300 years. Orchiston et al states “for the Project AF8 earthquake scenario, an Mw 8.2 rupture of AlpineF2K involves a fault rupture length of more than 400 km with c. 9 m of dextral-reverse surface displacement. This event has a likely recurrence interval of c. 300 years. The last such rupture is believed to have occurred in AD 1717. New and developing science indicates that recurrence intervals may be slightly shorter (c. 270-290 yr; Biasi et al., 2015; Cochran et al., in review) for the AlpineF2K source”. This is translated to give an estimated probability of a major Alpine Fault rupture (M8+) in the next 50 years at roughly 50 percent and climbing each year as the stress between the plates increases over time since last major rupture. This number is currently under review and an update is expected early in 2021 (Howarth et al).

3.120 A large Alpine Fault rupture would produce substantial ground accelerations/shaking, displacements and rockfalls and landslides (estimated at 30,000-70,000 by Robinson et al, 2016), avalanches, liquefaction of soils in the lower lying areas, rapid co-seismic landslide-induced tsunami in the lakes and fiords with possible catastrophic impacts. Other sources of tsunami include lakebed or offshore generated tsunami. More detailed description of potential localised impacts is provided in the geographic subsections that follow.

3.121 It is difficult to predict the exact timing of such an event, but the consequences could be catastrophic to visitors and lifeline infrastructure.

3.122 There are many different organisations and stakeholders who would help manage the immediate response to a severe hazard scenario, and the overarching management would rapidly transition to an Emergency Management Southland led response (the regional Civil Defence and Emergency Management authority). In the event of a major Alpine Fault rupture, it is likely that CDEM co-ordinators, resources and responders may be stretched to address widespread disaster needs across the region (refer to Orchiston et al, 2018).

3.123 Many of the hazard components of this scenario have been considered as part of the AF8 Hazard Scenario (Orchiston et al, 2016). It is understood that the AF8 project funding has been extended for 2020, and may continue in some form beyond that, to continue developing or maintaining awareness, communication pathways and responder capacity at community and organisational levels through a variety of forums.

3.124 As identified by the AF8 hazard scenario report (Orchiston et al, 2016), these hazards are likely to occur as a cascading sequence of events with both short- and long-term physical effects (see Figure 30). The main rupture and shaking would be followed by many aftershocks, and there would be delayed or longer-term effects such as formation and breaking of debris dams and realignment of rivers, whether as a direct result of the land deformation plus further re-mobilisation of landslides and movement of debris, during aftershocks and/or subsequent rainfall events. The figure and discussion do not attempt to address social and economic impacts, which would be widespread and long lasting.

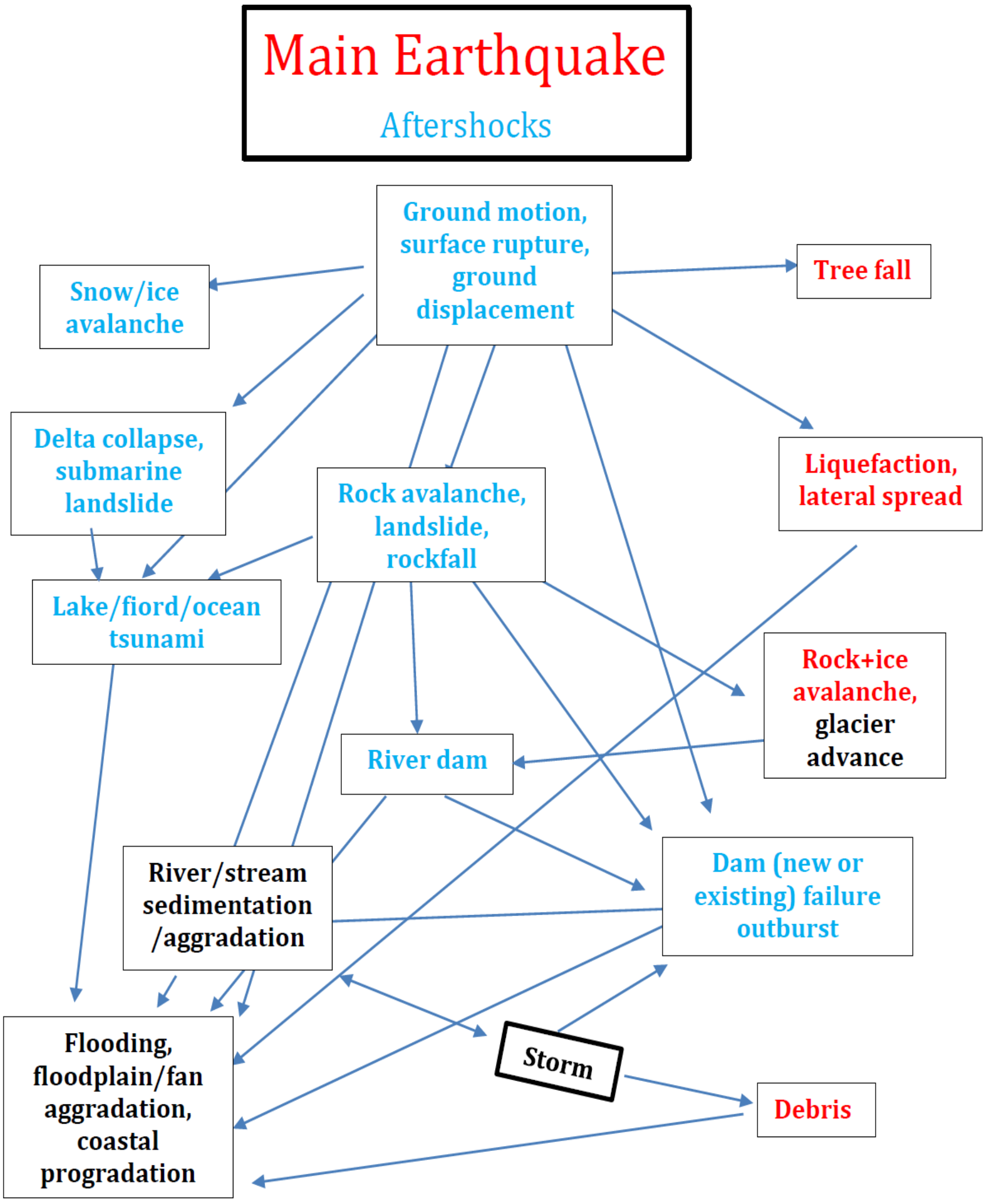


Figure 6: The range of geomorphic phenomena triggered by a major earthquake sequence, and their relationship cascade. The earthquake sequence & subsequent storms provide the drivers, and are shown in the boxes with thick black outline. The longevity of each resulting phenomenon is indicated by colour: short-term, immediate & prolonged, and **long-term**.

Figure 30: Cascade of effects from a major seismic event (from Figure 6 of the AF8 scenario report, Orchiston et al, 2016)

3.125 Further details of the hazard components and localised impacts of this scenario are provided through the remainder of this section.

3.126 Volcano risk in Southland is considered negligible (Glassey, 2006).

MILFORD SOUND PIOPIOTAHI

3.127 The highest number of fatalities in Milford Sound Piopiotahi would occur if an AF8 event took place during peak occupancy, potentially exposing in the order of 3,000 visitors and staff to substantial risk. Even if it happens overnight in winter, the outcome could still be many fatalities. A summary of the potential hazard sequence and localised impacts follows below.

3.128 Earthquake

As described above, there is a high probability of a large (circa M8.0) earthquake in the next 50 years, although this does not preclude moderate impact earthquakes which could happen much sooner, which could still trigger some of these outcomes.

Events of great magnitude in particular, or moderate earthquakes with a close epicentre, could cause sufficient ground accelerations to result in fatalities, due to falling objects in buildings or buildings collapsing. Other co-seismic effects are described below.

3.129 Falling rocks, tree slides, landslides, avalanche

Falling rocks, trees, landslides and co-seismic avalanche pose a major risk during a major seismic event. Risk is fairly high at the Milford Sound Lodge and Cruise Terminal that are near the bottoms of high and steep slopes. Material falling from heights can be projected a considerable distance at high speeds. A significant number of fatalities could occur as a result.

The Milford Sound Piopiotahi hydropower generator is also at risk. People along the road might be killed by rock falls or avalanche or trapped inside the Tunnel. An extended tunnel closure after a large Alpine Fault rupture is considered likely, which would severely hamper evacuation efforts. Similarly, hikers on the trails would also be at risk, and rockfall material would also hamper support reaching hikers (apart from by helicopter). This risk does not cease when the first shaking stops, as there are likely to be many aftershocks in the sequence for years to follow.

3.130 Landslide-induced tsunami

This topic was researched in a PhD thesis by Jesse Dykstra (Dykstra, 2012). He investigated the number and sizes of large landslide deposits on the floor of the fiord since the last Ice Age (over 17,000 years). Consideration was also given to landslides in the wider Fiordland area generated by historical events, including the recent 2003 Fiordland and 2009 Dusky Sound earthquakes as indicated below, plus data from landslides and landslide-induced tsunami around the world.

Figure 31: Aerial of the ~200,000 m3 rock fall in Gold Arm of Charles Sound which caused a ~4-5 m high tsunami during the 2003 Fiordland earthquake New Zealand. The wave travelled ~800 m across the fiord and stripped vegetation and soil 4–5 m above high tide level.

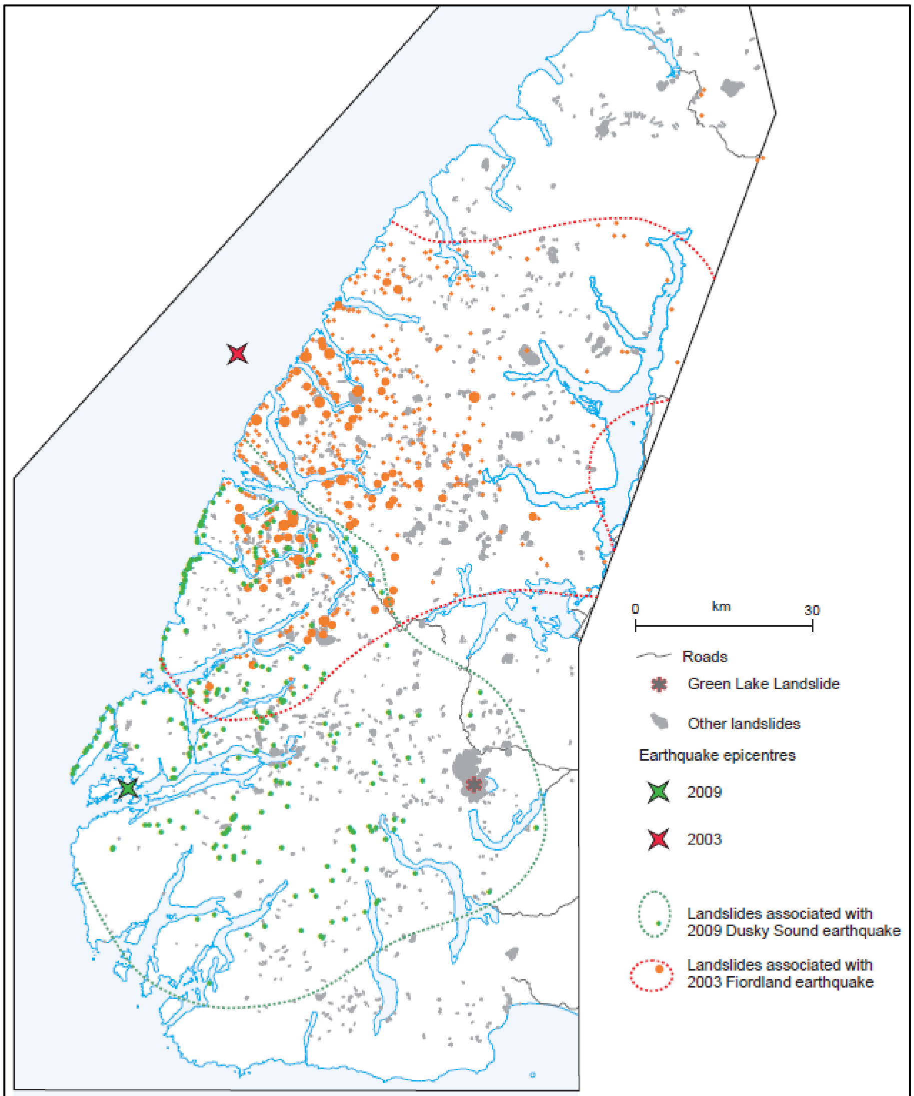


Figure 1.15: Large landslides in Fiordland, shaded in grey, ranging from complex rock slides to rock falls and rock avalanches. The Green Lake Landslide (marked) is one of the largest landslides on earth (27 x 10^9 m^3). The many landslides (mostly smaller debris flows and debris avalanches) that were triggered by the 2003 Fiordland and 2009 Dusky Sound earthquakes are shown in red and green, respectively, together with the earthquake epicentres. After Turnbull et al. (2010), figure 61 and Hancox and Perrin (2009).

Figure 32: Large historic landslides in Fiordland area (from Dykstra, 2012)

A GNS report commissioned by Environment Southland investigated "Milford Sound Piopiotahi risk from landslide-generated tsunami" (Taig et al, 2015) further refined the work started by Dykstra (2012). The 2015 report concluded the following among other metrics:

- 26 sizable landslide deposits were identified in the fiord post-glacial (i.e., the last circa 17,000 years). From these, a maximum amplitude of up to 87m is estimated to have occurred in Milford Sound Piopiotahi.
- Two out of every three landslides that have fallen into the fiord have caused tsunamis that would result in disasters with multiple deaths at Milford Sound Piopiotahi if they were to occur today.

Figure 33 shows probability of wave magnitudes from the assessment, which are further interpreted below.

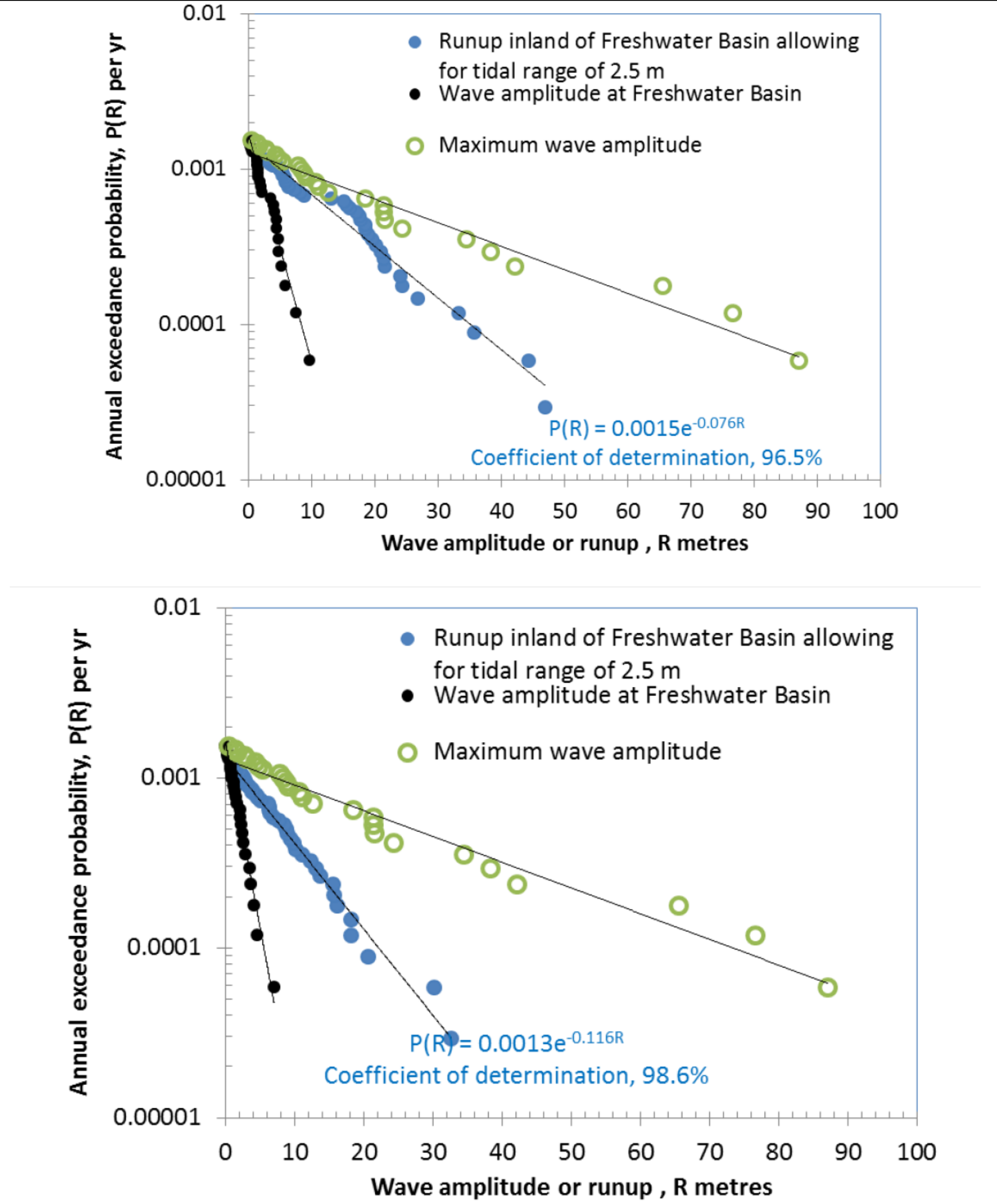


Figure 8 Quantitative measures of the tsunami hazard at Milford Sound allowing for wave attenuation with distance from source and one landslide for each underwater deposit. Upper plot is for attenuation (i) Gongjiafang landslide in Wu Gorge in 2008, Lower plot is for attenuation (ii) Loenvann, Norway in 1936. Blue dots are wave runup inland of Freshwater Basin. Runup probability allows for tidal range of 2.5 m. Black dots are wave amplitudes reaching Freshwater Basin. Green open circles are maximum amplitude of tsunami where generated, and are the same data in both plots.

Figure 33: Wave probability assessment from Taig et al, 2015 (simplified donor attenuation models)

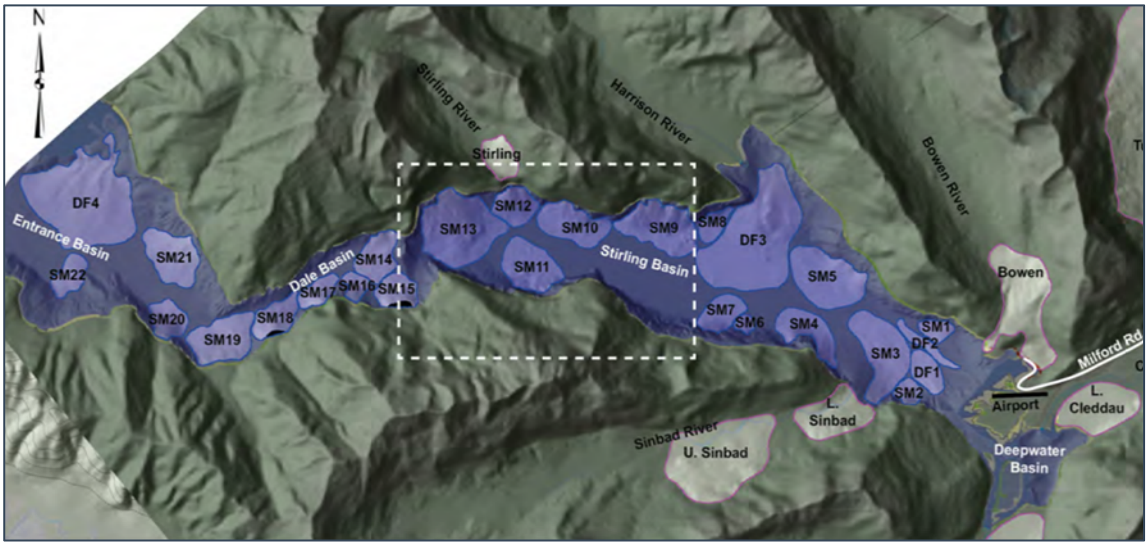


Figure 34: Historic landslide deposits (from Dykstra, 2012)

Table 3: List of underwater landslide deposits identified by Dykstra (2012), with estimates of wave heights by Taig, et al (2015) and additional comments on specific entries of interest.

Source deposit reference	Distance from delta (km)	Volume (million cubic metres)	slide path length (m)	Maximum amplitude (m)	Amplitude at Freshwater Basin (m)	Run-up at Milford Sound Piopiotahi (m)	Comment on specific entries
Subaerial landslides with submarine deposits							
SM1	1.2	1.0	560	8.7	**4.2**	**18.5**	Very short lead time
SM2	1.2	0.5	390	3.0	**1.5**	**5.8**	Very short lead time
SM3	1.7	2.2	560	10.7	**4.7**	**21.0**	Very short lead time
SM4	2.7	4.6	460	11.0	4.0	17.6	
SM5	2.8	4.8	970	21.3	**7.6**	**35.7**	Second highest runup
SM6	3.8	0.2	120	0.4	0.1	0.4	
SM7	4.2	1.5	480	4.7	1.3	5.0	
SM8	4.8	0.7	250	1.6	0.4	1.3	
SM9	5.3	11.0	440	21.5	4.8	21.4	
SM10	6.6	4.3	280	7.9	1.4	5.3	
SM11	7.1	2.3	1060	12.6	2.0	8.1	
SM12	7.5	4.9	130	4.3	0.6	2.2	
SM13	8.3	18.5	650	42.2	5.3	24.0	
SM14	9.3	1.7	1640	34.4	3.6	15.5	
SM15	8.9	3.9	1950	**87.2**	**9.7**	**46.9**	Highest max and runup
SM16	9.5	0.8	980	21.3	2.1	8.7	
SM17	10.3	3.0	190	18.4	1.6	6.3	
SM18	10.9	4.9	1490	76.6	**5.8**	**26.8**	Third highest runup, second highest max
SM19	11.6	6.7	1820	65.6	4.4	19.5	
SM20	12.5	2.3	1310	24.3	1.4	5.4	
SM21	13.5	4.3	1200	38.3	1.8	7.2	
SM22	14.2	0.9	820	8.2	0.3	1.1	
Granular submarine density flows							

Source deposit reference	Distance from delta (km)	Volume (million cubic metres)	slide path length (m)	Maximum amplitude (m)	Amplitude at Freshwater Basin (m)	Run-up at Milford Sound Piopiotahi (m)	Comment on specific entries
DF1	1.2	0.5	1100	2.7	1.3	5.2	
DF2	1.0	0.2	1600	9.0	**4.5**	**20.2**	Largest delta flow, short lead time
DF3	4.2	14.2	2400	5.3	1.5	5.7	
DF4	15.1	13.2	1500	1.3	0.0	0.1	

3.131 The above estimates by Taig et al (2015) were based on crude estimates of wave attenuation and runup derived by regression of wave form behaviour from other locations and may not reflect influence of local bathymetry on wave transformation. They may also be underestimated if air entrainment has not been adequately reflected in the estimation of initial amplitude. Air entrainment has been found an important factor in recent attempts to model past and recent landslide-induced Tsunami. New events have also occurred providing data that would not have been included in the above assessments, such as the 2015 Taan Fiord event in Alaska (which reached a runup of 193m, see George et al, 2017) and the 2017 Karra/Nuugaatsiaq event in Greenland. It is strongly advised that at least a subset of the past submarine deposits be modelled dynamically, in addition to modelling potential future landslide sources (ideally in a probabilistic framework) to better understand the spatial runup potential at Milford Sound Piopiotahi.

Figure 35: A geologist stands in front of a 5m diameter boulder moved by the Taan Fiord tsunami near where it reached its highest elevation (193m). Photo courtesy of Ground Truth Trekking

3.132 In order to facilitate the interpretation and discussion of hazards to staff and visitors, the sketch below has been prepared using elevation contours. It is important to remember that the wave heights are crude estimates, based on simplified approaches around past events, and may be subject to significant change if modelled more accurately.

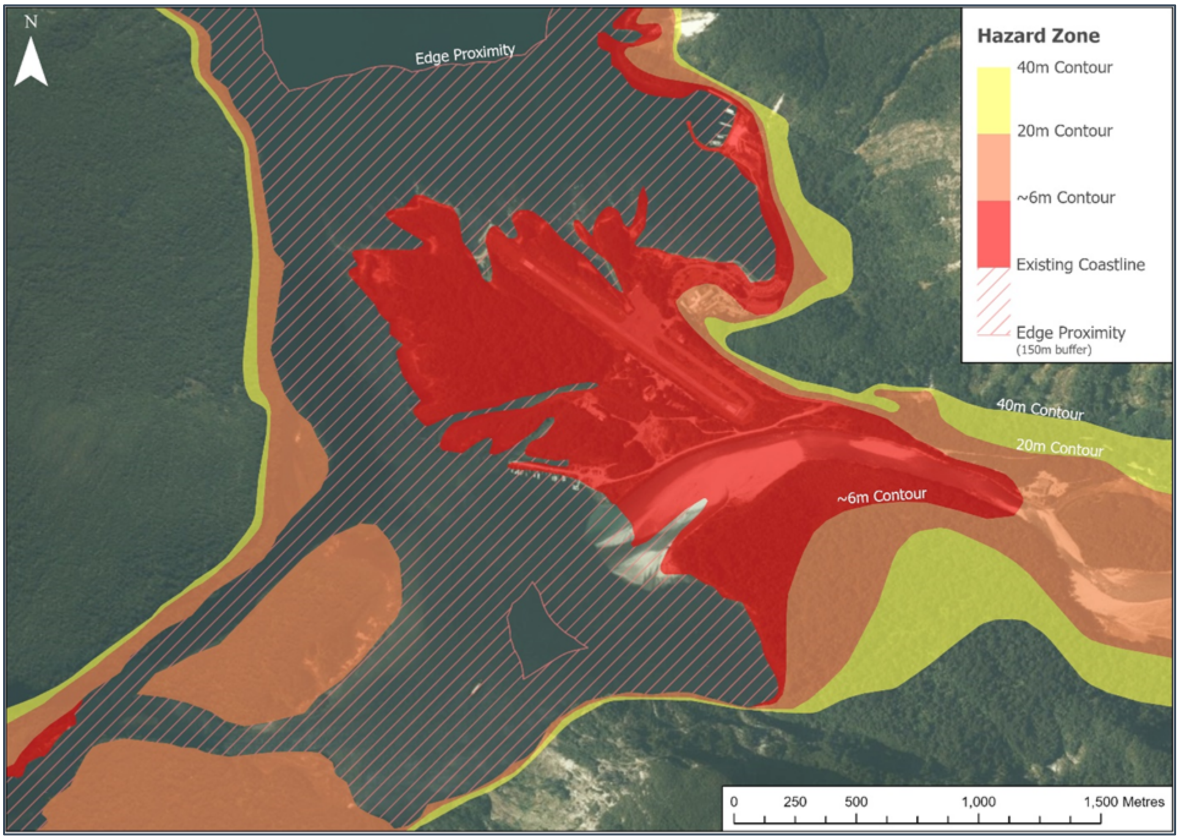


Figure 36: Illustrative simple hazard zone sketch (not yet based on computational modelling)

3.133 The first exposure to the landslide and tsunami would be boats on the water. A 150m buffer has been used to illustrate in the sketch where boats may be at increased risk of being hit by falling rocks and/or the more explosive initial wave, in addition to edge effects of the waves hitting against the side of the fiord creating taller and 'messier' waves. In the deeper water in the fiord, some boats with engines on power and pointing into the dominant wave may be fortunate enough to successfully negotiate small waves, but these waves move exceptionally fast and would be followed by refracted waves (bouncing off fiord sides) which could be a challenge to negotiate, especially for higher waves. Deep keel boats may be at higher risk due to their lower speed and yaw effect that is likely to be strongly influenced by undertow in the strong currents, whether at anchor or under power. Boats near the source area of a large amplitude wave would be at high risk even at a few hundred metres from the impact zone, and consideration could be given to creating a context-sensitive hazard zone that is more than 150m below the larger and higher source areas if these can be mapped (so far only historical source areas have been mapped, which might not correlate to future slips).

3.134 Heading toward Milford Sound Piopiotahi, the wave would transform (shoal, or 'jack up') in shallowing water. This wave energy would pose risk to boats in the wharfs or shallow water. Smaller waves as low as 1m in Freshwater basin would likely cause damage to boats, and some boats could be washed up onto shallows. Larger waves would be highly dangerous to all boats within this zone, and most boats would be at risk of overturning in the largest waves.

3.135 On shore, using the simple wave translation used by Taig et al (2015), a 1.5m wave in Freshwater basin would be expected to produce wave runup in the order of 6m (this has not been hydrodynamically modelled, and would not be uniform runup spatially). This would mean anyone caught in the red zone in the sketch would likely be washed off their feet even at this small apparent wave amplitude in the deep approach (which could give witnesses a false sense of security). Many of these victims could be severely injured, and some may be washed out into the fiord by the backwash and some could die from the impact or drowning. Even this relatively small wave could cause damage to many of the existing buildings, as they are not designed to withstand these forces. This relatively small wave amplitude is exceeded in around 60 percent of the historic cases, which translates to approximately 16 percent probability of exceedance over the next 50 years (roughly 1:300 chance per year).

3.136 These rough probability estimates are likely to be updated based on further modelling of the Alpine Fault scenario probability (Howarth, et al, 2021, in review). In addition to probabilistic modelling is strongly advised, to improve understanding of all stages of the tsunami (past and future source areas, landslide initiation and dynamics, tsunami initiation including air entrainment, wave attenuation through the fiord, near-shore wave transformation and spreading including sediment/debris entrainment, wave shapes, spatial distribution of depths and flow velocities).

3.137 Moving up the scale of wave amplitudes, around 27 percent of the past tsunamis presented in Taig et al (2015) reach around 20m of runup, which is the extent of orange in Figure 36 This is equivalent to around a 6-storey building and has an estimated 8 percent probability of exceedance over the next 50 years (roughly 1:600 chance per year). All existing infrastructure (which has not been specifically designed to withstand these tremendous forces) would likely be completely destroyed and given the short lead time very few people would be able to run to safety (with current level of information and pathways as outlined below). Even some mature trees could be stripped from the landscape, and considerable debris (trees, delta alluvium and cars) may be hurled around by the water.

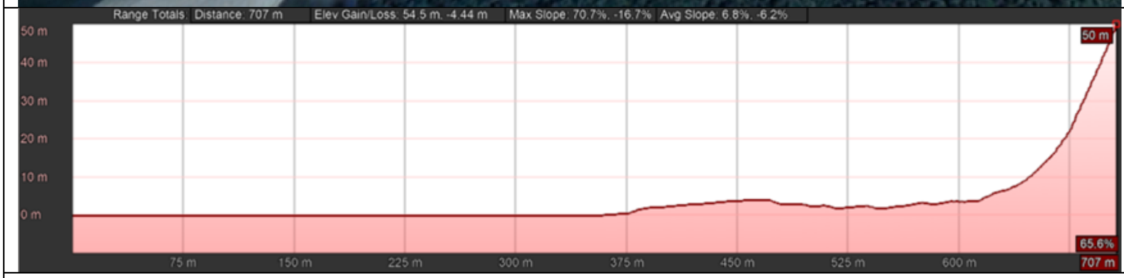
3.138 The 40m contour (edge of yellow) is exceeded by only the largest wave of the 26 historic post-glacial tsunamis. This is estimated to represent approximately 1 percent chance of exceedance over the next 50 years (roughly 1:4000 chance per year). Again, the probabilities and wave heights are based on crude extrapolations of past behaviour and simplified wave transformation regression from other locations. Further work is strongly advised to improve these estimates, whilst also helping to inform the mitigation design.

3.139 The tsunami waves move at tremendous speed, in the order of 30m/s. This translates to a travel time (lead time) of under 1 minute from nearby sources to around 7 minutes from landslides near the outer fiord. This severely limits potential routes / distances to run to high ground. Those who are reasonably fit and fortunate enough to be standing at the base of the bluff and make an immediate start should be able to cover the roughly 150m distance up to the existing small lookout platform behind the hotel at an elevation of around 30m within approximately 1 minute, but the path is narrow and will take much longer for a substantial number of people to climb. The other popular/busy locations such as the current ferry terminal, and the staff village (where most staff stay overnight, who are the cohort with the longest temporal exposure to the risk) are currently over 600m from the start of this path, and even if a slightly shorter cleared path existed would really struggle to make ~50m elevation in anything less than 5 minutes. Whilst the distance from the Lodge to ~50m elevation is only 300m, there is the additional risk of rockfall near the base of this steep slope. The illustrations below show some potential routes with indicative distance (these routes are not marked nor cleared currently to take significant numbers):

Table 4: Potential evacuation pathways (illustrative)

Pathway aerial view (Google Earth) with elevation profile and commentary

Route from ferry terminal, involving around 600m at low elevations plus another 100m at steep incline (shown in green on aerial oblique) to reach 50m elevation IF a path were created here. Whilst there is nearer land at 50m elevation, the terrain is steep, uneven, and may be subject to rockfall risk from Barren Peak such as occurred in May 2019.



Route from staff village / commercial wharf (indicative), involving around 600m at low elevations plus another 100m at incline to reach 50m elevation

Route from The Lodge showing approximately 300m up gradual incline to reach elevation 50m, however there is also some risk of rockfall in the potential refuge area at the base of this steep slope

3.140 All this serves to illustrate the low percentage of people who are likely to currently survive a large landslide-induced tsunami without further structural mitigation, even if new pathways were cleared and information/signage provided.

3.141 The risk when calculated by Taig et al (2015) for an individual day visitor is significant but was evaluated as not particularly exceptional or disproportionate compared to other moderate risk activities. The 2015 report provides the following textual summary for individual risk:

The risk comparison for visitors to Milford Sound Piopiotahi is more varied than for resident staff. The risk level associated with an overnight visit to Milford Sound Piopiotahi (some 4-7x higher than that of a day trip) is HIGH in comparison with overseas visitor mortality rates per day for many external causes (suffocation, poisoning, drowning, assault), and the risk per day participating in popular, active sports. The risk level is similar to overseas visitor mortality rates per day for the dominant causes (cancers, heart disease, road accidents, falls), some relatively safe activities (jet boating, bungy jumping) that are perceived as adventurous, typical length leisure walks or cycle trips at average risk levels on NZ roads. The risk level is LOW in comparison with the risk of travelling between Queenstown and Milford Sound Piopiotahi by road or (especially) by air, "high end" adventure activities such as mountaineering and white water rafting, and the risk of drowning for overseas visitors in the course of an entire visit to New Zealand.

3.142 For individual staff working on an annual basis, Taig et al reported the annual risk as marginally less than for staff working in mining or forestry, although both are widely regarded as high-risk working industries with dangerous activities. Depending on assumptions, the risk to staff could be even higher, and increasing until an AF8 event strikes. Workers should not be exposed to this risk on an ongoing basis without reasonable efforts to evaluate options, mitigate risk as far as reasonably possible, and provide information and training to help them manage the residual risk for themselves and visitors.

3.143 However, it is important to note that the Taig et al (2015) comparisons are based on comparator statistics from single or low number fatalities per event, divided by many thousands of journeys or working hours. In the case of a landslide-induced tsunami at Milford Sound Piopiotahi, there is the credible possibility of a catastrophic outcome (>100 fatalities, and possibly even >2000) in a single event. Society locally and worldwide tends to have a much lower tolerance for mass fatalities, whether from natural disasters or other causes. There is a high probability of a major Alpine Fault rupture in the next 50 years (probably >50%, although this number is currently review by Howarth et al, expected for publication early 2021). This puts the probability of a catastrophic outcome (>100 fatalities) possibly as high as 16 percent over the next 50 years, or 0.3% (1:300) chance per year. Given the credible catastrophic outcome, including possibility of thousands of fatalities, this risk seems very high, and worth significant effort to better understand and mitigate.

3.144 This is a risk that currently is not well publicised with visitors nor is it one that is easy to predict (in time), manage or mitigate. Options to help mitigate this risk and improve probability of survival should be carefully considered for the masterplan. This is likely to also require further modelling to better understand the probabilistic distribution of this hazard across the area. This may entail looking at the spatial distribution of water elevations and peak velocities for some of the past deposits, but also looking at future potential source areas, ideally with a probabilistic framework for the parameter uncertainties associated with source volume, elevation, tsunami initiation (including air entrainment), hydrodynamic wave attenuation, nearshore transformation and spreading including debris entrainment. The analysis of wave shape, nearshore and onshore, may help to better understand the hazard and inform mitigation measures.

3.145 The multiple (22) tourism-related fatalities that occurred when the Whakaari / White Island volcano erupted in December 2019 has highlighted this issue of societal versus individual risk. The volcano was generally known to be an active volcano, and the site had prior elevated activity and warning levels as reported by GNS), and yet the incident still attracted intense public and legal scrutiny by both the local and international community. Ongoing review by Worksafe may help to clarify the extent to which warnings were communicated and valid as waivers and may trigger greater awareness and highlight the need for better understanding, managing and communicating the societal acceptability on mass tragedies. It is recommended that a probabilistic risk to life framework is applied similar to that used for large dams. The Milford Sound Piopiotahi Opportunities project should consider options for far greater disclosure and management of the residual risks. There are a variety of other recommendations in the GNS report (Taig et al, 2015) including further numerical modelling, improvements to emergency response plans, improved and well-marked evacuation routes, better information for visitors (online and on site), consider moving overnight accommodation to safer locations. These and related ideas are explored in the Long List section later in this report.

LIQUEFACTION

3.146 A 2006 report by GNS (Glassey, 2006) on geological hazards indicates a high liquefaction risk in the Cleddau delta. This is also supported by the liquefaction risk classification from Environment Southland website (Figure 2 36). However, test pits for the development of Cleddau village (Grindley and Pepper, 2007) indicated that much of the material on the delta is coarse sand and gravel to cobble, with limited fines. This makes sense given the high energy river and steep contributing geology. Therefore, given the limited fines content, the risk of liquefaction could be considered medium rather than high. Even at a small scale, fines content can vary spatially, and detailed design would require site-specific assessment of foundation conditions to assess risk of liquefaction and variable settlement potential when designing foundations and buildings. The southern and eastern margins of Freshwater Basin are not marked on the Environment Southland liquefaction risk layer, probably due to the limited flat ground between the steep mountains and the water's edge relative to the spatial resolution of the mapping. However, a report by Stuart (2019c) indicates that some risk of liquefaction and lateral spreading is present based on testing for a possible multi-storey carpark. They also highlighted that liquefiable layers are variable and do not appear consistent across the site, which would highlight the need for site-specific testing to inform detail design.

3.147 Some liquefaction risk is expected to extend to the terminal area, the airport, and all development within the Deepwater basin area. During and shortly after the earthquake, liquefied soils could allow buildings to topple (depending on their design), damage to roads, the runway (potentially limiting usability for fixed wing aircraft), water and wastewater networks, and any rigid gas pipes.

3.148 Due to the slightly delayed and slightly slower nature of liquefaction (which can also help to dampen local shaking), the likelihood of deaths directly attributed to liquefaction is considered low.

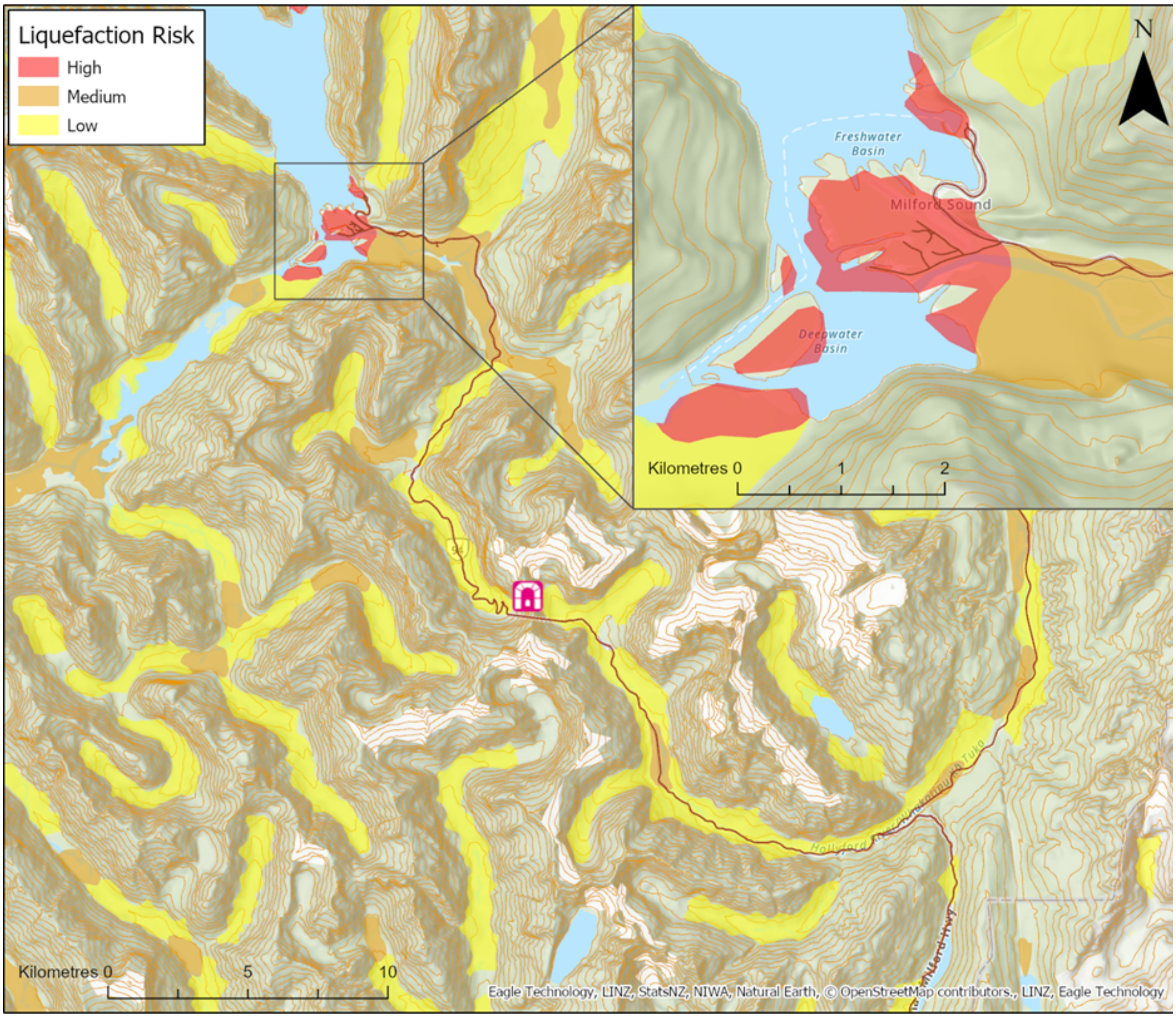


Figure 37: Liquefaction risk. Source: Environment Southland/GNS

COASTAL TSUNAMI

3.149 The Indo-Australian plate boundary offshore of Fiordland (beyond the south-western end of the Alpine Fault) forms the Puysegur subduction zone, capable of producing large earthquakes with magnitudes similar or greater than the magnitude 7.8 Dusky Sound earthquake (July 2009). This earthquake generated a local tsunami with wave runup of 2.3m and a ~1m wave was recorded at Jackson Bay, Westland approximately 260km from the epicentre. The Alpine Fault and the Puysegur subduction zone are predominately strike-slip (lateral movement more than vertical), therefore its potential to generate a very large tsunami is thought to be limited (Power, 2013, Orchiston et al, 2016). Therefore, despite the relatively short lead time (possibly as short as half an hour) the combination of some lead-time and moderate water levels may allow many people to find refuge if multiple routes and safe refuge areas were appropriately sign-posted and if effective immediate warning were given. Due to the terrain, it is likely that many people (notably elderly or infirm) would require assistance, and management of traffic and people in such cases would be a challenging part of the response. The availability and clarity of evacuation routes, and the effectiveness of issuing and responding to warnings are perceived to be lacking at present and should be considered for improvement through the masterplan). However, it is anticipated that measures to mitigate the risk of rapid landslide-induced tsunami will also be effective for mitigating against coastal tsunamis whether local or distant source.

3.150 A GNS report (Power, 2013) indicates that large distant-source coastal tsunamis are also possible. The frequency and source distribution curves are provided in Appendix 2. However, these are distant source events are today likely to come with longer lead time allowing most people to be evacuated by the authorities to a safe location.

EVALUATION

3.151 The probability of a major AF8 event in the next 50 years (or less) is very high at around 50 percent and climbing, and with this the likelihood of a high number of fatalities due to direct landslides and/or associated landslide-induced tsunamis. In the status quo, many of those fortunate enough to survive may be injured. There could be substantial challenges finding safe refuge in what remains of the building infrastructure (also considering many significant aftershocks and heightened ongoing risks of rockfall and landslide-induced tsunami) until a complete evacuation can be performed. Cold weather and lack of undamaged lifeline resources may shorten the survival window. Evacuation would most likely need to be by helicopter (weather permitting) to Queenstown or Te Anau, or as a last resort by boat (again weather permitting) to Bluff near Invercargill. Search and rescue resources in the region would likely be stretched, all of which reduce the potential survival rate. Lifelines such as clean water and power are likely to be compromised, and communication pathways could be damaged. Accurate weather forecasts for the evacuation journey may not be readily available depending on damage around the region.

3.152 This represents a very difficult situation to be in, or to manage. The practical and legal elements of the masterplan should consider that a high number of people will be short stop visitors with limited risk appetite or awareness, let alone survival skills. The masterplan should consider not only individual risk but societal risk (large scale impacts). The scenario is different from a built-up area like Wellington or Christchurch, where a higher proportion of people are resident, and the resilience opportunities/needs are very different but resources for refuge and recovery are also generally more readily available.

TE ANAU AND MANAPOURI

EARTHQUAKE

3.153 Te Anau and Manapouri are also found in a geologically active area. Although further from the Alpine Fault, they would still be substantially impacted by a major MM8 rupture of the Alpine Fault, plus there are other active faults nearer to these developments which can also produce moderate quakes. The risks associated with a major earthquake such as ground accelerations/shaking, landslides, and objects falling in urban areas, remain present and are relatively well understood. Some visitors from non-earthquake-prone countries may be less aware or have less auto-response in terms of Drop-Cover-Hold.

3.154 Doubtful Sound Patea is expected to have a relatively similar hazard potential to Milford Sound Piopiotahi, although there is not the same level of detailed analysis available due to the lower population exposure. Whilst aerial support by sea plane and helicopters may be feasible subject to weather conditions, there are fewer landing spaces which may lengthen the time taken to affect an evacuation.

LANDSLIDE-INDUCED TSUNAMI

3.155 Landslide-induced tsunami risk in the Lake Te Anau and Lake Manapouri were assessed by Hancox (2012). This report showed that Lake Te Anau has risk of landslides but wave runup generally lower than 3m at most locations of interest (up to 5m at Worsley Hut). See Appendix 1 for extract of results. At Lake Manapouri, wave runup was generally up to 1m at most sites of interest, apart from the Powerhouse and Freeman Burn Hut where potential runup of 25m is possible from landslide site F1.

3.156 Landslide-induced tsunami in Doubtful Sound Patea is thought to present a broadly similar hazard potential to that of Milford Sound Piopiotahi , although an evidence base for this fiord has not yet been prepared due to the lower population exposure.

LIQUEFACTION

3.157 The Environment Southland online hazards map website suggests that much of Te Anau is on Medium risk of liquefaction. Most of Manapouri is in the Low liquefaction risk category, although some liquefaction has been reported in the area from past moderate earthquakes (Glassey, 2006). These regionalised assessments are not a replacement for detailed site-specific investigation that would be required as part of detailed design. The risk of associated delta collapse and lateral spread for sites on the lake was also addressed in Hancox (2012), as shown in the extract in Appendix 1.

3.158 Although not classified on the Environment Southland liquefaction map, Doubtful Sound Patea is suspected to also be in the Low liquefaction risk category, but there is not a detailed evidence base for this estimate.

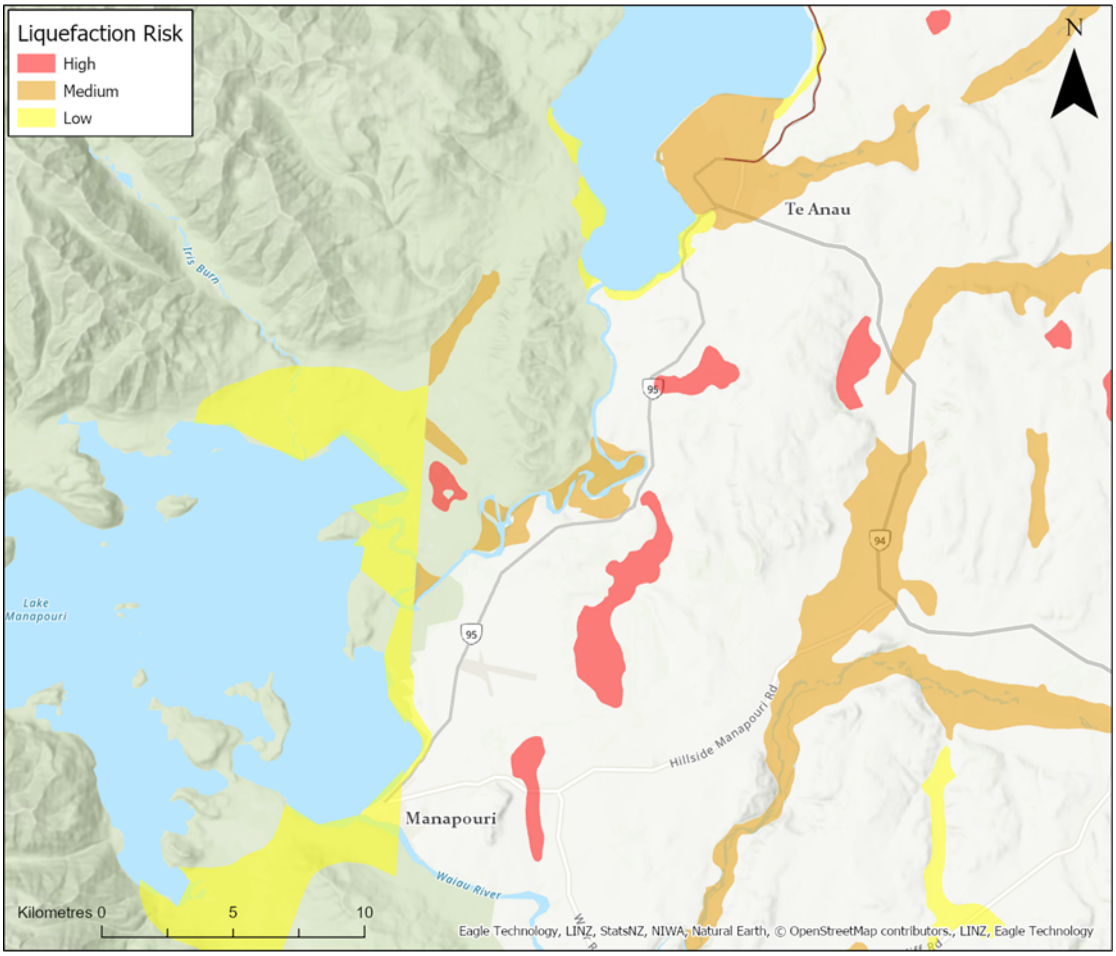


Figure 38: Liquefaction Te Anau / Manapouri (Source: Environment Southland/GNS)

COASTAL TSUNAMI

3.159 Risk associated with coastal tsunami in Doubtful Sound Patea, whether from near-source Pusegur subduction zone or distant source tsunami, is expected to show a broadly similar hazard potential to that of Milford Sound Piopiotahi (see Appendix 2), although with lower population exposure and probably a slightly lower hazard profile (e.g., maximum water depths/velocities). The Wilmot Pass road has a rise around 400m east of Wanganella / Deep Cove, which offers a potential tsunami refuge above the 40m contour (see Figure 39).

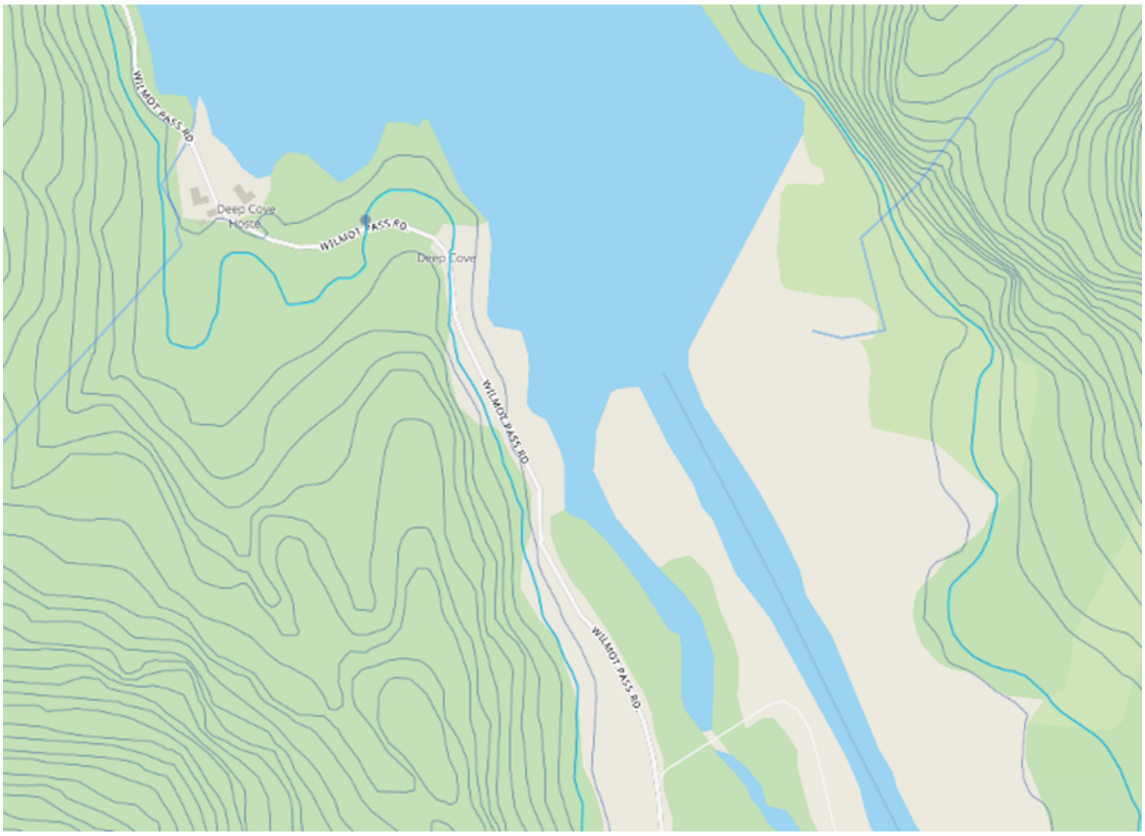


Figure 39: Wilmot Pass road near Deep Cove (possible tsunami refuge above the 40m contour – highlighted)

4 LONG LIST OPTIONS FOR DISCIPLINE

4.1 There is no such thing as a guaranteed safe day in Milford Sound Piopiotahi, but many hazards can be substantially reduced or mitigated through a combination of design and emergency planning. It is useful to remember the 4R's of Resilience, namely Reduction, Readiness, Response and Recovery. In the Long List stage, we seek to identify possible measures to help Reduce risk by design, plus measures that may help with Readiness, Response and Recovery.

4.2 This section of the report first looks at some high-level principles in terms of organisational arrangements and readiness / response capacity.

4.3 The report then addresses below key mitigation measures to reduce the current (status quo) visitor risk profile grouped by hazard type. These will be ordered approximately from the highest potential impact to lower impact hazard sources.

4.4 After discussion of the core mitigation measures by hazard type, we then provide additional commentary on other non-hazard-specific Long List Ideas from a hazard, visitor risk and resilience viewpoint.

4.5 Note some of the measures proposed in the long list stage may later be found too costly or impractical. This may result in them later being excluded, or only partially adopted or adapted. This may necessitate that more of the risk is passed to the individual visitor / participant, with appropriate informed consent and information or safety briefings to help them manage that residual risk.

ORGANISATIONAL ARRANGEMENTS

4.6 Organisational arrangements are covered under Main Idea 9 in the long list theme, as further discussed in the workstream 7 (Governance, Management and Legislation) report. Additional commentary here focusses specifically on risk management elements.

4.7 The status quo assigns hazard management responsibilities via a range of different Acts. This has the *potential* for some gaps in proactive ownership and appropriate intervention where responsibilities are shared or overlap. For example, the CDEM Act provides responsibilities for identification of hazards and an emphasis on development of resilience capacity (effectively how to make the best of a bad situation) but is less clear on potential remit to limit or stop activities that may be considered unsafe. Worksafe, under the Health and Safety at Work Act, has a clear remit to limit or stop unsafe activities, although this power is most often exercised based on numbers of accidents/deaths accumulated from past events rather than a proactive identification of potential future hazard. Some of the natural hazards under consideration may not be picked up in a traditional assessment of safety at a workplace. Local and Regional Councils have responsibilities under the Local Government Act and Resource Management Acts to identify hazards and consider these in future spatial planning, with incident response executed largely through CDEM. The Department of Conservation also applies and interprets various Acts in relation to assessing and managing visitor safety (e.g., National Parks Act, Conservation Act, Building Act, and the Occupiers Liability Act). In essence, despite the potentially confusing overlaps, there are generally provisions to make reasonable efforts at identifying, evaluating and mitigating risks to the extent reasonably practicable, including anticipated future circumstances. When making decisions, a range of options should be considered and suitably evaluated and documented to avoid being challenged for negligence if an incident does occur.

4.8 Going forward, it will be important to maintain clarity over legal responsibilities, whether as enhanced/clarified status quo or whether new legal entities are created (refer to Task 7 Governance, Management and Legislation report). An important part of the governance arrangements will be a focus on the 4R's of Resilience, namely Reduction, Readiness, Response and Recovery, with appropriate funding and ongoing monitoring. The outcomes of the White Island legal proceedings may create relevant precedent around the difference in tourism situations between individual risk, risk to staff (who are generally exposed longer to the hazards in question), and the societal acceptability (or otherwise) of potentially exposing a large number of people to a hazard at the same time leading to a potential major catastrophic incident (multiple deaths) that tends to attract greater scrutiny than a small number of deaths diffuse over time and/or space. The Milford Sound Piopiotahi potential maximum visitor risk exposure situation is clearly on a large scale and requires clear proactive understanding and management of risk.

4.9 Further elements of potential mitigation measures and resilience arrangements are embedded throughout the discussions below and elsewhere in this report.

READINESS AND RESPONSE CAPACITY

4.10 As discussed in the baseline section on organisational arrangements, there is considerable experience, capacity and equipment spread across the many organisations with risk management roles in the region. It is important that these are well captured and appropriately maintained and monitored going forward, and further developed where appropriate to meet potential scenarios. Some additional elements for consideration (e.g., additional warning and responder training suggestions) are discussed below under the various hazard types or long list ideas.

4.11 The isolation and weather of Milford Sound Piopiotahi adds an additional layer of complexity or challenge to many of the hazard response requirements. Even for relatively minor incidents, weather can hamper flying in help or evacuating those in need of medical attention. In a major disaster, with the Milford Road likely to be unpassable, and weather can add to evacuation delays by both air and by sea (for example evacuating by boat to Bluff / Invercargill). This adds importance to the value of lifeline infrastructure (water, food, heating, medical supplies, communications infrastructure, etc) to support survival and/or evacuation efforts following an event.

4.12 **Visitor information** on hazards/risks can help visitors be more informed which may enhance their reaction time and choices, and thereby their chances of survival compared to the current situation in which many visitors are probably unaware of some of the potential catastrophic hazard scenarios. This information needs careful wording/messaging, including central mitigation measures that are (or will be) in place by host organisations, and also how individual awareness can help them respond in the most effective and timeous way during different scenarios. Some of this targeted information should be available from point of sale (online, across the world) to signs and AR info and signage on site. Distinction is needed between the probabilities of individual visitors (so as not to cause unnecessary avoidance or alarm) versus staff and responders who need to have a greater understanding to provide consistent and well-informed advice to visitors during an event.

KEY MITIGATION MEASURES BY HAZARD TYPE

AF8 AND LANDSLIDE-INDUCED TSUNAMI

4.13 A large Alpine Fault rupture magnitude 8+ (AF8) as indicated in the baseline section of this report will comprise substantial shaking, avalanche (especially in winter/spring), and many rockfalls/landslides. The mitigation measures for avalanche and rockfalls are discussed in the next sections, whilst this section focusses specifically on landslide-induced tsunami in the fiord.

4.14 By way of summary of the status quo, there is a moderately high probability in the order of 16 percent probability over the next 50 years of a catastrophic incident due to a large landslide-induced tsunami. At the larger end of the spectrum, these waves have the capacity to strip mature trees from the landscape and kill most people on land or in buildings (especially those buildings that have not been specifically designed to withstand them). Overnight in winter, there may be in the order of 100 people, or at peak summer day close to 3000 people in Milford Sound Piopiotahi who would stand little chance of survival. There is very short lead time from the ground shaking to waves arriving (in the order of 1-7 minutes), with negligible safe refuge that can be reached by large volumes of people within that timeline. Access to high ground is restricted in most areas by dense vegetation and there are no clearly marked evacuation paths or muster areas. This risk is not widely communicated.

4.15 One key long list idea (referenced under theme Main Idea 3: Redesign of Milford Village, e.g. Sub-idea 3.2 and 3.3) would be at least one large central purpose-built building to provide a safe refuge for anyone who could reach it in time. This building could also provide food and shelter whilst awaiting evacuation after an event. This building could be designed for 'normal' day use as a visitor hub and food court on the first floor with viewing balconies, and hotel rooms on higher floors to bring additional revenue. Any glass on higher floors (not to be used on ground floor due to higher entrainment of rocks) would be high standard toughened glass to withstand the appropriate transient forces (both earthquakes and tsunami waves). With consideration for sea level rise and coastal source flooding, it may be worth using the ground level for vehicular services such as passenger pick-up and drop off, deliveries, etc. The façade of the building would be designed with irregular surfaces to introduce energy dissipation and/or air entrainment which serve to reduce transient pressure loadings as the wave 'hits' the building. Being set well back from where the Fiord bottom rises steeply to the Cleddau delta means waves are likely to have broken and already dissipated some energy (rather than curling up and 'slamming' into the building from above). The wave form and mitigation design should be further investigated by wave transformation modelling. Elements of the building could be greened to reduce visual impact (potentially borrowing some elements of the two images below, although further multidisciplinary design would be required). Foundations and structural strengthening members would be designed to withstand both earthquakes and tsunami transient loadings. External doors would open outwards to minimise unnecessary water ingress during the short duration wave surges. Depending on source location and initial tsunami wave height, there would probably be between 1 and 3 large waves arriving onshore in close succession (less than a minute apart), followed by a number of smaller waves as energy bounces around the fiord before gradually returning to equilibrium (over an estimated say half an hour). This would be confirmed by the modelling. The design concepts would be optimised later in the detailed design process considering, including modelling of different onshore wave transformation scenarios to inform the building design, including backwash as water returns from land to the sea. Whilst it may be challenging to balance the economics (cost vs revenue) from such a building, this must be evaluated in terms of overall resilience opportunities and the potential catastrophic consequences of the status quo without purpose-built resilient structures. It might need to be part-funded from other tourism sources, as it is could be considered the resilience 'key' that allows continued tourism access to Milford Sound Piopiotahi that might not be considered safe without it.

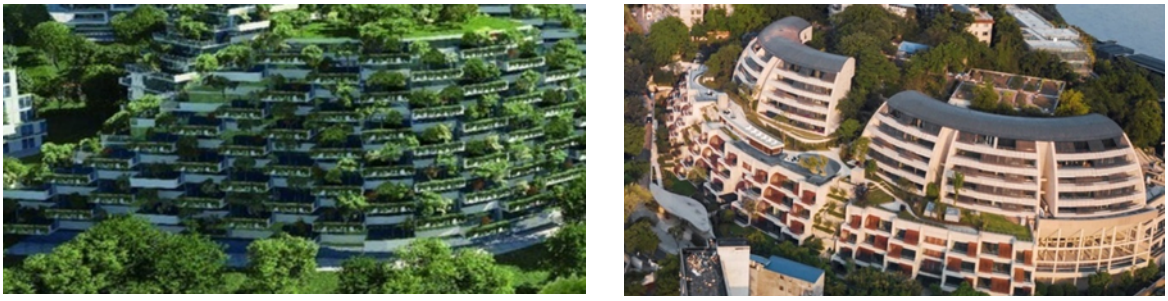


Figure 40: Illustrations of possible elements of visitor hub building forms to blend into the visual landscape (left) and keep a lower vertical aspect area to reduce extreme wave loading (right)

4.16 For other high concentrations of people on land (such as near the two wharfs, which are too far to run to the main hub above in approximately one minute), consideration could be given to somewhat smaller 'bunkers' that are built with a low profile to withstand tsunami flowing over the top. Doors would once again open outward so that they are forced closed by water, capturing enough air inside so that people could survive the few short-duration tsunami waves. For most of the time, these bunkers could serve as weather shelters and Maori interpretation spaces with stories about Piopiotahi's formation, information on natural hazards and resilience measures, ecological interest, etc. The design of these bunkers would be in keeping with the shelters elsewhere in the park, but with additional design considerations. The low-profile roofs could serve as slightly elevated viewing platforms. Since they would be non-habitable spaces (i.e. non-permanent, and no-one sleeping there overnight), they could be designed with allowance for occasional internal flooding (for example from extreme coastal storm surge with some sea level rise, and/or distant-source coastal tsunami). The designs could perhaps adopt some elements from the images below to blend in and minimise visual impact. Spacing between bunkers could be selected based on most people's ability to orient (find the direction to the nearest bunker, which may even be 'toward the danger') and run to it within approximately 1 minute. If longer duration flooding were expected, such as for coastal-source tsunami or storm surge, people should be rather evacuated to the central hub or the bluff behind the hotel. There is limited suitable space in the vicinity of the ferry terminal (and associated rockfall risk) making this location very challenging to mitigate.

Figure 41: Illustrations of possible elements of low profile bunkder refuge / shelter

4.17 Another idea that may help to mitigate at least a part of this risk or as an interim measure would be create/improve a wide clear pathway up the bluff behind the hotel to a semi-cleared muster area that could also potentially serve as a viewing point at other times. Given the volume of people at peak times, distance to some areas of the village, and response time allowing for those less able to run/climb fast, this is not considered an ideal or sustainable solution. However, it could possibly be implemented more quickly in early years of the project as an interim measure while the upgraded central hub proposed above is designed and being eventually built. Potential evacuation routes to consider were presented in Table 4.

Figure 42: Potential tsunami evacuation muster points (pink arrow at existing lookout ~30m, and white arrow on 80m contour)

4.18 If a centralised resilient visitor hub / hotel is not feasible, one alternative to partly mitigate risk to staff could be to remove all overnight staff and visitors away high hazard zones. Overnight visitors currently have longer exposure (and slower response when sleeping) compared to single day visitors, and resident staff have high exposure to risk through being on site at low elevations for large proportions of the year. There are limited suitable locations between Milford Sound Piopiotahi and the lower Hollyford valley, and any such move would probably involve considerable ecological impact and expensive infrastructure (including water supply, power, wastewater, etc). This option is therefore expected to score very poorly in any multi-criteria analysis.

4.19 Another high concentration of visitors that would need consideration during a landslide-induced tsunami are those on boats. The highest impact is obviously close to the sides of the fiord. Consideration should be given to exclusion zones of say 150m or more from valley sides to reduce likelihood of direct hits from falling debris, allow some energy dissipation and formation of a 'neater' wave which can be more predictably navigated. The exclusion zone could be refined in due course using computational modelling of event probabilities and hazard. A fairly large exclusion zone would also allow more time for pilots to react and turn their vessel to face the wave at the optimal speed and direction (apart from the very large cruise ships of course). Sailing boats may be at higher risk, and consideration should be given to limiting their access to the fiord or advising an even larger exclusion zone. Once carrying passengers, cruise boats should seek to minimise their time in the shore zone (where wave impacts would be dramatic), and head quickly out to deep water where there is probably a better chance of survival than in the shore zone. Consideration could be given to mandating lifejackets under every seat (for crew and visitors, with instructions upon boarding to allow rapid deployment instead of scrambling in a locker and passing around), or possibly even mandate wearing of life jackets. Pilots should receive periodic refresher training on handling their vessel types on high waves (say once every 3-5 years), in order to improve response time and stabilising manoeuvres in waves. This sort of training is normally given to sea rescue and coast guard pilots for handing rough conditions at sea. Bearing in mind the main waves will bounce off steep sides of the Fiord, there may be complex wave patterns that pilots would need to negotiate with speed and confidence. Further advice could also be sought from the Coast Guard and RNLI on whether the current fleet of cruise boats is fit for the task or may warrant replacement over time to craft better suited to successfully navigating this potential challenging life-threatening scenario. Initial conversations on this topic were nonconclusive but may benefit from the hydrodynamic modelling to better describe the range of wave conditions (including wave form and shoaling).

Figure 43: Large boat tackling a large storm wave illustrating the importance of pilot wave training (Photo: Scott Reid)

4.20 Occupants at Cleddau staff village and Milford Sound Lodge on the banks of the Cleddau River are protected from the smallest events due to their elevation above 5m. However, they are subject to risk from larger landslide-induced tsunami. The Lodge also has the disadvantage of poor lines of sight into the Fiord (even in the day, and more so at night, even with audible alarms) which may influence timely responses. Higher ground toward the hills may be subject to rockfall in a major AF8 event, so it may be worth considering 'bunker' type shelters as discussed above, to retain some distance from potential rockfall. These bunker shelters should be placed close to the Lodge or integrated into parts of the Lodge, to minimise response time required especially when occupants are asleep. Similar considerations could apply to overnight campervans if these are not removed in the access model.

4.21 All land-based staff should also undergo regular training and periodic drill exercises in conjunction with the Milford Sound Piopiotahi Emergency Response Team and regional Civil Defence & Emergency Management teams to put them in the best position to advise visitors quickly and with confidence to improve safety outcomes for all. Warning systems such as sirens or horns (without reliance on mains electric supply) should be considered, as an earthquake could cause temporary or permanent failure of the electricity supply.

4.22 Doubtful Sound Patea has a broadly similar natural hazard profile to Piopiotahi. The lower visitor numbers may mean it is less economically justifiable for an expensive purpose-built resilience hub. However, there is a high point on Wilmot Pass Road above Wanganella / Deep Cove (around 40m elevation, within 400m of the hostel) that could be formalised into an evacuation area with appropriate signage. The overall emergency management plan would include regular training of land-based staff and boat pilots to help mitigate the risks as far as reasonably possible. A boat exclusion zone adjacent to steep valley sides should be considered, as discussed above for Milford Sound Piopiotahi.

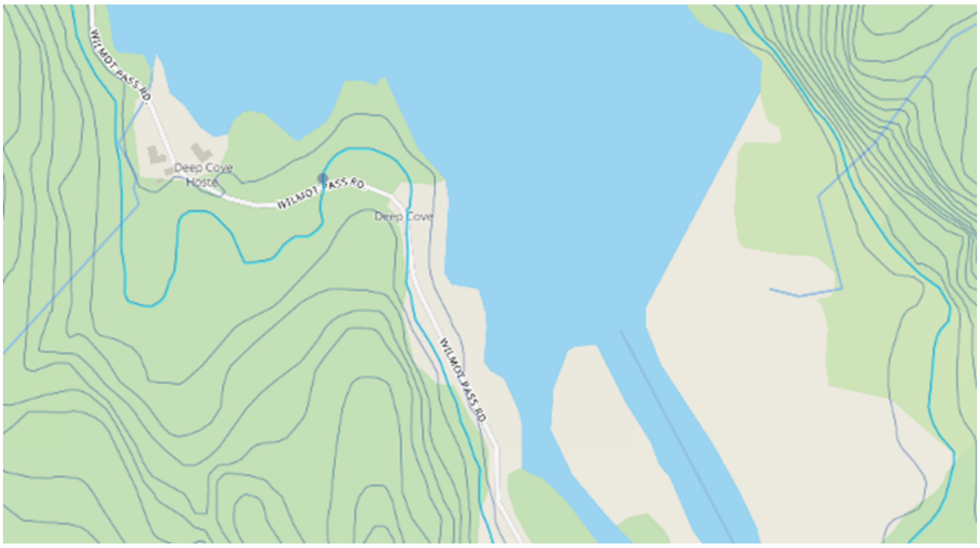


Figure 44: Wilmot Pass road near Deep Cove (possible tsunami refuge, above the 40m contour - highlighted)

4.23 On Lake Te Anau and Manapouri, there is also some risk from landslide-induced tsunami, although studies by GNS indicate that the wave runup at the wharfs and developed areas of the lakes are generally fairly low, and waves in deep water should therefore also be safely navigable, particularly if boat users are aware and appropriately trained (especially commercial operators who pilot larger boats with more passengers). A boat exclusion zone adjacent to steep valley sides should be considered based on the analysis in the GNS report, as discussed above for Milford Sound Piopiotahi.

AVALANCHE

4.24 The Milford Road Alliance already do a great job via their Avalanche Control Programme to monitor the snowpack and when the risk is particularly high to close the road and trigger avalanches using small, controlled explosives. This effort comes at a cost, and it is recommended that this is maintained with ongoing monitoring for opportunities to further improve the science and safe delivery of this essential service among their other roles.

4.25 Earthquakes in winter or spring could trigger several avalanches even if the ice conditions are not considered high risk for 'natural' initiation. This scenario is very difficult to predict and therefore mitigate. Some risk reduction is already in place by virtue of the MRA trying to monitor the avalanche start zones and keep their volume lower. Traffic on the road through the avalanche zones would be most at risk. The proposed increased use of buses (compared to the status quo of mixed buses and self-drive) would result in less queues at the Homer Tunnel which is good as it reduces exposure. There would not be a substantial change in the risk profile elsewhere, as roughly the same total number of people would be moving through the avalanche zone in each hour compared to the status quo at peak times.

4.26 Consideration could be given to extensions to the Homer Tunnel portals to provide some additional protection from seasonal or earthquake-induced avalanche. Depending on the condition of the ice pack (i.e., provided the avalanche risk is not considered very high), these may also allow a semi-sheltered viewing platform in all other weather conditions including in summer, as a potential stop location under the potential hop-off hop-on bus system. The Heritage, spatial, logistical and safety elements would require further detailed design in due course.

4.27 The current eastern portal is an old structure (has heritage values), not particularly well constructed, it took significant avalanche damage shortly after construction and was shortened as a result. In 2019 carparking space (shown in photo) was removed near the portal due to rockfall landing in the immediate area with visitors present, some risk remains with vehicles currently unprotected against rockfalls and avalanche (winter/spring) when long que's build from tunnel congestion.

Figure 45: Homer Tunnel eastern portal

4.28 The current western portal was put in place about approximately 2012, intended to be a temporary structure (to provide cover until and during removal of some loose rock on the slopes above the tunnel), but was then left in place. Only designed to withstand relatively small rocks (indicative ~grapefruit size), it has been fortunate (in respect of size and location of impacts) to have only sustained minor damage over the last ~7 years. Such structures will have 'design limits' and could be badly damaged by larger rocks, potentially rendering it more complex to dismantle and re-instate the damaged structure (potentially longer outage of road service than without portal but may help mitigate some risk to life).

Figure 46: Homber Tunnel western portal with temporary rockfall protection

ROCKFALL / LANDSLIDE

4.29 Rockfall, landslide and tree slides are common occurrence along the steeper areas of the corridor and in Milford Sound Piopiotahi as well as Doubtful Sound Patea. Whilst more common after heavy rain, they can occur at any time of the year and without warning. Earthquakes would trigger many rockfalls and landslides, again without warning. Those that occur without warning tend to be few, and smaller, compared to the widespread and potentially large slips that could occur during an AF8 event.

4.30 In terms of risk to vehicles, there is the possibility that buses carrying 40-50 people could be hit by falling debris in an AF8 event. Netting and rock anchors are already used by the MRA in some known high-risk locations, but this approach is not practical over a long distance and will not stop larger rockfalls. Generally, the low duration spent by any vehicle in any of the higher hazard spot translates to an acceptable hazard level, although quantitative probability analysis is beyond the scope of this masterplan.

4.31 To the extent that it might be feasible, an idea might be to consider (at long list stage) shifting large concentrations of visitors away from steep slopes, such as those at the Ferry wharf/terminal. The cliff closest to the northern side of the terminal is a little less than 200m high. A number of small rockfalls and tree slides ('regolith' containing earth and trees) have occurred in recent years, including a slip in 2016 that damaged a store shed in the parking area. Due to the fairly limited height, the probability of wide-scale destruction from this source is relatively low. However, a small rockfall in May 2019 was initiated at around 950m up Barren Peak which caused debris and boulders to career down the mountain and block a culvert near the Terminal. Fortunately, much of the debris and boulders were caught in a bend in the streambed it was following, which reduced the impact downstream. Large boulders from this height can project a considerable distance and cause substantial damage and risk to life. This event could be considered a close call and was initiated without an earthquake. An AF8 event could have more severe outcomes in this location, and it should at least be considered whether reducing visitor exposure and 'dwell time' in this location might be feasible. This could be achieved through use of a central visitor hub as discussed earlier, and 'pulsing' boat visitors through to the boats (e.g., on a tractor-train or high-volume short transit bus). The suggested location for the hub nearer the existing hotel site appears to have a significantly lower rockfall risk. The potential to swap the fishing and cruise wharfs is considered a possibility for discussion during long list, although relatively low water depth and occasional high fluvial flows make it more difficult for cruise ferries to get into Deepwater basin, so it is likely that this latter option will score poorly in MCA.

4.32 Similar principles regarding rockfall risk apply to The Lodge, although being 200m from the base of the main Barren Peak southern slope, the probability of The Lodge being destroyed by rockfall runout through dense vegetation is reasonably low. This assessment was confirmed by Shore and Macfarlane (2012).

4.33 Distributed risk, such as those on the hiking tracks, are very difficult to mitigate against rockfall. This and other risks to hikers (including avalanche, floods, tsunamis, etc) should be communicated with those booking hikes, from point of sale through to on site. Gradually falling cost of technological solutions such as Personal Locator equipment may allow these to become more commonplace or potentially mandatory in future in certain scenarios.

FLOOD AND DEBRIS FLOWS

4.34 Current flood risk to parts of the Milford Sound Piopiotahi village were assessed as part of the 2011 flood protection scheme, which was 'tested' in the February 2020 floods (in the order of a 1:200 chance per year event). Many people were evacuated from the village and Lodge, from Milford Road and some of the huts, all by helicopter due to the damage to the road. Despite the fairly rapid rate of rise of rivers, and the debris that they often carry, the risk to life is considered relatively low. High rainfall events are expected to increase in severity due to climate change, necessitating designs to cope with increased flows and debris. Following earthquakes or even large avalanches or landslides, there is likely to be a marked increase in debris carried by rivers especially during heavy rainfall events, which could cause localised increases in flood risk.

4.35 Debris dams can form from avalanche or slip material, which when can fill with water and then fail by piping or overtopping scour, producing a burst of high flow. A debris dam large enough to cause a dangerous or damaging dam burst flow would be more likely detected as the rockfall would probably produce substantial noise and a rockfall scar visible from a distance. The water level recorder on the Cleddau may also help to detect the notable drop in flow while a large debris dam was filling. Whilst detection is difficult to guarantee, the probability of an undetected life-threatening event seems low.

4.36 Upgrading Milford Road to be clear of all flooding and debris flows is likely to be very expensive and impractical given the high debris loads associated with rockfalls and rainfall events. There may be some structures that could be further improved following the 2020 floods, although many of these interventions are already under way by the MRA.

4.37 Any new future developments for the Milford Opportunities Project will be designed to make some provision for mobile rivers with high bed load, and flood flows with climate change increase in rainfall. These efforts will need to be balanced against cost and visual/environmental impacts. Cascade Creek in particular is set quite low on a mobile floodplain and even with landscaping some areas if developed may need to remain designated as flood-compatible and not used when heavy rain is forecast.

COASTAL TSUNAMI AND STORM SURGE WITH SEA LEVEL RISE

4.38 Whilst coastal source tsunami and extreme storm surge both usually arrive with some warning, it is possible that silent tsunamis can arise from submarine slides from relatively minor earthquakes. Currently access to high ground is restricted in most areas by dense vegetation and there are no clearly marked evacuation paths or muster areas.

4.39 Most of the ideas relevant for landslide-induced tsunami are relevant for this hazard too, such as a centralised visitor hub / hotel and (perhaps as an interim measure) a clearly marked evacuation path up to high ground on the bluff / spur behind the hotel, along with siren and staff training.

4.40 For any tsunami source with sufficient warning, which is hence likely to have larger volume and reside at flood level for longer, it would be preferable to remove people from the proposed low-lying emergency ‘bunkers’ to a higher elevation.

4.41 Part of the design of any developments will be to consider the latest climate change allowances (Ministry for the Environment, 2018) and adaptive pathway planning (e.g., Lawrence et al, 2020). Where feasible this may include risk-based consideration of water-compatible floor finishes so that these are not damaged by occasional flooding in future whether through sea level rise or tsunamis.

TRAVEL RELATED AND ‘BUSINESS AS USUAL’

4.42 Travel to and from Milford Sound Piopiotahi currently accounts for a significant portion of visitor risk exposure, whether by road, air or on foot (bicycles are allowed on the highway to Milford Sound Piopiotahi, but currently not allowed off-road in the FNP). This accumulated travel risk is because every person is exposed to at least some risks on their journey, which adds up to a large number of total journey exposures per year, whether or not there are earthquakes or tsunamis or floods during an individual’s visit. Whilst the risk for an individual traveller on an individual day may be within tolerable limits, the risks require ongoing management such as that delivered by the MRA and DOC.

4.43 The masterplan may point toward a variety of further safety improvements, such as road safety improvements (chevrons, no-overtaking lines, no stopping lines where appropriate, slow vehicle overtaking section, road surface improvements, etc), consideration of AFIS or similar air traffic support, bike and track safety, etc. However, site-specific level of detail over a long corridor is considered beyond the scope of this masterplan.

4.44 Comments on specific long list ideas are provided in the following section.

COMMENTS ON SPECIFIC LONG LIST ITEMS

MAIN IDEA 1: COMPELLING SUITE OF EXPERIENCES IN PIOPIOTAHI

4.45 Some of the proposed ideas refer to shoreline walks. These all require mitigation for landslide-induced tsunami risk in particular. Refer to earlier discussion above on mitigation ideas relating to this hazard.

The possibility of a walking route to Bowen Falls has been raised as an idea for related short activities in Piopiotahi. The residual risk to walkers of tree slides near the falls, and risk of landslide-induced tsunami in the Fiord, are both difficult to manage / mitigate due to the remoteness of the Bowen delta. Further site-specific investigation may be required to assess whether a safe elevated tsunami muster location could be found that is at low risk or partly protected from potential tree fall. Clear communication of residual risks is important before commencing the journey (as a minimum via signage and/or short safety briefings). There are three potential Bowen Falls access routes to consider:

- Use of only small boat to ferry passengers to the small Bowen River delta landing. This provides an opportunity for peak numbers on the delta to be managed by the boat operator.
- Low level existing route, which is currently closed due to significant existing tree slide and rockfall risk. Whilst the risk arises from comparatively small rocks and regolith / tree slides <200m high, it would take significant engineering cost to allow the existing route to be re-opened safely (such as by a combination of rock netting to capture some material plus partial cover to the walkway). A fairly detailed investigation was undertaken by Thompson (2002), although the photographs were not included in the copy of the report provided to us. Boardwalks could also be considered, although foundation conditions plus risks from wave action and boats would need further assessment. The combination of cost and residual risks may render this option unfavourable.
- High route, comprising steep stairs following roughly up the line of the hydropower pipeline and across toward the top of the falls (safe viewing location at suitable distance with guard rails, etc). The 'stairway to heaven' route would also be costly, and risk of falling from height would need to be managed, in addition to the visual impact and environmental considerations, which may render this idea unfavourable.

4.46 Ideas include multimedia experiences, which can also include information on natural hazards and mitigating actions that visitors should be aware of. This could potentially be delivered through mobile devices (phones or tables) using location-sensitive pages or Augmented Reality views on the mobile device.

MAIN IDEA 2: REDESIGN MILFORD VILLAGE

4.47 Some ideas reference redesign of the village mostly in relation the hotel site, which we would support with consideration for hazard mitigation. This may take the form of a centralised visitor hub / hotel complex and potentially additional refuge bunkers as discussed in the hazard section earlier in this chapter. The exact location relative to the existing site may be influenced by ground investigations (foundations/structure to earthquake/liquefaction codes and tsunami resilience) and visual impact analysis, although at a glance the closer to the bluff appears less susceptible to liquefaction and to rockfall, with the ability to integrate into the bluff to reduce visual impact (subject also to ecological assessment, etc).

4.48 Some ideas reference changes to flying arrangements. Whilst potentially worth considering the potential spatial and other benefits, the flying safety considerations will also require careful consideration as part of their detailed planning and implementation.

MAIN IDEA 3: ENHANCE THE MILFORD CORRIDOR EXPERIENCE

4.49 Some ideas reference more stopping locations along the corridor, which would need site-specific assessment of hazards as the description of the locations and nature of the stops is further developed. Most of the sites are expected to maximise use of existing disturbed footprint, and therefore the hazard profile is generally well understood. Within the avalanche zones is the least favourable, and no stopping would be advised in avalanche season. When looking at a potential 'super track head' idea in the vicinity of The Divide, initial screening suggests the lower Hollyford valley (Marian Lake carpark) is probably the best location, which could possibly function in tandem with The Divide itself, to link some low impact development allowing multiple walking tracks to be accessed (and possibly cycling in future if permitted in the FNPP review).

4.50 Some ideas reference additional accommodation and associated infrastructure at Knobs Flat and Cascade Creek. Again, these will need some site-specific assessment against natural hazard scape as the detail of these ideas develop further. As discussed earlier under the flooding hazard, Cascade Creek in particular may need some zones to be assigned that would be designated out of use when heavy rain is forecast.

4.51 One of the ideas includes more cycle paths. A meeting with cycling groups suggested the possibility of cycle access from Te Anau to Knobs Flat, with short easy grade loops near Knobs Flat and toward Cascade Creek, in addition to some more challenging terrain options for advanced riders (with a higher risk appetite/tolerance). In the higher altitude Alpine areas these will be increasingly challenging and costly not just to set out initially but also maintain after rainfall events and/or slips. Detailed site/route investigations have not been carried out as part of this report.

MAIN IDEA 4: DEVELOP TE ANAU AS A SUB-REGIONAL VISITOR HUB

4.52 Some of the ideas in the long list may require further development and/or site-specific research in order to provide relevant comment on their hazard profile. Generally, the hazards in Te Anau are relatively low compared to those in the corridor and at Milford Sound Piopiotahi. Further comments on ideas may be feasible depending on the shortlisting process and idea definition.

MAIN IDEA 5: EXPAND THE VISITOR OFFERING AROUND TE ANAU

4.53 Some of the ideas in the long list may require further development and/or site-specific research in order to provide relevant comment on their hazard profile. Generally, the hazards in Te Anau are relatively low compared to those in the corridor and at Milford Sound Piopiotahi. Further comments on ideas may be feasible depending on the shortlisting process and idea definition.

4.54 Some ideas reference more tracks in the Te Anau area. We are not currently able to drill down to site specific hazards outside of the main centres and corridor, partly because proposed extents have not yet been presented in detailed map form but also because of the diffuse and very site-specific nature of the hazards with low exposure footprint.

MAIN IDEA 6: OVERARCHING SUB-REGION COMPETITIVE ADVANTAGE

4.55 Some of the ideas in the long list may require further development and/or site-specific research in order to provide relevant comment on their hazard profile.

MAIN IDEA 7: NEW TRANSPORT MODEL

4.56 Some ideas reference reductions in self-drive vehicles to be replaced by predominantly bus travel. This would be helpful to reduce driving related and other hazards (drivers will know the route well, have regulated driving hours, follow scheduled times rather than drivers 'race-to-the-boat' and driving back exhausted, etc). This idea will also serve to reduce queues in avalanche zones near the Homer Tunnel, which reduces the visitor's hazard exposure.

MAIN IDEA 8: USE TOURISM TO IMPROVE CONSERVATION

4.57 Note that in addition funding conservation, tourism should also fund some of the emergency response capacity/training/equipment rather than this burden falling predominantly on general taxpayer money (and many volunteer responders).

MAIN IDEA 9: NEW GOVERNANCE AND MANAGEMENT STRUCTURES

4.58 Elements of governance and organisational arrangements to support resilience and recovery have been discussed earlier in this chapter.

5 RECOMMENDED OPTION

5.1 As discussed in the masterplan report, the project Recommended Option has developed through the multi-disciplinary inputs from various workstreams. The project team have engaged with SDC, Department of Conservation, Environment Southland, Waka Kotahi, Iwi and many more national, regional and local stakeholders. Ideas in development have been shaped and cross-examined by Reference Groups, the Project Working Group and the Governance Group.

5.2 Whilst presented in this section as a Recommended Option or suite of interventions, it is worth reiterating that the Recommended Option is (at time of writing) yet to be confirmed by the Governance Group. Furthermore, being at masterplan level, the ideas are expected to be further refined and evidenced through further engagement and more detailed studies (which may influence the shape or scale of some interventions) plus detailed site investigation and detailed design. Pointers toward further work are provided throughout this report, with key elements for future work summarised in Section 6: Summary and Conclusion.

5.3 The Recommended Option is a suite of interventions that collectively add value to the visitor experience whilst also improving visitor safety and creating revenue opportunities to help fund the project (capital and operational, including experiential and risk management plus conservation). The elements of the Recommended Option relevant to staff and visitor risk management are presented below, first for Milford Sound Piopiotahi and the corridor before touching briefly on Te Anau, Manapouri and Doubtful Sound Patea. Appendix 3 provides a high-level risk matrix per location showing where the risk profile is expected to change for each hazard type.

GENERAL / ORGANISATIONAL

5.4 **Ongoing** risk mitigation measures such as the standard procedures operated by Emergency Management Southland, SDC, DOC, Waka Kotahi (Milford Road Alliance), local asset management bodies and tourism operators are assumed to continue as currently operated, and where possible improve over time making use of research, scientific and technological advancements. The discussion below focuses on changes from the status quo rather than reiterating those elements of risk management that are already working. Some of these procedures will need to be updated to reflect new infrastructure and/or organisational arrangements associated with delivery of the masterplan.

5.5 **Organisational** arrangements are assumed to continue at least as effectively as currently. This should include encouraging clear ownership roles and legal or moral obligations for evaluating risks and limiting activities where justified or until suitable mitigation can be put in place. Limiting activity can be difficult when roles overlap or are not distinct. Clearer information for visitors and staff is required, from point of sale (or offer of employment) through to arrival on site. The information should be tailored differently for staff and responders compared to visitors who may have a different exposure profile and different level of risk awareness and risk tolerance.

5.6 **Emergency readiness and response** involves multiple organisations led by CDEM (in this case Emergency Management Southland). First responder capacity is often led by local volunteers like the Milford Sound Piopiotahi Emergency Response Team, many of whom are employees of the tourism operators, plus regional capacity including Mana Whenua networks, the Milford Road Alliance and helicopter operators (for search and rescue). The potential region-wide impact of an AF8 seismic event would stretch regional resources and likely require national support. Given the high probability of an Alpine Fault rupture over the next 50 years, responder capacity and skills development are an important need. The responder network and particularly onsite staff should undergo training and periodic exercising to be ready when an event occurs and provide consistent advice in an emergency, including those who staff boats.

MILFORD SOUND PIOPIOTAHI

5.7 The layout of the proposed Milford Sound Piopiotahi village referenced in the Masterplan report is influenced by the need to provide quick access to buildings that are resilient to an Alpine Fault earthquake and potentially very large waves from landslide-induced tsunami. There are very short lead times from severe ground shaking to wave impact (1-7 minutes depending on landslide location in the fiord), which limits refuge or evacuation options. Although the risk of a large rockfall from Barren Peak is relatively low, it is still best to minimise time spent in the area between the bluff and the ferry terminal where rockfall runout is more likely.

5.8 Landslide-induced tsunami is currently identified as an intolerable outlier in the current risk profile. It has a credible probability in the order of 16 percent over the next 50 years of producing a catastrophic event comprising over 100 fatalities (extending >2000 fatalities in the case of a large wave on a busy day). The potential wave height and short lead time means that even if there was an evacuation pathway up the bluff, very few people would be fit enough to run up to >50m elevation over >150m horizontal distance, in less than 1 minute. This drives a significant move in the Recommended Option towards a low number of consolidated earthquake-resilient buildings that can withstand wave overtopping. Elements of the proposed village layout are then influenced by this central philosophy, including keeping people in or near a safe refuge location as much as possible. Further elements of the plan are outlined below.

5.9 One key requirement is for a multi-function land-based robust **visitor hub** where visitors can arrive, refresh, orient and group be ticketed for scenic cruises in a safe location. Whether integrated with the visitor hub or standalone, **staff accommodation and hotel** should also be built to withstand the large earthquake and landslide-induced tsunami scenario. The engineering stability and cost/benefit of a single large building versus two or three smaller buildings can be evaluated further during detailed design. It represents significant engineering challenge and cost to design buildings that still have structural strength and integrity to withstand wave impact shortly after a major earthquake (in which building codes would normally permit some elements to be damaged). Therefore, a high specification to earthquake building code would be required, in addition to specific analysis on wave loadings. The building(s) would also provide food and shelter whilst awaiting evacuation after an event.

5.10 Another requirement for the buildings will be to have robust doors and doorframes (that do not get damaged in an earthquake). It is expected that many doors would be required to accommodate rapid ingress of a relatively large number visitors who may be outside near the building. This could be optimised by people movement modelling. The doors would open outward so that if mechanical controls failed then they would still be forced closed by water pressure. Glass should be avoided on the ground floor due to likelihood of high debris loads, and any glass on higher floors should be highly resilient toughened glass. With consideration for sea level rise and coastal source flooding, it may be worth using the ground level for vehicular services such as passenger pick-up and drop off, deliveries, etc, so that the main visitor concentration is slightly elevated for better views and safety. The façade of the building may be designed with irregular surfaces to introduce energy dissipation and/or air entrainment which serve to reduce transient pressure loadings as the wave 'hits' the building. Being set well back from where the Fiord bottom rises steeply to the Cleddau delta means waves are likely to have broken and already dissipated some energy (rather than curling up and 'slamming' into the building from above). The wave form and mitigation design should be further investigated by wave transformation modelling. Elements of the building could be greened to reduce visual impact as shown in Figure 40.

5.11 Where people are separated by more than say 150m (or perhaps 200m on flat terrain) from one of the robust buildings, smaller satellite **bunkers/shelters** should be built at key points to provide protection in these areas (such as the Freshwater basin, Cleddau delta, Deepwater basin and Lodge) to improve land-based survival rates. These shelters would be designed to have tourism functions at other times (information, interpretation, experience, etc). Doors would once again open outward so that they are forced closed by water, capturing enough air inside so that people could survive the few short-duration tsunami waves. The low-profile roofs could serve as slightly elevated viewing platforms. Since they would be non-habitable spaces (i.e. non-permanent, and no-one sleeping there overnight), they could be designed with allowance for occasional internal flooding (for example from extreme coastal storm surge with some sea level rise, and/or distant-source coastal tsunami). The designs could perhaps adopt some elements from the images in Figure 41 to blend in and minimise visual impact. Spacing between bunkers could be selected based on most people's ability to orient (find the direction to the nearest bunker after ground stops shaking sufficiently to move, bearing in mind the nearest shelter may be 'toward' the oncoming wave) and run to shelter within approximately 1 minute. If longer duration flooding were expected, such as for coastal-source tsunami or storm surge, people should be rather evacuated to the central visitor hub. There is limited suitable space in the vicinity of the ferry terminal to have a safe robust shelter capable of housing very large number of people, so the main shelter will be the hub with a smaller shelter near the ferry terminal. This is considered acceptable because the dwell time of large numbers of people at the ferry terminal will be substantially reduced by using shuttles to move people quickly from the visitor hub and straight onto a pre-determined boat. The existing terminal building is not considered a safe refuge from a landslide-induced tsunami, as it has not been designed to withstand this scenario.

5.12 Further probabilistic modelling is strongly advised, to improve understanding of all stages of the tsunami (past and future source areas, landslide initiation and dynamics, tsunami initiation including air entrainment, wave attenuation through the fiord, near-shore wave transformation and spreading including sediment/debris entrainment, wave shapes, depths and flow velocities). These would help inform the design features to dissipate and resist tsunami forces, along with earthquake, liquefaction, climate resilience and other design criteria. People movement modelling is also recommended to inform the satellite bunker spacing, doorways and emergency response spatial plans.

5.13 Another high concentration of visitors that would need consideration during a landslide-induced tsunami are those on **boats**. The highest impact is obviously close to the sides of the fiord. Therefore, exclusion zones should be established where boat traffic should be minimised. These would extend say 150m or more from valley sides to reduce likelihood of direct hits from falling debris, and to allow some energy dissipation and formation of a 'neater' wave which can be more predictably navigated. Shallow water near the sides of the fiord and delta are also higher hazard due to wave transformation in these areas. A simplistic starter for the concept of high hazard exclusion zones is illustrated in Figure 36, although it is not yet based on computational modelling. The landslide source and wave initiation modelling may allow the exclusion zones to be refined (i.e. enlarged in the higher hazard areas). The wave form modelling may also help to inform future cruise boat fleet choices in terms of their ability to handle potentially large and complex wave patterns. Consider adapting scenic cruise boats to have lifejackets and/or flotation aids more immediately accessible (e.g., lifejackets under each seat, with consideration for standing areas, or flotation aids that can be deployed by staff within seconds rather than minutes). Consider training pilots in heavy wave conditions to improve survival prospects, as the wave pattern may be complex as it bounces off the fiord walls and waves interfere. Sailing boats may be at higher risk (keel yaw and lower power to weight ratio), therefore consideration should be given to limiting their access to the fiord and/or providing clear messaging regarding residual risks even if wearing lifejackets. Once carrying passengers, cruise boats should seek to minimise their time in the shore zone (where wave impacts would be dramatic), and head quickly out to deep water where there is probably a better chance of survival than in the shore zone.

5.14 Large **cruise ships** are expected to be somewhat less vulnerable due to their size (relative to wave height) and better intrinsic stability. They carry far more passengers which increases exposure and have less ability to manoeuvre relative to any waves. However, even if capsized or run into a cliff by a large tsunami wave, the multiple buoyancy chambers are likely to give passengers longer time to board lifeboats and/or be rescued before it could sink. It is therefore considered that apart from a direct strike by landslide, the probability of large proportion of passenger fatalities is considered low.

5.15 Some discussion has been held on the benefits vs disbenefits of potentially excluding cruise ships from the fiord. Cruise ships require highly experienced pilotage. Milford Sound Piopiotahi represents a confined space relative to their size and turning ability, and night hours or adverse weather with poor visibility need 'blind pilotage' using electronic systems. With proper equipment and training incidents are rare, but things can go wrong as happened to L' Austral in 2017. This can present some risk to passengers or other water users. As indicated above, the risk of a large number of cruise ship fatalities from a landslide induced tsunami is considered relatively low. Therefore, the hazards perspective is unlikely on its own to be sufficient justification for excluding cruise ships from the Fiord, although this needs to be evaluated in conjunction with other considerations such as visual impact, air pollution, water pollution, etc.

5.16 When considering risk to an individual it is possible to aggregate a range of probabilities into a single metric such as annualised individual fatality risk, although the calculation and interpretation of these numbers can be quite complex. When considering the possible societal outcomes for comparatively rare but severe events, it is not easy to provide a single metric for measurement or comparison. This is because events of increasing rarity usually have very different outcomes that might be considered unacceptable at a societal level even if the individual level of risk may be considered tolerable by some. Therefore, a probabilistic framework is usually the preferred method, such as applied when reviewing or comparing safety and risk to life from large dams (refer to Figure 48 below).

5.17 A full computational assessment was not within the scope of the masterplan, but in order to illustrate the concept a rough approximation was made by breaking the exposed area down into sub-areas and separating the probabilities for moderate or high tsunami waves to occur in quiet times on a winter night (the minimum number of fatalities) through to peak occupancy on a summer day. Fatalities in each sub-area were estimated based on the wave height, although this is a subjective exercise in the absence of wave transformation modelling to inform the estimates. The table below shows the total estimated fatalities for different scenarios, under the existing and proposed situations. It is expected that the fatalities in the proposed option could be further reduced, but we are reluctant to reduce these too early without further modelling and more detailed assessment. Underestimation of residual risk could otherwise lead to complacency.

Table 5: Rough estimate of probabilities and potential fatalities from landslide-induced tsunami at Piopiotahi.

	Current (2019)		**Rec Option**	
Item Description	Max (Summer Day)	At least (Winter night)	Max (Summer Day)	At least (Winter night)
Landslide-induced tsunami: LOW ~6m runup probability	2%	16%	2%	16%
Landslide-induced tsunami: HIGH >20m runup probability	1%	8%	1%	8%
Estimated Fatalities: LOW ~6m runup event	**1900**	**25**	**120**	**1**
Estimated Fatalities: HIGH >20m runup event	**2800**	**250**	**440**	**30**

5.18 These figures are then presented graphically, together with some international examples of risk tolerability thresholds. It is worth noting that there are no risk tolerance levels set in NZ for societal risk, as far as we are aware. These international examples for imposed risk (such as dams) serve as illustration or qualitative comparison, which could be a catalyst for conversation to refine these values for Milford Sound Piopiotahi rather than defining them. These tolerability thresholds are usually subject to extensive consultation in affected communities, although this is made complex in Milford Sound Piopiotahi when such a high percentage of those exposed are itinerant (visiting rather than living in the affected area).

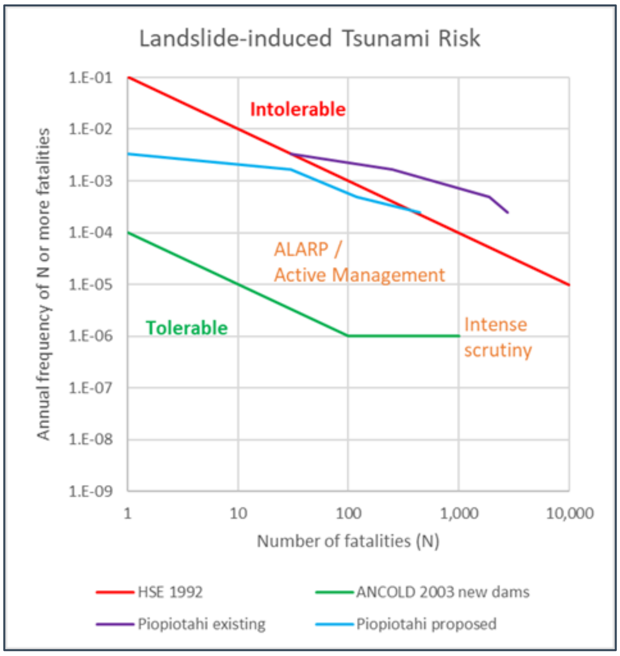


Figure 47: Chart of potential fatalities from landslide induced tsunami at Piopiotahi

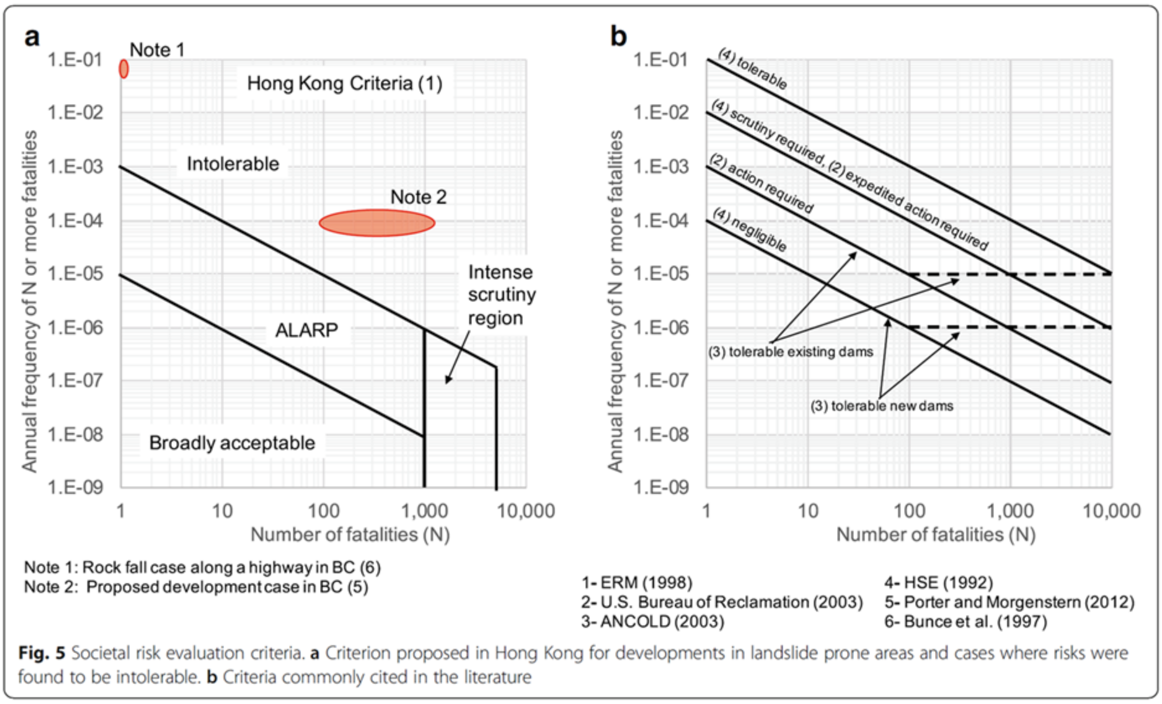


Figure 48: International risk evaluation examples (from Macciotta and Lefsrud, 2018)

5.19 In summary, for the highest current potential impact event of an AF8 event with landslide-induced tsunami at Milford Sound Piopiotahi , the collective mitigation measures are expected to transform probable outcomes from say a 10 percent survival rate in a large event to around 90 percent survival rate (possibly higher, subject to further modelling, detailed design, mitigation planning and revised probabilistic risk assessment). It is often not reasonably practicable to remove all risk, but the provision of mitigation plus information will put most people within a reasonable position to accept the residual risk and to respond in the best way to promote their survival. It is also appropriate to refine messaging for visitors who spend only a few hours per visit compared to staff and responder agencies who must be more aware of the potential societal impact and how best to react quickly during an event.

5.20 The assessment has been based on an approximate influx of 1000 visitors per hour to Piopiotahi, which has been used with an average 3.5 hours' time on site (i.e. 3500 maximum at any time). This informs the scale of infrastructure and risk mitigations. Larger numbers ought to be technical feasible with larger buildings and more comprehensive emergency modelling (people movement), but higher densities may detract from overall visitor experience. Therefore, we do not consider 1000 per hour as a hard limit from a risk mitigation viewpoint, although it is important that mitigation is scaled according to the final chosen numbers or follows an adaptive approach if the numbers are expected to scale significantly over the life of the masterplan.

5.21 Even if the anticipated AF8 event doesn't trigger an immediate co-seismic landslide-induced tsunami, it is likely that Milford Sound Piopiotahi and the Milford Road would be closed for a substantial period of time due to the heightened risk of aftershocks triggering further avalanches, rockfalls and landslides onto the road and/or into the Fiord (with associated tsunami). Such a closure to tourism could last a year or longer, depending on the effectiveness of mitigation and on the level of damage requiring re-build once aftershocks reduce to an acceptable level. Future economic planning should consider testing the impact this eventuality, including loss of earnings, and allowing for the reconstruction contributions that may come from EQC and commercial insurance in addition to top-up CAPEX/OPEX. There may be additional lessons that could be taken from the combined impacts of the February 2020 flood damage and reduced visitors from Covid-19.

5.22 Away from the main resilient buildings, exposure to hazard will be reduced by reducing dwell-time exposure in higher hazard areas. For example, we propose that visitors no longer use the existing ferry terminal as the primary location for congregating and waiting, as there is reduced potential to provide mitigation without further detracting from visitor experience at an already congested location. The congregating and any queuing and ticketing will take place at the resilient hub as mentioned above, with shuttles taking passengers to the ferry terminal to load and depart for deep water as quickly as possible, thus minimising time exposure in high hazard zones. Bunker/shelter provision should be considered to provide some level of protection at these remote locations, in each case considering entrance capacity for the peak number of nearby people at any time. Whilst there will be a recommendation for the use of the shuttles, any walkways between the hub and the ferry terminal should be kept alongside or near the road, and not much closer to the base of the steep valley sides. Maximising the distance from the base of the valley side allows a greater chance of rocks being arrested by the larger trees, although the possible risk of a large rockfall from Barren Peak in an AF8 event cannot be completely avoided.

5.23 On the Cleddau Delta and near Deepwater Basin, the risk of rockfall runout is lower but once again the exposure to even small landslide-induced tsunami is higher, which is mitigated by the presence bunker refuges as explained previously.

5.24 It is proposed to consider removal of the runway for reasons outlined in more detail in the Tourism report, including its visual impact and the current poor foundation conditions that may otherwise require substantial upgrade including raising to mitigate increasing flooding risk with climate change and sea level rise. Fixed wing aircraft have a shorter flying time to Te Anau or Queenstown, and a higher carrying capacity. However, it is not realistic to be fully reliant on fixed wing aircraft for evacuation, as the runway might be damaged during a major AF8 earthquake or potentially a major flood. In February 2020, over 300 people were evacuated, mostly by rotary wing, including from locations remote from Piopiotahi. This indicates that evacuation capacity alone is not sufficient motivation on its own to retain the runway. After a major event, equipment and materials for reconstruction would most likely arrive by boat or road (once it is repaired), rather than by air.

5.25 To cater for the loss of fixed-wing runway, a high-quality heliport is proposed to accommodate a higher number of helicopters (compared to baseline). The proposed location is on the raised area currently occupied by the Cleddau staff village. More detailed planning will be required to ensure appropriate separation of road users from airside staff, service vehicles and passengers. Whilst the Aerodrome Flight Information Service is currently assumed to remain operational, the requirements for ongoing air safety would require ongoing attention in conjunction with the spatial layout. With frequent adverse weather including low visibility, high number of small aircraft at peak times, pilots having long days and operating as 'tour guides' whilst flying, all contribute to additional risk especially during take-off and landing. Final spacing of the Final Approach and Take Off (FATO) area, taxiways and parking pads will require further refinement to maximise safe and compliant throughput. This will include consideration for existing and future helicopter fleet (e.g. use of wheeled helicopters or skids on trailers to manoeuvre). The FATO and at least some of the Touchdown and Lift-Off (TLOF) area should be suitable for large helicopters such as military class NH90 or similar that could be used during emergency evacuations or potentially some cargo transport. The remainder of the pads would be suitable for smaller helicopters used for scenic flights. An example is provided below of some of these concepts, from 'Ultimate Heliport' built in 2018 in South Africa.

Figure 49: Example of a modern heliport layout in South Africa

5.26 Possible interim measures (to help partly mitigate risk during early construction) include creating a wider and well-signposted pathway up the bluff ridgeline behind the hotel to a safer semi-cleared muster area at a suitable elevation (ideally higher than the current lookout platform, if feasible).

However, part of the risk reduction measures for construction staff may be to provide accommodation in an area of lower risk, or to provide emergency shelters such as containers anchored to deep piles to allow them to be overtopped by a wave. It is envisaged the enlarged bluff / spur high level pathway would be maintained to provide an elevated viewing location, potentially with elevated timber viewing platform to allow better views through the tops of the trees.

5.27 The **Milford Sound Piopiotahi Underwater Observatory** is a floating structure and has not been inspected in detail. We expect it would benefit from a structural analysis informed by the tsunami wave environment modelling and potentially structural improvements to resilience to improve visitor survival prospects in a tsunami event. For example, whether it remains anchored or may be torn free from its moorings, measures may need to be taken to reduce water ingress thereby retaining air and buoyancy capacity.

5.28 At **Bowen Falls**, a low-level pontoon link is proposed from the northern-most jetty at Freshwater Basin to the landing point near the base of the falls. The pontoon link should be separated from the base of the cliff by at least 5 meters to allow small rocks or tree fall into the water to minimise the probability of direct strike to the public. A significant tree fall may cause a small wave that could knock pedestrians off their feet, but handrails could offer some protection and life-rings and ladders could be installed to help anyone that did land up in the water. Considering the roughly 300m total run from the base of the falls to the terminal building/shelter, consideration should be given to capping numbers and ideally also providing a small shelter near the landing site if this can be integrated into the visual and natural landscape in a sensitive way. Any vertical venture such as a Bowen Falls funicular rail or cable car is considered challenging due to the cost of engineering a robust feature in this environment. It would require particular attention to geotechnical conditions, including measures to mitigate the risks during a major AF8 earthquake. Other risks at this location include tree slide, which could be managed through a combination of partial (surgical) management of vegetation and partly through debris shields / deflectors adjacent to the route (such as those adjacent to the Stoosbaan in Switzerland). At a concept level, it has been suggested to follow adjacent to the existing hydropower pipeline to the top of the hill, with a pathway from the top station to a viewing platform near the top of Bowen Falls. Analysis by Dykstra (2012) suggests the Bowen hanging valley near the falls has been subject to a major landslide deposit of Barren Peak material in the order of 9,000 years ago and indicates that another similar large failure in similar location with sufficient runout distance and volume to overlap the proposed route is unlikely. Smaller rockfalls from Barren Peak such as occurred in 2019 tend to follow a route further south from the pipeline, although may also divert into the small watercourse that flows westwards as it approaches ground level. The design of the base station and early elevation profile for the new feature would need to consider this watercourse in addition to rock and debris falls. The proximity to the hydropower pipeline may present some benefit for future inspection and maintenance of the pipeline but would also need to be designed so as not to undermine the structural integrity of the pipeline or the hydropower building at ground level.

5.29 **Milford Sound Lodge** is retained, with additional construction of one or two satellite bunker/shelter structures to provide protection for staff and visitors in the event of a landslide-induced tsunami.

5.30 The masterplan ideas have been influenced by the baseline hazard profile to maintain or reduce risk where possible. Their execution would be subject to further site-specific risk assessments and mitigation design through the consenting and ongoing risk management processes. Road safety and air safety are obviously key design considerations that will require further attention through detailed design.

SH94 CORRIDOR

5.31 **Homer Tunnel** portal risks could be reduced or at least managed whilst still affording viewing opportunities (outside high avalanche times) by creating a robust low-profile shelter at Loop 2 just below the western portal. The structure would need to be able to withstand regular avalanche and moderate rockfall. This is proposed to be achieved by strong roof structure, optionally semi-circular in shape and part-sunken into the terrain, plus additional gabion defences close to the landward side of the shelter to reduce impact damage to walls. Structure options would be considered in detailed design. Large rockfall associated with a major Alpine Fault earthquake may result in structural damage but the structures should be designed to not collapse on people as far as reasonably practicable. Ongoing road safety improvements are assumed, along with management of the 'standard' hazards for the Milford Road such as tree fall, rockfall, avalanche, black ice, flooding, etc. It is assumed that ongoing scientific and technological advances will be employed gradually over time to further reduce these risks where feasible.

5.32 There is already a tramping hut near the SH94 **Gertrude Saddle Car Park** just east of Homer Tunnel. The presence of scree and boulder fields in the valley highlight the potential risk from avalanche (especially in winter / spring), and more significant rock falls. The climb to the saddle is physically demanding and highly exposed. Any promotion of the Cirque viewing from the valley or climbs to the Saddle should be informed by more detailed site-specific risk assessment and communication of the residual risks to users.

5.33 **Whakatipu / Hinepipiwai Lake Marian** carpark 'super track head' is proposed for additional short stop and longer walks, which would be closed (strongly discouraged) in winter particularly in high avalanche periods. Site specific risk assessment will be required to optimise the routes and risk exposure and set the criteria for recommending track closures.

5.34 **Cascade Creek and Knobs Flat** both have some risk from fluvial flooding. Both sites would require some upgraded flood protection through appropriate landscaping and scour protection. Due to the high debris load in these watercourses, regular maintenance would be required, particularly following flood events or moderate rainfall events if there have been slips and increased debris load. Due to the highly mobile nature of the riverbeds, it may be feasible to obtain consents for periodic gravel extraction from the riverbed to maintain its approximate course and carrying capacity where required, along with the use of sensitively engineered flood protection bunds without excessive constraining of the floodplain corridor. Part of the landscaping at Cascade Creek may need to consider restoring some of the floodplain corridor to the river and have zones that are landscaped to different levels of risk that can be evacuated first or closed off ahead of forecast high rainfall events. If a hut is established in Mistake Creek valley, it should be sited clear of high rockfall risk and also set back from the river, to avoid damage and risk to life such as occurred at Routeburn Hut in 2020. It is likely that the continuation on to U-pass would not be upgraded to a Great Walks standard due to some very steep terrain and could potentially remain open for experienced climbers at own risk subject to suitable warnings. Site-specific risk assessment could possibly indicate a steel rope ladder or similar to improve safety on the steepest climb near the waterfall up to the hanging valley before U-pass. Again, seasonal risk would be managed by closing or discouraging use in winter or high avalanche risk periods. Site specific assessment will be required to balance investment in upgrade and maintenance costs against residual risk tolerance for the target user groups (e.g., Back Country Adventurers and Remoteness Seekers), being clear on the associated branding and messaging for the route to the hut and/or beyond the hut.

5.35 At the Eglinton Valley 'Reveal' parking area and Fiordland National Park entrance gateway, risks are generally lower but site-specific assessment and design would be required depending on final solutions adopted.

TE ANAU AND MANAPOURI

5.36 Te Anau developments are envisaged to support visitor hub, park and ride, bus facilities, etc. These are not yet fully developed in terms of site location and details, but the draft options/ideas do not appear to hold major hazards or risk differentiators. All sites would require more detailed road safety assessments and additional road safety improvements on the existing network. Risks from natural hazards are considered low and would be managed by SDC/EMS following existing standard procedures.

5.37 Manapouri has a broadly similar hazard profile to Te Anau, although less populated and not identified in the masterplan as a key change node. Therefore, no direct costs have been assigned for Manapouri in the masterplan Cost Benefit Analysis, although there will be spin-off increases in throughput and risk management can incorporate lessons learnt or issues identified through the improvements for Te Anau.

5.38 Doubtful Sound Patea was not identified in the masterplan as a key change node. Therefore, it is assumed that Doubtful Sound Patea will continue to operate in an enhanced status quo, informed where practicable by the mitigation solutions applied to Milford Sound Piopiotahi. For example, having a clearly marked evacuation pathway to a higher elevation on Wilmot Pass Road (see Figure 3 4), consider shoreline exclusion zones, training of staff, visitor information, etc. These minor enhancements have not been costed in the masterplan Cost Benefit Analysis.

SUMMARY MATRIX

5.39 Appendix 3 contains a high-level summary across all hazard types and location areas, based on a rapid qualitative desktop assessment. The intention with the summary is to highlight the areas where the risk profile has changed, rather than being a highly accurate computational assessment of baseline risk.

6 SUMMARY AND CONCLUSION

6.1 In summary for the status quo, the highest current potential impact event is an AF8 event with landslide-induced tsunami at Milford Sound Piopiotahi. Information on this hazard is currently not well communicated to staff or visitors. The probability of an individual day visitor dying from such an event may be considered reasonably rare, and some visitors may choose to accept this risk if they were given an informed choice and an awareness of how to increase their survival chances. However, from a societal perspective, the current risk appears unacceptably high when considering the risk of a catastrophic number of fatalities (> 100, or potentially >2000 fatalities in more severe cases at peak times).

6.2 The collective mitigation measures that form the Recommended Option are expected to transform probable outcomes from say a 10 percent survival rate in a large event to around 90 percent survival rate. This represents a positive move from the status quo, which justifies the investment in the Recommended Option. This achieves one of the core requirements of the project to provide resilience to risk and change. It may be possible to achieve higher survival rates subject to further modelling, detailed design, mitigation planning and revised probabilistic risk assessment. We do not want to suggest at this stage that almost all risk is automatically removed by the proposed interventions, as this could result in complacency. Further discussion is provided below on investigations that would be required to better understand and possibly reduce the risk further.

6.3 It is often not reasonably practicable to remove all risk, but the provision of reasonably practicable mitigation as proposed in the Recommended Option, plus carefully balanced information on residual risk will allow people to evaluate and accept the residual risk and to respond in the best way during an event to promote their survival.

6.4 It is not representative to have a single risk metric for events that can vary substantially in magnitude. Therefore, in future it is recommended that probabilistic assessments are carried out, especially for societal risk-to-life calculations, like those performed for large dam safety assessments. Some illustrations of these concepts from a rapid desktop assessment are presented in Appendix 3, although further work is required to refine these.

6.5 Even if the anticipated AF8 event does not trigger an immediate co-seismic landslide-induced tsunami, it is likely that Milford Sound Piopiotahi and the Milford Road would be closed for a substantial period of time due to the heightened risk of aftershocks triggering further avalanches, rockfalls and landslides onto the road and/or into the Fiord (with associated tsunami). Such a closure to tourism could last a year or longer, depending on the effectiveness of mitigation and on the level of damage requiring re-build once aftershocks reduce to an acceptable level. Being aware of the risks and providing robust infrastructure will help to lessen the social shock and help to shorten the recovery period.

RECOMMENDATIONS FOR URGENT FURTHER ASSESSMENT

6.6 Further modelling of landslide-induced tsunami is strongly advised early upon approval in principle of the masterplan, to inform subsequent implementation. Some elements in the assessment have greater uncertainty than others, which may help to inform the relative timing and/or level of detail of assessments. Elements to analyse include future source areas (as distinct from the past ones analysed by Dykstra), landslide initiation and dynamics, tsunami initiation including air entrainment, wave attenuation through the fiord, near-shore wave transformation and spreading including sediment/debris entrainment potential. The latter would also provide information on wave shapes, depths, flow velocities and potential forces or potential to damage buildings and sweep people off their feet. These would help inform the building design features required to dissipate and resist tsunami forces, along with earthquake, liquefaction, climate resilience and other design criteria. The wave form modelling may also help to inform future cruise boat mitigation measures and possibly even fleet choices in terms of their ability to safely handle large and complex wave patterns.

6.7 People movement modelling and emergency scenario planning will need to work closely with the placement and design of buildings to be able to receive rapid high influx of people in a short lead-time emergency. This will apply in particular to the visitor hub, and also to all satellite bunkers/shelters based on the maximum potential number of people at peak times. Distances between buildings and satellite bunkers/shelters can also be optimised in this way.

6.8 Customised messaging on hazards and residual risk should be developed separately for staff/responders and visitors to enable them to understand and accept the residual risk at an appropriate level of conceptual detail and to respond accordingly in an event. Some of this separate messaging will be required early during wider publication and consultation on the masterplan. Further refinements to the messaging will be required over time as the plan is implemented, including clear messaging included in staff job offers, at point of sale to the public, point of entry to the visitor experience and on site (visible emergency information such as evacuation pathways, plus staff inductions and periodic refresher training/exercising, etc).

7 REFERENCES

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- Milford Road Alliance: Kevin Thompson (team leader/manager), Simon Morris (avalanche expert)
- Emergency Management Southland: Angus McKay (Regional Group Manager/Controller, and chair of AF8)

- Environment Southland: Lyndon Cleaver (Regional Harbourmaster)
- University of Otago: Dr Caroline Orchiston (Deputy Director Centre for Sustainability, and AF8 Science Lead)
- Te Rūnanga o Ngāi Tahu: Maria Bartlett (advisor on climate change)
- Department of Conservation: various
- GNS: enquiries for Mauri McSaveney, author of the GNS 2015 report, but whom it was found has recently retired from GNS
- Victoria University Wellington: Jamie Howarth (AF8 scenario researcher)
- Southern Lakes Helicopters: Lloyd Matheson
- Te Anau Cycling Inc: James Reardon
- Fiordland Trails Trust: John Greaney
- Milford Sound Tourism (Milford Sound)
- The Lodge (Milford Sound)
- Go Orange / Real Journeys (Milford Sound)
- Mitre Peak Cruises (Milford Sound)
- Jucy Cruises (Milford Sound)

APPENDIX 1: LANDSLIDE-INDUCED TSUNAMI

Table 6: Tsunamis with runup of 50 m or greater in the past century. (Table from Higman et al. 2018)

Year	Location	Water Body	Cause	Latitude	Longitude	Max Runup (m)
1958	Lituya Bay, Alaska, USA	Fjord	Subaerial landslide	58.672	-137.526	**524**
1980	Spirit Lake, Washington, USA	Lake	Volcanic landslide	46.273	-122.135	250
1963	Casso, Italy	Reservoir	Subaerial landslide	46.272	12.331	235
2015	Taan Fiord, Alaska, USA	Fjord	Subaerial landslide	60.2	-141.1	**193**
1936	Lituya Bay, Alaska, USA	Fjord	Subaerial landslide	58.64	-137.57	149
2017	Nuugaatsiaq, Greenland	Fjord	Subaerial landslide	71.8	-52.5	**90**
1936	Nesodden, Norway	Fjord	Subaerial landslide	61.87	6.851	74
1964	Cliff Mine, Alaska, USA	Fjord	Delta-front failure	61.125	-146.5	67
1934	Tafjord, Norway	Fjord	Subaerial landslide	62.27	7.39	62
1965	Lago Cabrera, Chile	Lake	Subaerial landslide	-41.8666	-72.4635	60
1967	Grewingk Lake, Alaska, USA	Lake	Subaerial landslide	59.6	-151.1	60
1946	Mt. Colonel Foster, British Columbia, Canada	Lake	Subaerial landslide	49.758	-125.85	51
2004	Labuhan, Indonesia	Open Coast	Earthquake displacement	5.429	95.234	51
2000	Paatuut, Greenland	Fjord	Subaerial landslide	70.25	-52.75	50

Below are two striking examples from Alaska of landslide-induced tsunami, from the highest 1958 event and the recent 193m 2015 event. This is followed by local information on potential landslide-induced tsunami in Lake Te Anau and Manapouri which are lower in magnitude.

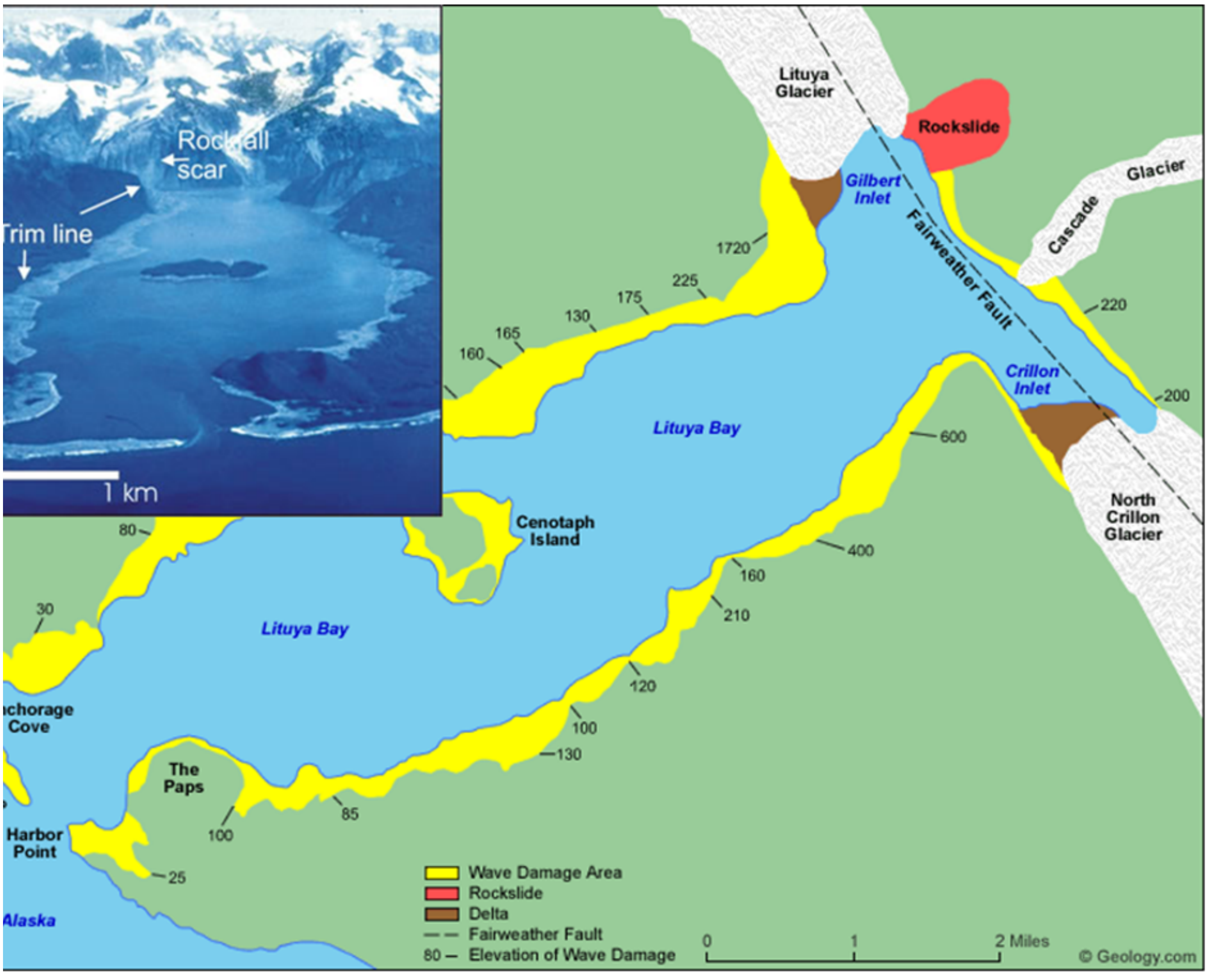

Figure 50: Lituya Bay Alaska, July 9, 1958, M7.7, landslide ~ 30x10^6 m3, largest wave ever recorded. There was also a 1936 event with run-up of 150m without associated earthquake.

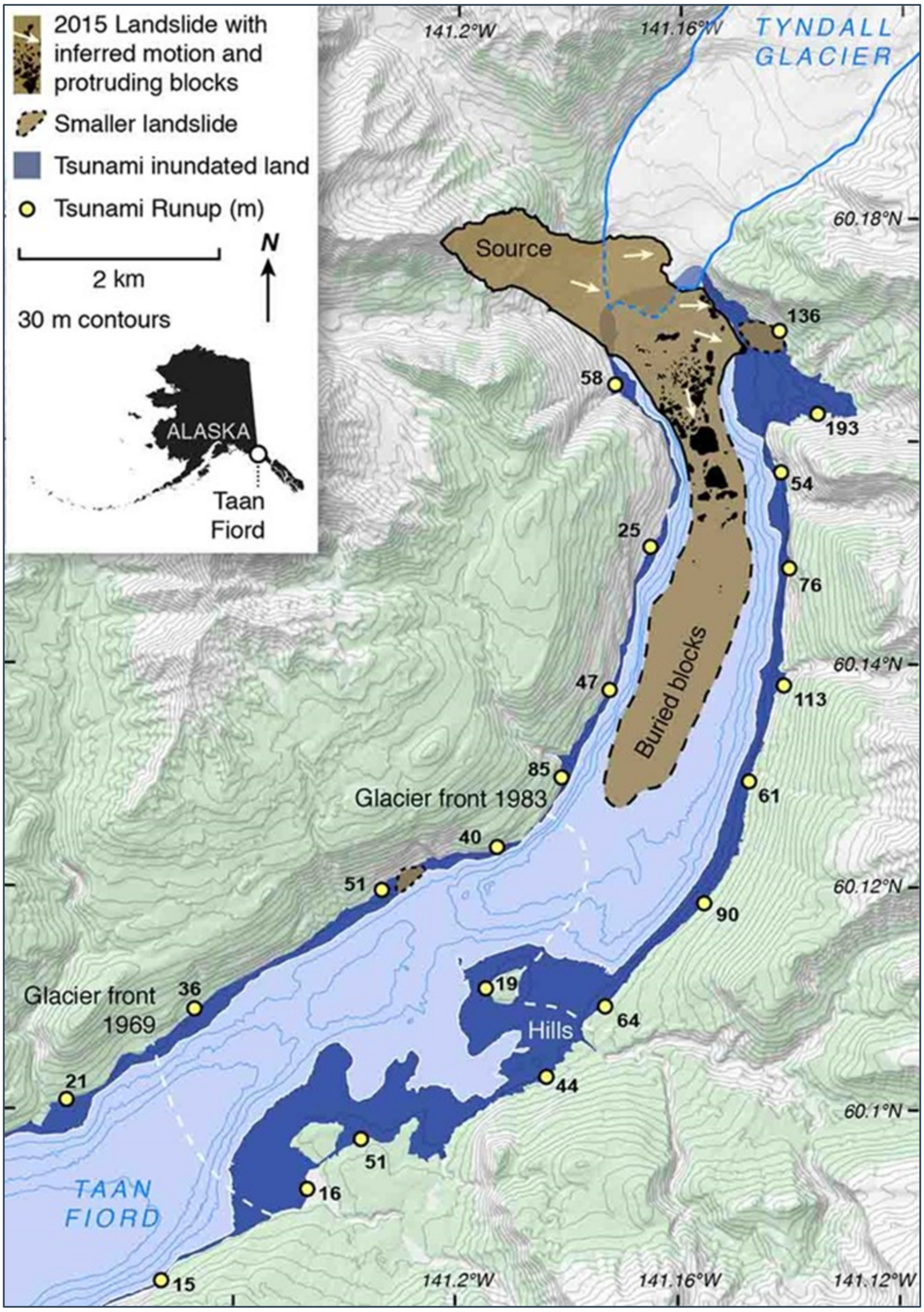

Figure 51: Taan Fiord landslide and tsunami, Alaska, 2015. (adapted from Higman et al. 2018.)

Figure 52: A geologist stands in front of a 5m diameter boulder moved by the Taan Fiord tsunami near where it reached its highest elevation (193m). Photo courtesy of Ground Truth Trekking.

Extracts from Hancox (2012) on potential for landslide-induced tsunami in Lake Te Anau and Lake Manapouri.

Figure 1. Map of Lake Te Anau showing sites of priority interest to Environment Southland *(information provided by Environment Southland 2011).*

Figure 2. Map of Lake Manapouri showing sites of priority interest to Environment Southland *(information provided by Environment Southland 2011).*

Table 5. Summary of landslide volumes and run-up heights of waves generated by potential landslides into lakes Manapouri and Te Anau and geological hazards in relation to facility sites.

Landslide Area (Site)	Estimated[1] Landslide volume (m^3)	Possible max wave run-up height (m)	Closest Facility Site[2] and Distance (km)	Other potential geological hazards at facility sites and explanatory comments[3]
Lake Manapouri				
A (2,3)	10^3–10^4	0.5–1	Powerhouse/wharf (0.5–1)	Landslides, delta col., lat. spread
B (1,2)	10^3–10^4	0.5–1	Powerhouse/wharf (2–3)	
C	10^3–10^4	0.5–1	Powerhouse/wharf (7)	
D	10^3–10^4	0.5–1	Freeman Burn Hut (2–3)	
E	$\leq 10^3$	0.5–1	Freeman Burn Hut (0.2–0.5)	Delta collapse, lateral spreading
F (1)	5×10^5–10^6	10–25	Powerhouse/Freeman B Hut (8)	
G	10^3–10^5	0.5–3	Powerhouse/wharf (12)	
H	10^4–5×10^5	5–10	Moturau Hut (17)	
I	10^3–10^5	0.5–3	NA, area remote	
J	1–2×10^5	3–5	Moturau Hut (12). Man. (14)	
K	10^3–10^4	0.5–1	Moturau Hut (10). Man. (13)	
L	10^2–10^4	0.5–1	Moturau Hut (7). Man. (11)	
M	10^3–10^4	0.5–1	Area remote. Man. (17)	
N	10^2–10^4	0.5–1	Manapouri, P/Harbour (3)	
O	10^3–5×10^5	1–5	Moturau Hut (5). Man. (12)	Failure probably less rapid[1].
Lake Te Anau				
A	10^3–10^4	0.5–1	Te Anau, Kepler Track (9)	
B	10^3–10^4	0.5–1	Te Anau, Kepler Track (15)	
C	10^3–10^5	1–3	Te Anau, Kepler Track (15)	
D	10^3–10^5	1–3	Te Anau, Kepler Track (20)	
E	10^3–10^4	0.5–1	Te Anau, Kepler Track (25)	
F (2)	10^3–10^5	1–3	Glow worm caves (10)	
G	10^3–10^5	0.5–1	Te Anau Downs Harb. (8)	~50% debris likely to reach lake
H	10^3–10^4	0.5–1	Te Anau Downs Harb. (13)	
I	10^3–10^4	0.5–1	Glaisnock Hut (1–4)	Delta collapse, lateral spreading
J	10^3–10^5	1–3	Te Anau Downs Harb. (11)	Failure less rapid (as in 1968)
K	10^3–10^4	0.5–1	Te Anau Downs Harb. (15)	
L	10^3–2×10^5	1–5	Worsley Hut (1–2), Glade Wh. (7)	Delta collapse, lateral spreading
M	10^3–10^6	0.5–3	Glade wharf (<0.1–0.5)	Debris flow, delta col., lat. spread
N	10^3–10^4	0.5–1	Te Anau Downs Harb. (10)	
O	10^3–10^4	0.5–1	Te Anau Downs Harb. (13)	
P	10^3–10^5	1–3	Te Anau Downs Harb. (20)	

Notes:
1. Estimated maximum volumes of possible landslides rapidly entering the lake at potential EIL sites.
2. The most hazardous areas or sites are shaded pink. The Freeman Burn and Glaisnock hut sites are likely to be hazardous because of the potential for lateral spreading and delta collapse waves at those sites.
3. Geological hazards could potentially affect the nearest facility site of interest to ES.

Figure 53: Lake Te Anau and Manapouri - Locations of interest and tsunami runup results (from Hancox 2012)

APPENDIX 2: OCEAN-SOURCE TSUNAMI

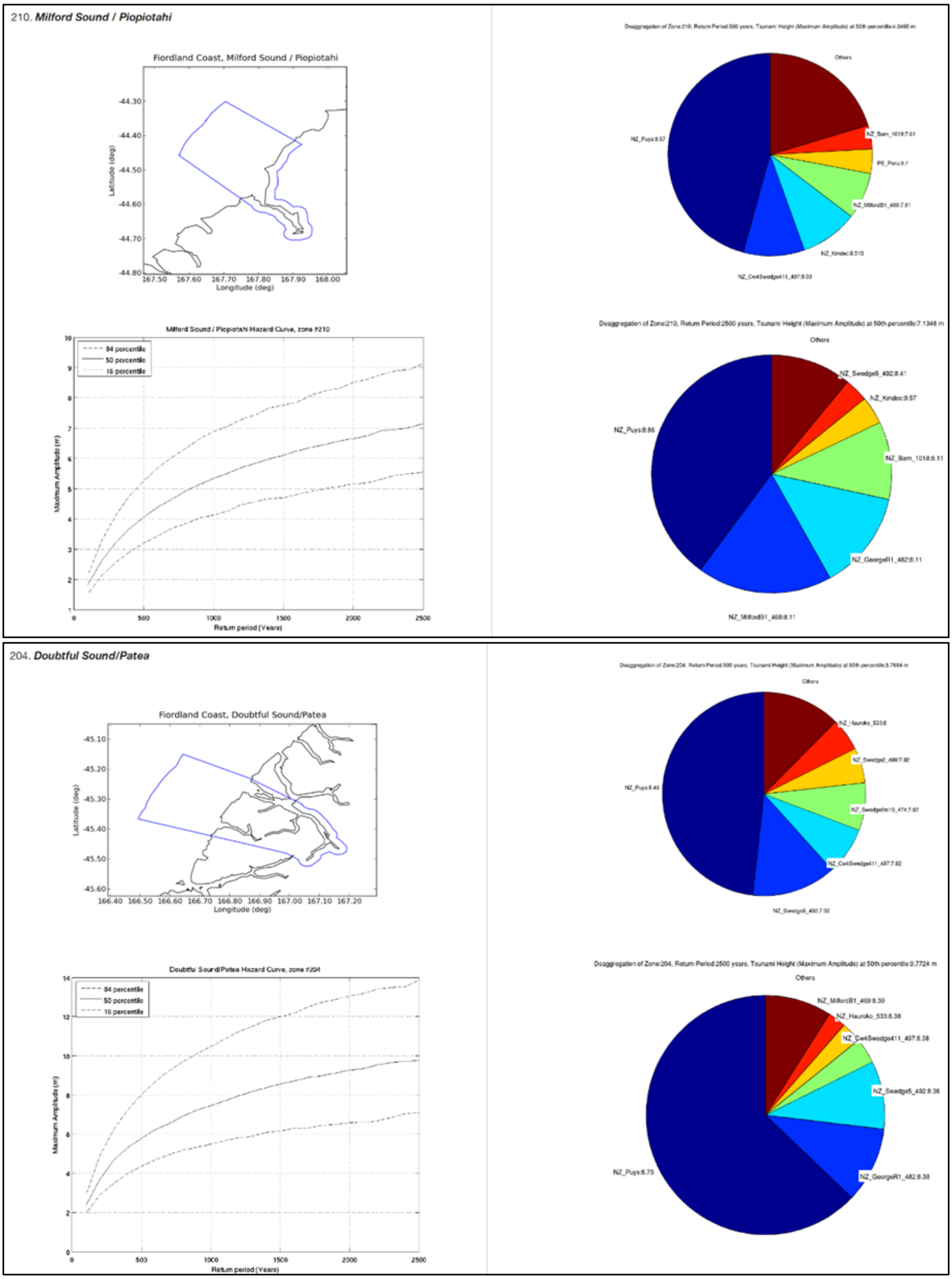

Figure 54: Ocean-source Tsunami

APPENDIX 3: RISK OVERVIEW MATRIX

Assessment scoring criteria used for overview matrix, adapted from DOC SOP (2018), with additional classes added for lower probability and higher impact events:

Risk consequence for visitors (adapted from DOC SOP table 6.1)

DOC	MOP	Descriptor	Consequence to participants	Consequence to the visitor experience
1	1	Negligible/not a risk	No injuries or injuries that don't require first aid; "fright factor". No incident follow-up.	Inconvenience - delay to plans (up to 1/2-hour loss).
2	2	Low (first aid)	Minor injuries requiring first aid treatment - managed by those at the visitor site, e.g., minor cuts and bruises. No incident follow-up.	Interruption to plans, e.g. forced track closure for a day or rescheduled plans/postponement.
3	3	Medium (medic assist)	Medical treatment required, including immediate off-visitor site assistance, e.g., follow-up emergency medical treatment. Incident reported.	Incident visitor site investigated. Interruption to plans, e.g., forced track closure (more than week) or trip cancellation.
4	4	High (serious injury)	Serious injuries to an individual requiring rescue party, or moderate injuries to multiple subjects. Incident investigated.	Incident visitor site investigated; future facility management assessed. Forced cancellation/ rescheduling of current visits.
5	5	Very High (fatality or multiple	Single person fatality or major injury to multiple (more than 3) victims. Search and rescue involvement. Incident investigated, possibly by coroner.	Incident visitor site and visitor site management investigated. Future visitor site management assessed. Current and future trips cancelled/ rescheduled.
6	6	Extreme (fatalities 2-100)	Multiple fatalities. Search and rescue involvement. Incident investigated by coroner.	Immediate visitor site closure and future visitor site management assessed. Current and future trips cancelled/ rescheduled.
	100	Catastrophic (>100 fatalities)	>100 fatalities, large number of injuries and/or mass evacuation	Immediate closure, likely to have long lasting impacts on tourism industry

Risk likelihood (adapted from DOC SOP table 6.2)

DOC	MOP	Descriptor	Measure	Explanation
	1	1:500	Approximately 1:500 (0.2%) chance per year	Rare, based on historical and/or probabilistic estimates
A	2	40+y	Predicted to occur once every 40 years or more	Possible, but no visitor risk assessment team member has knowledge of event occurring more than once during their career.
B	3	40-5y	Predicted to occur once every 5 years to once every 40 years.	Present day and/or a past staff has knowledge of the event. The event is likely to occur from time to time.
C	4	5-1y	Predicted to occur once a year to once every 5 years.	A team member has knowledge of the event occurring in the region. The event occurs occasionally.
D	5	1y-1m	Predicted to occur once a month to once a year.	Multiple team members have detailed knowledge of the event occurring in a Region. The event occurs regularly
E	6	1w	Predicted to occur at least once a week.	Occurs frequently, well known across all staff

Acceptability criteria used for overview matrix, adapted from DOC SOP (2018), with additional classes added for lower probability and higher impact events:

*MOP Risk score = MOP Probability score * (MOP Consequence score -1)*

This correlates closely with DOC tolerability matrix for Short Stop Traveller up to consequence 6

			Likelihood					
			1	2	3	4	5	6
			1:500	40+y	40-5y	5-1y	1y-1m	1w
Consequence	1	Negligible/not a risk	*0*	0	0	0	0	0
	2	Low (first aid)	*1*	2	3	4	5	6
	3	Medium (medic assist)	*2*	4	6	8	10	12
	4	High (serious injury)	*3*	6	9	12	15	18
	5	Very High (fatality or multiple injury)	*4*	8	12	16	20	24
	6	Extreme (fatalities 2-100)	*20*	20	20	20	25	30
	101	Catastrophic (>100 fatalities)	100	200	300	400	500	600

Green (up to 4) = Tolerable
Orange (up to 16) = 'Manageable' / When best practice management actions are implemented visitors can
Red (>16) = Intolerable
Black >100 = catastrophic

Summary of hazard score for existing status quo and with Recommended Option:

Hazard	Current	Proposed	Main changes
AF8: shaking, falling objects (man-made), road closure requiring evacuation	12	9	All new buildings to high EQ code
AF8: landslide (co-seismic direct impact, all types incl avalanche); note risk remains high for ~1y	200	20	Exclusion zones keep boats/ferries further from susceptible cliffs
AF8: landslide-induced tsunami; note risk remains high for ~1y	2000	20	Resilient visitor hub, buildings, shelters, minimise dwell time far from shelters (some risk remains - see probabilistic chart)
Coastal (offshore/distant source) tsunami	4.5	4	Ongoing management
Avalanche (winter/spring)	16	16	Ongoing management MRA/ACP, some residual risk remains
Rockfall/treeslide (without Avalanche trigger)	12	12	Ongoing management
Flooding including effects of debris and climate change	12	12	Ongoing management
Snow and ice (winter/spring) incl great walks	10	10	Ongoing management
Travel - serious or fatal accidents (road, air, boat)	8	8	Ongoing management
Other / business as usual (car parks, tree fall, fires, trips/falls/injuries, wasps, poisoning incl food/water, electrocution, drowning, adverse weather esp in winter) - all higher in back country trails	6	6	Ongoing management

The scores reflect a rapid simplistic single probability/outcome per event, across multiple locations. Scores may be subjective and further evidence is recommended to inform design. Mitigation options at conceptual level.

Would be recommended to use probabilistic framework, as followed by large dams (e.g., NZSOLD/ANCOLD) guidance, which looks at different probabilities of different magnitude events/outcomes, especially for risk to life / societal risk (which is not covered in DOC SOP). It would also be desirable to include cumulative risk to individual visitors per trip, although this requires multiple options for different journey types and risk tolerances (e.g., recognition that Back Country Adventurers Remoteness Seekers may plan their journey differently and have a different risk tolerance).

More modelling (hazards and people movements) recommended to optimise mitigation detailed design.

FINAL

Qualitative visitor risk matrix for status quo and Recommended Option

Hazard type	AF8: shaking, falling objects (man-made), road closure requiring evacuation					AF8: landslide (co-seismic direct impact, all types incl avalanche); note risk remains high for ~1y					AF8: landslide-induced tsunami; note risk remains high for ~1y					Coastal (offshore/distant source) tsunami					Avalanche (winter/spring)				
	Probability	Impact (current)	Risk (current)	Impact (proposed)	Risk (proposed)	Probability	Impact (current)	Risk (current)	Impact (proposed)	Risk (proposed)	Probability	Impact (current)	Risk (current)	Impact (proposed)	Risk (proposed)	Probability	Impact (current)	Risk (current)	Impact (proposed)	Risk (proposed)	Probability	Impact (current)	Risk (current)	Impact (proposed)	Risk (proposed)
LOCATION																									
Milford Sound Piopiotahi																									
Large cruise ships											1	5	4	5	4										
Ferry (scenic) on water						1	201	200	5	4	2	201	400	6	20	1	4	3	3	2					
Small boats (recreational & commercial fishing plus sailing)						1	6	20	5	4	2	6	20	6	20	1	5	4	5	4					
Kayaks on water						1	6	20	5	4	2	6	20	6	20	1	5	4	5	4					
Underwater Obs (3m)	3	4	9	4	9	1	5	4	5	4	2	6	20	6	20	1	5	4	5	4					
Ferry terminal (3m)	3	4	9	4	9	1	6	20	5.5	4.5	2	401	800	6	20	1	5.5	4.5	5	4					
Milford village (3-6m) incl airport and car parks	3	5	12	4	9	1	5	4	5	4	2	201	400	5.5	9	1	5.5	4.5	5	4					
Cleaddau village (5.2m) incl commercial wharf and overflow carpark	3	4	9	4	9						2	101	200	6	20	1	5	4	5	4					
Lodge (10m)	3	4	9	4	9	1	5	4	5	4	1	6	20	5.5	4.5										
Corridor Piopiotahi to lake Gunn																									
Homer Tunnel and portals	3	4	9	4	9	3	6	20	5.5	13.5											4	5	16	4.5	14
SH94 Piopiotahi to Lake Gunn	3	4	9	4	9	2	6	20	6	20											4	5	16	5	16
Hollyford and Divide (Whakatipu)	3	4	9	4	9	1	5	4	5	4											1	4	3	4	3
Great Walks (Milford Track, Routeburn Track & Key Summit, Gertrude	3	4	9	4	9	2	6	20	6	20											4	5	16	5	16
Lakes Gunn and Fergus	3	4	9	4	9	1	4	3	4	3	1	5	4	5	4						2	4	6	4	6
Corridor Cascade Creek to Te Anau																									
SH94 Cascade Creek to Te Anau	3	3	6	3	6	1	4	3	4	3															
Cascade Creek Campsite	3	3	6	3	6	1	4	3	4	3															
Knobs Flat	3	3	6	3	6	1	4	3	4	3															
Te Anau visitor hub (options risk all similar)	3	4	9	4	9						1	5	4	4.5	3.5										
Te Anau	3	4	9	4	9						1	5	4	4.5	3.5										
Manapouri - similar to Te Anau	3	4	9	4	9						1	5	4	4.5	3.5										
Patea / Doubtful Sound (similar but lower than Piopiotahi)	3	4	9	4	9	1	5	4	5	4	2	6	20	6	20	1	5	4	5	4					
Maximum per hazard type			12		9			200		20			2000		20			4.5		4			16		16

Hazard type	Rockfall/treeslide (without Avalanche trigger)					Flooding including effects of debris and climate change					Snow and ice (winter/spring)					Travel - serious or fatal accidents (road, air, boat)					Other / business as usual (car parks, tree fall, fires, trips/falls/injuries, wasps, poisoning incl food/water, electrocution, drowning, adverse weather esp in winter) - all higher in back country trails				
	Probability	Impact (current)	Risk (current)	Impact (proposed)	Risk (proposed)	Probability	Impact (current)	Risk (current)	Impact (proposed)	Risk (proposed)	Probability	Impact (current)	Risk (current)	Impact (proposed)	Risk (proposed)	Probability	Impact (current)	Risk (current)	Impact (proposed)	Risk (proposed)	Probability	Impact (current)	Risk (current)	Impact (proposed)	Risk (proposed)
LOCATION																									
Milford Sound Piopiotahi																									
Large cruise ships																					1	2	1	2	1
Ferry (scenic) on water	3	5	12	4	9																1	2	1	2	1
Small boats (recreational & commercial fishing plus sailing)	3	5	12	4	9																1	2	1	2	1
Kayaks on water	3	5	12	4	9																2	3	4	3	4
Underwater Obs (3m)	1	4	3	4	3																1	2	1	2	1
Ferry terminal (3m)	3	5	12	4.5	10.5	3	4	9	4	9	1	2	1	2	1						1	2	1	2	1
Milford village (3-6m) incl airport and car parks						2	4	6	4	6	1	2	1	2	1	1	5	4	5	4	1	2	1	2	1
Cleaddau village (5.2m) incl commercial wharf and overflow carpark						2	4	6	4	6	1	2	1	2	1						1	2	1	2	1
Lodge (10m)	1	4	3	4	3	2	4	6	4	6	1	2	1	2	1						1	2	1	2	1
Corridor Piopiotahi to lake Gunn																									
Homer Tunnel and portals	3	5	12	4.5	10.5						5	3	10	3	10										
SH94 Piopiotahi to Lake Gunn	3	5	12	5	12	3	5	12	5	12	5	3	10	3	10	2	5	8	5	8	1	3	2	3	2
Hollyford and Divide (Whakatipu)	1	4	3	4	3	2	5	8	5	8	3	3	6	3	6	1	4	3	4	3	1	3	2	3	2
Great Walks (Milford Track, Routeburn Track & Key Summit, Gertrude	3	5	12	5	12	3	5	12	5	12	5	3	10	3	10						2	4	6	4	6
Lakes Gunn and Fergus	3	4	9	4	9	1	3	2	3	2	4	3	8	3	8						1	2	1	2	1
Corridor Cascade Creek to Te Anau																									
SH94 Cascade Creek to Te Anau	1	4	3	4	3	2	3	4	3	4	5	2	5	2	5	2	5	8	5	8	1	2	1	2	1
Cascade Creek Campsite	1	4	3	4	3	4	4	12	4	12	4	2	4	2	4						1	2	1	2	1
Knobs Flat	1	4	3	4	3	1	3	2	3	2	4	2	4	2	4						1	2	1	2	1
Te Anau visitor hub (options risk all similar)						1	3	2	3	2	4	2	4	2	4	1	4	3	4	3	1	2	1	2	1
Te Anau						1	3	2	3	2	4	2	4	2	4	1	4	3	4	3	1	2	1	2	1
Manapouri - similar to Te Anau						1	3	2	3	2	4	2	4	2	4	1	4	3	4	3	1	2	1	2	1
Patea / Doubtful Sound (similar but lower than Piopiotahi)	3	5	12	5	12						1	2	1	2	1	1	4	3	4	3	1	3	2	3	2
Maximum per hazard type			12		12			12		12			10		10			8		8			6		6

Notes:

- Current (status quo) assumed existing mitigations in place (e.g. Avalanche Control Programme) - which continue with at least the same efficiency or improved where shown
- Potential impacts not necessarily the very rarest probability that could produce worse impacts (a probabilistic framework would be better to capture these rare events and higher potential risk to life)