Framework for evacuation routes

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Nāu te rourou, nāku te rourou, ka ora ai te iwi

With your food basket and my food basket the people will thrive.

Abbreviations and acronyms

CBD	central business district
CDEM	Civil Defence Emergency Management
EMA	emergency mobile alert
FENZ	Fire and Emergency New Zealand
GIS	geographic information system
IHMP	Iwi and Hapū Management Plan
LINZ	Land Information New Zealand
MCDEM	Ministry of Civil Defence & Emergency Management
NEMA	National Emergency Management Agency
VMS	variable messaging signage

Contents

Executive summary

This report sets out a framework and methodology for identifying, planning, designing and assessing emergency evacuation routes. The framework supports planning and preparedness for identifying evacuation routes in the event of a disaster caused by a natural hazard.

An evacuation is the movement of people away from an area facing a potential or imminent threat, which is necessary when there is an unacceptable risk to safety, or the consequences of an emergency have made the area uninhabitable. Evacuation routes include traversing land, water or air, with people travelling on foot or in vehicles, vessels and aircraft. People may use private, public and shared transport options, and routes could cross public or private land.

The objectives for this research study were:

- Identify and examine international and New Zealand experience, and best practice in planning and assessing evacuate routes.
- Establish the ideal characteristics of evacuation routes in New Zealand conditions for particular hazards.
- Construct a framework and methodology for evaluating evacuation routes.
- Test and validate the framework and methodology using two case studies.

The framework is intended for all organisations with an interest or role in evacuation planning, including Waka Kotahi NZ Transport Agency, Civil Defence Emergency Management (CDEM) groups and iwi.

The researchers undertook a review of the literature on evacuation routes and evacuation planning, focusing on current and emerging practices in New Zealand and internationally. The literature review included official guidance, published literature and existing evacuation plans, and identified factors relevant to evacuation route planning, including the characteristics of the communities being evacuated, the evacuation route and the receiving areas. The researchers also carried out a stocktake of existing evacuation route plans prepared by New Zealand CDEM groups and explored methods for modelling evacuation routes. Finally, the literature review considered the role of community, iwi, hapū and marae in an emergency response and evacuation.

The researchers supplemented the literature review by engaging with key stakeholders, including Waka Kotahi and CDEM groups across New Zealand. Key themes to emerge from the stakeholder engagement included:

- the need to understand the communities being evacuated and their transport requirements
- current practices and past experiences in identifying, assessing and publicising evacuation routes
- the need to consider receiving areas and communities, and the role of supporting facilities in enabling evacuations.

An Evacuation Routes Framework was then developed from the literature review and stakeholder engagement. The final framework presented in this report was tested and refined through two case studies.

The framework is divided into three components:

- *evacuation factors* – the factors which must be considered when developing evacuation scenarios
- *evacuation scenario(s)* – how the evacuation might play out
- *evacuation route identification and assessment* – the factors that must be considered when identifying and assessing potential routes.

The framework is dynamic, in that evacuation factors and scenarios may need to be reviewed once potential routes are reviewed and assessed.

Evacuation factors include:

- *hazard characteristics* – these inform the likelihood of the hazard occurring, the area potentially requiring evacuation, and how much coordination of evacuation is possible within the warning time
- *affected population* – this informs the evacuation options to consider, and what support is required to help people access and travel along evacuation routes
- *safe areas, supporting facilities and expected destinations* – to help identify the locations and facilities evacuees are likely to use, pass through, or seek temporary shelter in until the hazard or threat passes.

Evacuation scenarios are different scenarios in which an evacuation may play out. In each scenario there are different drivers and priorities for evacuation, and the ability to coordinate and prepare in advance varies. The evacuation scenarios are:

- *shelter-in-place* – staying in place at home or in other forms of shelter, provided it is safe to do so
- *pre-event, with sufficient warning time* – when there is sufficient warning time to coordinate the pre-evacuation of people within a potential hazard impact area. Evacuation plans can be activated, with people and resources directed to clear and optimise evacuation routes
- *during, or immediately pre-event and post-event* – in this scenario there is either no warning time, or very little warning time. There is little opportunity to prepare routes for evacuation, and the routes available may not be safe or traversable
- *post-event* – this scenario plays out once the immediate threat has passed, where people are likely to attempt to return home, which could be inside or outside the affected area. If supported evacuation is necessary, evacuation routes can open as the hazard footprint and impact becomes apparent.

Evacuation route options can be identified and assessed once potential evacuation scenarios are defined. This should involve:

- reviewing existing evacuation plans
- assessing transport resources and operational requirements (by mode)
- assessing risks and vulnerabilities
- assessing or modelling route demand and capacity
- identifying other priorities for the route
- identifying facilities and supplies en route and at receiving communities.

The report describes each of these points in detail, with examples. It also lists relevant datasets and information sources that support the identification and assessment of evacuation routes.

The Evacuation Routes Framework can be applied pre-event to identify and evaluate potential route options. It can also be applied during an event to help identify and re-evaluate evacuation routes in real time. A process for applying the framework is proposed, which includes the following steps:

1 preparing the necessary inputs, including maps

2 engaging with relevant stakeholders

3 identifying and assessing evacuation routes

4 identifying and implementing actions to address gaps in evacuation routes

5 reviewing, as required.

While this is the desirable process for applying the framework, many organisations involved in evacuation planning have limited resources available, including time and funding. Additional funding and support from central and local government may be required to enable this work to support the implementation of the framework, and to focus effort on the highest risk hazards and potential mass evacuation scenarios.

Two case study areas were selected to test the Evacuation Routes Framework across a range of hazards:

- a Wellington case study, focusing on an earthquake scenario
- a Nelson/Tasman case study, focusing on tsunami, flood and rural fire scenarios.

Recommendations for implementing this research are as follows:

- Investigate how the framework and other learnings from this research can be integrated into existing or proposed guidelines issued by the National Emergency Management Agency (NEMA).
- Share the key findings of the research widely among the transport industry and emergency management sector. This includes examples and learnings from applications of the framework.
- Undertake a further case study application of the framework for a volcanic hazard event, as this type of event was not included in the case studies for this project.
- Support better data sharing across organisations (for improved consistency and availability).

Potential areas for future research are as follows:

- Regarding potentially exposed communities, undertake further research to examine community makeup, vulnerability and dynamics, and the roles of local champions and education programmes in hazard awareness and responses to natural and official warnings to evacuate.
- Expand current research initiatives looking at mass evacuations from large urban centres, for example volcanic activity in Auckland, to other hazard scenarios and population centres. In addition to characterising evacuated populations and transport dynamics, this research should address the impacts of large-scale, potentially permanent population displacements on receiving centres/regions, including local and regional development and exposure to other future hazards.
- Scope the potential value of undertaking collaborative, co-creative research alongside emergency management groups, communities and research organisations into modelling methods for evacuation routes. This may include conventional network-based approaches and state-of-the-art agent-based models that incorporate community knowledge. Assessments of the effectiveness of evacuation signage and public information messaging may also be worth exploring.

Abstract

In a natural hazard-caused disaster, people are evacuated from the affected area if there is an unacceptable risk to their safety, or if the hazards involved render the area uninhabitable. Evacuation routes enable people to travel to safety, which may include crossing land, sea or air, using a range of transport modes.

This report sets out a framework and methodology for identifying, planning, designing and assessing emergency evacuation routes. The framework supports planning and preparedness for identifying evacuation routes in the event of a natural disaster.

The research includes a literature review of evacuation routes and evacuation planning, focusing on current and emerging practices in New Zealand and internationally. The literature review was supplemented through engagement with key stakeholders, including Waka Kotahi and Civil Defence and Emergency groups across New Zealand. The Evacuation Routes Framework was developed from findings in these initial stages.

The Evacuation Routes Framework described in this report is divided into three parts: ‘evacuation factors’, which details factors that must be considered to develop evacuation scenarios, ‘evacuation scenarios’, for which the drivers, priorities and ability to coordinate and prepare in advance vary, and ‘evacuation route identification and assessment’, which identifies and describes the factors that must be considered when identifying and assessing potential routes. Detailed guidance is provided for each component and factor.

The framework can be applied pre-event to identify and evaluate potential route options, or during an event to assess potential routes in real time. A process is proposed for applying the framework in a pre-event scenario. Two case studies demonstrate how the framework can be applied for different environments and hazards.

The report also makes several recommendations towards the future implementation of the framework and identifies areas for further research.

1 Introduction

Waka Kotahi NZ Transport Agency contracted Abley Limited to develop a framework and methodology for planning, designing and/or assessing the efficacy of emergency evacuation routes. The framework is intended to be specific to the New Zealand context, to support planning and preparedness for identifying evacuation routes should they be required.

The objectives for this research study were:

- Identify and examine international and New Zealand experience, and best practice in planning and assessing evacuate routes.
- Establish the ideal characteristics of evacuation routes in New Zealand conditions for particular hazards.
- Construct a framework and methodology for evaluating evacuation routes.
- Test and validate the framework and methodology using two case studies.

The framework is intended for all organisations with an interest or role in evacuation planning, including Waka Kotahi, Civil Defence Emergency Management (CDEM) groups and iwi.

The research underpinning this report was undertaken in late 2020 and 2021, and involved several stages of work, which included a literature review, stakeholder engagement, data review, the development of a draft Evacuation Routes Framework, followed by two regional case studies that helped refine the final framework. Each stage of the research was reported separately to the Project Steering Group.

1.1 Report structure

This report is organised as follows:

- Chapter 2 is a review of the literature on evacuation routes and evacuation planning, focusing on current and emerging practices in New Zealand and internationally.
- Chapter 3 summarises stakeholder feedback on the identification and assessment of evacuation routes, including local experiences and plans, and wider considerations such as community resilience and preparedness, evacuee welfare and the roles of different response agencies.
- Chapter 4 sets out the Evacuation Routes Framework developed from the learnings detailed in previous chapters and refined through the case studies (chapter 6).
- Chapter 5 describes a process model for applying the framework pre-event.
- Chapter 6 presents the findings of two regional case studies covering earthquake, tsunami, flood and fire evacuation scenarios in Wellington and Nelson/Tasman.
- Chapter 7 presents the conclusions and recommendations arising from the research.

2 Literature review

This chapter explores the literature on evacuation routes and evacuation planning, focusing on current and emerging practices in New Zealand and internationally. The following key research questions were developed to frame the literature search:

- What guidance for planning or evaluating evacuation routes already exists? Are there established/emerging methods for modelling these routes?
- What factors/characteristics must be considered when planning and evaluating evacuation routes for different types of hazard? What factors are most/least important?
- What are the key hazards in New Zealand for which evacuation planning is required?
- Where do evacuation routes or plans already exist in New Zealand? Where are evacuation routes required/planned?
- What are the established/emerging methods for modelling evacuation routes?
- What learnings can we extract from successful/unsuccessful evacuations?
- What are the inter-dependencies with other infrastructure and community services?
- What data/information is required to plan or evaluate an evacuation route? What is currently available and what is missing/needed?
- What are the key ingredients to ensuring evacuation routes are used in an event as intended?
- To what extent is community input necessary?

The researchers reviewed a combination of official guidance, published literature and existing evacuation plans and did a stocktake of existing evacuation route plans prepared by New Zealand CDEM groups.

2.1 Defining evacuations

For the purposes of this research, and drawing on existing literature, ‘evacuation’ is defined as the rapid movement of people out of an area of risk due to:

- a potential or imminent threat that poses unacceptable risks for the safety of people remaining in the area, or
- the consequences of an emergency rendering the area uninhabitable (Australian Institute for Disaster Resilience, 2017; Ministry of Civil Defence & Emergency Management (MCDEM), 2008; New Zealand Government 2015; Nunes et al., 2015).

Typically, evacuees make an eventual safe and timely return to their communities.

Evacuations can be further defined as:

- *mandatory evacuation* – when people are directed by emergency response agencies to leave hazardous areas when it is believed the risk to residents is too great to allow them to remain where they are
- *voluntary evacuation* – when people leave their current location because of actual or perceived risk without being directed to do so. This is a form of *spontaneous evacuation*
- *shadow evacuation* – when people outside evacuation zones choose to leave despite the fact they are not threatened by the hazard. This is another form of *spontaneous evacuation.*

2.2 Existing guidance

A review of the literature highlighted there is no single framework or approach for evacuation route planning and evaluation, although common themes were identified.

Four relevant international documents were reviewed. These documents address the wider process of planning for mass evacuations, with route planning a subset of activities within that. Of the documents reviewed, Nunes et al. (2015) and the Australian Institute for Disaster Resilience (2017) are the most comprehensive, with the Department of Homeland Security (2019) less so, but still containing useful information along similar lines. The Los Angeles Operational Area Alliance (2011) is quite specific in its guidance for evacuation of large urban centres.

Three New Zealand guidance documents were reviewed.

- The *Guide to the National CDEM Plan* (New Zealand Government, 2015) supports the National CDEM Plan 2015, which outlines principles, arrangements and frameworks applicable to emergency management.
- *Mass evacuation planning. Director's guideline for CDEM groups* (MCDEM, 2008) provides advice, templates and models for CDEM groups (regional level) and local authority emergency management officers (city and district level) to facilitate the development of comprehensive evacuation plans. This guideline includes information for planning the evacuation phase, including considerations for evacuation routes.
- *Tsunami evacuation zones. Director's guideline for CDEM groups* (MCDEM, 2016) provides more targeted guidance for tsunami evacuation in New Zealand, including a consistent approach for developing evacuation zones, maps and public information.

Together, these three guides highlight the importance of evacuation route planning and identify several necessary considerations which are included in section 2.4 below.

At a local level, regional CDEM plans provide guidance in terms of regional objectives and priorities for evacuation planning (as covered in section 2.5 below).

2.3 Hazards that require evacuation planning in New Zealand

MCDEM (2008) highlights that the need for hazard-specific evacuation plans is dependent on the results of regional hazard and risk assessments.

Guidance and existing CDEM plans consistently identify the following key hazards in New Zealand for which evacuation planning is required:

- tsunami
- earthquake
- volcanic activity
- flooding (riverine and flash flooding)
- widespread heavy storms
- fire (urban and rural /wildfire)
- landslip/landslide.

Note that this list is not definitive. Lifeline utility and infrastructure failure, hazardous substance spills, terror threats and civil unrest are also identified as hazards that may lead to evacuation.

2.4 Factors and characteristics for evacuation routes

Key factors and characteristics for planning and evaluating evacuation routes are grouped by theme: evacuation arrangements, the community affected, the evacuation route itself and the receiving area/community.

2.4.1 Evacuation arrangements

Mandatory evacuations are addressed in legislation in the New Zealand Civil Defence Emergency Management (CDEM) Act 2002. Section 86 of the Act – Evacuation of premises and places states:

> *If a state of emergency is in force and, in the opinion of a Controller or any constable, the action authorised by this section is necessary for the preservation of human life, that person or a person authorised by him or her may direct, within the area or district in which the emergency is in force,—*
>
> *(a) the evacuation of any premises or place, including any public place; or*
>
> *(b) the exclusion of persons or vehicles from any premises or place, including public places.*
>
> *This legislation empowers Emergency Management Controllers at the national, regional and local level to issue evacuation orders and oversee their execution, which includes liaising with other agencies (eg Police, Fire and Emergency New Zealand).*

As stated in New Zealand mass evacuation guidance (MCDEM, 2008), mandatory evacuation places a great burden on emergency service resources and places a duty of responsibility on authorities to ensure people who are evacuated are cared for. Further considerations for both mandatory and voluntary evacuations are presented below.

2.4.2 Communities to be evacuated and their transport needs

MCDEM (2008) highlights the importance of considering the nature of the hazard and demographics of the affected population in determining evacuation routes. Factors relating to the communities being evacuated and their transport requirements can be grouped into:

- hazard characteristics
- population exposure, vulnerability, preparedness
- resource considerations.

Each factor is complex but understanding them is important when determining suitable receiving areas and evacuation routes (refer sections 2.4.3 and 2.4.4). These factors also provide insights into how a community is expected to behave and respond to natural cues or official warnings and evacuation orders, and how evacuation route planning can be developed to meet specific community needs.

2.4.2.1 Hazard characteristics

The type of hazard can inform the type of evacuation, for example whether an immediate or staged evacuation is more suitable. Hazard-related factors include (Global Facility for Disaster Reduction and Recovery, 2014):

- frequency, which will determine if the hazard is high impact/low probability (eg tsunami) or low impact/high probability (rain storm within design parameters of storm water systems)
- footprint, or spatial extent
- intensity of hazard within its footprint, eg flood water depth, earthquake shaking intensity
- warning time, eg weather and flood hazards can be forecast, whereas earthquakes occur without warning. Tsunami can have a precursor earthquake to provide warning (near source), and official warnings may be possible for regional- and distant-source tsunami to enable evacuation hours before the event. Volcanic eruptions may have precursor seismic activity that serves as a warning.

2.4.2.2 Population exposure, vulnerability and preparedness

Understanding the locations and needs of potentially exposed populations and vulnerable people is a key component of evacuation planning (Barnhill, 2020; Los Angeles Operational Area Alliance, 2011; MCDEM, 2008). The following factors were identified to inform population preparedness and vulnerability:

- **geographic area affected** including the size of the area, topography, population and specific infrastructure within the area (MCDEM, 2008; Nunes et al., 2015)
- **evacuation zones**, which can be used to manage the logistical demands of evacuation (MCDEM, 2008; Nunes et al., 2015). Evacuation zones classify areas by risk, allowing jurisdictions to prioritise the evacuation of vulnerable areas first and reduce the need to evacuate large areas not yet exposed to the threat (Australian Institute for Disaster Resilience, 2017). The New Zealand tsunami evacuation zone director's guideline (MCDEM, 2016) provides a consistent approach to establishing and mapping tsunami evacuation zones using a three-zone approach. The red zone is the highest risk area, where people should evacuate if they have a natural or official warning. The orange zone is used for official warnings of distant or regional source tsunami and the yellow zone encompasses all maximum credible tsunami events. In the event of a long and/or strong earthquake, people should evacuate from all zones immediately. The guideline also seeks to align evacuation plans with official warnings and create public information for evacuations
- **time of day/year** (Nunes et al., 2015), which influences population exposure
- **community and individual preparedness**, including shared responsibility for their own safety, ability to act on advice and cues, community experience with similar threats, familiarity with evacuation plans and understanding likely responses to threat (Australian Institute for Disaster Resilience, 2017; Barnhill, 2020; Nunes et al., 2015)
- **organisations with specific evacuation needs**, which may include health care, education, prison and aged care facilities (Australian Institute for Disaster Resilience, 2017; Barnhill, 2020; MCDEM, 2008; Nunes et al., 2015). Specific evacuation plans for such facilities should establish how people will be managed during all stages of the evacuation process, including routes (Australian Institute for Disaster Resilience, 2017). These plans should be considered along with broader evacuation frameworks to ensure timely movement to appropriate safe zones (Nunes et al., 2015)
- **location of vulnerable groups and people needing transport support**, including people who are aged or infirm, remote or isolated, low income, women, children, persons with disabilities, people in prisons or residential institutions, tourists and ethnic minority groups (who may require translation services) (Australian Institute for Disaster Resilience, 2017; MCDEM, 2008; Nunes et al., 2015). It is also important to consider that some able-bodied individuals who do not need transport support may choose not to self-evacuate due to fear or other reasons (Nunes et al., 2015). Registries identifying people with disabilities and requiring support provide an additional tool to identify, locate and assist people during

emergency events; however, not all individuals are enrolled in such registries (Los Angeles Operational Area Alliance, 2011). Mason et al., (2019) explain how social vulnerability indicators have been developed to measure the exposure, susceptibility and resilience to natural hazards for different populations, including children, older adults and people with complex health needs. Mason et al., (2019) also consider measures of social connectedness and indicators that assess knowledge, awareness and skills to cope.

- **pet and animal ownership** – evacuees will often seek to bring their animals with them, and many will ignore evacuation orders if forced to leave their pets or livestock behind (Australian Institute for Disaster Resilience, 2017; Nunes et al., 2015)
- **potential for shadow evacuations**, where some residents beyond the evacuation zone boundaries will also choose to evacuate (Blake et al., 2017).

2.4.2.3 Resources

The availability of resources and facilities to support evacuation also has an impact on the planning and operation of evacuation routes. Resource-related factors include:

- **response services within the evacuation and neighbouring areas**, including emergency services and volunteer organisations (MCDEM, 2008)
- **early warning measures and communication methods** (Nunes et al., 2015). Some communities, such as those without access to telecommunications, are particularly vulnerable in emergencies (Northland CDEM Group, 2016). Warnings can be classified as natural (eg earthquake shaking prior to tsunami hazards), official (eg alerts issued via broadcast and other media, sirens and emergency mobile alerts), or informal (eg word-of-mouth, social media) (Barnhill, 2020; Tilley, 2020).
- **available transport modes and the coordination of these.** Evacuation transport options can include private and public transport, buses, trains, taxis, volunteer drivers, aircraft, helicopters and boats, along with cycling and by foot (Barnhill, 2020; MCDEM, 2008; Nunes et al., 2015). Some modes of transport may be unavailable depending on the nature of the hazard event, for example due to road damage caused by an earthquake. CDEM groups and emergency services can establish memoranda of understanding to commission, discontinue or alter services such as public transport in the event of evacuations (MCDEM, 2008).
- **assembly areas within the evacuation area**. Assembly areas are central locations where evacuees who require assistance to evacuate can gather and be transported out of the area[1]. These areas serve as temporary safe zones for evacuees before they are evacuated from the area (Los Angeles Operational Area Alliance, 2011). They should be large and well-known sites, such as shopping centres, libraries and schools. Infrastructure support resources for assembly areas are important, for example providing water, toilets and backup power; however, not all designated assembly areas (such as school sports fields) may have these facilities. It is important to note that people with disabilities may require assistance to reach assembly areas. Memoranda of understanding, implemented by relevant emergency management entities, can be used to formalise use of facilities for assembly areas in the event of an emergency (MCDEM, 2008).

[1] Note this is a different interpretation to ‘assembly areas’ as defined in New Zealand’s Coordinated Incident Management System (CIMS), Assembly areas in CIMS are areas managed by logistics teams, where resources are organised and prepared for deployment.

2.4.3 Evacuation route

Characteristics and factors to consider when determining a suitable evacuation route are presented below. Many of these will be considered by the responsible emergency management entity at the national, regional or local level:

- **evacuation signage and markings** (Australian Institute for Disaster Resilience, 2017), which raise public awareness and increase the efficiency of the evacuation. Signage may be permanent or stored for implementation in the event of an evacuation. Signs should be coordinated with the relevant road controlling authority (MCDEM, 2008). MCDEM (2008) also recommends that evacuation signage is standardised. New Zealand's tsunami risk management programme identifies signage as a key mechanism to support public information and response to tsunami by delineating evacuation zones, routes and safe areas (Tilley, 2020). Painted blue lines are used in some areas of New Zealand to raise awareness and identify safe areas for tsunami evacuation (Tilley, 2020). Consideration may be given to having multi-lingual signs
- **estimated evacuation clearance times** (Australian Institute for Disaster Resilience, 2017). Using an evacuation timing model can assist in determining the time available for ordering an evacuation, planning phased evacuations and monitoring the progress of the evacuation. Factors to be considered include the time required to mobilise resources and disseminate evacuation warnings, a warning lag, the movement of people to outside the evacuation zone and traffic safety (MCDEM, 2008; Nunes et al., 2015)
- **resilience and vulnerability of the transport network to hazards**, including potential for areas to be isolated due to road network damage and the location of potentially hazardous sites such as bridges and tunnels (Los Angeles Operational Area Alliance, 2011; MCDEM, 2008; Northland CDEM Group, 2016). For evacuations during volcanic eruptions, road network managers should consider dampening road surfaces to reduce ash remobilisation and improve visibility (Blake et al., 2018). Consideration also needs to be given to whether road surfaces are damaged or not (eg earthquake liquefaction or the impact of landslides) and how this will affect necessary modes of transport
- **interdependencies with lifeline utilities**, for example: traffic signals, electronic signage and fuel pumps require electricity to function, as do telecommunications and broadcast systems for information sharing, along with water supply for formal assembly areas. Damage to pipelines may affect fuel supply (Los Angeles Operational Area Alliance, 2011; New Zealand Lifelines Council, 2020)
- **route length**. Routes should ideally be the shortest path to the designated destination areas (Los Angeles Operational Area Alliance, 2011; Nunes et al., 2015), although this may depend on the nature of the hazard. For example, pedestrian evacuation from near-source tsunami should be the shortest path, whereas this may not be necessary with longer warning times
- **traffic demand**, including modal split (ie percentage of evacuees in private vehicles versus public transport, pedestrians etc) (Australian Institute for Disaster Resilience, 2017)
- **transport network capacity** for the modes of transport being used (Australian Institute for Disaster Resilience, 2017; Los Angeles Operational Area Alliance, 2011; MCDEM, 2008; Nunes et al., 2015). Consideration must be given to pedestrian, cycle or other modes in case road networks are damaged or impassable to vehicle traffic (eg post-earthquake)
- **traffic management measures** to control flow and increase capacity for events with sufficient warning time, including separation of different modes (for example pedestrians and vehicle traffic), exclusive bus routes, phased evacuation, use of designated markings, road barriers, reduced speed limits, entry restrictions and contra-flow lanes (Australian Institute for Disaster Resilience, 2017; Los Angeles Operational Area Alliance, 2011; MCDEM, 2008; Nunes et al., 2015). Contra-flow lanes enable lane flow

to be reversed and can increase capacity for egressing traffic. The Australian Institute for Disaster Resilience (2017) highlights the need to consider the resources required to initiate traffic management measures, including personnel. The Department of Homeland Security (2019) also identifies the need to provide ingress routes for emergency services

- **ability to disseminate real-time messages** to evacuees en route. Static and variable messaging signage can guide evacuees to safe zones, which can be particularly important for self-evacuees (Australian Institute for Disaster Resilience, 2017; Los Angeles Operational Area Alliance, 2011; Nunes et al., 2015; Tilley, 2020). For evacuations during volcanic eruptions, there should be advisories to use headlights and to ensure sufficient vehicle spacing and stopping distances (Blake et al., 2018)
- **lighting along the route**, for safety and security (MCDEM, 2008)
- **welfare and resources available en route**, such as fuel, toilets, water, shelter and emergency responders (Department of Homeland Security, 2019; MCDEM, 2008; Nunes et al., 2015). Fuel management is particularly important for large-scale evacuations. Managing fuel supplies in advance of an evacuation can mitigate the risk of fuel shortages, which affects travel patterns and slows evacuation. Key considerations are locations of fuel supplies along routes, routing to pass through communities with multiple fuel supplies, coordination with private sector partners and collaboration with fuel suppliers to install generators along evacuation routes to ensure fuel accessibility in the event of electricity loss (Department of Homeland Security, 2019)
- **contingencies and alternative routes** for use should the planned route(s) be compromised, for example due to vehicle breakdowns, road blockages and crashes (Australian Institute for Disaster Resilience, 2017; Department of Homeland Security, 2019)
- **traffic monitoring and damage assessment** during evacuation (Los Angeles Operational Area Alliance, 2011)
- **feedback**: it is desirable to gather information and feedback from evacuees about the evacuation route(s) (Australian Institute for Disaster Resilience, 2017)
- **end points** including the location of receiving areas and the location of assembly points within the evacuation area. The expected transport demands at these points is also important (Australian Institute for Disaster Resilience, 2017; Los Angeles Operational Area Alliance, 2011).

2.4.4 Receiving areas and receiving communities

Important factors and characteristics for determining suitable receiving areas include:

- **proximity to the evacuation area**, including ensuring the area is located outside the expected hazard impact area, while respecting the general preference for evacuees to remain as close to the evacuation site as possible (Australian Institute for Disaster Resilience, 2017; Nunes et al., 2015)
- **presence of vertical evacuation structures** for use in the event of a tsunami (Bay of Plenty CDEM Group, 2018; Federal Emergency Management Agency, 2019; MCDEM, 2016). Vertical evacuation structures must adhere to design standards to ensure resilience to earthquake shaking and tsunami loading; consideration must also be given to subsequently evacuating people from these structures
- **risk of damage due to the major hazard** and/or secondary hazards (Nunes et al., 2015)
- **self-shelter options**. Nunes et al. (2015) highlight that informal receiving areas, such as family, friends, local community and faith-based organisations are often the first port of call for evacuees. Self-shelter should generally be encouraged as it reduces resource requirements and promotes self-efficacy

(Australian Institute for Disaster Resilience, 2017). Considerations for these options include the location of such destinations, including holiday homes and the proportion of people who are likely to make their own arrangements. In addition, people may seek shelter at commercial accommodation they arrange themselves

- **shelter demand and capacity**, taking into account those who are likely to make their own arrangements (Nunes et al., 2015). This should include consideration of parking capacity if vehicular evacuation is expected (Australian Institute for Disaster Resilience, 2017)
- **iwi and marae resources** and their role in welfare and emergency response. Experience shows that during disruptive events they have a key role in looking after their kaumatua and kuia, and whanau, and they also open their marae to support the wider community. This is detailed in section 2.10.2
- **safety and security** including safe spaces for children and people with special needs, survivors of family violence and for people of diverse cultural, gender and sexual identities (Australian Institute for Disaster Resilience, 2017; Nunes et al., 2015). This may also be facilitated by having multi-lingual signage
- **potential negative impacts on hosting community**, for example how the influx of a large number of evacuees affects the work, school and social arrangements of those in the host community (Nunes et al., 2015)
- **accessibility for people with disabilities** (Australian Institute for Disaster Resilience, 2017; Nunes et al., 2015)
- **pre-agreements or memoranda of understanding** with likely receiving sites, such as schools, marae and places of worship. Liaising with these organisations can also assist in understanding attitudes towards displaced populations and identification of support needs (Nunes et al., 2015)
- **ability to provide for basic human needs**, including electricity and water, and/or the ability to connect to emergency supplies, bedding, heating/cooling, toilet and washing facilities (Australian Institute for Disaster Resilience, 2017; Nunes et al., 2015)
- **ability to accommodate welfare and support services**, such as first aid, counselling, information and referral, interpretation, and legal services (Australian Institute for Disaster Resilience, 2017; Nunes et al., 2015)
- **access to transport** to local population centres (Australian Institute for Disaster Resilience, 2017)
- **potential duration** of displacement period (Nunes et al., 2015)
- **special shelter arrangements for vulnerable individuals/groups** where basic shelter may be inappropriate (Nunes et al., 2015). This includes arrangements for evacuees who require special care, such as aged care facilities and people with chronic health issues, mental health issues or addiction. The capacity of options such as hospitals and aged care facilities should be identified (Australian Institute for Disaster Resilience, 2017)
- **sheltering for livestock and pets** (Nunes et al., 2015).

2.5 Existing evacuation routes and plans in New Zealand

The CDEM Act 2002 requires CDEM groups to prepare and approve a CDEM plan, which must specify the hazards and risks to be managed by the group (NEMA, 2020). Several of the 16 regional CDEM groups in New Zealand have developed evacuation plans and/or routes as part of their CDEM plan, sometimes in collaboration with partner agencies such as the New Zealand Police and Fire and Emergency New Zealand (FENZ).

A stocktake of publicly available evacuation plans and routes for each CDEM group is provided in Appendix A. In addition to the documents listed in this appendix, several CDEM groups and local authorities have additional evacuation plans that are not currently publicly available. For example, Northland CDEM Group (2016) refers to specific alternate route planning that is available for emergency services and response agencies.

Based on the CDEM stocktake, it is evident that evacuation plans and routes for tsunami scenarios are more developed than for other hazards. Generally, the existing public tsunami evacuation routes have a simple focus on moving to higher ground, which is often facilitated by permanent signage, markings and maps. Initiatives such as the 'Long? Or Strong? Get Gone' campaign[2], and the 'New Zealand Shakeout and Tsunami Hīkoi'[3], have been effective in raising public awareness and helping spur community response in recent tsunami events.

It should also be noted that certain groups and organisations may have specific evacuation plans. For example, hospitals, marae, schools and prisons may have their own plans.

2.6 Methods for modelling evacuation routes

Evacuation models simulate human behaviour and determine the time required to reach safe areas and optimise evacuation routes using a combination of behavioural and physical factors (Barnhill, 2020; Tilley, 2020). Outputs of these models can be used to plan evacuation route options and evaluate existing routes, meaning they are highly relevant to this research.

There is a voluminous amount of academic literature on evacuation modelling from a transport engineering perspective, but little evidence this is being informed by, or is informing, practical evacuation planning conducted by emergency response or transport agencies.

Within New Zealand, a variety of modelling methods including agent-based, geospatial least-cost distance and network-based modelling have been used to inform evacuation planning (Table 2.1). These methods have been used to simulate evacuation time, shortest paths and the influence of population and community factors on evacuation scenarios (Tilley, 2020). Tilley (2020) also provides an overview and example applications of these methods for tsunami evacuation, with advantages and disadvantages of each approach in Table 2.1.

- Agent-based modelling to simulate pedestrian evacuation of Petone, Napier and Sumner, Christchurch supports the research aims to model evacuation time, identify congestion points, gather community feedback and improve evacuation efficacy (Power et al., 2019).
- Least-cost distance modelling is a well-established method for tsunami evacuation modelling. It applies travel speeds to determine the likely route from origins to safe areas. The method has been applied to scenarios for Napier and Sumner and Wellington (Tilley, 2020).
- Network modelling is commonly used in traffic modelling. In 2012, a GIS tool 'ArcCASPER' (Capacity-Aware Shortest Path Evacuation Routing) was developed. The tool uses network capacity, evacuee density and congestion potential, and was recently applied to estimate pedestrian evacuation times for Tauranga City and vehicle evacuation times for coastal suburbs of Christchurch (Tilley, 2020).

[2] https://getready.govt.nz/emergency/tsunami

[3] https://getready.govt.nz/involved/shakeout/

Table 2.1 Comparison of evacuation modelling methods (adapted from (Tilley, 2018, 2020).)

Method	Advantages	Disadvantages
Agent-based modelling	• Has ability to control agent behaviour to simulate 'real-life' situations for different temporal scales. • Models various modes of evacuation (vehicle and pedestrian). • Can model individual evacuee behaviour.	• Significant amount of data is needed to model evacuee behaviour. • Models can be difficult to disseminate. • Difficult to validate and reproduce the model. • Software is expensive and not easily accessible.
Least-cost distance modelling	• Multiple modes of transport can be mapped. • Slope and landcover data can be used to calculate travel costs. • Compatible with ArcGIS.	• Limited to shortest path approach. • Travel cost is calculated for each raster cell which requires high-resolution data to ensure accuracy of results – this is not always easily accessible. • Difficult to validate model. • Only considers pedestrian evacuation.
ArcCASPER	• Open-source GIS extension tool available for anyone to download and use: however, it is only compatible with ArcGIS. • Three different traffic model algorithms available. • Easy to replicate models. Can be used to model various scenarios. • Output allows for the visualisation of route statistics and route congestion times, based on a world traffic estimation algorithm. • Can model various modes of evacuation (vehicle, pedestrian).	• Only compatible with the network analyst tool in ArcGIS • Requires a network dataset with no accuracy, alignment, or topological errors to function properly. • Can have shortcomings during the modelling process, which include optimising every road within the network, not considering complex turn restrictions, node breaks in road network. • Only optimises road network.

MCDEM (2008) also provides an evacuation timing model (refer Appendix B for details). To inform the movement component of the timing model, the guideline provides capacities to calculate indicative travel times for travel by road.

2.7 Learnings from evacuations

Records, debriefs and evaluations of past evacuations can identify successes and opportunities for improvement. The few published documents on route evaluations are official reviews of mass evacuation incidents, of which routes are a part, and community evaluations of routes proposed by researchers. Therefore, evaluation can mean different things in difference contexts. These contexts are:

- **Pre-event expert assessment.** This is the evaluation of routes, proposed by emergency response and evacuation coordination agencies by independent experts, for example representatives from other agencies, consultants and academic researchers.
- **Pre-event community assessment.** This is the evaluation of routes proposed by emergency response and evacuation coordination agencies, or researchers, by the communities affected.
- **Post-event assessment.** This is the official evaluation of established evacuation routes after a hazard event.

An example of post-event assessment is the US Department of Transportation/US Department of Homeland Security (2006) review of evacuations from Hurricanes Katrina and Rita on the United States Gulf Coast. Experiences in New Orleans in 2005 (Hurricane Katrina) accentuated the need to include all modes of transport in evacuation plans. A large proportion of the population in New Orleans could not evacuate in personal vehicles and the city was unprepared to evacuate so many persons using other modes. This report found that an important lesson was the need to have food, water, restrooms, fuel and shelter opportunities along evacuation routes.

Post-event debriefs have also been used within New Zealand to identify opportunities for improvement. For example (although not publicly available), the Northland CDEM Plan (Northland CDEM Group, 2016), which highlights the Northland Lifelines Group's debrief of a 2014 storm event, was used to inform their Lifelines Group Severe Event Plan[4] published in December 2014.

Another retrospective evaluation was undertaken of the tsunami evacuation that occurred in Christchurch, New Zealand, in November 2016. A review published the following year found that despite the evacuation maps released by various agencies, most residents did not understand where the evacuation zone was, what evacuation routes they needed to follow or to where they needed to evacuate (Christchurch City Council, 2017). The confusion was exacerbated by continuous then intermittent use of sirens. The review recommended that an evacuation plan specific to each community be co-created among agencies and residents (community evacuation plans). The community evacuation plan should include methods of evacuation (for example by foot, cycling) and specific exit routes that evacuees can follow to reduce traffic congestion, where possible. Additionally, the community evacuation plan should cater for the evacuation of vulnerable residents and visitors who are not able to self-evacuate. Consideration should be given to whether the community evacuation plan should cater for night versus day scenarios. Additionally, the evacuation of pets should be incorporated into each community evacuation plan.

An example of communities evaluating routes was also undertaken in New Zealand (Power et al., 2019). A research programme entitled Quicker, Safer Tsunami Evacuations, led by the government geoscience agency GNS Science, conducted agent-based modelling to simulate pedestrian evacuation from coastal suburbs with tsunami exposure in Petone (Lower Hutt), Napier and Sumner (Christchurch). The models were presented to the community via a series of local workshops, in which residents had the opportunity to provide feedback on model realism and identify additional pedestrian evacuation routes to incorporate in the models. The programme has significant potential to inform official local evacuation route planning and workshop attendees benefited by becoming more aware of the potential hazards and being prompted to consider their own evacuation plans.

Barnhill (2020) highlighted the limited studies on tsunami evacuation behaviour in New Zealand. While not necessarily relating to past events, Barnhill identified key themes from several studies, including 'reliance on using cars to evacuate, delayed evacuations due to gathering items… and checking on others, an expectation on receiving an official warning and a low-risk perception of tsunami due to the infrequency of events'. Lessons from evacuations due to tsunami generated by the 2016 Hurunui/Kaikōura earthquake included contradictory information sources causing confusion about whether evacuation was required, the evacuation zones and warning methods (Barnhill, 2020). In a post-event survey for Petone and Eastbourne in the Hutt Valley, Wellington region (Blake, 2018), most respondents evacuated, but only a third evacuated within the 10-minute natural warning evacuation threshold recommended for local-source tsunamis. Most used vehicles to evacuate, causing congestion. This study highlighted the need to better engage communities to best respond to natural and official warnings.

[4] No longer available online

While several learnings from previous evacuations are publicly available, it is likely that key authorities and stakeholders have internal debriefs that are unpublished. Findings from previous evacuations were discussed further in the stakeholder engagement phase of the research (refer chapter 3).

2.8 Interdependencies

The term ‘interdependencies’ is used to describe lifeline utilities, networks and infrastructure that rely on other services to function. There are several interdependencies supporting infrastructure and community services along evacuation routes and in receiving areas. CDEM group plans highlight several interdependencies, including access to telecommunications, electricity, gas, fuel, water supply and wastewater (Nelson Tasman CDEM Group, 2018; Northland CDEM Group, 2016).

The *New Zealand critical lifelines infrastructure national vulnerability assessment* (New Zealand Lifelines Council, 2020) summarises interdependencies among lifeline utility networks for business-as-usual and disaster scenarios. The results highlight that electricity, roads, fuel and telecommunications become increasingly relied upon in disasters. Blake et al. (2017) also emphasise that electricity supply is a key interdependency for land transport and evacuation. Electricity is required for traffic signals, variable message signage, fuel pumping and payment. Additionally, it is also required for some rail network operations.

Waka Kotahi recently developed a method for quantifying transport interdependencies (Hughes et al., 2020). While not specific to evacuation routes, the research identifies physical, digital, geographic and organisational interdependencies, and proposes a criticality and risk assessment approach to understand and manage interdependencies. The approach is yet to be piloted.

2.9 Community input

Community input is important when planning and evaluating evacuation routes. The process of planning is commonly considered of equal importance to the plan itself, primarily due to the value of community input. The benefits of community input include:

- developing ‘buy-in’, improving hazard awareness and personal readiness, increasing understanding of evacuation plans and fostering shared responsibility
- agreeing roles and responsibilities
- gathering local knowledge and information, often through mapping activities, including identification of hazard-prone areas, vulnerable communities, people who may require assistance to evacuate, and resources and routes
- integrating with specific evacuation plans, for example hospital evacuation plans
- ensuring the plans are culturally appropriate and support the needs of the community (Australian Institute for Disaster Resilience, 2017; MCDEM, 2008).

The Department of Homeland Security (2019) emphasises the need for a whole community approach. Involving stakeholders early and throughout the evacuation route planning process can ensure diverse individual needs and factors are accounted for. Tilley (2020) and Barnhill (2020) also highlight the potential for Māori communities to provide knowledge about interpreting natural warnings.

2.10 The role of iwi, hapū and marae

The vital roles that iwi, hapū and marae play in emergency response and evacuations are being increasingly recognised. Key considerations are presented below.

2.10.1 Understanding local hazards

Iwi and hapū management plans (IHMPs) are planning documents developed by iwi, or individual or collective hapū that address resource management issues in the region/district/rohe. They are lodged with the relevant local authority and must be taken into account when preparing or changing regional policy statements and regional and district plans. IHMPs may detail environmental, cultural, economic and spiritual aspirations and values areas of cultural significance, outline how the iwi/hapū expects to be involved in the resource management, development and protection, and document expectations for engagement and participation. A recent survey of IHMPs in the Bay of Plenty region found that only a minority of IHMPs contained sections on natural hazards, reflecting variable access to good quality information on hazards (Saunders & Kaiser, 2019). Māori communities, due to long-term ancestral connections to land, have often built up significant knowledge (mātauranga) of landscapes and environmental change (Hikuroa, 2017), and have encapsulated landscape characteristics in place names and oral traditions. This mātauranga has rich potential to inform wider understanding of landscape dynamics (Wilkinson et al., 2020), and documenting oral histories of historical disasters is broadening our understanding of their occurrence and impacts, and informing current disaster risk reduction initiatives (King et al., 2007; King et al., 2019; Thomas, 2018; Thomas et al., 2020).

2.10.2 Iwi/hapū responses and marae

Iwi, hapū and their associated marae have played, and will continue to play, a key role in providing shelter to evacuees. In previous earthquake events, they have a proven history of success in organising disaster response to support the wider community (Carter & Kenney, 2018; Kenney, 2015; Kenney et al., 2015; Lambert, 2014). As stated by Kenney & Phibbs (2014): ‘the prompt and effective Māori response to the Christchurch quake has acted as the genesis for increased engagement and collaboration between iwi, local authorities, government and private parties who are engaged in civil/disaster preparedness planning and urban rebuilding in Christchurch’. As pointed out by Carter & Kenney (2018): ‘Māori whānau as well as national and international relational networks constitute an equally significant resource, for ensuring timely operationalisation of personnel and material support in response to a major disaster’. This emphasises that Māori play a key role in wider emergency response and overall risk reduction.

Although historically lacking investment in infrastructure services that other facilities have taken for granted (Te Puni Kōkiri, 2012), marae are often essential resources in disaster response in local communities, due to their ability to host and shelter large numbers of affected and displaced people (Hudson & Hughes, 2007). In addition to marae being provided with tools to consider their own disaster resilience, a focus on improving structural resilience of marae buildings and supporting infrastructure will enable them to sustain this important role (Crum et al., 2019; Te Puni Kōkiri, 2017).

3 Stakeholder engagement

To provide further information for developing a framework for evacuations, a series of conversations were held with stakeholders at Waka Kotahi and CDEM groups across New Zealand. CDEM were interviewed from the following areas: Kaikōura District and Canterbury region, Nelson/Tasman, Hawke's Bay and Auckland.

All stakeholders expressed strong interest in the research project and were eager to contribute their knowledge and experience. Their generous insights were valuable for informing the Evacuation Routes Framework. All stakeholders were keen to see the results of the project to help their own planning and thinking on evacuations.

While considering evacuation routes, the conversations also raised wider issues of community resilience and preparedness, the intersecting roles of differing response agencies and a range of evacuee welfare issues. This important contextual information also supported the development of the Evacuation Routes Framework.

The feedback from stakeholders is summarised and reported using three key themes:

- the composition of communities to be evacuated and their transport needs
- the location and management of evacuation routes
- receiving areas and communities for evacuees.

3.1 Communities being evacuated

Understanding the demographic makeup of a community, how it may change over time (eg tourists) and the numbers and types of people with special needs, is essential for planning transport needs and receiving areas. An awareness of cultural diversity and specific cultural attitudes may also be important in determining the nature of receiving areas. This wider understanding of communities and their subsequent transport needs requires inter-agency collaboration and planning prior to evacuation events to ensure maximum safety for all. An understanding of community makeup must be translated into planning specific transport needs to be useful.

An important factor is the desire for people to evacuate with their pets, and for farmers and lifestyle block owners to meet their legal requirements to safeguard the welfare of their animals. Most individual householders have the capacity to leave with and care for household pets, but people with stock may need more direct assistance with transport to, and care at, receiving areas.

Education plays a key role in informing and preparing communities prior to evacuation events. Especially for rapid-onset events, an understanding of local hazards and their natural warning signs can lead to quicker evacuations. For areas with transient/tourist populations, easily accessible and understandable information on the nature of local hazards is beneficial.

Emergency mobile alerts (EMAs) are messages about emergencies sent by authorised emergency agencies to capable mobile phones. Alerts can be targeted to areas affected by serious hazards and can be used to direct people to evacuate. The EMAs, being concise in nature, could provide links to local territorial authority or CDEM websites for more information on evacuation requirements. Sirens are sometimes used as a formal warning for tsunami hazards; however, not every affected community has sirens.

Social cohesion is also important to ensure successful evacuation, for example through neighbours checking on and assisting each other, especially for rapid-onset events. While this may manifest more readily in

smaller tight-knit communities, encouraging similar cohesion in larger urban centres is important. Where appropriate the EMA could tell people to check on their neighbours.

Successful evacuation requires community involvement and leadership in evacuation planning, due to harnessing local knowledge of hazards and evacuation routes, and the sense of self-efficacy and self-responsibility for their own safety. Many communities have an individual or individuals who champion this social cohesion and self-responsibility, and these people can play an important role in mobilising others in both smaller rural and larger urban settings. The recent self-evacuation of Lake Ōhau from fires before the arrival of emergency services is a prime example of successful community planning and preparedness. Evacuation plans developed by CDEM groups and other agencies should be vetted by communities.

It should be acknowledged that there is a spectrum of abilities in the community, with many people being able to move independently to safety without assistance. Therefore, especially for mandatory evacuations, priority should be given to those who are infirm, without vehicles, or who otherwise need assistance. All otherwise able and independent persons should be encouraged to develop personal or family plans, so they will not require emergency service assistance.

For rapid-onset events, CDEM is increasingly favouring educating communities to be responsible for their own evacuation. For events that have warning times of at least several hours (eg distant source tsunami or possibly volcanic eruption), there is an opportunity to plan and phase the evacuation systematically, accounting for specific transport needs.

3.2 Evacuation routes

Waka Kotahi has pre-determined detour routes for state highway closures. When closures are necessary, NZ Police or FENZ close the roads and contractors help manage and maintain them. These pre-determined routes, which include district or local roads, are based on well-known recurrent hazards such as the snow closure of North Island's central plateau and South Island alpine passes. The use of manual 'flip signs' can assist drivers, and variable messaging signage (VMS) to inform drivers of detours complements these measures, although they are spread unevenly across the country. Detours and closures are also fed rapidly into Google Maps and in-vehicle navigation systems. Therefore, the Waka Kotahi detour management systems could be used for evacuation in some hazard events.

A key consideration for Waka Kotahi for evacuation events is the location and extent of current roadworks as part of capital works and maintenance programmes, and the ability to clear these for evacuees to use the roads, including liaising quickly with relevant contractors.

There is a need for better and wider data integration to address evacuations comprehensively. Although Waka Kotahi has local road information for pre-determined detour routes, they rely on local territorial authorities and contractors for other information on local roads. A whole-network approach needs to be applied that integrates state highway and local road information. Key information, acknowledged by Waka Kotahi and CDEM groups, will focus on bridge locations and capacities, reflecting the importance of interdependencies between infrastructure systems. Ensuring the resilience of critical infrastructure such as bridges across the road network is important. Understanding the location of power lines can also be important in case lines are downed.

CDEM groups are increasingly reluctant to rely on, or publicise, pre-designated evacuation routes for certain hazards. For example, roads and bridges may be damaged by earthquake shaking and co-seismic phenomena such as liquefaction and lateral spreading, which would hinder tsunami evacuation. This points to the need for communities to know their own area and presence of alternative routes. Awareness of

alternative routes is also a factor in preventing people from attempting to navigate flooded roads in fluvial (river) or pluvial (rain) flooding events.

In many coastal communities, routes to safety are often few and obvious to locals, and previous tsunami warning events have demonstrated that these routes are used. Larger urban centres, however, face large logistical issues in rapid evacuations, as demonstrated in Christchurch in November 2016.

Once the impacts of a hazard on roads and bridges are known, Waka Kotahi and CDEM groups will then be able to best determine evacuation routes and publicise these via VMS, broadcast and social media, and through updating Google Maps and in-car navigation systems. The identification of routes would be better facilitated by improved availability of data on local road and bridge capacities.

There is a need to plan for incidents and crashes along evacuation routes, and to have resources available to clear motor vehicle crashes. Another potential issue is that the numbers and dynamics of evacuees could hinder emergency and rescue services accessing the impact zones.

The impacts of evacuation on ‘pass-through’ communities need to be considered carefully. For example, after the 22 February 2011 Christchurch earthquake, self-evacuees from Christchurch consumed available fuel and grocery supplies in Kaikōura, with detrimental impacts on the local community. After the November 2016 Hurunui-Kaikōura earthquake closed State Highway 1 between Picton and Christchurch, leading to the use of the State Highway 7 inland route for all private and freight transport, retailers and accommodation providers in Murchison observed much greater unplanned demand. Better liaison between the responsible agencies and local retailers would have mitigated these issues.

In pre-planning for evacuation events, consideration should be given for investment in infrastructure. State highways and main arterial routes already receive significant investment to maintain high levels of service; however, local roads should be identified that may need added capacity for high traffic volumes in evacuation events, and road carriageways and bridges upgraded and maintained accordingly. Wider consideration should also be given to cell phone tower locations and telecommunications coverage in isolated areas to assist evacuees with wayfinding and updates.

3.3 Receiving areas

CDEM groups encourage evacuees to stay with family and friends whenever possible. When this is not possible, CDEM will facilitate and pay for evacuees to stay at motel/hotel accommodation for up to two weeks. If people are displaced longer than this, the Ministry for Building, Innovation and Employment will take over the supporting role. Accommodation options need to be considered. If the need is urgent and obvious, CDEM will establish temporary accommodation in cooperation with other agencies.

CDEM groups are reluctant to publicise pre-designated safe areas, including designated civil defence centres, prior to an event. This is to manage the public’s expectations about what resources and support services are available. Civil defence centres will be made safe and operational only after the hazard’s initial impacts are understood and people have been directed to these sites. Civil defence centres are intended to be one-stop information hubs on evacuation routes, providing accommodation and support services, and facilitating housing of animals where necessary. The concept of a ‘virtual’ online civil defence centre has been posed where information and support are available via mobile devices. The online centre could also minimise traffic to designated sites.

In the case of rapid-onset (near source) tsunami evacuations, some initiatives are underway to identify residents living on high ground willing and able to host evacuees from the hazard zone (eg Sumner, Christchurch). This is a work in progress, and more needs to be done to understand the associated social dynamics logistics and impacts on infrastructure services.

Another potential issue is that the number of evacuees in temporary accommodation could have an impact on the ability to house emergency and rescue services responding to the event.

Marae have served as support and accommodation centres in previous evacuation events, and indeed there is official guidance on using marae for such purposes. However, there is a tendency to assume that marae will by default play this role, without the necessary engagement pre-event to ensure this is the case. Marae need to be sufficiently resourced to provide this supporting role.

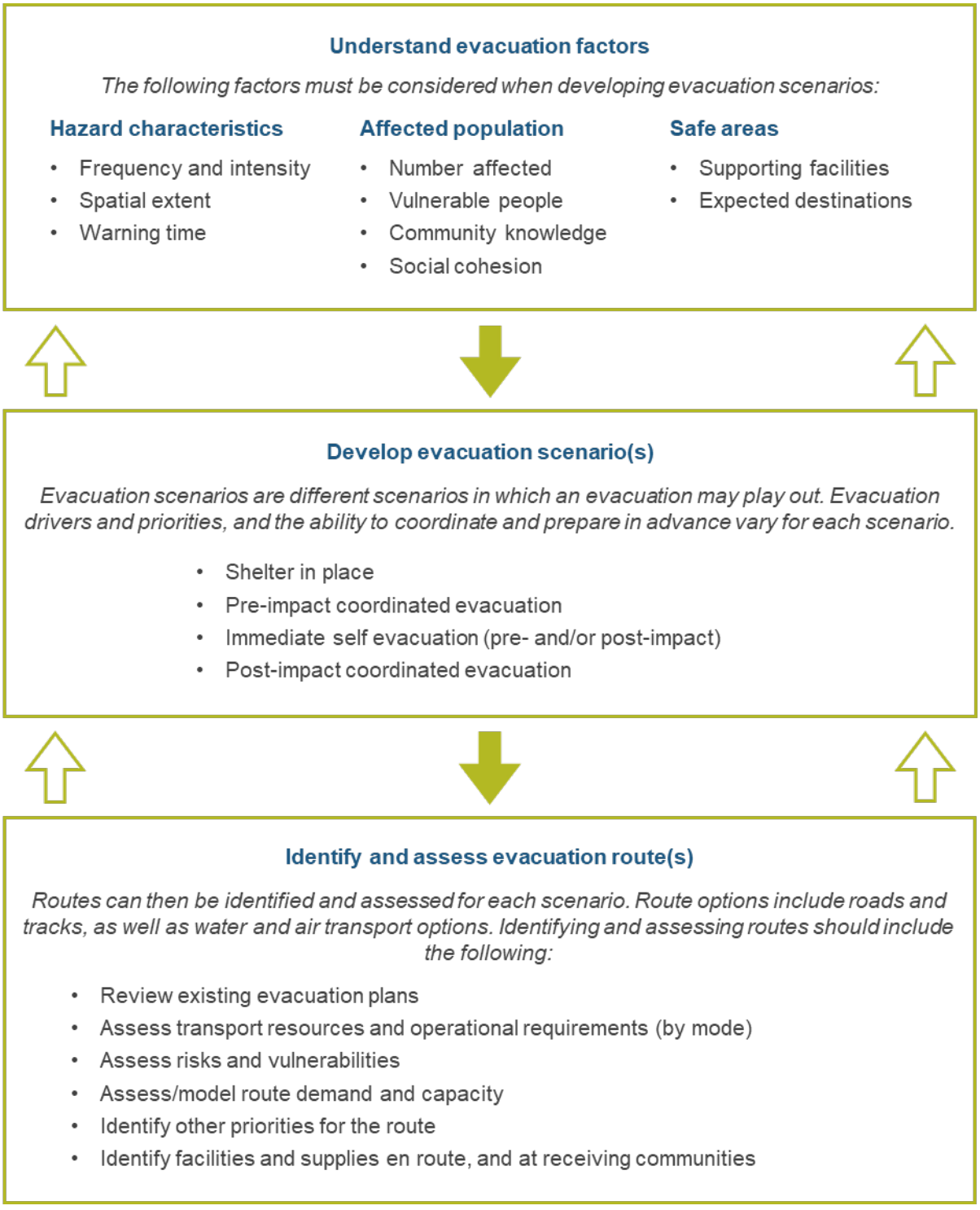
A little-considered issue is the need for road management in receiving areas, particularly if large numbers of evacuees arrive in urban centres. Regardless of the transport mode into the receiving areas, increased populations will have an impact on the local transport networks.

Large-scale evacuation events can lead to long-term inter-regional issues. For example, after the 22 February 2011 Christchurch earthquake, many former Christchurch residents moved to the Nelson/Tasman region, with impacts on a range of local services. If an eruption in the Auckland volcanic field permanently displaced a significant proportion of Auckland residents who migrated to other regions, what would be the responsibility of Auckland authorities to those displaced persons, versus the receiving region? While such a potential large-scale event would be addressed at the national level, it serves to illustrate that permanent evacuation would have significant impacts on a receiving area's own communities and infrastructure.

4 Evacuation Routes Framework

The Evacuation Routes Framework was developed from the learnings from the literature review and stakeholder engagement. An earlier draft of this framework was also tested and refined through the case studies (chapter 5). The framework is summarised in Figure 4.1.

Figure 4.1 Evacuation Routes Framework



Each part of the framework is discussed in this chapter, focusing on key considerations for evacuation planning prior to hazard events, as well as how to apply the framework once a hazard manifests. The framework is dynamic, in that evacuation considerations and scenarios may need to be reviewed once potential routes are reviewed and assessed. The framework should also be considered alongside current guidance on evacuation planning issued by NEMA.

4.1 Understand evacuation factors

This part of the framework identifies key factors that should be considered when planning for a potential evacuation, either prior to an event or to assist planning/implementing evacuations once the hazard event occurs. The key factors for consideration are:

- the characteristics of the hazard
- people potentially affected
- safe areas/expected destinations for evacuees.

4.1.1 Hazard characteristics

Hazard characteristics that should be considered are:

- the expected frequency and intensity
- the spatial extent or footprint
- warning time.

The hazard characteristics inform the likelihood of the hazard occurring, the area potentially requiring evacuation and how much coordination of evacuation is possible within the warning time.

The expected frequency, intensity and spatial extent for many hazard events has been modelled and researched, and there are ongoing scientific programmes exploring the threats posed by earthquakes, flooding, tsunami and volcanic eruptions. Agencies responsible for planning and managing evacuations may receive this information through their own organisations via research papers, guidance documents and conferences, and through national and regional infrastructure lifelines forums. Some territorial local authorities commission specific hazards research to inform their long-term planning.

4.1.1.1 Frequency and intensity

Evacuation route planning is typically undertaken for higher risk hazards. Understanding the frequency and intensity of hazards is important to assess the risk and identify whether evacuation route planning is needed. The phenomena of concern will usually be repetitive or higher-impact events that affect people and/or animals. CDEM group risk assessments will often include this hazard assessment.

Natural phenomena that occur infrequently but have significant potential impacts include geophysical hazards such as large-magnitude earthquakes, regional or distant-source tsunami, or volcanic eruptions. Weather events, such as significant low-pressure systems and ex-tropical cyclones, occur more frequently than large geophysical events but can also have hazardous results including fluvial flooding, wind-blown debris and electricity outages.

Intensity is relevant when assessing potential impacts to communities and infrastructure, including the potential for communities to be isolated and in need of evacuation. Examples of hazard intensity measures include water depth and velocity for tsunami and fluvial flooding, earthquake shaking intensity (eg modified Mercalli intensity), or accumulated thickness of volcanic ash.

For tsunami, the exposure of people to hazard intensities within the anticipated footprint represents a serious life safety concern. For fluvial and/or pluvial flooding and volcanic ash, beyond certain depths and thicknesses the hazard intensity may trigger evacuation and could affect evacuation routes.

4.1.1.2 Spatial extent/footprint

The nature of a hazard can help characterise its anticipated spatial extent or footprint. The spatial extent helps determine the people and infrastructure likely to be affected by the hazard. Low-frequency, high-intensity events often have an impact on large areas. It is also more difficult to plan evacuations for events with uncertain spatial extents as it is not clear who could be affected by it.

Distant-source tsunami threats from South America may affect much of New Zealand's eastern coastline and may penetrate further inland than smaller more frequent events. However, tsunami are relatively well constrained to the coastline and evacuation zones are mapped across New Zealand.

For earthquakes, surface ground rupture may be relatively well constrained if it occurs along known active faults, or on previously unidentified faults. These events can include regional shaking and co-seismic hazards (liquefaction and landslides) tens of kilometres from the activated faults.

With volcanic hazards, phenomena such as erupted ballistic projectiles, pyroclastic density currents and lahars are generally constrained to the immediate vicinity of the volcanic activity, or along flow paths and river networks. Volcanic ash fall is less constrained with a hazard footprint dependent on the explosivity of the eruption and prevailing winds.

River flooding is usually restricted to existing floodplains and known flood hazard areas. Wildfire, however, is characterised by a rapidly shifting footprint depending on environmental conditions (such as temperature, wind strength and direction), terrain and fuel loads.

4.1.1.3 Warning time

The final consideration is the potential warning time. Longer warning times give emergency agencies time to prepare and publicise evacuation routes, with greater coordination. There is also time for pre-event evacuations if necessary. Events with little or no warning time rely on individuals identifying and responding to environmental cues or emergency alerts to evacuate from hazard areas.

Modern weather forecasting can help inform anticipated spatial extents and intensities of low-pressure systems and potential flood hazards, sometimes several days before areas are affected.

In contrast, earthquakes generally occur without warning. Generalised forecasts of increased aftershock activity are possible following main shocks and probabilistic forecasts of earthquake occurrence on major faults can be made based on analyses of past events.

Earthquakes can serve as natural cues for impending local or regional-source tsunami, giving exposed populations minutes or tens of minutes to self-evacuate to safety. For sources further afield, oceanic monitoring networks can provide hours of warning time and modelling can estimate the hazard footprint and intensity.

For volcanic eruptions, precursor earthquakes signalling ascension of magma can serve as warning signals; however, there are significant uncertainties surrounding what the window of time may be and whether such volcanic unrest precedes an actual eruption event.

4.1.2 Affected population

Understanding the characteristics of affected populations is essential for understanding what evacuation options should be considered, and what supporting facilities and services are required to help people access and travel along evacuation routes. Key considerations are:

- the number of people potentially within the hazard footprint
- the number, location and needs of vulnerable people
- community knowledge and awareness of evacuation procedures
- social cohesion.

4.1.2.1 Number of people affected

There are various ways to identify and quantify populations within potential hazard footprints. Census data can be used to estimate resident populations and households at different spatial levels. National property boundaries and building footprint datasets can also be used to estimate population distribution. Ratings databases held by local authorities, and customer connection information from electricity distribution companies, can also provide estimates of household counts in specific areas.

Another important consideration is dynamic exposure, or how populations change spatially and over time. During daytimes on normal weekdays, urban centres receive large numbers of commuters and students travel to schools, but conversely there are fewer people in suburbs and peri-urban areas. This pattern reverses as workers and students return home in the evening. Commuting populations can be estimated using travel to work/travel to education data, potentially supplemented by traffic counts and public transport data.

On weekends, locations such as recreational areas, sports grounds and facilities, retail centres, event venues and places of worship all receive temporary influxes of people. As on weekdays, the weekend exposure of these locations decreases overnight as people return home.

Areas where people congregate for recreational activities are also influenced by season, with national parks, camping grounds, beaches, coastal marine areas and lakes popular in summer, and ski fields popular in winter. Further spikes in visitor numbers can occur during school holidays and on public holidays. Dynamic exposure also includes transient populations comprising travellers and tourists. International tourist populations are traditionally seasonal, with New Zealand usually receiving a large influx over the summer, although winter visitors also lead to temporary population increases at ski fields, alpine towns and resorts.

In addition to people located within evacuation zones, shadow evacuations may occur where people in the wider affected areas also evacuate, increasing the number of people using evacuation routes and associated facilities.

4.1.2.2 Vulnerable people

In this context, vulnerable people are those who may need assistance to leave their accommodation, find transport, and/or receive additional support at evacuation destinations.

Facilities hosting vulnerable people include hospitals and aged care facilities. While these facilities will have their own emergency procedures, moving unwell or infirm individuals can take considerable time. Prisons also have unique challenges for evacuation that should be recognised; however, these facilities should have plans for the emergency evacuation of staff, visitors and inmates.

Early childhood education providers and schools host potentially vulnerable populations. Schools usually have well-developed emergency procedures for a range of potential threats and ideally these are procedures shared with parents/caregivers. This is important, as separation from children in emergency situations can

lead to parents/caregivers placing themselves at risk attempting to reach them, which also increases the demand on evacuation routes.

Communities will also have a segment of the population that is elderly, infirm or with disabilities that affect people's mobility and ability to respond to emergency messaging. These people can be excluded from some evacuation route options, for example walking long distances or the ability to transfer across multiple modes, such as getting on and off boats. The accessibility of evacuation routes and facilities en route must be considered to accommodate people with disabilities.

Other vulnerabilities include limited access to telecommunications, language barriers and low rates of car ownership. Pet and animal ownership is another factor that makes evacuation more complicated. Ideally pet owners should be accommodated on evacuation transport services and at shelter locations.

The implications of vulnerable people for evacuation routes depend on the evacuation modes available. For example, in the Wellington case study (refer section 5.1), approximately 80,000 commuters could be stranded in central Wellington if a major earthquake occurs, with many of these people expected to walk home. However, not all these people will be capable of undertaking this journey on foot and alternative evacuation options should be considered.

Vulnerable people can be identified by location (such as hospitals, schools and aged care facilities), or from social vulnerability indicators such as the number of young children and older adults (aged over 65 years). For more complex scenarios Environmental Health Intelligence New Zealand has developed social vulnerability indicators that measure the exposure, susceptibility and resilience to natural hazards for different populations (Mason et al., 2019).

4.1.2.3 Community knowledge

Community knowledge refers to knowing about hazards, evacuation routes and safe areas/destinations, and the locations and needs of vulnerable people requiring assistance. This knowledge is held by local individuals, families, social/neighbour networks, iwi, hapū and other community organisations.

People who have lived in a community for a long time or have recently experienced a hazard event are often knowledgeable about how particular hazards play out. Community members can have a good appreciation for which weather conditions will lead to localised flooding or have witnessed how landscapes and infrastructure have responded to earthquakes (for example the 2010/11 Canterbury earthquake sequence). They know how to identify and act on natural cues to evacuate. However, as high-impact hazard events requiring evacuation are often rare occurrences, it is also possible that communities have no collective experience or memory of these threats.

Local knowledge can be valuable regarding evacuation routes, as community members understand local road conditions, potential pinch points, which modes of transport will be most appropriate for moving out of harm's way and which safe areas/destinations will be most suitable. They may also be aware of tracks and shortcuts, and evacuation options over private land.

Finally, local knowledge can be essential for warning vulnerable people of an impending hazard, and for assisting them to evacuate. An understanding of the skills and resources held within the community is a first step towards marshalling these to assist vulnerable people. This applies equally to assisting newcomers or visitors to the area, as locals will usually know where tourists are located and can guide them to safety. Formal warning systems such as EMA and tsunami sirens, and informal warning systems such as social networks, can facilitate evacuation. However, it is important that residents and visitors are aware of warning systems and how to respond to them.

People working in community engagement roles can have useful knowledge of community composition, skills and resources. These people exist within CDEM groups, local authorities, government agencies and within community-based non-governmental organisations.

4.1.2.4 Social cohesion

Social cohesion refers to the extent to which neighbours, social networks and wider communities take the initiative to warn each other of impending hazards and provide assistance where necessary. Social cohesion also reflects willingness to assist others with transport along evacuation routes, and the inclination of residents in destination areas to provide shelter and other necessities in advance of an official emergency response.

Communities consist of intersecting social networks of family, friends, neighbours, clubs and volunteer organisations. In smaller communities, individuals can belong to several of these groups and people are generally better known to each other than in larger urban centres. The presence of emergency services and volunteer organisations, such as volunteer fire brigades, also enhances social cohesion.

Populations disconnected from social networks may include transient worker populations, recent migrants and people with language barriers. Some migrant and seasonal worker communities also lead their own preparedness work. Such groups should be accessed using the specific channels they engage with. Previous disaster events in New Zealand and elsewhere have demonstrated that people will rescue and provide support to strangers during and following disasters. This is also likely to occur in evacuations.

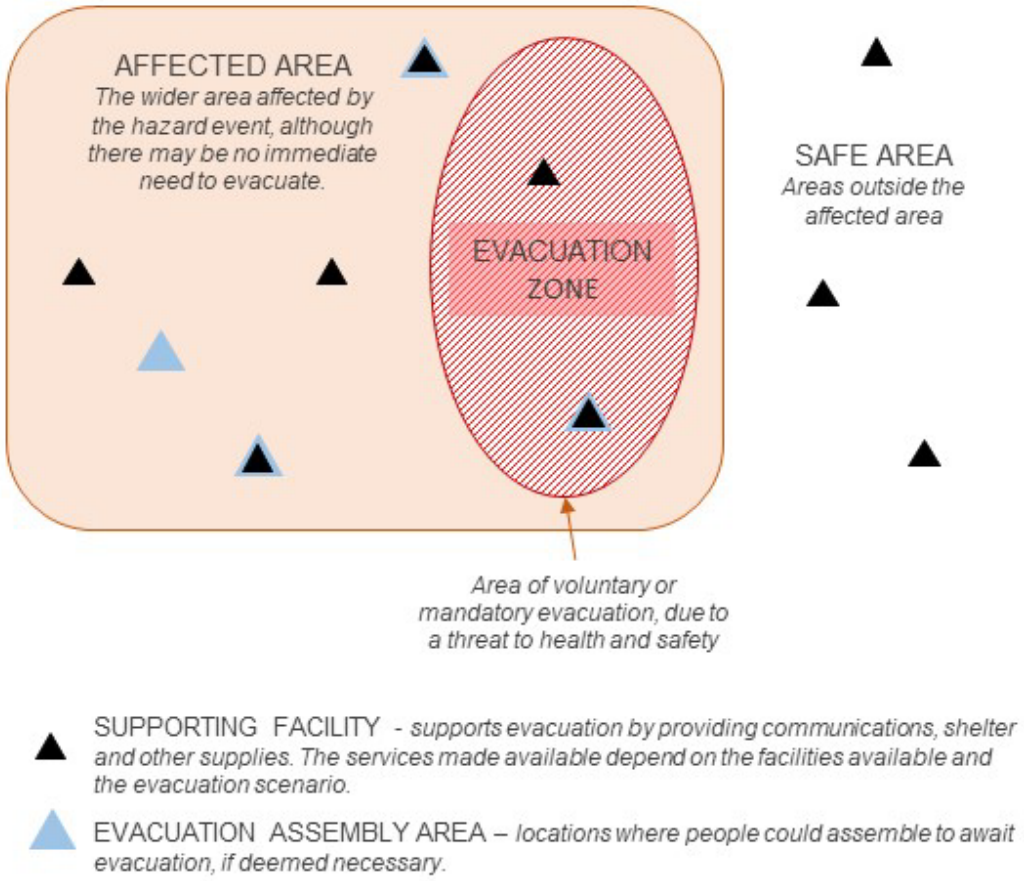
Social cohesion is not necessarily correlated with socio-cultural metrics captured in census data, nor in derived measures such as the NZ Index of Deprivation. Indeed, deprived communities can, through cultural norms, place high value on family, whānau and friend relationships that ensure mutual support and pooled resources. However, this cannot be assumed for all community members.

Finally, the role of iwi and marae must be emphasised. In previous disaster and evacuation events across New Zealand, marae played a critical role in response by sheltering and feeding evacuees, and providing welfare support services, often on their own initiative and independent of official response agencies. Beyond members of their own hapū and iwi, recipients of support have included refugees and other recent immigrants, tourists, and the wider community. The concept of manaakitanga (acknowledging the mana of others as having equal or greater importance than one's own, through the expression of aroha, hospitality, generosity and mutual respect) in Te Ao Māori helps explain these iwi-led responses. Further, whanaungatanga, or drawing on tribal kin relationships, enables a tapping and pooling of skills and resources from across takiwā/regions and the country in response to disasters. For these reasons, marae are becoming increasingly integral to emergency response and evacuation plans. Iwi-led responses to emergencies and disasters via marae constitute a vital connection that enhances wider social cohesion.

4.1.3 Safe areas, supporting facilities and expected destinations

The final component under evacuation considerations is the location of safe areas, supporting facilities and the expected destinations for evacuees. The relationship between these factors is demonstrated in Figure 4.2 and explained below. Note that the boundaries separating evacuation zones, affected areas and safe areas are unlikely to be clearly defined, and will be fluid as the hazard event unfolds.

Figure 4.2 The relationship between affected areas, safe areas, evacuation zones, supporting facilities and assembly areas



The *evacuation zone* is an area where there is an immediate or expected threat to human health and safety. People may be ordered to evacuate under a mandatory evacuation or may evacuate voluntarily due to a real or perceived threat, for example moving out of an earthquake-damaged central business district.

The *affected area* is the wider area impacted on by the hazard event, although there is no immediate need to evacuate this area. Services may be disrupted, including transport networks; however, people are able to shelter in place until services and networks are restored, or the threat of the hazard passes. Some people may choose to evacuate out of the affected area, for a variety of reasons. This includes commuters and visitors whose homes are in the safe area, residents whose homes or services are damaged to the point of being uninhabitable, and people whose support networks are located elsewhere. Evacuations may also occur between locations inside the affected area.

Conversely, a *safe area* is anywhere outside the hazard footprint, where people and infrastructure are largely unaffected by the hazard unfolding nearby.

Supporting facilities are buildings and locations that support evacuations by providing services such as communications, water, food, short-term shelter and medical support. These could include marae, schools and community facilities such as halls and community centres. They may be designated civil defence centres

or community emergency hubs. The type of services available at each facility will depend on what is available in that location, and what the evacuation needs are. For example, the facility could provide shelter if no other accommodation options are available locally. Supporting facilities can be in the evacuation zone, affected area or safe area, provided it is safe for them to operate in these locations. An example of a supporting facility in an evacuation zone could be a vertical evacuation structure.

Evacuee assembly areas are locations where people can assemble to await evacuation out of the evacuation zone or affected area. This might occur, for example, if roads are closed or impassable and people must assemble to be extracted by air or sea. It may also occur where a phased, controlled evacuation is required due to limited resources, network capacity or damage to the evacuation route. Some *supporting facilities* could function as evacuee assembly areas, but this also depends on the mode of transport involved. For example, airports, airstrips and large open spaces could be assembly areas for air evacuation.

Expected destinations are the final destinations of evacuees and where the evacuation route ends. They may include the homes of friends and family, or temporary accommodation such as hotels and motels. In mass evacuations these destinations may be assembly hubs in a safe area, for example ports and airports where the arrival of evacuees can be coordinated. Supporting facilities can be destinations for short-term evacuations but are unlikely to be suitable for longer-term habitation.

For scenarios in which high-impact/low-probability events cause significant and widespread destruction, it is possible that communities will be displaced for the medium-to-long term, or even permanently. This is where the consideration of expected destinations and pass-through communities is important. Community recovery processes not only affect areas within the hazard footprint, but also towns and cities in which evacuees may resettle.

4.2 Develop evacuation scenario(s)

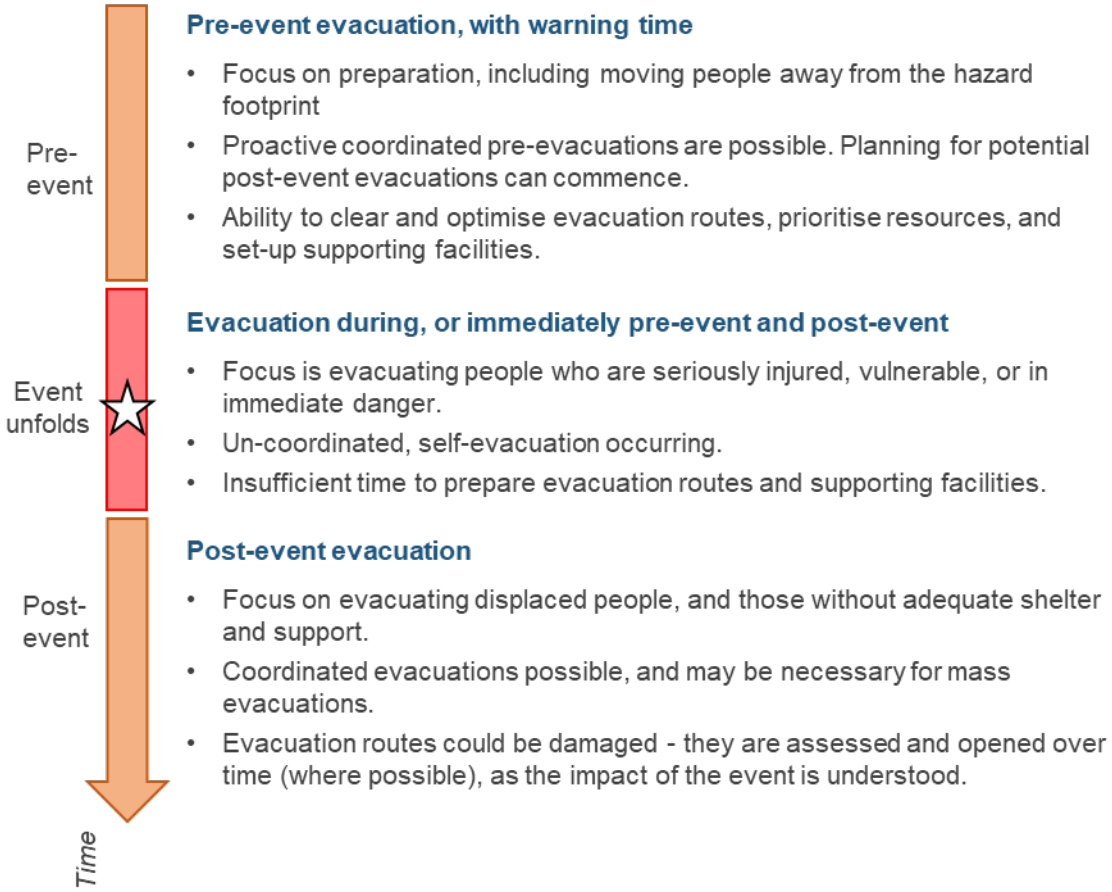
There are several scenarios for how an evacuation could play out.

Shelter-in-place is the preferred scenario in any event, provided it is safe for people to do so. It can be unsafe to travel during or after the event, as roads and transport facilities are damaged, closed or inoperable. It may not be possible to accommodate everyone who wants to evacuate using available transport modes and options. The shelter-in-place option assumes people have the resources to stay at home or a safe location, including food, water, safe shelter and sanitation for a fixed period. Evacuation is only necessary where the benefits of leaving outweigh the risk of staying in place. For more information on when shelter-in-place is an appropriate strategy, refer to MCDEM (2008).

If shelter-in-place is not viable, then the Evacuation Routes Framework identifies three possible evacuation scenarios, based on time (or more specifically the amount of warning time and the amount of time passed post-event). These scenarios are summarised in Figure 4.3.

In each scenario there are different drivers and priorities for evacuation, and the ability to coordinate and prepare for evacuation varies. This has implications for the types of evacuation routes that might be available and how they should be assessed. More than one of these scenarios may play out for any hazard event.

Figure 4.3 Evacuation scenarios



4.2.1 Pre-event evacuation (with sufficient warning time)

In this scenario there is sufficient time to instigate the pre-evacuation of people within an identified hazard footprint and evacuation zone (for example, a forecast rainstorm or river flood). If the hazard footprint is unclear, then there is still time to prepare potential routes and supporting facilities for the evacuations that may be required. The need for evacuations can also be mitigated by closing schools (for example) and advising people to avoid travel where it is appropriate to do so.

Evacuation plans can be activated and mandatory evacuations may be directed, or people may choose to self-evacuate based on information shared by emergency agencies. Examples of actions to prepare routes for evacuation might include implementing contra-flow lanes, coordinating public transport services, and ensuring contractors and emergency services are ready to support the evacuation and respond to incidents that may occur.

Note that no specific ‘ideal’ timeframe is provided for this type of scenario. The greater the warning time, the better prepared emergency coordinators/managers/responders can be, particularly for mass evacuation scenarios.

4.2.2 Evacuations during, or immediately pre-event and post-event

In this scenario there is either no warning time (such as an earthquake), or very limited warning time (for example a wildfire or local-source tsunami). This scenario also includes the time immediately after the event

where the focus for evacuation is getting people away from immediate dangers and evacuating people who are seriously injured.

People within the affected area will rely on natural cues to evacuate. There may also be official emergency messages; however, these will primarily be about the need to evacuate, not advising people of preferred evacuation routes. This scenario relies on people being sufficiently prepared to respond to the situation as it unfolds, for example moving away from coastal areas following a long and strong earthquake. Therefore, there is a strong reliance on community knowledge and social cohesion. Emergency services will be stretched and communications limited, so it will be difficult if not impossible to coordinate large-scale evacuations. Similarly, there is little opportunity to prepare routes for evacuation, and the routes available may not be safe or traversable.

The focus on supporting evacuations in this scenario is building community preparedness and implementing resilience measures to ensure people know when and how to evacuate, and to reduce the likelihood of potential evacuation routes being impassable or unsafe.

4.2.3 Post-event evacuation

Once the immediate threat has passed, people will probably attempt to return home, which could be inside or outside the affected area. If this is not possible, or if their accommodation is uninhabitable, then they will go to places of perceived safety from which further evacuation could be coordinated or supported. Some may choose to shelter-in-place before seeking/receiving assistance to leave.

In the hours and days after the event the hazard footprint and impacts will become clear to emergency response agencies. The shelter-in-place option should also be promoted where it is safe for people to do so.

When and where supported/mandated evacuation is deemed necessary, plans can be developed making use of available transport modes to facilitate population movements. This may include coordinated mass evacuations. However, factors such as secondary hazards, damage to roads, fuel supplies and the ability to operate vessels and aircraft will have an impact on the route options available.

The post-event phase can last hours to days, depending on the number and diversity of people affected. Areas initially deemed ‘safe’ can subsequently become unsafe for human life and habitation, for example because of outbreaks of disease due to poor sanitation, or the inability to restore water networks and food supply lines in a timely manner.

4.3 Identify and assess evacuation routes

Evacuation route options can be identified and assessed once potential evacuation scenarios are defined.

The first step is to identify potential evacuation routes and options – these are usually fairly apparent when examining a map of the affected area. Route options include roads and tracks, as well as water and air transport options. Routes could cross public and private land. Isolated coastal or rural communities may have a single route option, in which case there is only one evacuation option to evaluate. Large urban centres may have multiple egress routes, in which case it may not be necessary to highlight individual routes but recognise there are multiple route options available which can be assessed further.

4.3.1 Review existing evacuation plans

Existing evacuation plans, including institutional evacuation plans (eg hospitals, schools), regional evacuation plans and community evacuation plans should be included in the consideration of evacuation options for the wider community or affected area. These plans may have already identified routes and options that can be assessed further. These plans may also need to be revised based on updated

knowledge of the hazard, changing community dynamics and changes to transport infrastructure. They are also likely to address concerns around the evacuation of vulnerable people and prioritise the allocation of evacuation resources for these people (for example air evacuation of hospital patients and those injured in the hazard).

4.3.2 Assess transport resources and operational requirements (by mode)

Modes that should be considered include:

- on foot – walking and other non-motorised forms of transport
- private vehicles
- public transport or shared/supported transport options
- transport by water
- transport by air.

Some evacuation routes may require multiple modes, for example walking or driving to assembly areas, from which evacuees are transported by sea or air. In these cases, the selection of safe assembly areas is very important (refer section 4.3.6 below).

4.3.2.1 Dependencies for all transport modes

Regardless of the mode of evacuation, key dependencies are required for the operation of transport systems and networks:

- Electricity is required for electronic payment systems, traffic signal operations, and for port and airport operations. Consider how the loss of electricity would impact on the evacuation options available.
- Telecommunications and broadcast are required to exchange messages with evacuees during the evacuation across various modes (including mobile internet, EMA, radio communication with safe areas), and to communicate with transport providers, vessels and aircraft. Evacuation routes may travel through mobile phone blackspots, and communication networks can be damaged or overloaded in the hazard event. An internet service is required to enable electronic payment systems. Telecommunications and broadcast systems also require an electricity supply to function.
- Fuel is required to supply vehicles, vessels and aircraft. Fuel is likely to be a major factor affecting evacuation if supply lines are disrupted. Some fuel service stations have a communications link with the fuel company's central operating system to monitor operations, such as tank fill-levels.
- Emergency responders such as people and equipment that aid in evacuation are required, especially if located within or close to the affected area. In some cases, emergency responders may need to travel into the area to assist, which could require them to go against the flow of evacuation. Accommodation options for emergency responders could be limited if these options are being used to host evacuees.
- Contractors, traffic management and heavy equipment may be required, which will entail knowing the location of people and equipment to assist in clearing routes. This may include temporary repairs to roads, clearing slips and debris, clearing crashes and breakdowns, opening airstrips and coastal boat landing sites and providing traffic management support for road-based evacuation.

4.3.2.2 Walking and active modes

Walking (including bicycling and other active modes) could be an option if road networks are severely damaged, or large numbers of people need to move a short distance for a short-onset hazard, such as a

near-source tsunami. People may walk along roads, along paths and trails, or over open land. Some people will not have the ability to walk long distances, for example young children, and elderly and disabled people. Alternative options should be considered for evacuating or supporting these people.

Another challenge for those walking is appropriate equipment, such as good footwear and clothing, especially if walking long distances in adverse terrain or weather conditions.

4.3.2.3 Land-based transport (vehicles)

Transport by road, whether by private vehicle, public transport providers or shared transport options (such as carpooling) is feasible if roads are not severely damaged or can be readily restored. It is also necessary to consider that not everyone will have access to private vehicles, therefore alternative evacuation options should be considered to assist these people.

Public transport options are reliant on transport providers having the necessary vehicles (number, size, capability) with skilled drivers. They also need to be in a location where they can be readily deployed. The military and some tourism operators could provide vehicles capable of covering difficult terrain, such as large 4WD vehicles. Commercial public transport operators can provide buses to transport large numbers of people efficiently but the buses are less likely to operate on damaged roads.

There are many road datasets available that can help identify possible evacuation routes by road, and the attributes necessary to assess these routes. This includes the Waka Kotahi National Road Centreline, commercial datasets and open datasets. Waka Kotahi's detour management systems could be used for evacuation in some hazard events.

4.3.2.4 Sea/water evacuation options

Sea/water-based options can be used to evacuate coastal communities, or to bypass damaged roads along coastal routes. This can include private vessels, commercial ferry operators, barges, coastguard and military vessels. Considerations include:

- the ability to operate in adverse weather and varying tidal conditions
- the distance travelled, and the supplies and safety equipment required for this
- required landing and port facilities
- the availability of skilled crew, including experience navigating affected coastal areas
- fuel availability (if ports are damaged).

For example, barges may be appropriate for carrying people short distances over settled water but are impractical for longer journeys or carrying large numbers of people. Coastal water taxi and shuttle services have an intimate knowledge of local coastal conditions but may only be available to support evacuation during peak seasons when there are sufficient vessels and crew available.

4.3.2.5 Air evacuation options

Evacuation using fixed wing aircraft is an option provided airports are not severely damaged or alternative safe landing strips are available. Helicopters have more flexibility in where they can operate but are limited in the number of people they can carry. They may be prioritised for the evacuation of injured people and people at immediate threat of harm, or for reconnaissance and the transport of first responders. Poor weather conditions limit the use of helicopters and fixed wing aircraft in some situations.

4.3.2.6 Transportation of pets and animals

As has been noted elsewhere, consideration also needs to be given to the accommodation and transport of pets and livestock.

4.3.3 Assess risks and vulnerabilities

Potential evacuation routes may travel through hazard zones or be vulnerable to additional hazards and risk. The nature of these will depend on the primary event, for example a storm event could result in washouts, flooding and unstable slopes, or for earthquakes, secondary hazards could include landslides, liquefaction and the ongoing impact of aftershocks. It is also important to consider changing conditions and how that might impact on evacuation options and routes, for example weather conditions, tidal conditions and the time of day (night versus day). Some examples of risks and secondary hazards associated with evacuation include:

- re-entering the primary hazard zone, for example driving across a flood prone road, or travelling through a tsunami evacuation zone to reach safety
- walking around a coastal route at high tide
- travelling on or below an area of potential slope hazard, or an area known to be prone to liquefaction
- travelling past potentially hazardous buildings or sites, including earthquake-prone buildings, hazardous goods storage facilities, powerlines and gas lines
- travelling at night, without adequate lighting
- travelling through areas surrounded by flammable vegetation (in the case of wildfire).

Vulnerabilities in transport infrastructure along the evacuation route are sites and structures vulnerable to failure, and therefore unusable or unable to be readily restored after the event. This includes bridges and tunnels, as well as potentially unstable slopes and areas prone to washout. Where vulnerabilities are known and have been assessed, this will provide some estimation of how significant the vulnerability is, and how soon the infrastructure can be restored. Pinchpoints and areas likely to become congested in a mass evacuation are also vulnerabilities, and this can be assessed by modelling route capacity and demand (refer section 4.3.4).

Information that can support the assessment of risks, hazards and vulnerabilities includes maps showing known hazard zones, and infrastructure vulnerability assessments, which can be provided by the New Zealand Lifelines Council and regional lifelines groups.

Given uncertainties about how hazard events will play out, route options should include contingencies and alternatives where possible.

4.3.4 Assess/model route demand and capacity

Several modelling approaches can be applied at a macro or micro level to assess the capacity of route options for evacuating affected people (refer section 2.6 for specific examples). This will highlight which routes have the capacity to evacuate people within the warning time available (for slow-onset hazards) or following the event. Modelling can also be used to predict the arrival of evacuees over time, which in turn can support planning for pass-through and destination communities. As the event unfolds assumptions about route capacity can be reassessed if required.

Once the impact on road and transport networks is understood, options for modifying the capacity of roads through traffic management strategies should be considered. This might include traffic control points for

dispersing evacuees, reversing traffic flows (contraflow), modifying signal timings and closing active road work sites.

4.3.5 Identify other priorities for the route

The routes and options used by evacuees are unlikely to be used solely for evacuation purposes. The same corridors may need to be accessed to enable emergency responders and vehicles to access the affected area, to enable the delivery of supplies and to open access to key infrastructure and facilities, for example ports, fuel depots and hospitals. This can have both positive and negative impacts:

- There is a strong focus on restoring routes that have many overlapping priorities. There is also a stronger emphasis pre-event on ensuring these key routes are resilient to natural hazards before they occur.
- Vehicles, vessels and aircrafts delivering emergency responders, equipment and supplies into affected areas can be backfilled with evacuees leaving the area.
- Large flows of evacuees in one direction can impede emergency responders and emergency vehicles entering the affected area. This should be considered when assessing network capacity and traffic management strategies.

4.3.6 Identify facilities and supplies en route, and at receiving communities

Potential safe areas, assembly areas and expected destinations were identified in the ‘evacuation considerations’ stage of the framework (section 4.1.3). As route options are identified and assessed these locations and destinations can also be refined and reassessed.

The facilities required at these locations should be considered, based on the estimated number of people being evacuated and the expected duration of stay. This includes provision of water, communications and supplies.

Evacuating populations will require toilet facilities, food and water, and possibly medical support. Identifying relevant facilities and suppliers along evacuation routes will be necessary to assess their ability to service these needs.

Significant numbers of evacuees can potentially have detrimental impacts on fuel and food supplies in pass-through communities. How pass-through communities can support evacuation without having their own communities disrupted unduly needs to be considered. As the event unfolds emergency response and other government agencies need to liaise with the relevant local authorities to forewarn of imminent arrivals, and ensure sufficient facilities and services are available to provide shelter and support for evacuees.

The availability of real-time information systems along an evacuation route is another important consideration. It is beneficial to be able to disseminate real-time information to evacuees and gather information about the state of evacuation routes.

4.4 Data and information inputs for evacuation route planning

The framework cannot be applied without good information on the hazard, community affected and potential routes options. Much of this information can be found or analysed from public datasets and maps, and by consulting people with knowledge of the hazard, the communities affected and the transport options available. The depth of information required also depends on the scale and potential impact of the hazard scenario being considered.

The researchers carried out a data review prior to undertaking the case studies and finalising the final framework. This involved an extensive review of currently publicly available national and regional datasets. Much of this was found through either CDEM hazard maps, or via government open data websites. Regional CDEM groups, lifelines groups and regional and local authorities already hold much of the information required to plan and evaluate evacuation routes. Some of this is captured at a regional level within CDEM group plans. Individual communities may also have community response plans that identify risk areas, transport options and safe assembly areas.

In addition to data inputs, communities themselves can assist in the identification of hazard-prone areas, vulnerable communities, people who may require assistance to evacuate, and local resources and route options. Residents and community groups are usually the most knowledgeable of their local transport and potential evacuation routes.

National datasets and information sources that can be used to inform each stage of the framework are summarised below. They includes data that is currently being developed, or datasets identified as potentially available outside the public realm (data is constantly being developed, updated and made public). This review is a snapshot in time reporting on data that is currently publicly available. A detailed list of national datasets, including sources, is provided in Appendix C.

Table 4.1 Hazard characteristics

Hazard data	Description and availability
Tsunami hazard and evacuation zones	Tsunami evacuation zones are available and mapped in a consistent format across New Zealand. These can be viewed at a regional level using viewers or maps provided by each CDEM group.
Volcanic hazards	All volcanoes are different in nature, and they can generate a range of hazards, such as lahar, ashfall and pyroclastic flow. Areas of volcanic risk are understood in general terms, for example the Auckland Volcanic Field and Taranaki. Hazard zones may be available for some volcanoes and hazard types, and these are usually developed or provided by GNS Science, CDEM groups and universities.
Flood and slope failure hazards	Flood hazard areas and areas at risk of slope failure/landslide are mapped in some regions, but not consistently across New Zealand. Research into flood hazards is often undertaken by regional councils to information natural hazard plans. NIWA recently commenced a five-year research project to develop the country's first national flood map to aid evacuation planning.
Earthquake hazards	The Alpine Fault is the predominant earthquake hazard in New Zealand for which evacuation is likely. The AF8 programme provides a range of information on the Alpine Fault hazard and event preparedness, which is captured in the South Island/Te Waipounamu Alpine Fault Earthquake Response Framework (SAFER) (Project AF8, 2018). This includes detailed impact estimates covering shaking intensity, distribution of co-seismic landslides, as well as expected damage to roads, electricity infrastructure, telecommunications and airports. A Hikurangi subduction zone earthquake and a Wellington earthquake are two other earthquake hazards that are likely to cause significant damage. Information on regional earthquake hazards can be sourced from CDEM groups, regional councils, lifelines groups and research agencies, for example report on the Wellington earthquake hazard and impact area (MCDEM, 2018; Wellington Lifelines Group, 2012)
Fire hazard	Fire hazard varies by location, time of year and weather conditions. FENZ provides maps of fire risk, updated daily considering weather and environmental conditions. However, for evacuation planning it would be necessary to identify areas with a high baseline risk for wildfire irrespective of current weather conditions. Scion has developed methods for mapping high-risk areas for wildfires.

Table 4.2 Affected populations

Data type	Information and application
New Zealand Census (Statistics NZ)	Census 'place' profiles (small area, district or region) include dwelling counts, usual resident population and a broad range of other demographic statistics. These can also be sourced at SA1 (formerly meshblocks) or SA2 level (formerly area units). Census travel to work and travel to education data can help in estimating commuter flows between areas.
Urban/rural boundaries (Statistics NZ)	Classifies New Zealand into areas that share common urban or rural characteristics, ranging from 'major urban area' to 'rural settlement'.
Building footprints (Land Information NZ (LINZ))	A dataset of building outlines, covering New Zealand. This dataset does not define the use of the building; however, this data can be used to infer the spatial distribution of people within a hazard footprint.
Ratings databases	Rating information held by local authorities can be used to estimate the number of residential and commercial properties within a hazard footprint.
Visitor numbers	Information on visitor movements is collected by a range of agencies, including the Ministry of Business, Innovation and Employment's regional tourism forecasts, and by Statistics NZ. Regional and local tourism and development agencies may also collate and hold this data.
Hospitals	Provided by the Ministry of Health (certified providers hospitals), including location, service type and total beds.
Aged care	The Ministry of Health provides the location of registered age care facilities, including a map layer and address details. This data includes the services provided at each facility and the total beds available.
Health	District health boards may have knowledge of the locations of medically vulnerable people who are under care. This information is not publicly available but could be useful for detailed evacuation planning.
Education	The locations and size (roll) of tertiary education campuses, schools and childcare are available through educationcounts.govt.nz
Prisons	The Department of Corrections provides the locations of prisons in New Zealand.
Social vulnerability indicators	Mason et al., (2019) explain how social vulnerability indicators measure the exposure, susceptibility and resilience to natural hazards for different populations, including children, older adults and people with complex health needs. Mason et al., (2019) also consider measures of social connectedness and indicators that assess knowledge, awareness and skills to cope. This work was originally undertaken as a research project focusing on flooding in New Zealand, but the findings and indicators could be applied to other hazard types.

Table 4.3 Supporting facilities

Facility	Source/description
Safe areas	The location of safe areas varies depends on the hazard (refer section 4.1.3 regarding the identification of hazard and evacuation areas). For tsunami hazards, this can include vertical evacuation structures.
Civil defence centres	Information on civil defence centres/community emergency hubs is curated by CDEM groups. These may be in community facilities (see below). Some sites may be mapped and made public in advance of the hazard occurring, as in the example of Wellington's Community Emergency Hubs, or the locations are shared with the public by the CDEM group once they are operational.

Facility	Source/description
Community facilities	These are community facilities that could be used as a destination in an evacuation. Ideally, suitable facilities are identified by CDEM groups, and may include halls, schools and marae. Otherwise, this information can usually be sourced from local authorities.
Marae	The locations of marae are mapped (see Appendix C). However, the iwi, hapū or runanga should be consulted before assessing these as potential safe areas or destinations.

Table 4.4 Transport datasets

Transport datasets	Source/description
Roads	The Waka Kotahi National Road Centreline covers state highways and local roads across New Zealand, and includes attributes such as traffic volume, carriageway width and surface type. The One Network Road Classification can be used as a starting point for assessing the criticality of the road asset. Commercial road centreline and network routing datasets are also available from providers including TomTom and Here. Some CDEM groups may have already identified and mapped 'priority routes' for emergency response activities. These may not necessarily be aimed at evacuation but could provide a useful basis for further discussion on route priorities.
Paths/trails	There are some commercial providers that include off-road paths and trail datasets in addition to vehicle routing datasets. Free and open sources include OpenStreetMap and the LINZ Tracks dataset.
Public transport	Data on scheduled public transport services is made available electronically by regional councils as General Transit Feed Specification data, including routes and stops. However, the location of assets available for deployment, for example bus depots, may be more useful in the event of a large-scale evacuation.
Ports and airports	The location of ports, airports, air strips and wharves can be sourced from LINZ. Additional information can be sourced central government agencies if required.
Network models	A range of transport models throughout New Zealand is primarily used to support transport planning in urban areas, although regionwide models exist in some parts of New Zealand. These models are generally spatial, are owned by central and local government, and are developed and run in a range of specialist software platforms such as Cube, EMME, SATURN, AIMSUN and Tracks. The models can predict traffic demands now and into the future under a range of scenarios including modelling the impacts of road closures. They could also be applied to estimate the traffic volumes, speeds, travel times and congestion if significant volumes of traffic were diverted to an evacuation route(s) or if operational changes were applied to a transport network in response to an evacuation event.
Detour routes	Waka Kotahi Detour Routes Tool is available for planning detours for state highway closures.
Transport infrastructure vulnerability	These resources provide an assessment of assets at risk of damage from the hazard, including roads ports and airports, as well as structures such as bridges and tunnels. The New Zealand Lifelines Council provides guidance on assessing transport vulnerabilities and reports on the vulnerability of nationally significant infrastructure. Regional Lifelines groups and CDEM groups may also have lists and assessments of critical transport assets and vulnerabilities. Waka Kotahi provides public maps showing the resilience of the state highway network to earthquake, storm, volcano and tsunami hazards. This includes disruption state, availability and outage assessments for corridors and bridges.
Traffic management	Traffic management monitoring and VMS systems can support more efficient evacuation and provide information to evacuees on route. There is a variety of intelligent transport systems that may support evacuation route planning.

Transport datasets	Source/description
Service stations	Information on service stations is not readily available from a single provider but could be sourced from commercial transport data providers such as Here and TomTom or collated from oil company websites.
Rest areas	State highway rest areas can be sourced from Waka Kotahi, but these are not necessarily safe or appropriate for large scale evacuations.

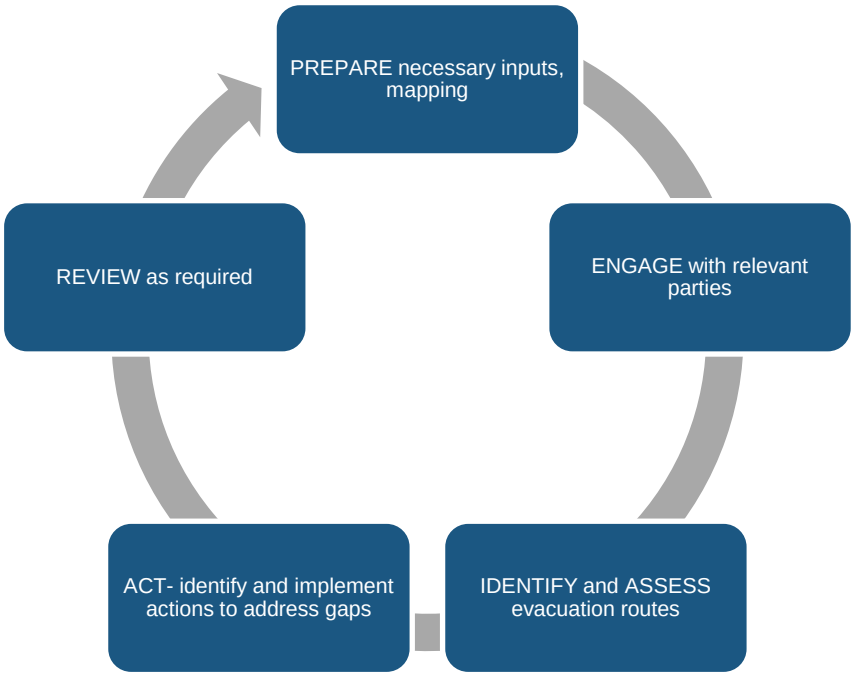
4.5 A note on uncertainty

Planning and assessing evacuation routes pre-event inherently involves uncertainty as the impact of the next natural disaster is unknown until it happens. There is also uncertainty in human behaviour, as trauma can cause people to react in unexpected ways. However, there is still merit in developing and planning for different scenarios and identifying opportunities to improve route choice and availability, and to assist in preparedness activities. Identifying contingencies and alternative route options can also reduce uncertainty.

5 Applying the Evacuation Routes Framework

The Evacuation Routes Framework, in its current form, is designed to be applied pre-event to identify and evaluate potential route options, but it could be adapted for application during an event to help identify and re-evaluate evacuation routes as the event unfolds. A proposed process for applying the framework pre-event is shown in Figure 5.1, with each step described in detail below.

Figure 5.1 Process for applying the Evacuation Routes Framework in a pre-event scenario



While this is the desirable process for applying the framework, many organisations involved in evacuation planning have limited resources available, including time and funding. Additional funding and support from central and local government may be needed to enable this work to go ahead, and to focus effort on the highest risk hazards and potential mass evacuation scenarios.

5.1 Triggers for evacuation route planning

An assessment of hazards and risks, and their potential impact on human life and safety will inform the need for planning evacuation routes. High regional and local hazard risks are profiled in CDEM group plans and this should align with CDEM guidance on hazard risk assessment. However, there may be other drivers for identifying and assessing evacuation routes by different agencies, including:

- community drivers:
  - community-led initiatives to improve resilience to natural hazards
  - population growth or changes in community profile that increase vulnerability to hazards
- transport drivers:
  - new potential route options, such as opening a new access road

  - changes in route capacity, quality or vulnerability, such as upgrading a bridge
  - long-term or permanent route closures, for example closing a road for long-term maintenance works or removing a water taxi service
- hazard drivers:
  - observing how other communities responded to hazard events
  - acquiring increased knowledge of hazards and risk due to new research
- parallel initiatives:
  - development of resilience programmes and projects
  - development of CDEM group plans and emergency response plans
  - other hazard research programmes.

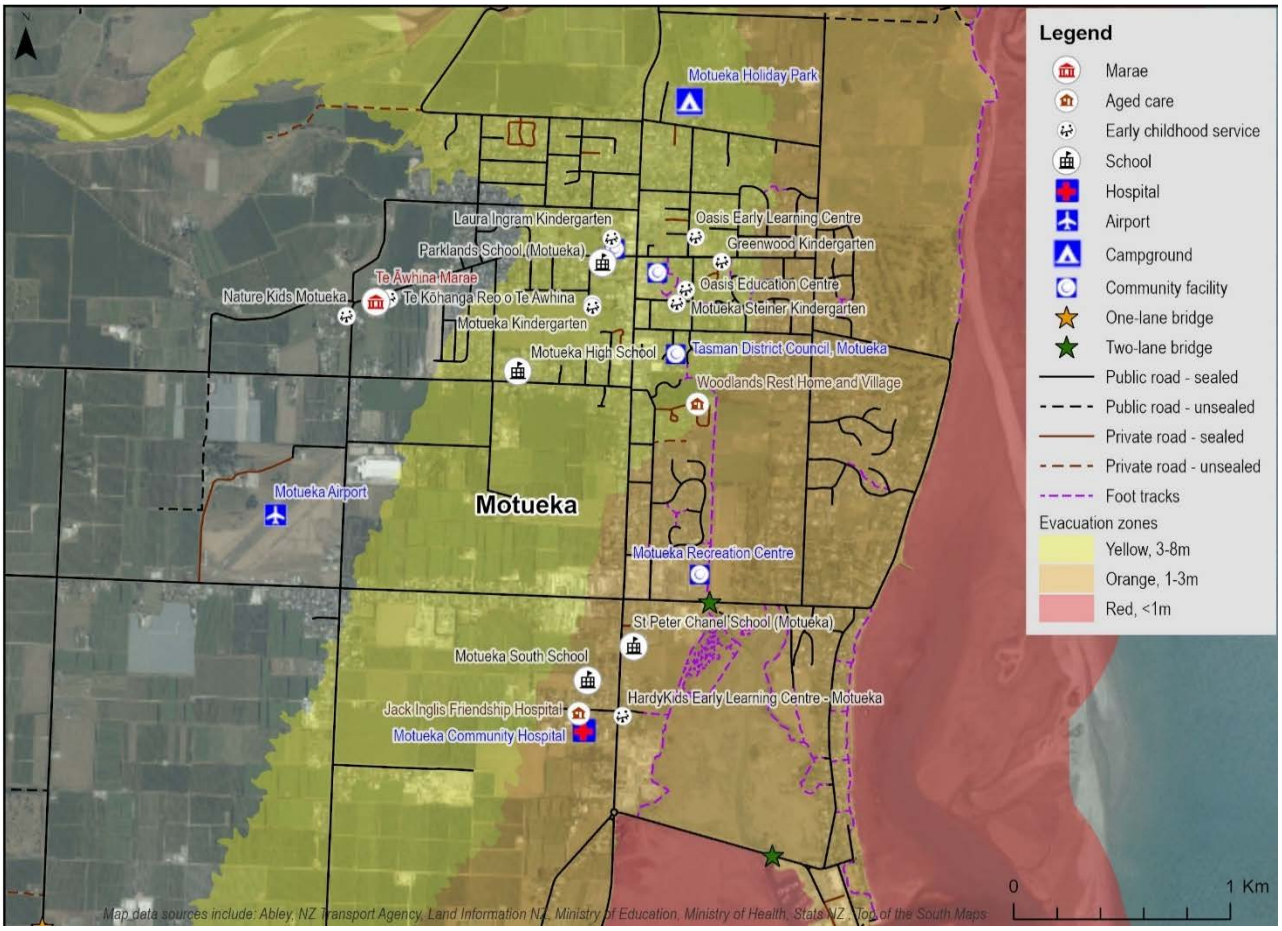
Regardless of the trigger for considering evacuation routes, some routes are likely to be critical evacuation routes for multiple hazard scenarios, especially where there are limited evacuation options for many communities. Therefore, a multi-hazard lens should be used when applying the framework.

5.2 Prepare necessary inputs

This stage involves collating the necessary inputs for applying the framework. The amount of effort required in this stage is proportional to the size of the community affected, and the complexity of the hazard or transport networks.

This information is best displayed using maps showing the potential hazard footprint in relation to affected populations and transport networks. An example of this is provided in Figure 5.2. In some instances, a basic map showing roads, tracks and community facilities overlaid with the hazard footprint would be sufficient.

Figure 5.2 Example of a map used to inform tsunami evacuation planning for Motueka



When considering evacuation routes for mass evacuations affecting large populations, it is more critical to understand the number of people or households likely to be affected, the capacity of key routes and location of vulnerable communities (such as schools, early childhood learning centres and hospitals). Spatial analysis may be required to overlay hazard footprints with other datasets to estimate who and what is inside, or outside the areas that could be affected.

5.3 Engagement and application

When applying the framework, it is important to involve people who have a shared interest in transport infrastructure and emergency planning. Each party can share information and knowledge, and gain an understanding of each other's priorities. This may include:

- CDEM groups
- lifelines groups
- councils
- health authorities
- government agencies
- iwi and Māori authorities
- utilities providers

- port and airport operators
- New Zealand Police
- Fire and Emergency NZ
- major tourism operators or employers
- major landowners
- community groups
- schools
- retirement villages and aged care facilities.

The extent and type of engagement with the Evacuation Routes Framework depends on the outcomes being sought. It could be workshops with multiple agencies in the room, or one-on-one consultation with selected individuals.

Evacuation routes may cross the jurisdiction of multiple organisations. The boundaries of these organisations may not align, for example boundaries and overlaps between territorial local authorities, CDEM groups, NZ Police districts and iwi rohe. When developing plans and actions from applying the framework, it is very important to consider how the support, control and coordination of evacuation routes transitions at these boundaries.

It is also crucial to engage with communities to capture this information and to use local knowledge to assess the feasibility of the framework. This will lead to communities having a sense of ownership in keeping themselves safe. Formalising and disseminating local knowledge on routes and safe areas/destinations can also help those unfamiliar with the area to evacuate quickly.

5.3.1 Identifying and assessing evacuation routes

Identifying and assessing evacuation routes should include:

- working through each consideration identified in the framework
- identifying alignment with existing or proposed plans and projects
- documenting priorities and opportunities to collaborate
- identifying actions and responsibilities.

It is important to be clear about the outcomes being sought and each organisation’s responsibilities in delivering actions that arise. In engaging with key groups, it is also essential to consider cross-boundary implications of evacuation routes and involve organisations whose remit overlaps the expected spatial boundaries of evacuation routes.

5.3.2 Identify actions

The purpose of the framework is to assist organisations to identify, assess or prioritise routes for evacuation purposes. Therefore, the outcome of the framework should include actions to address gaps identified in evacuation routes. The types of actions that might arise include:

- prioritising preferred evacuation routes and identifying alternative route options
- reviewing community and institutional evacuation plans or developing new evacuation plans

- undertaking further assessment if a knowledge gap is identified, for example assessing the vulnerability of infrastructure or undertaking more detailed route modelling
- identifying and addressing resource gaps at assembly areas, expected destinations and pass-through communities, for example the provision of water, shelter and communications
- highlighting where investment in improving routes or facilities is required, for example to improve resilience, to increase capacity for evacuation, or to improve radio/mobile phone communication networks
- maintaining further or recurring engagement with communities, emergency response agencies, iwi or other interested agencies.

In some scenarios, no further action is required. This may be the case where the evacuation route is obvious and straightforward, or there are many safe evacuation route options. Conversely some hazard scenarios may have high levels of uncertainty, either in how the event will unfold or who will be affected, and therefore it is nearly impossible to identify, assess and prioritise routes in advance.

Following the identification and assessment of routes, in some instances there may be no clear ‘preferred’ route, or network of routes, with all route options having some vulnerabilities or capacity constraints. In this instance options for improving the capacity and/or security of routes should then be assessed.

5.4 Review

The framework should be reapplied periodically, particularly in response to changing environments and evacuation drivers (as described in section 5.1).

6 Case studies

Two case study areas were selected to test a draft version of the Evacuation Routes Framework. The location and scope of the case studies were chosen in consultation with the Project Steering Group and cover a range of hazards across different scales and environments:

- **Case study 1**: Wellington earthquake scenario
- **Case study 2**: Nelson/Tasman scenarios:
  - a tsunami scenario affecting coastal communities in the Tasman District
  - a flood scenario affecting Nelson City
  - a rural fire at an urban interface: Mārahau/Kaiteriteri.

The researchers undertook the case studies using the following methodology:

1. They sourced available data and map layers, and a series of A1 maps created showing the hazard zones, communities at risk, transport networks and vulnerabilities. These maps are provided as an electronic Appendix D to this report.
2. The project team met with representatives from the CDEM group, lifelines group and iwi representatives in a round-table workshop to discuss the hazard scenario, exploring themes developed in the draft Evacuation Routes Framework and using the maps and data to generate discussion.
3. The learnings from the case studies were then used to finalise the Evacuation Routes Framework.

This chapter sets out the case study scenarios and the outcomes of the case study workshops. Each case study in this chapter is formatted against the components of the Evacuation Routes Framework and presented in a table format.

6.1 Wellington case study – earthquake scenario

This scenario is an earthquake occurring during daytime on a weekday. The earthquake is magnitude 7.5 and located on the Wellington Fault, with an epicentre in the Wellington Harbour area.

The earthquake risks in Wellington are well studied and significant thought and planning has gone into earthquake preparedness (for example, refer to Wellington Lifelines Regional Resilience Project, 2019). Key documents for the development of this case study are the *Wellington Earthquake National Initial Response Plan* (MCDEM, 2018), and *Lifeline utilities restoration times for metropolitan Wellington following a Wellington Fault earthquake* (Wellington Lifelines Group, 2012).

The Wellington Earthquake National Initial Response Plan (MCDEM, 2018) contains the following assumptions that were applied to this scenario and affected area:

- Cascading and secondary hazards include aftershocks, tsunami, fire, landslides, liquefaction and subsidence.
- Wellington is isolated by road, as are areas outside of Wellington.
- Rail is inoperable.
- Electricity networks, water reticulation networks and gas networks will be inoperable or degraded.
- Wellington Airport runway is operational (at least partially) within 48 hours for some military aircraft.

- CentrePort Wellington will have some level of functionality within five days to accept roll on/roll off ferries and geared ships (with their own cranes).
- National assembly areas are operable, including ports (Auckland, Napier, New Plymouth, Tauranga and Lyttelton) and airports (Ohakea and Kāpiti).
- Community-led responses will begin automatically and individuals will support each other with the resources they have available.
- Automatic ordered mass evacuation of large portions of the general population out of the affected area does not occur.
- Supported evacuation will occur, with air, sea and land transport vehicles moving into the region and departing with evacuees on board.
- Spontaneous self-evacuation will occur: some individuals or groups will attempt to evacuate and move between affected regions by walking, using vehicles or by private boats.

This case study is focused on post-event evacuation; however, discussions also explored evacuation due to tsunami and secondary hazards such as fire.

A primary assumption is that instead of mass evacuations, people are directed to shelter-in-place post-event. The shelter-in-place option is contingent on people having access to sufficient water, food and other necessary supplies for up to a week after the event. Communities are expected to be largely self-sufficient until strategic supply networks are established to bring in supplies from regional sources. This option is also conditional on engineered resilience initiatives for water systems successfully continuing to provide water to households from day eight after the earthquake. If re-establishing road transport into the affected area is significantly delayed, or if there is little prospect of opening government ministries, schools or other key services in the affected areas in a timely manner, this could also weigh against the shelter-in-place approach. If multiples of these scenarios occur, then mass evacuation will be considered for some areas.

Table 6.1 Wellington earthquake scenario: evacuation considerations (partly sourced and adapted from MCDEM, 2018)

Evacuation consideration	Discussion
Hazard characteristic	A magnitude 7.5 earthquake occurs on the Wellington Fault, with the epicentre located in the Wellington Harbour area. On the fault itself there is 4–5 m maximum horizontal displacement and up to 1 m vertical movement. There are high levels of shaking across the region. In areas of shaking intensity MMI 9, landslides occur on steep slopes and many weak masonry buildings are destroyed. In areas of shaking intensity MMI 10, landslides are widespread in susceptible terrain and reinforced masonry buildings are heavily damaged, with some collapsing. Severe liquefaction and lateral spreading occur in unconsolidated fill and sediments around Wellington's waterfront and further afield, leading to significant ground deformation and damage to structures and underground infrastructure. A combination of crustal displacement along Wellington Fault and strong shaking leads to tsunami and seiche[5] hazards on shorelines around Wellington Harbour. Fires breaks out in residential and commercial areas from damaged gas lines and are difficult to control given the damage to the water supply, and additional demands placed on emergency services. Large aftershocks in the hours and days after the main earthquake are ongoing, generating further slips and rockfalls.
Affected population	The population of the Wellington region is approximately 500,000 residents (Census 2018). Divided across the local authority areas, this is approximately: • Wellington City – 200,000 residents • Porirua City – 57,000 residents • Upper Hutt City – 44,000 residents • Lower Hutt City – 105,000 residents • Kāpiti Coast District – 54,000 residents • Masterton District – 26,000 residents • Carterton District – 10,000 residents • South Wairarapa District – 11,000 residents. The central business district (CBD) is within the Pukehīnau/Lambton Ward, which has a resident population of approximately 46,000 people (including surrounding hillside suburbs). This area receives an estimated 80,000 weekday commuters, including employees in the government, retail and service sectors, along with students at city secondary schools and Victoria University. The CBD is expected to be the first major source of evacuees immediately post-event. Key vulnerable populations within affected areas include people located in hospitals and rest homes, as well as people seriously injured in the earthquake.

[5] A seiche is an oscillating standing wave in an enclosed or semi-enclosed water body such as a lake or harbour. The 'sloshing' effect of the seiche can cause damage to infrastructure and resources located close to the water, for example piers and boats.

Evacuation consideration	Discussion
Safe areas/expected destinations	After the initial shaking, people in coastal areas move to higher ground in anticipation of tsunami and head to designated safe areas beyond the blue lines painted on many Wellington streets. Once tsunami and seiche hazards pass, people may return to their residences in the immediate vicinity or further afield if they are able to. Where fires break out, people inhabiting commercial premises and residential buildings self-evacuate to open spaces or look for alternative shelter options. In the CBD and other built-up areas, large numbers of people self-evacuate buildings for areas of greater perceived safety, including parks and open urban spaces. From there, people may attempt the 'long walk home', provided they are physically able to do so, and have appropriate footwear and clothing. Destinations for those walking or cycling home include residential areas in: • the suburbs surrounding the CBD and farther afield • the Hutt Valley and potentially as far as the Wairarapa • Porirua and further north via the Kāpiti Coast. There are 127 community emergency hubs across the region, located at community facilities and some schools. Hubs in affected areas are activated, with community members working together to support people in their neighbourhoods. These hubs can become destinations for people seeking support, and from there volunteers can direct them to accommodation and other assistance as required. Across the region, marae will play a vital role in sheltering and supporting iwi members and the wider community. As the recovery unfolds CentrePort, Seaview Marina (or Petone foreshore) and Wellington Airport operate as transport hubs for personnel and supplies entering the area and evacuees leaving the area. These are interim destinations for evacuation by sea and air, respectively. Access to these sites will be enabled as roads are restored. Regional and national assembly areas in wider regions and across the country will be activated after the earthquake and will receive evacuees by sea and air (refer Figure 6.1).

Figure 6.1 Wellington emergency supply chains and the movement of people (source: MCDEM, 2018)

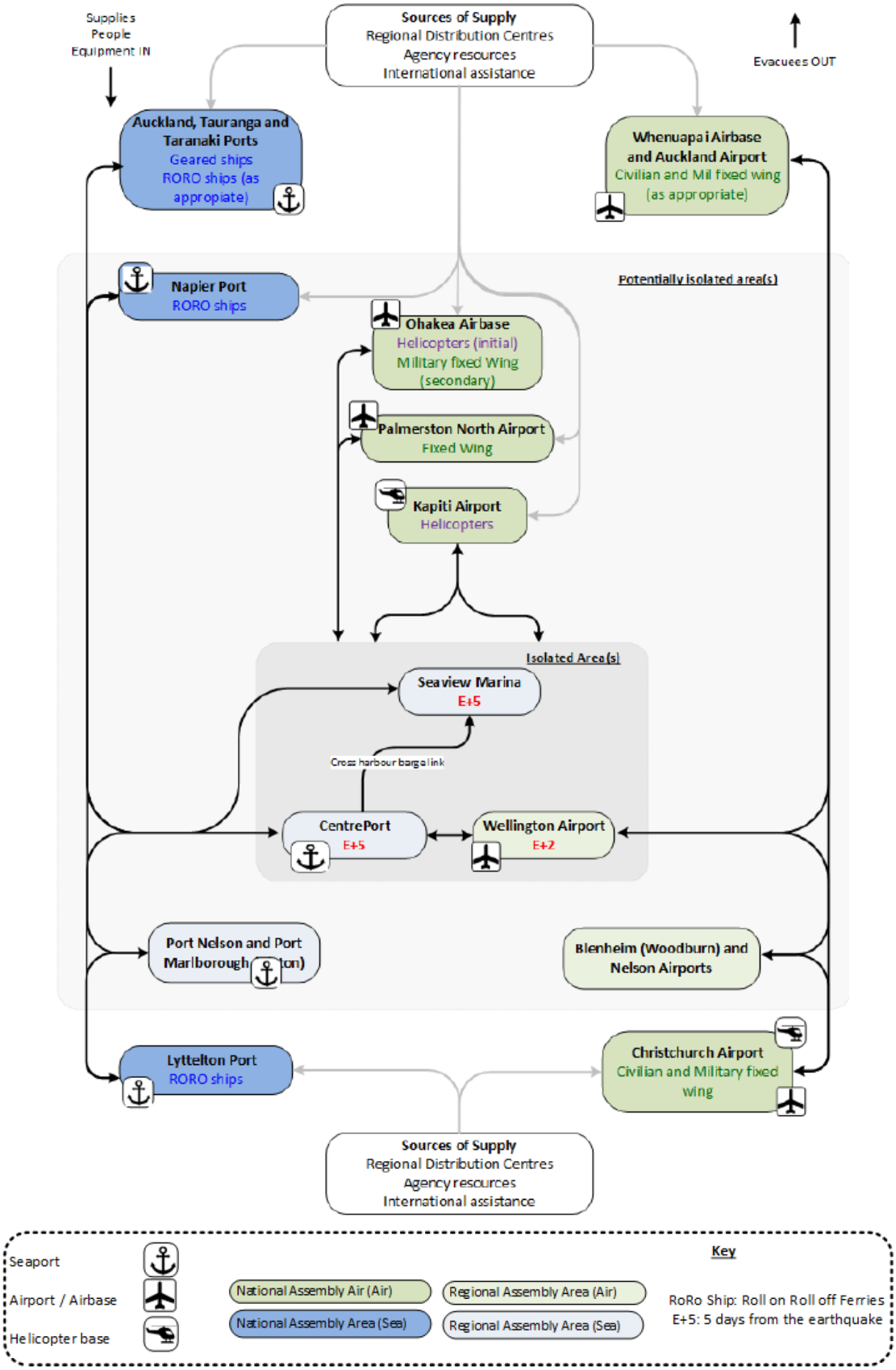


Table 6.2 Wellington earthquake scenario: evacuation scenarios (partly sourced and adapted from MCDEM, 2018)

Evacuation scenario	Description
During or immediately post-event	• The earthquake occurs without warning, so no pre-impact evacuation is possible. • Earthquake shaking serves as warning of a potential tsunami threat. People in coastal areas self-evacuate to high ground. • Where uncontrolled fires break out, people self-evacuate to safe areas in urban and suburban open spaces, or to nearby shelter.
Post- impact	People in Wellington CBD attempt the 'long walk home' to: • surrounding suburbs to the west-northwest, southeast, southern bays and Miramar Peninsula • Hutt Valley (and potentially into the Wairarapa) • Porirua and further north along Kāpiti Coast. Assisted evacuation to national and regional assembly hubs is given to hospital patients, earthquake casualties, key government personnel, visitors and other vulnerable people (as prioritised in the Wellington Earthquake National Initial Response Plan 2018). People wanting to leave due to loss of housing, psychological distress or for business purposes may also seek assisted evacuation by sea and air, and these people will be prioritised for evacuation by the Wellington region emergency coordination centres/emergency operation centres. Additionally, ordered mass evacuation may be required in the following circumstances: • no imminent recovery of infrastructure services, possibly exacerbated by ongoing aftershocks • failure of infrastructure resilience initiatives to supply potable water to households • delays in bringing food and other supplies to affected areas • fire/conflagration • sustained closure of schools, government departments/agencies.

Table 6.3 Wellington earthquake scenario: evacuation route options and assessment (partly sourced and adapted from MCDEM, 2018)

Route options	Description and assessment
Land	The initial phase of evacuation of CBD commuters on foot will be largely self-directed, with individuals and groups finding their own way home or out of harm's way. CBD evacuees returning to the nearby suburbs will be likely to take routes most used/known to them or be aware of shortcuts/routes more appropriate for moving on foot. Roads may be damaged from shaking and liquefaction, or wholly or partially blocked by rock fall or other debris. Some people may attempt to use motor vehicles, but obstructions and road damage will hinder this. For evacuees heading to the Hutt Valley, State Highway 2 and the rail corridor will be a natural route to follow. However, this route follows the Wellington Fault, and surface rupture along the fault is likely to cause severe damage to road and rail infrastructure. Landslides are also likely along the route, possibly ongoing with large aftershocks. Evacuees heading to Porirua and the Kāpiti Coast face similar issues to those heading up the Hutt Valley, having to navigate around the fault rupture zone, road damage and landslides. However, land-based route options will probably become apparent, such as State Highway 1, the Transmission Gully Motorway, or via roads and tracks through the north-western hill suburbs. Given the large numbers of people evacuating on foot along constrained and potentially dangerous corridors, consideration must be given to how this can be facilitated to reduce exposure to secondary hazards. For example, emergency responders can direct people from walking into high-risk areas, identify safe alternatives, or provide safe assembly areas for people to gather and wait until walking routes are assessed and made safe. Depending on the extent of damage and the availability of appropriate equipment and machinery, regional priority road routes will be opened over time**.** These are, in order of priority:

Route options	Description and assessment
	• spine routes to key locations, such as CentrePort, Wellington Airport and Wellington Regional Hospital • access to key infrastructure, including water reservoirs, supermarkets • access to vulnerable communities • access to other residential communities. Isolated 'island' communities are gradually reconnected and supply routes reopened. Note that significant numbers of rescue and recovery personnel and equipment will also use these routes as part of the emergency response, creating a two-way flow of people and vehicles. Opening these routes will assist evacuation in the days and weeks following the initial earthquake. However, because these routes open access to supermarkets and other services, this supports the 'stay-in-place' approach and reduces the demand for wider evacuations.
Sea	Flotillas of private and commercial vessels may be able to assist with evacuation between the CBD and bays around Wellington Harbour and to the Hutt Valley, to support the initial evacuation of the CBD and to support the long walk home. Boats can also assist people travelling around hazardous coastal areas on the Kāpiti Coast. It was noted at the case study workshop that some iwi members have boats and could facilitate this. Boat owners in the affected areas can also use their own boats to self-evacuate if their residence is uninhabitable, or if they otherwise feel staying-in-place is untenable. It is also possible that private and commercial vessels spontaneously arrive from out of the affected region to evacuate friends and family, and to assist other evacuees. Access to fuel within the affected area is likely to be a major constraint on the extent to which sea-based evacuation using private vessels is possible. Other constraints to sea-based evacuation in the initial stages include earthquake or tsunami damage to boats, wharves and supporting infrastructure, access to sufficient provisions, and weather and tidal conditions. After the first three days, and dependent on the condition of CentrePort facilities, roll on/roll off ferries, naval vessels and other shipping should start arriving with material and personnel to support the response and recovery effort. Provided that priority routes are cleared and made safe, people prioritised for assisted evacuation will assemble at CentrePort for sea evacuation. It is estimated approximately 3,000 people per day can be evacuated by sea to national and regional assembly areas (refer Figure 6.1).
Air	Helicopter transport is an option for immediate evacuation; however, the availability of aircraft will be limited due to the number of suitable helicopters available and the demand on them for reconnaissance and emergency evacuations. Priority evacuations by helicopter, for example seriously ill patients and earthquake victims, may occur from hospitals or designated community emergency hubs. Part of the Wellington Airport runway can be made safe for military and commercial turboprop aircraft. Provided priority road routes are cleared and made safe, people prioritised for air evacuation can make their way to Wellington Airport. For both supported evacuation and mandated mass evacuation, approximately 15,000 people per day can be evacuated by air to national and regional assembly hubs (refer Figure 6.1).
Assembly areas	Assembly areas can be organised (formally or potentially informally) irrespective of the mode of the route option available within the affected areas to support assisted evacuation. Community emergency hubs, marae and large open-space areas can function as local assembly areas if required. Emergency hubs and marae can also provide pass-through support for evacuees, supplying or directing them to food, water and accommodation, and alerting evacuees to conditions across the wider region through formal and informal communication networks. Anticipated regional assembly areas within the Wellington region are CentrePort, Wellington Airport, Seaview Marina and/or the Petone foreshore (for sea and air evacuation).

Table 6.4 Wellington earthquake scenario: uncertainties

Uncertainty	Implication
Hazard footprint and intensity	The scenario for this case study is a hypothetical Wellington Fault magnitude 7.5 earthquake. The severity and areas affected are difficult to anticipate. A major earthquake event affecting Wellington could be triggered by any one of several known faults in the wider region. Although widespread landslides are expected and general locations of slope instability are known, precise locations and their runout areas are also difficult to predict. The extent of vertical crustal movement in Wellington Harbour, to the east of the Wellington Fault, is unknown and therefore the tsunami hazard is difficult to assess. Likewise, the extent to which shaking will induce in-harbour seiche and consequent coastal flooding is unknown. This will make navigation uncertain for sea-based evacuation.
Built environment performance	This scenario anticipates widespread and severe damage to structures and infrastructure systems. Anticipating the performance of buildings, transport and infrastructure components is difficult prior to the event. Resilience initiatives for transport and infrastructure systems and strengthening of buildings may mitigate some impacts.
Time of year	The focus of this scenario is the resident and commuter population. However, domestic tourism and business/conference travel to Wellington can also influence the number of people affected and the evacuation options for those people. The location and number of people within the city will also depend on the season and weather conditions.
Time of day	This scenario assumes an earthquake during the day when most commuters are in the central city. However, the event could also occur during morning or evening rush hour, when commuters are in cars, on roads, in buses or on trains. This would result in very different population distribution and immediate evacuation dynamics. If the event occurs at night, much smaller numbers will be exposed to hazards in the CBD.
Human behaviour	The behaviours of individuals and groups will be decisive in life safety and evacuation dynamics. Spontaneous support networks comprising colleagues or passers-by are likely to form, and ordinary people will engage in rescue activities and lead groups to safety. While it is likely that many coastal residents or people working in coastal areas will evacuate spontaneously in response to earthquake shaking in anticipation of possible tsunami, the extent to which this will be done is unknown. Finally, the psychosocial impact of the initial earthquake and aftershocks for some people should be considered as an additional evacuation driver, even if there is no immediate threat to their health and safety, and they have sufficient resources to shelter-in-place. A strong desire to leave may result in people ignoring official advice to stay home, self-evacuating via hazardous routes despite clear and present dangers to life and safety.

6.2 Nelson/Tasman case study

Three scenarios were tested in the Nelson/Tasman case study area (Figure 6.2):

- a tsunami scenario affecting coastal communities in the Tasman District
- a flood scenario affecting Nelson City
- a rural fire at an urban interface: Mārahau/Kaiteriteri.

Figure 6.2 Nelson/Tasman context map: Tasman coastal communities and Nelson City

Key themes that emerged across all these scenarios were:

- The Nelson/Tasman region includes three national parks, as well as several Department of Conservation (DoC) or managed forest parks and conservation areas. There are high numbers of visitors in these areas during the peak season, particularly in coastal camping areas such as at Tōtaranui and Kaiteriteri. This means:
  - high visitor numbers may create additional challenges in evacuation planning
  - the range of sea-based transport options available, such as water shuttles and taxis, varies considerably by the time of year
  - DoC is an important stakeholder in evacuation planning for these areas.
- Workshop participants noted the challenges of traffic congestion in and around Richmond and Nelson on several occasions, and how disruptions on some parts of the road network can result in the wider network becoming congested for many hours. This represents a vulnerability to the road network in

scenarios where rapid road-based evacuation is required, especially as many residents in Richmond commute to Nelson for work (and vice versa). State Highway 6 Rocks Road is particularly vulnerable to slips and coastal hazards that might arise from earthquake, tsunami and storm events.

- The wider region is experiencing major growth in the number of retirement-aged residents, including several new retirement homes under construction or opened recently.
- Nelson Port and Nelson Airport are vulnerable to coast hazards and earthquake liquefaction.

6.2.1 Tasman District tsunami scenario

The hypothetical scenario presented at the case study workshop was a major tsunami affecting the coastline from Collingwood to Richmond. The tsunami was generated due to an offshore earthquake with an estimated arrival time of one hour. This scenario requires the evacuation of communities within the published red, orange and yellow tsunami evacuation zones.

Table 6.5 Tasman tsunami scenario: evacuation considerations

Evacuation consideration	Discussion
Hazard characteristic	Major tsunami affect coastal communities with the spatial extent limited to/around known evacuation zones. Warning time of about one hour. It is assumed the affected population either feels the initial earthquake and responds to the 'long or strong get gone' direction, and/or are alerted to the event by emergency messaging.
Affected population	Because the tsunami evacuation zones are mapped and the spatial extent of the hazard area is broadly understood, it is possible to estimate the affected population in advance using Census 2018 data. Almost 13,000 residents are located both within an evacuation zone and a defined urban area, and a further approximately 3,900 people are likely to be affected in rural areas. The largest affected communities are Motueka with approximately 7,000 affected residents and Richmond with approximately 2,150 affected residents. Note that these population estimates need to be considered in the context of seasonal variations (such as seasonal workers and increased visitor numbers during summer), weekday travel patterns (people moving in or out of the evacuation zones for school or work), and population growth since 2018. For example, workshop participants noted there can be up to 7,000 additional people in the Abel Tasman National Park during summer. There are 13 schools and 17 early childhood centres in the affected area, with a combined roll of approximately 3,200 students. This includes approximately 660 children in early childhood care. Most of these facilities are in Motueka and Richmond. There are three aged care facilities in the affected area, with up to 215 beds providing rest home, geriatric and dementia care services. There is one hospital in the affected area, the Nelson Bays Maternity Unit/Te Whare Whanau in Motueka. The average New Zealand Index of Deprivation was assessed for each affected community to test its value as a proxy measure for vulnerability, community knowledge and social cohesion. However, the workshop participants noted that deprivation was not a good indicator of the demand for evacuation assistance or the need for support. It was the experience of workshop participants that deprived communities seemed less likely to ask for help, whereas people from areas with low deprivation tended to have higher expectations and demands for support. Visitor populations are less likely to be aware of evacuation procedures; however, some visitor destinations (such as campsites) have evacuation plans in place. There are no tsunami warning sirens along the Tasman coast. Some visitors might expect to hear a tsunami siren warning before evacuating, particularly those who come from areas where sirens already exist (eg Christchurch).
Safe areas/expected destinations	Safe areas are areas outside the evacuation zone. These areas can be reached by going uphill or inland.

Evacuation consideration	Discussion
	The workshop participants noted that visitors would most likely head to the nearest and most obvious high points, such as Tākaka Hill, even if it were safer and more convenient to travel inland. Residents are otherwise generally knowledgeable about the safe areas and how to reach them. Post-event it is expected some people will want to leave the local area immediately (particularly visitors). Other people may want to travel between communities to reach friends and family. The iwi representative in the workshop noted that iwi could provide support to evacuees in some areas, particularly around marae.

Table 6.6 Tasman tsunami scenario: evacuation scenarios

Evacuation scenario	Description
Pre-impact	People move themselves out of evacuation zones into safe areas. Due to the relatively short warning time (one hour) there is little CDEM groups and emergency services can do to facilitate evacuation in this time.
During or immediately post-event	Once the tsunami passes, people return home to locations within or outside the affected area (but may be unable to do this due to damage to road networks). If unable to return home, people move to locations where they can find shelter and support.
Post-impact evacuation	Visitors return home to locations outside the region. Temporary or semi-permanent relocation of residents may occur due to tsunami damage.

Table 6.7 Tasman tsunami scenario: evacuation route options and assessment

Route options	Description and assessment
Land	The workshop participants focused primarily on access roads in and out of communities and the ability to evacuate people post-event. Once the tsunami threat is apparent there is little official agencies can do to facilitate evacuation. It would be difficult to prevent people moving through the hazard zones and putting themselves at risk in doing so. In most communities the safe areas are apparent and there are land-based options that enable people to reach safe zones. Considering post-event evacuation, most coastal communities are accessed by one or two roads. These roads often follow the coast, are prone to slips and rockfall, or involve crossing vulnerable bridges. Rīwaka, for example, is located between two vulnerable bridges (Riuwaka River and Motueka River bridges on State Highway 60), and the only inland route via the Motueka Valley is vulnerable to earthquake damage. Access across Tākaka Hill could be severely affected if the tsunami is accompanied by a significant earthquake. It is reasonable to expect that many communities will be cut off and isolated for an extended period, until roads and bridges can be repaired to enable post-event evacuation and recovery. Vulnerabilities to tsunami and earthquake damage are known for the state highway network; however, the same is not known for local roads. It is reasonable to assume that all coastal roads and infrastructure will be damaged to some degree in this scenario. Damage to a hazardous substances plant in Richmond is expected in a tsunami event, which will require an exclusion zone for evacuees and emergency workers if hazardous airborne substances are present. The lack of access to fuel (for both vehicles and boats) was a major concern for the workshop participants.
Sea	Evacuation by sea is feasible for many coastal communities. There are several coastal water taxi and shuttle services that could be used to evacuate visitors and residents. Accessing some communities by sea requires skilled crew to navigate tides and local conditions. The availability of water services varies considerably during peak and off-peak seasons; however, with more boats

Route options	Description and assessment
	and crew available during peak season to match the demand for access to the Abel Tasman National Park.
Air	The only airport among the coastal communities is Tākaka Airport. This airport is outside the evacuation zone. There may be other landing strips across Tasman District that could be used for evacuation purposes. The working group did not consider air evacuation was a feasible option for any significant evacuation.

Table 6.8 Tasman tsunami scenario: uncertainties

Uncertainty	Implication
Pre-cursor (earthquake) event and wider regional impacts.	If there is earthquake damage to roads and infrastructure such as bridges, and secondary hazards on main routes, this will greatly limit evacuation route options prior to the tsunami arriving. Options for evacuation post-event are also significantly affected. It is also reasonable to assume the impact of the event extends to communities outside the Tasman District. The impact is exacerbated if wider areas are affected by a large earthquake. This will impact on post-evacuation planning as it is difficult to identify expected destinations that may or may not also be affected by the hazard.
Hazard intensity	Although it is assumed for this scenario that all evacuation zones are affected, the intensity of the tsunami will vary across the area, with areas closest to the coast more affected than inland areas.
Time of year	During summer there are high visitor numbers in coastal communities, including people visiting coastal campsites as well as visitors in the Abel Tasman National Park. This creates uncertainty in the number of people affected. However, there are many water taxi and shuttle services available during the peak season to assist with evacuations.
Time of day	Given the one-hour warning time, some people may feel they have time to travel to collect friends and family, or to travel home from places of work. However, in doing so they may place themselves in harm's way by travelling on coastal roads and bridges. This is more likely during the weekday when schools and workplaces are active.
Human behaviour	This focuses on assumptions about how different people may respond to the evacuation event. Broad assumptions can be made about the behaviour of different types of people, for example long-term residents versus visitors, but this may not play out in real time. Some residents may be reluctant to leave hazard areas despite receiving warnings about the impact of the hazard.

6.2.2 Nelson City flood scenario

The scenario presented at the case study workshop was a flood event affecting the Maitai and York River catchments. Although the case study was developed with central Nelson in mind, workshop participants pointed out that the storm-induced slips and landslides, and debris flows caused by forestry slash are of greater concern for evacuation across the region, as these types of hazards present a more immediate and unpredictable threat to health and safety.

As such, this case study also addresses the evacuation implications of flood, landslide and debris flow hazards across the wider Nelson/Tasman region.

Table 6.9 Nelson flood scenario: evacuation considerations

Evacuation consideration	Discussion
Hazard characteristic	The area likely to be affected by the flood event with a 1% annual exceedance probability (under current climate conditions) has been modelled and mapped (Tonkin & Taylor, 2017). Other flood scenarios for different annual exceedance probabilities and sea level rise predictions have also

Evacuation consideration	Discussion
	been modelled and provide some certainty about the extent and depth of flooding for the Nelson central city area. The weather event that leads to flooding could also create slips and landslides. Areas of slope instability were recently mapped and published by the Nelson City Council (Beca, 2020). Workshop participants were also concerned about debris flows of forestry slash given the amount of forestry in the wider district. A previous example of debris flow in a flood occurred in Tapawera in 2010, which resulted in the evacuation of 22 households (NZ Herald, 2010). Warnings of heavy rainfall are provided in advance by weather forecasting agencies. The severity of the flood will also depend on tidal conditions. Slips, landslides and debris flows will have a much shorter warning period, although the impending risk of these events can be detected through slope deformation and observations upstream of affected properties.
Affected population	The potentially affected population will vary by time of day and time of week. The Maitai/York flood hazard area includes residential areas such as The Wood, the commercial business area of Nelson City, as well as light industrial and residential areas along the York River. The number of residents, workers and students in the affected flood area can be estimated using Census 2018 usually resident population, travel to work and travel to education datasets. If evacuations are required at night or weekends, this will most likely affect residents, whereas a day-time weekday evacuation will more likely affect school children and workers (commuters). Workshop participants noted that if evacuation due to flooding was required, it was likely to be at a micro-scale: for example, a block, group of buildings or street. It is more likely that people are stranded at work or school due to flooding or a slip affecting the road network, and this will most likely be temporary until roads are reopened. Therefore, advance planning for flood evacuation is not considered a high priority in terms of the number of people likely to be affected. People with property in the modelled hazard area will be aware of the flood risk, having received notification of the hazard by letter in the last year, or because flood information is attached to property files. The flood risk has been widely publicised by the Nelson City Council and through the media.
Safe areas/expected destinations	If flooding requires evacuation, the safe area will be any area outside the flood zone. There are community facilities outside the flood zone that could host temporary evacuees, including people unable to travel home due to flood or storm damage on key transport corridors.

Table 6.10 Nelson flood scenario: evacuation scenarios

Evacuation scenario	Description
Pre-impact	Weather forecasters issue warnings about heavy rain in the days before the event. The need for pre-impact evacuation due to flooding can be avoided by CDEM encouraging people to stay at home and avoid travelling to work or school within or through the affected area.
During or immediately post-event	Rising flood waters are reported to the council and/or FENZ. Those potentially affected can then be assisted with evacuation, noting this type of evacuation is likely to be localised and affect a relatively small number of people. People may be unable to return home (commuters, students) immediately because transport routes are damaged by flood waters or slips, for example the closure of State Highway 6 Rocks Road. Some households can be evacuated due to slips, debris flows or flood damage.
Post- impact	Evacuation due to longer-term closure of access roads was raised in relation to coastal communities, with the example of damage to Cable Bay Road in the November 2011 flood which isolated people in the Cable Bay community. In this situation, the need and type of evacuation may be similar to what could occur in a tsunami or earthquake scenario affecting coastal communities (refer to the tsunami case study in section 6.2.1 for more information on this option).

Table 6.11 Nelson flood scenario: evacuation route options and assessment

Route options	Description and assessment
Land	Options for reopening affected roads are identified and assessed after the event. The assessment of possible routes involves the same considerations as in the tsunami scenario, except the impact of this event will be more localised and the damage less extensive.
Sea	Sea evacuation can be an option for isolated coastal communities (refer to the tsunami case study in section 6.2.1 for more information on this option).
Air	Evacuation of people by helicopter is possible when there is an immediate threat to human life and no safe evacuation option is available. This is also an option where houses are uninhabitable post-event and there is no other viable evacuation route or shelter options.

Table 6.12 Nelson flood scenario: uncertainties

Uncertainty	Implication
Dam burst	Workshop participants noted the risk of flooding associated with dam burst, for example the Maitai Dam or Cobb Reservoir. However, this is more likely to occur following an earthquake than a storm. Dam burst is an immediate and serious threat to human life, and the evacuation scenario should take this into account.
Forestry and land instability	Large parts of the region are covered in forestry at different stages of growth and harvest. Large amounts of forestry slash can lead to dangerous debris flows. Likewise, areas downstream of major land development are also more prone to debris flow due to the amount of exposed earth.
Tide and weather conditions	The spatial extent and intensity of flooding is linked to tidal conditions. Weather events causing storm surges will create additional coastal inundation. The potential impact of the event can be assessed in advance and monitored as the event unfolds.
Timing	Time of day and day of week influences where people are located, relative to the hazard impact areas: at home, work or school.

6.2.3 Mārahau/Kaiteriteri fire scenario

The scenario presented at the case study workshop was a fire in or around the communities of Mārahau and Kaiteriteri. This scenario could readily apply to any other community with a high risk of fire due to the surrounding land cover and land-use activity.

Table 6.13 Mārahau/Kaiteriteri fire scenario: evacuation considerations

Evacuation consideration	Discussion
Hazard characteristic	Rural fire is a significant risk for the region, due to the amount of forestry and highly flammable land cover. Fire risk varies over time, depending on weather, climate conditions and fuel availability. Fire is a known potential hazard for the Mārahau and Kaiteriteri communities, and the workshop participants noted they had been involved in planning for fire hazards and evacuation in these locations. The Lake Ōhau fire in 2020 raised awareness of the risk of wildfire in these communities and in other communities in the wider region. At St Arnaud for example, extensive multi-agency planning for fire risk has been undertaken, including evacuation planning.
Affected population	The workshop attendees had a good sense of the local communities in these areas, their community knowledge, cohesiveness and capacity to evacuate. The homes of residents in Mārahau and Kaiteriteri are in pockets spread out along the coast and up valleys. The workshop attendees noted the residents were very aware of the fire risk and were generally very resilient.

Evacuation consideration	Discussion
	Visitor numbers peak over the summer period when the fire danger is often highest. Visitors may be in high-risk areas such as the Kaiteriteri Mountain Bike Park. The Kaiteriteri Recreation Reserve has plans in place to respond to fire, including evacuation plans. Both Mārahau and Kaiteriteri have volunteer fire brigades which can provide support in the event of an evacuation.
Safe areas/expected destinations	Safe areas need to be identified and assessed based on the extent and expected spread of the fire, and the degree to which the fire extends along transport corridors. The coastline is a safe assembly area if no other viable safe areas can be reached. Nearby towns and communities can serve as intermediate destinations for evacuees.

Table 6.14 Mārahau/Kaiteriteri fire scenario: evacuation scenarios

Evacuation scenario	Description
Pre-impact	The threat of wildfire will not be established until a fire is detected, although people may be aware of increased fire danger due to weather and environmental conditions. There is the ability to evacuate residents and visitors located in areas in and around an established fire event. The warning time will vary depending on the behaviour of the fire and the firefighting response, from a few hours to a few minutes.
During or immediately post-event	Evacuation during or immediately after the event will depend on the footprint and behaviour of the fire. People will need to move away from the fire but avoid routes that could be cut off by the fire itself. The coastline may be the only option if no other routes are available.
Post- impact evacuation	Post-impact evacuation will be from assembly points in safe areas to nearby towns and communities. For evacuation by road the closest towns are Rīwaka and Motueka.

Table 6.15 Mārahau/Kaiteriteri fire scenario: evacuation route options and assessment

Route options	Description and assessment
Land	Once safe assembly areas for evacuation are established, the best road options for reaching these safe areas can be identified. There is one road connecting Mārahau and Kaiteriteri, and two road options connecting Kaiteriteri to State Highway 60. These access roads and much of the wider road network are surrounded by potentially flammable vegetation. The fire risk along roads is a significant concern and it is critical to consider the possibility of people being trapped by fire as they evacuate. This consideration applies when assessing key access roads as evacuation routes, as well as potential routes linking communities to assembly areas within Mārahau or Kaiteriteri.
Sea	Workshop participants noted it is possible to evacuate via sea from the coast at Split Apple. However, access is tidal as there is no beach at high tide for boats to land on, and evacuees would have to travel through dangerous fuel areas to get there. In summer there are a lot of boats available to respond. In the off-season there are fewer boats, but there are also fewer visitors and the fire risk is lower.
Air	Although not discussed among the workshop participants, evacuation by helicopter could be an option if no other evacuation options are available.

Table 6.16 Mārahau/Kaiteriteri fire scenario: uncertainties

Uncertainty	Implication
Hazard footprint	Once a fire establishes its spread, the hazard footprint will depend on many factors, including wind strength and direction. This could create uncertainty about which routes and assembly areas are available in some localities, and decisions about evacuation route options will need to be made as the hazard unfolds.

6.3 Additional case study learnings

In addition to discussing evacuation scenarios, several other learnings and insights were raised:

- An initial high-level risk assessment is required to first determine high-priority hazards for evacuation and emergency planning. CDEM groups should have undertaken this assessment, and there is potential to align the Evacuation Routes Framework with existing hazard risk assessment guidance.
- Workshop participants found the maps prepared for the case study immensely valuable for stimulating discussion. The maps and framework are a starting point for identifying route options, vulnerabilities and pinchpoints (for example).
- CDEM staff members and people in community engagement roles have a very good understanding of different communities, including community composition, emergency preparedness and social cohesion.
- For most communities and hazard scenarios the evacuation routes are obvious. Often there are only one or two viable options. However, in some scenarios the attributes of different routes will have to be weighed up against each other, particularly if the framework is being applied to prioritise potential routes for resilience improvements. An example given was having to choose between a vulnerable route with good capacity, and a more reliable route that has limited capacity.
- There is immense value in getting a range of agencies around the table to discuss evacuation routes, particularly for option identification and assessment. This could include as relevant: FENZ, NZ Police, local authorities, Waka Kotahi, CDEM, iwi representatives and lifelines groups. Each party will have their own community insights and priorities. They can share intelligence about particular roads and routes and identify interdependencies and shared interests, for example corridors that could be prioritised to evacuate residents, as well as provide access for emergency and recovery services. The value of engaging with stakeholders is reflected in the ‘engage’ component of the process for applying the framework (refer Figure 5.1).
- Over time new research into hazards is released, resilience projects are implemented, and new roads and transport infrastructure built. Therefore, the Evacuation Routes Framework should be revisited from time to time.
- The actions resulting from the application of the Evacuation Routes Framework could include a checklist or ‘aide memoire’ to support evacuation planning following a major natural hazard.

7 Conclusions and recommendations

This research highlights evacuations as a critical risk reduction strategy to minimise loss of life and injury when natural hazards occur. The uncertain nature of natural hazards, diversity of potentially exposed communities, and complexity of human responses and evacuation dynamics, require that evacuation planning and execution be both well prepared and flexible. This research also emphasises that planning and assessing routes is part of the wider evacuation planning process, requiring a sound understanding of both affected communities and receiving areas.

7.1 Conclusions

The purpose of this research was to develop a framework and methodology to plan, design and assess the efficacy of emergency evacuation routes. The framework is intended to be specific to the New Zealand context, to support planning and preparedness for identifying evacuation routes in the event of a natural disaster.

The objectives for this research study were to:

- Identify and examine international and New Zealand experience and best practice in planning and assessing evacuate routes.
- Establish the ideal characteristics of evacuation routes in New Zealand conditions for particular hazards.
- Construct a framework and methodology for evaluating evacuation routes.
- Test and validate the framework and methodology using two case studies.

Chapter 2 presents a review of literature on New Zealand and international best practice on evacuation planning, particularly focusing on evacuation route planning.

The literature review (chapter 2), stakeholder engagement (chapter 3) and case studies for the Nelson/Tasman and Wellington regions (chapter 6) helped establish characteristics of evacuation routes for natural hazards in New Zealand. The learnings from these chapters informed the Evacuation Routes Framework set out in chapter 4, and the application of the framework described in chapter 5.

The Evacuation Routes Framework (chapter 4) distils the learnings from this research and provides a structure for identifying and assessing evacuation routes. The framework presents an approach that is easily understandable and applicable by response agencies and communities, in both the planning and response phases.

The Evacuation Routes Framework identifies the following factors that define evacuation scenarios:

- hazard characteristics
- affected population
- location of safe areas, supporting facilities and expected destinations.

Evacuation scenarios may include all or some of the following:

- shelter-in-place
- pre-event evacuation and preparation if there is sufficient warning time
- evacuation during, or immediately pre-event and post-event
- post-event evacuation.

In each scenario there are different drivers and priorities for evacuation, and the ability to coordinate and prepare for evacuation varies. This has implications for the types of evacuation routes that might be available and how they should be assessed.

Routes can be identified and assessed for each scenario. Route options include roads and tracks, as well as water and air transport options. Each route is assessed by considering the following factors:

- existing evacuation plans
- transport resources and operational requirements (by mode)
- risks and vulnerabilities
- assessments of route demand and capacity
- other priorities for the route
- facilities and supplies en route and at receiving communities.

A process for applying the framework is also provided in chapter 5, representing a theoretical methodology for assessing evacuation routes in a pre-event scenario. This identifies potential triggers for assessing evacuation routes, for example because of a risk assessment by a CDEM group, a community initiative, new knowledge about a hazard, or to support parallel initiatives such as resilience and lifelines programmes.

While this is the desirable process for applying the framework, many organisations involved in evacuation planning have limited resources available, including time and funding. Additional funding and support from central and local government may be needed to enable this work to go ahead, and to focus effort on the highest risk hazards and potential mass evacuation scenarios.

7.2 Recommendations

Recommendations for the implementation of this research are as follows:

- Investigate how the framework and other learnings from this research can be integrated into existing or proposed guidelines issued by NEMA.
- Share the findings of the research widely among the transport industry and emergency response sector. This includes examples and learnings from applications of the framework.
- Undertake a further case study application of the framework for a volcanic hazard event, as this type of event was not included in the case studies for this project.
- Support better data sharing across organisations (for improved consistency and availability).

Potential areas for future research are as follows:

- Regarding potentially exposed communities, undertake further research to examine community makeup, vulnerability and dynamics, and the roles of local champions and education programmes in hazard awareness and responses to natural and official warnings to evacuate.
- Expand current research initiatives looking at mass evacuations from large urban centres, for example volcanic activity in Auckland, to other hazard scenarios and population centres. In addition to characterising evacuated populations and transport dynamics, this research should address the impacts of large-scale, potentially permanent population displacements on receiving centres/regions, including local and regional development and exposure to other, future hazards.
- Scope the potential value of undertaking collaborative, co-creative research alongside emergency management groups, communities and research organisations into modelling methods for evacuation

routes. This may include conventional network-based approaches and state-of-the-art agent-based models that incorporate community knowledge. Assessments of the effectiveness of evacuation signage and public information messaging may also be worth exploring.

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Appendix A: Stocktake of publicly available evacuation plans and routes

Civil Defence Emergency Management Group	Evacuation planning and routes
Northland	Community response plans provide localised evacuation maps, including locations of evacuation zones, walkways, schools, marae and tsunami evacuation zone maps (Northland Regional Council, 2020). Online maps of tsunami evacuation zones, sirens, marae and education institutions are provided at a regional level.
Auckland	Auckland Civil Defence and Emergency Management (2016) includes major tsunami evacuation zones and refers to a multi-hazards Auckland Evacuation Framework and an Operational Evacuation Plan, although this is not publicly available.
Waikato	Waikato Region CDEM Group (2012) outlines the group framework, principles and assumptions for evacuation, communication processes, roles and responsibilities and a framework for formalising local plans. The plan does not identify evacuation routes; however, it provides an overview of factors that need to be considered. The plan identifies key hazards for evacuation, several major evacuation scenarios, an overview of vulnerable groups and key infrastructure constraints. Maps within the plan show locations of population centres, marae, waterways, hospitals, campuses, prisons, airports, ports, lifeline utilities, major road hazards, and major road detour routes and times.
Bay of Plenty (BoP)	As part of a case study, BoP Civil Defence developed evacuation routes for tsunami evacuations for six coastal areas (Bay of Plenty CDEM Group, 2018). The maps identify evacuation zones, safe locations, walkway/accessways, footbridges, schools, marae and walking routes (Tauranga City Council, 2019).
Tairāwhiti Gisborne	The Gisborne CDEM Group Volcanic Contingency Plan provides evacuation plan guidelines. It notes that it is not practical to create and maintain evacuation plans for all likely volcanic scenarios, and instead provides guidelines to prepare a plan for a given situation. The guideline includes a brief checklist for evacuation routes (Gisborne CDEM Group, 2012). The CDEM group also provides flood evacuation contingency plans for specific communities. These outline evacuation considerations but do not define routes. A map of tsunami evacuation routes for Gisborne city is also available (Gisborne District Council, 2020). This specifies vehicle and foot routes, inundation zones and safe zones.
Taranaki	Volcanos are a key natural hazard for the region. Taranaki CDEM Group (2020) specifies evacuation zones and states that there will be sufficient time to plan and implement evacuations in the event of volcanic unrest. The group also provides maps of tsunami evacuation zones for a marine threat, 2 m wave, 4 m wave and 10 m wave (no routes specified).
Manawatū-Whanganui	Tsunami evacuation zones are specified by Horizons Regional Council (2020) and the regional CDEM group plan identifies an action to develop a mass casualty evacuation plan within one to five years (Manawatu-Wanganui CDEM, 2018).
Hawke's Bay	The Hawke's Bay CDEM Group (2018) identifies potential evacuation scenarios. The group status maps include state highway closures and restrictions, recent earthquakes and Waka Kotahi NZ Transport Agency traffic cameras. Napier City Council (2020) has online hazard and civil defence maps, which include numerous considerations such as sirens, railways, service stations, medical centres, airports, coastal hazard zone, flood zone and liquefaction vulnerability. Users can enter an address and the map identifies the nearest facilities such as civil defence centres, schools, fire stations and police stations. Specific evacuation routes are not provided.

Civil Defence Emergency Management Group	Evacuation planning and routes
Wellington Region	The Wellington Region Emergency Management Office (2020) provides online tsunami zones. Evacuation planning for other hazards and evacuation routes are not provided.
Nelson Tasman	The Nelson Tasman CDEM Group Plan includes maps detailing critical infrastructure and key natural hazards (tsunami, flood and storm inundation, and earthquake) (Nelson Tasman CDEM Group, 2018). Specific evacuation routes are not provided.
Marlborough	Marlborough CDEM Group (2018) Public Information Map highlights state highway road closures and restrictions, the most recent 100 earthquakes and weather watches and warnings. The group plan identifies a need for tsunami evacuation plans for coastal communities at risk.
West Coast	West Coast CDEM (2020) includes identification of community emergency centres and an Official Public Information and Emergency Situation Map, which includes state highway closures, restrictions and cameras, weather stations and alerts, unplanned power outages, recent earthquakes, forecast positions for active hurricanes, cyclones and typhoons. There are no confirmed evacuation routes available; however, West Coast CDEM are currently working with coastal communities to develop them.
Canterbury	Environment Canterbury Regional Council (2020) provides online maps of tsunami evacuation zones for the region. Kaikōura District Council (2020) provides a map of natural hazards with information about fault rupture, liquefaction, debris inundation, flooding and tsunami risks. Suggested evacuation routes for coastal Christchurch communities are available (Barnhill, 2020).
Chatham Islands	The Chatham Islands Council (2020) has developed tsunami evacuation zones, which are available on an online map).
Otago	Online maps provide tsunami evacuation zones (Otago Civil Defence Emergency Management Group, 2018).
Southland	Emergency Management Southland (2020) provides an online map that locates civil defence centres, community emergency hubs, civil defence incident points (including hazard types and locations, critical infrastructure, evacuation points), road closures, hazard areas and weather alerts. There is also a map of tsunami evacuation zones for the region.

Appendix B: Evacuation timing model (New Zealand)

Below is MCDEM's (2008) evacuation timing model. To inform the movement component, the guideline provides capacities to calculate indicative travel times for travel by road. These values were determined by reducing the maximum observed capacity by 50% to factor for changes to driving conditions, such as weather and crashes.

Evacuation timings

An evacuation timing model is useful during planning in assessing time limitations affecting an evacuation and in order to calculate timings required for ordering an evacuation.

The evacuation timing model below shows time considerations for:

- Mobilisation of resources;
- Dissemination of evacuation warnings;
- Warning Acceptance Factor (WAF) – the time taken for people to accept that a waning is real;
- Warning Lag Factor (WLF) – the time allowance for packing and getting ready to leave;
- Movement of people within the area to outside of the evacuation zone; and
- Traffic Safety Factor (TSF) to allow for breakdowns and road crashes.

This model can be used for multiple neighbouring geographic areas when considering phased evacuations and can also be used operationally to monitor the progress of the evacuation.

Evacuation timing model

The example below illustrates an evacuation timing model showing time considerations[6]. This model can then be used to calculate timings required for ordering an evacuation:

Road Type	Capacity (vehicles/lane/hour)
Motorway	1200
Rural	1000
Urban	500

Appendix C: Data stocktake

Information sources identified in the data review

Information or dataset	Source(s)
Tsunami evacuation zone maps	https://www.civildefence.govt.nz/get-ready/get-tsunami-ready/tsunami-evacuation-zones/
Volcanic areas (GeoNet)	https://www.geonet.org.nz/volcano/aucklandvolcanicfield
FENZ fire risk maps	https://fireweather.niwa.co.nz/nationalmaps
Census 2018	https://www.stats.govt.nz/2018-census/
StatsNZ urban/rural boundaries	https://datafinder.stats.govt.nz/layer/104269-urban-rural-2020-generalised/
NZ Building Outlines	https://data.linz.govt.nz/layer/101290-nz-building-outlines/
NZ Index of Deprivation	https://ehinz.ac.nz/indicators/population-vulnerability/socioeconomic-deprivation-profile
Hospitals	https://www.health.govt.nz/your-health/certified-providers/public-hospital https://hub.arcgis.com/datasets/2340b390407642859ee4a43fd20d490f?geometry=167.937%2C-39.812%2C178.390%2C-38.319
Prisons	https://www.corrections.govt.nz/about_us/getting_in_touch/our_locations
Education	https://www.educationcounts.govt.nz/directories
Aged care	https://www.health.govt.nz/your-health/certified-providers/aged-care
Social vulnerability indictors (EIANZ)	https://www.ehinz.ac.nz/our-projects/social-vulnerability-indicators/
Road networks	https://www.nzta.govt.nz/about-us/open-data/national-road-centreline-faqs/ www.here.com https://www.tomtom.com/en_gb/traffic-index/auckland-traffic/
State highway resilience maps	https://nzta.maps.arcgis.com/apps/MapSeries/index.html?appid=5a6163ead34e4fdab638e4a0d6282bd2
Paths and trails	https://www.openstreetmap.org/ https://data.linz.govt.nz/layer/52100-nz-walking-and-biking-tracks/
Detours	https://detours.myworksites.co.nz/
Ports and airports	https://data.linz.govt.nz/
Lifelines groups	https://www.civildefence.govt.nz/cdem-sector/lifeline-utilities/lifelines-groups/
Rest areas	https://fyi.org.nz/request/2399-rest-areas#incoming-7858
Marae locations	https://maorimaps.com/

Appendix D: Case study maps

Available as separate electronic documents for download with this research report at www.nzta.govt.nz/resources/research/reports/681.