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Landslide-induced tsunami risk communication advice for visitors and workers in Milford Sound / Piopiotahi

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CONTENTS

FIGURES

TABLES

APPENDICES

APPENDIX TABLES

EXECUTIVE SUMMARY

Coseismic landslides are capable of falling into the fiord and displacing large volumes of water, generating tsunami that pose a risk to life in Milford Sound / Piopiotahi. The nearby Alpine Fault is estimated to have a 75% chance of rupturing in the next 50 years and, based on the record of past events, scientists infer that there is a 44% chance of a large landslide entering the fiord and causing a tsunami in a future Alpine Fault event. This suggests a credible risk to visitors and workers in the area that needs to be communicated to support informed decision-making. However, communicating the risk of these cascading, high-consequence events with different audiences can be challenging. This report summarises the existing literature on landslide-induced tsunami risk in Milford Sound / Piopiotahi, describes different audiences who may potentially be exposed to the risk and provides advice for communicating risk tsunami across the range of people who may spend time in the region. This study incorporates scientific literature, expert input and a high-level audience assessment informed through a site visit to Milford Sound / Piopiotahi in January 2025.

Effective risk communication aims to inform at-risk populations about the likelihood and potential consequences of hazards, as well as actions that they can take to reduce their risk and enhance safety. Communicating landslide-induced tsunami risk at Milford Sound / Piopiotahi requires a multi-faceted approach, targeting tourists and workers at various stages of their planning, visit or work activity. Clarity, accessibility, tailoring of information and consistency of messaging are crucial. Information should be readily accessible to those visiting Milford Sound / Piopiotahi for recreation or work and empower them to make informed decisions regarding their potential exposure to natural hazards and risks. A strong emphasis should be placed on pre-trip risk communication for all visitors and workers. Once tourists and visitors have decided to travel, on-journey and on-site communication should shift toward sharing mitigation information. Communication placed at locations across key sites at Milford Sound / Piopiotahi should focus on actions people can take to minimise their risk and enhance their safety. The information available to workers on-site should include aspects of hazard, risk and mitigation. This review emphasises the importance of (1) providing simple direction-focused tsunami evacuation messages for all visitors and workers, (2) training on natural hazard and risk information for staff and (3) exploring more ‘what to do messaging’ for all visitors and workers.

There are still many uncertainties associated with landslide-induced tsunami risk at Milford Sound / Piopiotahi and, until these have been refined and reduced through an updated risk assessment, a conservative approach to communication should be taken due to the threats to life safety. It is important to note that previous published risk-metric calculations are considered to be under-estimates, as these are likely to under-represent both population exposure and hazard likelihood. Previous calculations were based on a 2012 estimate that the Alpine Fault has a 27% chance of a large rupture in the next 50 years, but this value is now widely accepted to be nearly three times higher at 75%. To support interim risk-communication efforts until the risk is refined, we provide a simplified modification of the existing risk metrics and hazard values to better reflect the increased awareness of the nearly three times increase in Alpine Fault seismic hazard. The modified values enable a conservative approach to high-level communication and consideration of comparative risks. While the hazard and risk communication challenge at Milford Sound / Piopiotahi has unique aspects, there are numerous examples of hazard- and risk-communication products and content from other contexts that can provide valuable inspiration and guidance.

1.0 Introduction

Earthquake-induced landslides have the potential to create large, rapid-onset tsunami within fiords and lakes across the world. Although these events are rare in Milford Sound / Piopiotahi, recent studies suggest that the tsunami risk associated with a large Alpine Fault earthquake may be higher than previously thought (Howarth et al. 2021). Communicating the risks associated with such cascading, multi-hazard, high-consequence events is challenging due to the complexity and uncertainty of the risk variables, as well as social and cognitive factors that may influence audience engagement with risk messages.

The Milford Sound Stakeholder Group engaged GNS Science to undertake a short-term review of tsunami hazard and risk communication to develop tailored advice for communicating tsunami risk in Milford Sound / Piopiotahi with visitors and workers in the area. This report summarises the findings of this review and presents advice on communicating landslide-induced tsunami risk for the Stakeholder Group. This work also aims to support wider risk management efforts on behalf of the wider natural-hazard response group, including Milford Sound Tourism Limited (MSTL), Emergency Management Southland, the National Emergency Management Agency (NEMA), the Department of Conservation (DOC), Environment Southland and Southland District Council.

1.1 Approach and Methodology

This project was approached using three stages carried out between December 2024 to February 2025:

- **Stage 1:** Review and summarise existing knowledge about tsunami hazard and risk in Milford Sound / Piopiotahi with input from GNS Science experts. Identify key published hazard and risk information needed to feed into communication efforts (e.g. inundation areas, evacuation aspects, comparative levels of risk).
- **Stage 2:** Describe visitor and worker audiences and assess potential hazard- and risk-communication contact points and channels with these groups. Conduct a site visit to ground-truth any assumptions and observe audience behaviours.
- **Stage 3:** Analyse the outcomes of Stages 1 and 2 in the context of relevant risk-communication literature and established good practise and create new bespoke tsunami risk-communication advice.

The key outcome of this work is this report, which includes suggested messaging for future communication products, as well as more general communication advice. It is beyond the scope of this project to conduct any new hazard or risk assessments, to advise on acceptable or tolerable levels of risk to any party or to provide bespoke mitigation options. Due to time constraints, a comprehensive systemic literature review, user testing and communication product development were also outside of scope. It is important to emphasise that the advice provided in Stage 3 is based on the existing hazard and risk knowledge available in Stage 1. Future work should prioritise an up-to-date hazard assessment of the area using modern and state of practise tsunami-hazard assessment techniques, which will help refine the expected wave height and run-up, as well as inundation extent, depth and velocities. This information is likely to influence the localised risk and mitigation advice provided in this report.

1.2 Study Area

Milford Sound / Piopiotahi, situated within Te Rua-o-Te-Moko Fiordland National Park and the Te Wāhipounamu UNESCO World Heritage site in Aotearoa New Zealand's Southland region (Figure 1.1), is a highly popular tourist destination. The International Visitor Survey (MBIE 2025) indicates that 11.8% of surveyed tourists visiting Aotearoa New Zealand between 1 July and 30 September 2024 included a trip to one of the Fiordland sounds (Milford Sound / Piopiotahi, Dusky Sound / Tamatea or Doubtful

Sound / Patea), making it the second most-visited attraction after Aoraki Mt Cook (12%). Milford Sound / Piopiotahi itself welcomed approximately 800,000 visitors in 2024, with international tourists comprising approximately 85% of the total (Milford Sound Tourism Limited 2024). Furthermore, over 205,000 visitors and crew are anticipated to travel through Fiordland, including Milford Sound, aboard more than 30 cruise ships during the 2024/25 summer season (NZCA [2025]).

Predominantly a tourist destination, the 2023 Census recorded a usually resident population of 78 people in the Milford Sound area. However, on Census night, 285 individuals were counted, including visitors, permanent residents and temporary workers (Statistics New Zealand 2023, 2024). It is important to recognise the eight Papatipu Rūnanga who have shared interests in the Piopiotahi and Te Anau basin area, these are: Te Rūnanga o Ōraka Aparima, based in Riverton Aparima; Te Rūnanga o Makaawhio, based in Hokitika; Te Rūnanga o Awarua, based in Bluff Motupōhue; Waihōpai Rūnaka, based in Invercargill; Hokonui Rūnaka, based in Gore; Te Rūnanga o Moeraki, based in Moeraki; Kāti Huirapa ki Puketeraki, based in Karitane; and Te Rūnanga o Ōtākou, based on the Otago Peninsula (Milford Opportunities 2021).

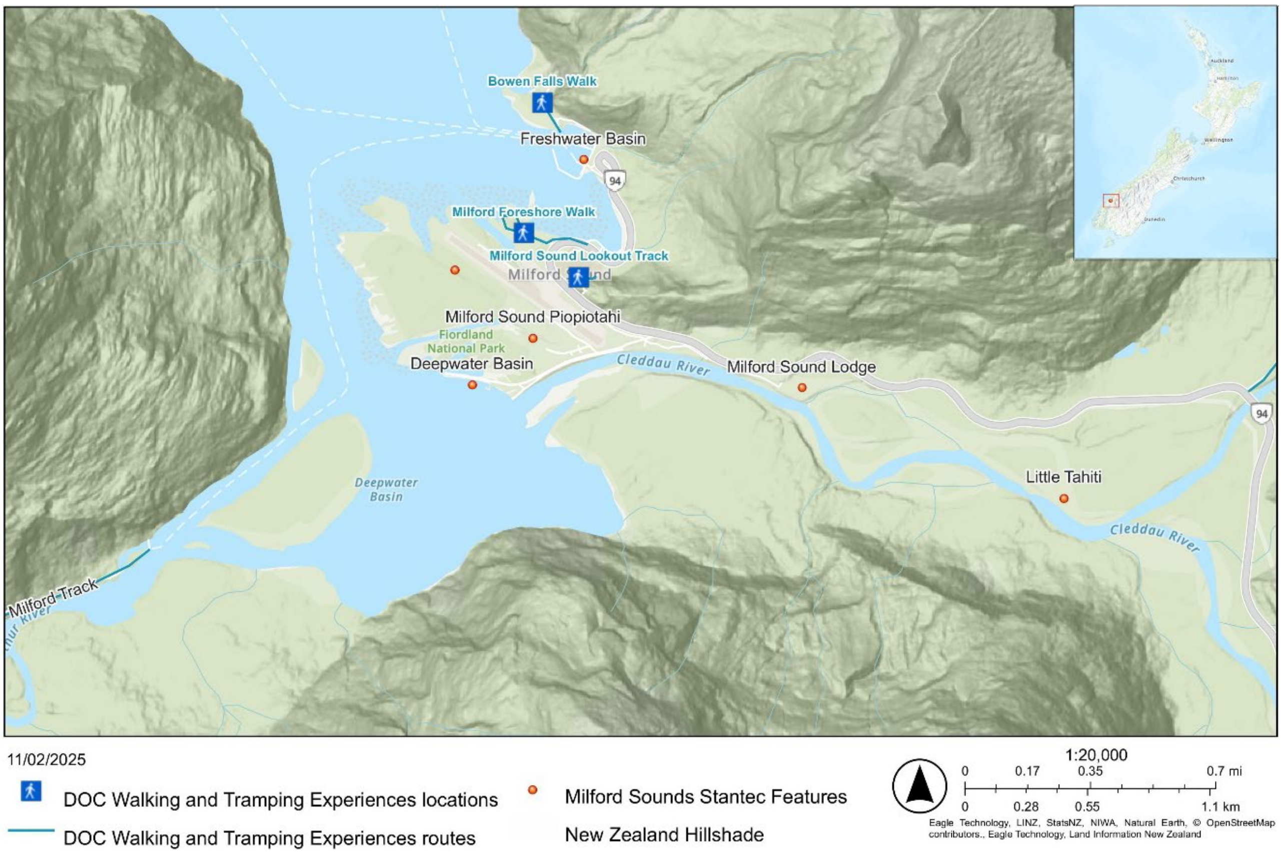

Figure 1.1 Map of Milford Sound / Piopiotahi showing an overview of the area.

2.0 Stage 1: Natural Hazard and Risk Overview of Milford Sound / Piopiotahi

Tsunami hazard and risk in Milford Sound / Piopiotahi has been well-documented in published literature and reports over the last decade (Appendix 1). Although the general magnitude of the landslide-induced tsunami risk has been well described in this work, notable uncertainties remain due to limitations in available data and modelling (e.g. a lack of hydrodynamic tsunami modelling, precise LiDAR elevation data and bathymetry data) (Craig and Chinn 2021). Here, we review the existing body of work on tsunami risk in Milford Sound / Piopiotahi, with a focus on earthquake-induced landslides triggering tsunami events. We summarise key findings of past work that have relevancy for informing risk communication and mitigation advice (Table 2.1).

While this report focuses on the cascading sequence of earthquake-induced (or coseismic) landslide-induced tsunami, it is important to note that many other natural hazards exist in Milford Sound / Piopiotahi, including delta collapse, liquefaction, rock fall, sea-level rise, flooding, avalanche and ocean-source tsunami and that these also present a risk to visitors and workers in the area (Otero and Almanzar 2024).

Tsunami are waves generated when large volumes of water are rapidly displaced. Tsunami can be far-reaching and powerful, capable of inundating low-lying areas far beyond the shoreline and causing extensive damage and loss of life. In Aotearoa New Zealand, these are commonly generated by underwater fault ruptures during earthquakes or by landslides falling into bodies of water. Although the Alpine Fault sits ~5 km offshore from the mouth of Milford Sound / Piopiotahi, this plate-boundary fault is predominately strike-slip (lateral movement), which means that its potential to generate large tsunami through fault rupture alone is considered limited or very low (Power 2013; Orchiston et al. 2016). However, the intense ground shaking expected when the Alpine Fault ruptures could trigger large landslides that fall into the fiord to generate large, rapid onset tsunami. Further offshore, the Puysegur subduction zone is considered capable of megathrust earthquake events that could also be tsunamigenic, although the likelihood of rupture is lower than that of the Alpine Fault (Orchiston et al. 2024). For the purposes of this review, ‘large landslides’ are considered to be those with volumes on the order of 10^6 m^3 or greater (Dykstra 2012; McColl and Cook 2024).

2.1 Coseismic Landslides

Landslides can be generated through multiple processes in Milford Sound / Piopiotahi, including earthquake ground-shaking, rainfall and other slope-erosion processes. However, ground shaking caused by earthquakes is thought to be the most common large-volume landslide trigger in the area (Dick 2021; Dykstra 2012). Coseismic landslides can stem from ground shaking generated by different types of seismic activity in the region, including subduction zone events, intra-plate events and plate-boundary earthquakes on the Alpine Fault (Gerstenberger et al. 2022; Otero and Almanzar 2024).

The ground acceleration needed to trigger large landslides at Milford Sound / Piopiotahi is approximately 0.2–0.3 g (Hancox et al. 2002). Aotearoa New Zealand’s National Seismic Hazard Model (NSHM) estimates that the annual probability of exceeding this ground shaking in Milford Sound / Piopiotahi is 0.01, with an average recurrence interval of 100 years (Gerstenberger et al. 2022; Otero and Almanzar 2024). This suggests that an earthquake with sufficient energy and ground motion to generate landslides has at least a 1% chance of occurring in any one year at Milford Sound / Piopiotahi, and, on average, there will be some large coseismic landslides generated every 100 years. This estimate does not consider recent advancements in understanding of the Alpine Fault events and therefore may under-estimate the likelihood.

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Table 2.1 Summary of coseismic landslide tsunami hazard for Milford Sound / Piopiotahi from literature. AIFR = annual individual fatality risk.

Hazard	Description	Key Risk Variables	Scale/Size	Areas Exposed	Cues	Risk Mitigation	Risk-to-Life Calculations
Earthquake	• Primary sources of seismicity include the offshore Puysegur subduction zone, the Alpine Fault or intra-plate faults • Alpine Fault movements are predominantly strike-slip (lateral rather than vertical), meaning fault rupture alone is unlikely to cause a tsunami • 75% probability of a central section Alpine Fault rupture in the next 50 years [1] • 0.2–0.3 g ground acceleration needed to generate opportunity for landslides; this is expected to be exceeded throughout Milford Sound / Piopiotahi in a future Alpine Fault earthquake[8]	• Earthquake magnitude • Rupture directivity • Energy release • Ground motion (length and strength of shaking) • Fault displacement • Topographic amplification of ground motion	• An Alpine Fault earthquake has a 4 out of 5 chance of being M_W 8+[7] • The National Seismic Hazard Model (NSHM) 100-year recurrence interval level of shaking expected at Milford Village, from all sources, is also sufficient to cause damage and generate coseismic landslides	• All • Ground shaking strongest closer to fault rupture location	• Ground shaking • Loud noises	• Secure objects prone to falling • Adhere to seismic Building Code • Strengthen or support weak structures • Encourage protective actions – ‘drop, cover, hold’ • Provide signage and communication • Educate and train staff	N/A
Coseismic landslide	• Seismicity is the most common trigger of large and very large landslides in the area • In any one year, there is a 1% chance of earthquake shaking that has sufficient energy to trigger coseismic landslides • Steep slopes in the Milford Sound / Piopiotahi area make it prone to landslides and rockfall with high fall velocity • 44% likelihood that an Alpine Fault rupture could cause a large landslide that enters the fiord in a future event[3]	• Slope stress and slope landslide susceptibility • Landslide shape, density and material behaviour (rheology) • Volume • Velocity (source height and fall path) • Location	30,000–70,000 landslides across the South Island likely in a future Alpine Fault M_W 8 earthquake[7]	• All • Concentrated where ground shaking is strongest, where ground conditions amplify shaking and where strong shaking coincides with unstable slopes (i.e. steep + weak material) • Substantial risk at Freshwater Basin[5] • Rockfall runout from Barren Peak possible[4]	• Loud noises • Dust in the hills • Rumbling sounds	• Build shelters to protect from falling debris and rock • Site buildings away from susceptible slopes • Minimise time near Barren Peak between ferry terminal and bluff • Provide signage and communication • Educate and train staff	Typical exposure windows of between 30 and 180 minutes in the Freshwater Basin landslide/tree slide/rockfall hazard area
Tsunami	• Can be generated by underwater fault movements and/or landslides entering the fiord • 44% likelihood that a future Alpine Fault rupture could cause a large landslide that enters the fiord and generates a tsunami[3] • 150-year return interval for Alpine Fault earthquake-induced landslide-induced tsunami in Milford Sound / Piopiotahi [4] • The first tsunami wave is not always the largest wave, and ongoing aftershocks could mean multiple tsunami-triggering events • Damage caused by flooding, wave impact on structures and erosion. Fatalities can be caused by drowning, physical impact or other trauma associated with turbulent, debris-laden waves	• Bathymetry and depth of water at landslide entry (subaerial or submarine) • Tsunami source amplitude and volume; height at shoreline • Wave attenuation or amplification • Wave superposition from reflection and refraction (not yet understood) • Sea level (tides or incremental rise over time) • Number of landslides entering the water • Re-mobilisation of submarine slopes or landslide deposits. Nature of subaqueous runout • Topography of inundated area	• Tsunami run-up (maximum height above sea level) of 45 m considered plausible • Landslide-induced tsunami travel time to village will likely be 1–7 minutes	• Everywhere below 50 m elevation • Only 5.2% of people able to be safely evacuated in best-case scenario; 0% in worst[6]	• Rapid recession of water • Unusual water behaviour • Unusual noises coming from the water • Large wall of water rapidly approaching	• Evacuate people to above 50 m in the event of an earthquake – ‘long or strong, get gone’ • Establish and mark evacuation routes • Create evacuation centres • Re-locate staff accommodation above 50 m elevation • Re-design Milford Village structures to withstand wave loading and enable vertical evacuation; add bunkers[5] • Provide signage and communication • Educate and train staff • Reduce dwell-time exposure in higher hazard areas	For 0–16 m above sea level, for every 1 m gained in elevation, the likelihood of being killed by tsunami decreases by 11%; above 16 m, the reduction is ~ 46% per 1 m [3] * For day visitors, risk of death from landslide-induced tsunami per visit ranges from 7.9×10^{-8} to 6.9×10^{-7} [3] * For overnight lodge visitors, this risk is 4–7 times higher than for day visitors, ranging from 4.0×10^{-7} to 4.7×10^{-6} [3] * For staff, AIFR ranges from 1.5×10^{-4} to 1.7×10^{-3}; risk to life for staff is similar to staff in the forestry and mining sectors.[3] 0.016–0.3% annual change of catastrophic outcome (>100 fatalities) [3, 5]

[1] Howarth et al. (2021); [2] Dykstra (2012);[3] Taig and McSaveney (2015); [4] Porter (2024); [5] Craig and Chinn (2021); [6] Harris (2023); [7] Orchiston et al. (2016); [8] Gerstenberger et al. (2022).

* Likely under-estimates, as it under-represents Alpine Fault rupture likelihood and population exposure.

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The current probability of an Alpine Fault rupture is notably higher than the long-term average, and the NSHM does not fully account for time since the last rupture. Recent work suggests that the central section of the Alpine Fault has a 75% probability of rupture in next 50 years (Howarth et al. 2021). The southern onshore portion of the Alpine Fault does not seem to have ruptured for ~307 years and therefore is relatively late in its recurrence cycle. Future ruptures on the Alpine Fault are expected to be either M_W 7–8 or M_W ≥8, but work to date is unable to define which mode of earthquake will occur next (Howarth et al. 2021) nor on which segment(s) of the fault.

Although the exact magnitude, rupture direction and ground-motion amplification of a future Alpine Fault earthquake is unknown, some generalised Alpine Fault scenarios were produced for the Alpine Fault 8 (AF8) programme (Orchiston et al. 2016). Based on modelled peak velocities for these scenarios (Bradley et al. 2017), ground shaking in Milford Sound / Piopiotahi is expected to be at a level sufficient to induce landslides in a future event (~0.4 g). Large landslide deposits (volumes of 0.2–18.5 x 10^6 m^3) preserved in the bottom of the Milford Sound / Piopiotahi fiord also indicate that many coseismic landslides have entered the fiord over the past 17,000 years since glacial retreat in the area (Dykstra 2012). Records of Alpine Fault coseismic landslides over this time (22 submarine landslide deposits from 50 ruptures, assuming one landslide per rupture event) suggest that there is a 44% likelihood that a future Alpine Fault rupture could cause a large landslide that enters the fiord and generates a tsunami (Taig and McSaveney 2015).

While landslides associated with an Alpine Fault earthquake event pose a significant threat due to the fault's high probability of occurrence within the next five decades, other seismic sources are also capable of creating large coseismic landslides. In 2003, more than 1852 landslides (Cox 2024) with volumes up to 700,000 m^3 were triggered by a M_W 7.2 subduction zone interface earthquake in Fiordland (Hancox et al. 2003). Although this event was sufficiently distant to have minimal direct impact in Milford Sound / Piopiotahi, it did cause a 1–2-m-high tsunami in Taiporoporo Charles Sound (80 km south) that damaged shorelines and a helipad (Reyners et al. 2003; Hancox et al. 2003).

Rainfall-induced landslides are generally smaller volume than coseismic landslides in this area but can be large enough to produce localised tsunami (Taig and McSaveney 2015). While the information about rainfall-induced landslides is poorly constrained, it suggests possible minor variations in seasonal hazard, with slightly higher rainfall averages occurring in the summer months (Macara 2013). In February 2020, prolonged heavy rainfall caused a landslide that hit a hut in Fiordland, housing more than 30 visitors at the time (Taig 2022). Similar landslides could potentially fall into the fiord to generate a tsunami.

Coseismic landslides can result in significant damage and deaths even if a tsunami is not triggered. Damage can be caused by the impact of falling rocks and force of sliding debris or structural failures due to stress from ground shaking and liquefaction. Fatalities can occur from traumatic injury and asphyxiation (Petrucci 2022).

2.2 Landslide-Induced Tsunami

Landslides that enter the fiord can rapidly displace large volumes of water to generate a local tsunami. Based on the Howarth et al. (2021) estimate of 75% likelihood of an Alpine Fault rupture on its central section in the next 50 years and the Taig and McSaveney (2015) estimate that an Alpine Fault earthquake has a 44% likelihood of a large landslide entering the fiord, Porter (2024) estimated a 150-year return period for landslide-induced tsunami in Milford Sound / Piopiotahi. Nearby fault displacements from the earthquake rupture have the potential to generate tsunami waves in the fiord, but the tsunamigenic potential and associated wave amplitudes and run-up are thought to be much less than that of landslide-induced tsunami (Downes et al. 2005; Otero and Almanzar 2024). One reason for this is that the local segments of the Alpine Fault experience predominantly lateral movement (rather than vertical) (Otero and Almanzar 2024).

The 26 landslide-induced tsunami that have been identified in the post-glacial period at Milford Sound / Piopiotahi are estimated to have had wave amplitudes (height of the wave above sea level) that ranged from 0.4 m to 87 m (Dykstra 2012; Taig and McSaveney 2015). Accounting for wave attenuation, the process by which a tsunami wave's size or amplitude decreases as it travels away from source, the highest run-up of water (run-up is a measurement of the height of the water onshore observed above a reference sea level) on the shore is estimated to have been about 47 m (Taig and McSaveney 2015). Using a magnitude-frequency relationship, Dykstra (2012) estimated that tsunami waves with an amplitude of 4 m and run-up of up to 17 m have occurred about once every thousand years at Milford Sound / Piopiotahi. In a future Alpine Fault event, tsunami of 0.3–10 m amplitude and run-up heights of 1.1–47 m are expected at Freshwater Basin near the visitor terminal (Taig and McSaveney 2015). Although past subaerial landslide volumes are estimated to have reached up to 18.5 x 10^6 m^3 of material, it is thought that even the smaller range of large landslide volumes (1 x 10^6 m^3) could generate a very large displacement wave directed towards the Milford airport and village if it fell into the shallower water of Deepwater Basin (50 m) (Dykstra 2012). Submarine slope failures can also generate large tsunami in the area (Porter 2024).

Tsunami can be destructive and deadly. Damage results from inundation, wave impact on structures and erosion. Casualties caused are drowning, physical impact or other trauma when people are caught in the turbulent, debris-filled waves. Strong tsunami-induced currents can erode foundations and collapse structures (ITIC c2024). Craig and Chinn (2021) use elevation contours to create a general high-level depiction of tsunami hazard areas in Milford Sound / Piopiotahi by describing three categories of possible inundation areas (Figure 2.1). The simplified map, which they emphasise is not based on modelling, shows four hazard areas:

1. **An offshore wave-hazard area 150 m from the coast**, where edge effects from refracting waves, high wave energy, shoaling waves and rockfall would pose a risk to boats in all tsunami events.
2. **A 6 m run-up area**, expected to be generated by a small 1.5-m-amplitude tsunami wave, which was exceeded in approximately 60% of events in the post-glacial record and is estimated to have a 16% probability of exceedance in the next 50 years (or 1:300 chance in any one year). An event of this size is expected to be capable of causing damage to buildings, injury and possible loss of life.
3. **A 20 m run-up area**, which was exceeded in 27% of events in the post-glacial record and is estimated to have an 8% probability of exceedance in the next 50 years (or 1:600 chance in any one year). An event of this size is expected to destroy any buildings and infrastructure not designed to withstand tsunami forces, as well as significant loss of life.
4. **A 40 m run-up area**, which is estimated to have a 1% chance of exceedance in the next 50 years (1:4000 chance in any one year) and would be reached by an extremely large and powerful wave, thought to only be exceeded by the largest of the 26 historic post-glacial tsunami.

Although based on 'crude extrapolations', the zones help convey the distribution of potential tsunami hazard in the area (Craig and Chinn 2021).

Tsunami generated by coseismic landslides will likely occur rapidly and are expected to reach Milford Village within 1–7 minutes, depending on the precise location of the landslide, for evacuation to run to high ground. Fitness levels, mobility, age and proximity to access routes to high elevation will greatly influence ability to successfully evacuate above expected wave run-up heights (Craig and Chinn 2021).

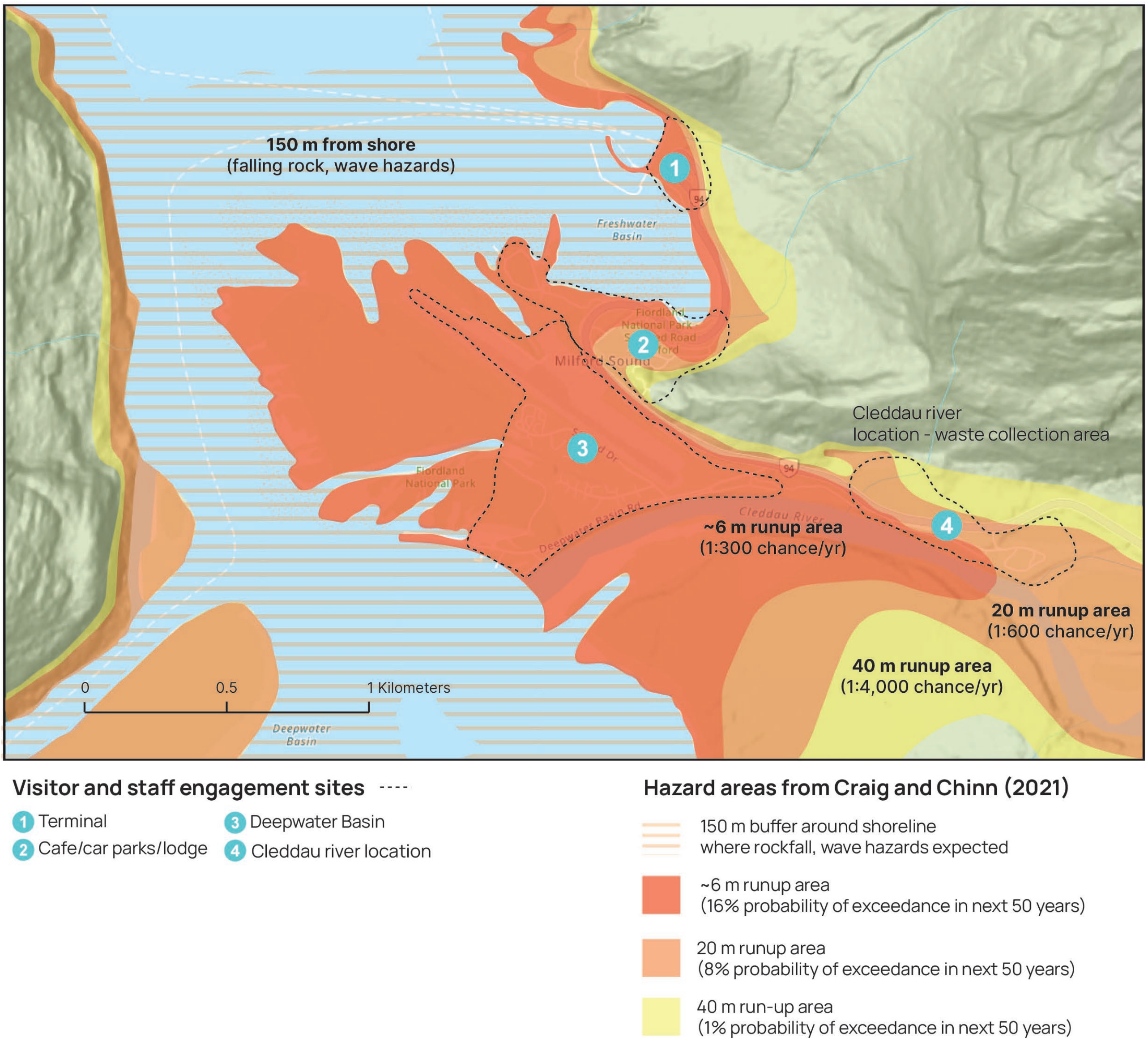

Figure 2.1 Hazard areas for landslide-induced tsunami that have occurred in the past at Milford Sound / Piopiotahi, modified from Craig and Chinn (2021).

There is limited research available on the hazard and impacts from landslide tsunami to those people on watercraft in a fiord setting globally (see Section 4.3.1 for more detail).

2.3 Landslide-Induced Tsunami Risk

Risk is the likelihood and consequences of a hazard (Civil Defence Emergency Management Act 2002). More specifically, risk is a function of hazard probability, asset exposure (e.g. presence or concentration of visitors in relation to hazards, including visitor vulnerability; structures) and the impact (direct and indirect threat to life, health, property, etc.) (Craig and Chinn 2021). Risks can be assessed at an individual level or at a wider societal level. Individual risk to life concerns the annual probability of death of a person, whereas societal risk concerns the probability of an event with many fatalities (Toka Tū Ake EQC 2023). A landslide-induced tsunami in Fiordland is identified as a hazard of national significance in the Southland Civil Defence and Emergency Management Group Plan due to its high levels of societal risk (SCDEMG 2017). A number of key sites and accommodation where visitors and workers spend time in Milford Sound / Piopiotahi are exposed to tsunami hazards (Figure 2.1). Previous studies estimate that there is a 16% probability over the next 50 years (or 0.3% probability per year) of a catastrophic tsunami that could cause over 100 fatalities (Taig and McSaveney 2015).

Using a population-exposure analysis, Dykstra (2012) first estimated that the long-term risk from landslide-induced tsunami in Milford Sound / Piopiotahi was 0.38 deaths/year, assuming that 50% of people will be on shore and 50% on boats. He estimated that this was roughly equivalent to the risk of tsunami in Norwegian fiords. However, this risk estimate is now considered to under-estimate population numbers and over-estimate wave run-up height (no wave attenuation is considered, which is very unlikely) (Taig and McSaveney 2015; Craig and Chinn 2021; Harris 2023). It is important to note that the situations and contexts in Norway and Aotearoa New Zealand are very different. Taig and McSaveney (2015) calculate risk metrics for Aotearoa New Zealand, including Annual Individual Fatality Risk (AIFR) and societal risk, accounting for two plausible wave-attenuation scenarios. Their findings suggest that:

- **for day visitors**, risk of death from landslide-induced tsunami per visit ranges from 7.9×10^{-8} to 2.7×10^{-7};
- **for overnight lodge visitors**, the risk of death from landslide-induced tsunami per visit increases fivefold due to the increased exposure time, ranging from 4.0×10^{-7} to 1.5×10^{-6};
- **for onshore staff**, AIFR ranges from 1.5×10^{-4} to 5.5×10^{-4}, with risk to boat staff slightly less than this; and
- **at the societal risk level**, the probability of an event causing more than 100 fatalities ranges from 1.8×10^{-4} to 6.4×10^{-4} (0.02–0.06% chance per year).

In terms of comparative risk, which is summarised in Table 2.2, Taig and McSaveney (2015) estimate that:

- **for day visitors**, the risk of death from landslide-induced tsunami per visit is roughly equivalent to the risk of death associated with bungy jumping (1.0×10^{-6});
- **for overnight visitors**, it is roughly equivalent to the risk of death from doing an Aotearoa New Zealand cycle trail (1.0×10^{-5}); and
- **for onshore staff**, the AIFR is similar to that of staff working in the forestry and mining sector (1.0×10^{-4}).

The Australian Geomechanics Society (AGS) approach to risk assessment (AGS 2007) is well recognised as best practise in Aotearoa New Zealand and has been used in many risk assessments across the country (Toka Tū Ake EQC 2023). An AIFR of 10^{-4} or a 1-in-10,000 chance of death per year is widely considered to be a moderate, or tolerable, level of individual risk using the AGS guidelines (Toka Tū Ake EQC 2023). The AGS risk-zone descriptor for Milford Sound / Piopiotahi staff's AIFR based on the Taig and McSaveney (2015) estimate is 'high', beyond moderate risk-tolerance levels ($>1.0 \times 10^{-4}$). Hazard-exposure time strongly influences overall risk. Workers who live in Milford Sound / Piopiotahi throughout the year experience a higher level of risk than visitors due to the duration of their time in the hazard area. For example, someone who is at Milford Sound / Piopiotahi 80% of the year will be exposed to approximately 1750 times greater risk than a visitor who only stays for a single four-hour period (Craig and Chinn 2021).

Table 2.2 Comparative fatality risk for tsunami in Milford Sound / Piopiotahi from Taig and McSaveney (2015), with data collected prior to 2014 from the New Zealand Transport Agency, Maritime New Zealand, the Department of Conservation, A J Hackett Bungy, the New Zealand Parachute Industry Association, the Ministry of Transport, the New Zealand Household Travel Survey, WorkSafe New Zealand, the Department of Labour (now the Ministry of Business, Innovation & Employment), the Ministry of Economic Development, the Ministry of Health, the Accident Compensation Commission (ACC) and Water Safety New Zealand.

Risk	**Day Visit (7.9×10^{-8} to -2.7×10^{-7})**	**Overnight Visit (4.0×10^{-7} to 1.5×10^{-6})**	**Staff (1.5×10^{-4} to 5.5×10^{-4})**
Higher than:	-	An overseas visitor’s risk of death from other accidental causes	Average risk levels in the accommodation and food/ beverage industry and recreational sector
	Team and fitness sports (e.g. swimming, soccer)		-
Similar to:	• An overseas visitor’s risk from other accidental causes, e.g. jet boating or bungy jumping experience	• An overseas visitor’s risk from ill health and road accidents • 30 km cycle ride or 10 km walk on Aotearoa New Zealand trails	-
	• Travelling to Milford Sound / Piopiotahi by bus • Day out fishing (mostly drowning risk)		-
Less than:	• Travelling to Milford Sound / Piopiotahi by air or car • Adventure activities (e.g. rafting, mountaineering) • An overseas’ visitor’s risk of drowning while in Aotearoa New Zealand		Average risk levels in the mining and forestry industries
	An overseas visitor’s risk from ill health and road accidents	-	-

Although individual risk to visitors is considered ‘low’ using the above metrics and AGS descriptors, the internationally accepted HSE (2001) approach to risk assessment states that societal risk often plays a larger role in deciding whether a risk is unacceptable or tolerable (HSE 2001; Toka Tū Ake EQC 2023). The upper estimate of a 0.06% annual likelihood of a catastrophic outcome (an event causing more than 100 fatalities) identified by Taig and McSaveney (2015) indicates potentially high levels of societal risk. A revised approximation of the societal risk carried out by Craig and Chinn (2021) suggests that this likelihood could even be as high as 0.3% per year. Additionally, Craig and Chinn (2021) roughly estimated that a large tsunami (run-up > 20 m) on a summer day with maximum visitor numbers could cause up to 2800 fatalities. They identified this societal risk level as intolerable and suggested that a tolerable threshold would need to be confirmed through consultation with key stakeholders and communities (Craig and Chinn 2021).

The risk metrics by Taig and McSaveney (2015) above calculate the probability of death for a person at a given location using a function of the elevation of the location and tsunami height (Taig and McSaveney 2015; Dykstra 2012). Tsunami life-safety risk is strongly related to elevation. Taig and McSaveney (2015) estimate that, from 0 m to 16 m above sea level in Milford Sound / Piopiotahi, every 1 m increase in elevation decreases the likelihood of being killed by tsunami by 11%. Above 16 m, the reduction is ~ 46% per 1 m gained. However, the short wave travel-time and limited number of accessible pathways to evacuate to high ground contribute to the risk in Milford Sound / Piopiotahi, as there are negligible safe refuge sites that can be reached by large volumes of people before the wave arrives (Harris 2023).

Evacuation time is a key factor in survivability for tsunami events. Recent work by Harris (2023) uses an agent-based modelling approach to assess evacuation scenarios for a 17 m landslide-induced tsunami and two potential evacuation points (Lookout Track and the highway). Using different possible exposure conditions (i.e. seasonal and time-of-day variations) and recent 2021 population estimates, the findings suggest that, currently, in the best-case scenario of a slower tsunami arrival of approximately seven minutes, only 5.2% of people are able to safely evacuate to these evacuation points in a winter night-time scenario and 0.1% in a summer day-time event when many people are exposed. Speed, location and population exposed were key variables to safe evacuation. Evacuation to high ground in Milford Sound / Piopiotahi is constrained by steep, narrow and limited evacuation routes that could be easily congested (Harris 2023).

2.3.1 Caveats and Limitations to Applying Existing Risk Metrics

It is important to note that all of the above risk metrics are now considered under-estimates, as the values are likely to under-represent both population exposure and hazard likelihood. The calculations used to make the comparisons are based on a 2004 value that under-estimates the number of annual visitors (640,000) to Milford Sound / Piopiotahi by 260,000 compared to 2019 values (900,000). Current trends also suggest that 2019 visitor numbers will soon be exceeded as the tourism sector continues to recover from the impacts of the COVID-19 pandemic (MSTL 2024).

The calculations are also based on a 2012 estimate that the Alpine Fault has a 27% chance of a large rupture ($M_W \geq 8$) in the next 50 years (Berryman 2012), but this value is now widely accepted to be nearly three times higher at 75% (Howarth et al. 2021; Craig and Chinn 2021). Taig and McSaveney (2015) further note that, without mitigation measures, the risk slowly increases over time, as the probability of an Alpine Fault rupture increases as the seismic cycle progresses. When an event does occur, the ongoing risk will be dynamic, as long-term and delayed effects play out through processes such as aftershock events, formation and breakage of debris dams, deformation, and re-mobilisation of landslides (Taig and McSaveney 2015; Orchiston et al. 2016). The tsunami-modelling values used in previous work are also considered to have limited scientific accuracy, as key risk variables – such as run-up heights and wave-travel velocities – have not been calculated using modern state of practise numerical modelling techniques (Craig and Chinn 2021; Porter 2024).

In the existing risk metrics, the same vulnerability is assumed for people exposed on land and on boats in the water, but the risk to populations on larger watercrafts could be lower than that of populations on land (Taig and McSaveney 2015). Large cruise ships are thought to be less vulnerable to tsunami threats due to their size and stability (Craig and Chinn 2021). Those in smaller boats may be more vulnerable due to their high exposure and lack of rapid mitigation options.

2.4 Mitigation

Tsunami generated by coseismic landslides are expected to arrive rapidly in Milford Village after ground shaking, and modelling suggests that only a fraction of the anticipated population in the area will be able to safely evacuate within that time (Harris 2023). Mitigation at Milford Sound / Piopiotahi is particularly challenging due to the lack of warning and complex terrain. The resulting life-safety risk has been underscored by previous studies, described above, which also propose several potential mitigation options to reduce this risk. Previous work suggests focusing on education, training and communication; evacuation planning; and reducing hazard exposure through infrastructure improvements, re-location or new construction to mitigate the risk (Craig and Chinn 2021; Dykstra 2012; Otero and Almanzar 2024; Harris 2023). Below, we summarise existing work regarding the mitigation strategies of education, training, communication and evacuation, as these are most relevant to the scope of this project.

2.4.1 Education, Training and Communication

Public education is a key tool used in tsunami risk management in Aotearoa New Zealand, with an approach that centres on empowering people to recognise and respond to natural warning signs without waiting for an official warning. Awareness of tsunami risk in Aotearoa New Zealand is thought to have increased in recent years in response to national campaigns such as 'Long or Strong, Get Gone', which emphasises evacuation to high ground after experiencing significant ground shaking at the coast (Johnston et al. 2013). However, recent work shows that tsunami evacuation preparedness remains relatively low and that there is poor understanding of evacuation procedures across Aotearoa New Zealand (Blake et al. 2018; Dhellemmes et al. 2021). Raising awareness of tsunami risk and evacuation behaviours is particularly important in a heavy-tourism setting where overseas visitors may have variable exposure and experience to tsunami risk and preparedness information. Raising awareness of the tsunami risk in the Milford Sound / Piopiotahi context is also important for both overseas and domestic audiences, as landslides and fiords may be less likely to be associated with tsunami, which are more commonly reported on in the context of ocean tsunami and long, exposed coastlines.

Previous research comments on the need for increased information available to both tourists and workers. Craig and Chinn (2021) suggest that:

> *"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 how individual awareness can help them respond in the most effective and timely way during different scenarios."*

Otero and Almanzar (2024) recommend the implementation of a communication plan to ensure effective dissemination of information and coordination among all stakeholders.

Both Craig and Chinn (2021) and Dykstra (2012) emphasise the importance of differentiating risk communication for tourists and workers. While tourists should not be unduly alarmed, workers require more in-depth knowledge to effectively advise visitors during an incident. 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 and Emergency Management teams to put them in the best position to advise visitors quickly and with confidence to improve safety outcomes for all (Craig and Chinn 2021).

2.4.2 Evacuation and Evacuation Planning

While evacuation is generally considered the most effective tsunami mitigation strategy (Kubisch et al. 2020), landslide-induced tsunami in confined water bodies such as those possible in Milford Sound / Piopiotahi present a unique challenge due to extremely short tsunami travel times (Harbitz et al. 2014; Wood and Peters 2015). Compounding this issue is that Milford Sound / Piopiotahi currently lacks clearly marked evacuation paths and muster areas, and access to higher ground is limited by dense vegetation and steep slopes (Craig and Chinn 2021). Despite these challenges, studies suggest that evacuating all but essential personnel after a major earthquake (regardless of tsunami generation) is crucial (Taig and McSaveney 2015). Taig and McSaveney (2015) also demonstrated a significant decrease in tsunami-related mortality risk with increasing elevation, particularly up to 16 m above sea level (11% reduction per metre) and even more so above 16 m (46% reduction per metre). This underscores the importance of effective evacuation planning in Milford Sound / Piopiotahi, yet such planning remains limited (Harris 2023).

While Taig and McSaveney (2015) recommend evacuating to elevations above 50 m, the practicalities of rapid evacuation during a large earthquake at Milford Sound / Piopiotahi pose significant challenges. Given the proximity of the Alpine Fault (approximately 5 km from the fiord's mouth), a rupture would likely generate shaking intensities of at least MMI 7 (Bradley et al. 2017), making it difficult to even stand (Dowrick 1996). Consequently, evacuation efforts would likely be delayed until after the shaking subsides.

Evacuation efforts could be further hampered by panic and congestion on existing routes, such as the Milford Sound Lookout Track (Figure 1.1). Harris (2023) suggests that evacuees will likely continue to ascend the Lookout Track even after it reaches capacity, creating a bottleneck and potentially preventing those at the top from leaving due to downstream congestion and crushing. Harris (2023) concludes by stating that evacuation signage could be used in Milford Sound / Piopiotahi to increase the risk perception and awareness of evacuation routes.

2.4.3 Summary of Natural-Hazard and Risk Research on Landslide-Induced Tsunami at Milford Sound / Piopiotahi

A summary of the earthquake, landslide and tsunami hazard information presented in Section 2 is summarised in Table 2.1 and below. Milford Sound / Piopiotahi faces numerous natural hazards, including severe weather, flooding, landslides, rockfall, tree slides, tsunami, earthquakes, liquefaction and avalanches. The area is seismically active due to the proximity of the Puysegur subduction zone and the Alpine Fault, with a 75% probability of a major Alpine Fault earthquake in the next 50 years. Large earthquakes can trigger landslides, which can then fall into the fiord, resulting in landslide-induced tsunami. Based on the frequency of past large landslide events entering the fiord, scientists infer that there is a 44% chance of a large landslide entering the fiord and causing a tsunami in a future Alpine Fault earthquake. A tsunami in Milford Sound / Piopiotahi is estimated to reach between 1 and 47 m in elevation and is expected to arrive rapidly in 1–7 minutes after earthquake shaking starts. The size and arrival time of the tsunami will depend on how and where the landslide enters the water. There can be multiple waves, and the first wave may not be the biggest. Anywhere beneath 50 m in elevation could be reached by the tsunami. Ocean or distal-source tsunami are unlikely to be larger than landslide-induced tsunami in Milford Sound / Piopiotahi. There is no current monitoring or warning system for these landslide-induced tsunami in Aotearoa New Zealand.

While the risk for day visitors is relatively low (7.9×10^{-8} to -2.7×10^{-7}), risk increases the longer you spend in the area, for example, if an individual stays for an overnight visit or works in the area. The annual likelihood of a catastrophic outcome (over 100 fatalities) is estimated to be between 0.02% and 0.3%. Previous research states that people should evacuate to a height of 50 m above shore level as quickly as possible if a tsunami were to occur. However, strong shaking and associated landslides can damage buildings and roads, making evacuation difficult. Shaking can make it hard for people to stand up; therefore, it is unlikely that evacuees will be able to start evacuating quickly. Modelling also suggests that, currently, evacuation to a specific lookout point will not be possible for most people.

3.0 Stage 2: Audiences of Natural-Hazard and Risk Information for Milford Sound / Piopiotahi

Milford Sound / Piopiotahi, a major Aotearoa New Zealand tourist destination, also serves as a workplace and temporary home for many tourism-industry workers. Visitors and workers are the two primary groups exposed to the area's dynamic and hazardous landscape. These groups, including their respective sub-groups (Table 3.1), are the key audiences in this risk-communication study, as they are likely to experience the highest levels of life-safety risk.

Effective hazard and risk communication requires understanding audience motivations, experiences and expectations regarding risk acceptance and decision-making. This section provides an overview of the audiences for geological hazard and risk information in Milford Sound / Piopiotahi; maps visitor journeys from initial consideration to arrival; and summarises key interactions, decisions and contact points. Our aim is to consider as many different aspects of communication as possible, namely: 'who is it for?', 'how should it be designed?', 'where should it be placed?' and 'when should it be emphasised?'. The following assessment of audience communication pathways and their anticipated needs will support the creation of advice in Stage 3.

3.1 Natural-Hazard and Risk Information Audience Overview

Effective communication begins with considering the intended audience. It is essential to identify the primary group(s) who will receive and act on information so that communicators can tailor their message in a suitable style and deliver it in an appropriately targeted channel to meet the audience's needs (WHO 2017). There has already been substantive work on visitor demographics, which is available in the Milford Opportunities Project Tourism Report (Jones et al. 2021). We have used a combination of results from that report alongside new information gathered during a one-day summer-season site visit to Milford Sound / Piopiotahi in January 2025 to describe 'key audiences' from a hazard and risk perspective. Due to the limited time available, we have used estimates provided by MSTL for people numbers at different sites. The site visit was primarily used for ground-truthing assumptions and performing high-level audience observations.

In general, there are two primary groups exposed to the dynamic landscape of Milford Sound / Piopiotahi on the water and the land: firstly, the people who visit the region to explore the Sound, sightsee and/or take part in recreational activities (e.g. boat trips, kayaking, hiking, fishing); and secondly, those who work in the area for one of the many concessions, operators or agencies or who undertake commercial fishing. These two groups can be further subdivided based on their purposes for visiting and the length of time spent in the area. There are no permanent residents or community population present at Milford Sound / Piopiotahi. Table 3.1 details the five audience sub-groups at Milford Sound / Piopiotahi.

Table 3.1 The five main audience groups at Milford Sound / Piopiotahi. The term 'audience' is used to describe all groups below. The overview includes the main reasons for going to Milford Sound / Piopiotahi, the estimated time spent there, assumptions of nationality or familiarity with the area and main mode of transport to Milford Sound / Piopiotahi for each group.

Audience Groups	Main Modes of Transport to Milford Sound / Piopiotahi
Independent tourists (A) – Recreation Also known as 'free independent travellers' (FITs). These individuals arrive and undertake activities at Milford Sound / Piopiotahi independently (mostly self-driving) but may also go on tours once they have arrived on site (e.g. boat, kayak) or head to the Milford Track. FITs typically visit for a few hours, although they generally have more flexibility and may stay longer than group tourists. Some stay overnight in the lodges or on boats. FITs can be either domestic or international.	• Vehicles (rental/private) • Airplanes (including charter flights) • Helicopters • Boats (low numbers)
Group tourists (B) – Recreation These individuals are part of group tours mostly departing from Queenstown and Te Anau. Travellers in this group often only visit for a few hours, undertaking one of the tours. Cruise-ship passengers are also included in this group but these passengers stay on the water only. This group may comprise a high percentage of internationals, including non-English speakers. Individuals within this group are less likely to reside in Aotearoa New Zealand.	• Vehicles (buses) • Airplanes (including charter flights) • Helicopters • Cruise ships
Boat/watercraft users (C) – Both These individuals are often locally based and use watercraft out on the fiord. This group also includes commercial fishermen; loading and unloading at the wharf. They typically spend up to a day in the area. It is difficult to estimate the number of boat users as they are not required to register.	• Vehicles with boat in tow • Boats (low numbers)
Workers/employees – day only (D) – Working Some employees work on-site in Milford Sound / Piopiotahi, commuting each day from locations such as Te Anau. Workers may be domestic or international.	• Vehicles • Plane/helicopter
Workers/employees – who stay overnight (E) – Working Some employees (roughly 200–300) temporarily reside on-site in Milford Sound / Piopiotahi for a few days through to months and years. They live in staff accommodation on-site and often get to know the area quite well. Workers could be domestic or international.	• Vehicles • Plane/helicopter

Note: Using Department of Conservation (2021) definitions, we define local visitors as "New Zealanders who regularly visit places near where they live for diverse reasons". Domestic visitors are "New Zealanders who are travelling outside their local area and have often taken time to plan their trip and book activities in advance". International visitors are people who are travelling from overseas and will have often invested considerable time in planning their trip. Some will have limited knowledge of the places, associated values or local expectations. We define workers as those who are employed to work in the region.

3.1.1 Tourists (Groups A and B)

The largest proportion of people at Milford Sound / Piopiotahi during the day are tourists, especially in the peak summer season (December through February). The estimated maximum number of people in Milford Sound / Piopiotahi during peak times is estimated to be over 3000 per day (Craig and Chinn 2021). In winter, it can be less than 1000 (Craig and Chinn 2021). There is strong seasonal variation in tourist numbers, with the summer months seeing considerably more visitors compared with the winter months. Milford Sound / Piopiotahi is more popular with tour groups and package tourists than other destinations in Aotearoa New Zealand. A package-tour tourist is defined as someone who primarily travels within Aotearoa New Zealand as part of a pre-arranged tour or group (Jones et al. 2021).

Approximately 800,000 people visited Milford Sound / Piopiotahi in 2024, 85% of which were international visitors (MSTL 2024). The remaining 15% resided within Aotearoa New Zealand. It is projected that the number of visitors could reach nearly 900,000 in 2027 (Jones et al. 2021). The above number does not include the large number of cruise-ship visitors who do not disembark onshore. Over 30 cruise ships carrying a total of over 205,000 visitors and crew will travel through the Fiordland regions, including Milford Sound / Piopiotahi during the 2024/25 season (NZCA [2025]).

In terms of activities, an estimated 95% of tourists go on a boat cruise utilising one of the tourism operators (Jones et al. 2021). These operators have their base in the visitor terminal; therefore, many tourists pass through this location, spending around 30 minutes in the terminal prior to departure (Preston 2025). Around 5% of those visiting Milford Sound / Piopiotahi do not take a boat cruise and instead undertake other activities, including scenic flights, tramping, walking, climbing, scenic observation, hunting, diving and snorkelling, visiting the cafe, kayaking with a tour or independently, camping and taking the ferry to the Milford Track starting point at Sandfly Point (Jones et al. 2021).

The majority (95%) of tourists arrive via the single access road (Jones et al. 2021), with some arriving by aircraft (5%). There are an estimated 530 car parks around Milford Sound / Piopiotahi, with 240 in the main car park and 150 in the overflow car park (Craig and Chinn 2021). The remaining car parks are spread around Milford Village, alongside road verges and on unoccupied land. In 2019, there were over 190,000 in-bound vehicle movements, of which 91% were private vehicles (cars and camper-vans). Buses (tour coaches and mini-buses) carried 50% of passengers while accounting for 9% of vehicle movements (Jones et al. 2021).

In terms of nationality, data collected between 2014 and 2019 found that Australia is the largest source of international visitors to Milford Sound / Piopiotahi, followed by the United States of America, China, the United Kingdom and Germany (Jones et al. 2021; MSTL 2024). Around 92% of international visitors to Milford Sound / Piopiotahi are adults. Data collated from between 2014 and 2019 shows that Milford Sound / Piopiotahi attracts a higher proportion of younger people (15–34 years – 40% of total) and seniors (55+ years – 34% of total) than Aotearoa New Zealand as a whole, and a lower proportion of people aged 35–54 years (26% of total) (Jones et al. 2021). While a significant portion of international travellers opt for independent travel, organised tours still account for a notable share of tourism in Milford Sound / Piopiotahi. According to Jones et al. (2021), approximately 73% of international visitors explore Milford Sound / Piopiotahi independently, while the remaining 27% participate in organised tours. Although based on a small sample size and with a focus on Chinese tourists, research suggests that people who undertake organised tours may feel that they are exposed to less risk. In their recent research, Cui et al. (2023) spoke to tourism agents / service providers and response personnel on the West Coast of Aotearoa New Zealand and found that they believe that some tourists from China assumed there were limited risks in organised tours (compared to independent travel). Cui et al. (2023) also found that the tour guides who they surveyed found that Chinese group tourists relied heavily on their tour leader or tour guide to manage risks for them.

Te Anau and Queenstown are the most popular bases for overnight stays when visiting Milford Sound / Piopiotahi, accommodating 79% of overnight visitors. Seventeen percent (17%) of visitors stay closer to the fiord itself, either in Milford Sound / Piopiotahi or along the Milford corridor, while only 4% choose Manapouri for their overnight accommodation (Jones et al. 2021).

3.1.2 Boat/Watercraft Users (C)

There is a smaller group comprising those who use watercraft for recreation and commercial purposes on the Sound (estimated 20–30 per day). However, watercraft-user numbers will vary considerably depending on the season, weather and fish/stock numbers. The wharf is used at Deepwater Basin for recreational boat and watercraft launches, as well as commercial fishing-boat launches and processing. Part of Milford Sound / Piopiotahi is designated as a marine reserve.

3.1.3 Workers – Day or Resident (D and E)

In 2021, 282 concessions operated at Milford Sound / Piopiotahi, encompassing diverse tourism, recreation and infrastructure activities (Jones et al. 2021). These concessions, categorised by Jones et al. (2021) as either 'recreation' or 'infrastructure', support employment at Milford Sound / Piopiotahi, including roles such as coach drivers, hospitality staff or service staff. Concession sites are in three main areas: Milford Sound / Piopiotahi itself, the Milford Road Corridor and the wider Te Anau / Manapouri area. Infrastructure concessions are concentrated in the Milford Village / Deepwater Basin area, while the Milford Sound / Piopiotahi primary destination area hosts concessions for boat cruises, foreshore walks, the airport, the Milford Track exit and some coach parking. Boat-cruise and related land-transport concessions, along with, but to a lesser extent, aviation concessions, correlate with higher visitor numbers.

Workforce housing is provided at Milford Sound / Piopiotahi due to its remote location and long commute from the nearest residential areas in Te Anau. Staff are housed at two locations: (1) behind the cafe / visitor centre (estimated 100 people in summer and between 50 and 75 in winter) and (2) the Cleddau village adjacent to the aerodrome / airport runway (estimated 200–300 people). Operators provide accommodation for varying durations, reflecting staff-rotation schedules and seasonality. While some positions, such as seasonal staff, may rotate weekly during peak season, others, such as boat skippers and senior staff, may reside in Cleddau village for a year or more (Jones et al. 2021). Overall, there is a wide variation of hours spent at Milford Sound / Piopiotahi by employees due to different hours of work, days, rostering, seasonality and annual leave.

3.1.4 Summary

People visiting Milford Sound / Piopiotahi fall into one of five groups: (A) independent tourists, (B) group tourists, (C) boat/watercraft users, (D) workers who commute in for the day and (E) workers who reside on-site. Individuals from groups A and B represent most people present at Milford Sound / Piopiotahi. Across all of these groups, people's level of risk acceptance and tolerance, hazard awareness and understanding, decision-making contexts, language comprehension and accessibility needs vary considerably.

3.2 Mapping Visitor Journeys: Opportunities for Natural-Hazard and Risk Communication

The five key audience groups identified for Milford Sound / Piopiotahi (Table 3.1) have diverse motivations, experiences and expectations regarding life safety and risk. Individual risk acceptance, tolerance, perception, awareness, understanding, decision-making contexts, language comprehension and accessibility needs will vary, requiring nuanced risk-communication strategies.

While this study focuses on natural-hazard and risk communication, it is important to consider the psychological factors involved in tourist experiences. These play a role in how effective a communication approach will be for meeting its intended purpose. A review by Thomas et al. (2018) found that there are three key interrelated factors influencing what kind of experience a particular tourist is seeking (and how it can be satisfied). These three factors consist of: (1) motivation (the desire to go to certain places and participate in specific activities), (2) expectation (the mental image created of a particular destination) and (3) satisfaction by the actual experience of the destination. How these three factors may influence the willingness of an individual to understand the hazard and then take associated risks should be taken into consideration during the development of natural-hazard- and risk-communication strategies.

While there is a level of individuality, almost all people who travel to Milford Sound / Piopiotahi go through several steps from before point of sale (or offer of employment) through to arrival on site. The steps of a visitor/worker journey are the high-level steps taken by an individual from the moment they are inspired to travel or work in the region to the actual trip/experience/job. For this purpose, we have simplified the user journeys presented in Jones et al. (2021) into four key steps for an individual:

1. **Considering –** the process of contemplating and considering whether Milford Sound / Piopiotahi is a place that they will visit or work (workers may be requested to work at Milford Sound / Piopiotahi by their employer).
2. **Planning and booking –** the experience of searching, planning and booking their trip after deciding to visit or work in Milford Sound / Piopiotahi.
3. **Travelling –** the actual journey to Milford Sound / Piopiotahi; the scope of this study constrains this to starting locations in Aotearoa New Zealand only.
4. **At Milford Sound/Piopiotahi (on-site) –** the experience/time spent at Milford Sound / Piopiotahi; this may vary substantially across groups.

It should be recognised that not all audience groups will experience and undertake these steps in the same way, and some may not undertake steps 1 or 2 at all, or only briefly. Figure 3.1 shows how each audience group typically maps across these steps.

Everyone will make decisions (some about risk) along this journey and will also interact with information to help them decide whether to proceed. To help understand and identify potential risk-communication opportunities, hypothetical journeys for each audience group were qualitatively mapped as a pathway across the four steps. Two examples are shown in Figure 3.2, with the remainder included in Appendix 2. We used existing work (Jones et al. 2021) and information gathered from the site visit to identify decision and interaction points, as well as communication opportunities.

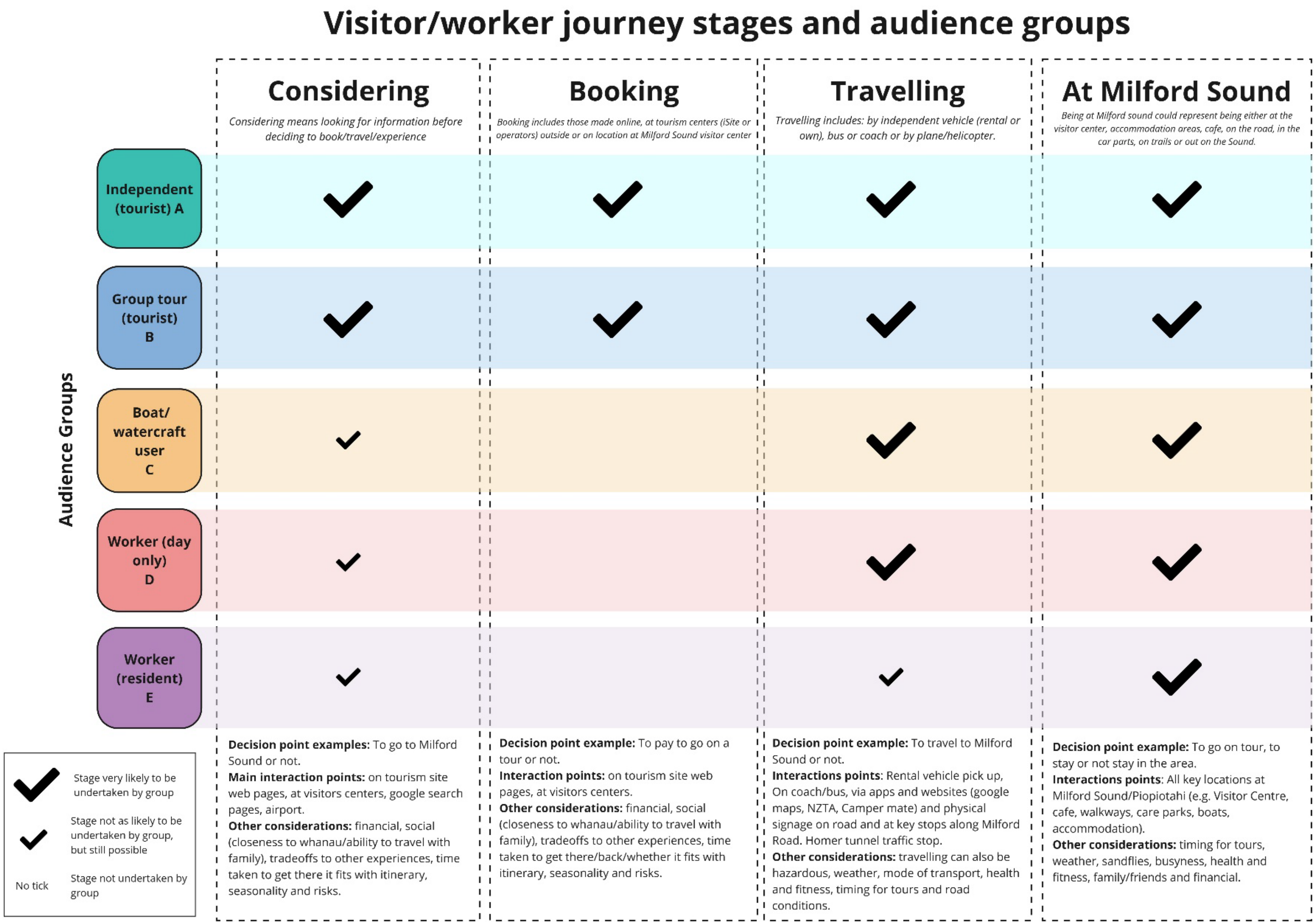

Figure 3.1 General overview of visitor-journey steps and audiences. Note that the time spent on each of the steps will vary. Information derived from site visit and Jones et al. (2021).

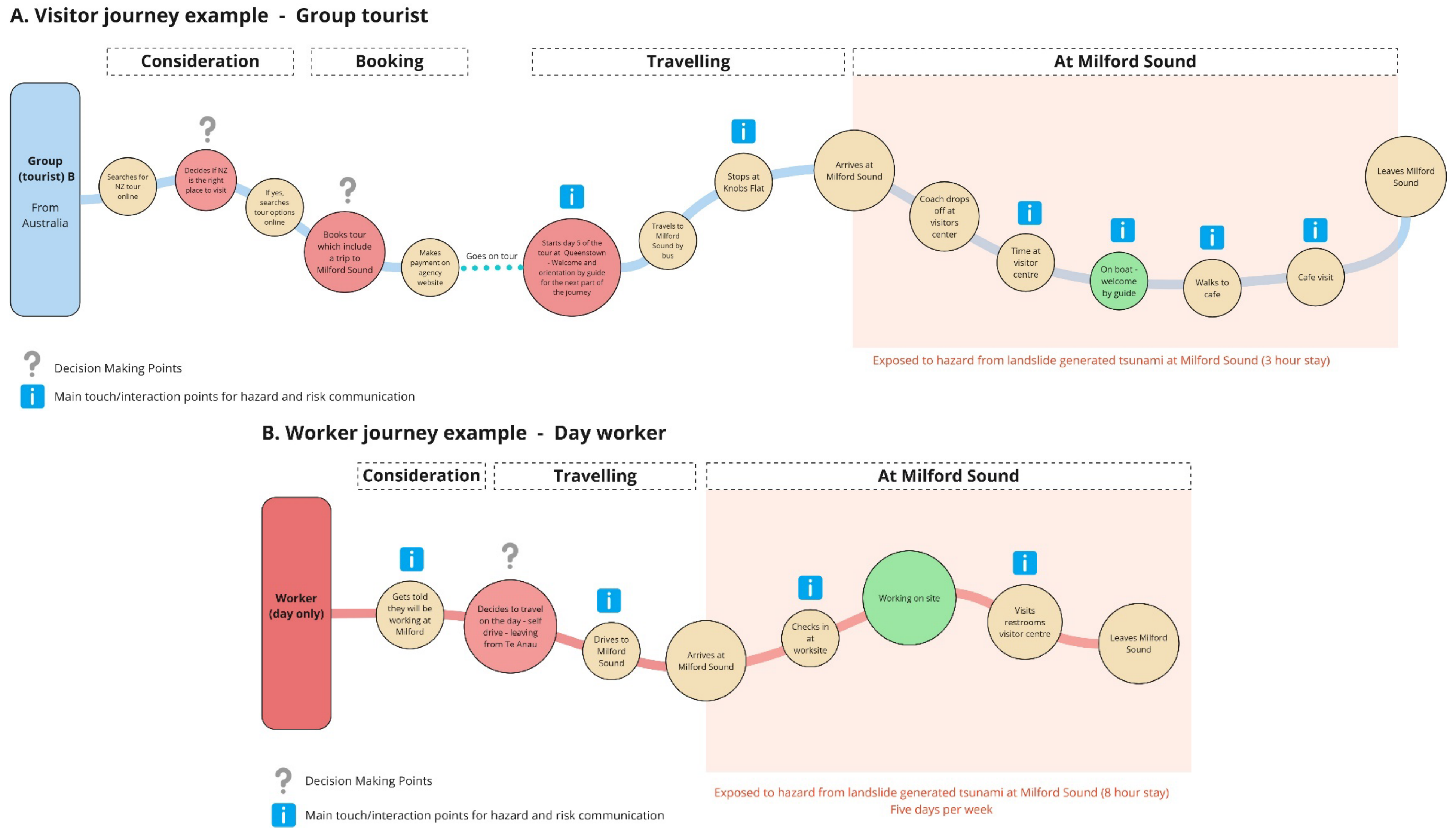

Figure 3.2 Example journey maps for a hypothetical (A) group tourist and (B) day worker. All journey maps are shown in Appendix 2. The beige circles are actions, the red circles are decisions and the green circles are experiences or activities.

3.3 Identified Risk-Based Decisions and Decision Points

Many decisions are made (whether consciously or subconsciously) by visitors to Milford Sound / Piopiotahi related to travel and safety. In making their decisions, tourists are guided by what is commonly referred to as 'push' and 'pull' motivations (Thomas et al. 2018). 'Push' motivations are often described as the internal, affective aspects that lead individuals in their decision-making around 'whether' to travel. Pull motivators are described as the external, tangible aspects of potential destinations that guide individuals in their decision-making around 'where' to travel (Uysal and Jurowski 1994). Information on hazard and risk at their destination can affect both the push and pull motivations. Taig (2022) states that, when conveying information about risk levels at a particular site to visitors, the aim is to help those visitors decide:

(a) Do they want to go ahead and expose themselves (and their party) to this risk at all?

(b) If they go ahead and visit, what special hazards should they be aware of and how can they best control them? Or,

(c) Could they comfortably go ahead visiting this site without taking precautions over and above the general good sense needed when visiting outdoor/remote locations?

In terms of decision-making responsibility in public conservation lands and waters, the Department of Conservation (DOC)'s visitor-safety principles state that "visitors are responsible for their decisions about the risks they take and for any others under their responsibility" (DOC 2023). In a decision-making sense, the presence of 'risk' refers to the possibility of danger or negative outcomes in a situation.

Based on our visitor/worker journey-mapping exercise (previous section), we have identified key decisions that may have natural-hazard and risk components connected to them (Table 3.2). These decisions have been broadened beyond the risk-specific decisions highlighted by Taig (2022) above. This is because, in this context, it is unlikely that visitors to the region will know about landslide-induced tsunami risk generally. Therefore, it will not be in their mind to consider. However, recent national media coverage on tsunami risk in Milford Sound / Piopiotahi may have increased awareness domestically by releasing articles such as:

- *Scientists are racing to understand tsunami risk* – *New Zealand Geographic*, 13 September 2024[1]
- *Best-case scenario: 5% survive Milford Sound tsunami* – *Newsroom*, 12 January 2024[2]
- *Tsunami risk for Milford Sound* – *Stuff*, 16 April 2015[3]

Analysing visitor and worker decision-making processes can highlight the most effective points for hazard and risk communication. It is important to recognise that individuals consider a range of risks, including financial implications, in addition to immediate life-safety concerns related to natural hazards.

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1 https://www.nzgeo.com/newsletter/the-weekender-september-13-2024-gmail/?frame=0#:~:text=Scientists%20are%20racing%20to%20understand%20tsunami%20risk

2 https://newsroom.co.nz/2024/06/12/best-case-scenario-5-survive-milford-sound-tsunami/

3 https://www.stuff.co.nz/southland-times/news/67803273/tsunami-risk-for-milford-sound

Table 3.2 Summary of decision points and possible considerations during visitor/worker journey steps for relevant audience groups, assuming that no hazardous event is occurring.

Decision	Possible Considerations / Other Risks	Journey Step	Audience Groups
Choosing to visit Milford Sound / Piopiotahi	Weather, timing, financial, meets expectations, hazard and risks	Consideration	A, B, and C
Deciding to work at Milford Sound / Piopiotahi	Financial, timing, hazard and risks, staffing, skills, career factors, enjoyment	Consideration	C, D and E
Planning where to stay and the itinerary; booking tours and travel	Weather, financial, timing, meets expectations, hazard and risks	Consideration and booking	All groups
Deciding to travel to Milford Sound / Piopiotahi on the day	Weather, financial, clothing and equipment, road conditions, traffic, hazard and risks	Travelling	A, B, C and D
Undertaking an experience at Milford Sound / Piopiotahi	Safety meets expectations, financial, weather	On-site at Milford Sound / Piopiotahi	A, B and C
Going to work at Milford Sound / Piopiotahi	Financial, safety, career factors, hazard and risks	On-site at Milford Sound / Piopiotahi	D and E

The focus in Table 3.2 is on regular decision-making during times when no geohazards are actively occurring. Extra questions would come up if a geohazard event occurred (e.g. large earthquake felt locally); these could include:

- Something is happening; is it a threat to me or my party?
- What should I/we do?
- What are authorities telling me to do?
- Should I/we follow what others are doing?

3.3.1 Risk Tolerance and Awareness across Audiences

Levels of individual risk acceptance, preference and tolerance are influenced by factors such as age; culture; socio-economic status; health and fitness; experience and major life events; content; and the type of risk, knowledge and awareness (Baláž et al. 2024; Shou et al. 2023; Paton et al. 2005; Slovic 1987, 2000). According to Craig and Chinn (2021), the majority of international visitors, and a significant portion of domestic visitors to Milford Sound / Piopiotahi, fall into DOC's 'short-stop traveller' category. This group typically has low risk tolerance, or readiness to bear the risk, and may lack the awareness, experience, fitness or skills to adequately manage risks in a remote environment (DOC 2018). Natural-hazard risk awareness could be lower (in general) for those visitors arriving in Aotearoa New Zealand from places that do not experience earthquakes, landslides and tsunami at the same frequency as Aotearoa New Zealand (e.g. Australia, the United Kingdom). International tourists to Aotearoa New Zealand (especially those who do not speak English as their first language) may also find it challenging to understand and respond to hazard information, impending events or evacuation instructions due to language barriers, limited social support and a lack of resources such as appropriate clothing, safety equipment or transportation (Kelman et al. 2008; Fountain and Cradock-Henry 2020; Cui et al. 2023). It is crucial to note that the details above are generalisations, and individual tourists within any audience group will have varying levels of risk awareness and tolerance that will influence the way that they interpret and respond to risk-communication messages.

3.4 Information-Interaction Points/Sites

Information-interaction points/sites refer to the specific places (physical or online) where a visitor or worker engages with and accesses any information. These are the touchpoints where information is exchanged, whether this be through a website, app, physical information board, brochure or conversation with a local guide. By identifying common interaction points across our visitor and worker 'journeys', we can understand the most effective and efficient ways of delivering information.

Using information from Jones et al. (2021), a site visit and insights from Dhellemmes et al. (2016), we have identified interaction points or sites (both online and physical) where different audiences could interact with information on landslide-induced tsunami hazard and risk. These are divided into interaction points that are (1) online, (2) physical locations not at Milford Sound / Piopiotahi and (3) physical locations at Milford Sound / Piopiotahi.

3.4.1 Online

Tourists intending to visit Milford Sound / Piopiotahi could interact with online information for a variety of reasons before travelling. A summary is shown of the main websites/apps in Table 3.3. Visitors could begin their search online to see whether Milford Sound / Piopiotahi is the right destination for them, navigating to pages such as the newzealand.com website, MSTL main site or DOC national park webpage. They could use sites such as Wikipedia, Google and general tourism sites, blogs and forums to understand more about the area and what they could see/experience. They could use concession site pages to book tours and experiences. Closer to the time of the journey, people could check for more up-to-date information on the weather or road conditions via MetService, DOC and Google Maps. Most of these sites have mobile application versions. Local and domestic visitors (including workers and recreational boat users) may access the information they need about Milford Sound / Piopiotahi through more social networks, such as local Facebook groups. Some travellers are also using artificial intelligence (AI) assistants, such as ChatGPT and Google's Gemini, to plan their travel itinerary.

Some websites (e.g. MSTL and Southern Discoveries) have information about natural hazard and risk at Milford Sound / Piopiotahi on their website stating that Milford Sound / Piopiotahi is susceptible to both local and distant-sourced tsunami events. DOC national park webpages have alert information related to current events. The predominant audience group using online information to inform their decisions (throughout their whole journey) are independent tourists (Group A).

Table 3.3 Online interaction points for information related to Milford Sound / Piopiotahi.

Online Interaction Points for Information Related to Milford Sound / Piopiotahi
• Wikipedia page for Milford Sound / Piopiotahi (https://en.wikipedia.org/wiki/Milford_Sound) • Google main search page (https://www.google.com/search?q=milford+sound) • newzealand.com (https://www.newzealand.com/) • Fiordland: Beyond Belief (https://www.fiordland.org.nz/) • Concession-holder site pages (e.g. https://www.realnz.com/en/destinations/milford-sound/) • MSTL page (https://milfordsoundtourism.nz/) • DOC main track and park pages (https://www.doc.govt.nz/parks-and-recreation/places-to-go/fiordland/places/fiordland-national-park/places-to-go/milford-road-milford-sound-area/; https://www.doc.govt.nz/parks-and-recreation/places-to-go/fiordland/places/fiordland-national-park/things-to-do/tracks/milford-track/) • Cruise-ship booking sites • Weather sites (e.g. MetService, Accuweather, NIWA [National Institute of Water & Atmospheric Research]) • Blog sites and travel forums (e.g. TripAdvisor: https://www.tripadvisor.com/ShowForum-g255121-i7782-Milford_Sound_Southland_Region_South_Island.html)

Online Interaction Points for Information Related to Milford Sound / Piopiotahi
• Travel guides (Lonely Planet, etc.) (e.g. https://www.lonelyplanet.com/new-zealand/fiordland-and-southland/milford-sound) • New Zealand Transport Authority Waka Kotahi (https://www.nzta.govt.nz/) • Southland area fishing rules guide (https://www.mpi.govt.nz/fishing-aquaculture/recreational-fishing/fishing-rules/southland-fishing-rules/) • Civil Aviation Authority guide for flying in and out of Milford Sound / Piopiotahi • Official responding agency sites (Emergency Management Southland, GNS Science, NEMA, etc.) • Google Maps • Mobile applications (e.g. CamperMate, Rankers – Camping NZ, Great Walks) • Travel influencers through social media • Social media accounts for all of the above

3.4.2 Physical Interaction Sites outside Milford Sound / Piopiotahi (including Milford Corridor)

All visitors and workers could interact with information about Milford Sound / Piopiotahi at key sites, usually before travelling. Information formats include brochures, posters and in-person conversations. Table 3.4 lists key locations where these interactions could occur. One of the biggest stopping-points for tourists is Queenstown. Locations within Queenstown that provide tourist information include the iSite (Figure 3.3; left), the DOC Visitor's Centre, the airport and tourism-operator offices/booths. Te Anau also includes all of the above. Posters, signage and physical brochures are used at these sites to provide information (Figure 3.5).

State Highway 94 (SH 94) / the Milford Corridor (and multiple stops along the way) is also a place where people would come across information about the region (Figure 3.3; right). People reading information at these locations often want to learn more about the local environment (nature, cultural, geological). Maps with 'you are here' labels are common along the Milford Corridor to help with situational awareness. Limited information on geological hazard and risks was observed at these locations. However an in-depth survey across all sites was not undertaken. The DOC Te Anau Milford Highway brochure has a brief section on safety. Rockfall warning signage is placed along parts of SH 94 closer to Homer Tunnel. The predominant visitor groups using sites outside Milford Sound / Piopiotahi are independent tourists (Group A) and group-tours travellers (Group B). However, the predominant group can change depending on the site. Almost all visitors and workers will use the Milford Corridor road to get to Milford Sound / Piopiotahi.

Table 3.4 Physical interaction sites outside Milford Sound / Piopiotahi (including Milford Road).

Physical Interaction Sites outside Milford Sound / Piopiotahi
• Queenstown and Te Anau iSite visitor information centres (Figure 3.3; left) • Queenstown and Te Anau DOC visitor centres • Concession offices in Queenstown and Te Anau (e.g. RealNZ, GreatSights) • Milford Corridor stop points (Figure 3.3; right) • At accommodation in the region • Lay-by locations in towns along highways (e.g. Mossburn, Garston) • Along the Milford Corridor – physical signage used by the New Zealand Transport Agency

Figure 3.3 (Left): Milford Sound / Piopiotahi information at the iSite in Queenstown; (right) information boards at Upper Eglington along the Milford Corridor (State Highway 94).

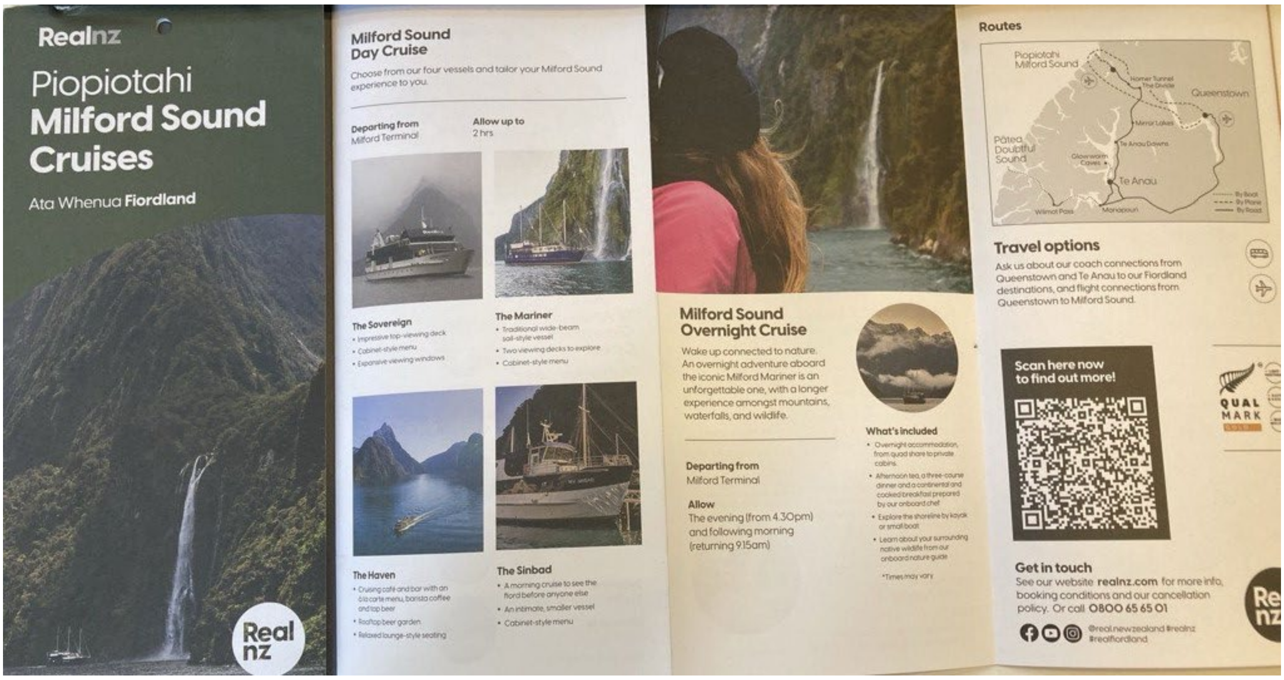

Figure 3.4 Tourism brochure from RealNZ.

3.4.3 Physical Locations at Milford Sound / Piopiotahi for Information Interaction

Once people are at Milford Sound / Piopiotahi (north of Homer Tunnel), there are six main locations where visitors could interact with information. Figure 3.5 shows these locations alongside the visitor groups that are likely to be present at the location. More detail on each of these locations is shown in Tables 3.5–3.10. All of these sites are within the potential tsunami-inundation zones as identified by (Craig and Chinn 2021); see Figure 2.1. The following tables provide site-specific details gathered from visits and discussions with MSTL. The potential communication and mitigation options listed in Tables 3.5–3.10 are preliminary observations and do not constitute formal advice. Formal advice will be provided in Stage 3.

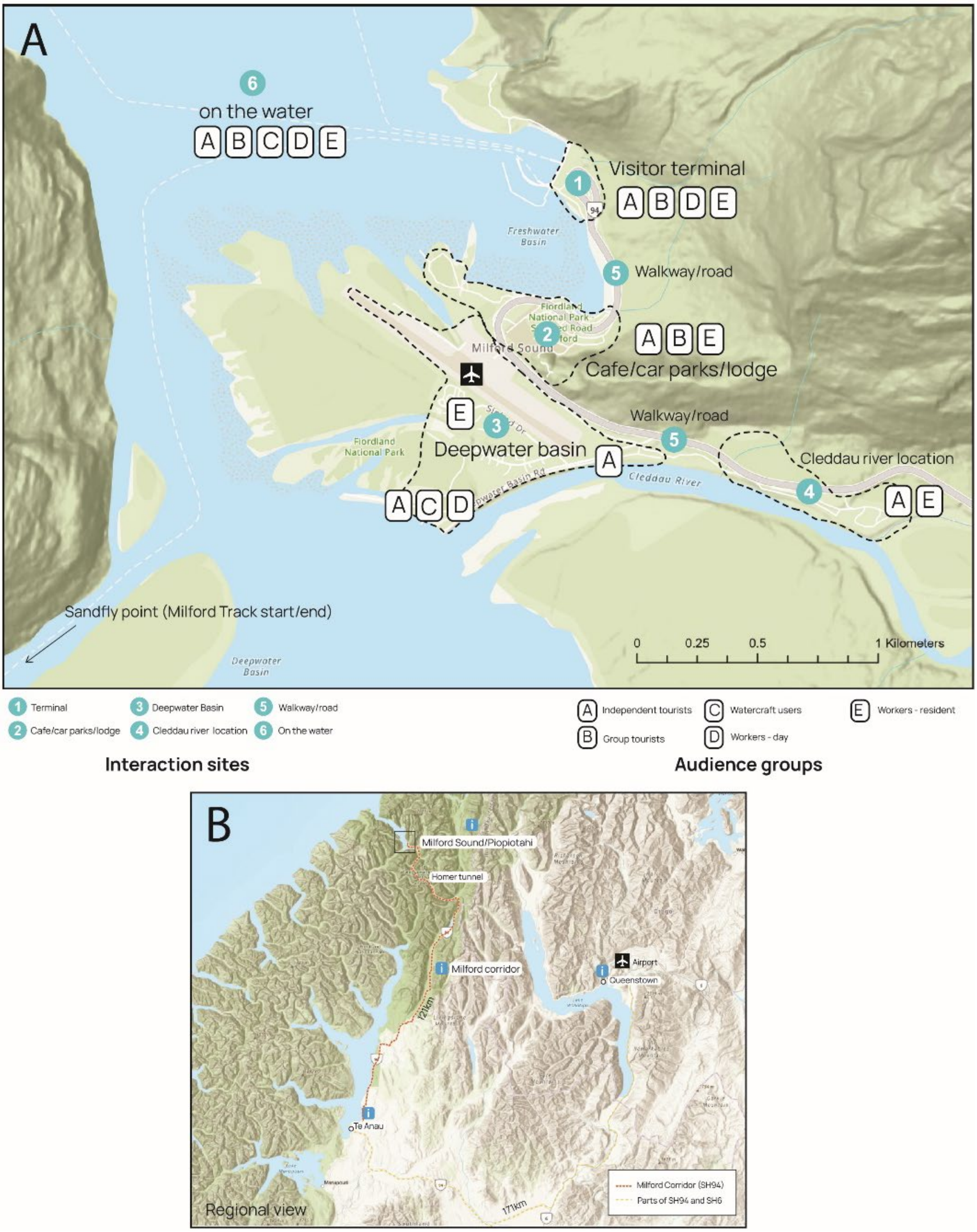

Figure 3.5 Locations of interaction sites and areas where visitor groups are likely to be located. (A) Milford Sound / Piopiotahi. (B) Regional view.

Table 3.5 Description for site 1: visitor terminal and main wharf.

Site 1 Description

Who is likely to be in this location:

- Tourists (Groups A and B): Independent travellers and those within tour groups waiting for and booking boat tours. Tours arrive in the coach drop-off area. People can collect or buy tickets for tours and use the area as a waiting area for tours – they load on and off the boat and wait for a coach. People can also pay for parking here, and there is a large toilet block at the terminal.
- Staff working in the visitor terminal, staff on cruise vessels, the harbour controller, coach drivers and guides, contractors and suppliers.
- The predominant groups are A and B.

Exposure numbers (relative, not exact):

- High numbers of tourists and staff during the day-time. Limited numbers at night. Tourists spend minutes or hours here. Workers could be present for 7–8 hours during the day. Estimated peak visitor concentration: 1000 (Craig and Chinn 2021).

Examples of existing communication:

- Some information on the area and its history (Figure 3.5).
- Emergency-response booklet available at two locations. Not clear that it is publicly accessible (Figure 3.6; middle).
- No natural-hazard and risk communication present.

Potential information spaces:

- Inside and outside visitor centre. Information could also be provided inside toilet cubicles. Could be digital / on a screen. There is lots of wall space inside and outside.

Communication considerations:

- People milling through, therefore opportunity to share information with them (captive audience). Lots of waiting around for tours or coaches.

Potential mitigation options for tsunami*:

- Evacuation to higher ground possible.

Mitigation considerations:

- The building is near steep slopes and trees (Figure 3.6; right). Therefore, rock and tree falls could prevent evacuation. The centre directly faces the Sound with the wharf in front, so there may be debris washing ashore into the buildings. The visitor-centre building is two storeys. It can be very busy during peak times. The water and fiord slopes can be seen directly from here in clear conditions.

*Potential mitigation options are not advice.

Figure 3.6 Site 1: (left) Milford Sound / Piopiotahi visitor terminal; (centre) emergency-response procedures at visitor terminal; (right) environment around Milford Sound / Piopiotahi visitor terminal.

Table 3.6 Description for site 2: car parks, cafe and Mitre Peak Lodge, including lookout track and foreshore walk.

Site 2 Description
Who is likely to be in this location:
• Tourists – independent travellers and those within tour groups (big and small) parking cars or vans (space for 240 cars) and visiting the cafe (Figure 3.7; left). Tourists could also stay at Mitre Peak Lodge (estimated 50 people). Mitre Peak Lodge is seasonal and only open for track walkers during the peak season. Another toilet block is here. There are also two short walks: Lookout Track and the loop walk around the shoreline (small numbers of people).
• Staff working at the cafe and lodge. Workers' accommodation at night for Southern Discoveries (estimated 75–100 people) (five working in lodge).
• The predominant groups are A (day) and E (night).
Exposure numbers (relative, not exact):
• Medium numbers of tourists and staff during the day-time. Workers and tourists at night. Tourists modestly transient, spending variable amounts of time in this area.
Examples of existing communication:
• Information boards in the cafe and along the foreshore walk.
Potential information spaces:
• Inside and outside the cafe for tourists. Inside toilets. Could be digital / on a screen. Lots of wall space inside. Along the loop trail – lots of existing signage (Figure 3.7; right).
• Emergency-response procedures for staff.
• Within tourist and staff accommodation.
Communication considerations:
• Not all visitors will visit this area but some may visit the cafe and stay for longer.
Potential mitigation options for tsunami*:
• Evacuate to Lookout Track point only for people in this area – although it is not suitable for rapid mass evacuation. Track is thin and steep-sided. Not big enough. Not sign-posted from main area.
Mitigation considerations:
• Could have people moving in and out of this area fast. Some people spend a long time at the cafe, whereas some people are only moving through the area and parking. Those rushing could miss signage if this was the only location for it. Water can be seen from here. There are gaps in 4G signal coverage.

*Potential mitigation options are not advice.

Figure 3.7 Site 2: (left) visitor cafe; (right) signage along the foreshore walk.

Table 3.7 Description for site 3: airport, staff accommodation and jetty/wharf at Deepwater Basin.

Site 3 Description
Who is likely to be in this location: • Tourists (A): Independent travellers attending kayak tours and/or parking. Airport users. Milford Track water taxi also departs from here (Figure 3.8; left). • Recreational users and day use, but this is seasonal (C). Commercial fishermen. • Workers (D and E): Staff working at the kayak tour/rental station (not a solid building). Workers at yards and fisheries. Workers' accommodation at night for all other concessions (estimated 200–300 people). • The predominant groups are A and C (day) and E (night). **Exposure numbers (relative, not exact):** • Moderate numbers of tourists are present in this area compared to others, mostly recreational boat users, commercial fisheries staff and tourism staff during the daytime. Resident workers at night. **Examples of existing communication:** • Signage at wharf/jetty. • Emergency-response procedures for staff (booklet) in each room/unit. **Potential information spaces:** • At boat jetty/wharf and car park; potentially clearer signage on the road to higher ground. **Communication considerations:** • Mobile coverage good as a cell tower is in this area. Handheld radio network for staff. **Potential mitigation options for tsunami*:** • Evacuate up and along the road away from the water. Could climb to rooftops; however, the building would need to be assessed for structural integrity. The MSTL area has a ladder for climbing onto the roof (flooding), grab bags, life jackets, torches and a radio in each unit (Figure 3.8; right). However, not all operators do this. **Mitigation considerations:** • The old toilet building may provide some protection. Workers' accommodation could be an option for refuge but this would need to be checked for structural integrity and inundation height. There is a fence around the airport, stopping evacuation across this area. The Fire Emergency New Zealand location is also here – many workers are volunteers. The area is surrounded by water on three sides. River curves around. Water cannot be seen from accommodation but can be seem from other parts of the area. However, these are subject to risk from larger landslide-induced tsunami.

*Potential mitigation options are not advice.

Figure 3.8 Site 3: (left) wharf at Deepwater Basin; (right) example of workers' accommodation/village.

Table 3.8 Description for site 4: Cleddau River location, including waste-transfer station and Milford Sound / Piopiotahi Lodge.

Site 4 Description
Who is likely to be in this location: • Tourists – independent travellers staying at the lodge overnight and visiting the restaurant/bar (A). • Workers at the lodge and waste-transfer station (day and night) (D and E). • The predominant visitor group is A. **Exposure numbers (relative, not exact):** • Low numbers of tourists and workers (compared to other regions). Higher at night. **Examples of existing communication:** • None observed. **Potential information spaces:** • Within hotel rooms. • Worker/staff evacuation procedures. • Clearer signage on road. **Communication considerations:** • Lots of single villas/buildings, with a central reception and restaurant present (Figure 3.9; left). **Potential mitigation options for tsunami*:** • Evacuate up and along the road away from the Sound (Figure 3.9; right). Could climb to rooftops as a last resort. No obvious evacuation route. **Mitigation considerations:** • This location holds a hotel and motorhome. This location is slightly upstream away from the fiord and the bush cover is dense. Craig and Chinn (2021) state that occupants of Milford Sound / Piopiotahi Lodge on the banks of the Cleddau River are protected from the smallest events due to their elevation above 5 m. However, they are subject to risk from larger landslide-induced tsunami. Although slightly higher in elevation than some of the other sites, the lodge and transfer station also have poor lines of sight into the fiord. As these are slightly further back from the water, they may not experience visual clues of tsunami.

*Potential mitigation options are not advice.

Figure 3.9 Site 4: (left) Milford Sound / Piopiotahi Lodge car park; (right) road in and out of the lodge back onto State Highway 94.

Table 3.9 Description for site 5: transit zones, walkways and roads.

Site 5 Description

Who is likely to be in this location:

- All – mostly tourists and workers walking between locations and operating their cars.
- The predominant visitor group is A.

Exposure numbers (relative, not exact):

- Low in most areas, except between the car park and visitor centre. Cars cannot go from car parks to the visitor centre – coaches only.

Examples of existing communication:

- Information signage on various environmental topics.
- Maps of the area.

Potential information spaces:

- Walkways – people walk fast, but some signage is already in the area (Figure 3.10).
- Mobile coverage intermittent – 4G.
- Radio network.

Communication considerations:

- Easy-to-read signage could be useful here.
- Add any new detail onto existing maps.

Potential mitigation options for tsunami*:

- Evacuate to higher ground closest to current location. This could be variable.

Mitigation considerations:

- Some tourists rush through this area, some do not. The walkways are next to the road, so people could travel along the road if needed. The water cannot be seen all of the time except further back along the road. It is not always clear what direction the water is. Roads and paths can be damaged and blocked in a large earthquake.

*Potential mitigation options are not advice.

Figure 3.10 Site 5: (left) covered walkway to visitor terminal; (right) information signage on walkway near the cafe.

Table 3.10 Description for site 6: on the water.

Site 6 Description
Who is likely to be in this location: • Tourists on boats and cruises (Figure 3.11; left) – some cruises stay out overnight in the Sound. Tourists on kayaks. Tourists travelling by boat to Sandfly Point (the start/finish of the Milford Track) (Groups A and B). • Recreational boaters and commercial fisherman (Group C and D). • Workers on boats and with kayakers (Groups D and E).
Exposure numbers (relative, not exact): • During peak times (11:00 am – 3:00 pm), there are estimated to be 2000–2500 people in total at one time during the peak season. It is difficult to estimate numbers of recreational watercraft users, so they are not accounted for. If cruise ships are in the water, the number will be considerably higher.
Examples of existing communication: • On boat signage.
Potential information spaces: • Harbourmaster alerting system through the radio network. • On boats and spoken by guides. • Emergency procedures are currently available for staff.
Communication considerations: • Integrity of the radio network and wharf after a large earthquake.
Potential mitigation options for tsunami*: • Limited. The existing advice from NEMA is not appropriate for this situation; the advice for boat users in response to an ocean-source tsunami (head to deeper water) may not be applicable in the narrow sounds. However, advice for turning boats perpendicular to the tsunami could still be somewhat useful for communication.
Mitigation considerations: • In clear and calm conditions, this group may be the first to see and experience landside tsunami hazard (Figure 3.11; right).

*Potential mitigation options are not advice.

Figure 3.11 Site 6: (left) cruises waiting to depart; (right) heading out from the wharf past the jetty.

3.5 Natural-Hazard and Risk Communication: Audience Summary

This section describes the 'who', 'how', 'where' and 'when' related to natural-hazard and risk communication at Milford Sound / Piopiotahi. People at Milford Sound / Piopiotahi fall into five groups: independent tourists, group tourists, boat/watercraft users, day-commuting workers and resident overnight workers. These audience groups vary significantly in risk perception, natural-hazard awareness, language preferences and accessibility needs. Visitor and worker journeys involve key decisions at various steps (consideration, booking/planning, travel and on-site experience), which are all potentially influenced by natural-hazard and risk information. Recreational visitors could seek information on Milford Sound / Piopiotahi online and at visitor centres, while on-site information is available at six main locations, including the visitor terminal, cafe and accommodation buildings (lodges). Workers will likely not access the same information at the same places compared to tourists. Workers could interact with information within their employee contracts, onboarding material, at their staff induction and/or at their staff accommodation.

Visitor and worker demographics vary by location and time of day, with resident workers having the longest on-site exposure. Effective natural-hazard communication requires targeted messaging tailored to each group's common locations, as well as broader information online and outside Milford Sound / Piopiotahi. The Milford Corridor (SH 94) is a key access point for nearly all who visit or work in the region, which could be used to leverage communication efforts. Although generalisations have been made, it is important to recognise that individuals will have their own awareness and tolerances to individual risk.

4.0 Stage 3: Communication Advice for Landslide-Induced Tsunami Hazard and Risk

Risk communication aims to inform at-risk populations about the likelihood and potential consequences of natural hazards, while also encouraging them to take steps to reduce their risk and improve their safety (Paton 2006; Gstaettner et al. 2020). Part of good-practise natural-hazard and risk communication is ensuring that the content and key messages are conveyed via a variety of means (e.g. text, visual) that are fit for purpose for both the context and the audience. Here, we bring together the information summarised in Stage 1 with the audience characteristics in Stage 2 to create simple key messages / content that could be used by the Milford Sound Stakeholder Group in its future communication products (Section 4.1; Table 4.1). The information presented in Table 4.1 is supported by information on natural-hazard and risk probabilities and comparisons, considerations for general communication and specific mitigation advice (Sections 4.2 and 4.3). These considerations are informed by global good practise and expert experience in creating natural-hazard and risk communication products both in Aotearoa New Zealand and overseas. This section concludes with a series of examples that could be adapted for the Milford Sound / Piopiotahi context and used in the future (Appendix 3).

4.1 Natural-Hazard, Risk and Mitigation Messages

A suite of key messages is presented in Table 4.1, based on current knowledge of the natural-hazard and risk posed by coseismic landslide-induced tsunami in Milford Sound / Piopiotahi, summarised in Stage 1 (Table 2.2). The messages are based on current understanding of hazard and risk in the region. Hazard-intensity values, risk metrics and associated messaging should be updated as scientific understanding evolves. We advise that these messages are stronger when presented together as a narrative or a story. This may also help when new information is available, and updated advice needs to be communicated. However, there may also be occasions where only a short message could be possible. In these cases, the priority messages in Table 4.1 should be shared as a minimum. We recommend that these are used as a consistent foundation for all communication materials related to this natural hazard in the region. Examples of short- and long-form messages are shown in Appendix 3.

Table 4.1 Suggested natural-hazard/risk and mitigation messages identified by this study. Ticks under each step represent where this message could be used. Audience groups are (A) independent tourists, (B) group tourists, (C) local watercraft users, (D) workers: day (E) workers: night. Priority messages are crucial to communicate if only a small amount of text can be used on a product. * = similar messages tailored slightly differently for different audiences. For more information and detail on tsunami action messages, please see: https://www.civildefence.govt.nz/cdem-sector/consistent-messages/tsunami/response-what-to-do-during-a-tsunami

Priority Message	Natural-Hazard/Risk and Mitigation Messages	Reasoning/ Commentary	Steps				Audience Groups
			1 Consideration	2 Booking	3 Travelling	4 At Milford Sound / Piopiotahi	
General Natural-Hazard and Risk Information							
-	*Milford Sound / Piopiotahi is a dynamic and changing environment. Its beautiful landscape was created by powerful geological forces that continue to shape the landscape we see today.*	Positive environmental message about the changing environment. Hazards are not always negative.	✓	✓	✓	✓	All
-	*Earthquakes, landslides, rockfall, tsunami, avalanche and severe weather are all dangerous natural hazards that can happen in Milford Sound / Piopiotahi.*	Awareness of all natural hazards at Milford Sound / Piopiotahi.	✓	✓	✓	✓	All
Yes	***Earthquakes, landslides and landslide-generated tsunami have all occurred in Milford Sound's past. These natural hazards can occur again at any time, without warning.***	**Sense of urgency and unpredictability – similar to Tongariro National Park messaging.**	✓	✓	-	✓	All
Yes	***These natural events can devastate infrastructure and the environment, and they pose a serious risk to life to anyone in the area.***	**Connecting to impact and risk.**	✓	✓	-	✓	All
Yes	***It is extremely unlikely that an event could happen while you are at Milford Sound / Piopiotahi, especially for a short stay. However, there is still a risk.***	Likelihood.	✓	✓	-	✓	A, B, C
Yes*	*During a three-hour visit to Milford Sound / Piopiotahi, there is a 1 in 500,000 chance that a life-threatening tsunami caused by an Alpine Fault earthquake-generated landslide could happen. The risk of death is roughly similar to that of doing a Great Walk in New Zealand or driving to a New Zealand National Park.*	Short-visit comparison.	✓	✓	-	-	A, B and C

Priority Message	Natural-Hazard/Risk and Mitigation Messages	Reasoning/ Commentary	Steps				Audience Groups
			1 Consideration	2 Booking	3 Travelling	4 At Milford Sound / Piopiotahi	
-	*During a one-day visit to Milford Sound / Piopiotahi, there is a 1 in 50,000 chance that a life-threatening tsunami caused by an Alpine Fault earthquake-generated landslide could happen. The risk of death is roughly similar to that of a typical mountaineering activity (e.g. rock climbing).*	Day-visit comparison.	✓	✓	-	-	C, D and E
Yes*	*If you spend a month in Milford Sound / Piopiotahi, there is a 1 in 1800 chance that a life-threatening tsunami caused by an Alpine Fault earthquake-generated landslide could happen. The risk of death is 20 times the rate of death of working in the mining sector.* *If you spend a year in Milford Sound / Piopiotahi, there is a 1 in 150 chance that a life-threatening tsunami caused by an Alpine Fault earthquake-generated landslide could happen. The risk of death is 20 times the rate of death among registered motorcycle owners in Aotearoa New Zealand.*	Longer-term-stay comparison. Not needed for tourists.	✓	✓	-	-	D and E
Yes	***These hazards pose a risk to life in Milford Sound / Piopiotahi. If you choose to visit or work in the area, you cannot avoid all of the risk entirely.***	**Cannot avoid the risk if you visit Milford Sound / Piopiotahi. Linked to decision-making.** **Repeated key message.**	✓	✓	✓	✓	All
Yes*	***The longer you spend at Milford Sound / Piopiotahi, the higher the risk is.***	**The longer the time, the greater the risk. Conveys that time spent in the area is a component of risk.**	✓	✓	✓	✓	A, B and C
Yes*	***With each passing day and night spent in Milford Sound / Piopiotahi, and as time elapses without a significant earthquake on the Alpine Fault, the potential for experiencing earthquakes, landslides and landslide-generated tsunami slightly increases.***	**Workers' message: the longer the time, the greater the risk. Conveys that time spent in the area is a component of risk.**	✓	-	-	✓	D and E

Priority Message	Natural-Hazard/Risk and Mitigation Messages	Reasoning/ Commentary	Steps				Audience Groups
			1 Consideration	2 Booking	3 Travelling	4 At Milford Sound / Piopiotahi	
Earthquakes, Landslides and Cascading Hazards							
-	*Milford Sound / Piopiotahi is a seismically active area. The main sources of earthquakes include the offshore Puysegur subduction zone and the Alpine Fault.*	Milford Sound / Piopiotahi has earthquakes.	✓	✓	✓	✓	All
-	*The Alpine Fault is a major fault that runs along the western side of New Zealand's South Island. It is about 600 kilometres long and marks the boundary between the Pacific and Australian tectonic plates. Research shows that there is a 75% probability of a large Alpine Fault earthquake occurring in the next 50 years . To learn more about the Alpine Fault, check out the AF8 website.* [https://af8.org.nz/]	High probability of earthquakes in the region – most likely from Alpine Fault. Links to wider AF8 programme for more information.	✓	✓	-	✓	All
-	*An Alpine Fault earthquake of M8+ could rupture several hundred kilometres of the earth, causing extensive strong shaking across regions of the South Island of Aotearoa New Zealand that could damage buildings and infrastructure.*	Context of large magnitude and wide impacts.	✓	✓	-	-	All
Yes	*Large earthquakes can also trigger landslides and rockfall on Milford Sound / Piopiotahi's steep slopes. Both earthquakes and landslides can be destructive and dangerous; they can cause injury and death.*	Earthquakes can cause slope failures – there is potential for injury here too.	✓	✓	-	✓	All
Yes	*Landslides can sometimes fall into the water in Milford Sound / Piopiotahi and cause a tsunami. The tsunami is expected to travel very fast.*	Awareness of landslide-induced tsunami.	✓	✓	✓	✓	All
Tsunami: Landslide-Induced and Other Sources							
-	*New Zealand's entire coastline (including Milford Sound / Piopiotahi) is exposed to tsunami hazard.*	Bringing back to wider risk acceptance	✓	✓	✓	✓	All

Priority Message	Natural-Hazard/Risk and Mitigation Messages	Reasoning/ Commentary	Steps				Audience Groups
			1 Consideration	2 Booking	3 Travelling	4 At Milford Sound / Piopiotahi	
-	*Landslide-generated tsunami are a serious concern for Milford Sound / Piopiotahi, Ongoing research is crucial to better understand and prepare for future events.*	Emphasising that research is needed.	✓	✓	-	✓	All
Yes	***Tsunami are not like other water waves or floods. They are turbulent, fast-travelling and could contain debris. There can be multiple waves, and the first wave may not be the biggest. They can cause death by drowning and injury.***	**Tsunami are not like floods. Unlikely to survive.**	✓	✓	-	✓	All
-	*The arrival time of a tsunami depends on where a landslide enters the water. The closer a landslide is to Milford Village, the quicker a tsunami could arrive.*	Some uncertainty around the size and timing.	✓	✓	-	✓	All
-	*Science suggests that large landslides have occurred in the past, triggering large tsunami that reached Milford Village.*	Links to the past and history.	✓	✓	-	✓	All
-	*Approximately 26 landslide-generated tsunami have occurred in the last 17,000 years since the glaciers receded from the fiord.*	Frequency and history.	✓	✓	-	✓	All
-	*Tsunami caused by landslides have happened in other parts of the world such as Greenland, Alaska, Canada and Norway.*	Connections with other parts of the world.	✓	✓	-	✓	All
Warning Signs and Risk Mitigation, including Evacuation							
-	*There is no way to predict earthquakes or whether an earthquake-generated landslide will cause a tsunami.*	No prediction possible.	✓	✓	-	✓	All
-	*Scientists estimate that there is a 44% chance that a future Alpine Fault earthquake will cause a tsunami in Milford Sound / Piopiotahi.*	History and likelihood. This is conditional upon an earthquake happening.	✓	✓	-	✓	All

Priority Message	Natural-Hazard/Risk and Mitigation Messages	Reasoning/ Commentary	Steps				Audience Groups
			1 Consideration	2 Booking	3 Travelling	4 At Milford Sound / Piopiotahi	
Yes	***You will not receive an official warning if a landslide-generated tsunami occurs; it will happen too quickly.***	**Limited warning time – no official warning.**	✓	✓	-	✓	All
-	*Depending on where a landslide happens it could take between 1 and 7 minutes for a triggered tsunami to reach the Milford Village area.*	Limited warning time.	✓	✓	-	✓	All
-	*The geography of Milford Sound / Piopiotahi, with its busy, narrow roads, paths, and steep slopes, makes evacuation challenging. However, there are actions you can take to protect yourself if a tsunami happens.*	Providing the individual with some options for protective actions.	✓	✓	-	✓	All
Yes	***If you are near a shore, you need to act immediately if you experience any of the following:*** • ***Feel a strong earthquake that makes it hard to stand or a long earthquake that lasts more than a minute.*** • ***See a sudden rise or fall in water level, or unusual waves or water behaviour without an obvious cause.*** • ***See or hear signs of landslides or rock falls into the water.*** • ***Hear loud or unusual noises from the water or surrounding area.*** ***Do not wait for official warnings. Move immediately to the nearest high ground or as far inland as possible.***	**Adapted NEMA messaging. Providing information on environmental cues – reminder at all steps.**	✓	✓	✓	✓	All
Yes	***Remember: Long or Strong, Get Gone.***	**National messaging reminder.**	✓	✓	✓	✓	All
Yes	***Don't delay: move uphill or inland as soon as possible. Every metre gained can increase your chance of survival. Every minute counts.***	**Positive self-efficacy.**	-	-	-	✓	All

Priority Message	Natural-Hazard/Risk and Mitigation Messages	Reasoning/ Commentary	Steps				Audience Groups
			1 Consideration	2 Booking	3 Travelling	4 At Milford Sound / Piopiotahi	
-	*If evacuation is impossible, go to the higher floor of a building or climb a tree. This should only be used as a last resort.*	Last-resort message.	-	-	-	✓	All
	If you are tied up at a dock, leave your boat and move immediately uphill or inland.	Action message – moored boats.	-	-	-	-	C, D and E
-	*If you are on the water, listen to the instructions of your crew or the harbourmaster.*	Action message.	-	-	-	✓	All
-	*If you are alone on the water and can reach shore before the tsunami, head uphill or inland.*	Last-resort message.	-	-	-	✓	A, C, D and E
-	*If you are on a vessel in shallow water and do not think you can disembark and evacuate (on foot) to high ground quickly enough, stay inside the boat, secure your lifejacket and grab on to something that floats.*	Action message – boats.	-	-	-	✓	C, D and E
-	*If you are on a vessel in deep water and see a tsunami wave approaching, point the bow towards the main wave and prepare for refracting wave movements. If you see the landslide and tsunami initiate inland of where you are and clear of the mouth of the fiord, exit the fiord to the sea as soon as possible. You may be at sea for many hours.*	Action message – boats. Guidance for Harbourmaster.	-	-	-	✓	C, D and E
-	*If you are on a vessel, your risk of being directly impacted by a rockfall or landslide increases the closer you are to the fiord walls.*	Risk message.	-	-	-	✓	C, D and E
-	*Observe your surroundings, noting your orientation from the sea and identifying the nearest high ground.*	Environmental awareness – active voice noting reader could do this at any time.	-	-	-	✓	A, B, C and D
-	*Practise drills for evacuating your accommodation or place of work.*	Regular drills for evacuating outside.	-	-	-	✓	D

Priority Message	Natural-Hazard/Risk and Mitigation Messages	Reasoning/ Commentary	Steps				Audience Groups
			1 Consideration	2 Booking	3 Travelling	4 At Milford Sound / Piopiotahi	
Yes	***For more information on this risk and what to do, visit:*** **[link to further information]**	**Connects to more information if needed. People may want more information.**	✓	✓	✓	✓	All
-	*Milford Sound / Piopiotahi is a special place – knowing what to do when you recognise natural warning signs can reduce your risk from earthquakes, landslides and tsunami, and play a role in keeping others safe.*	Wrapping up with a positive message.	✓	✓	-	✓	All

4.1.1 Natural-Hazard and Risk Values and Comparisons

As noted in Section 2.3.1, the risk metrics available in the existing literature are no longer considered reliable due to known increases in the seismic hazard (i.e. probability of an Alpine Fault rupture) and increased population exposure (i.e. more annual visitors to Milford Sound / Piopiotahi). The previous estimates of tsunami height and run-up height used in these risk metrics are also considered to be an oversimplification of the tsunami hazard, which needs to be refined using modern approaches that include hydrodynamic modelling and updated bathymetry and LiDAR. It is not possible to re-calculate accurate risk metrics until a new risk assessment is carried out. However, we acknowledge that communicating the degree or level of hazard and risk may enhance the efficacy and prioritisation of communication efforts for some audiences. We therefore describe how the published values can be modified to create a more representative approximation of the hazard and risk to support interim communication efforts until further risk assessment and refinement of these values is completed. We emphasise that these approximations are rough estimates and based on several assumptions.

4.1.1.1 Approximate Probability of a Coseismic Landslide-Induced Tsunami

Using published values for the annual probability of an Alpine Fault earthquake ($P_{(AF)}$) and the probability of a large landslide entering the fiord in a future Alpine Fault event ($P_{(LT)}$), a basic approximation of the probability of an Alpine Fault coseismic landslide-induced tsunami occurring in Milford Sound / Piopiotahi/ ($P_{(T)}$) can be estimated over time:

$$P_{(T)} = P_{(AF)} \, x \, P_{(LT)}$$

Using the published values from Table 4.2, the annual $P_{(T)}$ value can be calculated and then divided to consider the hazard probability over time. Table 4.3 summarises the resulting approximate probabilities of an Alpine Fault coseismic landslide-induced tsunami over different potential exposure times of visitors and workers. Note that there is a wide variation of hours spent at Milford Sound / Piopiotahi by employees due to of different hours of work, days, rostering, seasonality and annual leave. We have included many options in Table 4.3 to reflect this diversity in exposure time.

Table 4.2 Published value of separate natural-hazard probabilities (Howarth et al. 2021; Taig and McSaveney 2015). *P* = probability.

Variable	*P*	Source
Probability of a central section Alpine Fault earthquake in the next 50 years	0.75	Howarth et al. (2021)
$P_{(AF)}$: Probability of an Alpine Fault earthquake in the next year	0.015	Howarth et al. (2021)
$P_{(LT)}$: Probability that, were a landslide to occur, this would fall into a body of water and generate a tsunami	0.44	Taig and McSaveney (2015)

Table 4.3 Approximate probability of an Alpine Fault coseismic landslide-induced tsunami. Note that some of the natural frequencies are rounded down to the nearest 1000.

Time Window	$P_{(T)}$	Percent	Natural Frequency
Per 3 hours	2.3×10^{-6}	0.00023%	1 in 500,000
Per 12 hours	9.0×10^{-6}	0.0009%	1 in 110,000
Per 24 hours	1.8×10^{-5}	0.002%	1 in 50,000
Per 48 hours	3.6×10^{-5}	0.004%	1 in 25,000
Worker option 1^: 730 hours (1 month night/day stay)	5.5×10^{-4}	0.06%	1 in 1800
Worker option 2^: 2185 hours (1 week on and 1 week off over 6 months)	1.6×10^{-3}	0.16%	1 in 600
Worker option 3*: Per 80% of the year (7012 hours)	5.3×10^{-3}	0.53%	1 in 190
Per year (8760 hours)	6.6×10^{-3}	0.66%	1 in 150

* To align with staff exposure discussed in Craig and Chinn (2021); see Section 2.3.

^ Requested by MSTL to reflect a more accurate staff-exposure time.

Although there are inherent uncertainties in the $P_{(AF)}$ and $P_{(LT)}$ values used (Howarth et al. 2021; Taig and McSaveney 2015), these high-level approximations of the hazard, particularly the natural frequency values, can be used to indicate the general likelihood of this life-threatening event happening when visiting or working in Milford Sound / Piopiotahi. It is important to note that the approximate probabilities in Table 4.3 will slightly increase with time until the Alpine Fault ruptures, which means that these values should be re-evaluated over time. For example, the probability 25 years from now will be slightly higher than today's approximation if there has not been an Alpine Fault earthquake between 2025 and 2050. These probabilities also do not capture the hazard from a non-Alpine Fault triggering event.

4.1.1.2 Approximate Risk Metrics

Taig and McSaveney (2015) present a range of different risk metrics, described in Section 2.3. For their calculations, Taig and McSaveney (2015) use a 27% chance of an Alpine Fault rupture in the next 50 years, or probability of 0.0054 per year, as the hazard value. Today, the expected probability of an Alpine Fault earthquake is 75% in the next 50 years, or 0.015 per year (Table 4.2). This new hazard value is 2.8 times higher (0.0015/0.0054) than that used in the Taig and McSaveney (2015) risk calculations. In the risk equation provided by Taig and McSaveney (2015), risk of death ($R_{(D)}$) is proportional to this hazard frequency ($P_{(H)}$):

$$R_{(D)} = P_{(H)} \times P_{(S:H)} \times P_{(T:S)} \times V_{(D:T)}$$

where ($P_{(S:H)}$) is the probability of the tsunami reaching a certain location, ($P_{(T:S)}$) is the probability that a person is present at the location when the tsunami reaches it, and ($V_{(D:T)}$) is the vulnerability of that person to dying from a tsunami. Accordingly, risk metrics provided by Taig and McSaveney (2015) can be modified by multiplying the values by 2.777. Using this simplified approach, risk metrics increase almost threefold:

- **For day visitors**, the upper estimate of risk of death from landslide-induced tsunami per visit increases from 2.7×10^{-7} to 7.5×10^{-7}.
- **For overnight lodge visitors**, the upper estimate of risk of death from landslide-induced tsunami per overnight visit increases from 1.5×10^{-6} to 4.2×10^{-6}.
- **For onshore staff**, the upper estimate of annual fatality risk increases from 5.5×10^{-4} to 1.5×10^{-3}, which increases the AGS risk-zone descriptor (Table 4.6) from 'high' to 'very high'.

A full modification of the risk metrics presented in Taig and McSaveney (2015) is presented in Table 4.4. We do not advise using these specific numbers for communication to the general public but provide them as a potential resource to support considerations regarding the need for further risk assessments and the prioritisation of communication plans. When considering the 2.8x increase in hazard alone, the indicative annual fatality risk for workers increases from ‘high’ to ‘very high’ based on the AGS risk-zone descriptors (Table 4.6). Using the DOC risk thresholds for natural-hazard risk management (Table 4.5; DOC 2022), the modified ‘day visitor’ fatality risk falls within the zone of risk reduction required to “reduce to as low as reasonably practicable”. For overnight visitors, ‘overnight lodge’ sits within the risk reduction required for the ‘Continue only after high level review’ category.

These estimates should be used with caution and are not the focus of this study , as other components of the risk equation also need to be re-evaluated. The models used in previous work are simplified and, in comparison to modern numerical-modelling techniques, do not include current-state-of-practise tsunami modelling. Using hydrodynamic models and high-resolution topography will improve/change understanding of the probability of the tsunami reaching a certain location ($P_{(S:H)}$), as well as the inundation depths and velocity that define the probability of a person being killed if caught in a tsunami ($V_{(D:T)}$). This is considered the minimum standard for tsunami modelling. It is possible that there could be localised variability in the inundation and run-up hazard onshore such that some options for escape and/or mitigation may be found for Milford Village, but this can only be confirmed through future modelling. However, buildings at low elevation immediately adjacent to the coast are the most exposed to any tsunami risk, and it is unlikely that a revised risk assessment using hydrodynamic-based assessment will ultimately show zero risk at these locations.

4.1.1.3 Risk Comparison

While we advise caution in any application and communication of the modified risk metrics presented in Table 4.4 due to the high uncertainties associated with these values, the overall increase in risk and the corresponding risk levels in Tables 4.5 and 4.6 underscore the importance of communicating potential risk levels to those who are choosing to visit or work in Milford Sound / Piopiotahi.

When lives are at stake, it is best to be conservative in the face of large uncertainty. Therefore, as an alternative to communicating the modified risk metrics in Table 4.4, a conservative approach can be taken to communicate risk, based on assuming a vulnerability of 1.0 (i.e. 100% probability that a tsunami will result in death), alongside the values presented in Table 4.3. Using this approach, the hazard values from Table 4.3 can be considered conservative risk-of-death values that can be used to communicate comparative risk associated with other activities that may be familiar to these audiences (Taig 2022) (Table 4.7). Risk comparisons can be a useful tool for communicating unfamiliar risks, as these can help place it in perspective with more familiar or known risks to the audience (Roth et al. 1990). However, as with the hazard values these are based on, they do not consider the risk of death from other potential hazards that may occur simultaneously, such as the landslide, rockfall or ground-shaking, and they do not consider the risk of death from other seismic sources.

Table 4.4 Selected risk metrics from Taig and McSaveney (2015), and the same values multiped by 2.777 to reflect the increased Alpine Fault rupture-probability hazard. Note: these updated estimates should be used with caution, as other components of the risk equation also need to be re-evaluated. The models used in previous work are a simplified comparison to modern numerical-modelling techniques and do not include current-state-of-practice tsunami modelling. We do not suggest that the Milford Sound Stakeholder Group use these multiplied numbers for public communication at this stage. AIFR = annual individual fatality risk.

Value	Estimate	AIFR		Risk per Visit			Societal Risk (≥100 fatalities)		
		Shore Staff	Boat Staff	Day Trip	Overnight at Lodge	Overnight on Boat	Staff and Visitor	Staff	Visitor
Taig and McSaveney (2015)	Lower [2]	1.50×10^{-4}	1.40×10^{-4}	7.90×10^{-8}	4.00×10^{-7}	3.00×10^{-7}	2.90×10^{-4}	1.20×10^{-4}	1.80×10^{-4}
	Upper [3]	5.50×10^{-4}	5.20×10^{-4}	2.70×10^{-7}	1.50×10^{-6}	1.10×10^{-6}	$9.20 X 10^{-4}$	5.90×10^{-4}	6.40×10^{-4}
2.777x Alpine Fault hazard [1] increase factor	Lower [2]	4.17×10^{-4}	3.89×10^{-4}	2.19×10^{-7}	1.11×10^{-6}	8.33×10^{-7}	8.05×10^{-4}	3.33×10^{-4}	5.00×10^{-4}
	Upper [3]	1.53×10^{-3}	1.44×10^{-3}	7.50×10^{-7}	4.17×10^{-6}	3.05×10^{-6}	2.55×10^{-3}	1.64×10^{-3}	1.78×10^{-3}

[1] Accounts for a 2.777 increase in Alpine Fault rupture probability (P = 0.015 per year).

[2] Loenvann attenuation applied (modelled with more rapid attenuation, based on an event in Norway in 1936).

[3] Three Gorges Reservoir attenuation applied (modelled with slower rate of attenuation, based on an event in China in 2008).

Table 4.5 Department of Conservation risk thresholds for natural-hazard risk management for a lower risk-tolerance visitor site (DOC 2022).

Risk Level	Fatality Risk (1 trip/day)	Level of Risk-Reduction Response Required
Extreme	$>1.0 \times 10^{-4}$	Close the site
High	$1.0 \times 10^{-5} – 1.0 \times 10^{-4}$	Close the site
Substantial	$1.0 \times 10^{-6} – 1.0 \times 10^{-5}$	Continue only after high-level review
Moderate	$1.0 \times 10^{-7} – 1.0 \times 10^{-6}$	Reduce to as low as reasonably practicable
Low	$<1.0 \times 10^{-7}$	No risk reduction required (beyond standard measures) but monitor for changes

Table 4.6 Australian Geomechanics Society descriptors for risk zoning using life-loss criteria (AGS 2007).

Risk-Zone Descriptor	Annual Individual Fatality Rate
Very High	$>1.0 \times 10^{-3}$
High	$1.0 \times 10^{-4} – 1.0 \times 10^{-3}$
Moderate	$1.0 \times 10^{-5} – 1.0 \times 10^{-4}$
Low	$1.0 \times 10^{-6} – 1.0 \times 10^{-5}$
Very Low	$<1.0 \times 10^{-6}$

Table 4.7 Conservative-approach risk comparisons using hazard-probability data from Table 4.3 and assuming a vulnerability of 1.0.

Chance of a Landslide-Induced Tsunami Triggered from an Alpine Fault Event	Fatality Risk Comparisons
During a three-hour visit to Milford Sound / Piopiotahi is roughly 1 in 500,000	• Similar to the risk of death on a Great Walk in Aotearoa New Zealand [1] • Similar to the risk of death while driving to an Aotearoa New Zealand national park [1]
Within a 24-hour visit is roughly 1 in 50,000	Similar to the risk of death during a typical mountaineering/ climbing activity [1]
During a one-month stay is roughly 1 in 1800	Three times higher than the annual risk of death from working in the mining sector [1]
During a roster of one week on and one week off over six months is roughly 1 in 600	Eight times higher than the annual risk of death from working in the mining sector [1]
During an up-to-one-year continual stay is roughly 1 in 150	• Similar to the risk of death on a single ascent of Mount Everest [1,2] • Around twenty times more than the rate of death per registered motorcycle [3]

[1] From Taig (2022) – Great Walk maximum (2 standard deviations): 3×10^{-5}; driving to a National Park maximum (2 standard deviations): 10^{-5}; mountaineering/climbing activity (2 standard deviations): 2×10^{-5}; mining sector maximum (2 standard deviations): 2×10^{-4}; single ascent of Mount Everest (2 standard deviations): 5×10^{-3} to 10^{-2}.

[2] Note that this compares an annual risk to a risk associated with the duration of a one-off activity; however, it has been chosen for its likely familiarity among audiences – the motorcycle rate of death is a more valid comparison timeframe but may be less familiar to some audiences.

[3] From the Ministry of Transport (c2020) – 56 deaths in 2023 out of 183,493 registered motorcycles in Aotearoa New Zealand (0.03% or 3×10^{-4}).

While risk comparisons can be useful for natural-hazard risk communication (Savadori et al. 2022), many authors also urge that risk comparisons should be very carefully chosen, as these can also have unintended or undesired effects on risk perception, acceptance and trust (Covello et al. 1988; Slovic et al. 1990; Johnson 2004; Visschers et al. 2009). Collectively, this body of work recommends that chosen risk comparisons are tested or consulted on with audiences to account for pertinent relationships between communicator intentions and audience needs. We advise testing any comparative risk messages with audiences to ensure clarity and consistency of message. We also support the advice provided by Taig (2022) to avoid, where practicable, presenting risk (or hazard occurrence) as a single number and instead presenting it as a graphic that illustrates the range of uncertainty associated with the estimates. Updated natural-hazard and risk messaging will help inform new and potentially better risk comparisons. While we are not able to present a range for the values in Table 4.3 within the scope of this report, we have provided simple comparative risk messaging in Table 4.1 that could support communication regarding the degree or level of risk. Icon arrays can be an effective visual method used to communicate likelihoods, especially the risk of something negative happening (Fansher et al. 2022).

4.1.2 Steps 1 and 2: Communication at the 'Considering' and 'Booking' Steps (Pre-Trip Communication)

Milford Sound / Piopiotahi is an extremely popular tourist destination in Aotearoa New Zealand. Many people consider visiting the region due to its scenery, unspoiled environment and range of outdoor activities. Previous work indicates that, in general, it is important that tourists are aware of and properly prepared for the natural hazards they could face during their travels and that they possess the capacity to recognise the warning signs of natural-hazard events and understand the appropriate way to respond (Drabek 2000; Bird and Gisladóttir 2020). While tourism managers may find it challenging to alter these factors, they can potentially improve tourist preparedness by using effective risk communication messages and strategies. This should be done *before* tourists are exposed to a potential natural hazard (Cui et al. 2023).

At the consideration step, individuals decide whether Milford Sound / Piopiotahi is a place they intend to visit or work. Once a decision has been made to visit Milford Sound / Piopiotahi, visitors search, plan and book their trip. Not all groups will experience these steps in the same way, and some may not undertake these steps at all. We have grouped both consideration and booking as one here, as these can happen quite closely spaced in time and both happen before travelling to the region.

In terms of considering natural-hazard and risk communication at these steps, some individuals may already seek natural-hazard and risk information (for example, an Aotearoa New Zealand resident with prior experience or high awareness of tsunami or of the risks associated with mountainous terrain). However, we assume that most visitors would either be completely unaware that the area is exposed to natural hazard and risks or would have a general awareness that earthquakes could happen in the region but not link those with landslide-induced tsunami. Overall, we assume that information about the tsunami hazard and risk in Milford Sound / Piopiotahi could come as a surprise to many visitors (especially international visitors), but further work is needed to understand baseline levels of risk perception. To reach a broad audience with potentially low levels of risk awareness, we recommend that risk information is provided in a clear and simple way while still providing enough information to inform their decision-making. Where appropriate, priority messages could be translated into different languages to increase reach and accessibility of the information. Risk comparisons could be presented visually (Taig 2022).

The main aim at this step is to communicate that there are hazards present at Milford Sound / Piopiotahi and that these hazards can cause loss of life and injury. Visitors and workers should also be made aware that, once they are at Milford Sound / Piopiotahi, they cannot avoid the risk. The longer someone spends in the area, the more the risk increases. Further information should be provided on the hazard, risk and potential mitigation options if an event were to occur. However, more emphasis should be placed on natural-hazard and risk information at this step rather than mitigation. Hazard-risk comparisons could be used at these stages to help with understanding and decision-making.

An overview of information by step and audience is shown in Figure 4.1. Examples of what could be shared at the pre-arrival steps are shown in Appendix 3.1.

Some potential product and channel ideas include:

- Key natural-hazard and risk messaging on websites.
- Key risk messaging on ticket or booking confirmation.
- Key natural-hazard and risk messaging at physical tourist visitor sites, transport hubs and accommodation.
- Messages could be provided in brochures available at most locations.
- Visual infographics, posters or videos could be utilised.
- Tourist agents could also be provided and trained with the necessary information to convey any key messages and answer questions. This will also inform their own decision-making if they are travelling with a tour group.

Once information has been *shared, seen* and *understood*, an individual can either choose not to visit due to the risk being deemed unacceptable, or they can choose to visit accepting that there are risks. Feedback and testing is advised where possible to ensure clarity of messages and consistent comprehension.

4.1.3 Steps 3 and 4: Communication while Travelling and On-Site

Visitors in Groups A–C, having already invested significant time and money in their journey to Milford Sound / Piopiotahi, are unlikely to change their plans upon learning about landslide-induced tsunami risks – although this assumption needs to be tested. Many individuals may be part of pre-booked tours, further reducing their flexibility. While pre-trip awareness is ideal, on-journey communication should acknowledge the presence of natural hazards and risk in the area but shift the focus from hazard to mitigation messages (Figure 4.1). Overly alarming messaging at this stage could cause unnecessary distress and potentially hostile reactions toward those delivering the message. Therefore, we recommend a two-pronged approach:

1. **Prioritise pre-trip awareness:** Maximise efforts to inform visitors about the risks *before* they travel to Milford Sound / Piopiotahi. This empowers them to make informed decisions *before* committing to the trip. Details on this are mentioned in the previous section.
2. **On-journey and on-site communication focused on mitigation:** During their travel to Milford Sound / Piopiotahi, remind visitors and workers that they are entering an area exposed to various natural hazards, including landslide-induced tsunami. Focus on what *actions* they can take to minimise their risk and enhance their safety. This includes highlighting the messages on *warning signs and risk mitigation* provided in Table 4.1.

This approach also necessitates careful consideration of tour-guide decision-making. Tour guides (and their organisations) are responsible for the safety of their employees, and robust procedures for dynamic risk assessment and management in the field are often required. They need clear guidelines and training to make informed decisions on behalf of their tour groups. Information provided in Table 4.1 can help support these decisions and should be communicated to such groups and guides.

General product and channel ideas:

- Milford Corridor (SH 94): Basic reminder of natural-hazard information (new or utilising existing signage).
- Short natural-hazard and mitigation messaging could be applied to existing or additional signage at key locations (any of the six on-site locations in this study). Other locations include high-foot-traffic areas, such as walkways and car parks (including at Sandfly Point).
- More developed messaging could be provided to tourists through the visitor’s terminal, toilets and cafe.
- Tourist accommodation on-site could have evacuation/mitigation information on the back of the room doors or on fridges (if available).
- The wharf/jetty could have tailored information for watercraft users (targeting Group C).
- Limited mitigation messaging is available for boats due to limited understanding of the impact of a tsunami on vessels of different sizes, but messages could explain the increased risk of being impacted by a landslide with increased proximity to the slopes and walls of the fiord. High-level natural-hazard information could be provided on boats and cruise ships to raise awareness, with the intent to refine mitigation messaging in the future with more information.
- Staff accommodation and offices should have all of the available information in Table 4.1 to hand in a variety of different formats, i.e. text, visual and video.

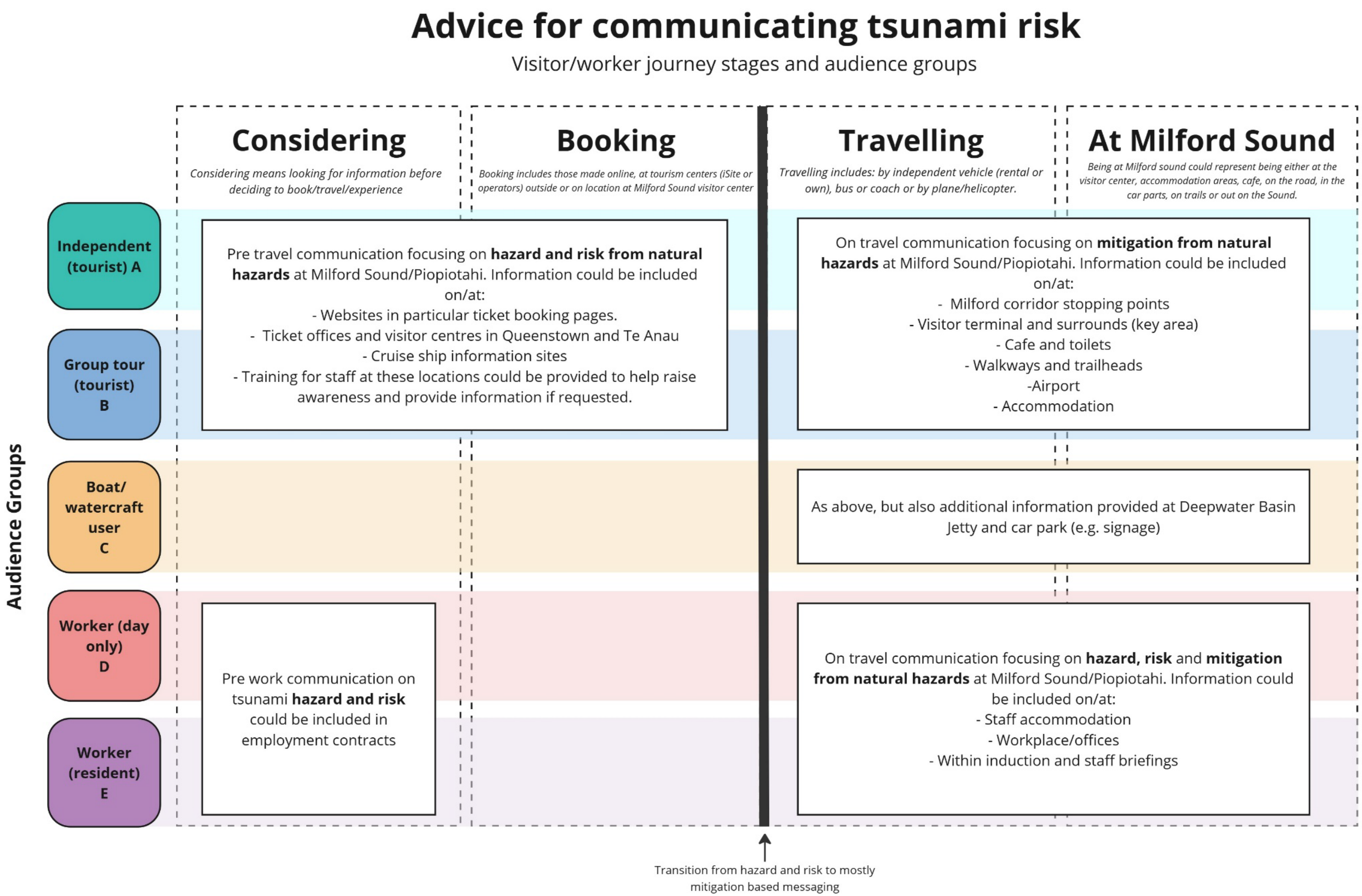

Figure 4.1 Adapted visitor stages/steps and audiences with added summary advice for communicating landslide-induced tsunami hazard for Milford Sound / Piopiotahi.

4.2 General Communication Considerations and Advice

Effective natural-hazard and risk communication is crucial for enabling individuals to make informed decisions about their own risk and the appropriate actions. Effective risk communication in tourism requires a delicate balance. It must prioritise tourist safety and preparedness without causing undue alarm or negatively impacting the destination's attractiveness (Bird and Gisladóttir 2020; Gstaettner et al. 2020; Cui et al. 2023). We acknowledge that there may be tension between providing natural-hazard and risk information and maintaining a positive destination image. However, we emphasise the advantages of building trust with an audience through transparency and knowledge-sharing. The messaging advice provided in Table 4.1 provides foundations that could be developed into an effective risk communication strategy for Milford Sound / Piopiotahi that could be integrated alongside existing marketing strategies.

Below, we present eight high-level communication considerations based on global best-practise, current Aotearoa-New-Zealand-based social science research (Becker et al. 2024; Cui et al. 2023; Rafliana et al. 2022; Fearnley et al. 2018; Dhellemmes et al. 2016; Becker et al. 2015; Leonard et al. 2014; Johnston et al. 2013) and existing practise for other natural hazards and risks in Aotearoa New Zealand.

Our communication considerations are:

- **A1: Communicate the same messages across different channels.** Information about natural hazards and risks should be readily available in multiple locations, both online and physically, to reach visitors at multiple points of their journey. Individual journeys will vary in their time, pathway and scope, and increased opportunities for exposure to the information is likely to increase the likelihood that an individual will engage with the content. This may increase awareness of the natural-hazard risks associated with visiting Milford Sound / Piopiotahi before an individual arrives to the area and support informed decision-making about their choice to spend time in the area. The goal is to ensure that people encounter this information repeatedly but without being overwhelming. To maximise reach, utilise diverse communication channels, including websites and physical signage. However, do not rely on signage as a single mechanism for relaying information. Some cultures and individuals may prefer information in a more direct, up-front way (Cui et al. 2023), such as through conversation or physical brochures.
- **A2: Use a multi-hazard narrative approach.** Include multiple natural hazards in communications to support a fuller understanding of the cascading sequence of such events that can result in a tsunami threat in Milford Sound / Piopiotahi. Understanding the causes and potential impacts of a risk can support decision-making. A narrative or storytelling approach may help clearly communicate the different relationships and variables that influence the risk. This can help raise awareness that the region and people within it are exposed to dynamic risks associated with earthquake, landslide, rockfall and tsunami hazards, as well as many other environmental and meteorological hazards. This may improve outcomes in the event of an earthquake and landslide that does not eventuate in a tsunami.
- **A3: Ensure clarity, simplicity and accessibility.** Communication about hazards and risk must be clear, simple and accessible to everyone, regardless of their background or abilities. Language barriers are known to pose challenges for risk communication. Given the diverse visitor population at Milford Sound / Piopiotahi, communication messages should be provided in clear, jargon-free, non-technical language. Consideration should be given to reproducing priority messages in multiple common languages likely to be used by visitors, such as Mandarin, Spanish and German. Follow accessibility standards to ensure that messages can be accessed by people with disabilities and strive for culturally inclusive messaging where possible (e.g. partner with appropriate iwi to incorporate te ao Māori perspectives).

- **A4: Integrate visuals.** Effective communication should combine text with compelling visuals. Maps, diagrams, illustrations and other visual aids can help communicate the low probability but high consequence associated with tsunami in Milford Sound / Piopiotahi. Visuals can simplify information, highlight key points and make the communication more engaging. For example, diagrams can help explain complex processes such as landslide-induced tsunami. Using visuals in this context may help reduce the text needing to be translated. We also support the advice from Taig (2022) that suggests avoiding, where practicable, presenting risk as a single number but always as a graphic illustrating the range of uncertainty associated with the risk estimate.
- **A5: Maintain national and regional consistency.** Tsunami-related messaging and evacuation messaging should align with national standards established by the NEMA, as well as messaging from the AF8 programme and Emergency Management Southland. This consistency is crucial for ensuring clarity and avoiding confusion, especially during emergencies. Familiarity is especially important for domestic tourists, as they will likely recognise and understand the meaning of Aotearoa New Zealand's tsunami signage (MCDEM 2008).
- **A6: Communicate uncertainties within the science.** Openness and honesty are essential for building trust and credibility. Clearly articulate both what is known about the hazards and risks and what remains uncertain. Highlighting these uncertainties and limitations in the available information demonstrates a commitment to accuracy and allows individuals to make informed decisions based on the best available, albeit sometimes incomplete, understanding. Being transparent about what we do not know is just as important as communicating what we do know.
- **A7: Focus on worker/employee risk for tailored messaging before and during their stay at Milford Sound / Piopiotahi**. Effective communication requires tailoring the message to the specific situation. Workers should also have access to the same natural-hazard information, but they should be informed that their risk is higher as they spend longer in the region. Worker information should be relevant and contextualised for the specific location and context. It is important that employees are aware of the risks associated with working at Milford Sound / Piopiotahi before they decide to take on employment. The risk-comparison messages shown in Table 4.1 can help with this. We have included a range of options in terms of exposure time. If not considered already, tour companies and concession holders/operators could have dynamic processes for assessing and then communicating risk for their own employees. Communication pathways include: onboarding material, health and safety documentations, site inductions and accommodation information.
- **A8: Evaluate and improve messaging when needed**. Evaluate the effectiveness of communication efforts to identify areas needing improvement. Implement and identify those messages that really resonate with people. To do this, set up feedback mechanisms to gather responses from the public. Then, use this feedback and what has been learned to make future communication products more effective.

4.3 Mitigation Considerations and Advice

This section outlines mitigation advice linked to communication only. These apply at the current time, while formal evacuation procedures are still to be confirmed. We advise focusing on (1) providing simple direction-focused tsunami-evacuation messages for all visitors and workers, (2) training on natural-hazard and risk information for staff, (3) exploring more 'what to do' messaging for all visitors and workers. We have also discussed the current challenges with mitigation advice for those who happen to be on the water at the same time as occurrence of a landside-induced tsunami.

- **M1: Prioritise simple and direction-focused evacuation messaging.** The primary goal is to direct people away from the coastline and to higher ground as quickly as possible, emphasising the urgency of the situation and stressing that every metre of elevation and every minute saved can be crucial. Currently, we do not have enough certainty on the estimated tsunami run-up thresholds or clearly defined evacuation routes to be specific. Therefore, the messaging should focus on ‘getting to high ground or away from the coast as quickly as possible’ rather than aiming for a specific route, point or height. Future development of location-specific evacuation messaging, such as directing people at the visitor terminal to high ground to the left of the building (if safe to do so), should be explored and implemented as more detailed information becomes available. The ‘evacuate to the roof’ messaging should clearly state this is a last resort, only to be considered if evacuating away from the coast or uphill is impossible.

- **M2: Training could be provided on natural hazards and risks of Milford Sound / Piopiotahi to new workers in the area**. This is so they can inform themselves and play a role in informing others and answering questions. The key messages in Table 4.1 could be packaged into a video or frequently-asked-questions ‘toolkit’ that needs to be read as a condition of employment. Staff at the visitor terminal could be trained to answer questions about landslide-induced tsunami risks and provide mitigation advice if requested.
- **M3. Explore communicating ‘mitigation/risk-reduction actions’ for other hazards.** The messaging in Table 4.1 has focused on mitigation advice for landslide-induced tsunami only. This is due to (1) the scope of this project and (2) the short arrival-time of landslide-induced tsunami, meaning that people may not have time to ‘drop, cover and hold’ if they want to reach high ground in time. It is recommended that the usefulness of other natural-hazard mitigation messaging, particularly for earthquakes and landslides, be explored. More discussion is required over the use of ‘drop, cover, hold’ messaging in the context of a rapidly arriving tsunami.

4.3.1 Advice for Watercraft Users and the Harbourmaster

Tsunami caused by landslides pose a threat to infrastructure and boat traffic in Milford Sound / Piopiotahi. However, there is limited research and general information on how to survive a landslide-induced tsunami while on a watercraft in a fiord. NEMA’s national advice for ‘what to do while you are on a boat and a tsunami occurs’ may not be applicable to the landslide-induced tsunami context at Milford Sound / Piopiotahi. Because the fiord is narrow, tsunami reflections could cause multiple waves with complex patterns and the timing for evacuation is so short. A tsunami caused by a landslide may not act the same as a tsunami from the open ocean. However, Craig and Chinn (2021) suggest that:

> *“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* [reflected] *waves (* [steering toward and] *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.”*

Research by Harrison et al. (2025) highlights the use of ‘common sense’ by mariners based in Aotearoa New Zealand in making decisions about whether to evacuate off their boats onto land or stay on board and orientate/move the boat accordingly during a tsunami threat. Harrison et al. found that mariners’ decisions about whether or not and how to evacuate appears to depend, at least in part, on the individual’s context at the time of receiving a tsunami warning or alert; primarily if they are (1) on land (away from their boat), (2) at the marina/shoreline on or near their boat, (3) on their boat moored in a bay or (4) already out at sea. Additionally, time and distance were also strong factors in decision-making processes about when, how and where to evacuate in relation to their boat. With limited information available, we adopt the Craig and Chinn (2021) advice to inform our messaging in Table 4.1. In general, moving out of the fiord as quickly as possible could also be useful guidance for those ships that closer to the fiord entrance, such as cruise ships.

Consultation with the Harbourmaster and watercraft users could inform and refine the suggested messaging for the Milford Sound / Piopiotahi context. In addition, more detailed analysis of watercraft impacts from landslide tsunami in fiord settings are required to better inform messaging and advice.

5.0 Conclusions and Future Work

Communicating landslide-induced tsunami risk at Milford Sound / Piopiotahi requires a multi-faceted approach, targeting both tourists and workers at various stages of their journey to the area. Clarity, accessibility, tailoring and consistency are key. However, there is information that could be shared now with those who visit Milford Sound / Piopiotahi for recreation or for work that will help them make decisions about their exposure to natural-hazard risk. The information presented in Table 4.1 and the examples shown in Appendix 3 could be adapted and tailored for use in future communication products. Emphasis should be placed on making information available in the pre-trip step for all visitors and workers. We advise that efforts should be maximised to inform visitors and workers about the risks *before* they travel to Milford Sound / Piopiotahi. This empowers them to make informed decisions *before* committing to the trip. We acknowledge there may be tension between providing natural-hazard and risk information and maintaining a positive destination image but emphasise the importance of sharing knowledge to empower informed decision-making.

Once individuals have decided to travel to Milford Sound / Piopiotahi, on-journey and on-site communication should be focused on mitigation. During their travel to Milford Sound / Piopiotahi, remind visitors and workers that they are entering an area exposed to various natural hazards, including landslide-induced tsunami. Focus on what *actions* they can take to minimise their risk and enhance their safety (such as getting to high ground in the event of an earthquake as fast as they can). In addition, we advise focusing on (1) providing simple direction-focused tsunami evacuation messages for all visitors and workers, (2) providing training on natural-hazard and risk information for staff and (3) exploring more ‘what to do’ messaging for all visitors and workers.

The messaging in Table 4.1 is purposely high-level and simple; this is to reflect the high uncertainties within current physical-science research. The risk from landslide-induced tsunami is present; however, any estimates of future tsunami run-up heights are hugely uncertain and variable. More research to define natural hazard, risk, mitigation, human behaviour and communication aspects could refine and improve the messaging.

While the natural-hazard and risk communication challenge at Milford Sound / Piopiotahi is unique, there are many examples of natural-hazard and risk communication products and content from other hazards. Volcanic activity is another example of a natural hazard that poses direct life-safety threat and warrants communications. At Tongariro National Park, a series of maps have been co-developed with DOC, applying some of the same considerations as we have presented here (Figure 5.1a). It is important to highlight the layers of information and focus on simple key messaging in these products. Lahar (volcanic mudflow) evacuation signage has also played a role in reminding skiers in the region of what to do if a lahar happens (Figure 5.1b). Although a very different hazard, this simple and bright signage could be replicated. A final example is from tsunami. In Aotearoa New Zealand, many of the Civil Defence and Emergency Management (CDEM) regional groups create and install signage to communicate tsunami-hazard and evacuation information. While not directly applicable in this situation, and beyond the scope of the Milford Sound Stakeholder Group to create and install CDEM evacuation signage, elements of the signage could be adapted and used, particularly elements on the left-hand side of the example shown in Figure 5.1c.

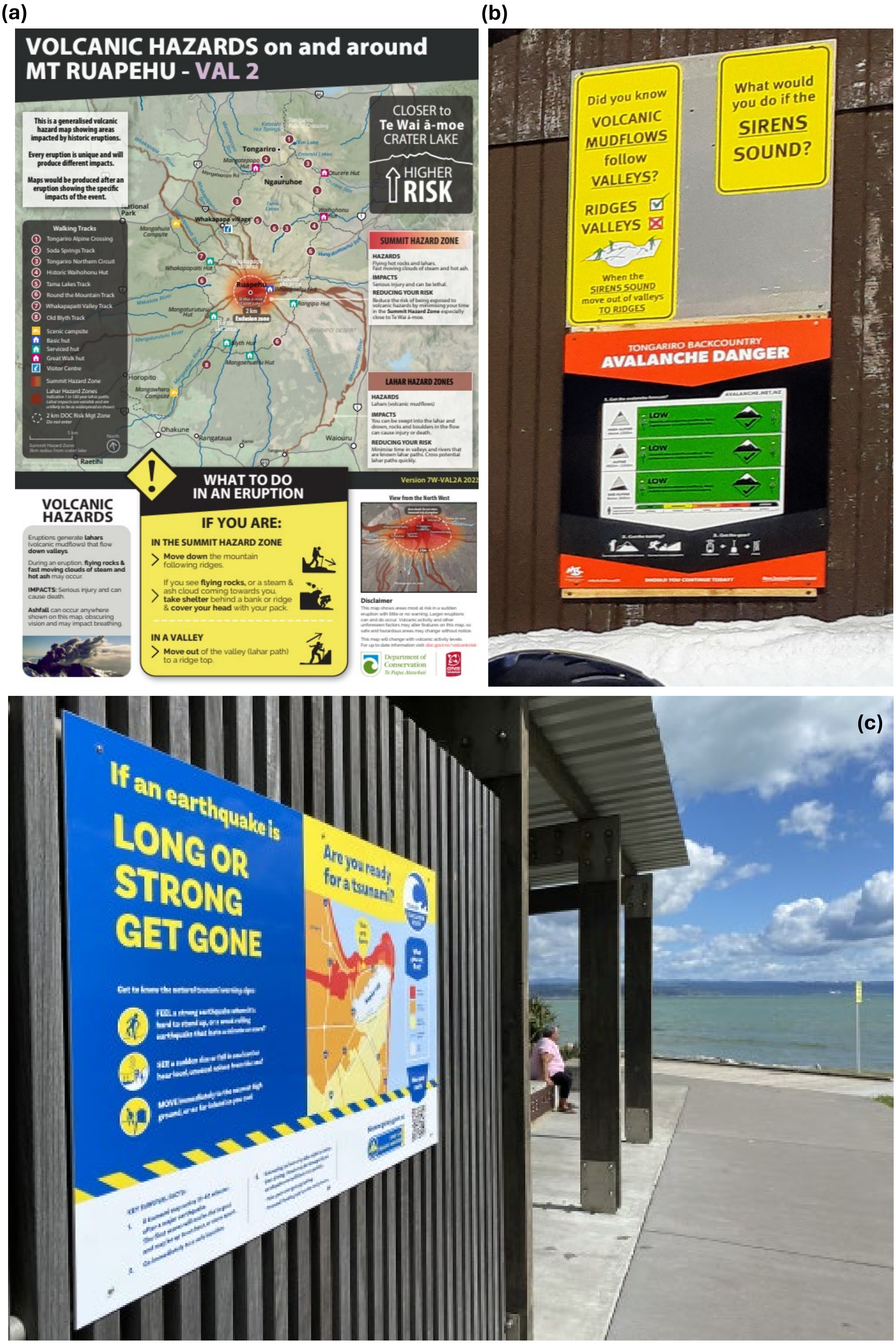

Figure 5.1 Examples of natural-hazard and risk communication products and content. (A) Volcanic hazards on and around Mount Ruapehu (Source: DOC and GNS Science). (B) Example of lahar evacuation signage on Mount Ruapehu (Source: G. Leonard). (C) Tsunami evacuation information board in Napier (Source: Hawke’s Bay CDEM).

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APPENDICES

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APPENDIX 1 Hazard and Risk Literature Summary

Table A1.1 Relevant literature describing the tsunami risk and/or risk management in the Milford Sound / Piopiotahi area. Note that none of the below resources are built upon hydrodynamic tsunami modelling or precise, high-resolution bathymetry and topographic LiDAR elevation (which is considered the modern standard for tsunami hazard assessment).

Resource	Description	Key Findings Regarding Tsunami Risk
Milford Opportunities Project: natural hazards assessment. Part A: preliminary screening analysis Porter (2024)	First screening analysis for risk identified some areas at higher risk for the Milford Opportunities Project	• This report presents the results of the preliminary screening analysis (Part A), which is then used to highlight areas of concern for further site-specific basic-level risk assessment (Part B). • Screening analysing grouping sites into different hazard classes (1–3). • Milford Sound visitor terminal, Freshwater Basin Cleddau Delta and Deepwater Basin are all in Class 3a (highest) and Milford Sound / Piopiotahi Lodge is Class 3.
Assessment of Milford Sound geology, seabed bathymetry and hazards Otero and Almanzar (2024)	Reviewed and summarised existing literature	• There is a credible tsunami hazard that needs attention. 50 m elevation safe zone. • Escape and evacuation routes need to be well defined from all areas within the Cleddau Delta area. • Implementation of a communication plan is crucial to ensure effective dissemination of information; coordination among all stakeholders is essential.
Agent-based modelling of evacuation scenarios for a landslide-generated tsunami in Milford Sound Harris (2023)	University of Canterbury Master of Science thesis examining risk and evacuation from tsunami at Milford Sound / Piopiotahi.	• Agent-based modelling of evaluation of Milford Sound / Piopiotahi, largely based on a tsunami run-up scenario of 17 m (the 1-in-1000 year ~4 m amplitude wave from Dykstra [2012]). • In the best-case scenario, just 5.2% of people in Milford Sound / Piopiotahi at the time of the tsunami are safely evacuated before the longest wave-arrival time. • In the modelled scenarios, for an evacuee agent to be safely evacuated (24 m) they must have reached either of two evacuation points at the top of Lookout Track or on State Highway 94 (SH 94) before the wave arrival time. • Irrespective of the wave arrival time, at least 95% of the exposed population in Milford Sound / Piopiotahi at the time of the event is expected to be in the inundation zone when the wave arrives. • The biggest factor controlling the number of evacuee agents safely evacuated appears to be speed of travel, particularly for those heading to the SH 94 evacuation point.
Tsunami hazard curves and deaggregation plots for 20 km coastal sections, derived from the 2021 National Tsunami Hazard Model Power et al. (2023)	Tsunami hazard curves and deaggregation plots.	• Tsunami hazard curves for Aotearoa New Zealand derived from the 2021 National Tsunami Hazard Model. • Maximum tsunami amplitude as a function of return period (Coastal section 210 at the Milford Sound / Piopiotahi mouth has an average (50th percentile) 500-year annual recurrence interval of 3.32 m). • No modelling of travel and wave behaviour within Milford Sound / Piopiotahi, nor landslide-induced sources. • Delivers tsunami wave height at the coast from regional and distal sources: onshore and subduction zone. Hazard deaggregated into seven sources.

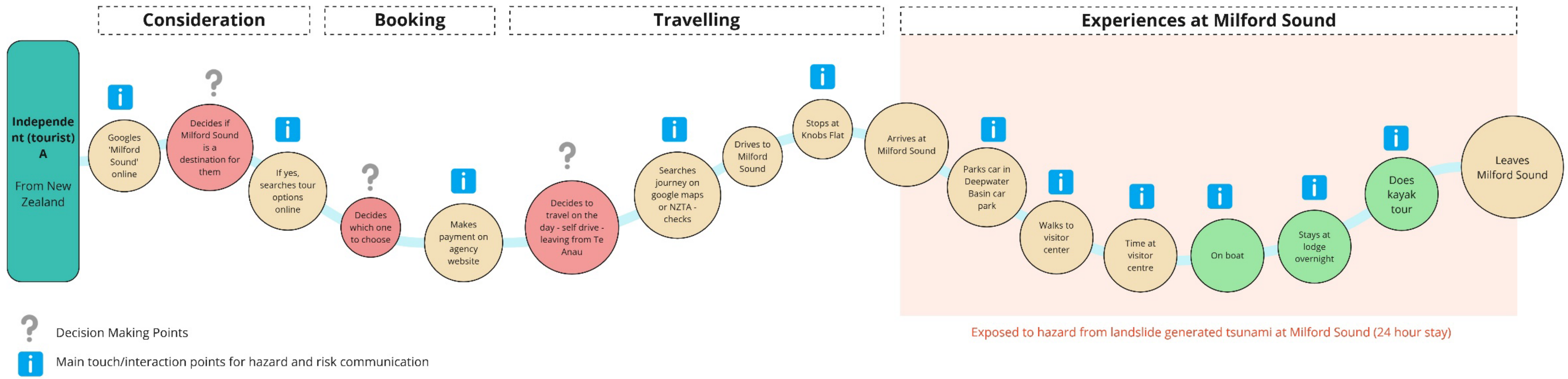
Resource	Description	Key Findings Regarding Tsunami Risk
Guidelines for DOC on dealing with natural hazard risk Taig (2022)	A study to assemble risk comparisons to help the Department of Conservation (DOC) develop guidance on the appropriate response to natural-hazard risk for visitors to and staff working on Aotearoa New Zealand public conservation land	• The most appropriate risk metrics (for use by DOC) to inform decisions about safety risk on public conservation land are: - For workers: annual individual fatality risk (AIFR). - For visitors: fatality risk per visitor day (but acknowledgement that this is difficult – advises visual representation of risk metrics to help avoid confusion with small values). • The accident risk per day spent in a National Park is broadly similar to the average accident risk per day spent living in Aotearoa New Zealand for residents, or per day spent in Aotearoa New Zealand for visitors (Fiordland is on the higher end of risk levels for the parks). • Aotearoa New Zealand residents appear to experience higher risk than international visitors, perhaps because a high percentage of international visitors to Fiordland are day-trippers, who come by bus to enjoy a few hours' scenic visit, whereas a higher proportion of Aotearoa New Zealanders are engaged in tramping, climbing or other more potentially hazardous activities. • Fiordland fatality risk is similar in range to the Grand Canyon and Yosemite national parks (in the United States of America).
Milford Opportunities Project: hazards and visitor risk review report Craig and Chinn (2021)	Hazard and risk assessment to support the Milford Opportunities Project	• Three levels of hazard exposure scenarios are discussed. After discussion on hazards, a long list of options are presented and a recommended option shared. • The recommended option is intended to transform probable outcomes from, say, an estimated 10% baseline survival rate in a large event to an aspirational target in the order of a 90% survival rate.
What lies beneath: investigating the distribution and dynamics of landslides in lakes, and fjords of New Zealand Dick (2021)	Newcastle University PhD thesis	• Re-mapped landslide deposits outlined by Dykstra (2012). Re-assessed volumes and runout. Back-analysed five deposits to model runout and landslide rheology. • Many have relatively low mobility and high resistance to motion. The lack of topographic confinement and change in slope dissipates energy at the front of the landslide. • Observations of landslide dynamics and runout are clearly important for tsunami wave-height modelling, which previously treated the landslide as an incompressible rigid block rather than granular flows. Velocities in this study were lower than those of Dykstra (2012). • Suggests initial near-field wave amplitudes may have been over-estimated in previous work. A re-assessment was recommended using coupled landslide-tsunami wave models.

Resource	Description	Key Findings Regarding Tsunami Risk
Milford Sound risk from landslide-generated tsunami Taig and McSaveney (2015)	GNS Science consultancy report to review hazard and risk for Environment Southland.	• The large landslides that have fallen into the fiord in 44% of Alpine Fault earthquakes over the past 17,000 years have generated tsunami at point of origin ranging between 0.2 and 87 m. • Attenuation of wave amplitude with distance of travel from landslide entry point is important for calculating shoreline wave height and run-up, as well as hazard to village and boats. • Applied empirical attenuations (from China and Norway) that indicated tsunami wave heights ranging from 0.3 to 10 m in Freshwater Basin and tsunami run-up between 1.1 and 47 m on land around the settlement. • Two out of three of these tsunami could cause disasters with multiple deaths at Milford Sound / Piopiotahi if they were to occur today. • Risk is marginally lower for workers than in the forestry and mining industries (AIFR).
The post-LGM [Last Glacial Maximum] *evolution of Milford Sound, Fiordland, New Zealand: timing of ice retreat, the role of mass wasting & implications for hazards* Dykstra (2012)	University of Canterbury PhD thesis examining hazard and risk from large landslides – field work, exposure age dating, assessment of geomorphology to constrain landslide age and size.	• Used high-resolution bathymetry and onshore mapping to establish the spatial distribution of 33 submarine and subaerial landslide deposits. • Eighteen (18) very large (10^6 – 10^7 m^3) post-glacial rock avalanche deposits cover 40% of the floor of Milford Sound / Piopiotahi. There are 10 very large to giant (10^6 – 10^8 m^3) terrestrial landslide deposits. • Established an expected tsunami size range – impulse wave heights and maximum run-up (in this case, based on simple analytical models). • Generated a hazard magnitude-frequency curve (exemplifying a 1-in-1000 ~4 m wave with ~17 m run-up) that indicates range of possible tsunami. • Total aggregate risk (0.38 deaths per year).
Southland Civil Defence Emergency Management Group Plan 2017–22 SCDEMG (2017)	Outlines how Emergency Management Southland intends to focus on community engagement to educate and inform their people about local hazards, plan with them for emergencies and empower communities to make decisions to help themselves in an emergency.	• A large tsunami at Milford Sound / Piopiotahi is a nationally significant event
Milford Sound Community response plan EMS [2024]	A brief document outlining some of the key risks and hazards for Milford Sound / Piopiotahi.	• Short overview of response plan. • Does not include emergency-response procedures. • Southland has no sirens. • Tsunami is not highlighted.

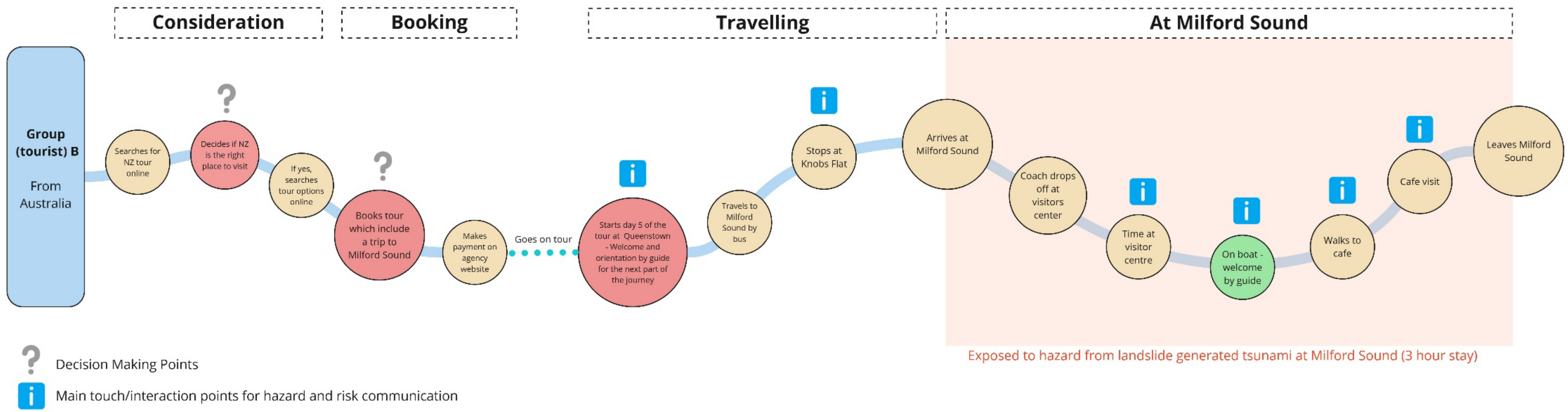
Resource	Description	Key Findings Regarding Tsunami Risk
Darling (in prep.)	In progress: University of Canterbury PhD thesis on dynamic risk modelling	• Work to classify temporal changes in population and risk. • Uses Wi-Fi and cellphone connections to quantify visitors. • Examples and background: https://resiliencechallenge.nz/using-data-sensors-to-understand-tourist-disaster-risk/ • https://www.linz.govt.nz/sites/default/files/bbrs_mat-darling_20191008.pdf

APPENDIX 2 Full Set of Visitor/Worker Journeys

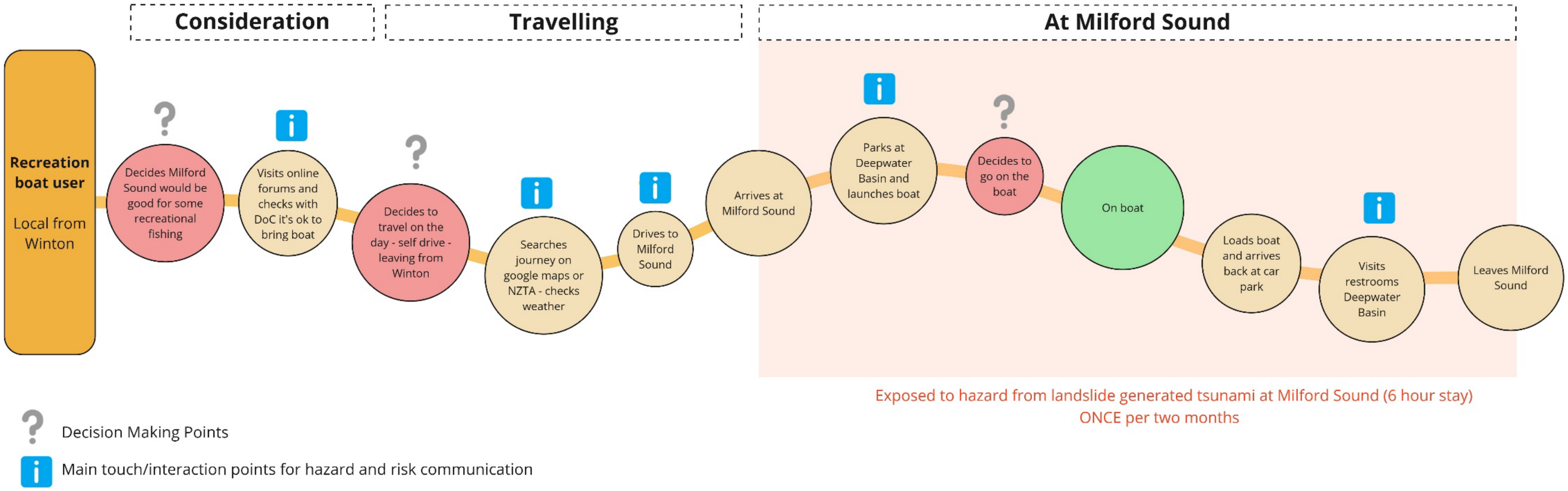
User journey example - Independent traveler A



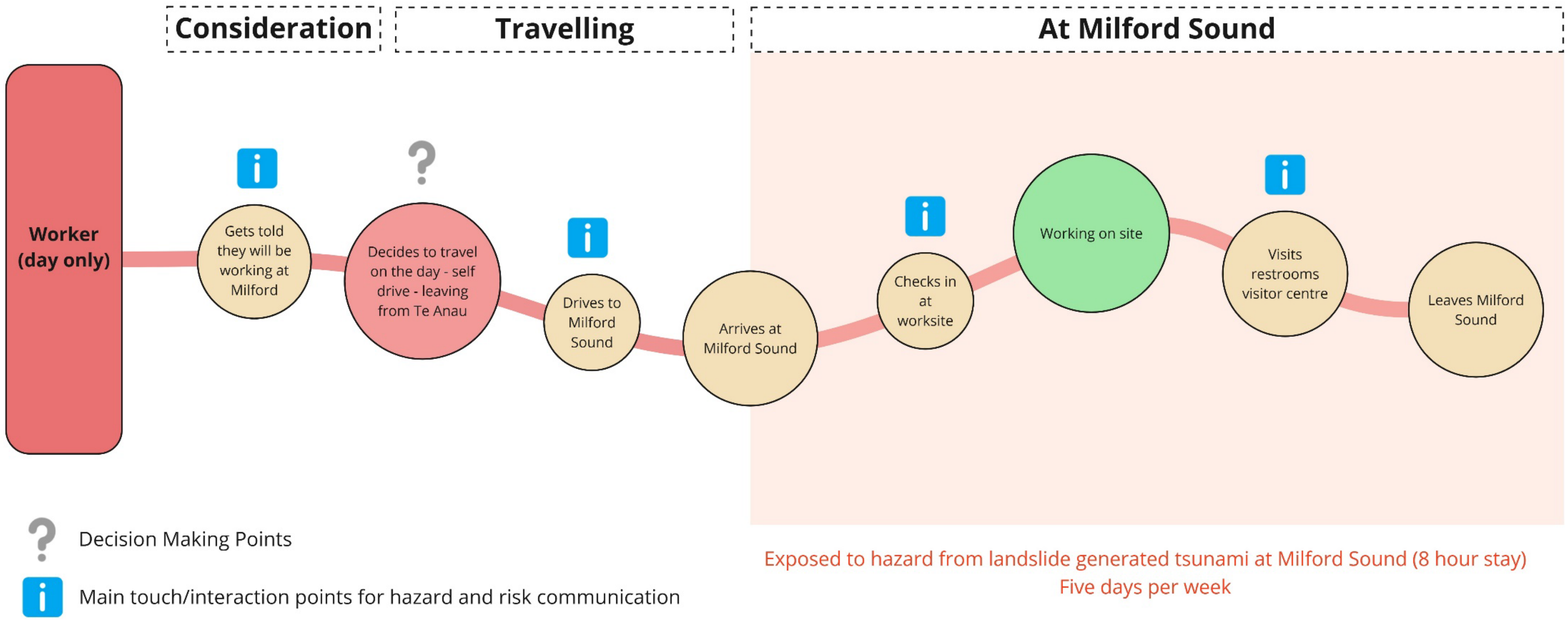
Visitor journey example - Group tourist



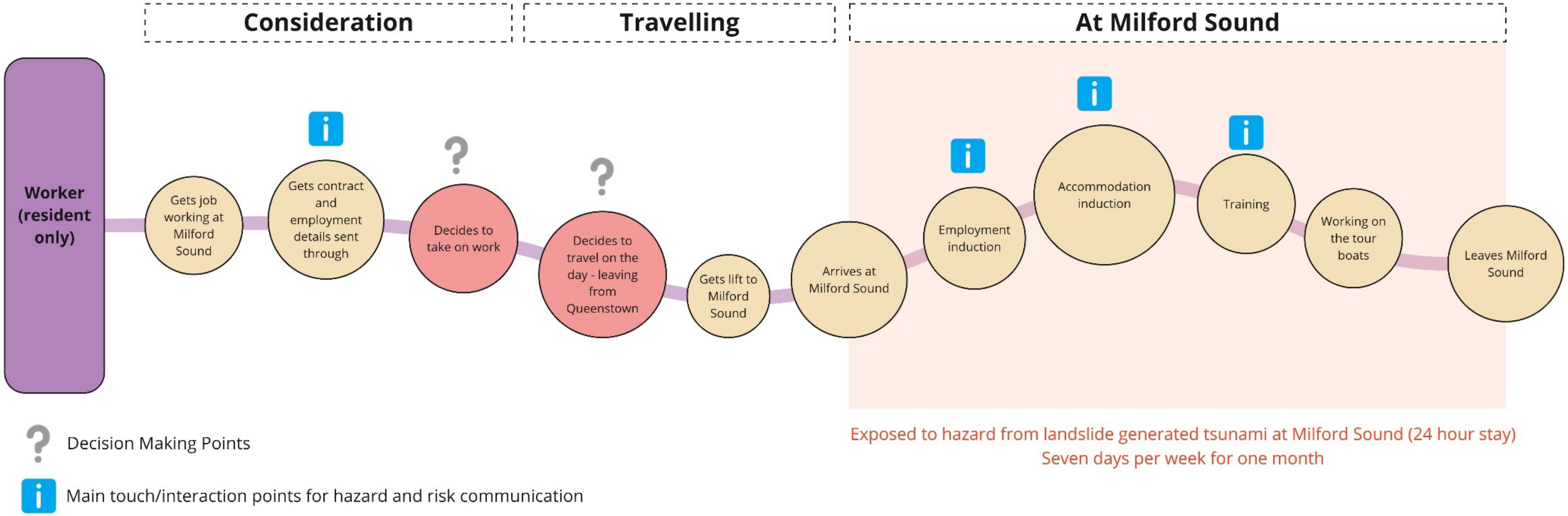
Visitor journey example - Recreational boat user C



Worker journey example - Day worker



Worker journey example - Resident worker E



APPENDIX 3 Messaging Examples: Before Arrival and at Milford Sound / Piopiotahi

Using the messages in Table 4.1, we have constructed example text that could be used to communicate with people who have yet to and arrive at Milford Sound / Piopiotahi. Do not copy and use these directly, as they will need to be tailored to the context. These examples could be adapted and visualised in future communication products. We have provided two sets of examples, which could be used (1) before people arrive at Milford Sound / Piopiotahi and (2) while people are on their way or on-site.

A3.1 Pre-Arrival Information/Text Examples

These examples could be used within products that are aimed toward the consideration, booking and travelling steps. They are applicable across all audience groups.

A3.1.1 Short-Text Example

This example could be added to ticket/booking pages.

Milford Sound/Piopiotahi is exposed to earthquakes, landslides and tsunami generated by landslides, as well as other environmental and meteorological hazards. These hazards can have destructive impacts, causing loss of life and injury.

Earthquakes, landslides, rockfall and tsunami have happened in the past and can occur again at any time, without warning. These natural events can devastate infrastructure and the environment, and they pose a serious risk to life to anyone in the area. It is extremely unlikely that an event could happen while you are at Milford Sound / Piopiotahi, especially for a short stay. However, there is still a risk. If you choose to visit or work in the area, you cannot avoid all of the risk. The longer you spend at Milford Sound / Piopiotahi, the higher the risk is.

For more information visit: [link to long-text source]

A3.1.2 Long-Text Example

These examples could have specific posters and/or be added to dedicated webpages on natural hazards and risk.

Natural Hazard Risk at Milford Sound / Piopiotahi

<u>Introduction to the Region</u>

Milford Sound / Piopiotahi is a dynamic and changing environment. Its beautiful landscape was created by powerful geological forces that continue to shape the landscape we see today. Earthquakes, landslides, rockfall, tsunami, avalanches and severe weather are all dangerous natural hazards that have happened in the past and can happen in Milford Sound / Piopiotahi.

<u>Risk Messaging</u>

Earthquakes, landslides, rockfall and tsunami can occur again at any time, without warning. These natural events can devastate infrastructure and the environment, and they pose a serious risk to life to anyone in the area. It is extremely unlikely that an event could happen while you are at Milford Sound / Piopiotahi, especially for a short stay. However, there is still a risk.

If you choose to visit or work in the area, you cannot avoid all of the risk. The longer you spend at Milford Sound / Piopiotahi, the higher the risk is. During a three-hour visit to Milford Sound / Piopiotahi, there is a 1 in 500,000 chance that a life-threatening tsunami caused by an Alpine Fault earthquake-generated landslide could happen. The risk of death is roughly similar to that of doing a Great Walk in New Zealand or driving to a New Zealand national park.

Key Mitigation Message

If a tsunami happens while you are at Milford Sound / Piopiotahi, you need to evacuate immediately. You will not receive an official warning if a landslide-generated tsunami occurs; it will happen too quickly.

Key Facts on Earthquakes and Landslides at Milford Sound / Piopiotahi

- *Earthquakes can happen at Milford Sound / Piopiotahi. The main sources of earthquakes include the offshore Puysegur subduction zone and the Alpine Fault.* [map]
- *The Alpine Fault is a major fault that runs along the western side of New Zealand's South Island. It is about 600 kilometres long and marks the boundary between the Pacific and Australian tectonic plates. Research shows that there is a 75% probability of an Alpine Fault earthquake occurring in the next 50 years. To learn more about the Alpine Fault, check out the AF8 website.* [https://af8.org.nz/]
- *Large earthquakes can trigger landslides and rockfalls on Milford Sound / Piopiotahi's steep slopes. Both earthquakes and landslides can be destructive and dangerous; they can cause injury and death.*
- *Landslides can sometimes fall into the water in Milford Sound / Piopiotahi and cause a tsunami.* [visual of how landslides can cause tsunami]

Key Facts on Tsunami at Milford Sound / Piopiotahi [utilise existing graphics and colours for tsunami]

- *New Zealand's entire coastline (including Milford Sound / Piopiotahi) is exposed to tsunami.*
- *Landslide-generated tsunami are a serious concern for Milford Sound / Piopiotahi, with the potential to generate large, rapid tsunami. Ongoing research is crucial to better understand and prepare for future events.*
- *Tsunami are not like other water waves or floods. They are turbulent, fast-travelling and could contain debris. There can be multiple waves, and the first wave may not be the biggest. They can cause death by drowning and injury.*
- *The size and arrival time of the tsunami depends on how and where the landslide enters the water.*
- *Science suggests that large landslides have occurred in the past, triggering large tsunami that reached Milford Village. Approximately 26 landslide-generated tsunami have occurred in the last 17,000 years since the glaciers receded from the fiord.*
- *Tsunami caused by landslides have happened in other parts of the world such as Greenland, Alaska, Canada and Norway.*

Warning and Monitoring

- *There is no way to predict earthquakes or whether an earthquake-generated landslide will cause a tsunami. Scientists estimate that it is about as likely as not (44% chance) that a future Alpine Fault earthquake will cause a tsunami in Milford Sound / Piopiotahi.*
- *You will not receive an official warning if a landslide-generated tsunami occurs; it will happen too quickly. Depending on where the landslide happens, it could take between 1 and 7 minutes for a triggered tsunami to reach the Milford Village area.*

Evacuation [utilise existing graphics and colours for tsunami evacuation]

- *The geography of Milford Sound / Piopiotahi, with its busy, narrow roads, paths, and steep slopes, makes evacuation challenging. However, there are actions you can take to protect yourself if a tsunami happens.*
- *If you are near a shore, you need to act immediately if you experience any of the following:*
  - *Feel a strong earthquake that makes it hard to stand or a long earthquake that lasts more than a minute.*
  - *See a sudden rise or fall in water level, or unusual waves or water behaviour without an obvious cause.*
  - *See or hear signs of landslides or rockfalls into the water.*
  - *Hear loud or unusual noises from the water or surrounding area.*
- *Do not wait for official warnings. Move immediately to the nearest high ground or as far inland as possible. Remember: Long or Strong, Get Gone.*

Milford Sound / Piopiotahi is a special place – knowing what to do when you recognise natural warning signs can reduce your risk from earthquakes and tsunami, and play a role in keeping others safe.

For more information on this risk and what to do visit: [add link]

A3.2 On-Site Information/Text Examples

These examples could be used within products on location at Milford Sound / Piopiotahi. They are mostly tourist-focused.

A3.2.1 Short-Text Example

This example could be added alongside existing signage where the focus is on other information.

Earthquakes, landslides, rockfall and tsunami can occur again at any time without warning at Milford Sound / Piopiotahi. These natural events can devastate infrastructure and the environment, and they pose a serious risk to life to anyone in the area. It is extremely unlikely that an event could happen while you are at Milford Sound / Piopiotahi, especially for a short stay. However, there is still a risk.

There are actions you can take to protect yourself if a tsunami happens. If you are near a shore, you need to act immediately if you experience any of the following:

- *Feel a strong earthquake that makes it hard to stand or a long earthquake that lasts more than a minute.*
- *See a sudden rise or fall in water level, or unusual waves or water behaviour without an obvious cause.*
- *See or hear signs of landslides or rockfalls into the water.*
- *Hear loud or unusual noises from the water or surrounding area.*

Do not wait for official warnings. Move immediately to the nearest high ground and as far inland as possible. Every metre gained can increase your chance of survival.

For more information visit: [link to long-text source].

A3.2.2 Long-Text Example

These examples could be added to information boards, accommodation information packs for tourists, posters within rooms, and posters and multi-media within the visitor terminal.

Natural Hazard Risk at Milford Sound / Piopiotahi

Introduction to the Region

Milford Sound / Piopiotahi is a dynamic and changing environment. Its beautiful landscape was created by powerful geological forces that continue to shape the landscape we see today. Earthquakes, landslides, rockfall, tsunami, avalanches and severe weather are all dangerous natural hazards that can happen in Milford Sound / Piopiotahi. These have happened in the past.

Risk Messaging

Earthquakes, landslides, rockfall and tsunami can occur again at any time without warning at Milford Sound / Piopiotahi. These natural events can devastate infrastructure and the environment, and they pose a serious risk to life to anyone in the area. It is extremely unlikely that an event could happen while you are at Milford Sound / Piopiotahi, especially for a short stay. However, there is still a risk.

Key Mitigation Message

If a tsunami happens while you are at Milford Sound / Piopiotahi, you nust evacuate immediately. You will not receive an official warning if a landslide-generated tsunami occurs; it will happen too quickly.

Key Facts on Earthquakes and Landslides at Milford Sound / Piopiotahi

- *Earthquakes can happen at Milford Sound / Piopiotahi. The main sources of earthquakes include the offshore Puysegur subduction zone and the Alpine Fault.* [map]
- *The Alpine Fault is a major fault that runs along the western side of New Zealand's South Island. It is about 600 kilometres long and marks the boundary between the Pacific and Australian tectonic plates. Research shows that there is a 75% probability of an Alpine Fault earthquake occurring in the next 50 years. To learn more about the Alpine Fault, check out the AF8 website.*
- *Large earthquakes can trigger landslides and rockfalls on Milford Sound / Piopiotahi's steep slopes. Both earthquakes and landslides can be destructive and dangerous; they can cause injury and death.*
- *Landslides can sometimes fall into the water in Milford Sound / Piopiotahi and cause a tsunami.* [visual of how landslides can cause tsunami]

Key Facts on Tsunami at Milford Sound [utilise existing graphics and colours for tsunami]

- *New Zealand's entire coastline (including Milford Sound / Piopiotahi) is exposed to tsunami.*
- *Landslide-generated tsunami are a serious concern for Milford Sound / Piopiotahi, with the potential to generate large, rapid tsunami.*
- *Tsunami are not like other water waves or floods. Tsunami are turbulent, fast-travelling and could contain debris. There can be multiple waves, and the first wave may not be the biggest.*
- *Tsunami caused by landslides have happened in other parts of the world such as Greenland, Alaska, Canada and Norway.*

Evacuation [utilise existing graphics and colours for tsunami evacuation]

You will not receive an official warning if a landslide-generated tsunami occurs; it will happen too quickly. Depending on where the landslide happens, it could take between 1 and 7 minutes for a triggered tsunami to reach the Milford Village area.

The geography of Milford Sound / Piopiotahi, with its busy, narrow roads, paths, and steep slopes, makes evacuation challenging. However, there are actions you can take to protect yourself if a tsunami happens.

Observe your surroundings, noting your orientation from the sea and identifying the nearest high ground.

If you are near a shore , you need to act immediately if you experience any of the following:

- *Feel a strong earthquake that makes it hard to stand or a long earthquake that lasts more than a minute.*
- *See a sudden rise or fall in water level, or unusual waves or water behaviour without an obvious cause.*
- *See or hear signs of landslides or rockfalls into the water.*
- *Hear loud or unusual noises from the water or surrounding area.*

Do not wait for official warnings. Move immediately to the nearest high ground or as far inland as possible. Every metre gained can increase your chance of survival. Remember: Long or Strong, Get Gone.

- *If evacuation is impossible, go to the higher floor of a building or climb a tree. This should only be used as a last resort.*
- *If you are on the water, follow the instructions of your crew or the Harbourmaster.*
- *If you are alone on the water and can reach shore before the tsunami (under one minute), head uphill or inland.*

Remember: Long or Strong, Get Gone.

Milford Sound / Piopiotahi is a special place – knowing what to do when you recognise natural warning signs can reduce your risk from earthquakes and tsunami and play a role in keeping others safe.

For more information on this risk and what to do visit: [add link]

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