Guidelines for Natural Hazard Risk Analysis on Public Conservation Lands and Waters

Part 5: Preliminary hazard and exposure analysis for tsunami

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EXECUTIVE SUMMARY

This report presents an updated version of a preliminary screening methodology for assessing exposure to tsunami hazards at specific locations ('point sites') within public conservation lands and waters (Department-of-Conservation-managed land), such as huts, visitor centres and carparks.

The preliminary screening methodology covers life-safety considerations and can be used to identify and prioritise areas within public conservation lands and waters for further risk analysis and risk-management actions, such as more detailed studies and relatively inexpensive risk-management actions, e.g. improved signage and communications.

The methodology is based on using existing information on tsunami hazard to classify the level of exposure to tsunami hazards. The method can be used to evaluate the hazard and exposure to individual visitors and workers, or the societal hazard and exposure applicable to the total number of people at a site.

Tsunami are long-duration waves produced by displacement of a body of water. Most commonly they are caused by earthquakes but can also be caused by landslides or volcanic events. Though large tsunami are infrequent events, when they occur, they can be very deadly to the people exposed to them. The primary means of reducing tsunami risk to people is by ensuring that individuals in tsunami-vulnerable areas are able to evacuate before the wave reaches them.

Data on tsunami hazard at the coast from the 2021 National Tsunami Hazard Model is used in combination with empirical formulae, developed for evacuation zoning, to outline locations that are potentially subject to inundation. When combined with information on the exposure, which may be the total number of visitors or the proportion of time spent at the site, a hazard and exposure class can be calculated. The hazard and exposure class represents the unmitigated level of risk at the site. Effective mitigation of the tsunami risk requires that:

- people at the site are able to know that a tsunami is imminent, and
- people are able to make a safe and timely evacuation to a safe location.

In order to achieve this, the risk-management actions associated with hazard and exposure class are:

1. **Class 1*:** No further risk analysis required. These sites are outside of the tsunami evacuation zone, so risk mitigation by evacuation is not expected. Information and evacuation maps displayed at popular locations in this category may still reduce the risk to visitors or staff who travel to the coast from these sites.
2. **Class 1:** No further risk analysis required. DOC should develop appropriate risk-management plans and re-evaluate the risk-management plan if there is a change in hazard activity or the number of people exposed.
3. **Class 2 and Class 3:** Basic risk-mitigation analysis required. For tsunami, the basic analysis will determine if a further quantitative risk analysis ('advanced' analysis) is required. The distinction between Classes 2 and 3 is used in the basic analysis to determine the acceptable level of risk mitigation.
4. **Class 4:** An advanced risk-analysis study is required. The basic risk-mitigation analysis will also be required as a pre-requisite in order to provide data to inform the advanced analysis.

Any further risk-management actions, including risk analysis, are at the discretion of DOC on the advice of the expert panel. It is also important to note that, for the preliminary screening methodology, the uncertainties on the information provided are relatively large.

This report outlines the key features of the basic-level analysis, which, for tsunami, is primarily a site-specific assessment of the existing and potential measures that can be used to mitigate the risk. If a satisfactory level of risk mitigation cannot be achieved using relatively inexpensive measures (such as providing signage), then an advanced analysis may be required.

1.0 INTRODUCTION

1.1 Purpose

This report describes a methodology intended to provide a classification of the level of hazard and exposure from tsunami at point sites (such as huts or carparks) within the public conservation lands and waters. It is an updated and revised version of the methodology previously provided to the Department of Conservation (DOC) in 2020 (Power and Burbidge 2020).

The method is a preliminary screening tool that is intended to be used to identify and prioritise areas within the public conservation lands and waters for further investigations and risk analysis and to plan relatively inexpensive risk-management actions, such as improved signage and communications. It is also intended to inform the next 'basic' stage of analysis where this is recommended. 'Advanced' analysis of the tsunami risk where it may be high is beyond the scope of this report.

1.2 Concept

The purpose of the screening tool is to identify whether more analysis and/or risk mitigation is needed at a site. The Part 1 report sets out a flow chart that guides the user through the process, which ultimately ends with assigning the site a hazard and exposure class. It is intended that the tsunami hazard and exposure at each site is initially analysed using the screening tool. The relative hazard and exposure matrix is broadly based on the risk-management framework contained in the original Risk Management Guidelines Companion to AS/NZS 4360:2004, which is now superseded by AS/NZS 31000:2009 (AS/NZS 2009).

The outputs of the screening tool are used in conjunction with DOC's risk-tolerability guidance, which provides a consistent set of risk-tolerability criteria across public conservation lands and waters. The guidance classifies visitor sites into three different risk-tolerance levels, as shown in Table 1.1.

Table 1.1 Department of Conservation natural hazard risk thresholds for visitor sites.

Natural Hazard Risk Thresholds – three acceptable risk thresholds for quantitative risk assessments	
Risk Threshold	**Type of DOC Visitor Site**
Lower Risk	• Short walks • Walking tracks • Grade 1 and 2 cycle trails • Campsites • Amenity areas
Medium Risk	• Easy tramping tracks, including Great Walks • Grade 3 and 4 cycle trails • Promoted marine sites, such as Goat Island
Higher Risk	• Tramping tracks • Routes • Grade 5 and 6 cycle trails

There are three risk thresholds for natural hazard risk management at visitor sites (Figure 1.1). Linked to these thresholds are DOC's risk-reduction-response categories (see Figures 1.1 and 1.2) The DOC risk-reduction-response categories are also associated with internal DOC risk-management actions (Figure 1.2). For workers, DOC's risk-tolerability guidance outlines the tolerance to risk for workers and sets the risk level that is associated with each hazard and exposure class.

The results would then go to DOC and the expert panel (see the Part 1 report for more information) to confirm what the level of any future analysis might be. The hazard and exposure classes therefore help DOC determine whether further risk-management decisions are required, as each of the hazard and exposure classes have risk-management actions associated with them (see Table 1.2). Any further risk-management actions, including risk analysis, are at the discretion of DOC on the advice of the expert panel (see the Part 1 report).

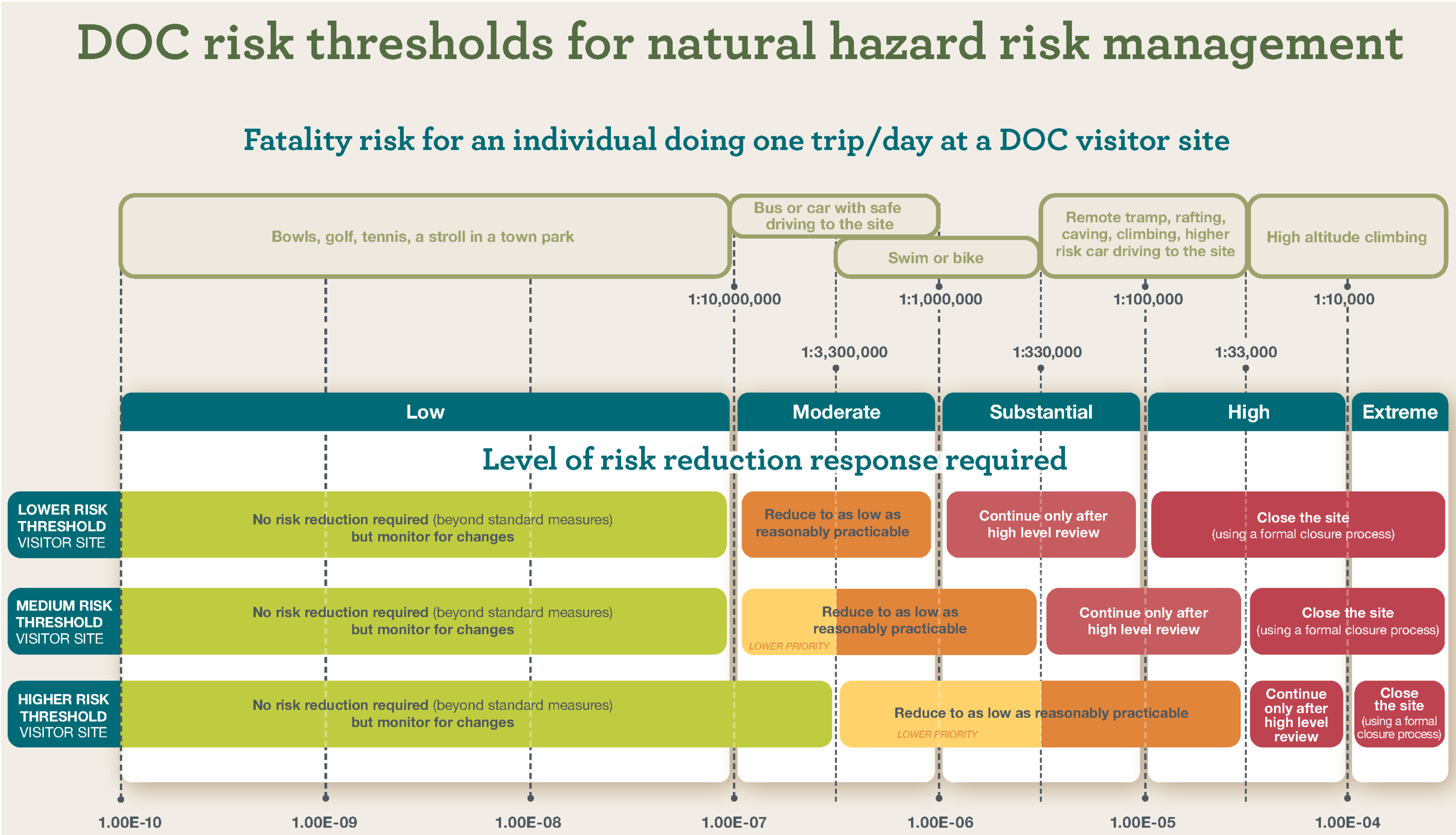

Figure 1.1 Department of Conservation natural hazard risk thresholds for visitor sites and associated level of risk-reduction response.

Natural hazard risk reduction response

What the risk reduction response categories mean for DOC:	
No risk reduction required (beyond standard measures)	**Risk is low.** • Follow DOC's normal visitor asset management and visitor safety communication standards. • Informally monitor for changes.
Reduce to as low as reasonably practicable	**Operations Manager leads a team process to establish suitable mitigations.** • Use local team and experts to decide on necessary actions using the hazard management guideline. • Ensure that the mitigations selected are proportional to the risk. Avoid costly and resource intensive measures. • Reassess the risk if the hazard changes – a formalised monitoring regime may be required to identify changes.
Continue only after high level review	**Regional Director leads a team process to understand if the risk is acceptable and establish mitigations.** • Use local team and experts to identify suitable risk reduction options. • Consider significant changes to reduce risk like moving infrastructure. • A Trigger Action Response Plan (TARP) may be needed, along with a formal monitoring regime to identify changes and respond to increased risk. • Close the site using the Visitor Safety Closures SOP if risk cannot be reduced to an acceptable level.
Close the site	**Close the site using the Visitor Safety Closures SOP.** • Regional Director and experts across DOC decide the site's future. Brief the Senior Leadership Team on the discussions and decisions made. • Unless the site can be redesigned to eliminate the risk (such as moving a hut or rerouting a track), permanent closure and disposal of the site's assets is very likely at this risk level.

Figure 1.2 The four Department of Conservation risk-reduction-response categories and associated internal actions.

Table 1.2 Risk-management actions and associated hazard and exposure class.

Class	DOC Risk-Reduction-Response Categories	Risk-Management Actions
Class 1*	No risk reduction required (beyond standard measures) but monitor for change	No further risk analysis required. These sites are outside of the tsunami evacuation zone, so risk mitigation by evacuation is not expected. Information and evacuation maps displayed at popular locations in this category may still reduce the risk to visitors or staff who travel to the coast from these sites.
Class 1	No risk reduction required (beyond standard measures) but monitor for change	No further risk analysis required. DOC should re-evaluate the risk if there is a change in hazard activity or the number of people exposed.
Class 2	Reduce to as low as reasonably practicable	Basic risk-mitigation analysis required. For tsunami, the basic analysis will determine whether a further quantitative risk analysis (‘advanced’ analysis) is required. The distinction between Classes 2 and 3 is used in the basic analysis to determine the acceptable level of risk mitigation.
Class 3	Continue only after high-level review	
Class 4	Close the site (using a formal closure process)	Urgent action is required. An advanced risk-analysis study is required. The basic risk-mitigation analysis will also be required as a prerequisite in order to provide data to inform the advanced analysis.

The methodology is designed to use existing hazard information to estimate the level of hazard and exposure at specific DOC point sites, or at specific points along a linear site. Specifically, it makes use of tsunami hazard curves from the 2021 National Tsunami Hazard Model (2021 NTHM) and the ‘Level 2’ empirical methods for defining evacuation zones. Because of the high uncertainty associated with these currently available data sources, and the possibility of inappropriate application, the methodology avoids explicit quantification of risk in favour of a hazard and exposure classification scheme, although the thinking behind it is risk-based.

Explicitly quantitative tsunami risk-analysis methods are being developed (e.g. Power et al. 2016), but these require detailed input datasets and specialist tsunami-inundation modelling tools and skills. A possible use for the hazard and exposure classes provided here is to identify locations where such more-advanced (and expensive) analysis would be of most benefit. Fully quantitative risk analysis may also be important in situations where it is necessary to compare the risks between different hazards, for example, post-earthquake tsunami evacuation in an area prone to landslides.

1.3 Scope

The methodology is only concerned with life-safety considerations for visitors and workers within the public conservation lands and waters. Workers may include DOC staff, contractors, volunteers and concessionaires. The methodology only considers tsunami generated in the ocean or sea by large earthquakes.

Assessment of the risk from tsunami generated by the alternative mechanisms listed below would require more detailed source-specific and site-specific analysis than described here:

- tsunami caused by other mechanisms, such as submarine landslides or volcanic eruptions;
- tsunami and seiches generated within lakes; and
- rockslide-generated tsunami within fjords and sounds.

If the feature of interest is located near a lake, fjord, sound or volcano, or is otherwise close to an area of known coastal-cliff instability, the DOC expert panel should be referred to for advice on potential further risk-management actions, including risk analysis (which may still include use of the preliminary screening tool).

The methodology is designed to be applied to specific sites, typically buildings such as huts or visitor centres. It could be adapted to linear sites by applying it at specific points along a linear site. These specific points may include locations with known high tsunami hazard or points where persons may congregate (such as viewing or picnic areas). However, it is not designed to assess the cumulative risk of, for example, walking along a track.

1.4 Materials

It is assumed that the practitioner undertaking the risk evaluation for a site has access to:

- Tsunami evacuation maps of the site (if they exist).[1]
- Tsunami hazard-curve data from the 2021 NTHM.[2]
- An estimate of the minimum elevation of the site [3] above high-tide level (above Mean High Water Springs [4], MHWS).
- An accurate ground model of the area with which distances can be measured (e.g. Land Information New Zealand [LINZ] Topo50 maps).
- Information on exposure (occupancy and time spent), to be provided by DOC.

Information on the visitor-site risk threshold (lower-, medium- or higher-risk) is to be provided by DOC.

1.5 Structure of Report

In Section 2, we provide an overview of tsunami hazard in New Zealand and summarise methods and data sources relevant to the risk analysis. Section 3 describes the specific steps required to conduct the hazard and exposure classification, which is the main output of this report. Section 4 outlines reporting requirements. Section 5 outlines the basic risk-mitigation analysis to assess the site-specific measures by which tsunami risk may be mitigated. Lastly, Section 6 contains discussion and summarises the conclusions of the report.

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1 Evacuation maps for different regions of New Zealand can be found using the links here: https://www.civildefence.govt.nz/get-ready/get-tsunami-ready/tsunami-evacuation-zones/. However, not all evacuation maps linked from this page comply with the National Emergency Management Agency (NEMA; formerly the Ministry of Civil Defence & Emergency Management) tsunami evacuation map guidelines (MCDEM 2016).

2 Available from https://www.gns.cri.nz/data-and-resources/2021-national-tsunami-hazard-model/

3 Elevation is an important parameter for tsunami risk, and a practitioner applying the methodology presented here would be expected to use the best available estimates. Where no better data exists, elevation estimates from the LINZ 8 m Digital Elevation Model may be used as a minimum standard, but, as this dataset is based on interpolation of 20 m contours, the errors are large and hence more accurate data should be used where available. Where elevation data quality is low, a site-visit may be required to collect better data.

4 See definition here: https://www.linz.govt.nz/sea/tides/introduction-tides/definitions-tidal-terms. Data on tide levels can be found from LINZ.

2.0 BACKGROUND

2.1 Tsunami

Tsunami are a surge of water with a long wavelength produced by the displacement of a body of water. Causes of tsunami include an earthquake causing offset (uplift or subsidence) of the sea bed, a volcanic eruption or a large landslide (including sector collapse). Landslides or icefalls into lakes or fjords may also generate tsunami. The height of a tsunami is influenced by the morphology of the coastline that it travels towards. The speed of a tsunami ranges between 10–100 km/hr in shallow areas and up to 800 km/hr when crossing deeper waters. All of New Zealand's coastline is exposed to some level of tsunami hazard (see, for example, Figure 2.1; Power 2013; Power et al. 2022).

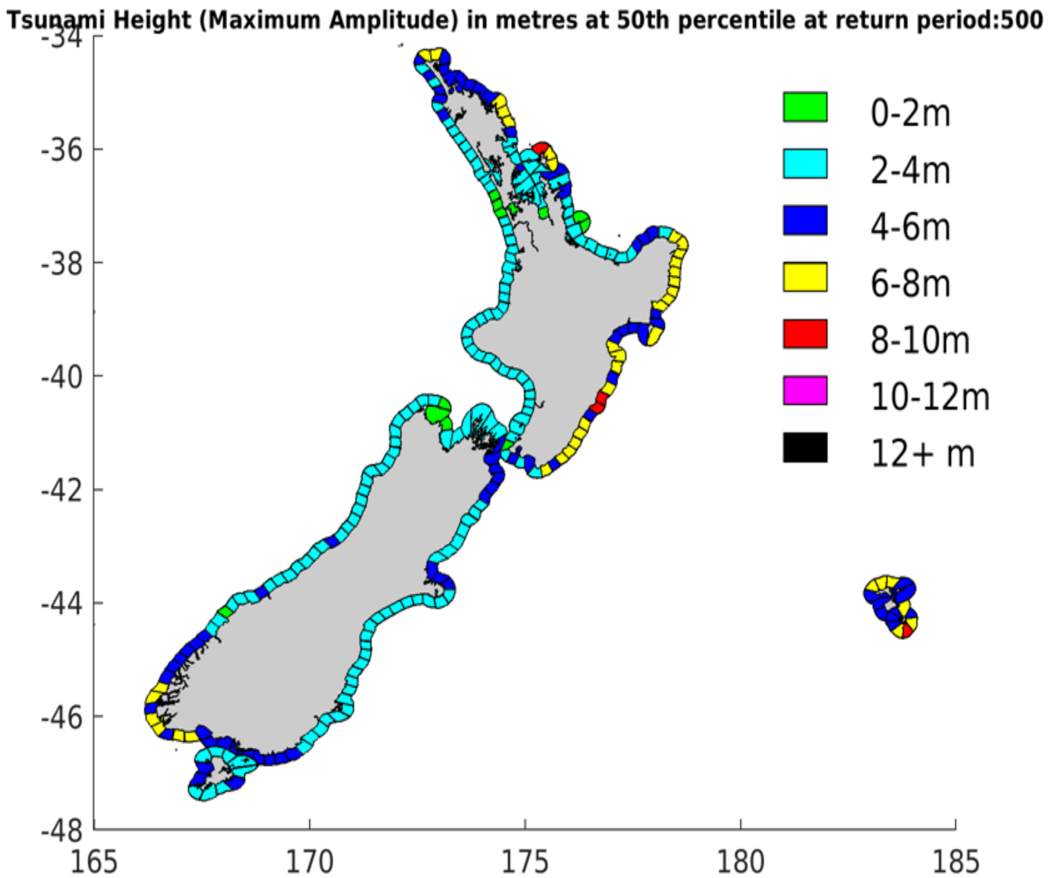

Figure 2.1 Expected maximum tsunami height in metres at 500-year return period for tsunami generated by earthquakes. The height shown is the median (50th percentile) of epistemic uncertainty (from Power et al. [2022]).

2.2 Tsunami Impacts and Consequences

The potential direct impacts of tsunami on people are (Power 2013):

- drowning;
- being washed off feet, including subsequent impacts with structures;
- being impacted by debris transported by the tsunami; and
- injury or illness due to contact with contaminated water.

Tsunami can result in a range of direct impacts on the built and natural environment, as well as a range of indirect social, infrastructure and economic impacts (Power 2013).

Vulnerability is defined as the probability of death (or injury) if caught by a tsunami. Fragility curves, based on historical data, have been developed to relate the probability of death or injury to the depth of water to which people were exposed. Figure 2.2 shows an example of these curves.

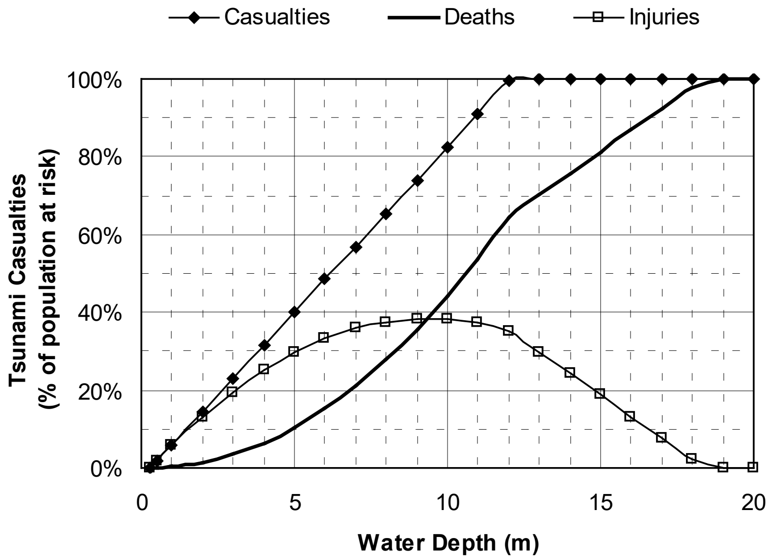

Figure 2.2 Models for casualty, death and injury rates for people impacted by tsunami. Casualties = deaths + injuries; water depth is at the location where person(s) are impacted (from Berryman [2005]).

2.3 Hazard Curves

Hazard curves show the maximum tsunami height as a function of return period, usually for a point or section of the coast, and typically evaluated either at the shoreline or at a given depth offshore. The tsunami 'height' here is the maximum positive amplitude of the tsunami wave, or, equivalently, the maximum water elevation of the tsunami [5], as it is usually measured offshore or at the shore and is not the same as the tsunami run-up height, which is the maximum elevation of the tsunami at the inland limit of inundation. Run-up height can be larger or smaller than the offshore tsunami height, depending on factors such as the coastal topography. Figure 2.3 shows an example of the hazard curve for Wellington from Power et al. (2022) for tsunami height at the shore. The solid line shows the expected maximum tsunami height at the coastline that can be expected to be exceeded at the given return period. The dashed lines show uncertainty in terms of the 16th and 84th percentile.

5 Usually this excludes the effects of the tide.

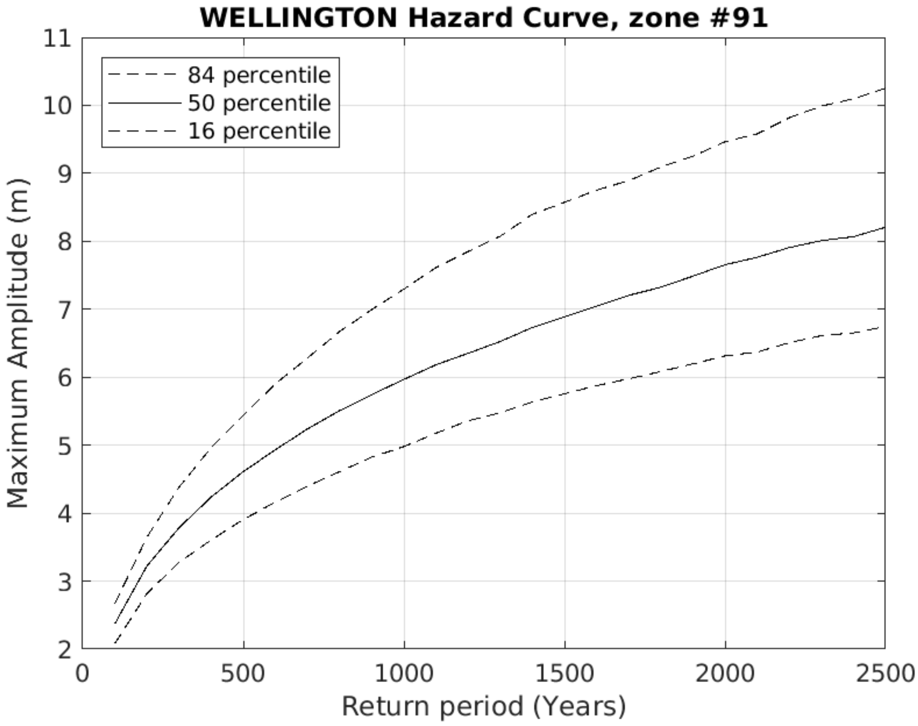

Figure 2.3 Tsunami hazard curve for Wellington (from Power et al. [2022]).

The maximum tsunami height is shown for the 20 km coastal section (small 'boxes' in Figure 2.1) containing Wellington. In practice, the maximum tsunami height is only likely to occur at one location within the 20 km coastal section and will be lower elsewhere; hence, the use of these curves is typically conservative (pessimistic). The degree to which the maximum tsunami height varies within a 20 km section can be quite large, especially where the coastline is irregular, so this is an important consideration to be kept in mind when interpreting the analysis in Section 3 that depends on these curves.

2.4 Empirical 'Level 2' Evacuation Zoning

A simplified process for drawing-up 'interim' evacuation zones was developed based on analysis of historical tsunami run-up height data like that shown in Figure 2.4.

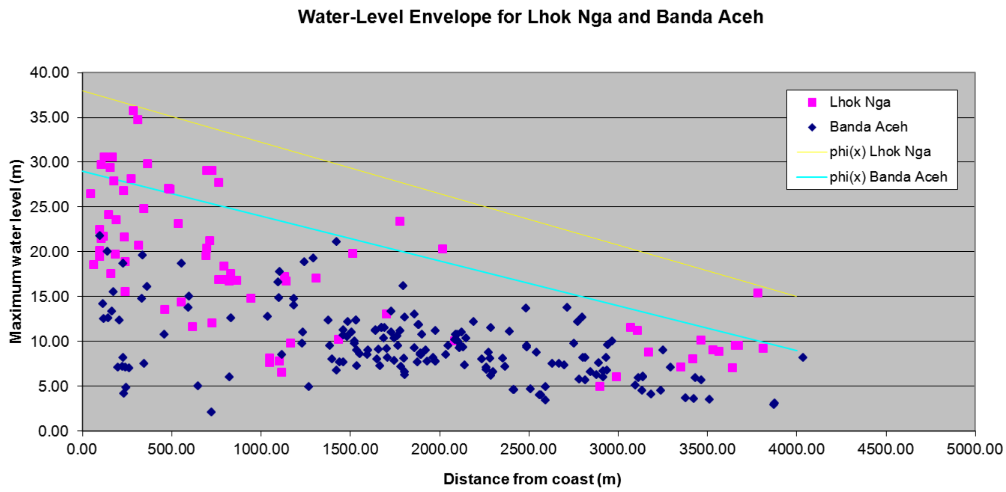

Figure 2.4 Water level plotted as a function of distance from the coast, using field survey data from the districts of Lhok Nga and Banda Aceh, as recorded by Lavigne et al. (2009) following the 2004 Indian Ocean tsunami (from Power [2013]). The yellow and blue lines are trends in the envelopes of the water level data (see Power [2013] for details).

The methodology is based on doubling the expected shoreline tsunami height. This is assumed to be the maximum possible run-up height and corresponds to situations that are most conducive to large run-up heights, e.g. channelling of the tsunami into V-shaped valleys. This maximum possible run-up height then reduces inland at a rate of a 1 m decrease for every 200 m inland (Figure 2.4).

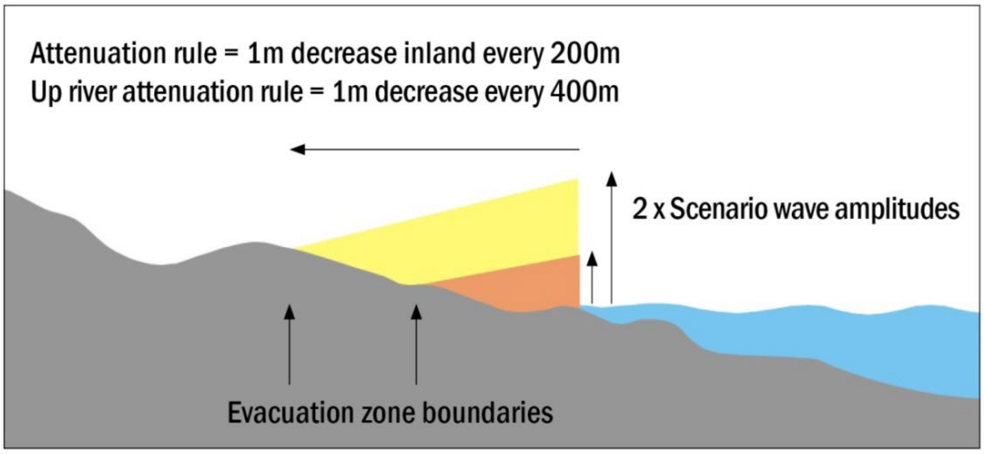

Figure 2.5 Cross-section at the coast showing how evacuation zone boundaries are determined using the 'Level 2' method (from MCDEM [2016]).

Additional attenuation rules were developed to cover tsunami propagating up rivers and the propagation of tsunami within shallow, narrow-mouthed harbours. An analysis of evacuation zones drawn up in this manner is given by Fraser and Power (2013). This approach is referred to as 'Level 2' in the NEMA (National Emergency Management Agency, formerly MCDEM) evacuation zone guidelines (MCDEM 2016).

This approach is deliberately conservative and tends to result in larger evacuation zones than developed by more detailed modelling. This conservatism arises because the rules are designed to put an envelope around the maximum run-up heights (see Figure 2.4) rather than based on 'typical' run-up heights. This conservatism is important to bear in mind when interpreting results in Section 3 that make use of these rules.

2.5 Hazard and Exposure and the Relationship to Risk

The methodology described here can be applied to 'societal hazard and exposure classes', where it applies to the most likely number of people present at a site, or to 'individual hazard and exposure', where it applies to a single person present at the site.

The societal or individual risk may be defined as:

$$Risk = Hazard \times Exposure \times Vulnerability$$

where *Hazard* is the probability of a tsunami occurring, *Exposure* is the average number of people in the locations inundated (for Societal Risk) or the proportion of time spent at a site (for Individual Risk)[6], and *Vulnerability* is the probability of death (or injury) if caught by a tsunami.

6 That is, the spatio-temporal probability of the individual being at the site.

For the simplified analysis given here, we assume that vulnerability is independent of location and the specifics of tsunami, so that:

$$Risk \propto Hazard \times Exposure$$

Taking logarithms, this becomes:

$$log_{10}\, Risk = log_{10}\, Hazard + \; log_{10}\, Exposure + constant$$

The methodology used here involves calculating a hazard and exposure rating by adding hazard and exposure ratings that are all (approximately) based on the logarithms of the corresponding variables:

$$Risk\ rating \;\approx log_{10}\, Risk + c_r$$

$$Hazard\ rating \;\approx log_{10}\, Hazard + c_h$$

$$Exposure\ rating \;\approx log_{10}\, Exposure + c_e$$

To the extent that our goal is a ranking, rather than an exact probability, we do not have to worry about the constants.

$$Risk\ rating \;\sim Hazard\ and\ Exposure\ rating = \; Hazard\ rating + Exposure\ rating$$

This relationship forms the basis of the hazard and exposure matrices in Sections 3.2 and 3.3. ‘Hazard and exposure’ are referred to rather than ‘risk’ because of the assumptions about vulnerability (including the assumption of no evacuation) that are needed if the above equation is used to describe risk.

3.0 METHODOLOGY

The process for determining the hazard and exposure class for a site of interest is outlined in the flowchart in Figure 3.1. Three exposure metrics are used:

1. **Individual spatio-temporal probability of a visitor:** The proportion of time (P) over a 24-hour period that the individual of interest spends at a given location on the site, either for a single trip or per day if the site is visited repeatedly.
2. **Individual spatio-temporal probability of a worker:** The proportion of time (P) per day that the individual of interest spends at a given location on the site.
3. **Number of people present:** The most likely number of people at a site at any one time over the course of a year (N).

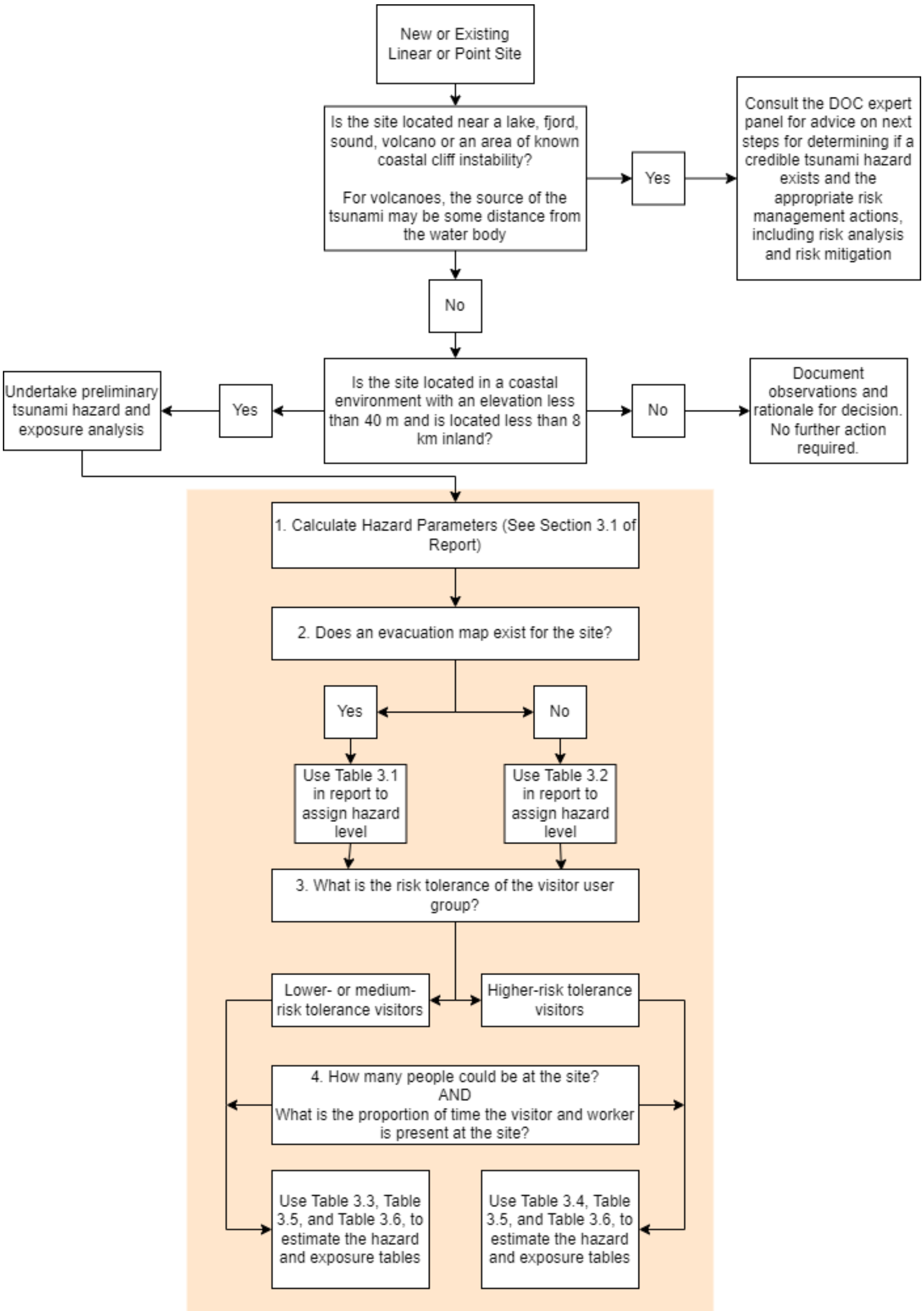

Figure 3.1 Flowchart outlining the process for determining the hazard and exposure class.

3.1 Hazard Level

The hazard calculation is based on a simplified implementation of the 'Level 2' evacuation-zoning methodology described in Section 2.4 (see also MCDEM [2016]). Sites that are above 40 m elevation, or more than 8 km inland, can be immediately identified as 'outside of the hazard footprint' for offshore seismic sources and do not need to be considered further.

The following are the steps that are used to identify the hazard level, which will later be used to determine the hazard and exposure class:

3.1.1 Does an Evacuation Map Exist for the Site?

If there is an evacuation map developed according to NEMA tsunami evacuation map guidelines (MCDEM 2016), then identify whether the site of interest lies within any of the tsunami evacuation zones. If it is outside of all mapped tsunami evacuation zones, then the hazard level is 'Very Low'. No risk mitigation by evacuation is expected for sites with 'Very Low' hazard, although providing information about tsunami may still be helpful to reduce the risk to people travelling closer to the coast from the site.

If the site is within an evacuation area, or if no map exists, then the procedure outlined in Sections 3.1.2 to 3.1.3 should be used to estimate the hazard level (which corresponds to the 'hazard rating' in Section 2.5) at the site. Together with the exposure at the site, this can be used to estimate the hazard and exposure class as described in Sections 3.2 and 3.3.

3.1.2 Calculation of Parameters

1. Estimate the elevation *h* of the site (point feature of interest) above MHWS and the distance *x* of the site to the nearest shoreline [7] (all in metres).
2. Calculate $S_{overland}$ using the formula below:[8]

$$S_{overland} = \frac{h}{2} + \frac{x}{400}$$

3. Is the site within 2 km of a river?[9] If **'no'**, let S = $S_{overland}$ and skip to Step 7; if '**yes**', continue to the next step.
4. Estimate the distance *u* upstream from the river mouth (in metres) and the distance *d* from the site to the nearest point on the river [10] (also in metres).
5. Calculate S_{river} using the formula below:[11]

$$S_{river} = \frac{h}{2} + \frac{u}{800} + \frac{d}{100}$$

7 For the purpose of this analysis, the shoreline includes all tidal coastlines (i.e. including tidal estuaries, harbours, sounds, fjords, lagoons and so forth, as well as the open coast).

8 $S_{overland}$ can be interpreted as the minimum tsunami height at the coast that is potentially capable of inundating a site at elevation *h* above MHWS at a distance *x* from the coast, assuming the tsunami travels over land.

9 'Rivers' should include all watercourses identified as rivers in the NIWA River Maps website https://shiny.niwa.co.nz/nzrivermaps/, although practitioners should have the discretion to additionally include creeks, streams and other waterways if they have reason to believe these would facilitate tsunami inundation.

10 If the site is close to two rivers, or the river has pronounced ox-bows, it may be necessary to repeat Steps 6 and 7 for multiple points on the river(s) and use the lowest value of S_{river} found in Step 7.

11 S_{river} can be interpreted as the minimum tsunami height at the coast that is potentially capable of inundating a site at elevation *h* above MHWS at a distance *u* upstream from the coast by river and at a distance *d* from the river bank.

6. Let S be the smallest out of $S_{overland}$ and S_{river}:

$$S = min\ (S_{overland}, S_{river})$$

7. Using the 2021 NTHM hazard curve data for the site location, find H_{100}^{50}, H_{1000}^{50} and H_{2500}^{84}, where H_{rp}^{pct} is the height of the curve at return period *rp* at level of confidence percentile *pct*.[12]

3.1.3 Estimation of Hazard Level

The evaluation of the hazard from this point proceeds slightly differently according to whether or not a tsunami evacuation map that has been developed according to MCDEM guidelines exists for the site.

3.1.3.1 If a Tsunami Evacuation Map Exists

If a tsunami evacuation map created according to MCDEM guidelines exists, then assess the hazard level using the following table:

Table 3.1 Criteria for finding hazard level when there is an evacuation map available.

Criteria	Hazard Level
Site is outside of all mapped tsunami evacuation zones	Very Low
$S > \mathrm{H}_{1000}^{50}$ but site is within mapped evacuation zone	Low
$\mathrm{H}_{1000}^{50} > S > \mathrm{H}_{100}^{50}$	Medium
$\mathrm{H}_{100}^{50} > S$	High

3.1.3.2 If a Tsunami Evacuation Map Does Not Exist

If a tsunami evacuation map created according to MCDEM guidelines does not exist for the site, then asses the hazard level using the following table:

Table 3.2 Criteria for finding hazard level when an evacuation map is not available.

Criteria	Hazard Level
$S > \mathrm{H}_{2500}^{84}$	Very Low
$\mathrm{H}_{2500}^{84} > S > \mathrm{H}_{1000}^{50}$	Low
$\mathrm{H}_{1000}^{50} > S > \mathrm{H}_{100}^{50}$	Medium
$\mathrm{H}_{100}^{50} > S$	High

Although the tsunami hazard has been categorised into the same labelled categories that are used for the other hazards in this framework (i.e. ‘Very Low’, ‘Low’, ‘Medium’ and ‘High’), there are some important differences that need to be understood. In general in this framework for the other perils, these categories refer to the following return periods: ‘Very Low’ > 10,000 years, ‘Low’ 1000–10,000 years, ‘Medium’ 100–1000 years, ‘High’ <100 years. However, for tsunami:

12 We use H_{2500}^{84} instead of H_{10000}^{50} because the 2021 NTHM only goes up to return periods of 2500 years and because it gives consistency with the definition of the Yellow zone in evacuation maps. The use of H_{2500}^{84} instead of H_{10000}^{50} is part of the approximate nature of this particular methodology, which uses currently available information. See also Footnote 8.

- The boundary between 'Very Low' and 'Low' is set at the 2500-year return period at the 84th percentile of confidence (or at the edge of the Yellow evacuation zone, where an evacuation map is available). This is because the 2021 NTHM only goes up to return periods of 2500 years and in order to maintain consistency with the definition of the Yellow evacuation zone in the MCDEM (2016) guidelines.
- Because of the conservative bias in the use of 2021 NTHM tsunami hazard curves (Section 2.3) and in the evacuation zone attenuation rule (Section 2.4), the correct interpretation is that the 'hazard could potentially be as high as' the indicated hazard category (whether that is 'Low', 'Medium' or 'High').[13]

3.2 Individual Most Exposed

3.2.1 Visitor Exposure

The hazard and exposure class for the individual of interest to the hazard at a site (which may be in a single trip for a one-off visit to the site or per day if the person repeatedly spends time at the same location) is estimated by combining the estimated hazard level with the spatio-temporal probability (proportion of time *P* over 24 hours) that the individual of interest spends at a given hazard level. To calculate the hazard and exposure class for visitors at lower- and medium-risk threshold visitor sites, Table 3.3 is used. To calculate the hazard and exposure class for visitors at higher-risk threshold visitor sites, Table 3.4 is used.

Table 3.3 Hazard and exposure matrix for a visitor (individual of interest) per trip at lower- and medium-risk-threshold sites.

Exposure			Hazard Level			
Proportion of Time Spent at Point Location in 24 Hours	**Equivalent to:**	**Example Activity**	**Very Low**	**Low**	**Medium**	**High**
>0.1	More than 3 hours	Staying in a hut	Class 1*	Class 1	Class 2†	Class 3
0.1–0.01	30 minutes to 3 hours	Picnic spot	Class 1*	Class 1	Class 1	Class 2†
0.01–0.001	2 minutes to 30 minutes	Stopping at viewing area	Class 1*	Class 1	Class 1	Class 1
<0.001	Less than 2 minutes	Walking a track	Class 1*	Class 1	Class 1	Class 1

* Class 1* sites are outside of the tsunami evacuation zone, so risk mitigation by evacuation is not expected. Information and evacuation maps displayed at popular locations in this category may still reduce the risk to visitors or staff who travel to the coast from these sites.

† For medium visitor-risk-threshold sites, Class 2 designation should have lower priority for risk-management actions than higher visitor-risk-threshold sites, including any mitigation.

13 When an advanced risk analysis is made, we anticipate that it may often be found that the preliminary analysis hazard category may have been significantly too high, even at the order of magnitude level.

Table 3.4 Hazard and exposure matrix for a visitor (individual of interest) per trip at higher-risk-threshold sites.

Exposure			Hazard Level			
Proportion of Time Spent at Point Location in 24 Hours	**Equivalent to:**	**Example Activity**	**Very Low**	**Low**	**Medium**	**High**
>0.1	More than 3 hours	Staying in a hut	Class 1*	Class 1	Class 2	Class 2
0.1–0.01	30 minutes to 3 hours	Picnic spot	Class 1*	Class 1	Class 1	Class 2
0.01–0.001	2 minutes to 30 minutes	Stopping at viewing area	Class 1*	Class 1	Class 1	Class 1
<0.001	Less than 2 minutes	Crossing a swing bridge	Class 1*	Class 1	Class 1	Class 1

* Class 1* sites are outside of the tsunami evacuation zone, so risk mitigation by evacuation is not expected. Information and evacuation maps displayed at popular locations in this category may still reduce the risk to visitors or staff who travel to the coast from these sites.

The hazard and exposure classes are related to the risk per trip per day. Details are given in Appendix 1.

3.2.2 Worker Exposure

To calculate the hazard and exposure class for workers, Table 3.5 is used, where the individual of interest is the worker who spends the most time exposed to a tsunami hazard for any one day (i.e. the most exposed worker). As the most exposed worker may spend varying times at the site, the hazard and exposure classes are calculated for the different length of times that a worker may be present at the site, using information provided by DOC. The cumulative time spent over the course of a whole year should be summed to determine the total time exposed (e.g. if a worker is present in a hazard footprint for 10 minutes a day for three months a year, the total time exposed is 15 hours a day). The hazard and exposure class for the individual of interest is estimated by combining the estimated recurrence interval with the spatio-temporal probability of the individual of interest (Table 3.5).

The hazard and exposure classes are related to the AIFR. Details are given in Appendix 1.

Table 3.5 Hazard and exposure matrix for the worker (individual of interest).

Spatio-Temporal Probability of the Worker	Temporal Probability			
Total Time per Year that an Individual Spends at a Given Hazard Level	**Very Low**	**Low**	**Medium**	**High**
More than 3 months year	Class 1*	Class 2	Class 3	Class 4
3 months to 10 days a year	Class 1*	Class 2	Class 2	Class 4
10 days to 1 days	Class 1*	Class 1	Class 2	Class 2
1 day to 3 hours	Class 1*	Class 1	Class 1	Class 2
3 hours or less	Class 1*	Class 1	Class 1	Class 1
><1/2 hour	Class 1*	Class 1	Class 1	Class 1

* Class 1* sites are outside of the tsunami evacuation zone, so risk mitigation by evacuation is not expected. Information and evacuation maps displayed at popular locations in this category may still reduce the risk to visitors or staff who travel to the coast from these sites.

3.3 Societal Hazard and Exposure

The hazard and exposure class for the societal exposure is estimated by combining the hazard level with the most likely number of people at the site at any one time over the course of a year (N), using Table 3.6.

Table 3.6 Matrix for calculating societal hazard and exposure class using the hazard level and exposure *N* as inputs.

Exposure (*N*)	Hazard Level			
	Very Low	Low	Medium	High
>40	Class 1*	Class 3	Class 4	Class 4
5–40	Class 1*	Class 2	Class 3	Class 4
1–4	Class 1*	Class 1	Class 2	Class 3
<1	Class 1*	Class 1	Class 1	Class 2

* Class 1* sites are outside of the tsunami evacuation zone, so risk mitigation by evacuation is not expected. Information and evacuation maps displayed at popular locations in this category may still reduce the risk to visitors or staff who travel to the coast from these sites.

3.4 Risk-Management Actions

The aim of the preliminary screening tool is to identify and prioritise areas within public conservation lands and waters for further risk analysis and risk-management actions. As such, the hazard and exposure classes from 1 to 4 have associated actions for further risk analysis/management. Table 3.5 outlines the actions for each class. Any further risk-management actions, including risk analysis, are at the discretion of DOC on the advice of the expert panel (see the Part 1 report). It is important to note that, at this preliminary screening tool stage, the uncertainties on the information provided will be relatively large.

Table 3.7 Risk-management actions associated with hazard and exposure classes.

Class	DOC Risk-Reduction-Response Categories	Risk-Management Actions
Class 1	No risk reduction required (beyond standard measures) but monitor for change	No further risk analysis required. These sites are outside of the tsunami evacuation zone, so risk mitigation by evacuation is not expected. Information and evacuation maps displayed at popular locations in this category may still reduce the risk to visitors or staff who travel to the coast from these sites.
Class 1*	No risk reduction required (beyond standard measures) but monitor for change	No further risk analysis required. DOC should re-evaluate the risk if there is a change in hazard activity or the number of people exposed.
Class 2	Reduce to as low as reasonably practicable	Basic risk-mitigation analysis required. For tsunami, the basic analysis will determine whether a further quantitative risk analysis (‘advanced’ analysis) is required. The distinction between Classes 2 and 3 is used in the basic analysis to determine the acceptable level of risk mitigation.
Class 3	Continue only after high-level review	
Class 4	Close the site (using a formal closure process)	Urgent action is required. An advanced risk-analysis study is required. The basic risk-mitigation analysis will also be required as a prerequisite in order to provide data to inform the advanced analysis.

4.0 REPORT REQUIREMENTS

The information derived for each feature as set out in Section 3 should be summarised by the consultant in a short letter report. This report should document the data gathered, the logic applied and the conclusion reached so that the decisions that determined the hazard and exposure class can be defended.

The general data to be presented, with reference to the study area boundary, include:

a. Executive summary that outlines the following:
    i. Summary of findings from the report.
    ii. Hazard and exposure classes.
    iii. Assumptions and uncertainty associated with the findings.
b. List of data sources used, including any existing evacuation maps.
c. Description of the calculation route to determine the hazard level.
d. A map showing the hazard footprints in relation to the point location (i.e. a tsunami evacuation map, where one is available).
e. Assessed hazard and exposure classes for the sites with identified tsunami hazard.
f. Recommendations for future analysis / risk mitigation.

Where any of the above is not or cannot be completed, the report should document the missing elements, including an explanation as to why.

5.0 OUTLINE OF BASIC RISK-MITIGATION ANALYSIS

5.1 Background

Effective tsunami risk mitigation requires that:

1. People at the site are able to know that a tsunami is imminent.
2. People are able to make a safe and timely evacuation to a safe location.

The knowledge that a tsunami could be imminent may come from either the natural warning signs of long or strong earthquake shaking, or by receiving a warning in the form of a message, e.g. from Civil Defence.

For local tsunami, i.e. those with less than an hour travel time, it should be expected that the primary warning will come from the natural warning signs, in particular, long or strong earthquake shaking if it is an earthquake-generated tsunami.[14] To mitigate the risk, the occupants of the site must know or be told how to interpret this natural warning.

For regional (1–3 hours) or distant (3 hours plus travel time) tsunami, a warning message must be received in sufficient time to allow people to evacuate to safety. Depending on location and time available, the message could be received by radio or loudspeaker or by sending someone to the location to inform the occupants.

Once a warning has been received, the occupants of the site need to be able to make a safe and timely move to a safe location. This may require building and/or signing evacuation routes appropriate to the occupants of the site. Evacuation routes need to be safe against hazards that may be present post-earthquake, such as rockfall.

Having evacuated to a safe location, it is important that people who have evacuated can be safe from the weather for the duration that they must remain there. This may require providing some shelter appropriate to the site occupants. If people must remain evacuated for long periods, then water supply may also need to be considered.

5.2 Outline

For the basic risk-mitigation analysis, the consultant will need to evaluate the existing and potential methods for:

- Communicating a warning message to the occupants of the site.
- Informing the occupants about what they should do in the event of receiving a warning message or observing a natural warning sign.
- Relocation of the occupants to a safe location with suitable shelter.

14 It is important to stress the ‘or’ in the ‘long or strong, get gone’ message, as there are situations in which the natural warning does not include strong shaking but is only provided by the long earthquake duration. While this could potentially apply to any location, there are two regions of particular concern: the Tairāwhiti (Gisborne / East Cape) region, where there is a historical record of tsunami caused by long but weakly-felt earthquakes (Bell et al. 2014), and the Bay of Plenty (including the eastern Coromandel and Great Barrier Island), where modelling suggests that tsunami from the Kermadec Trench may arrive in less than an hour but not be strongly felt. For these locations, rapid receipt of warning messages is particularly important for mitigating the local tsunami hazard.

These will all need to be considered in the context of the specific tsunami hazard at the site, including the range of potential tsunami sources, which may be informed by the deaggregation charts in the 2021 NTHM and travel times of tsunami from these sources to the site. The potential for other hazards to be present after or following an earthquake (e.g. landslides, bad weather) should also be considered. *A site visit will be needed to perform these evaluations.*

The consultant should consider how well the tsunami risk can be mitigated by relatively inexpensive measures (compared to the cost of an advanced analysis), e.g. provision of evacuation maps and signage, providing satellite phones to hut wardens.

We define ‘good’ mitigation as being able to provide safety for most (>~90%) occupants in most (>~90%) events requiring evacuations.

We define ‘excellent’ mitigation as being able to provide safety for almost all (>~99%) occupants in almost all (>~99%) events requiring evacuations.

If a site with hazard and exposure Class 2 can have ‘good’ mitigation using only relatively inexpensive measures, or a site with hazard and exposure Class 3 can have ‘excellent’ mitigation using only inexpensive measures, then work should proceed towards implementation of those measures.

If those levels of mitigation cannot be achieved, or if the hazard and exposure class is 4, then the risk analysis should proceed to the advanced level.

6.0 CONCLUSIONS

The methodology presented in this report is intended to help DOC prioritise tsunami risk-mitigation measures. It is based on life-safety considerations for visitors and staff and only considers tsunami generated in the ocean or sea by large earthquakes.

The methodology is designed to be applied to specific sites, typically buildings such as huts or visitor centres. It is not designed to assess the cumulative hazard and exposure of, for example, walking along a tramping track. The methodology can be used to assess both societal hazard and exposure, applicable to the total number of visitors to a site, or individual hazard and exposure to staff and long-term visitors.

Applying the process presented here results in a classification that can be used to prioritise locations for mitigation according to the approximate level of tsunami risk and should be used to determine whether further risk analysis is required. It does not include tsunami generated by other mechanisms than by earthquakes, or tsunami and seiches generated in lakes, which should be considered separately.

The assessment of tsunami risk is a procedure that is in its infancy, and many of the techniques and data sources used for this report include major simplifications of complicated and sometimes poorly understood processes. The results must be viewed as approximate, and the methodology should be regarded in terms of representing our ‘best endeavours’ at the current time.

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APPENDICES

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APPENDIX 1 RISK CALCULATIONS FOR HAZARD AND EXPOSURE TABLES

To determine the hazard and exposure classes for visitors, the classes are approximately related to the risk per trip per day (Table A1.1).

Table A1.1 Matrix for calculating the individual hazard and exposure class using the temporal probability and spatio-temporal probability of the individual as inputs, using lower- to medium-risk-threshold sites.

Exposure			Hazard Level			
Proportion of Time Spent at Point Location in 24 Hours	**Equivalent to:**	**Example Activity**	**Very Low**	**Low**	**Medium**	**High**
>0.1	More than 3 hours	Staying in a hut	Class 1*	Class 1	Class 2†	Class 3
0.1–0.01	30 minutes to 3 hours	Picnic spot	Class 1*	Class 1	Class 1	Class 2†
0.01–0.001	2 minutes to 30 minutes	Stopping at viewing area	Class 1*	Class 1	Class 1	Class 1
<0.001	Less than 2 minutes	Walking a track	Class 1*	Class 1	Class 1	Class 1

* Class 1* sites are outside of the tsunami evacuation zone, so risk mitigation by evacuation is not expected. Information and evacuation maps displayed at popular locations in this category may still reduce the risk to visitors or staff who travel to the coast from these sites.

† For medium visitor-risk-threshold sites, Class 2 designation should have lower priority for risk-management actions than higher visitor-risk-threshold sites, including any mitigation.

This relationship assumes that the vulnerability of a person exposed to a tsunami is 0.1.

The relationship can be illustrated by example. Consider a picnic site at the medium temporal probability (100–1000-year return period) that the visitor visits for between half an hour and three hours (0.1–0.01 proportion of a 24-hour period). The annual probability of the hazard occurring at the site is therefore 10^{-2}–10^{-3}. The annual probability is divided by 365 days to calculate the daily probability of the hazard occurring. As vulnerability is assumed to be 0.1, the risk per trip per day is of the order of 10^{-7}–10^{-9}. Taking the geomean of this range on a logarithmic scale and rounding the calculated risk value to the nearest number, the risk per trip per day is derived to be of the order of 10^{-8}.

Table A1.2 shows the resulting relationship between hazard and exposure class and the Annual Individual Fatality Risk (AIFR). The relationship can be illustrated by example. Consider a Department of Conservation hut site at the medium temporal probability (100–1000-year return period) that the worker visits for between half an hour and three hours per day (0.1–0.01 proportion of a 24-hour period) over a three-month period. The total time of being exposed to the hazard is between 1 and 10 days a year. As vulnerability is assumed to be 0.1, the AIFR is of the order of 10^{-5}–10^{-7}. Taking the geomean of this range on a logarithmic scale, the AIFR is derived to be of the order of 10^{-6}.

Table A1.2 Hazard and exposure matrix for the worker (individual of interest).

Spatio-Temporal Probability of the Worker	**Temporal Probability**			
Total Time per Year that an Individual Spends at a Given Hazard Level	**Very Low**	**Low**	**Medium**	**High**
More than 3 months year	Class 1*	Class 2	Class 3	Class 4
3 months to 10 days a year	Class 1*	Class 2	Class 2	Class 4
10 days to 1 days	Class 1*	Class 1	Class 2	Class 2
1 day to 3 hours	Class 1*	Class 1	Class 1	Class 2
3 hours or less	Class 1*	Class 1	Class 1	Class 1
><1/2 hour	Class 1*	Class 1	Class 1	Class 1

* Class 1* sites are outside of the tsunami evacuation zone, so risk mitigation by evacuation is not expected. Information and evacuation maps displayed at popular locations in this category may still reduce the risk to visitors or staff who travel to the coast from these sites.

In the case of tsunami, we have two extra caveats:

- Because of the conservative biases in the procedure for determining the hazard levels for tsunami (see Sections 2.3, 2.4 and 3.1), these should be interpreted as that the equivalent AIFR ‘could potentially be as high as’ these orders of magnitude.
- Instead of a 10,000-year return period, the boundary between ‘Very Low’ and ‘Low’ hazard categories is set at the 2500-year return period at the 84th percentile of confidence (or at the edge of the Yellow evacuation zone, where an evacuation map is available). This is because the 2021 NTHM only goes up to return periods of 2500 years and for consistency with the definition of the Yellow evacuation zone.

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