Assessing tsunami evacuation behaviour and dynamics of a near-source threat – the case study of Kaikōura township following the 2016 Kaikōura earthquake

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Master of Science in Disaster Risk and Resilience

By

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Frontispiece

Kaikōura “Be Prepared, not scared” – Kaikōura District Council Civil Defence Emergency Management

Abstract

Recent global tsunami events including the 2004 Indian Ocean tsunami and the 2011 Great East Japan tsunami, have reinforced the importance of improving scientific understanding of tsunami hazard risk assessment and implementation of tsunami risk management. During an earthquake-tsunami event, evacuation is considered the primary risk reduction strategy for preventing casualties. Empirical data on evacuation behaviour and movements during and after past tsunami events has the potential to inform future disaster risk management and evacuation response planning. To date however, the majority of tsunami evacuation behaviour research has focused on specific aspects of evacuation response such as tsunami preparedness, risk awareness, or evacuation intentions. There have been limited contributions to capturing a comprehensive overview of a 'real-event' complete evacuation process to enhance knowledge on response to warnings and evacuation decision-making, evacuation movements, and additional activity after evacuation. Moreover, tsunami evacuation modelling has been an increasingly applied risk management tool to assess evacuation potential for at risk communities however, very few publications have used 'real-event' evacuation parameters to improve realistic evacuation modelling outputs.

In this Masters of Science thesis a New Zealand case study is used to address this gap in global tsunami research literature with an analysis of the evacuation of Kaikōura residents following the 2016 Kaikōura earthquake and tsunami, which is used to inform the development of a network-based evacuation model. A survey was developed with disaster risk management practitioners involved during the response phase of the 2016 Kaikōura earthquake to enhance understanding of:

- Local awareness of tsunami hazard and the need to evacuate before and after the 2016 Kaikōura earthquake
- The influence of risk awareness on evacuation-decision-making by residents
- Which warnings prompt evacuation actions
- Evacuation dynamics including origin-route-destination and congestion barriers
- Earthquake and tsunami preparedness actions taken before and after the 2016 Kaikōura earthquake.

A total of 1055 surveys were distributed in Kaikōura township, with 131 returned (12.4% return rate). Key survey findings indicate that prior to the 2016 Kaikōura earthquake, respondents had a 'good' (44%, n=55) or 'very good' (25%, n=31) level of knowledge on tsunami hazard and the need to evacuate. This contributed to a large proportion (79%, n=88) of respondents who reported that they evacuated due to the potential tsunami threat during and immediately after the 2016 Kaikōura earthquake. The vast majority (95%) of those living in the tsunami evacuation zone at the time (n=64)

reported that they evacuated. Almost half (45%) of respondents who were residing outside tsunami evacuation zones (n=42) evacuated, with most reporting that they did so because of 'severe shaking and aftershocks'. Reported congestion barriers included bridge failures, fallen lamp post, and road damage due to subsidence caused by the earthquake. These barriers slowed down evacuation time of some residents, particularly along Churchill Street and Killarney Street, adding minutes to their total evacuation time. More than half (55%) of respondents evacuated prior to the first tsunami wave was recorded after the earthquake (within 10 minutes). Ninety percent of respondents reported they evacuated by the time at which the tsunami's highest point was measured on the Kaikōura sea level gauge (40 minutes after the earthquake). The duration time at which survey respondents reported they stayed at their evacuation point ranged from 30 minutes to 48 hours. The most common reported time was 6 hours (18%). Over half (52%, n=45) of respondents reported they returned from their evacuation point when they felt it was safe to do. Thee three commonly reported preparedness actions residents have made following the 2016 Kaikōura earthquake include, prepared an emergency kit with essential items (57%, n=70), discussed an evacuation plan with friends and family or household members (54%, n=67), and prepared a go bag containing essential items (43%, n=53).

Evacuation behaviour and movements from the survey results informed key parameters for developing a network-based vehicular model. The model utilises Kaikōura's road network and evacuation density to predict evacuation times and congestion potential for future events. Key findings under an 'ideal' night-time scenario predicted a total evacuation time of 12:05 minutes for Kaikōura Township to evacuate to safety. This time estimate is a concern for future local-source tsunami threats which could result in tsunami waves arriving at the coast in a matter of minutes. Households in South Bay, located along Avoca Street (west of Kaikōura Peninsula), and north of the township are expected to take the longest time to evacuate (greater than 5 minutes). The response actions reported by Kaikōura residents during the 2016 Kaikōura earthquake aligned well with the results of the network-based evacuation model. Evacuation times, congestion pin points and safe zone capacity of the evacuation model were consistent with the 2016 response actions. However, further analysis could refine the evacuation model to include evacuation delay time, congestion restrictions, and incorporation of both pedestrian and vehicle evacuation.

This thesis A) advances the understanding of a complete evacuation response process of a local-source earthquake and tsunami event in New Zealand and B) develops a network-based vehicular evacuation model informed by realistic evacuation behaviour data and movements of residents following the 2016 Kaikōura earthquake, which can be used to inform evacuation planning for Kaikōura and other coastal communities exposed to local-source tsunami. The methods and results presented in this thesis highlights the critical need for such work to be conducted for communities exposed to tsunami hazard risk, specifically areas susceptible to local source tsunami that would require immediate evacuation. Understanding real-event evacuation response provides valuable opportunities to analyse and inform disaster risk management and emergency response planning to increase national and global tsunami resilience.

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Last, but certainly not least, a massive thank you to my friends, family, and partner for being my greatest support and encouragement throughout my university studies. None of this would have been possible without you.

List of Acronyms

ABM	Agent Based Model
CCC	Christchurch City Council
CCC CDEM	Christchurch City Council Civil Defence Emergency Management
CDEM	Civil Defence Emergency Management
Canterbury CDEM	Canterbury Civil Defence and Emergency Management
CASPR	Capacity-Aware Shortest Path Evacuation Routing
DRM	Disaster Risk Management
DRR	Disaster Risk Reduction
ECan	Environment Canterbury
EWS	Early Warning System
GIS	Geographic Information Systems
GNS Science	Institute of Geological and Nuclear Sciences
KDC CDEM	Kaikōura District Council Civil Defence Emergency Management
LCD	Least Cost Distance
LINZ	Land Information New Zealand
MCDEM	Ministry of Civil Defence & Emergency Management (now NEMA)
MMI	Modified Mercalli Index
NEMA	National Emergency Management Agency
NIWA	National Institute for Water and Atmospheric Research
NWS	National Warning System
NZCD	New Zealand Civil Defence
PTWC	Pacific Tsunami Warning Centre
RMF	Risk Management Framework
UC	University of Canterbury
UN	United Nations
UNDRR	United Nations Office for Disaster Risk Reduction (formally known as UNISDR
UNESCO	United Nations Educational, Scientific, and Cultural Organization

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Chapter 1: Introduction

1.1 Research context

A tsunami is a natural phenomenon consisting of a series of waves when a large volume of water becomes displaced that can cause considerable impacts on exposed coastal communities (Power, 2013). Tsunami occur in a range of magnitudes from various sources (Power, 2013) (defined in Chapter 2). Recent examples include the catastrophic and more infrequent events such as the 2004 Indian Ocean tsunami and the 2011 Great East Japan tsunami, and the more frequent, smaller and less damaging events such as the 2009 Samoa tsunami, the 2015 Illapel tsunami (Chile), and the 2016 Kaikōura tsunami (Arcos et al. 2019; Fraser et al. 2013; Power, 2013). Tsunami impacts depend on magnitude, source, and coastal topography. In addition to the direct consequences on coastal environments, people, critical infrastructure and property, tsunami impacts include indirect, ongoing social and economic consequences (Power, 2013). Globally, in the last two decades, tsunami events have caused more than 250,000 fatalities and resulted in USD$280 billion in damages (Imamura et al. 2019).

During an earthquake-tsunami event, evacuation is considered the primary risk reduction strategy for preventing casualties (MCDEM, 2016; Power et al. 2019; UNESCO, 2011). Empirical data on evacuation behaviour and movements during and after past tsunami events has the potential to inform future disaster risk management and evacuation response planning. To date however, the majority of evacuation behaviour research has focused on specific aspects of evacuation response such as tsunami preparedness, risk awareness, or evacuation intentions (Arce et al. 2017; Currie et al. 2014; Couling, 2014; Dhellemmes et al. 2016: Fraser et al. 2013; Johnston et al. 2013; Johnston et al. 2003; Makinoshima et al. 2020). There have been limited contributions to capturing a comprehensive overview of a 'real-event' complete evacuation process to enhance knowledge on response to warnings and evacuation decision-making, evacuation movements, and additional activity after evacuation (Makinoshima et al. 2020). Similarly, although tsunami evacuation modelling has been an increasingly applied risk management tool to assess evacuation potential for at risk communities, very few studies have used 'real-event' evacuation parameters to improve realistic evacuation modelling outputs (Kubisch et al. 2019; Kubisch et al. 2020; Makinoshima et al. 2016; Wood et al. 2018).

This Master of Science addresses this gap in the research with a case study analysing the broader evacuation in the small New Zealand coastal town of Kaikōura following the 2016 Kaikōura earthquake and tsunami. This tsunami was considered a moderate event, with a maximum wave run up of 6.9

metres measured at Goose Bay, south of Kaikōura, and is the latest of a number of tsunami to impact the Kaikōura coast, from local, regional and distant tsunami sources (GeoNet, n.d; Power et al. 2017). Kaikōura is a seaside settlement, located in the northern Canterbury region on the east coast of New Zealand's South Island. With a total resident population of 2,898 (Statistics New Zealand, 2018a), and positioned where the main North-South highway hugs the coast, Kaikōura is a popular tourist destination, hosting over 125,000 international and domestic visitors annually (Cradock-Henry & Fountain 2019; Statistics New Zealand, 2018b). The location of this small town and the large volume of visitors travelling through Kaikōura increase the settlement's exposure to tsunami hazard risk.

In addition to addressing a gap in global understanding of evacuation behaviours in the immediate aftermath of an earthquake and tsunami, the findings of this research will be of particular value in New Zealand, and to those involved in planning to reduce the risk posed, in this country, by near source tsunami.

Empirical evidence of historical and modern tsunami records, including oral histories, indicate that New Zealand has a long history of tsunami (De Lange & Healy, 1986; Downes et al. 2017; GNS Science, 2014; King et al. 2007; King, 2015). New Zealand's entire coastline is at risk to tsunami hazard from local, regional, and distant sources (Power, 2013), and has experienced frequent tsunami events from the Peruvian subduction zone (South America). This country's greatest tsunami threat, however, is posed by a local source tsunami generated by an earthquake along the Hikurangi margin (East Coast Lab, 2020; Power 2013). This subduction zone starts near Kaikōura and extends up the east coast of the North Island, and is capable of producing earthquakes greater than Magnitude 9.0, producing tsunami comparable to that generated by the 2011 Mw 9 Great East Japan earthquake (East Coast Lab, 2020; Power, 2013) (discussed further in Chapter 2).

New Zealand's exposure to tsunami hazard risk requires effective disaster risk reduction strategies to increase resilience and community's awareness and preparedness for future hazard events. Disaster risk assessments including understanding response and evacuation behaviour of past events are an essential foundation for decision-making processes and the basis of informing disaster risk reduction plans, policy and guidance (UNESCO, 2020). To date, New Zealand tsunami risk management initiatives such as evacuation planning has been informed from global practice and international research findings (Jack & Schoenfeld, 2017). New Zealand has experienced a series of poorly executed warnings and evacuations from over the past 15 years in the lead up to the Kaikōura tsunami, including the 2009 Samoa and 2010 Chile events. The tsunami generated by the Kaikōura earthquake provided a valuable opportunity to conduct research to better understand response and evacuation behaviours in this recent New Zealand context. Findings constitute empirical real-world evidence to inform evacuation modelling, and emergency response planning.

1.2 Research aims and objectives

This thesis has two aims. The first aim is to develop an empirical evidence-base that provides a comprehensive understanding of human evacuation behaviours and dynamics following this recent New Zealand earthquake and tsunami event. The second aim is to improve current evacuation modelling methods through the input of real-event evacuation behaviour characteristics. Understanding human behaviour characteristics of a local source event, and using these to inform more accurate and useful tsunami evacuation modelling will help to inform national and global tsunami evacuation preparedness and will contribute to mitigating the number of casualties in future events through appropriate tsunami risk management and response initiatives.

This thesis uses the following two objectives to address these aims:

1) using the 2016 Kaikōura earthquake and tsunami as a case study to understand immediate reactions to natural warnings and evacuation behaviour dynamics (Chapter 3). This objective was achieved through utilisation of a questionnaire survey developed in collaboration with natural hazard risk management and emergency management practitioners actively involved in response phase of the 2016 Kaikōura earthquake and tsunami.

2) apply evacuation response behaviour and movements to inform realistic rules and interactions for the development of a network-based tsunami evacuation model to produce evacuation time indications (Chapter 4).

The methodology used to answer the thesis research objectives is described in detail below;

Objective 1: Understand evacuation response behaviour and evacuation dynamics of Kaikōura residents following the 2016 Kaikōura earthquake and tsunami.

- Develop a new survey tool with natural hazard risk management and emergency management practitioners to collect data on the immediate response and evacuation behaviour of a local-source earthquake event. This includes understanding of warning and evacuation decision-making, evacuation movements and associated dynamics, and risk awareness influence on evacuation response.

- Perform a statistical and geospatial analysis of self-reported survey data to review response actions and evacuation behaviours of Kaikōura residents following the 2016 Kaikōura earthquake and tsunami.
- Conduct a comparative analysis of survey data with other national and global studies.
- Present broad evacuation behavioural trends and characterise factors that were influential for evacuation decision-making.
- Present a dataset to inform tsunami risk management strategies for at-risk communities in New Zealand and globally.

Objective 2: Develop an evacuation modelling framework and test by modelling likely evacuation behaviours of coastal Kaikōura residents, to ensure that it is applicable to other communities at risk from tsunami in New Zealand and international. This will be achieved by integrating:

- Develop a population and asset inventory to define the population and assets exposed within Kaikōura's tsunami evacuation zones. Use this synthesised exposure inventory as base data for the development of a network-based model.
- The survey dataset from objective 1 to inform real event evacuation rules and interactions for the network-based model.

1.3 Conceptual approach to disaster risk reduction (DRR)

1.3.1 Disaster risk reduction (DRR) and disaster risk management

"Disaster risk reduction is aimed at preventing new and reducing existing disaster risk and managing residual risk, all of which contribute to strengthening resilience and therefore to the achievement of sustainable development" (UNISDR, 2017). Disaster risk management defined as "the application of disaster risk reduction policies and strategies to prevent new disaster risk, reduce existing disaster risk and manage residual risk, contributing to the strengthening of resilience and reduction of disaster losses (UNISDR, 2017). In order to achieve the goal of DRR, integrated and inter-disciplinary measures that prevent and reduce hazard exposure and vulnerability to disaster, increase preparedness for response and recovery and strengthen resilience should be implemented at all levels (UNISDR, 2015). Risk information provides a critical foundation for managing disasters (GFDRR, 2014). Risk can be expressed qualitatively and or quantitatively, where it is derived as a combination of the likelihood and/or magnitude of the hazard and its consequences (UNISDR, 2015). Risk is typically characterised into three principal components; hazard, exposure and vulnerability (Figure 1.3-1).

Figure 1.3-1: Risk assessment process. (Source: PreventionWeb, 2017).

Disaster risk assessment is the systematic processes used to determine the nature and extent of risk, by considering hazards, and evaluating exposure and vulnerability of people, property, critical infrastructure and the environment (UNDP, 2010; UNISDR, 2015) (Figure 1.3-1). Risk assessments are fundamental for effective DRR decision-making and policy and practice (UNDP, 2010, UNISDR, 2015).

1.3.2 DRR terminology

Hazard refers to 'a process, phenomenon or human activity that may cause loss of life, injury or other health impacts, damage to property, economic and social disruption or environmental degradation (UNISDR, 2017). Hazards are described by their frequency of occurrence and/or intensity (UNISDR, 2017).

Disasters can occur when a natural hazard such as an earthquake, landslide, tsunami, volcanic eruption which has an associated likelihood and intensity, interacts with societal conditions of exposure, vulnerability and capacity triggering serious disruption of a community and causing: human, material, economic and/or environmental losses and impacts (GFDRR, 2014; UNISDR, 2017).

Exposure refers to "the situation of people, infrastructure, housing, production capacities and other tangible human assets located in hazard-prone areas," (UNISDR, 2017).

Vulnerability can be defined as the "conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards," (UNISDR, 2017). For example, conditions may include demographic composition such as income, insurance, age, gender, as well as dependence on resources or services. Vulnerability can be reduced by capacities.

Capacities are the set of strengths, attributes and resources an individual, household or community may have access to, that allow them to resist, cope, and recover from a disaster (Wisner et al., 2004; UNISDR, 2017). These resources may include understandable and available information, practised evacuations, and having skills and assets that allow self-sufficiency and that allow adaptiveness.

Risk is defined by UNISDR as ""The potential loss of life, injury, or destroyed or damaged assets which could occur to a system, society or a community in a specific period of time, determined probabilistically as a function of hazard, exposure, vulnerability and capacity." (UNISDR, 2017).

Impact refers to the effects of a hazardous event (UNISDR, 2017). Impacts are typically negative but can be positive. In the context of DRM, impact refers to what might happen to people and/or assets during an event (GFDRR, 2014).

Preparedness involves building knowledge and capacities to manage disasters (UNISDR, 2009). It can be achieved or facilitated by governments, communities, individuals, and organisations (UNISDR, 2009). To facilitate preparedness strategies, knowledge of the risk is required (GFDRR, 2014). Preparedness activities can be linked to the development of early warning systems, stockpiling supplies, contingency plans, and education and training (GFDRR, 2014; UNISDR, 2009).

Resilience is "the ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of it's essential basic structures and functions through risk management" (UNISDR, 2017).

Residual Risk is the 'risk that remains after risk treatment has been applied to reduce the potential consequences' (MCDEM, 2019).

Risk Perception is a personal assessment of the consequences that may be caused by a hazard (Lindell, 2013). Risk perception is largely influenced by psychological, cultural, and social aspects (Dzialek, 2013; Fraser et al. 2016).

1.3.3 Global DRR and DRM

Despite global efforts to mitigate or reduce impacts of disasters, the last two decades have seen geophysical and climate related disasters causing 1.3 million deaths, 4.4 billion people injured, homeless, displaced or in need of emergency assistance, and direct economic loss of US$2,908 billion (CRED &UNISDR, 2018). Over half (56%) of total deaths were attributed to earthquake and tsunami events (CRED &UNISDR, 2018).

The United Nations Office for Disaster Risk Reduction (UNDRR, formerly UNISDR), is the DRR focal point for United Nations (UN) member states. The UNDRR coordinates international efforts and provides a platform for information exchange and supports the implementation of the Sendai Framework for Disaster Risk Reduction 2015-2030 (Sendai Framework). The Sendai Framework (which is the successor instrument to the Hyogo Framework for Action 2005-2015) provides a method to "achieve the substantial reduction of disaster risk and losses in lives, livelihoods and health and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries over the next 15 years" (UNISDR, 2015). The Sendai Framework outlines seven targets, and four priorities of action to prevent new and existing disaster risks. The four priorities of action are:

Priority one: "Understanding disaster risk;

Priority two: Strengthen disaster risk governance to manage disaster risk;

Priority three: Investing in disaster risk reduction for resilience;

Priority four: Enhancing disaster preparedness for effective response and "Build Back Better" in recovery, rehabilitation and reconstruction" (UNISDR, 2015).

In addition to the Sendai Framework, the UN's global 'Sustainable Development Goals' (SDG's) and the 'Paris Agreement on Climate Change' are existing global agenda agreements that align with the Sendai Framework's purpose to increase resilience for a more sustainable future (CRED &UNISDR, 2018).

This thesis seeks to contribute to Sendai priorities one: understanding disaster risk and four: enhancing disaster preparedness, by contributing an understanding of risk to population and relevant assets exposed to tsunami hazard in Kaikōura and present an empirical evacuation behavioural dataset to inform tsunami preparedness and response planning.

1.3.4 DRM in New Zealand

New Zealand's hazard risk landscape is increasingly complex and uncertain (MCDEM, 2019). New Zealand is recognised internationally for its integrated approach to DRR and managing hazard risk through the applied effort over the 4Rs; reduction, readiness, response and recovery (IFRC, 2014; LGNZ, 2014). This approach includes coordinated investment and efforts to: identify, evaluate and reduce disaster risk impacts; implement community public education awareness and preparedness campaigns; implement early warning systems; and develop and apply effective risk management, response and recovery legislation (MCDEM, 2019).

The 4Rs:

- "Reduction - identifying and analysing long-term risks to human life and property from hazards; taking steps to eliminate these risks if practicable, and if not, reducing the magnitude of their impact and the likelihood of their occurring;
- Readiness - Developing operational systems and capabilities before a civil defence emergency happens; including self-help and response programmes for the general public, and specific programmes for emergency services, lifeline utilities and other agencies;
- Response - actions taken immediately before, during, or directly after a civil defence emergency to save lives and protect property, and to help communities recover;
- Recovery - the coordinated efforts and processes to bring about the immediate, medium and long-term holistic regeneration of a community following a civil defence emergency" (NEMA, n.d.a).

As a UN member state, the New Zealand Government has ratified the International Sendai Framework for Disaster Risk Reduction 2015-2030, which requires that governments implement the Framework, and report implementation progress on disaster risk management, including New Zealand's tsunami risk management. The Sendai Framework provides a method to build research outputs, to enhance capabilities and decision-making to plan and prepare across the 4Rs.

The statutory landscape that drives DRR in New Zealand at a national, regional and local level is represented by the CDEM framework (see Figure 1.3-2). Legislation that governs DRR in New Zealand includes the Civil Defence Emergency Management Act 2002, the Resource Management Act 1991, the Building Act 2004, The Local Government and Official Information Meetings Act, and the Local Government Act 2002.

Recent global tsunami events (2004 Indian Ocean tsunami and 2011 Great East Japan tsunami) have reinforced the importance of improving scientific understanding of tsunami hazard risk assessment and implementation of tsunami risk management in New Zealand (MCDEM, 2016). The establishment of New Zealand's national 'Tsunami Risk Management Programme' aims to support evidence-based, end-to-end tsunami risk management for New Zealand, through the implementation of early warning systems, national guidance and policy, and public education awareness (NEMA, n.d.b) (discussed further in Chapter 2). The programme draws on expertise from tsunami hazard research, risk assessments, risk management, planning, social science and public education across government and research agencies.

A number of agencies and organisations responsible for implementing DRR in New Zealand includes: the National Emergency Management Agency (formally known as the Ministry of Civil Defence & Emergency Management), the Ministry for the Environment, the Ministry for Business Innovation and Employment, the Department of Conservation, the Earthquake Commission, the National Infrastructure Unit (within Treasury), Regional councils, Territorial authorities, Crown Research Institutes (CRIs), CDEM groups, infrastructure lifelines groups, universities, commercial players such as insurance companies, reinsurers, and banks, as well as community groups, households and individuals (LGNZ, 2014).

Figure 1.3-2: New Zealand Civil Defence and Emergency Management Framework. Retrieved form the National Emergency Management Agency (n.d.).

In addition to the CDEM Framework and DRR legislation, New Zealand has recently developed a DRR strategy named the 'National Disaster Resilience Strategy' (MCDEM, 2019) which adheres to the CDEM Framework (see Figure 1.3-2) and sets out goals and objectives for Civil Defence Emergency Management to improve on how New Zealand responds to natural disasters and other emergencies.

The strategy sought to take a holistic approach to achieve a 'resilient' New Zealand over the next 10 years, with the primary goal to "strengthen the resilience of the nation by managing risks, being ready to respond and recover from emergencies, and by empowering and supporting individuals, organisations, and communities to act for themselves and others, for the safety and wellbeing of all" (MCDEM, 2019). The National Disaster Resilience Strategy sets out three main priorities:

1. Managing risk
2. Effective response and recovery from emergencies
3. Enabling, empowering and supporting community resilience

In the context of the National Disaster Resilience Strategy, this research seeks to contribute to all three priorities through identifying societal risk and contributing an evacuation behavioural dataset and evacuation model that builds on knowledge from past emergency events. The results of this thesis helps to increase the understanding of resident's response actions to natural warnings and preparedness actions as a results of national education campaigns and tsunami evacuation planning.

1.3.5 Conceptual Framework; the Risk management Framework

The New Zealand Risk Management Framework (AS/NZ: 31000 Risk Management Framework) has been developed to provide a systematic and robust risk management approach, which aims to reduce risk through nationally standardised processes of risk identification, risk analysis, risk evaluation and risk treatment (Standards New Zealand, 2009). Since this standardised process is used by local authorities, CDEM Groups, infrastructure lifeline agencies, research institutes and the private sector, it facilitates a coordinated approach to risk management across these sectors.

The AS/NZ: 31000 Risk Management Framework is the conceptual approach informing this Masters research (Figure 1.3-3). It structures the assessment of tsunami risk in Kaikōura, the analysis of the immediate evacuation behaviour of Kaikōura residents following the 2016 Kaikōura earthquake, and informs the network-based modelling developed using this empirical data from immediate evacuation behaviours following the Kaikōura earthquake. Using the New Zealand risk management framework in this thesis, aligns with best practice in New Zealand emergency management sector, where the embedment of this framework is contributing to emergency management, specifically tsunami risk management.

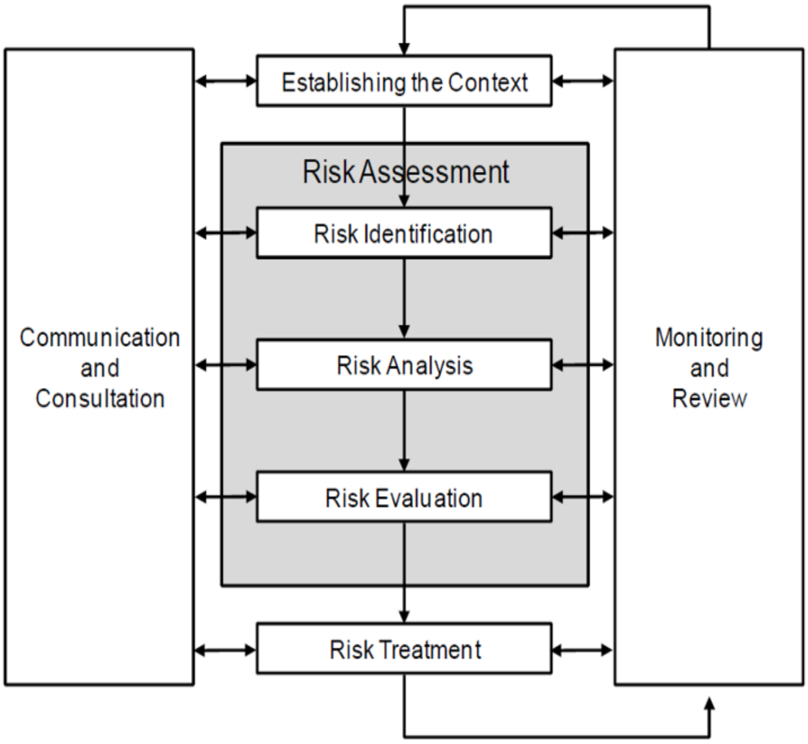

Figure 1.3-3: New Zealand Risk Management Framework. Retrieved from Standards New Zealand (2009).

The terms used in the risk management framework are defined by the following equation:

Risk = Hazard x Vulnerability

The **risk assessment** framework is used as the conceptual basis of this thesis, which has been mapped across the following three (AS/NZS) risk assessment phases.

1. **Risk identification:** the first phase of risk assessment consists of identifying all the elements of risk, including the potential extent and magnitude of hazards and possible social consequences for the population at risk from the hazard (Standards New Zealand, 2009). In the tsunami context, risk identification is achieved through reviewing relevant literature on tsunami hazard assessments, including inundation modelling, to inform evacuation zone mapping and identify the populations and assets located within those hazard zones (UNESCO, 2020).

   The risk identification conducted as part of this Masters research included identifying Kaikōura's exposed populations, and assets located in official tsunami evacuation zones, and analysing resident populations, buildings and road networks (Chapter 4).

2 **Risk analysis and risk evaluation:** the second phase involves two stages of risk analysis and evaluation, to further investigate and determine the level of risk the population is exposed to: acceptable, unacceptable, or tolerable, to identify actions that if taken will reduce impacts and therefore risk (AS/NZS, 2009). Understanding the vulnerability of exposed populations is

necessary to establish the foundation for risk analysis and evaluation. Factors that can contribute to potential vulnerability include demographic composition e.g. the age and gender and health of household members, evacuation delay times, evacuation infrastructure and road evacuation capacity.

In this Masters research the risk analysis and evaluation phase involved two components. Firstly, self-reported survey data concerning the immediate response of Kaikōura residents following the 2016 Kaikōura earthquake and tsunami to evaluate evacuation potential against tsunami hazard risk was analysed (Chapter 3). Then this data was used to develop a network-based tsunami evacuation model framework which was tested to analyse and evaluate evacuation time estimates for the Kaikōura community (Chapter 4).

3 **Risk treatment**: after a risk assessment has been carried out, assessment of the treatment options to reduce overall risk to the affected population is undertaken. Tsunami risk treatment strategies can include structural initiatives (vertical evacuation structures, resilient evacuation infrastructure, tsunami defence systems), and non-structural initiatives (early warning systems, public education campaigns, and evacuation planning).

The treatment measures reviewed in this Masters research are non-structural, since the focus is on evacuation response planning. The findings are expected to contribute to risk treatment by providing an empirical dataset detailing immediate reactions to warnings and evacuation decision-making and behaviours following the 2016 Kaikōura earthquake and tsunami, and a network-based comprehensive evidence-based evacuation modelling framework. Both are expected to be of value to those involved in tsunami evacuation planning.

1.4 Introduction of the case study: Kaikōura, New Zealand

Kaikōura is a seaside settlement located in the north of the Canterbury region, on the east coast of New Zealand's South Island, with a resident population of 2,898 in 2018 (Statistics NZ, 2018; see Figure 1.4-1). Known for its cultural significance, renowned scenery, ecosystems and adventure experiences (Fountain & Cradock-Henry 2019; Hendtlass, et al. 2018), the Kaikōura district motto is 'Where the mountains meet the sea' (Fountain & Cradock-Henry 2019; Kaikōura District Council, 2017). As this would suggest, this settlement provides abundant opportunities for recreation and wildlife viewing that have made it a popular destination for international and domestic visitors (Fountain & Cradock-Henry 2019), hosting over 125,000 tourist visitors annually (over the last 5 years), including both day stops and longer visits (Fountain & Cradock-Henry 2019; Simmons et al. 2017; Statistics New Zealand, 2017). The popularity of the destination is also due in large part to its location on State Highway 1 (SH1) halfway between Christchurch (the largest city in the South Island) and Picton (the sole departure point for ferries to the North Island). The main north-south highway in the South Island, and the only route that hugs the east coast, this road is the most travelled for tourists traversing the country (Fountain & Cradock-Henry, 2019). Tourism is a major economic driver in Kaikōura, with approximately half of the local workforce (50.4%) directly employed in the tourism industry (Fountain & Cradock-Henry 2019; Simmons et al. 2017). The region's tourism industry is highly seasonal; the months between December and April experience high visitor population counts, however winter months experience a decline in visitor numbers (Fountain & Cradock-Henry 2019; Simmons et al. 2017).

Figure 1.4-1: Case study context map of place names mentioned throughout this thesis. The insert map is an aerial map of Kaikōura.

The Kaikōura district is exposed to multiple natural hazards including earthquakes, landslides (including submarine), floods, wildfire, storms, and tsunami (Kaikōura District Council, 2020). Prior to the 2016 Kaikōura earthquake (discussed in section 1.4.2), there had been a clear recognition of tsunami risk in Kaikōura (Barryman, 2005; Mueller et al. 2019: NIWA, 2015:2004; Walters et al. 2006a:b). A number of studies have conducted numerical modelling to determine inundation extents and tsunami wave characteristics (Barryman, 2005; Lane et al. 2014; Muller et al. 2019: NIWA, 2015; 2004; Walters et al. 2006a:b). Findings indicate that there are three possible sources that put Kaikōura at high risk from tsunami. A major earthquake rupture on the Hikurangi Subduction zone is expected to generate a large near source tsunami that will inundate low lying areas on the east coasts of both the North and South islands, likely to impact Kaikōura within 10 – 30 minutes or so hours, depending on source location (Mueller et al. 2019). Nearer source events pose more immediate risks. A submarine landslide generated in the Kaikōura canyon, (approximately 1 kilometre off the coast of the settlement), and seismic ruptures along local active faults that extend off the coast, such as the Kekerunga Bank Fault and the Wairarapa faults are particularly dangerous due to the proximity of the tsunami source (NIWA, 2015; Walter et al. 2006a:b). Scientists estimate that local earthquake and/or submarine landslides could generate tsunami waves that could reach Kaikōura's coastline in a matter of minutes (Walters et al. 2006a:b). Although a tsunami generated by a submarine landslide in the Kaikōura canyon or a local fault rupture poses more immediate risk, the potential impact from a tsunami generated from an earthquake rupture on the Hikurangi subduction zone is considered a possible 'worst-case scenario'.

To address the immediate risk to tsunami, risk reduction and preparedness initiatives have been implemented within the Kaikōura community over the last 10 years (H Jack, Natural Hazard Analyst, Environment Canterbury, pers. Comm). Tsunami risk management initiatives include community disaster preparedness workshops (see Figure 1.4-2), public education awareness campaigns (Long or Strong, Get Gone), evacuation drills (ShakeOut), and implementation of tsunami evacuation zones (Kaikōura District Council, 2020; Figure 1.4-3) (New Zealand tsunami risk management initiatives are presented further in Chapter 2).

Kaikōura District Council Civil Defence Emergency Management (KDC CDEM) motto is 'Prepared not scared' (Kaikōura District Council, 2020). This motto means 'preparing the community so that residents can take care of themselves, others and visitors in future emergency events (Kaikōura District Council, 2020). KDC CDEM provides three key messages to prepare for an emergency 1) make a plan, 2) know your tsunami survival, and 3) know where to get information from. Kaikōura's tsunami survival education encourages residents and visitors to identify if they are located in a tsunami evacuation zone, if so, know what to do and where to go e.g. identify evacuation routes and move immediately to high ground or further inland if a long and/or strong earthquake is felt, hear unusual sounds from the sea or observe a sudden rise or fall in sea level (Kaikōura District Council, 2020). KDC CDEM, encourage residents and visitors to not wait for an official warning and use natural cues as the first point of warning as this may be their only warning before a tsunami reaches land, and to identify if they live, work, or play in a tsunami evacuation zone (Kaikōura District Council, 2020).

"If you feel a long (more than one minute) or a strong (hard to stand up) earthquake, leave the red and orange evacuation zones immediately. Do not wait for an official warning, sirens, an emergency mobile alert or for someone to tell you to go. Stay out of the zone until you are told it is safe to go back" (Environment Canterbury, 2020).

Figure 1.4-2: Kaikōura tsunami risk management initiative - Kaikōura community disaster preparedness workshop (Photo source: Kaikōura District Council, (2020).

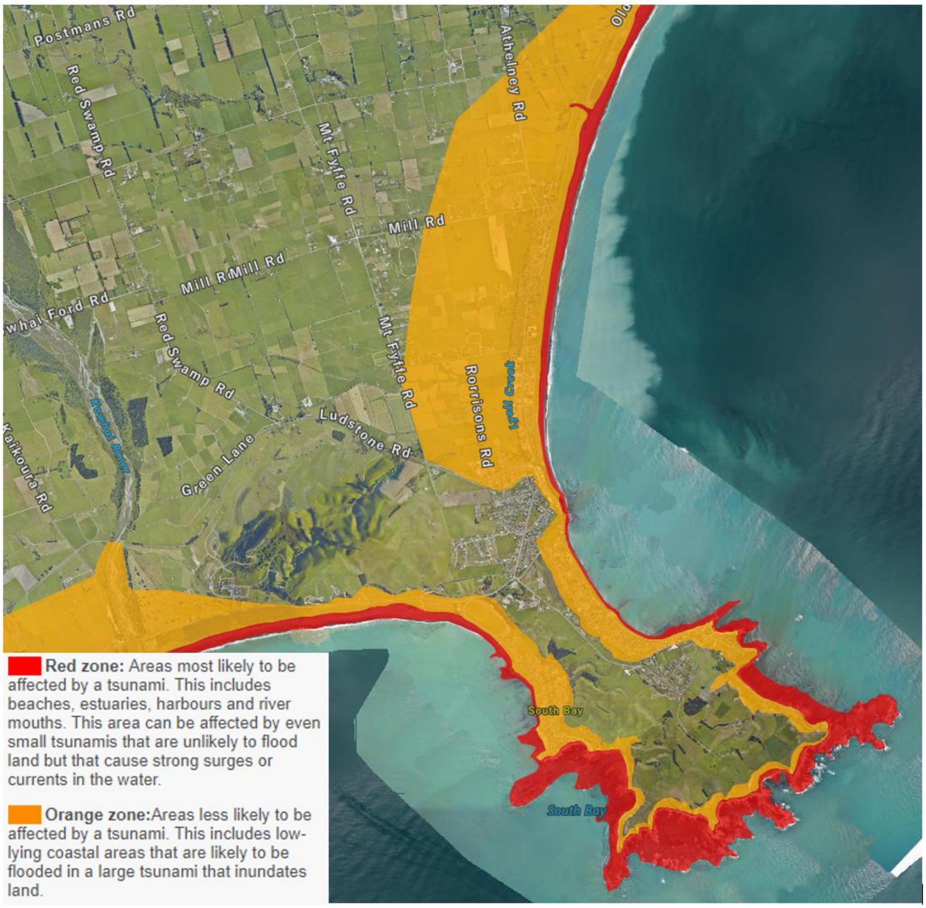

Figure 1.4-3: Kaikōura tsunami risk management initiative- Kaikōura tsunami evacuation zones (definitions on tsunami evacuation zones are presented on the map and in Chapter 2. Source: Canterbury Maps (2020).

The frequent nature of visitors travelling through or stopping in Kaikōura, and potential limited knowledge of local hazard risk, increases Kaikōura's district exposure to natural hazards, in particular the immediate threat of tsunami. This was observed during the 2016 Kaikōura earthquake.

1.4.1 2016 M_w 7.8 Kaikōura earthquake and tsunami

At 12:02:56 a.m. on November 14, 2016 (NZDT) a magnitude M_w 7.8 earthquake ruptured in Wairua, near Kaikōura, in the South Island of New Zealand. Although the epicentre of the earthquake originated on land, the tectonically complex event led the earthquake to rapidly spread north-east off shore, rupturing approximately 21 faults (Borrero & Lane, 2018; Hamling et al. 2017). The resulting extended multiple-fault ruptures generating New Zealand's largest local source tsunami since the 1947 Gisborne earthquake and tsunami (Borrero & Lane, 2018; Power et al. 2017). The rupture lasted nearly 2 minutes and was widely felt throughout New Zealand. The tsunami risk prompted evacuation of coastal communities of both the North and South islands of New Zealand (Kardos, 2017). The resulting waves were measured as far south as Banks Peninsula in the South Island, and observed as far north as Castle Point in the North Island (GeoNet, n.d; see Figure 1.4-1). Wave run up heights measured 1-4 metres along the east coast, with the maximum wave run up height of 6.9 metres at Goose Bay, south of Kaikōura, making this earthquake induced tsunami a moderate event (Power et al. 2017; see Figure 1.4-1 and Figure 1.4-4). Fortunately, due in part to low tide and the sizeable earthquake uplift of sea-bed and coastline, the tsunami had minimal effects on coastal buildings and infrastructure, with the exception of a destroyed dwelling located on the Little Pigeon Bay beachfront, on Banks Peninsula (Lane et al. 2017; see Figure 2.1-2). However, earthquake shaking caused extensive damage to critical infrastructure, particularly close to fault ruptures, leaving some communities without access to road, rail, electricity, telecommunications and utilities such as domestic potable and rural stock water supplies (New Zealand Lifelines Council, 2017). State Highway 1 (SH1) road access was cut both north and south of the Kaikōura Township, placing excessive demands on the local community to assist response and recovery agencies managing human displacement in the days and weeks following the 2016 Kaikōura earthquake (Schoenfeld, 2018). Scientists have found that the repercussions of the earthquake and tsunami could have been even worse if the earthquake were to have occurred during the day and generated on an incoming tide (Handtless et al. 2018).

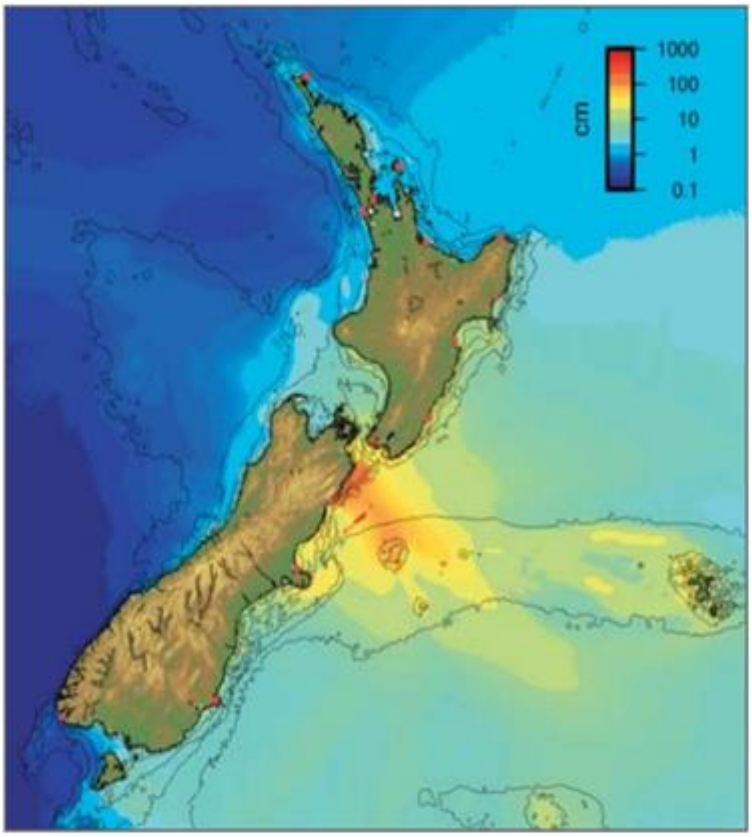

Figure 1.4-4: Regional propagation pattern of the tsunami generated by the 2016 Kaikōura earthquake. Red colour represents higher tsunami wave amplitude. Red dots show GeoNet tsunami gauges. Source: Handtless et al. 2018.

1.4.2 Emergency response to the 2016 Kaikōura earthquake

The nature of the 2016 Kaikōura earthquake required and contributed to an unusually complex disaster response operation (Schoenfeld, 2018), and this was particularly evident in the tsunami threat and tsunami warnings following the initial earthquake shaking (MCDEM, 2018a). As updated scientific data clarifying new earthquake characteristics became available it informed a number of rapid changes in tsunami threat and warning information (MCDEM, 2017b). Since the Kaikōura earthquake was a local-source event, Civil Defence Emergency Management (CDEM) had very little time (approx. 10 minutes) to issue an official warning before the first wave arrived at the Kaikōura coast (GeoNet, n.d.a). This time constraint meant that emergency management agencies needed to rely on the public awareness of the need to self-evacuate in response to natural warnings that had been generated through public messaging and education campaigns in the years leading up to this event. In any case, since all communication into, and out of, Kaikōura was severely disrupted by earthquake damage to telecommunications utilities, again meaning that in the immediate aftermath of the event the emergency response operation was heavily reliant on community awareness of the need to self-evacuate along the coast (Giovinazzi et al. 2017).

In the hours following the onset of earthquake shaking, government tsunami threat and tsunami warning advisories changed rapidly. Thirty minutes after the earthquake, a tsunami was observed on the Kaikōura tide gauge. The Ministry of Civil Defence and Emergency Management (now known as the National Emergency Management Agency, NEMA) issued a national advisory message at 12:40 a.m. stating that there was no tsunami threat to New Zealand, since the epicentre of the earthquake was onshore. Twenty minutes later, at 1.00 a.m. the same agency reversed that initial advice, by issuing a tsunami threat for all of New Zealand's eastern coastline, which was based on new information about the complex off-shore fault ruptures involved in the event (Kardos, 2017). The complexity of this messaging and the severity of the earthquake event is particularly important to understand how the public responded to this natural warnings (strong ground shaking), in the absence of clear and consistent messaging from authorities. A summary of the national, regional (Canterbury,) and christchurch official warning response is shown in the Figure 1.4-5 and a detailed decription is presented in Appendix C.

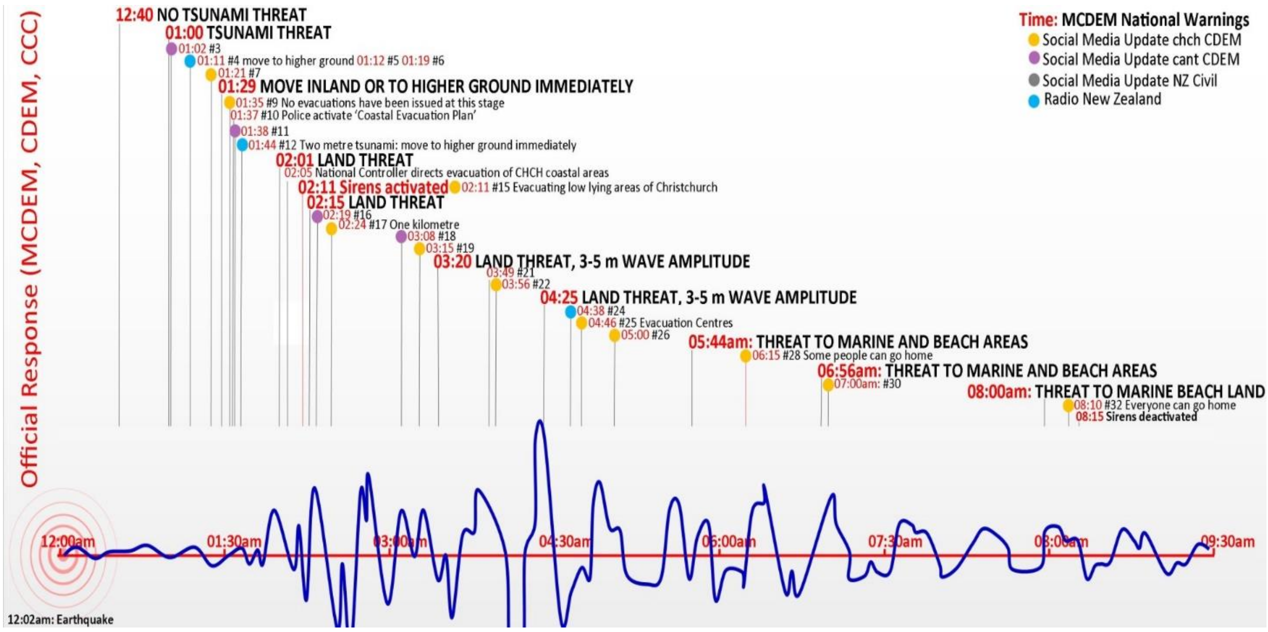

Figure 1.4-5: Official warning response to the 2016 Kaikōura earthquake and tsunami (Source: Thomas, 2017).

1.5 Research methodology and thesis structure

This thesis comprises of five main chapters, with the risk management framework used as a conceptual basis throughout.

Chapter 1 establishes the context of the study, by detailing the aims and objectives of this thesis. The risk identification process starts by providing an overview of the study area and the effects of 2016 Kaikōura earthquake and the official emergency response.

Chapter 2 provides the basis for the risk identification process and this Masters research project with a comprehensive literature review of New Zealand tsunami hazard and risk assessment, tsunami risk management strategies implemented in New Zealand, evacuation survey research on the evacuation process derived from finding of past tsunami events globally and in New Zealand, and evacuation modelling research. This chapter identifies the gap in global tsunami evacuation research which informs the methodology for Chapter 3 and 4.

Chapter 3 reports risk analysis and evaluation findings, reporting on survey data concerning warning and evacuation decision-making, evacuation response and movements, and risk awareness influence on evacuation response self-reported by coastal Kaikōura residents who experienced the 2016 Kaikōura earthquake. Discussion relates these findings and the real-event evacuation behaviour they reveal to the findings of other research that has analysed evacuation behaviour of at risk communities. Limitations of the methods are discussed, as are recommendations for future research.

Chapter 4 reports on the development of a tsunami exposure inventory, and a network-based tsunami evacuation model that include and are informed by the findings reported in Chapter 3. Findings on evacuation modelling outputs are discussed, and limitations are presented on the evacuation modelling planning framework, informing key future research recommendations.

Chapter 5 presents a summary and draws conclusions of this research. Key findings on understanding how Kaikōura resident's response to 2016 Kaikōura earthquake (natural warning) and the importance of including real event evacuation dynamics to inform and improve evacuation modelling techniques are presented. Key recommendations are provided for tsunami risk management applications and future work.

Chapter 2: Literature review

This chapter presents a literature review framing the context of research objectives 1 and 2 of this thesis. First, the phenomena of tsunami is explained, including global impacts. This is followed by an overview of New Zealand's tsunami risk assessment and risk management strategies. Lastly, a literature review is presented on global evacuation behaviour to identify a global tsunami research gap.

2.1 Tsunami hazard assessment

As noted in the introductory chapter, a tsunami is a natural phenomenon consisting of a series of waves when a large volume of water in the sea or in a lake becomes rapidly displaced" (Power, 2013). Tsunami are primarily generated by a large coastal or submarine earthquake, but can also be generated by submarine landslides, volcanic activity, and atmospheric blasts (Barryman, 2005; Power, 2013; Power & Leonard, 2013). The distance between tsunami waves (wavelength) can vary from several kilometres to over 400 kilometres and can result in wave travel speeds of up to 500km/h in deep water (Berryman, 2005). As the tsunami propagates into shallower waters near the coast, energy dissipates and wave amplitude increases however, the first tsunami wave may not be the largest and waves may continue to arrive many hours after the arrival of the first wave (Barryman, 2005; Power, 2013; see Figure 2.1-1 for tsunami wave terminology).

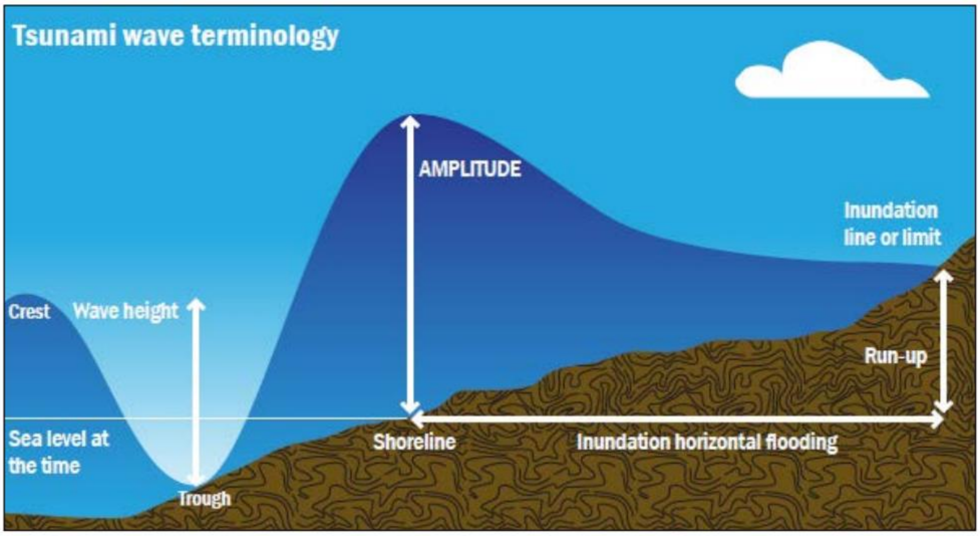

Figure 2.1-1: Tsunami wave terminology (MCDEM, 2016)

Tsunami are known to be one of the most powerful and destructive natural hazards to impact on coastal communities (Power, 2013). Tsunami can occur in a range of magnitudes from various sources (Power, 2013). Recent examples include catastrophic and more infrequent events such as the 2004

Indian Ocean tsunami, the 2010 Chile tsunami and the 2011 Great East Japan tsunami, and the more frequent, smaller and less damaging events such as the 2009 American Samoa tsunami, the 2015 Illapel earthquake and tsunami, the 2016 Kaikōura tsunami, and the 2019 Palu tsunami (Figure2.1-2). The scale of impact is dependent on source, magnitude, and coastal topography (Power et al. 2013). In addition to the direct consequences on coastal environments, people, critical infrastructure and property, tsunami impacts include indirect, ongoing social and economic consequences (Power, 2013). In the past two decades, global tsunami events have caused more than 250,000 fatalities and resulted in USD$280 billion in damages, see Figure 2.1-3 (Imamura et al. 2019).

Figure 2.1-2: Tsunami damage observed from the 2015 Illepel tsunami (left) and the 2016 Kaikōura earthquake and tsunami (right). Photos provided by James Williams.

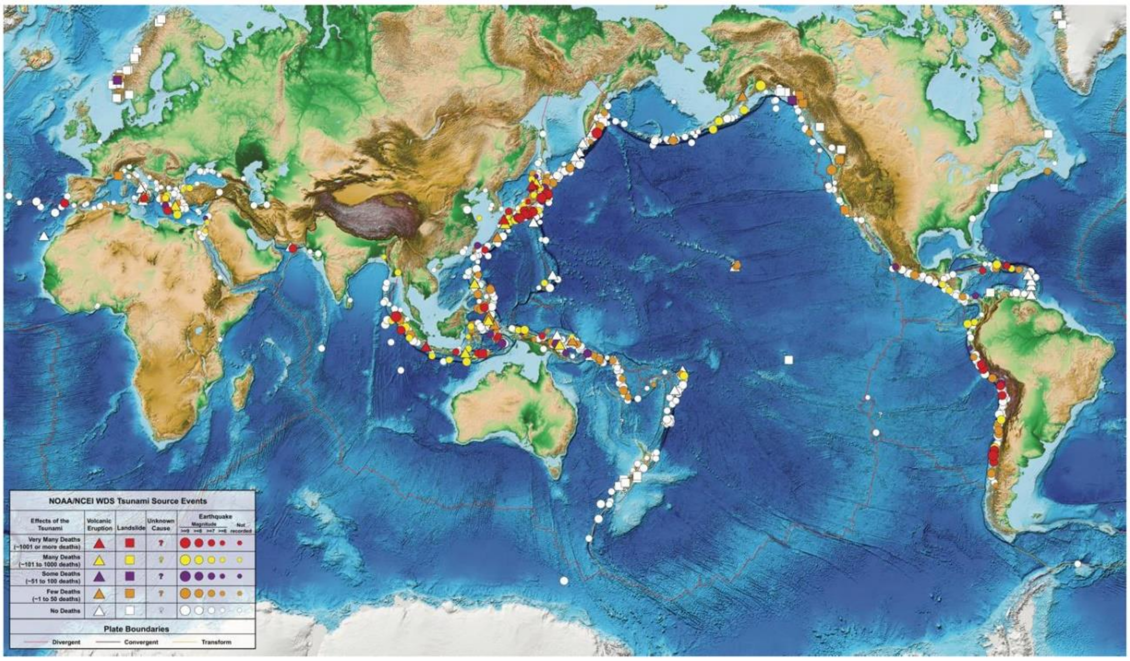

Figure 2.1-3: Global tsunami sources from earthquakes, volcanic eruptions, landslides, and other causes from 1610 BC to AD 2017. The colour of the shape represents the number of deaths (red= very many deaths). Source: NCEI, ITC, (NOAA) 2018

2.2 New Zealand tsunami hazard and risk assessment

Over the last two decades, New Zealand continues to increase scientific understanding of tsunami hazard risk (Power, 2013). Numerical and empirical modelling methods have been used to determine potential source mechanisms, tsunami generation, propagation, flow velocity, depth, and inundation extents for coastal areas at risk to tsunami (King, 2015; Lane et al. 2014; Power et al. 2010; Walters et al. 2006). Local level tsunami risk modelling has advanced in recent years since the development of New Zealand's first National Probabilistic Tsunami Hazard Model in 2013 (Power, 2013). New Zealand's National Probabilistic Tsunami Hazard Model encompasses all likely sources that put New Zealand at high risk from tsunami. New Zealand classifies tsunami sources by their arrival time from the source to impact location, they are;

- 'Distant source - defined by tsunamis that are expected to take longer than 3 hours to arrive at New Zealand's coast for example; South America, Cascadia subduction zone, or Japan.
- Regional source - defined by tsunamis that are expected to have wave arrival times of 1-3 hours to reach New Zealand's coast for example; Tonga-Kermadec trench and South New Hebrides trench.
- Local source - defined by the immediate threats directly off New Zealand's coast with wave arrival times of less than an hour for example off shore faults, Hikurangi subduction zone and Puysegur subduction zone' (Power, 2013; Figure 2.2-1).

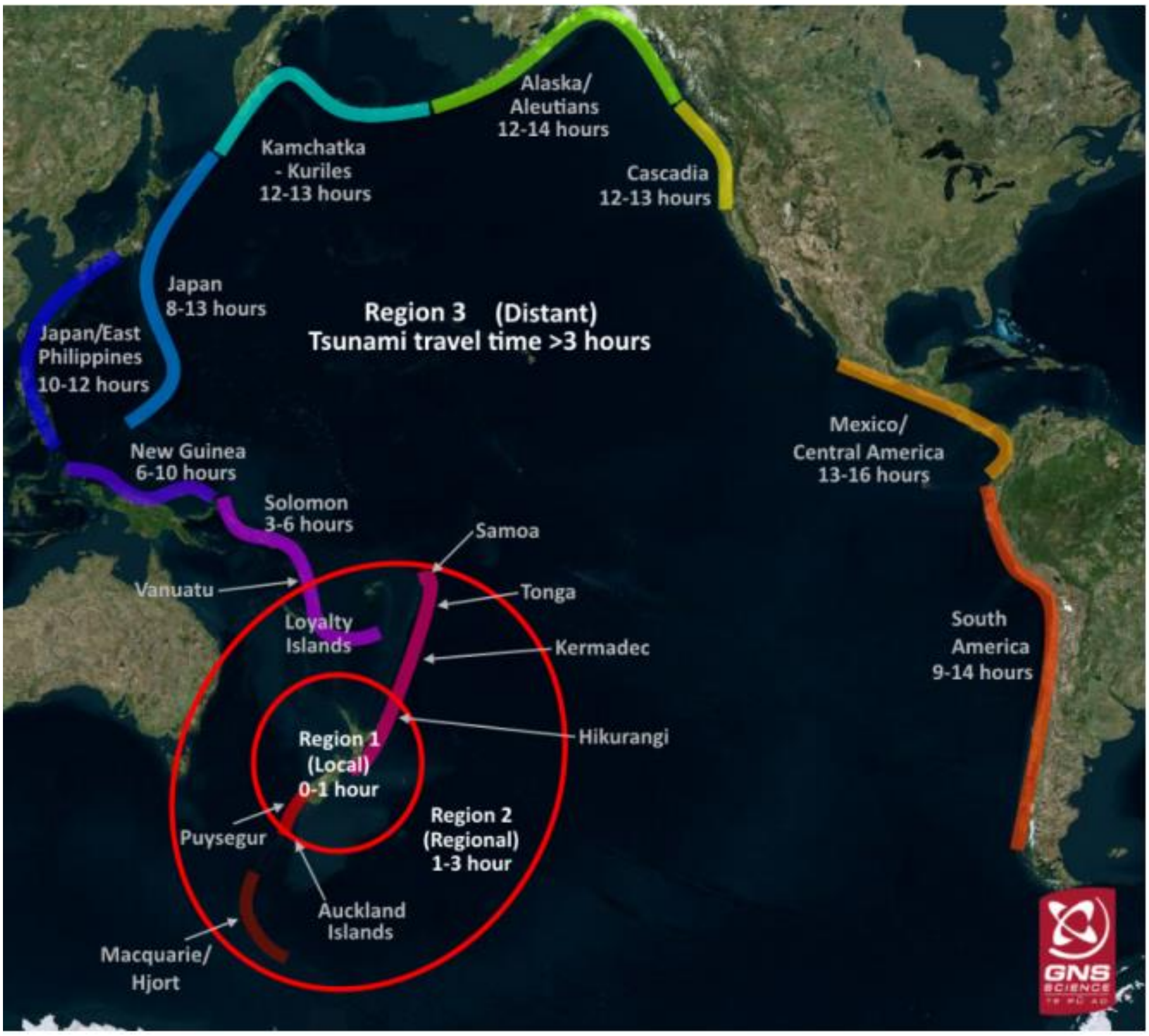

Figure 2.2-1: Tsunami sources that New Zealand is exposed to (MCDEM, 2018a). Region 1 represents local source tsunami (0-1hr) tsunami, region 2 represents regional source tsunami (1-3 hours), and region 3 is distant source tsunami around the Pacific Ring of Fire (>3 hours).

New Zealand has a relatively short written historical tsunami record of about 200 years. Despite this, New Zealand has been impacted by at least 80 events from 1835 to 2011 (Downes et al. 2017). Of these, 27 originated from distant sources, 12 from regional earthquake sources, 28 from local sources and 13 from unknown sources (Downes et al. 2017; Power, 2013). Figure 2.2-2 shows the location of historical tsunami events to impact New Zealand's regions.

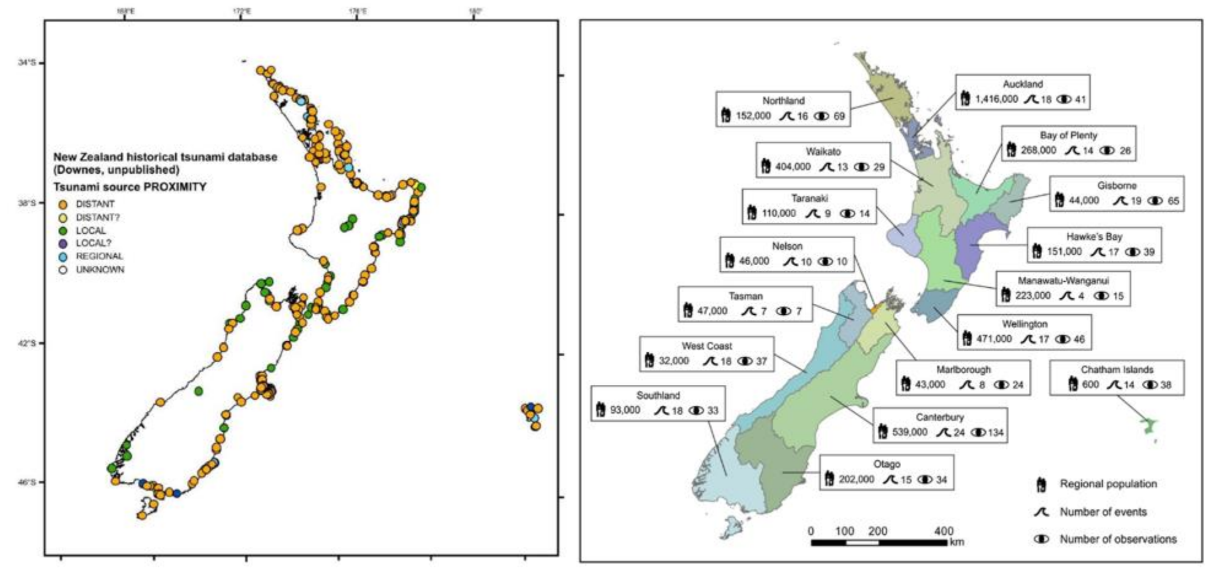

Figure 2.2-2: Left: Sources of tsunami that have affected New Zealand since 1835 (Power, 2013). Right: 'Map distribution of tsunami impacts in New Zealand by region. The box for each region shows approximate population in the present day, the number of tsunami impact events (wave symbol), and the number of observations (eye symbol)' (Downes et al. 2017)

Historic and pre-historic tsunami records indicate New Zealand has been affected by tsunami generated by landslides (including submarine) and volcanism (De Lange and Healy, 1986; GNS Science, 2014). New Zealand's greatest tsunami threat, however, is posed by a local source tsunami generated by an earthquake along the Hikurangi margin (East Coast Lab, 2020; Power, 2013). The subduction zone starts proximal to Kaikōura and extends up the east coast of the North Island offshore of Gisborne, and is capable of producing earthquakes greater than Magnitude 9.0, producing tsunami comparable to that generated by the 2011 Mw 9 Great East Japan earthquake (East Coast Lab, 2020; Fraser et al. 2016; Power, 2013). The immediate threat of a Hikurangi subduction zone tsunami, results in potentially short arrival times of approximately 10 minutes depending on the source of the rupture. This poses a great risk to coastal communities located in Canterbury, Marlborough, Wellington, Hawkes Bay and Gisborne (East Coast Lab, 2020).

New Zealand's coastal locations are favoured areas for human settlement, with 65% of New Zealand's population residing within 5 kilometres of the coast, compared with 40% globally residing within 100 kilometres of the coast (Statistics New Zealand, 2006, United Nations, 2017). The increasing trend of population migration to coastal areas and New Zealand's complex and dynamic tsunami hazardscape, increases New Zealand's exposure to tsunami. A recent study by Paulik et al. (2020) conducted New Zealand's first national-scale assessment on population and built-environment exposure located within New Zealand's tsunami evacuation zones (discussed in section 2.3). Key findings from this assessment estimate New Zealand has 'considerable' population, built-land, and asset exposure in tsunami evacuation zones. Just under 10% of New Zealand's population residing in 399,000 residential buildings are in evacuation zones, supported by a further 5400 critical buildings and 6300 kilometres of road transport network. To address the increasing risk of New Zealand's exposure to tsunami, continual efforts are needed for effective tsunami risk management.

2.3 New Zealand tsunami risk management

The impacts of the 2004 Indian Ocean tsunami and the 2011 Great East Japan tsunami reinforced the importance for effective early warning systems and tsunami risk management planning in New Zealand (MCDEM, 2016). In 2007, a National Tsunami Working Group was established to help guide New Zealand's tsunami risk management programme (MCDEM, 2008a). New Zealand's tsunami risk management programme supports evidence-based, end-to-end tsunami risk management across the 4Rs (NEMA, n.d.b). The programme draws on expertise from tsunami hazard research, risk assessments, risk management, planning, social science and public education across government and research agencies (NEMA, n.d.b). Projects listed under the programme include tsunami risk assessment, early warning systems and response, public education and awareness, and tsunami evacuation planning. These projects are designed to inform local and regional Civil Defence Emergency Management (CDEM) Groups to increase community level tsunami awareness and preparedness and knowledge on appropriate protective actions to take in future events (NEMA, n.d.b).

As mentioned in the introductory chapter, evacuation is considered the primary risk reduction strategy for preventing casualties (MCDEM, 2016). In New Zealand, evacuations are triggered by two types of tsunami warning:

1. **Natural warnings** such as a long and/or strong earthquake, loud or unusual noises from the sea, or sudden rise or fall in sea level. These warnings are the primary warning for local source tsunami (MCDEM, 2017a). Given the close proximity of local source tsunami and the short travel time (less than 1 hour), it is unlikely that there will be sufficient time to issue an official warning (Couling, 2014; Kardos, 2017; MCDEM, 2018a). For this reason, NEMA and local CDEM Groups advise and rely on the public to self-evacuate immediately to higher ground or further inland (Blake et al, 2018; MCDEM, 2016; MCDEM, 2018a).
2. **Official warnings** Official warnings are used to inform the public of a distant or regional source tsunami threat. National tsunami warnings are issued by NEMA with technical support from GNS Science/GeoNet's Monitoring Centre, who assess messages received from the Pacific Tsunami Warning Center (PTWC, based in Hawaii) and/or tsunamigenic data received from seismic sensors, tsunami gauges, DART (Deep Ocean Assessment and Reporting of Tsunamis) buoys around New Zealand (MCDEM, 2018). National warnings are disseminated to local CDEM Groups and media through the National Warning System to then be

disseminated to vulnerable communities (MCDEM, 2018a). Once a local CDEM Group has received a warning through the NWS, CDEM Groups can coordinate a local response for their vulnerable communities. Official warnings can be disseminated through multiple channels, including social media, websites, television, radio, emergency mobile alerts, and sirens (MCDEM, 2018a).

Recent advancements have been made to New Zealand's national warning system including 24/7 monitoring capability, establishment of the New Zealand DART Buoy Network and Emergency Mobile Alert (EMA) system. These advancements progress towards New Zealand's commitment to 'speed up' official tsunami warnings for at risk coastal communities (New Zealand Government, 2019).

To increase awareness of the types of tsunami warnings, effective evacuation planning is needed. Evacuation planning is "the process of identifying areas potentially at risk from tsunami, and the actions required to ensure the safety of people whilst evacuating from hazardous areas" (MCDEM, 2016). Therefore, it is a fundamental New Zealand has a nationally consistent approach to tsunami evacuation planning and to have a common understanding and align with processes for official tsunami warnings. New Zealand's primary components of tsunami evacuation planning include delineating evacuation zones, public education, evacuation boards and signs, exercises and drills and evacuation response plans including evacuation modelling. The National Emergency Management Agency (NEMA) has a comprehensive range of evacuation planning guidance, standards and national plans to guide Civil Defence Emergency Management Groups to implement tsunami evacuation planning at a local level (see Figure 2.3-1) including;

- Director's Guideline: Mass Evacuation Planning [DGL 07/08] (MCDEM, 2008)
- Directors Guideline: Tsunami Evacuation Zones [DGL 08/16] (MCDEM, 2016)
- Technical Standard: Tsunami Warning Sirens [TS 03/14] (MCDEM, 2014)
- Technical Standard: National Tsunami Signage [TS 01/08] (MCDEM, 2008a)
- Supporting Pan: Tsunami Advisory and Warning Plan [SP 01/17] (MCDEM, 2018a)
- Directors Guideline: Assessment and Planning for Tsunami Vertical Evacuation [DGL 21/18] (MCDEM, 2018)
- Technical Information: Tsunami Loads and Effects on Vertical Evacuation Structures. Ministry of Business, Innovation & Employment (MBIE, 2020)

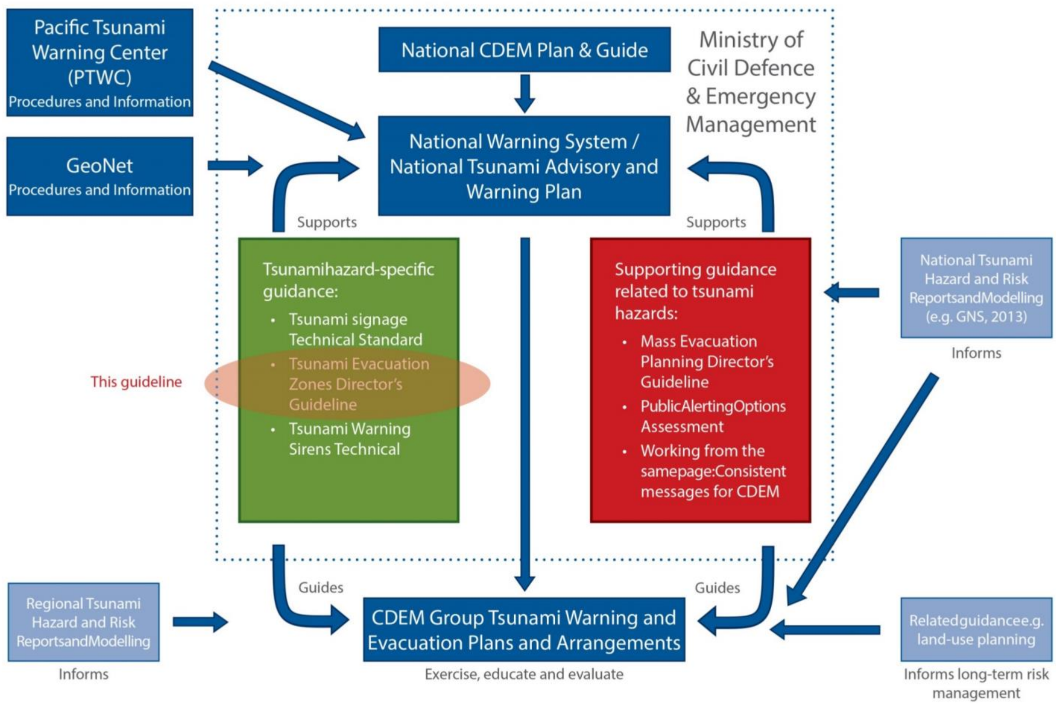

Figure 2.3-1: Process used to inform CDEM Group tsunami evacuation planning. Note, technical Information on tsunami loads and effects on vertical evacuation structures is not included on this diagram, however, should be considered for future evacuation planning. Retrieved from Ministry of Civil Defence & Emergency Management (MCDEM, 2016).

Tsunami evacuation zones are fundamentally about life safety (MCDEM, 2016). The New Zealand Tsunami Evacuation Zone Director's Guideline [DGL 08/16] provides a consistent national approach to map tsunami evacuation zones, create public information for evacuation response and align tsunami evacuation plans and processes with official tsunami warnings (MCDEM, 2016). Although informed by tsunami inundation modelling, evacuation zones are not tsunami hazard zones, tsunami risk zones, or inundation zones, they are areas that authorities recommend people evacuate from as precaution if they feel a long or strong earthquake or in an official tsunami warning (Jack & Schoenfeld, 2017; MCDEM, 2016).

The Directors Guideline [DGL 08/16] recommends a three zone approach (red, orange and yellow) (minimum of two) to encompass most, if not all local, regional and distant source scenarios:

Red Zone – represents the highest risk zone that is most likely to be affected by a tsunami. This includes beaches, estuaries, harbours and river mouths (marine and beach exclusion zone). People should evacuate from this zone if they feel a long or strong earthquake or receive and official warning.

Orange Zone – represents the zone to be used for official warnings of distant or regional source tsunami and should be linked to a particular threat level. This zone should encompass the potential inundation of the largest tsunami that can be expected in a 500 year return period. The intent of this zone is to provide a 'middle zone' to avoid over evacuation.

Yellow Zone – represents the areas to cover all maximum credible tsunami events including the highest impact events. It should be defined so that it encompasses the area expected to be inundated by a 2500 year return period tsunami.

Four development levels are recognised for establishing tsunami evacuation zone boundaries. To date, tsunami evacuation zone maps have been developed for all CDEM Groups, providing national coverage for New Zealand's coastline at risk to tsunami (Paulik et al. 2020).

Education is an important tool in tsunami risk management as it helps to improve public understanding towards tsunami risk (UNESCO, 2020). Tsunami education initiatives in an important aspect of New Zealand tsunami risk management programme (NEMA, n.d). National education initiatives are led by NEMA, which consists of national media campaigns and school programmes to support CDEM Groups to build on education campaigns at the community level. New Zealand's education campaigns and school programmes including 'Get Ready, Get Thru' 'and 'Long OR Strong, Get Gone' aims to improve public awareness and understanding of interpreting official and natural warnings and knowledge of appropriate protective actions to make before, during and after a response (Fraser, 2014; Fraser et al. 2013; Johnston et al. 2008; Løvholt et al., 2014; MCDEM, 2017a: see Figure 2.3-2). New Zealand's education campaigns focus on improving household, work place, schools and marae's preparedness to be ready for emergencies. Education resources are easily accessible and primarily advertised through television, radio, newspapers, school resources, and social media campaigns (NEMA, n.d).

Figure 2.3-2: National tsunami and earthquake public education campaigns. Top: Get Ready, Get Thru - What's the plan Stan. This campaign encourages households, work place, schools and marae, to develop a plan before an emergency happens. Bottom: education campaign on protective actions to take if New Zealand experiences a large natural warning Source: MCDEM (n.d.).

Tsunami signage is an integral part of New Zealand's tsunami risk management programme. Tsunami signage supports public education and response to tsunami through identifying evacuation zones, evacuation routes, and safe zones locations. (Fraser, 2014; MCDEM, 2008). Tsunami signage increases public awareness prior to an event whilst providing immediate guidance during an evacuation by informing people on where to evacuate to (Dengler, 2005; Lonergan et al., 2015). New Zealand's Technical Standard for Tsunami Signage [TS01/08] is designed to support public education and preparation and assist recognition and understanding of tsunami signage by tourists and visitors (Figure 2.3-3). Tsunami signage has been implemented in a number of communities across New Zealand, especially in high risk areas including but not limited to; Northland, Auckland, Hawkes Bay Wellington and Canterbury.

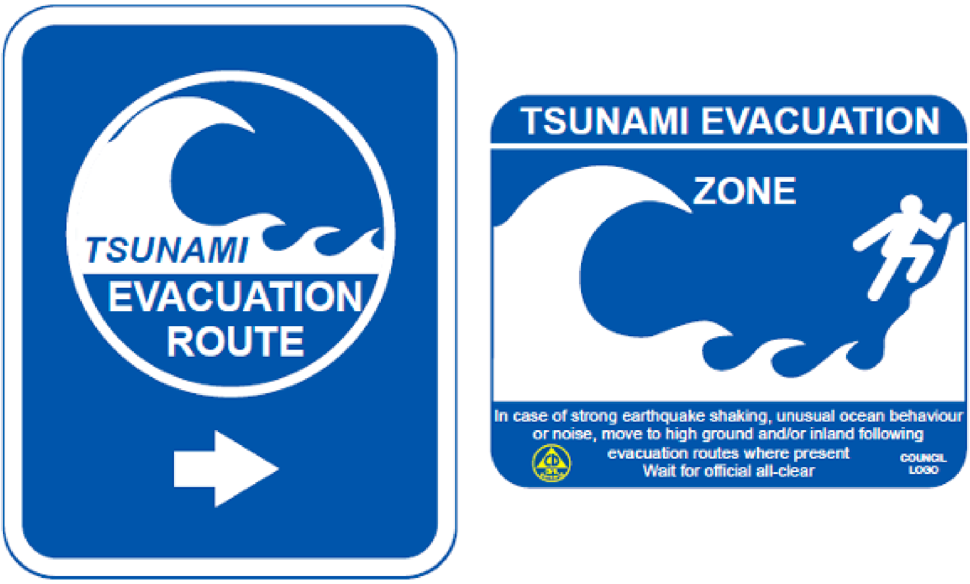

Figure 2.3-3: New Zealand tsunami evacuation signs (in Technical Standard [TS 01/08]) (MCDEM, 2008). Left: tsunami sign that directs evacuees to safe zones. Right: tsunami sign informs people on what tsunami evacuation zones they are in, and includes descriptions of natural warnings.

Tsunami boards, are an example of tsunami signage in which they assist community understanding of the risk and appropriate response to enable effective response to tsunami warning (MCDEM, 2008). Tsunami boards provide information on tsunami hazard characteristics, tsunami evacuation guidance, warnings and response information, local tsunami history and evacuation maps (Currie et al. 2014; MCDEM, 2008). Tsunami boards are recommended to be placed in high-use coastal areas, including beach access points, commercial holiday homes, shops, public buildings, and tourist facilities to reach the highest and at most risk populations (MCDEM, 2008; MCDEM, 2016). Local authorities have implemented a number of tsunami boards to increase local tsunami risk awareness. Areas include but not limited to: Wellington (Figure 2.3-4), Christchurch, Tauranga, Timaru, and Wanganui.

Figure 2.3-4 Tsunami information board for Island Bay in Wellington.

Blue-lines represent safe places to evacuate following a long and/or strong earthquake shaking (WREMO, n.d). The Blue Lines concept was developed by a collaborative effort between residents in Island Bay (Wellington) and Wellington CDEM Group. This approach aimed to develop an education campaign to raise awareness of the maximum inundation level of a worst case scenario (WREMO, n.d). Blue lines have been recognised as an effective tsunami risk management initiative to increase awareness across the Wellington Region, however it is noted that further improvements could include information signage to explain the purpose of the blue lines (Currie et al., 2014). Since 2012, Blue Lines have been painted in Hutt Valley and the Wairarapa (WREMO, n.d, see Figure 2.3-5)

Figure 2.3-5: Example of blue lines in Wellington (Source: Fraser et al. 2014).

Evacuation drills and exercises combine evacuation planning and education, and enable the public to practice their evacuation routes and identify areas that would reduce their vulnerability in a tsunami event. Shakeout, held across the world and recently adopted in New Zealand's, is New Zealand's annual earthquake drill. In recent years NEMA has encouraged the incorporation of a tsunami hīkoi (walk), which encourage schools, work force and households to exercise response actions for a local source earthquake (natural warning) and practice their evacuation hīkoi (walk) (Vinnel et al. 2020; McBride et al. 2019). Currently, there is over 400,000 participants signed up to participate in New Zealand's 2020 ShakeOut drill (NEMA, n.d.c).

Evacuation modelling methods are an increasingly applied tsunami risk management initiative to assess residual risk of populations needing to reach safety (Fraser et al. 2014: MCDEM, 2018; Power et al. 2020; Wood et al. 2018:2013). Evacuation models are a tool to calculate the time to reach safety and assess evacuation route capacity and optimal evacuation routes through the incorporation of behavioural and physical elements such as evacuation delay time, movement rates, route availability and variability of population exposure and vulnerability (Fraser, 2014; Wood & Schmidtlein, 2013). Outputs of evacuation models provides emergency management with evacuation routing options, assessment of the performance of implementing existing evacuation response plans and evacuation drills, and the capability of overlaying data regarding evacuation safe points, potential congestion barriers, and optimal evacuation routes (González-Riancho et al., 2013; UNESCO, 2020; Wood & Schmidtlein, 2013). New Zealand evacuation modelling research is discussed in the following section (Section 2.4).

2.4 Evacuation modelling approaches and New Zealand evacuation modelling literature

The following section provides an overview of current global evacuation modelling approaches and recent New Zealand applications. Following the summary of these modelling approaches and key findings, a summary figure is presented outlining advantages and disadvantages on each evacuation modelling approach. Recent applications inform the reasoning for applying ArcCASPER extension tool for the development of vehicle network based evacuation model for Kaikōura (Chapter 4).

Evacuation modelling approaches including Agent-based modelling, Geospatial Least-cost distance modelling and Network-based modelling have been an increasingly applied evacuation planning tool in New Zealand. These approaches have primary focused on evacuation time simulations, simulations of shortest paths to reach safety, and influence of population demographics and socio-economic factors to predict hypothetical evacuation scenarios (Fraser, 2014).

A recently applied evacuation modelling method in New Zealand is Agent-based modelling (Power et al. 2019). This is an approach to the simulation of the movement of 'agents' (people) during an evacuation event (Mas et al. 2015, 2012; Power et al. 2019; Shahabi & Wilson, 2014; Wang et al. 2016). This modelling technique estimates evacuation time to represent realistic characteristics of the population including walking speed and evacuation delay time, and can incorporate the effects of interactions between agents such as the effects of congestions and evacuation response time. Power et al. (2019) developed an agent-based modelling approach to simulate pedestrian evacuation of three at risk coastal communities in New Zealand: Petone (Wellington) (see Figure 2.4-1), Napier, and Sumner (Christchurch). The aim of this research project was to model evacuation time and identify potential congestion pinch points, and receive community feedback from the public about how to improve the models and improve evacuation speed and safety. Local knowledge and discussions with local CDEM practitioners provided recommendations to make tsunami evacuations quicker and safer (e.g. implementation evacuation bridges, vertical evacuation structures and community awareness initiatives).

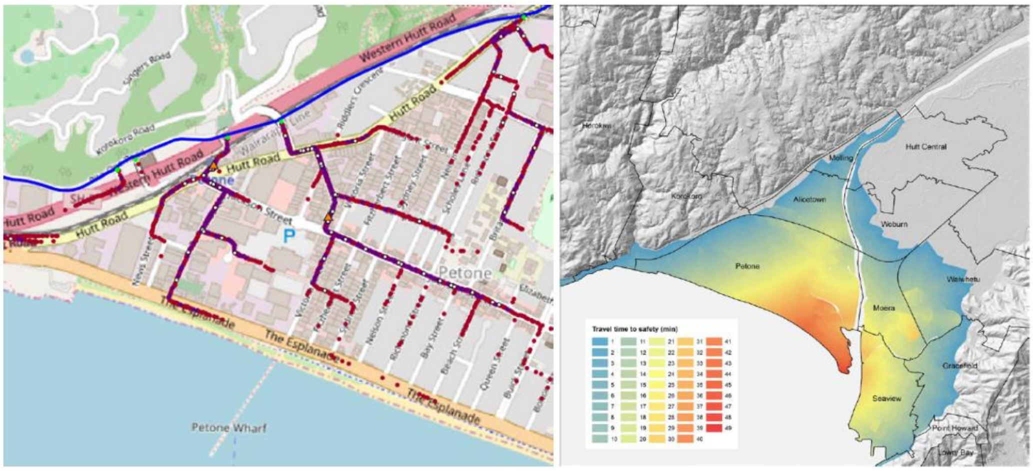

Figure 2.4-1: Tsunami evacuation modelling techniques. Left: Agent-based tsunami evacuation model for Petone, Lower Hutt, New Zealand. Red dots represent individual evacuees and purple indicates likely congestion. Right: Least-cost distance model for Petone, Lower Hutt, New Zealand. Evacuation time estimates a presented based on topographic characteristics.

Least cost distance (LCD) modelling is an well-established modelling method for tsunami evacuation planning, particular in international research (Fraser et al. 2014a; González-Riancho et al. 2013; Wood & Schmidtlein, 2013, 2012; Graehl & Dengler, 2008). This method applies travel speeds to a cost distance surface to generate a time surface representing the time to travel from origin source to safe zone destinations (Wood et al. 2013). A couple of studies have been conducted applying least cost distance modelling approach in New Zealand. This includes the work of Fraser et al. 2014b who developed a method to incorporate time-variable exposure, distributed travel speeds and uncertain evacuation departure time into an existing LCD framework, and applied it to two coastal communities of Napier and Hawkes Bay. Le (2016) applied a similar methodological framework but for three 'extreme' scenarios for the coastal suburb of Sumner in Christchurch. The results of this work presented spatio-temporal distribution of variable population groups to reflect diurnal and seasonal population variation. More recently, Lukovic et al. (2017) developed evacuation time estimates for local source tsunami for Wellington suburbs, New Zealand, which indicated that evacuation travel times for several suburbs exceed the arrival time of the first tsunami wave for a worst-case scenario. Figure 2.4-1 provides an example of the results of the LCD modelling approach.

Network based modelling is a common approach used in traffic modelling literature (Shahabi, 2012; Shahabi & Wilson,2018; You, 2013). Although traffic modelling literature is well established in many other research disciplines, little research have incorporated traffic parameters into evacuation modelling for tsunami research. Shahabi (2012) addressed this research gap by developing a Network Analyst extension tool 'ArcCASPER' (Capacity-Aware Shortest Path Evacuation Routing) following the 2011 Tohoku earthquake and tsunami. The extension tool includes an evacuation routing algorithm to determine traversal speeds for each road segment based incorporating network capacity, evacuee density and congestion potential. Shahabi (2012) applied the tool for San Francisco, U.S, to determine evacuation time through minimising the effects of congestion. ArcCASPER has been an increasingly applied tool to determine evacuation time estimates for communities at risk to tsunami in New Zealand. Knook et al. 2015, was the first study to apply this tool in New Zealand. This work developed a network-based tsunami evacuation model for Tauranga City, Bay of Plenty. Findings of this work estimated pedestrian evacuation times of up to 180 minutes for the entire city to evacuate to safety. Evacuation was optimised through the inclusion of vertical evacuation structures which reduced evacuation time estimate to 70 minutes. Tilley (2018), applied the ArcCASPER network analyst tool for coastal suburbs of Southshore, South New Brighton and North New Brighton in Christchurch. The tool was used to determine vehicle evacuation times per household, evacuation times to travel along certain road segments, and vehicle density count along the study area's road network. A key finding of this research estimated a total evacuation time for all households to reach safety, could take up to 100 minutes. Evans (2020) applied the ArcCASPER tool to assess evacuation times for Riversdale Beach in the Wairarapa, Wellington Region. Results of this research, estimated a total evacuation time of 110 minutes for a maximum occupancy night-time scenario (see Figure 2.4-2). A recent study by Barnhill (2020), applied the ArcCASPER tool, to assess evacuation time estimates for coastal communities in Banks Peninsula. The results of the evacuation modelling tool estimated evacuation times of up to 8 minutes for certain bays in Banks Peninsula.

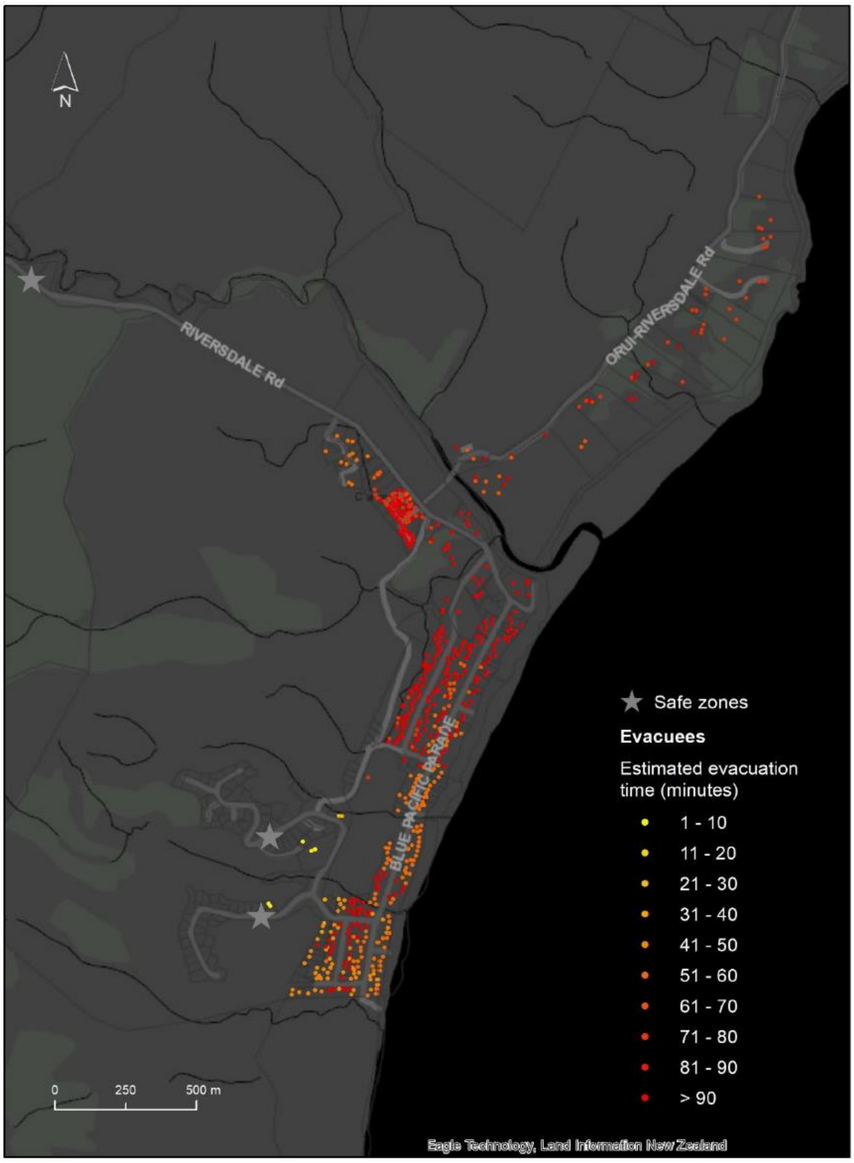

Figure 2.4-2: Arc CASPER Network Evacuation model for Riversdale Beach in the Wairarapa (Source: Evans, 2020)

Evacuation Method	Advantages	Disadvantages	References
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 with in ArcGIS • Requires a network dataset with no accuracy, alignment, or topological errors to function properly • Can have shortcomings during the modelling process. Shortcomings include optimising every road within the network, not taking into account complex turn restrictions, node breaks in road network • Only optimises road network	• Alabdouli, 2015 • Harris, 2015 • Shahabi, 2012: 2014 • You, 2013
Agent-Based Modelling	• 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	• Mas et al. 2015; 2012 • Yeh, 2014 • Affan et al. 2012 • Anh, et al. 2012
Least-Cost Distance Modelling	• Multiple modes of transportation can be mapped • Slope and land cover 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	• Le, 2016 • González Riancho et al. 2013 • Wood & Schmidtlein, 2013

Figure 2.4-3 Advantages and disadvantages of three evacuation modelling methods. Source: Tilley, 2018.

To date, New Zealand tsunami risk management initiatives including evacuation planning has been informed from global practice and international research findings (Jack & Schoenfeld, 2017). A significant focus of this has incorporated response and evacuation behaviour of recent global tsunami events including the 2011 Great East Japan tsunami. However, tsunami events continue to affect vulnerable coastal communities globally and in New Zealand. Key findings on evacuation behaviour of recent tsunami events is vital to inform best practice for tsunami evacuation planning in New Zealand. Section 2.5 provides an overview of global and New Zealand tsunami evacuation behaviour survey research and findings.

2.5 Global and New Zealand tsunami evacuation behaviour research

Natural hazards are of unpredictable nature and often precludes the collection of pre-disaster data and information on prior experiences, risk and impact assessments, plans and evacuation intentions. Over recent decades, research on evacuation from natural disasters has been increasingly published across several disparate disciplines such as sociology, psychology, engineering, natural hazards, risk assessments and management, and traffic management (Thompson et al. 2017). Evacuation research have explored factors and predictors that help explain evacuation behaviour of natural hazards such as hurricanes, floods, wildfires, volcanic eruptions, and tsunami (Dash & Gladwin, 2007; Hasan et al., 2011; Jumadi et al., 2018; Lindell et al., 2011; Maghelal et al., 2017; Potter et al., 2018; Thompson et al., 2017; Toledo et al., 2018). Several common factors that influenced evacuation behaviour include but not limited to demographics such as gender, age and living situation, knowledge of hazards and warnings, evacuation intentions, preparedness actions, and prior disaster and evacuation experiences.

Although a substantial body of research has analysed evacuation behaviour for hurricanes, floods, and wildfires, tsunami evacuation literature remains limited due to the infrequent nature of considerable size tsunami events that has required evacuation (Fraser et al. 2016). To date, global research on tsunami warnings and evacuation behaviours have demonstrated the complexity of understanding the biological, psychological, social, and environmental reasoning's leading to response behaviour (Fraser et al. 2016; Lindell et al . 2015; Bird et al. 2011; Gregg et al. 2006). Studies have investigated various aspects of human behaviour such as tsunami preparedness, risk awareness, evacuation intentions, and evacuation behaviour and dynamics of past earthquake and tsunami events (Makinoshima et al. 2020; Dhellemmes et al. 2016; Currie et al. 2013; Couling, 2014; Johnston et al. 2003).

An important review paper by Mikinoshima et al. (2020) concludes after reviewing numerous publications and reports on survey research understanding evacuation behaviour of past tsunami events, no comprehensive overview of a complete tsunami evacuation process has been reported in global evacuation survey literature. Understanding this gap, Makinoshima et al. (2020) used the findings of a recent study to develop a framework (see Figure 2.5-1) to guide future survey research to understand a complete tsunami evacuation process. This process consists of various components such as notifications (warnings) and individual movements across three evacuation process phases: response phase, evacuation movement phase, additional phase. This section provides an overview of a complete tsunami evacuation process through lessons learnt from past global and national events. The results presented in the next chapter (Chapter 3) contributes to this global tsunami research gap by contributing an empirical dataset of a complete evacuation response of a local source event in New Zealand (as outlined in Section 1.2).

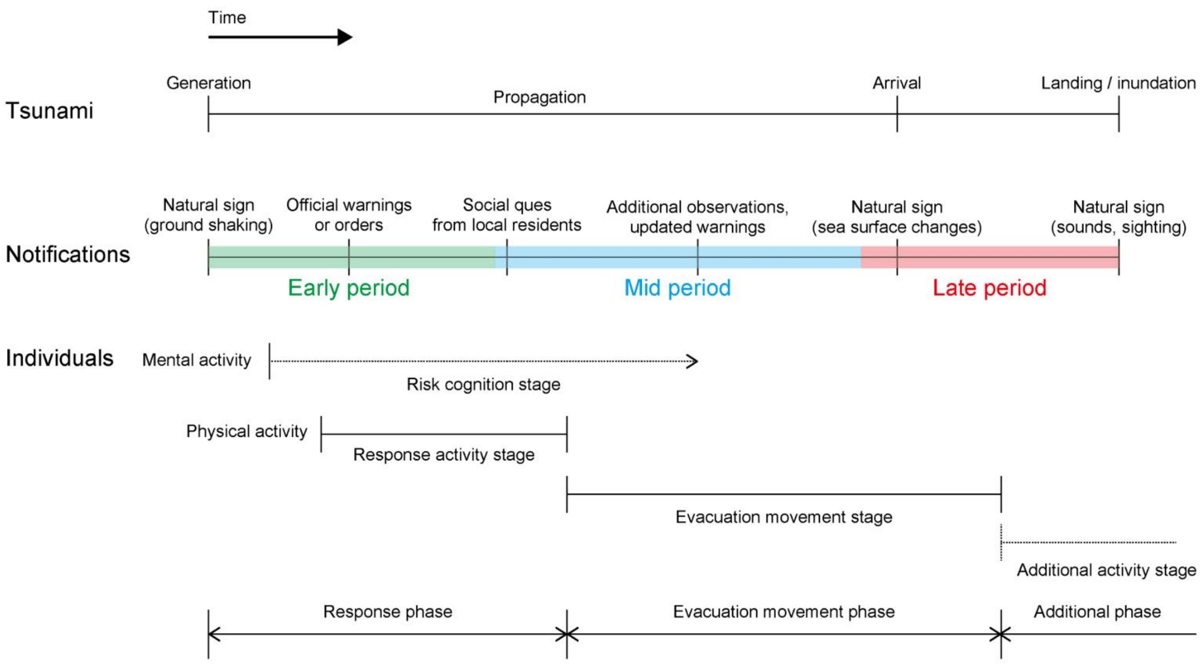

Figure 2.5-1: tsunami evacuation planning process developed by Makinoshima et al. 2020.

Tsunami notifications (Warnings)

When a tsunami is generated due to a natural phenomenon, evacuation is necessary to save lives. In many cases, there is a lead time between the generation of the tsunami and the time at which the first tsunami waves reaches land. During this lead time, various types of notifications e.g. tsunami threat and warning messages are issued for at risk populations. When a notification is issued quickly this enables people to prepare and take appropriate protective actions accordingly.

During the early notification period, the first warning for a local earthquake-induced tsunami is strong ground motions (natural cues). A number of survey studies found a strong correlation of strong ground shaking prompting evacuations or indication of a possible tsunami threat (Blake et al. 2018; Cabinet Office in Japan. 2012; Harnantyari et al. 2020; Lindell et al. 2015; Murakami et al. 2012; Ushiyama & Imamura, 2003). Contradictory to this, survey research conducted by Gregg et al. 2006 and Gaillard et al. 2008 found reports that strong ground shaking did not influence evacuation intentions during the 2004 Indian Ocean tsunami. Distant source tsunami notifications are reliant on official warnings due the unfelt ground shaking or other natural cues. Official warnings are primary issued through media such as radios, TV's, social media, emergency mobile alerts and sirens (Perry, 2007). Advanced technology has improved global tsunami early warning systems by assessing tsunami source characteristics efficiently and more accurately, this information is essential for officials and emergency response personnel. Survey research has indicated a reliance of evacuation warnings from officials as a contributing factor to evacuate (Bake et al. 2018; Cabinet Office in Japan , 2012; Goto et al. 2013; Ikeda et al. 2017; Lindell et al. 2015; Murakami et al. 2012; Togawa et al. 2018; Yoshi et al. 2008). However, underestimation of tsunami impact can lead to misunderstanding of tsunami risk and create distrust on officials during future events (Suppasri et al. 2016).

After experiencing natural warnings or receiving an official warning during the early period, people start to take protective actions. Response behaviours can function as social cues and are considered informal warnings (Minkinoshima et al. 2020). Survey research have reported social cues such as family members or neighbours initiating evacuation (Blake et al. 2018; Cabinet Office in Japan, 2012; Goto et al. 2012; Hiroi et al. 2005; Kato et al. 2009; Lindell et al. 2015; Mikinoshima et al. 2020; Okumura et al. 2010), and seeing other people evacuate can trigger response actions (Gaillard et al. 2008; Haranantyari et al. 2020; Lindell et al. 2015; Murakami et al. 2012; Goto et al. 2013). An important social cue that saved lives during the 2011 Great East Japan tsunami, was tsunami risk education in schools, also known as "Kamaishi Miracle', which influenced the surrounding adults who has less awareness of tsunami to evacuate to safety (Katada & Kanai, 2016). In addition to the social cues, early warning systems continually updates earthquake and tsunami source information, therefore, authorities can update or disseminate warnings or evacuations orders (Makinoshima et al. 2020).

During the late period, tsunamis can start to impact coastal areas (Makinoshima et al. 2020. This can been observed from natural warnings such as sea level changes and the sea receding. Sighting of receding sea has been a commonly reported natural cue in past survey research, particularly during the 2004 Indian Ocean tsunami and the 2009 American Samoa tsunami (Bird et al. 2011; Dudley et al. 2011; Gaillard et al. 2008). Hearing unusual sounds from the sea or sighting of the tsunami is considered the last warning before tsunamis effect coastal communities (Makinoshima et al. 2020). This was reported during the 2004 Indian Ocean tsunami, where 69% of survey respondents reported they saw unusual changes in the ocean and 5% heard unusual sounds (Gregg t al. 2006). Similar experience were reported during the 2009 American Samoa tsunami where survey respondents stated that the tsunami sounded like "an aeroplane about to take off" and "war machine guns" (Dudley et al. 2011).

Individual activities

Risk cognition stage is considered when notifications are perceived by local residents who have knowledge of natural hazards and past disaster experiences, environmental backgrounds, and motivate diverse risk cognition and response activities. Although all residents receive the same notification, the degree of perceived risk and response behaviours vary from persons due to diverse backgrounds (Makinoshima et al. 2020). Key findings of previous research suggest that the existence of knowledge of earthquake-generated tsunami is essential for people to interpret natural warnings. A study conducted by Mcadoo et al. 2006 discussed the importance of indigenous knowledge towards appropriate response actions and minimising tsunami loss.

An effective evacuation process requires minimal response activity. This increases the time to conduct evacuation movements to safety before the first tsunami wave arrives on land (Makinoshima et al. 2020). Preparations and response activities prior to evacuation have been observed during past tsunami events. Common response activities reported in survey literature revealed that seeking or collecting information from officials or family members and neighbours, and checking if family and neighbours are safe influenced the shift from response to evacuation movements (Blake et al. 2018; Cabinet Office in Japan, 2012; Fraser et al. 2016; Lindell et al. 2015; Sun et al. 2017; Ushiyama & Imamura, 2003). Such behaviour, in particular checking on family members and neighbours, can influence where people are located e.g. schools and retirements homes located on higher ground. Once people decide to evacuate they might take preparation actions (Makinoshima et al. 2020). Preparation actions taken in past tsunami events include; packed an emergency kit, collect valuable items, locked the house and checked the house for damage (Goto et al. 2012; Harnantyari et al. 2020; Lindell et al. 2015). If people perceive they are not at risk to tsunami, they do not shift to the evacuation movement stage and shift focus to the impacts caused by the earthquake (Goto et al. 2012). Some people don't evacuate until they have received cues in the late notification period (Makinoshima et al. 2020).

The evacuation movement phase starts with the end of the response activities. At the beginning of the evacuation movement phase people decide on the on their evacuation safe zone destination, evacuation route and mode of transport (Makinoshima et al. 2020). Once this is decided people begin their evacuation movements. Evacuation survey research has reported that evacuees generally head to high ground or to strong structures nearby. Common reports of popular safe zone locations during recent tsunami events include schools, churches, public halls, family member homes or outside areas on higher ground (Cabinet Office, 2010; Cabinet Office in Japan, 2012; Harnantyari et al. 2020; Lindell et al. 2015; Yoshii et al. 2008). Very few surveys have analysed evacuation route decision-making however a number of studies have compiled congestion barriers that were observed during the 2011 Great East Japan tsunami. Makinoshima et al. 2016 there were major traffic congestion barriers on main roads that usually carry large volumes of traffic. Similar observation were reported during the event in Banda Aceh in 2011 (Goto et al. 2013). An increasingly explored evacuation movement aspect has been evacuation travel mode. Pedestrian evacuation is strongly encouraged to avoid evacuation delay e as a result of potential congestion, however, a preference towards vehicular evacuation has been observed during past tsunami events (Blake et al. 2018; Cabinet Office, 2010; Cabinet Office in Japan; Lindell et al. 2015; Makinoshima et al. 2016; Murakami et al. 2012; Sun et al. 2017; Yoshi et al. 2008). Reasons have been presented for vehicular evacuation which include a place of warmth, portable assets and a place of shelter, unaware of congestion potential, long distance to reach a safe zone, evacuate with family, and receive information via car radio (Cabinet Office in Japan; Lindell et al. 2015; Togawa et al. 2018). In contrast to this, pedestrian evacuation was dominant during the 2018 Sulawesi tsunami, this was argues as a result of low car ownership (Harnantyari et al. 2020).

Once people have completed their evacuation movements, people often take additional activities or evacuation movements (Mikinoshima et al. 2020). Once people reach their safe zone locations people congress and communicate with other evacuees. As a result evacuees realise they are less prepared and return home to retrieve personal belongings, check on family members or neighbours and collect necessities for long-term shelter. Returning to at risk areas causes an additional evacuation movement phase which poses greater tsunami risk to evacuees (Cabinet Office in Japan, 2012; Institute of Socio-Information and the University of Tokyo Communication Studies, 1994). For effective evacuations, it is essential to conduct an efficient evacuation and to remain at safe zone destinations until there is no official tsunami warning messages and the clearance has been given by officials.

2.6 Research gaps

An evacuation response is a complex and dynamic process, largely influenced by personal characteristics, recognition and interpretations of warnings, perception of risk and decision-making (Lindell & Perry, 1992). Understanding real-event evacuation behaviour and associated dynamics of past tsunami events, offers important knowledge to contribute to a better understanding on response actions warnings and the associated behaviours. Such knowledge could improve on current tsunami risk management and preparedness initiatives to improve public's awareness on tsunami risk and protective actions to take in future events. As stated in Section 2.5, an important review paper by Makinoshima et al. (2020), concluded that whilst evacuation behaviour research of past tsunami events have been investigated for various aspects such as tsunami preparedness, risk awareness, or evacuation intentions, no survey research has captured a comprehensive overview of a complete evacuation process on past tsunami events.

In addition to this research gap, recent global tsunami events have highlighted the importance of integrating social science approaches and evacuation modelling methods, by incorporating empirical data to inform future tsunami evacuation planning (Kubisch et al. 2020; UNESCO, 2020). Social science literature suggests survey questionnaires focusing on evacuation intentions and/or human behaviour observed during past tsunami events have been key input parameters for improving evacuation model techniques (Dash & Galdwin, 2007; Kubische al. 2019; Lindell & Prater, 2007; Power et al. 2019). Such parameters have been incorporated to represent variability in evacuation response and decision-making, for example, evacuation delay time and congestion barriers, to improve on and present realistic modelling results (Wood et al. 2018). However, limited understanding of a complete evacuation process (as outline above) has led to the inclusion of modelling inputs informed from observed evacuation behaviour of other natural hazards, specifically hurricanes in the United States (Baker, 1991; Lindell & Prater, 2007). Although recent advancements have been made towards including evacuation behaviour of past tsunami events into current evacuation modelling approaches such as agent-based modelling (Kubisch et al. 2020), further research is required to incorporate real-event evacuation behaviours more holistically for accurate outputs.

This research addresses this global tsunami science research gap by contributing an empirical dataset that has analysed a complete evacuation response of residents located in the Kaikōura township following the 2016 Kaikōura earthquake. Improving understanding on immediate reactions and evacuation behaviours of a large local-source tsunami could inform and/or improve on current tsunami risk management and awards initiatives for coastal areas at risk to local-source tsunami in New Zealand or globally.

Chapter 3: Tsunami evacuation behaviour and movements following the 2016 Kaikōura earthquake and tsunami

3.1 Introduction

The purpose of Chapter 3 is to address research objective one: understand evacuation behaviour and dynamics of Kaikōura residents following the 2016 Kaikōura earthquake and subsequent tsunami. First, a summarised literature review on tsunami evacuation behaviour research is presented, identifying a research knowledge gap and highlighting the importance of the present research. Second, an overview of the development of the 2016 Kaikōura earthquake tsunami evacuation survey is presented followed by a methodology for the design, distribution, collection and analysis of the aforementioned survey. Third, the survey results are classified by three key areas aspects: (1) warning and evacuation decision-making, (2) evacuation response and movements, and (3) risk awareness and its influence on evacuation response. Fourth, a discussion is presented, drawing on key themes of survey results and comparatives from international and New Zealand evacuation behaviour literature. Recommendations are provided to inform tsunami evacuation planning and support disaster resilience in New Zealand and globally.

As noted in the introductory chapter, tsunamis are known to be one of the most powerful and destructive natural hazards to impact on exposed communities (Williams, 2020). Many of New Zealand's coastal communities including Kaikōura, are vulnerable to local source tsunamis that could potentially inundate low-lying areas within a matter of minutes (MCDEM, 2016; Power 2013; Barryman et al. 2005). During a tsunami event, evacuation is considered the primary risk reduction strategy for preventing casualties, thus it is imperative to increase at risk communities awareness and preparedness towards taking protective actions during future tsunami events (MCDEM, 2016). As stated in Chapter 2, In New Zealand, the Civil Defence and Emergency Management sector educate the public who live, work, or play near the coast on the importance of using natural warnings for self-evacuation in the case of a considerable local-source event; if an earthquake is long (longer than one minute), or strong (difficult to stand up) evacuate immediately to higher ground or move further inland (MCDEM, 2018). It is important to understand the practical challenges and behaviours that could occur during an evacuation response such as warning dissemination and communication, preparedness and response capacity including evacuation movements, and disaster risk knowledge (Fraser et al. 2016). Globally, research on tsunami warnings and evacuation behaviours have demonstrated the complexity of understanding the biological, psychological, social and environmental reasoning's leading to response behaviour (Fraser et al. 2016; Lindell et al . 2015; Bird et al. 2011;

Gregg et al. 2006). To date, tsunami evacuation literature has primarily focused on a specific phase of the evacuation response process for example; tsunami preparedness, risk awareness or evacuation intentions however, an important recent review paper by Makinoshima et al. (2020) concludes no research has captured a comprehensive overview of a complete evacuation process on previous tsunami events. This research addresses this global tsunami science research gap by contributing an empirical dataset that has analysed a complete evacuation response of Kaikōura residents following the 2016 Kaikōura earthquake and subsequent tsunami. Understanding real-event evacuation behaviour and movements of a considerable local-source earthquake response can provide other at risk communities with valuable information to consider for future disaster risk management and support evacuation response planning.

3.2 2016 Kaikōura earthquake and tsunami evacuation survey methodology

This section provides an overview of the conceptual and methodological development of the 2016 Kaikōura earthquake tsunami response survey.

In 2018, tsunami disaster risk and resilience researchers from University of Canterbury, GNS Science, National Institute for Water and Atmospheric Research (NIWA), Massey University, and natural hazard risk management and emergency management practitioners actively involved in the 2016 Kaikōura earthquake response (Environment Canterbury, Canterbury CDEM, Christchurch City Council (CCC) CDEM, and Kaikōura District Council CDEM) began a collaborative study which aimed to understand the evacuation response of 14 November 2016 Kaikōura earthquake across the Canterbury region and in other case-study locations across New Zealand (Barnhill, 2020; Blake et al. 2018). This master's thesis is part of this wider collaborative project, contributing by focusing on understanding the spontaneous evacuation response of residents and accommodation providers who were living in Kaikōura at the time of the 2016 Kaikōura earthquake and tsunami (a community proximal to the tsunami source). Barnhill (2020) conducted research in parallel to this thesis by analysing evacuation behaviour of coastal suburbs in Eastern Christchurch and Banks Peninsula (communities which were medial to distal to the tsunami source).

3.2.1 Evacuation survey development

Questionnaire surveys are a well-established tool used across sectors including but not limited to scientists, government agencies, and non-governmental organisations for collecting information on participant characteristics, behaviours, and reasons for actions (Bird, 2009: Dillman et al. 2014). The application of surveys have been used to address gaps in research or solve a problem or answer a question, especially for post-disaster research where emergency management and researchers seek to gain an understanding of people's behaviour and reactions during an event, to improve DRR and resilience initiatives for at risk communities (Bird et al. 2011; Harnantyari et al. 2019; Mas et al. 2015). A survey was decided to be used for this research as a tool to collect as many resident responses on actions and evacuation behaviour following the 2016 Kaikōura earthquake, and align with national tsunami survey research to ensure a consistent approach.

For this study, a survey instrument was designed which directly addresses the global tsunami research gap outlined in Section 3.1 and Chapter 2, by developing a questionnaire survey to record the entire evacuation process of Kaikōura residents in Kaikōura at the time of the 2016 earthquake event. The survey asked questions on warning and response decision-making, evacuation behaviour and movements, prior risk awareness influence on evacuation response, and preparations made following the 2016 Kaikōura earthquake. The survey was developed from a previous survey instrument from Blake et al. 2018, who analysed response actions and behaviours of residents in Petone and Eastbourne following the 2016 Kaikōura earthquake, who in turn had developed their survey from the work of Johnston et al. 2003, who conducted New Zealand's first national tsunami risk awareness survey and subsequent survey research that followed (Blake et al. 2018; Couling, 2014; Dhellemmes et al. 2016; Fraser et al., 2016; Fraser et al. 2013; Johnston et al. 2003). Key additional methodological develop steps for this survey included adding questions to better record evacuation dynamics (especially designed to inform geospatial evacuation modelling, see below) and to explore the role of pre-event tsunami hazard and risk preparedness activities – which had been a major focus of disaster risk management agencies (ECan and KDC CDEM) in Kaikōura. This was done in close partnership with natural hazard risk management and emergency management practitioners from ECan and KDC CDEM.

The design of this survey aimed to record the entire evacuation process of Kaikōura residents in Kaikōura at the time of the 2016 earthquake event.

The questionnaire survey consisted of 42 questions (see Appendix A), approximately 30 of these were adapted and modified from Blake et al. (2018), suitable to Kaikōura's context. Question style ranged from multi-single choice check box, open-ended, and geospatial maps, with most questions having an additional section to provide comments. Questions used in this research survey additional to Blake et al. 2018 survey includes:

- In addition to the geospatial map supplied, there was an option of providing a detailed description of their evacuation route (Q11 – see Appendix A)
- Did you evacuate individually, or with others? If with others, please describe (Q21 – see Appendix A)
- Did you encounter any traffic congestion or were you aware of congestions problems? If yes, which roads or areas were congested? Please indicate these roads on the map (Q23 and Q24 – see Appendix A)
- Following the evacuation response to the 2016 Kaikōura earthquake, would you consider a different evacuation route – map supplied to draw alternative evacuation route (Q33 – see Appendix A)
- Prior and following to the 2016 Kaikōura earthquake, how would you describe your knowledge of tsunami and the need to evacuate? (Q37 and Q41 – see Appendix A)
- How did your prior awareness of tsunamis influence your behaviour BEFORE and IMMEDIATELY after the 14th November earthquake (Q39 and Q40 – see Appendix A)
- Which of the following preparations have you made in the case of a significant earthquake and tsunami evacuation? (Q42 see Appendix A)

Once the survey questions were developed, a hard-copy questionnaire survey was the primary means of collecting responses (Appendix A), however an online version of the questionnaire survey was developed using Qualtrics, a data analyses and management platform designed for survey research (Qualtrics 2019, University of Canterbury). In addition to the questionnaire survey, an information sheet and consent form were provided with both the hard-copy and online version of the survey. The consent form had to be completed before the participants could proceed to the survey. It was estimated that the questionnaire survey would take 15-20 minutes to complete based on the length of the survey and question types. A prepaid envelope addressed to the former Geological Sciences Department at the University of Canterbury was attached to the survey for collection.

Ethical considerations were a key part of methodological design. This research was conducted following the approval and guidelines of a Low Risk ethics application by University of Canterbury Human Ethics Committee (HEC 2018/100/LR) (See Appendix A for the complete Human Ethics application form). A central consideration was that this survey could trigger distressing emotions from the 2016 earthquake and tsunami disaster and acknowledged that the Kaikōura community was still in the recovery phase of the disaster response at the time when this survey was conducted. Therefore, it was made clear that participation was voluntary and there was no obligation to engage in the research process, and to foreground information provided in the survey for those wishing to access support from the Mental Health Education and Resources Centre. Considerations were also given around the sensitivities of conducting the survey 28 months after the event, included triggering of distressing emotions and secondary stressors such as financial hardship, dealing with insurers or other impacts (see Appendix A on ethical risks and actions to mitigate and manage these).

3.2.2 Evacuation survey distribution, collection and analysis

The primary survey distribution method was a hard-copy letter box drop. This method was used to align with other national survey research and to ensure consistency. The distribution of hard-copy surveys was conducted in March 2019, approximately 28 months after the 2016 Kaikōura earthquake. A three-member UC-based research team distributed 1055 hard copies of the survey to every residential and accommodation provider letterbox within the Kaikōura township and South Bay (Figure 3.2-1). This area was chosen due to the exposure to tsunami, with the majority of residential properties located in a tsunami evacuation zone. A link to the online version of the questionnaire survey was posted to an online community Facebook group 'Kaikōura Notice Board 'website on the 12th February 2019 (Facebook, 2019) to reach residents outside of the study are zone who were willing to participate in this research or those who did not have a letter box. An article on the evacuation survey research, linking the online survey tool was advertised in the Kaikōura Star (local newspaper), the week following the field survey distribution (Kaikōura Star, 2019). One hundred hard-copy surveys were also made available at the Kaikōura District Council Library for any other residents to complete.

When hard copies of the survey were received, results were manually transcribed in a Microsoft Excel spreadsheet. Survey results received through the online survey tool were extracted from Qualtrics (Qualtrics, 2019) and combined in to the same Excel workbook. The Microsoft Excel Spreadsheet fields were added to incorporate both hardcopy and online survey responses. Once all surveys were received by the deadline (April 1st 2019) and transcribed or uploaded in the Microsoft Excel spreadsheet, data and correlation analysis was performed in Microsoft Excel.

Figure 3.2-1: Kaikōura study area and outline (red) of evacuation survey letterbox drop.

3.3 Survey results

The following section presents the results of the 2016 Kaikōura earthquake and tsunami evacuation survey. Results are represented by descriptive statistics and geospatial information on the behaviours and associated evacuation dynamics of Kaikōura residents during and immediately following the 2016 Kaikōura earthquake. To understand the entire response process, results are separated into three key focus areas;

1. Warning and evacuation decision-making
2. Evacuation movements and associated dynamics

3. Risk awareness influence on evacuation response

Appendix A 1.3 presents tabulated results of all 42 questions asked in the survey.

3.3.1 Survey response rate

One thousand and fifty-five surveys were distributed in letterboxes around the Kaikōura Township, and 100 copies were left at the Kaikōura District Council Library. A total of 131 responses were received, resulting in a 12.4% survey response rate (Table 3.3-1). This response rate is similar with previous tsunami survey research in New Zealand (Barnhill, 2020; Blake et al. 2018; Dhellemmes, et al. 2016; Johnston et al. 2003). The majority of questionnaire surveys were returned by mail (n=119) and 12 were completed using the online Qualtrics survey tool. Figure 3.3-1 shows the extent of survey response locations with returns received from inland of Kaikōura Township to Mangamaunu and Oaro.

Table 3.3-1: Statistics on survey distribution, returns and survey response rate.

Number of surveys distributed	Number of surveys returned	Survey response rate
1055 hard-copies	131 including hard-copies (119) and electronic version (n=12)	12.4% return rate

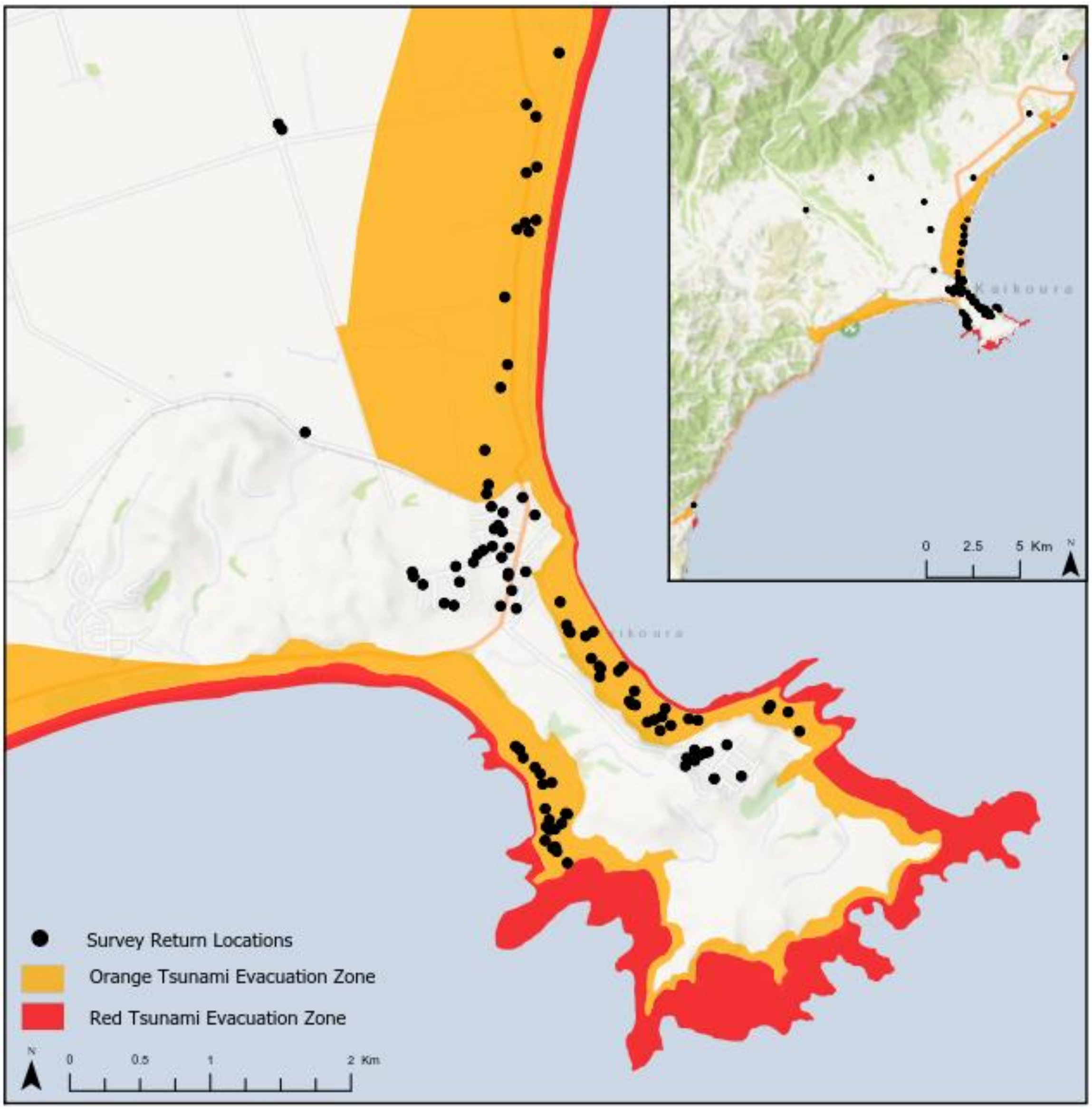

Figure 3.3-1: Map displaying approximate residence locations of survey participants overlaid with official CDEM tsunami evacuation zones. See Chapter 1 for explanation on Canterbury's tsunami evacuation zones

3.3.2 Kaikōura survey return demographics

The majority of survey respondents were female (62%), of those, 61% are aged 15-64 years (Table 3.3-2). Although a smaller proportion of respondents were male (35%), the majority (70%) are aged 65 years and older. Of the total respondents, 75% reported they are family without children (Table 3.3-2). When the survey respondent's demographic information is compared to the New Zealand Statistics demographic information of Kaikōura's (township) population in Table 3.3.-2, we see a considerable survey bias of survey returns towards females and older people compared to the inhabitants in Kaikōura. Interestingly survey returns show a strong bias towards family without children (75%) relative to the inhabitant proportion of 24.7%.

Table 3.3-2: Demographic composition of the Kaikōura Township and survey respondents

Demographic information on Kaikōura Township and survey respondents			
		Census 2018	**Survey respondents**
Population			
Population Count (n)	Total count (n)	2,223	131 (n)
	Median age (n)	47.7	
	Males (n)	49.8%	35 %
	Females (n)	50.2%	62 %
Age and sex (%)			
Under 15 years	Male	14.9%	-
	Female	13.7%	-
15-64 years	Male	59.6%	30%
	Female	59.9%	61%
65 years and over	Male	25.5%	70%
	Female	26.3%	39%
Housing and living situation			
Occupied dwelling	-	915	-
Unoccupied dwelling	-	459	-
Family without children		24.7%	75%
Family with Children		72.2%	20%

3.3.3 2016 Kaikōura earthquake warning and evacuation decision-making

During an evacuation response, natural cues are encouraged as the first point of warning (MCDEM, 2018). The first section of the questionnaire survey seeks to understand how natural warnings influence evacuation response of the 2016 Kaikōura earthquake. This sub-section provides the survey results to better understand:

- Perceived shaking intensity and duration of the 2016 Kaikōura earthquake,
- 2016 Kaikōura earthquake immediate response,
- pre-evacuation actions,
- evacuation response, and
- reasons for evacuating.

3.3.3.1 Perceived shaking intensity and duration of the 2016 Kaikōura earthquake

The 2016 Mw 7.8 earthquake woke the majority of the survey respondents (82%, n=103). 16% (n=20) stated they were already awake at the time of the earthquake, and only 2% (n=3) reported to had slept through the earthquake. Respondents were asked to provide their perception on the 2016 Kaikōura earthquake shaking intensity and duration. Of the total 131 participants who provided a response on perceived shaking intensity, 56% (n=73) described the earthquake felt 'Violent', 37% (n=49) perceived the intensity to be 'strong or powerful', and 5% (n=6) reported the earthquake felt 'moderate'. Figure 3.3-2 provides a breakdown of the total response to perceived shaking intensity question. The respondent that selected 'not felt' was in Christchurch at the time of the 2016 Kaikōura earthquake.

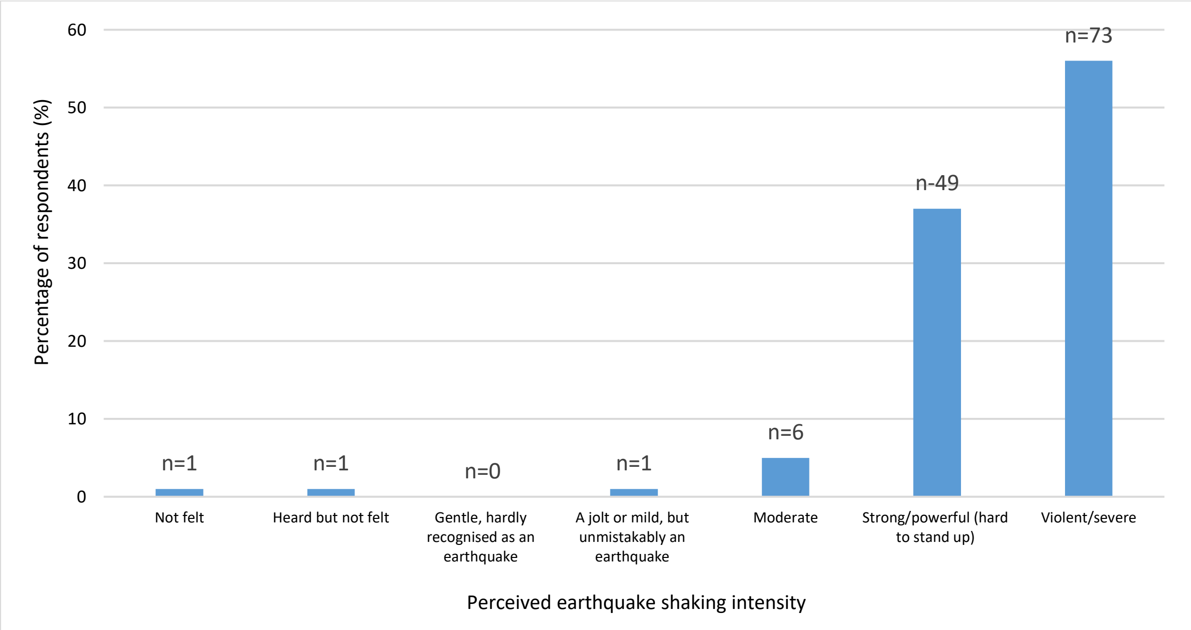

Figure 3.3-2: Bar graph representing respondent's perceived shaking intensity of the 2016 Kaikōura earthquake.

Figure 3.3-3 provides a comparative analysis of respondent's perceived shaking intensity against the dissolved shake map of the 2016 Kaikōura earthquake developed by USGS (USGS, 2016). According to the dissolved shake map, the Kaikōura Township experienced Modified Mercalli Intensity Scale (MMI) VII 'very strong' shaking intensity. Respondents who provided their location and perceived shaking intensity are shown on Figure 3.3-3.

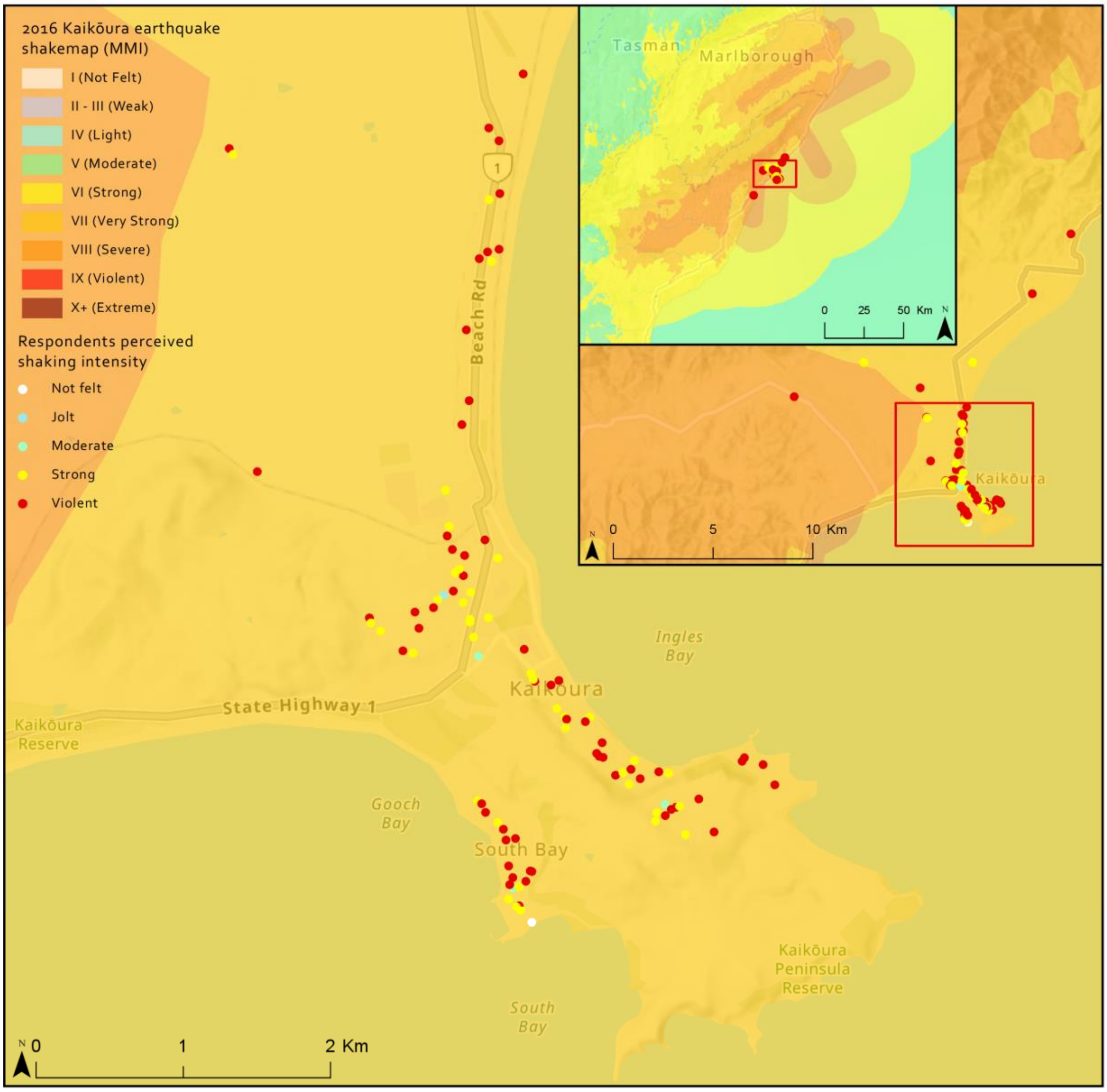

Figure 3.3-3: Map displaying USGS dissolved Shakemap of the 2016 Kaikōura earthquake overlaid with respondent's perceived shaking intensity. Respondents perceived shaking intensity is colour coded in respect to the USGS Shakemap intensity colours.

In addition to earthquake shaking intensity, respondents were asked to provide their best estimate on earthquake shaking duration. The survey results revealed that 27% (n=31) estimated shaking duration of approximately 120 seconds, 22% (n=25) of respondents reported shaking duration of 60-120 seconds, 16% (n=19) stated that they 'don't know' or could not remember, 12% (n=14) estimated shaking duration greater than 120 seconds, 10% selected shaking duration felt less than 60 seconds and 1% (n=1) selected not felt (Appendix B). The box and whisker graph (Figure 3.3-4) shows the range of estimated shaking duration. The earthquake shaking duration range was between 5 seconds to 300 seconds, with a mean of 102 seconds and median equalling 100 seconds. Respondents who stated earthquake shaking duration of 300 seconds and 240 seconds were considered outliers.

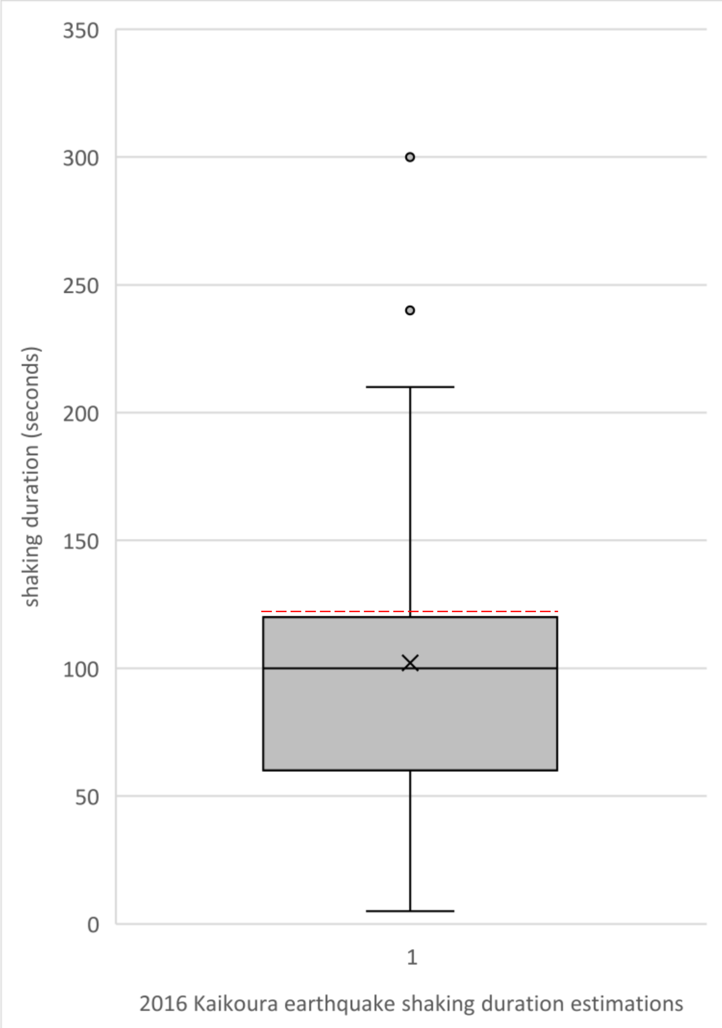

Figure 3.3-4: Box and whisker graph displaying the range of perceived shaking duration estimations. The red dashed line represents the 121 second instrumental earthquake shaking of the 2016 Kaikōura earthquake. The 'x' represents the median value of perceived earthquake shaking.

3.3.3.2 2016 Kaikōura earthquake immediate response

The next stage of the evacuation process is gaining an understanding of the immediate response following the initial shaking of the earthquake. Respondents were asked to provide a detailed explanation of their behaviour and movements following the earthquake shaking. Key conclusions drawn from respondent's answers include:

- Many respondents jumped out of bed (with family) and evacuated to outside of their property or on the road.
- Many residents said they evacuated immediately and drove to higher ground
- A number of respondents said they grabbed essential items e.g. torch, evacuation kit, warm clothes, handbags and keys.
- A few respondents said they turned off the hot water cylinder before evacuating, and others checked for damage to property.

- A number of respondents experienced difficulty getting their vehicles out of the garage due to no power or damage to garage.

Figure 3.3-5 represents the most frequent words used in respondent's statements on immediate response and gives insight as to what were the key response actions taken immediately after the 2016 Kaikōura earthquake by Kaikōura residents.

Figure 3.3-5: Wordle representing the most frequent words (words that are bold and larger) of respondents explanations of their immediate actions following the 2016 Kaikōura earthquake.

3.3.3.3 Pre-evacuation actions

Participants were asked what actions were taken prior to evacuating. Respondents were asked to tick all relevant actions they took before deciding to evacuate. Of the total respondents, 33% (n=36) reported they evacuated immediately, 32% (n=33) gathered with family or household members, and 20% (n=21) reported gathering life essentials. For a detailed breakdown of the question results, see Figure 3.3-6 below.

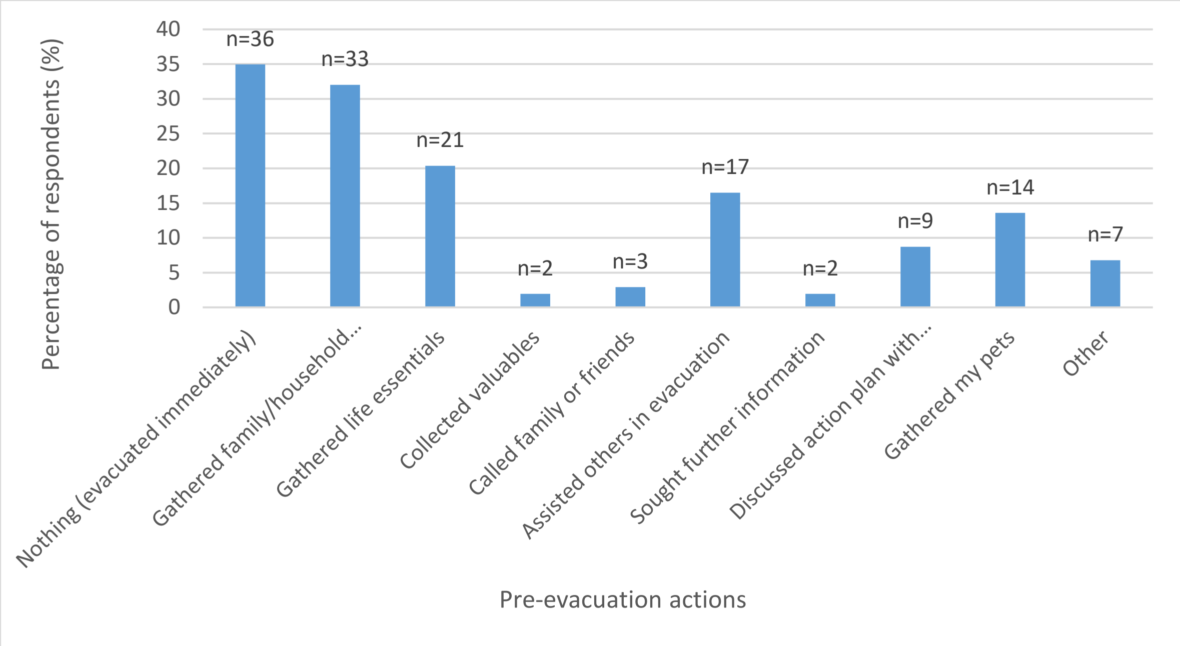

Figure 3.3-6: Bar graph displaying pre-evacuation actions following the 2016 Kaikōura earthquake.

3.3.3.4 Evacuation response

Following the survey questions on perceived shaking intensity and duration, the survey asked if participants evacuated following the 2016 earthquake shaking. Of the total that responded to this question (n=127), 69% (n=88) of respondents reported they evacuated and 31% (n=39) did not evacuate (see Figure 3.3-7). Of the respondents who reported that they did not evacuate (31%), the reasons were due to:

- No need as they were already inland or on high ground (n=27)
- Felt safe in their home (n=8)
- Could not evacuate (either needed assistance or had damage to the property) (n=8)

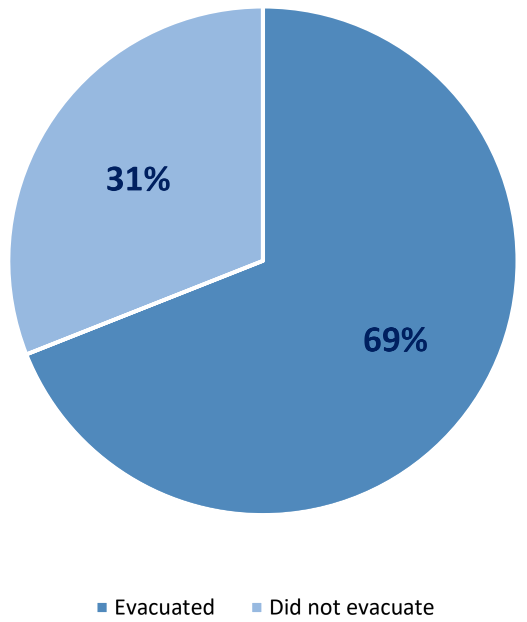

Figure 3.3-7: Pie chart representing the proportion of respondents who evacuated and did not evacuate following the 2016 Kaikōura earthquake.

Of those who provided their origin address and their response decision, 95% (n=61) who lived in a tsunami evacuation zone at the time of the 2016 Kaikōura earthquake evacuated during the 2016 Kaikōura earthquake. Five percent of respondents resided in a tsunami evacuation zone and should of evacuated following the 2016 earthquake. In addition, those who resided in an evacuation zone and evacuated, 45% (n=19) of respondents who resided out of a tsunami evacuation zone stated they evacuated (Table 3.3-3).

Table 3.3-3: Table displaying evacuation rates of respondents who lived in and out of a tsunami evacuation zone at the time of the 2016 Kaikōura earthquake.

Evacuation Response	**Respondents who lived in a tsunami evacuation zone during the 2016 Kaikōura earthquake**	**Respondents who did not live in tsunami evacuation zone during the 2016 Kaikōura earthquake**	**Total**
Evacuated	95% (n=61)	45% (n=19)	n=80
Did not evacuate	5% (n=3)	55% (n=23)	n=26
Total	100% (n=64)	100% (n=42)	n= 106

3.3.3.5 Reasons for evacuating

Participants were asked what factors influenced their reasoning for evacuating. Of the total who responded to this question (n=86), 79% (n=68) reported they evacuated because of a possible tsunami. The 21% (n=18) that reported that they evacuated but not because of possible tsunami, stated that they evacuated because they did not feel safe in their home (n=11), they wanted to be with friends and/or family (n=4), and a couple of respondents stated they were instructed to evacuate by NZ Police or Fire and Emergency New Zealand (n=2).

Survey respondents were asked their main reason for evacuating. Approximately 71% (n=63) selected the earthquake (strong ground shaking) itself was the main reason for evacuation, 10% (n=9) evacuated because of other family/household members and 7% (n=6) selected 'other community members' as their main reason for evacuating (see Figure 3.3-8). Respondents who stated 'other' included reasons such as the possibility of a tsunami due to the close proximity of living close to the sea and to look for family and friends. General comments in relation to the main reason for evacuating included;

- A natural reaction to evacuate to high ground after such a violent earthquake and being so close to the sea
- The tide receding
- Evacuated for personal safety reasons.

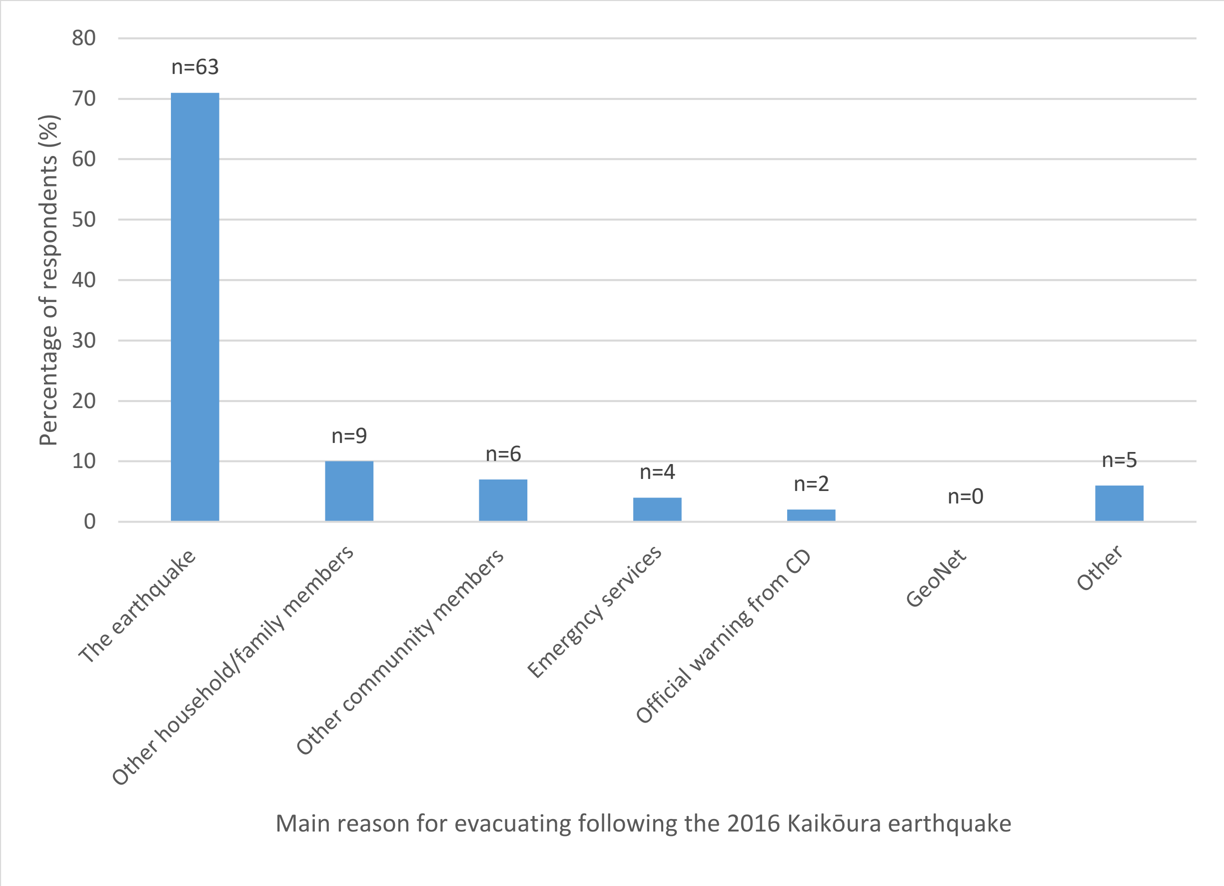

Figure 3.3-8: Bar graph displaying survey respondent's main reasoning for evacuating following the 2016 Kaikōura earthquake.

Participants were asked what warned them of a possible tsunami. Of the total who responded to this question (n=109), 75% (n=82) reported the earthquake itself as a natural warning, 15% (n=16) reported other household or family members warned them of a possible tsunami, 13% (n=14) selected other community members evacuating was a sign of a possible tsunami, and 12% (n=13) of respondents reported they received an official warning from Civil Defence. For a detailed breakdown of the total response to this question, see Figure 3.3-9. Respondents who selected 'other' stated additional reasons that warned them of a possible tsunami which included:

- Seeing other people evacuate in their cars (n=4)
- Listening to the radio (n=4)
- Knowledge of the 'Long OR Strong, get gone' public education campaign (n=5)
- Experience/knowledge of prior earthquake e.g. Canterbury Earthquake Sequence, 2011 Japan Earthquake and Tsunami and the 2004 Indonesian Tsunami (n=5)
- Observations of the ocean receding further out than usual (n=3).

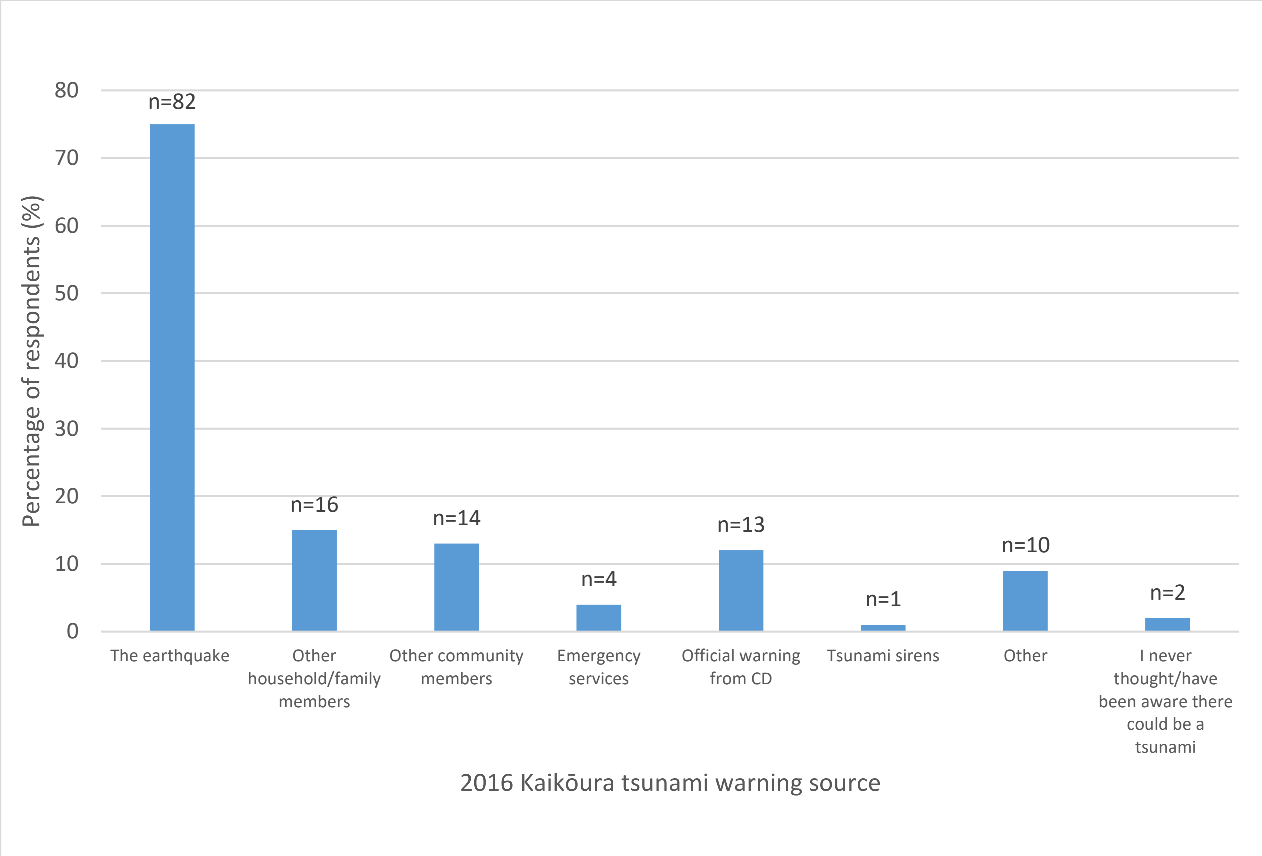

Figure 3.3-9: Bar graph displaying tsunami warning sources during the 2016 Kaikōura earthquake.

3.3.4 2016 Kaikōura evacuation behaviour and movements

It is important for emergency managers, communities and other stakeholders to have an understanding of the origin – evacuation route – safe zone destination process participants took during the 2016 event. The results presented below provide valuable information to assist and inform emergency management with future evacuation response planning. This sub-section provides the results of the survey to better understand:

- 2016 evacuation response: origin-route-destination,
- traffic congestion and speed estimates,
- evacuation response time, and
- additional evacuation dynamics.

3.3.4.1 2016 evacuation response: origin-route-destination

To understand evacuee origin – route – destination response to the 2016 Kaikōura earthquake, participants were asked to draw their evacuation route on a map provided in the questionnaire booklet or to provide a detailed description of their evacuation route. Figure 3.3-10 and Figure 3.3-11 represents a geospatial map of the 60 evacuation responses to the question. The purpose of this map is to identify key safe zone locations and evacuation routes taken during the night of the earthquake, and to identify congestion and any common commuting patterns following the 2016 Kaikōura earthquake. Geographic information systems (GIS) was used to develop a heat map, representing the density of evacuees along a particular route (see Figure 3.3-10 and Figure 3.3-11). Dark red represents a greater number of evacuees along a particular route. The results reveal that the majority of evacuees evacuated to higher ground (on top of Kaikōura Peninsula or further inland) and a few respondents evacuated further inland. Due to the restricted road network to reach higher ground or further inland, many of the respondents evacuated along Torquay Street and Killarney Street, shown by the darker red colour (Figure 3.3-10). Beach Road and South Bay Parade – SH1 South also experienced high traffic volumes. Popular evacuation safe zone locations were the Kaikōura cemetery on Scarborough Street (top of Kaikōura Peninsula), Seaview subdivision as this was the highest elevation point, Churchill Park, and near the water towers, west of Kaikōura Peninsula (see Figure 3.3-10 and Figure 3.3-11). A few respondents stated that they tried evacuating further inland along Mill Road, however had to redirect their evacuation route to higher ground due to bridge failure and road damage. Subsidence was reported as a common obstacle during a number of evacuee's evacuation response routes, particularly respondents who had to evacuate along SH1 from South Bay Parade.

Figure 3.3-10: Geospatial heat map representing respondent's evacuation routes and common safe zone locations during the 2016 Kaikōura earthquake (Township scale). Arrows indicate the directions of where respondents evacuated to along the road network.

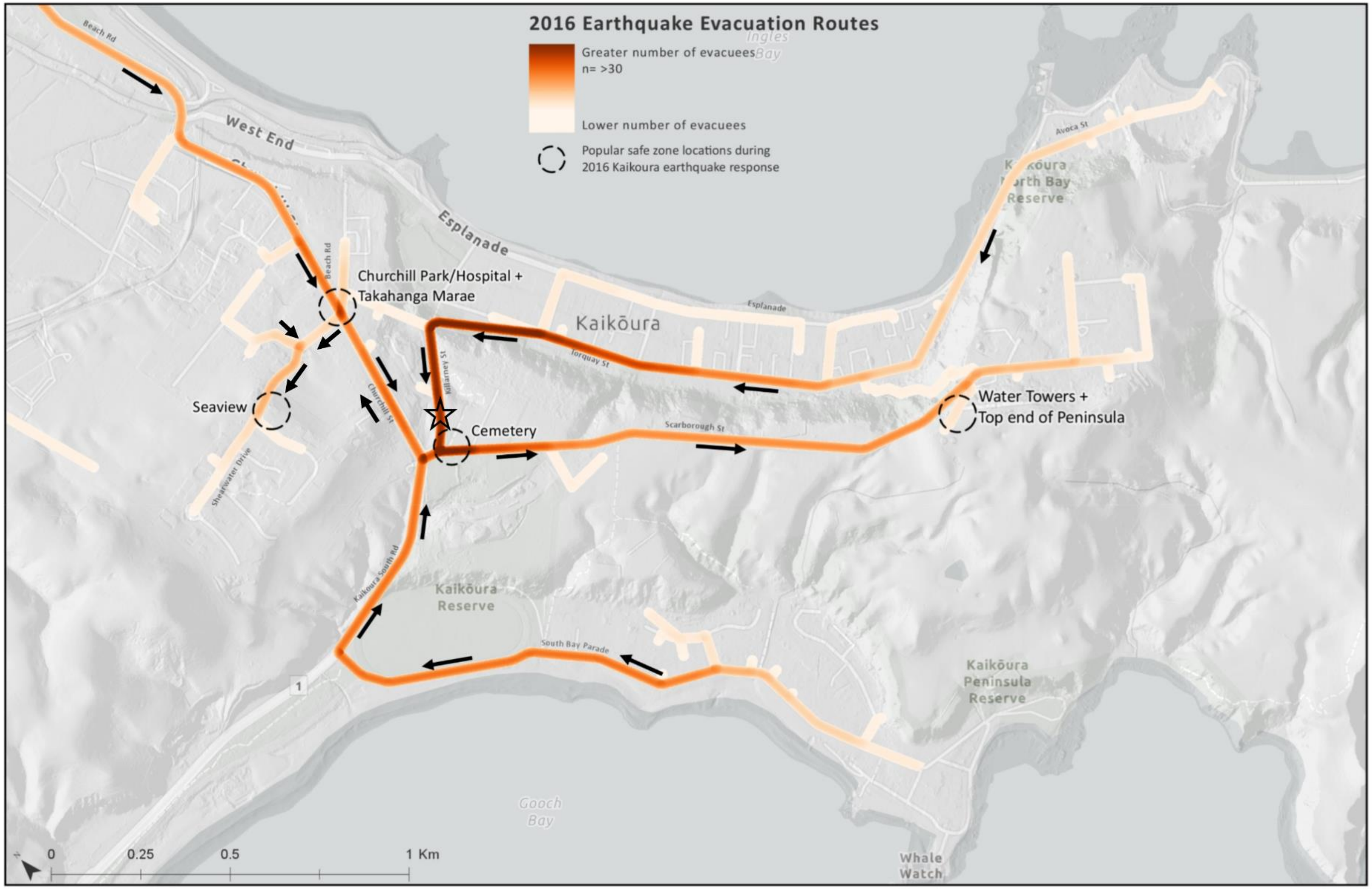

Figure 3.3-11: Geospatial heat map representing respondent's evacuation routes and common safe zone locations along Kaikōura Peninsula during the 2016 Kaikōura earthquake. Arrows indicate directions of where respondents evacuated along the road network. The star represents where a lamp post fell cross the road during the 2016 Kaikōura earthquake.

3.3.4.2 Traffic congestion and speed estimates

In addition to evacuee density along the road network as shown on Figure 3.3-9 and Figure 3.3-10 evacuee density results correspond to the observed traffic congestion during the 2016 Kaikōura response. Forty percent (n=35) of respondents, reported that they observed surges of traffic particularly along Killarney Street, also known as Post Office Cutting (see Figure 3.3-11), where numerous respondents stated a lamp post fell onto the road due to strong ground shaking. According to the respondents, a number of people were driving over the lamp post to get to higher ground. Another area the experienced traffic congestion was along Churchill Street. Many residents stopped near Churchill Park not allowing for other to pass to get to higher ground (see Figure 3.3-10 and Figure 3.3-11). Many respondents stated they observed high volumes of traffic at the Seaview subdivision (see Figure 3.3-11).

Respondents were asked to provide their best estimates of when traffic surges were observed. The time at which traffic surges were observed were soon after the earthquake shaking had stopped up until 04:00 a.m. the morning of the earthquake. Participants were also asked to provide their best estimate of how slow traffic was moving in these congested areas. The box and whisker graph displays the range of traffic speed estimates of vehicles during the 2016 Kaikōura response (Figure 3.3-12). Thirty-six respondents provided an answer for this question which resulted in vehicle speeds ranged of 0km/hr to 60km/hr with the mean traffic speed estimate of 18km/hr and median of 15km/hr.

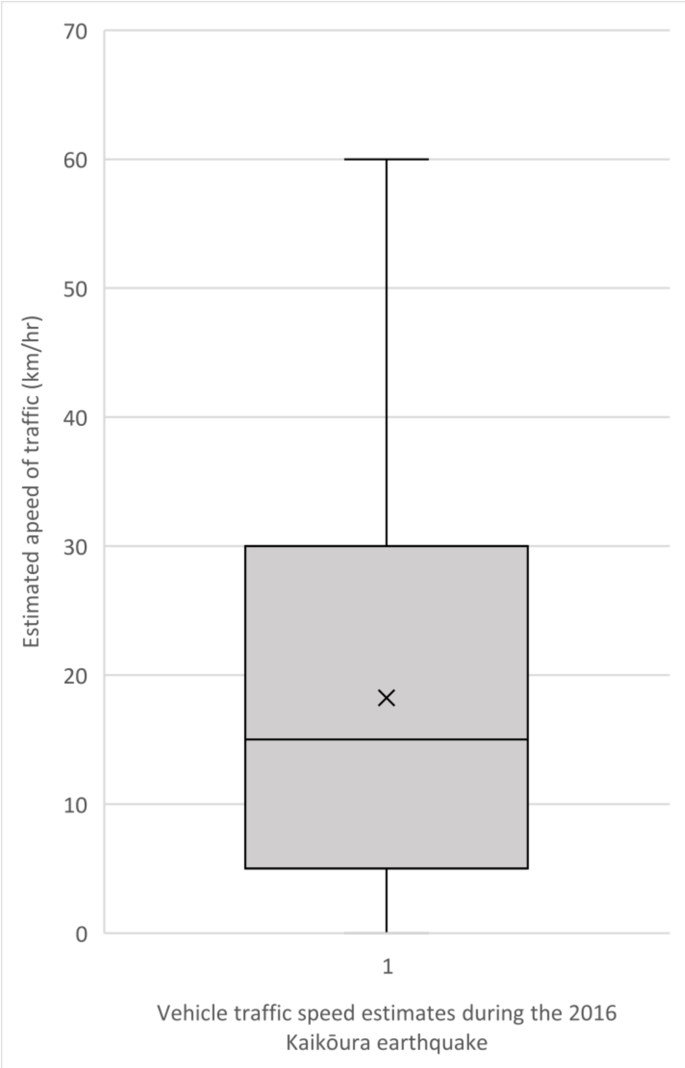

Figure 3.3-12: Box and whisker graph displaying the range and mean (X) traffic speed estimates of vehicles during the 2016 Kaikōura earthquake.

3.3.4.3 Evacuation response time

Figure 3.3-13 displays the proportion of evacuees versus the time at which they decided to evacuate. Approximately 13% of respondents evacuated immediately after the earthquake shaking stopped. More than 55% of respondents had evacuated before the arrival of the first tsunami wave reached Kaikōura's coastline (within 10 minutes) and over 90% of respondents had evacuated by the time of which the tsunami highest point was measured on the Kaikōura sea level gauge 40 minutes after the earthquake (Borrero & Lane et al. 2017). A few respondents commented that they evacuated out of Kaikōura a couple of days after the earthquake as part of the official evacuation response.

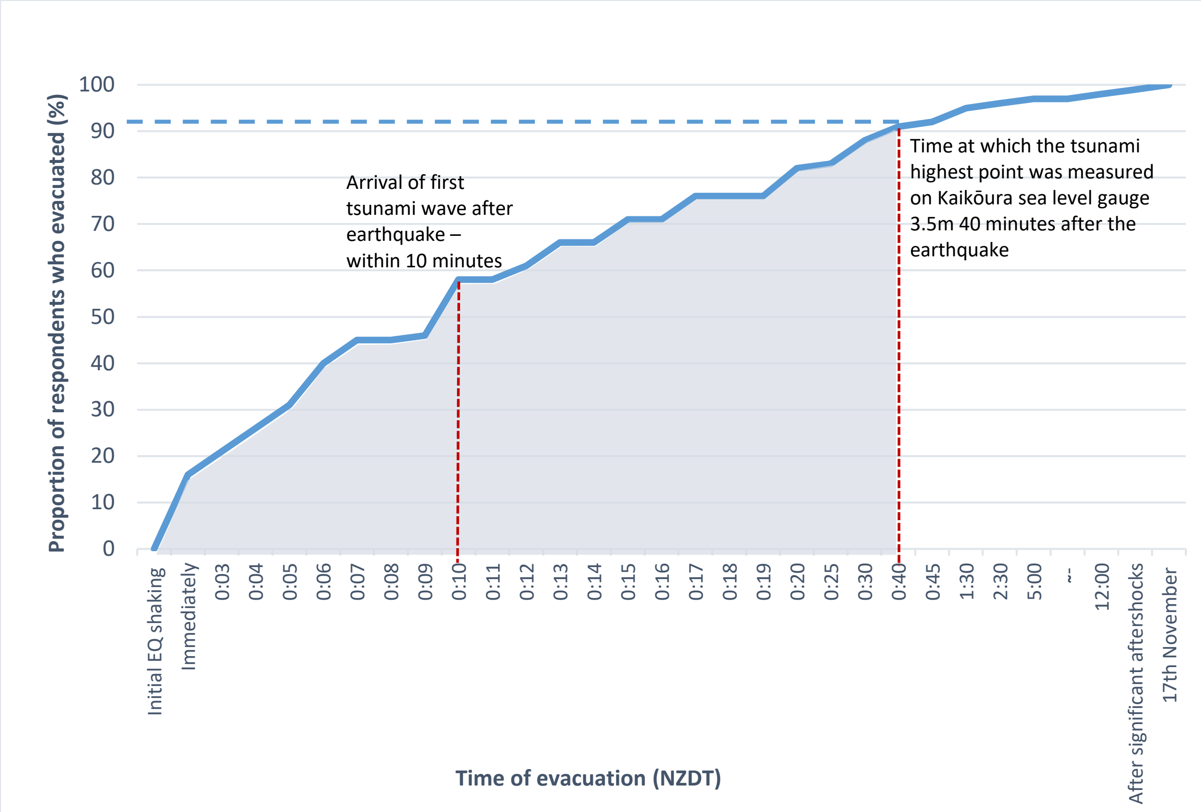

Figure 3.3-13: Correlation graph on the proportion of respondents who evacuated vs. the time at which they evacuated.

Participants were asked how long it took to reach their safe zone location once they started evacuating. The mean time it took for respondents to reach their safe zone locations was 6.6 minutes, and a median of 5 minutes. The fastest evacuation time was one minute and the longest time a respondent took to evacuate was 25 minutes (who reported evacuated on foot). Figure 3.3-14 examines the correlation between times taken to evacuate against the distance needing to reach safety. The R^2 value of 0.12 indicates that there is a strong negative correlation for these two factors.

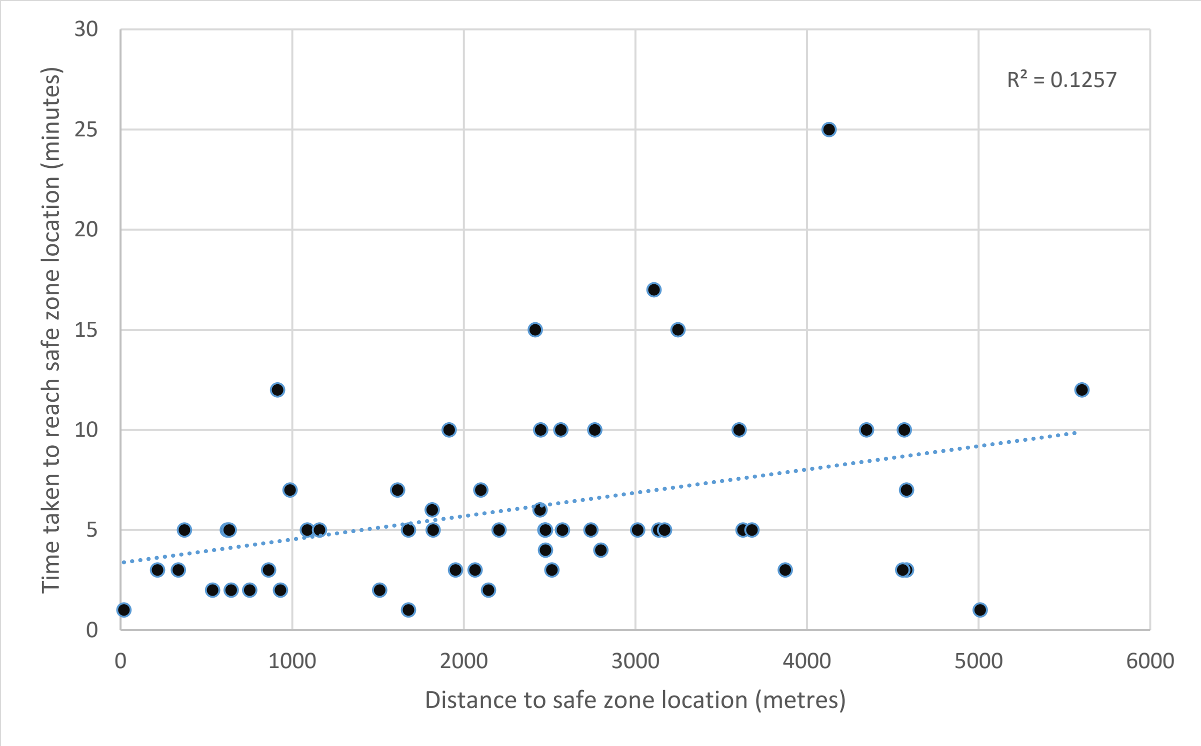

Figure 3.3-14: Correlation graph of survey respondent's time taken to evacuate to safety vs. the distance to reach safety.

3.3.4.4 Additional evacuation dynamics

Participants were asked if they evacuated more than once, of the total respondents 83% (n=91) of respondents did not evacuate more than once and the remainder of the respondents 17% (n=19) reported they evacuated at least once. Respondents reasoning's for evacuating more than once included:

- The need to check on friends and family (n=3)
- Evacuated multiple times due to large aftershocks (immediately after the earthquake and days following) (n=5)
- Going back to their property to retrieve personal belongings (n=2)
- Instructed to do so following the official warning (n=2)

Eighty nine percent (n=81) of participants were not in need of assistance during their 2016 evacuation response. Correspondingly, 11% (n=10) of respondents reported that they were in need of assistance to evacuate. All respondents that were in need of assistance, reported they received the assistance needed to evacuate. Respondents reported they needed assistance because of 'not having transport' (n=3) or were immobile or injured (n=2).

Respondents were asked how long they stayed at their evacuation point. Duration times ranged from 30 minutes to 48 hours. The most reported duration length was 6 hours (18%). Respondents were asked for their reasoning's for deciding to return from their evacuation point. Of the total respondents who answered this question (n=87), 52% (n=45) of respondents reported they returned home when it felt safe to do so, 24% (n=21) reported they went home after discussing with others, and 20% of respondents went home after a reasonable time. Figure 3.3-15 provides a breakdown of the detailed results. One commonly reported reasoning's for deciding to return from their evacuation point include to assess property damage during daylight.

Figure 3.3-15: Bar graph of survey respondents reasoning's for returning from safe zone evacuation points.

3.3.5 Risk awareness and preparedness influence on evacuation behaviour

The results presented in this section provides and insight on respondent's level of tsunami risk awareness prior and after the 2016 Kaikōura earthquake and preparedness initiatives made to increase their resilience to future events. This was of particular interest to DRM agencies, ECAN and KDC CDEM, as it had been a major focus of preparedness efforts in the ten years prior to the Kaikōura earthquake (see Chapter 1).

Prior to the 2016 event, 44% (n=55) of respondents stated they had a 'good' understanding of tsunami risk and the need to evacuate in a long or strong earthquake, 25% (n=31) reported they had a very good level of knowledge, 21% (n=26) believe they had a fair level, and the reminding 10% reported they had poor, very poor or non-existent knowledge of tsunami risk prior to the 2016 Kaikōura earthquake (see Figure 3.3-16). Comparing respondents perceived level of tsunami hazard knowledge following the 2016 Kaikōura earthquake show a considerable increase. The percentage of respondents who reported themselves having a 'good' level of tsunami risk knowledge stayed around the same (46%, n=57). Notably there was a 25% increase of responds who classified themselves having a very good knowledge of tsunami hazard and the need to evacuate after the 2016 earthquake. Figure 3.3-16 provides a breakdown of the survey results comparing tsunami knowledge prior and after the 2016 Kaikōura earthquake.

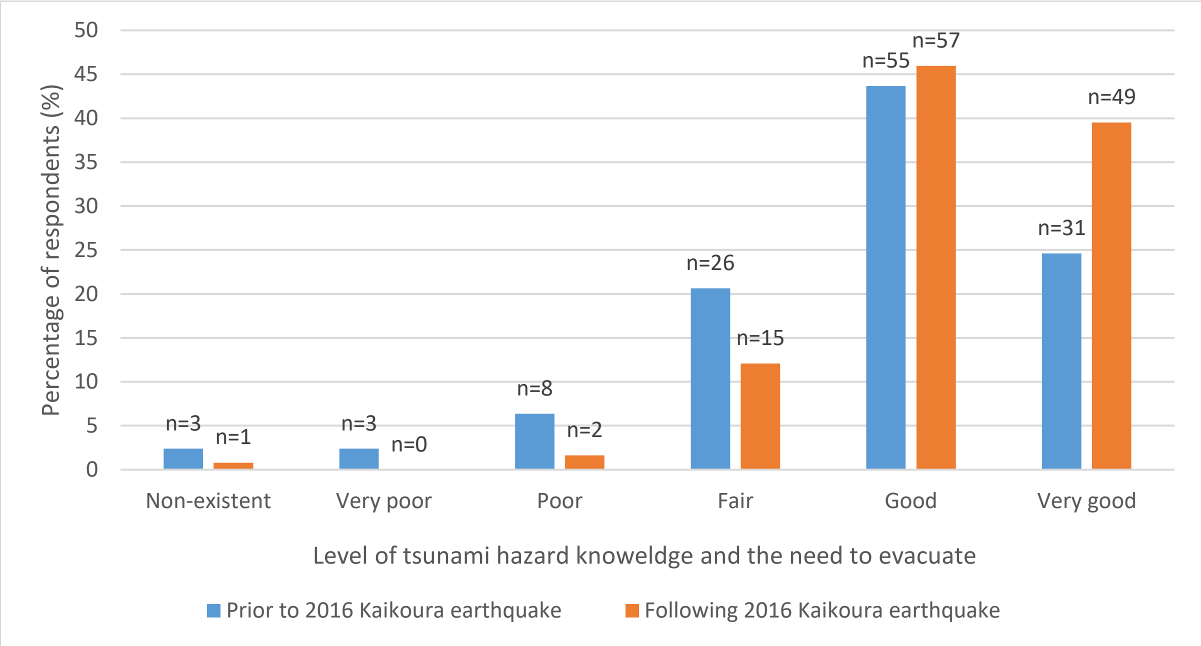

Figure 3.3-16: Bar graph of respondents level of tsunami knowledge and the need to evacuate prior to and following the 2016 Kaikōura earthquake.

Given the high level of tsunami hazard and evacuation education efforts prior to the 2016 Kaikōura earthquake, participants were asked what sources of information informed them about tsunami hazard and the need to evacuate. The four most commonly reported sources were media coverage on previous events (56%, n=69), Civil Defence information (50%, n=62), documentaries (44%, n=54), and discussions with friends and family (41%, n=51). Figure 3.3-17 provides a detailed breakdown of the total response to this question.

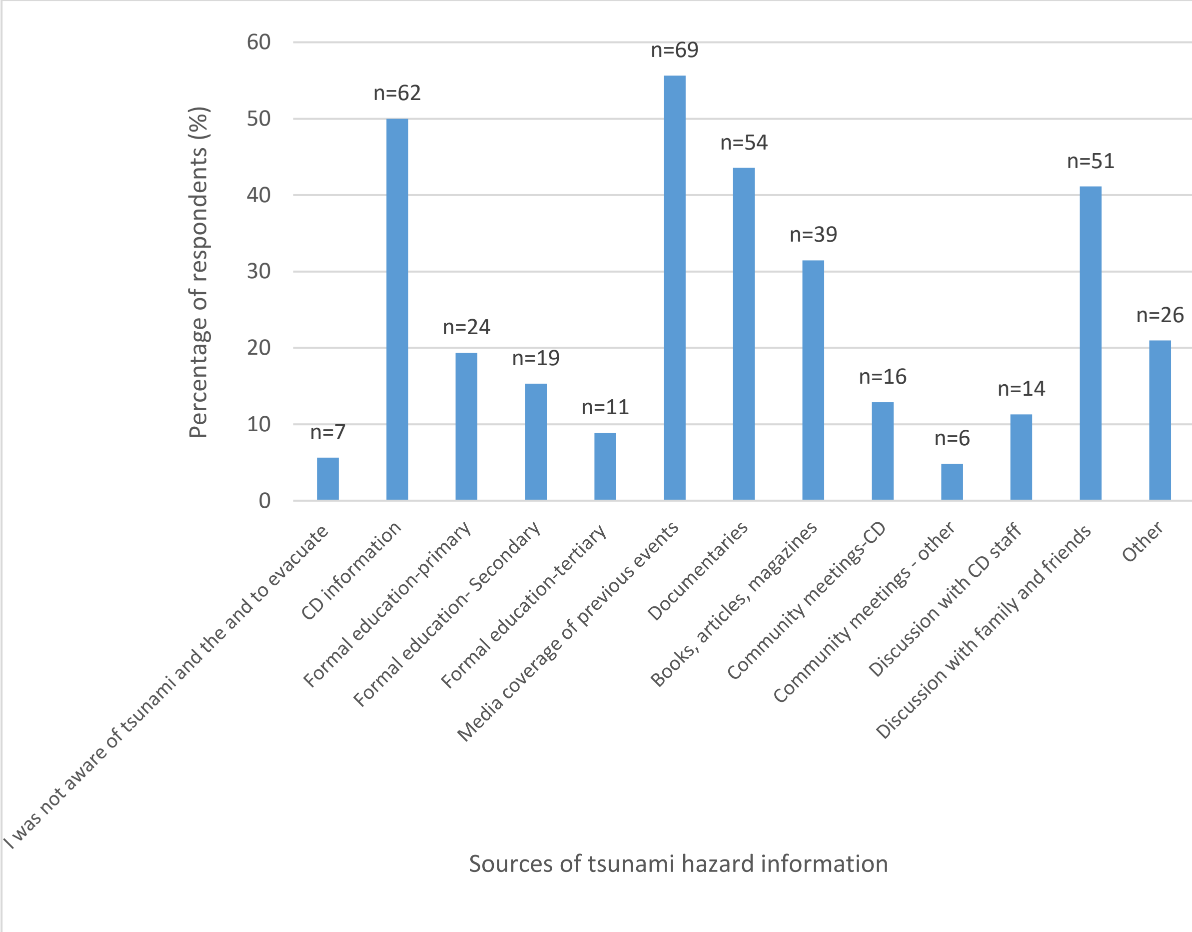

Figure 3.3-17: Sources of information on tsunami hazard and evacuation prior to the 2016 Kaikōura earthquake.

Respondents were asked what preparedness actions they took before and after the 2016 Kaikōura earthquake. Figure 3.3-18 compares common actions taken before and after the 2016 event. Notably, a significant increase has occurred across all disaster preparedness actions. Over half of respondents stated they have discussed or prepared an evacuation plan with their family or household members and have prepared an emergency kit. Over 40% have prepared a go-bag containing essential items. Additional preparedness initiatives respondents have made since the 2016 Kaikōura earthquake include making themselves aware of Kaikōura tsunami evacuation zone information (17%, n=21), identified evacuation routes and safe zone destinations (37%, n=46), and 7% (n=9) of respondents have ensured easy access to online information updates in the case of a future event.

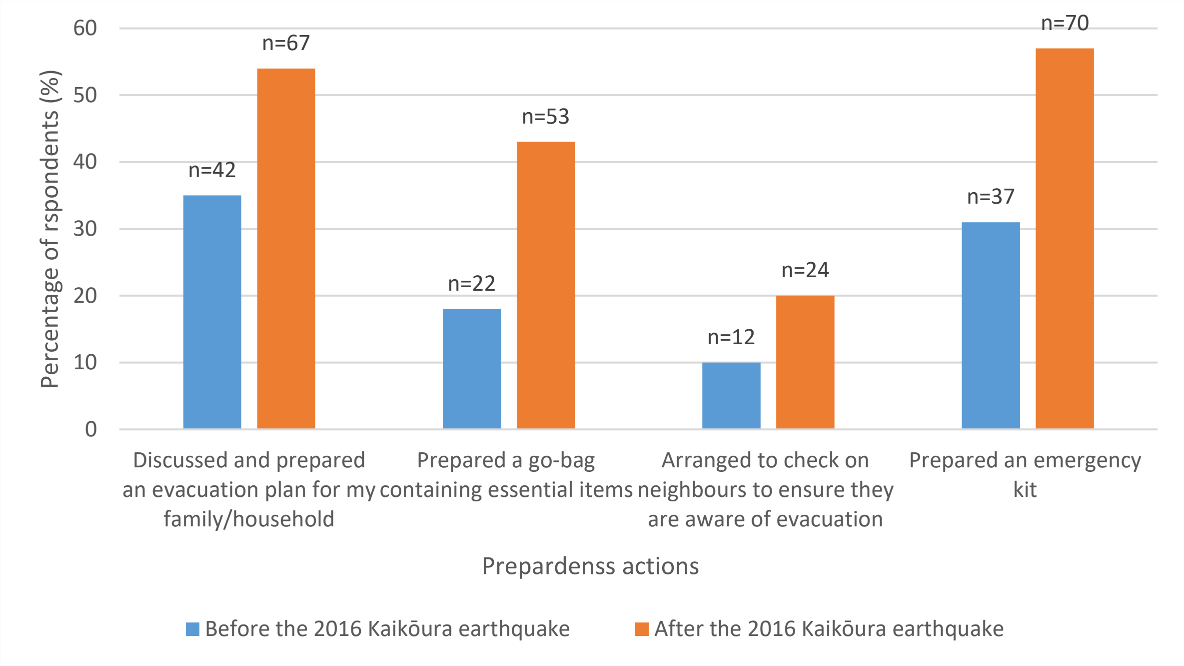

Figure 3.3-18: Earthquake and tsunami preparedness actions taken before and after the 2016 Kaikōura earthquake.

3.4 Discussion

This section presents a discussion on the main findings and themes from the results of the 2016 Kaikōura evacuation survey. Key themes are discussed in relation to the complete evacuation processes framework developed by Makinoshima et al. (2020) presented in Chapter 2, section 2.4, with the addition of tsunami risk awareness influence on evacuation response. This section is presented for four key evacuation aspects.

i. Tsunami risk awareness
ii. Response phase
iii. Evacuation movement phase
iv. Additional phase

3.4.1 Tsunami risk awareness

As mentioned in Chapter 2, national and local Civil Defence Emergency Management in New Zealand has invested heavily in public education campaigns including 'Gets Ready' and 'Long OR Strong, Get Gone', to increase New Zealand's public awareness on earthquake and tsunami hazard risk and appropriate protection actions in the case of a large earthquake and tsunami event (MCDEM, 2018). These education campaigns reiterates the importance of using natural warnings (earthquake) to self-evacuate if an earthquake is long or strong (Fraser et al. 2016; MCDEM, 2016). The Kaikōura community has experienced over ten years of Civil Defence Emergency Management engagement on increasing awareness on local earthquake and tsunami risk (H Jack, Natural Hazard Analyst, Environment Canterbury, pers. Comm). Tsunami risk awareness initiatives include community engagement meetings and workshops (Kaikōura District Council, 2018), implementation of public education campaigns 'What's the Plan Stan' and 'Long Or Strong, Get Gone' through media outlets and resources (brochures and pamphlets), evacuation drills and exercises (ShakeOut), evacuation zone maps, and the recent development of 'Kaikōura Gets Ready' initiative, which provides Kaikōura District Council with community details to send real-time alerts during an emergency (Kaikōura Ditrict Council, 2018). Results on tsunami risk awareness presented in this chapter indicates the effectiveness on the implementation of these tsunami risk management initiative. A key finding of this is that prior to the 2016 Kaikōura earthquake, respondents reported they had a 'good' (44%, n=55) or 'very good' (25%, n=31) level of knowledge on tsunami hazard and the need to evacuate. Fifty percent of respondents acknowledged their prior awareness was attributed to Civil Defence Emergency Management information. This is likely to have contributed to a large portion (79%) of respondents who reported they evacuated did so due to a potential tsunami during and immediately after the 2016 Kaikōura earthquake. Another key finding that indicates potential successful implementation of education and awareness on earthquake and tsunami risk in Kaikōura can be a reflection of a high proportion (71%) of respondent using the natural cue (earthquake) as the main reason to evacuate. A number of respondents reported they had knowledge on 'Long OR Strong, Get Gone'.

Prior to the 2016 Kaikōura earthquake, tsunami evacuation zones had not been developed for Kaikōura (H Jack, Natural Hazard Analyst, Environment Canterbury, pers. Comm). However, the vast majority (95%) of those living in a tsunami evacuation zone at the time of the 2016 Kaikōura earthquake (n=64) reported they evacuated. This finding indicates respondents were aware of the immediate tsunami threat posed to the Kaikōura community.

Risk cognition can vary due to experience of past disaster events (Makinoshima et al. 2020). Knowledge or experience of significant earthquake-tsunami disasters can influence how the public perceive risk and the protective actions needing to take during an event. A number of respondents stated that they were aware of past earthquake-tsunami events including the 2004 Indian Ocean tsunami and the 2011 Great East Japan tsunami as well as a number of respondents has experienced the effects of the 2010 Canterbury Earthquake Sequence. Having this knowledge of past events may have prompted immediate response actions during this event. Further research should explore this correlation including what actions they took immediately after the earthquake (e.g actions prior to evacuating and perceived earthquake shaking intensity).

3.4.2 Response phase

During the early response phase of an evacuation process, the first warning for a local earthquake induced tsunami is strong ground shaking (natural cue). The existence of knowledge that links strong ground shaking to the possibility of an earthquake-induced tsunami is essential for the interpretation of natural warnings and influence on evacuation decision-making (Gillard et al. 2018). The majority of respondents (17%, n=63) reported the main reasoning for evacuating during the 2016 Kaikōura event was the earthquake. Although the earthquake was the main reasoning for evacuating, 75% of respondents reported the earthquake was the warning of a possible tsunami. Figure 3.3-3 provides a geospatial output of respondent's perceived shaking intensity of the 2016 Kaikōura earthquake. Many respondents perceived the shaking intensity to be strong (37%) or violent (56%). This could indicate strong or violent perceived ground shaking intensity prompted respondents to evacuate during the 2016 event. A few respondents commented that it 'is a natural reaction to evacuate to high ground after such a violent earthquake and being proximal to the sea'. Perceived shaking intensity and the need to evacuate could also be a reflection of the results presented in Table 3.3-3. Respondents who resided out of a tsunami evacuation zone (located on high ground or further inland) at the time of the 2016 Kaikōura earthquake, 45% reported they evacuated. The main reasoning's for this included; not feeling safe in their home, strong aftershocks, and wanting to be with friends and family. The results of the immediate reaction to strong ground shaking indicates that Kaikōura respondents have a high level of knowledge of linking strong earthquake shaking intensity and the need to evacuate. A number of evacuation behaviour studies of past tsunami events have also found a strong correlation of strong ground shaking prompting evacuations or indication of a possible tsunami threat (Blake et al. 2018; Cabinet Office in Japan. 2012; Harnantyari et al. 2020; Katada et al. 2003; Lindell et al. 2015; Murakami et al. 2012; Ushiyama & Imamura, 2003). Figure 3.4-2 provides a correlation analysis of perceived shaking intensity and duration of the 2016 Kaikōura earthquake. Whilst, the importance should focus on shaking intensity for the Kaikōura context (proximal source is likely to experience strong shaking rather than long shaking), Figure 3.4-2 shows that strong and violent shaking intensity was perceived across all binned perceived shaking duration times.

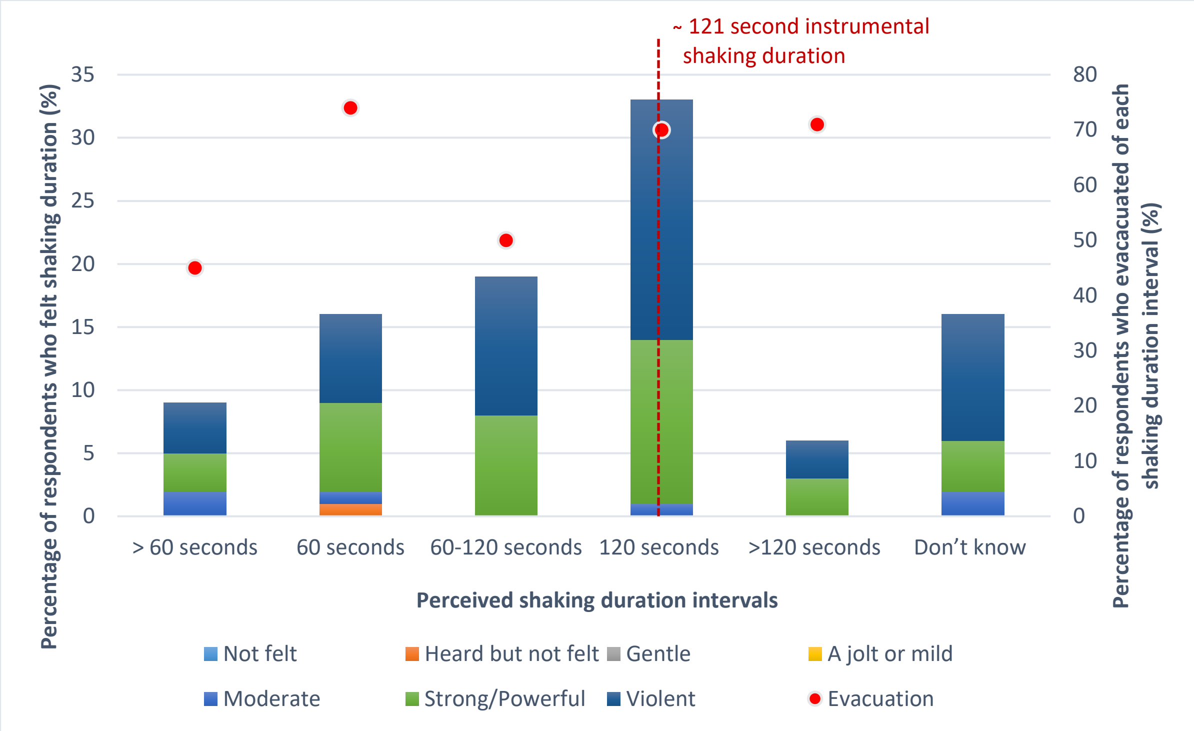

Figure 3.4-1: Percentage of respondents who evacuated compared with their perceived shaking intensity and shaking duration of the 2016 Kaikōura earthquake.

Although the survey results indicate the natural cue (earthquake and strong ground shaking) prompted evacuation response of Kaikōura respondents, recent evacuation survey research in New Zealand suggests the public has a heavy reliance on official warnings before deciding to evacuate, this includes receiving an official tsunami threat or warning message via radio, social media and television, or sounding of tsunami sirens which ultimately result in a delay in evacuation departure (Barnhill, 2020; Blake et al. 2018; Hall et al. 2017; Fraser et al. 2016; Currie, 2013; Fraser et al. 2013).). Although similar evacuation rates were observed in Blake et al. (2018) and Barnhill (2020) to what was reported in this research, these studies analysed evacuation behaviour following the 2016 Kaikōura earthquake tsunami at a regional scale response (1-3 hours for tsunami wave to arrive at the coast). Blake et al. (2020) analysed evacuation behaviour of two coastal areas in the Wellington region: Petone and Eastbourne. Blake et al. 2018 results concluded 70% of respondents evacuated at some stage after the 2016 Kaikōura earthquake, however the highest proportion (21%) of respondents evacuated because of an official warning. Barnhill (2020) analysed evacuation behaviour of Eastern Christchurch and Banks Peninsula following the 2016 Kaikōura earthquake. The results revealed that Eastern Christchurch had an evacuation response rate of 81% and a 50% evacuation rate for Banks Peninsula, however a heavy reliance was on tsunami siren activation to prompt evacuation. However, it important to note, and as outlined in Chapter one, Canterbury and other regions in New Zealand experienced an inconsistent official warning environment (see Section 1.4-2).

For an effective evacuation process, the response phase of pre-evacuation actions should be minimum to allow for sufficient time to evacuate to safety (Makinoshima et al. 2020). Makinoshima et al. 2020 concludes that various response activities have been observed in past tsunami events. A common response activity is collecting additional information to inform their evacuation decision (Lindell, et al. 2015; Fraser et al. 2016; Blake et al 2018). The results of this survey reveal the highest proportion of respondents (35%) took no pre-evacuation actions and evacuated immediately. This indicates Kaikōura respondents had a minimum delay time prior to evacuating. The prompt evacuation movement without conducting pre-evacuation actions reflects the relatively high rate of respondents evacuating within 10 minutes (55%) (Figure 3.3-12). This was a higher compliance rate compared to what was observed during the 2011 Great East Japan tsunami where only 32.5% of people started evacuating before 10 minutes and approximately 50% conducted their evacuation within 30 minutes of the earthquake (Makinoshima, 2020). However, it did take 40 minutes for 90% of respondents to evacuate to safety. This raises concerns around evacuation movement time for future local-source tsunami events, especially tsunami generated from a submarine landslide in the Kaikōura Canyon or an earthquake rupture along the southern end of the Hikurangi subduction zone, which could results in tsunami waves arriving at the coast in a matter of minutes (Power et al. 2017).

3.4.3 Evacuation movement phase

One area that has received little attention in evacuation behaviour literature, are factors that influence the decision on the mode of transport taken during a tsunami evacuation response, such as the use of personal vehicles, walking or running, or using public transport (Makinoshima, et al. 2020; Wood et al. 2018). Due to the sudden onset and little to no warning for a local source tsunami, the use of vehicles in a spontaneous response can result in evacuation complications such as congestion and gridlock traffic (Wood et al. 2018 Shimamoto et al. 2017; Mas et al. 2013; Okushima & Yamanaka, 2012). Although previous studies have identified that evacuating by foot would be more safe and efficient (Henry et al. 2017; Di Mauro et al. 2013), international survey literature reveals that private vehicles are the primary travel mode during a tsunami evacuation response (Fraser et al. 2013). This was observed in during the 2009 Samoa Earthquake and tsunami (53.8%), Illepal (Chile) Earthquake and Tsunami (59.8%), 2011 Great East Japan tsunami (52.5%). This was reported during the 2016 Kaikōura earthquake response, where 85% of survey respondents evacuated by car and only 15% evacuated on foot (walk or ran). Given the close proximity to high elevations (Kaikōura Peninsula) and short distances to reach safety, an assumption would have been a higher pedestrian evacuation response rate. However, many factors could have influenced respondents decision to evacuate by car including the time of day at which the earthquake occurred (00:02 NZDT), checking on friends and family, transporting family member's and essential items, and having a place of shelter during the hours following the earthquake.

Comparatively, vehicle rates align with other tsunami survey studies in New Zealand. Barnhill (2020) survey results revealed that 96% (n=15) of respondents in Banks Peninsula and Eastern Christchurch evacuated by car and only 3% (n=4) evacuated on foot and Blake et al. (2018) survey results reported that 64% of all survey respondents evacuated by car. Additional survey research looking at evacuation intentions in New Zealand found a similar result of around 60% of respondents reporting that they intend to evacuate by car (Currie et al. 2013; Fraser et al. 2013). Moreover, international literature corresponds to these findings where Murakami et al. (2012) analysed evacuation behaviour following the 2011 Japan earthquake which reported 65% or respondents evacuate bay car. Further work should understand the reasoning's of deciding to use a vehicle, particularly for Kaikōura, given the close proximity to safety. Understanding the favoured travel modes essential for evacuation planning.

An important factor that could influence evacuation response rates and time taken to evacuate, is analysing the demographic composition of households. The results of survey enable an analyses of living situation influence on the time taken to evacuate to safety (Figure 3.4-4). The highest proportion of respondents stated that they were classed as 'family without children', majority of which lived with their spouse or partner (based on comments provided). Of this composition, the highest percentage of respondents evacuated in 4 minutes of less (20%, n=17), followed by 5 minutes to evacuate (14%, n=11). The second highest proportion of respondents who evacuated in 4 minutes or less were 'family with children' (7%, n=6). Notably the composition of respondents who took longer to evacuate (11 minutes or greater) were respondents who classified their living situation as 'alone'.

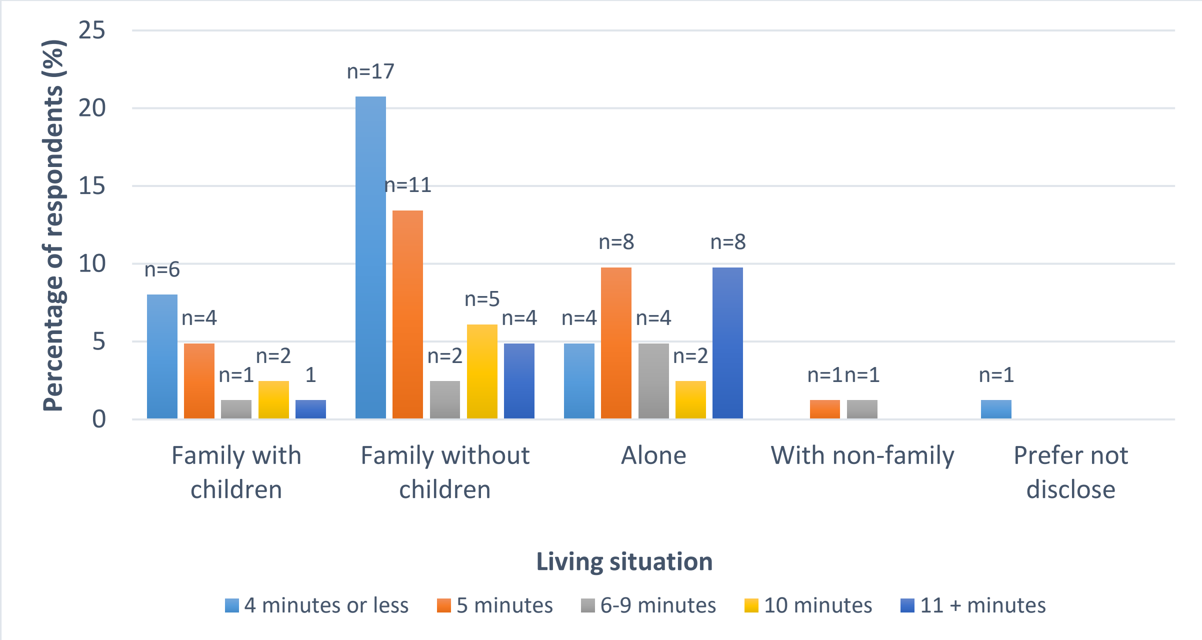

Figure 3.4-2: Living situation influence on the time taken to evacuate during the 2016 Kaikōura earthquake.

Participants were asked if they would take an alternative route in the case of a future event. Seventy six percent (n=67) of respondents stated they would not consider an alternative evacuation route to the evacuation response route they took during the 2016 Kaikōura earthquake. This likely due to the restricted road network leading to higher ground (State Highway 1 -SH1). Twelve percent (n=11) of respondents reported they would take an alternative evacuation route in the case of a future earthquake and tsunami event, see Figure 3.4-5 for reported alternative routes. The majority of respondents who reported that would use an alternative route stated they would evacuate on foot along designated tracks leading to the top of Kaikōura Peninsula.

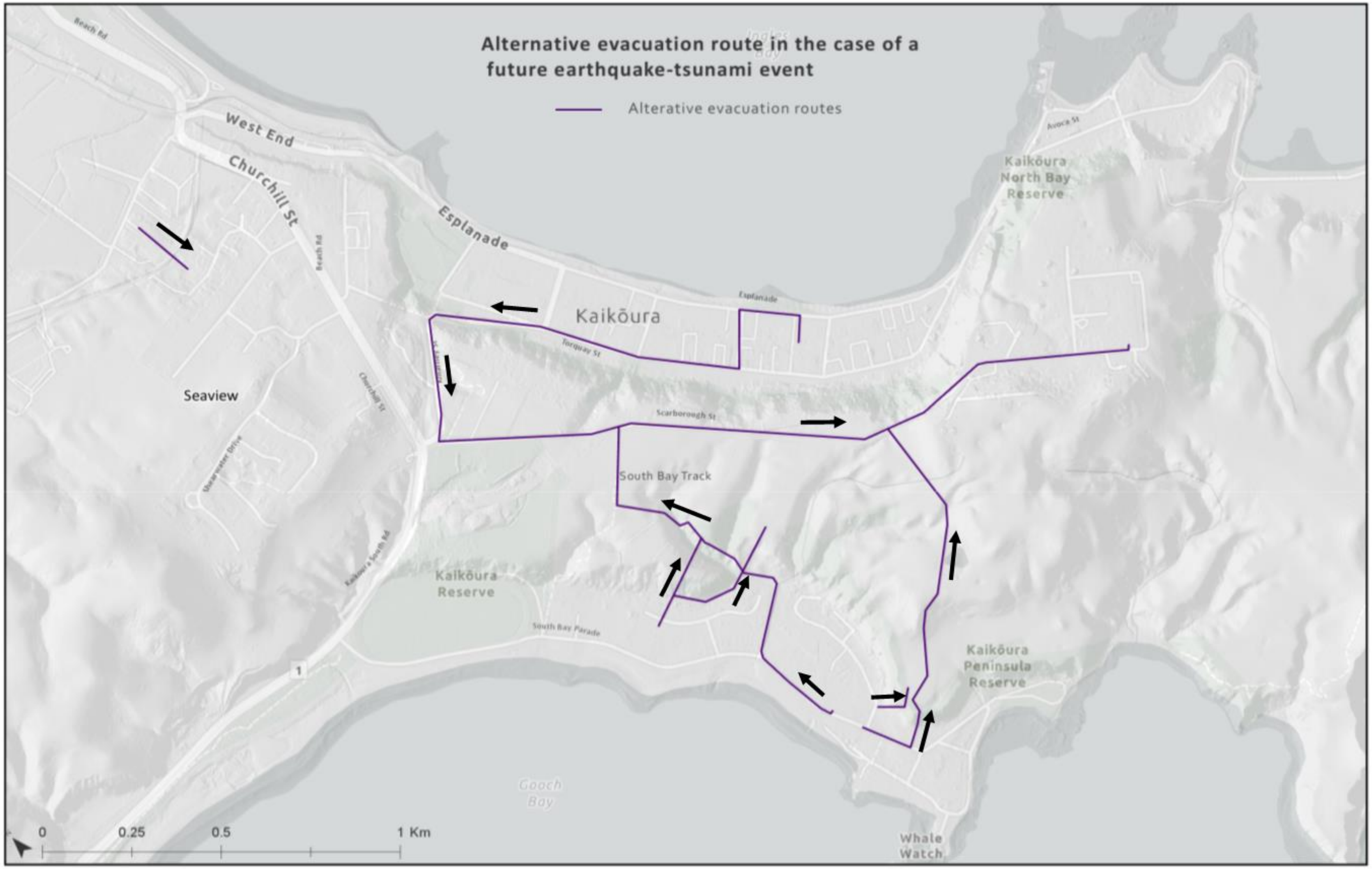

Figure 3.4-3: Geospatial map displaying alternative evacuation routes for a future earthquake and tsunami event.

3.4.4 Additional phase

Once respondents complete their evacuation movements to safe zone locations, people may take additional actions (Makinshima et al. 2020). For example return to their homes to retrieve additional belongings or check on friends or family members (Makinoshima et al. 2020; Cabinet Office, 2012). Additional evacuation actions were reported by Kaikōura respondents, this includes checking on neighbours and convened once they had reached their safe zone location, went back to their property to check for damage and/or to collect essential items such as warm clothing, and collecting family members after evacuating.

3.5 Recommendations

This section presents recommendations addressing key conclusions drawn from the discussion presented in Section 3.4 and results presented in Section 3.3. Recommendations are provided to increase Kaikōura and New Zealand's tsunami risk management and evacuation response planning in the case of a future event.

Public education is a key component of raising awareness on disaster risk and preparedness, which ultimately increases community resilience for future events (Fraser et al. 2013). Preparedness ensures that people have the necessities in order to survive (Paton et al. 2008). Although survey respondents reported they had a high level of tsunami risk awareness, continued efforts through public education and engagement could advance risk awareness and preparedness through a better understanding of tsunami hazard, exposure and potential impacts. Efforts could focus on potential impacts and evacuation time estimates of the immediate tsunami threats posed by the Hikurangi trench and Kaikōura Canyon. This could be achieved through

- Continued efforts of promoting the 'Long or Strong, Get Gone' and 'Get Ready, Get Thru' national and local level public education campaigns. Further efforts could be continued on CDEM engagement through communication channels and community workshops. Fifty percent of survey respondents reported their tsunami risk awareness prior to the event, was attributed to Civil Defence Emergency Management information, therefore, through continuing these efforts, education campaigns are likely to increase Kaikōura population awareness on local-source tsunami risk. This would be beneficial for residents that have recently moved to Kaikōura and/or transient populations (seasonal workers).
- National, regional, and local level evacuation drills, including annual participation in New Zealand's national earthquake drill 'ShakeOut' and tsunami hīkoi. Practicing pre-planned

evacuation routes, annually or bi-annually will increase resident's confidence in their evacuation plan, by having knowledge of pre-identified routes, safe zone locations and estimates of the time taken to reach safety. It is recommended that all schools, work places and households participate in New Zealand's ShakeOut drill. Evacuation response actions could also be practiced of National Tsunami Awareness Day.

- Implementation of tsunami signs, tsunami information boards, and tsunami 'Blue Lines' (WREMO, n.d). All three of these public education tools will be highly relevant for Kaikōura, especially spatio-temporal fluctuations of visiting populations travelling through or visiting Kaikōura. This would create awareness of the potential extent of a large earthquake and knowing how far to evacuate, directions of optimal evacuation routes, and awareness of tsunami evacuation zones. Recommended areas for the implementation of these initiatives includes:
  - Signs and information boards located along the Esplanade, Beach Road, South Bay and popular visitor attractions, for example the seal colony located on Kaikōura Peninsula.
  - Blue lines representing areas outside of the tsunami evacuation zone. However if Blue lines are considered, it should be encouraged that people keep evacuating past the blue lines to allow for other behind them to evacuate. This should be considered for potential congestion along Churchill Street and Killarney Street.
- Use key findings of this survey instrument to increase local tsunami risk awareness and knowledge of past experiences of the 2016 Kaikōura earthquake. This could be implemented through community meetings or workshops to increase the public's awareness on reported evacuation behaviour and movements trends such as designated safe zone locations, congestion observations, and evacuation delay time influence the potential of experiencing traffic congestion. Having an understanding of evacuation response of past events could improve future evacuation response.

Survey research - The results of this survey provides an improved understanding of response to natural warnings and evacuation behaviours of residents located in Kaikōura at the time of the 2016 earthquake. The survey instrument developed for this research could be applied for other coastal communities to assess evacuation response behaviour during and following a future tsunami evacuation event.

Kaikōura, and many other coastal townships in New Zealand are dynamic places in terms of visitor populations thus, further survey research should explore evacuation response intentions of transient populations. The survey instrument develop for this research could be applied and adapted to improve this understanding. Findings from this recommendation would be particularly useful for Kaikōura District Council CDEM to inform future tsunami evacuation planning.

Evacuation infrastructure - Eight-five percent of survey respondents evacuated by vehicle. To align with national campaigns and consistent public education messaging, pedestrian horizontal evacuation should be encouraged, particular for areas that are expected to experience traffic congestion in future events. Due to the high use of vehicles used in the 2016 Kaikōura earthquake response, results of survey such as known congestion barriers or areas can inform evacuation resilient infrastructure. This could include the development or improvements of designated tracks for example walking tracks north and south of the base of Kaikōura Peninsula (Dempsy Track, South Bay Track). Improvements such as handrails and lighting would ensure safer and more efficient evacuation.

One aspect this research wish to have explored was to capture Maori narratives and oral histories of tsunami hazard and learning opportunities of the 2016 Kaikōura earthquake. Capturing this knowledge and information may be valuable for iwi, hapu, awareness of tsunami risk and how this can inform decision-making, communication and Maori response and recovery plans.

3.6 Limitations

This section outlines the limitations and uncertainties on the methodology and results of the 2016 Kaikōura earthquake tsunami evacuation survey.

Firstly, the aim of the survey was to capture as many survey response from residents and hoteliers located in Kaikōura at the time of the 2016 Kaikōura earthquake. Of the total surveys distributed (n=1105), 131 were retuned. The results presented in this chapter only represents a portion of Kaikōura township's response actions and evacuation behaviours following the 2016 Kaikōura earthquake. Therefore, limitations to this approach may include a bias towards certain evacuation and response actions made and/or observed during the event and does not account for all evacuations behaviours and actions that may have been taken by other residents following the 2016 Kaikōura earthquake.

Whilst the 12.4% survey return rate of this research aligns with other national tsunami survey research return rates (Barnhill, 2020; Blake et al. 2019; Dhellemmes et al. 2016; Fraser et al. 2016), the survey return rate is relatively low. This could be a reflection of the research being conducted more than two years after the 2016 Kaikōura earthquake. The delayed time of conducting this research more than two years after the 2016 event may have led to a bias of respondents who completed the survey e.g.

demographic bias. Another limitation of conducting this research 2 years after the event could be the influence on accurate estimations and perceptions of evacuation response behaviours and dynamics respondents took following the 2016 Kaikōura earthquake. An example of this could be estimated evacuation travel speeds and evacuation delay times. Therefore the results presented in this chapter relies on accurate and honest answers reported in the survey booklets.

Another limitation of the evacuation instrument was survey incompleteness. Many of the survey respondents to did not complete all questions of the survey booklet. Response rate varied for certain questions in particular certain sections of the survey. Many respondents provided answers for the first third and last third part of the questionnaire. A low response rate was received particularly on questions asking about congestion observations, evacuation time estimates, and origin-route-destination maps (middle section of the survey). A number of reasons could allude to incompleteness of survey booklets for example, the longevity of the survey. It was estimated to take between 15-20 minutes to complete the 42 questions provided in the booklet. Respondents may have perceived this survey instrument to take too long to complete therefore, only answering the tick-box questions or leaving certain questions blank.

Manual digitisation was applied to develop maps representing the evacuation response of the Kaikōura Township (see Figure 3.3-10 and Figure 3.3-11). Respondents who provided their origin – route – destination evacuation response on the geospatial map is assumed to be accurate, however respondents who provided a written explanation of their evacuation response was manually digitised. Therefore, the results of the maps provided in Section 3.4, incorporates estimated evacuation routes based on written descriptions.

After reviewing the results of the survey, there was a missed opportunity to explore certain aspects on the tsunami evacuation response. Additional questions that could have be incorporated into the survey instrument could include questions on:

- Awareness and knowledge on current national and local tsunami public education campaigns including knowledge on actions to warnings (natural and/or official) and the need to evacuate (Long Or Strong, Get Gone).
- Emergency Mobile Alerts – analyse the capacity of respondents receiving an official warning, or understanding if EMA's would influence evacuation response.
- Participation rates in evacuation practice drills – understanding if respondents have participated and/or seek to participate in future earthquake drills and tsunami evacuation hīkoi's.

3.7 Future research and opportunities

To address the limitations discussed in Section 3.6, this section suggests additional tsunami evacuation research and future work to increase tsunami risk preparedness in Kaikōura. Suggestions can directly be applied at a national and global level.

- Further research could look into the applicability of the information derived from the results of the surveys to inform tsunami evacuation planning. This could include development of tsunami response plan for Kaikōura or other at risk communities in New Zealand. Response plans could include designated evacuation centres in the case of a future event, informing placement of tsunami evacuation signs and other tsunami awareness resources such as blue lines, and prioritising emergency personnel and assisting those in need of evacuating.
- Although this survey gained an insight on the level of tsunami risk awareness and preparedness of Kaikōura residents, future survey research could explore participation rates on community engagement meetings and workshops to analyse how such initiatives can influence disaster risk preparedness.
- Further work could analyse human displacement following the 2016 Kaikōura earthquake (days – years). This could include a comprehensive overview of the official evacuation response of the 2016 Kaikōura earthquake and recovery process that took place following the immediate response. This should be an addition to the observations and results of the survey used in this research that has analysed the immediate evacuation response, to inform future emergency response planning.
- The survey used in this research was designed to collate evacuation response information from residents and hoteliers who resided in Kaikōura at the time of the 2016 Kaikōura event. However, very limited data was captured from hoteliers. To produce a more comprehensive overview of the 2016 Kaikōura evacuation response, including behaviours of visitors in Kaikōura at the time of the 2016 Kaikōura earthquake, surveying hoteliers individually could improve the complete understanding of the 2016 Kaikōura earthquake response.
- Future survey research could include additional questions on warning technology such as Emergency Mobile Alerts (EMA) and the influence on evacuation response. This could include analysing the capacity to receive EMA warnings and gather perceptions if EMA's would be an influential reason for evacuating. This is more broadly applicable to coastal areas communities that may experience a regional or distant source tsunami warning.
- Analyse how national evacuation behavioural survey research could be used to inform natural hazard land-use planning.

3.8 Conclusion

A questionnaire survey tool was developed to analyse Kaikōura resident's evacuation response following the 2016 Kaikōura earthquake and subsequent tsunami. The design and results of the 2016 Kaikōura earthquake tsunami survey contributes to addressing the global tsunami research gap by understanding a complete evacuation response of a real-event local source tsunami threat. Survey results of 131 Kaikōura residents was analysed to obtain a comprehensive understanding on warning and evacuation decision-making, evacuation behaviour and movements, and risk awareness and preparedness influence on evacuation behaviour. Key findings of the survey results include:

- Prior to the 2016 Kaikōura earthquake, respondents had a 'good' (44%, n=55) or 'very good' (25%, n=31) level of knowledge on tsunami hazard and the need to evacuate.
- Of the total survey respondents (n=131), 69% evacuated.
- A large proportion (79%, n=88) of respondents who reported that they evacuated did so due to the potential tsunami threat during and immediately after the 2016 Kaikōura earthquake.
- The vast majority (95%, n=64) of those living in the tsunami evacuation zone at the time reported that they evacuated. Almost half (45%) of respondents who were residing outside tsunami evacuation zones (n=42) evacuated, with most reporting that they did so because of 'severe shaking and aftershocks'.
- Reported congestion barriers included bridge failures, fallen lamp post, and road damage due to subsidence caused by the earthquake. These barriers slowed down evacuation time of some residents, particularly along Churchill Street and Killarney Street, adding minutes to their total evacuation time.
- More than half (55%) of respondents evacuated prior to the first tsunami wave was recorded after the earthquake (within 10 minutes). Ninety percent had reported they evacuated by the time of which the tsunami highest point was measured on the Kaikōura sea level gauge 40 minutes after the earthquake.
- The time at which respondents stayed at their evacuation point ranged from 30 minutes to 48 hours. The most common reported time respondents stayed at their evacuation point was 6 hours (18%).
- The three most commonly reported preparedness actions residents have made following the 2016 Kaikōura earthquake include; prepared an emergency kit with essential items (57%, n=70), discussed an evacuation plan with friends and family or household members (54%, n=67) and prepared a go bag containing essential items (43%, n=53).

The methodology and results of this chapter provides a framework to inform future tsunami evacuation research to better understand evacuation behaviour for other at risk communities in New Zealand and globally. In addition to this, the findings of this chapter can directly contribute to local, national and global tsunami risk management and tsunami response planning.

3.9 Summary and link to next chapter

This chapter addressed Objective one of this thesis: understand evacuation behaviour and dynamics of Kaikōura residents following the 2016 Kaikōura earthquake and subsequent tsunami. Through the use of a survey instrument, results on respondent's evacuation response was analysed and presented in the form of quantitative and qualitative statistics, graphs and geospatial maps. The following chapter uses key findings of the survey results to inform the development of a more realistic network-based tsunami evacuation model for Kaikōura.

Chapter 4: Network evacuation model for Kaikōura

4.1 Introduction

The purpose of this chapter is to address research objectives 2: develop an evacuation modelling framework and test by modelling likely evacuation behaviours of coastal Kaikōura residents, to ensure that it is applicable to other communities at risk from tsunami in New Zealand and internationally. First, a summarised literature review on tsunami evacuation modelling is presented, identifying a research knowledge gap and highlighting the importance of the present research (Section 4.1), an overview of the developed framework and method used to determine evacuation time estimates applying a network-based model is presented (Section 4.2). Third, the results of the exposure inventory and network-based evacuation modelling outputs are presented. Fourth, a discussion draws upon key findings of the evacuation modelling results, with a focus on the contribution to the identified knowledge gap. Fifth, limitations and a summary is presented on the evacuation planning tool framework used to determine the results of the network-based tsunami evacuation model in this chapter (Section 4.5).

Prompt evacuations of at-risk coastal areas can prevent or minimise loss of life from tsunamis (Fraser et al. 2014; Shahabi & Wilson, 2014; Power et al. 2020). As noted in chapter 1 and 2, local source tsunami can potentially inundate low-lying coastal communities within a matter of minutes, thus it is vital evacuation planning is carried for exposed and/or vulnerable areas (Power, 2020; UNESCO, 2020). Evacuation preparedness should include well-planned evacuation routes and refuges to maximise the number of evacuees reaching safe zone locations during an event (Wood et al. 2014). Evacuation modelling is an important tool for estimating exposure to tsunami hazard and the time taken to evacuate out of the hazard zone to safety (Fraser et al. 2014; Le, 2016; Wood et al. 2018;). To date, a number of evacuation modelling methods have been applied to tsunami evacuation research however, very few publications have incorporated 'real event' evacuation parameters to improve realistic evacuation modelling outputs (Kubisch et al. 2020; Wood et al. 2018). This research addresses this global tsunami science research gap by incorporating an empirical dataset detailing immediate reactions to warnings and evacuation behaviours following the 2016 Kaikōura earthquake and tsunami (chapter 3), to develop a more realistic network-based tsunami evacuation model of the Kaikōura Township and South Bay. The methodological framework developed and used in this chapter provides a new approach for evacuation modelling in New Zealand, particularly in regards to the application of empirical data from the 2016 Kaikōura earthquake response. The method and results presented in this chapter can be an informative tool for tsunami evacuation planning and disaster risk management for coastal areas susceptible to tsunami in New Zealand and in the Pacific.

4.2 Network-based modelling evacuation planning tool method

This section provides an overview of the conceptual and methodological development of the network-based modelling evacuation planning tool. The aim of this framework is to be applicable for other coastal areas vulnerable to tsunami in New Zealand.

This section uses Geographic Information Systems (GIS) and data manipulation tools to demonstrate how to model and analyse exposure and produce evacuation modelling outputs, to better inform DRR initiatives. Figure 4.2-1 reflects the overall methodological framework used to determine the results in section 4.3. The following sections discusses the key components used to develop a tsunami evacuation model, using Kaikōura as a case study.

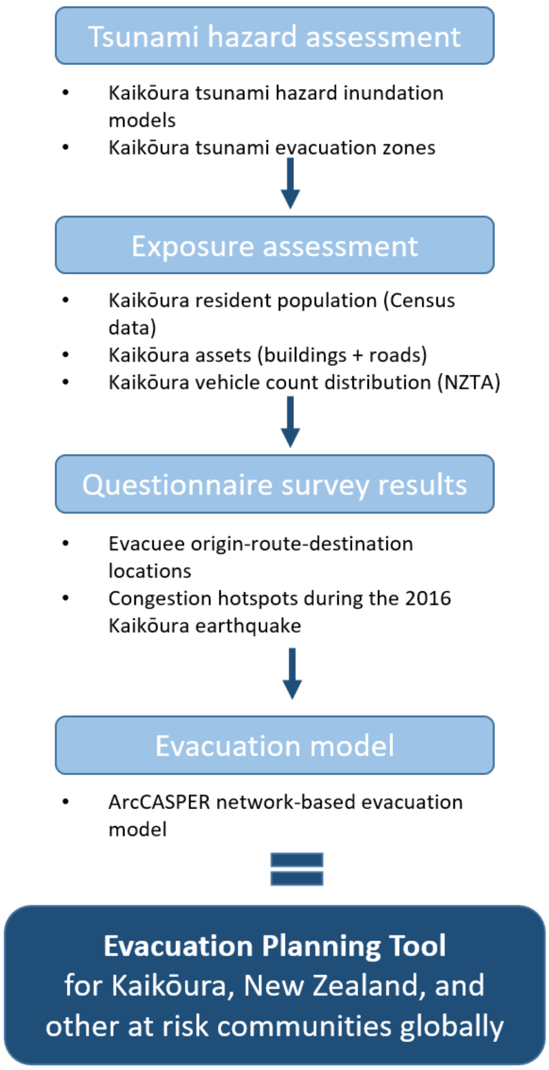

Figure 4.2-1: Methodological framework to develop a novel evacuation planning tool. The process identifies key input components to inform the development of the evacuation planning tool.

4.2.1 Hazard assessment

Numerical tsunami inundation modelling has been conducted to model tsunami from local, regional and distant sources posed to Canterbury, including Kaikōura (Lane et al. 2014; Meuller et al. 2019). As noted in Chapter 2, tsunami evacuation zones are informed by numerical inundation models, incorporating a conservative approach (MCDEM, 2016). Tsunami evacuation zones have been used to determine maximum exposure of vulnerable communities in New Zealand and are considered an effective education tool to communicate tsunami risk and response information for natural and official warnings (MCDEM, 2016; Paulik et al. 2020). Kaikōura tsunami evacuation zones were used in this research as the hazard footprint to determine population and asset exposure. Kaikōura has two evacuation zones;

1. Red Evacuation Zone: shore exclusion zone to account for beaches and rivers, and
2. Orange Evacuation Zone: low-lying coastal areas likely to be inundated by a large tsunami. The envelope of this zone represents many possible 'credible' source tsunami scenarios with a 0.04% chance of happening in any one year (Environment Canterbury, 2020).

4.2.2 Exposure assessment

Effective tsunami risk management begins with assessing tsunami risk through the process of identification, analysis, and evaluation (MCDEM, 2019). This includes understanding the characteristics of the exposed population, assets and critical infrastructure exposed to tsunami for evacuation planning (MCDEM, 2019). An exposure inventory was developed as the fundamental output to determine population and assets in Kaikōura exposed to tsunami. Population statistics, building footprints and Kaikōura's road network were overlaid with the hazard footprint identified in Section 4.2.1, to determine the location and count of population and assets exposed within the Kaikōura Township and South Bay. The outputs of the exposure assessment are presented as maps and statistics (Section 4.3) to support tsunami risk management efforts in Kaikōura such as community level response plans.

4.2.2.1 Data collection, preparation and processing

Tsunami exposure assessments require accurate and reliable data to be sourced to perform geospatial analysis and data manipulation (adding, deleting, or modifying data). Online, open-source data portal (Koordinates, n.d) was used to download the most up-to-date asset and population spatial data and statistics for the Kaikōura district. Once the data inputs were sourced, both ArcGIS and Microsoft Excel were used to manipulate the three datasets to determine tsunami exposure of the Kaikōura Township (datasets presented in Table 4.2-1).

- Kaikōura population was identified using Statistics New Zealand '2013 Census Meshblocks' 'usually resident population count' statistics (Statistics New Zealand, 2020).
- Buildings were used for the asset layer of the exposure inventory. Land Information New Zealand (LINZ) 'Building Outlines' shapefile was used as the base layer to determine building-use (LINZ, 2020a.) ArcGIS software was used to convert building polygons to centroid points. This dataset was digitally altered using Google Earth imagery to accurately assign a building-use category for each centroid point. The RiskScape building-use criteria was used for this dataset. This was applied to ensure an accurate representation of building-use for emergency management planning purposes and align with other local and national building exposure datasets.
- LINZ 'NZ Road Centrelines' were used for the critical infrastructure asset layer (LINZ, 2020b). The national layer was clipped to the case study area of this research.

Upon completion of data collection an editing, ArcGIS and Microsoft Excel were used to conduct a quantitative assessment and produce a map of population, assets and critical infrastructure exposed in Kaikōura tsunami evacuation zones.

Table 4.2-1: Open source data used for the exposure inventory.

Name of dataset	**Description of attributes used**	**Reference**
New Zealand Statistics 2013 Census	2013 Census meshblock level dataset used to identify usual resident population count clipped to Kaikōura Township. At the time of when this research was conducted this was the most up-to date meshblock level dataset available.	https://datafinder.stats.govt.nz/layer/8437-population-by-meshblock-2013-census/
NZ Buildings Outlines	Clipped dataset of New Zealand Buildings Outlines. This dataset captures outlines of polygons from the latest aerial imagery	https://data.linz.govt.nz/layer/101290-nz-building-outlines/
NZ Road Centrelines (Topo, 1:50k)	New Zealand's road network dataset clipped to Kaikōura District	https://data.linz.govt.nz/layer/50329-nz-road-centrelines-topo-150k/

4.2.3 ArcCASPER Network-based evacuation model

First this section discusses data preparation and editing processes used to prepare inputs for the network-based tsunami evacuation modelling tool (ArcCAPSER). This is followed by the ARCASPER routing methods used to determine evacuation speeds and evacuee density along the road network.

ArcCASPER (Capacity-Aware Shortest path Evacuation routing) is a tool to perform capacity-constrained evacuation routing (Shahabi & Wilson, 2014). ArcCASPER is an extension of the ArcGIS Network Analyst tool designed as a prescriptive evacuation routing method. The tool is designed to perform evacuation modelling using more realistic parameters than the basic shortest path routing methods (Shahabi, 2012). The algorithm determines realistic traversal speeds for each road segment based on road capacity and the density of evacuees, to create optimal evacuation routes to ultimately minimise traffic congestion and evacuation times (Shahabi, 2012). An overview of inputs, process and outputs of the ArcCASPER network analyst tool is presented in Figure 4.2-2.

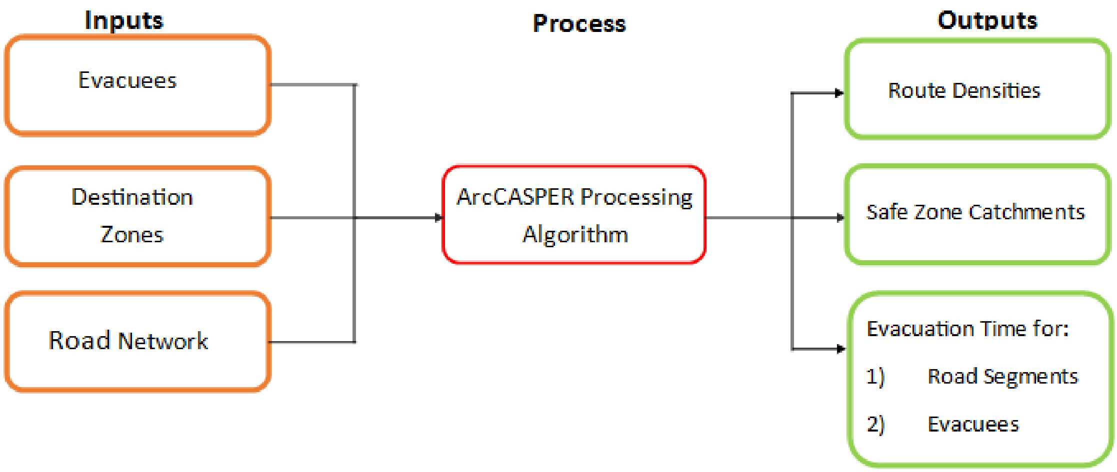

Figure 4.2-2: Overview of ArcCASPER network analyst evacuation model process. From Tilley (2018).

4.2.3.1 ArcCASPER data preparation

ArcCASPER requires four inputs for successful evacuation routing:

1. Road network – represents the road network which includes vertices and directional edges. Each edge has an impedance and capacity value. The road network input needs to be cleansed (remove unnecessary vertices) prior to modelling (Shahabi & Wilson, 2018);
2. Origin locations –represents the evacuee locations or origin points and contains the vertices of where the evacuees are located prior to evacuating. Each origin point generates just one path to the destination point, whilst the evacuation path created uses a set of connected road segments that directs the evacuee to a safe zone (Albdouli, 2015);

3. Safe zone destination points – represents the safe zone locations that evacuees will evacuate to. This input is similar to the source points in that the safe zones contain the vertices were the evacuees are evacuating to (Alabdouli, 2015);
4. Traffic model – the traffic model assigned (Section 4.2.3.2) helps to predict traffic delays on certain road segments. These models represent real-world traffic parameters and ensures that there is minimal congestion, resulting in efficient flow of traffic.

4.2.3.1.1 Road Network

The road shapefile used in the exposure assessment (noted in Section 4.2.2.1) was the input used to build the road network dataset for the evacuation model. To accurately build the road network for ArcCASPER, every intersection in the road network had to be topologically correct i.e. each segment 'knows' it is connected to another one. This was manually completed using the 'Split' tool in the editing toolbar in ArcGIS. Several other attributes were required to build a road network appropriate for use in ArcCASPER evacuation modelling, attributes include;

i. Length and time attribute of every road segment (polyline). The length of each segment was determined using the 'calculate geometry' tool in ArcGIS; this provided distance of each polyline in kilometres for the entire road network. New Zealand's road speed in urban areas is typically 50km/hr. A speed of 50km/hr was assigned to all roads, representing realistic travel speeds. The 'Field Calculator' tool was used to determine time in minutes using the equation: Time= (Length (metres/50)*60).
ii. Lane capacity attribute. A lane count attribute was already present in the New Zealand Transport Authority (NZTA) Road Centreline dataset. Primary and secondary roads in Kaikōura's road network has a lane count of two, with the exclusion of one-way bridges. For the purpose of this model it was assumed all roads in Kaikōura has a lane count of two.
iii. A travel mode. 'Vehicle' was assigned to represent the common evacuation travel mode reported in the Kaikōura earthquake and tsunami survey (see Chapter 3).

4.2.3.1.2 Origin locations

The building asset centroid shapefile derived in the exposure assessment was used as the origin location input for the evacuation model. An additional attribute was added to this layer to represent vehicle count of each origin point. A value of "1" was assigned to each origin point. For the purpose of this evacuation model it was assumed every household would evacuate in one car, thus the number of people in each car is not considered relevant for the purpose of the model.

4.2.3.1.3 Safe zone destination

A shapefile was created to represent four designated safe zone locations. The four safe zones locations were informed by the results of the 2016 Kaikōura earthquake tsunami evacuation survey (Chapter 3). The four safe zone locations reported in the survey were:

- Churchill Park
- Seaview subdivision
- Kaikōura Cemetery
- Takahanga Marae

4.2.3.1.4 ArcCASPER traffic model

ArcCASPER's algorithm determines realistic travel speeds for each road segment based on road capacity, the number of evacuees and potential congestion barriers. ArcCASPER provides three optimisation methods:

1. Shortest Path (SP) – this method searches for the shortest possible route for each evacuee. It is the simplest and quickest method, however it ignores all capacity components, thus providing less accurate results (Shahabi, 2012).
2. Capacity Constrained Route Planner (CCRP) – is a method that incorporates capacity while using the original evacuation network. CCRP gives priority to evacuees who have longer predicted evacuation times. Once the road network is fully saturated and becomes a bottleneck, the algorithm routes the rest of the evacuees on alternative routes (Shahabi & Wilson, 2014).
3. CASPER – this method sorts evacuees by distance from the origin point to the closest safe zone. Starting with evacuees farthest away, the shortest route is identified and the evacuee assigned to it. The process is repeated until all evacuees have been assigned an evacuation route. During the process, CASPER updates each route segment travel cost based on the number of assigned evacuees and the edge capacity. The overall results will generate a route that will guide each evacuee to the best safe areas based on their origin point (Shahabi, 2012).

The CASPER method was chosen as the optimal evacuation method to model tsunami evacuation time estimates for Kaikōura. This was selected as other studies have shown that CASPER presents the most realistic model when incorporating behavioural or real-world data (Alabdouli, 2015).

4.2.3.2 ArcCASPER vehicle evacuation model for Kaikōura

The ArcCASPER vehicle evacuation model used in this research represents an ‘ideal’ (no evacuation obstacles e.g. bridge collapse) residential night-time scenario. Vehicular mode of transport was selected for this model to represent the high portion (85%) of survey respondents reported evacuating by car during the 2016 Kaikōura earthquake and tsunami. Although a range of travel speeds were reported in the 2016 Kaikōura earthquake tsunami evacuation survey (0-60km/hr, mean=18 km/hr), in an ideal evacuation scenario, evacuees would travel at the speed limit. Therefore, a time attribute of 50 km/hr was assigned to all roads.

Figure 4.2-3 displays the evacuation settings used for the vehicle evacuation model for Kaikōura. Most of the properties were assigned the default option. Recommended by the developers of ArcCASPER, the Dynamic Mode was set to ‘Smart’; this meant that every time the road network altered, the affected evacuees were rerouted. The ‘Intl Delay Cost Per Evacuee’ setting represents the initial space between evacuees that are sharing their start location. This translates to evacuee density on each road segment. This assigned default value was used for the evacuation model. ‘Cost per Safe Zone Density’ was also left as the default value 0. This represents unlimited capacity of evacuees assigned to each safe zone. ‘Saturation Density per Unit Capacity’ was left at the default value of 500; this value represents a demand increase on the road. The ‘Flocking Model’ was enabled for this research; this model simulates each evacuee (vehicle) second by second on the road network from origin to destination. The ‘Flocking’ simulation model allows for the identification of congestion hot spots through a more detailed analysis of evacuation routes. s

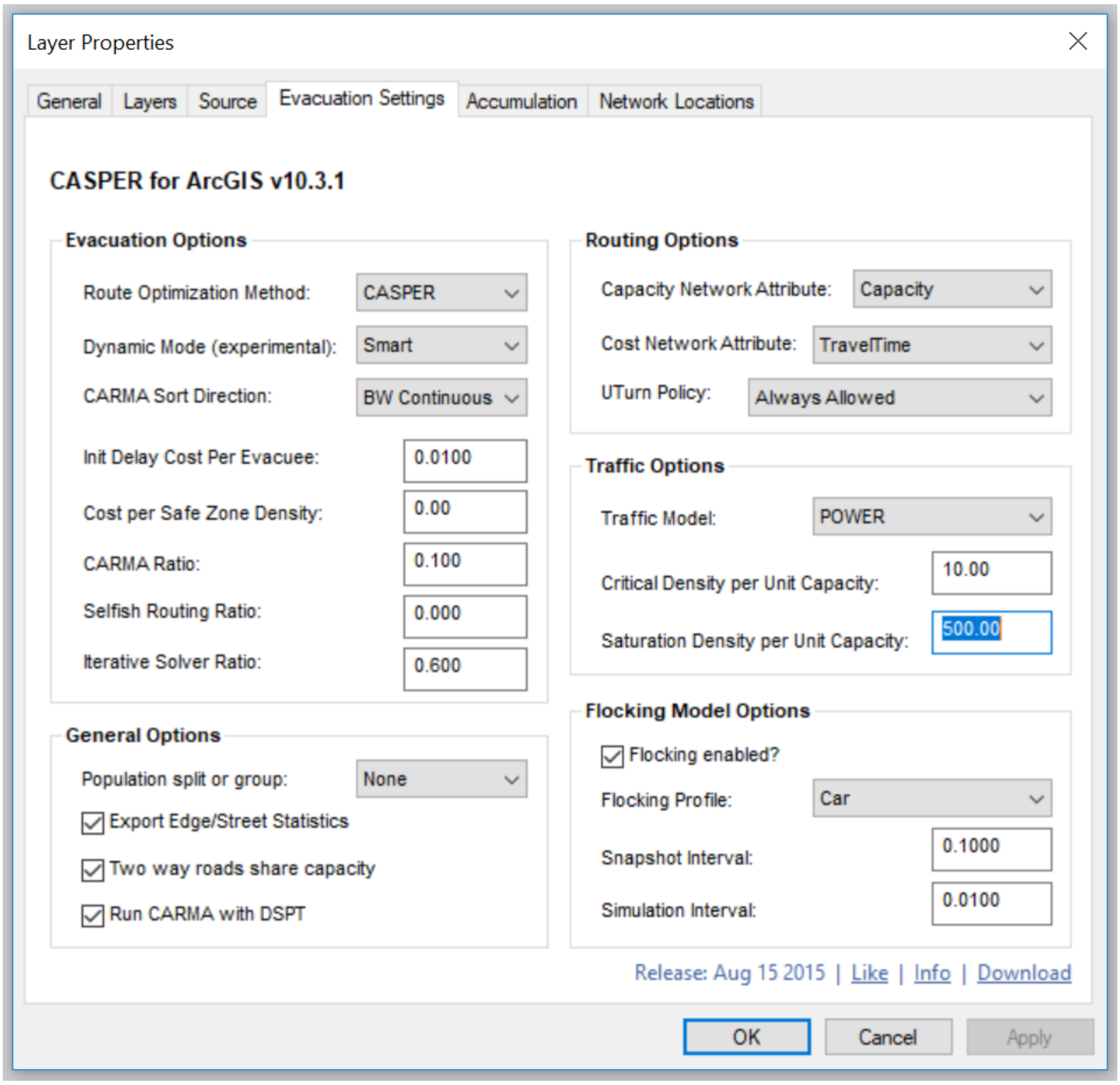

Figure 4.2-3: Evacuation settings applied to Kaikōura vehicle evacuation model. See text for details.

To improve accuracy of the ArcCASPER evacuation model, evacuation information gathered from survey respondents (Chapter 3) was used to inform realistic evacuation behaviour and movement. Survey questions used to inform and validate the evacuation model include:

- How did you travel to your evacuation destination? (mode of transport)
- Where did you evacuate to (origin-route-destination evacuation response)
- Did you encounter any traffic congestion or were you aware of congestion problems? (congestion barriers)
- On average, how slow do you think traffic was moving in these congested areas? (travel speed).

Based on the high percentage (85%) of survey respondents reporting they evacuated by car, a vehicular evacuation model was produced for Kaikōura.

4.3 Results

This section presents the results of the tsunami exposure assessment, network-based evacuation modelling results, and field observations of pedestrian evacuation drills. The results presented below contribute to understanding risk to tsunami and evacuation planning in Kaikōura, and are applicable to other coastal areas exposed to tsunami in New Zealand.

4.3.1 Results of the tsunami exposure assessment

Table 4.3-1 provides a quantitative summary of population, assets and critical infrastructure located in Kaikōura tsunami evacuation zones. The exposure assessment methodology concluded approximately 70% of Kaikōura's 'usually resident' population is located in Kaikōura orange tsunami evacuation zone. Topography and location of residential buildings located in Kaikōura are a contributing factor to this statistic. A total of 1056 buildings (assets) are located in the orange tsunami evacuation zone, majority of which are classified as residential dwellings (n=895) (see Figure 4.3-1). One hundred and eleven commercial business buildings are located in the tsunami evacuation zone, followed by 45 (n) commercial accommodation buildings, 4 (n) education facilities and 1 (n) emergency services building (Kaikōura Volunteer Fire Brigade). Very few assets were located in the red tsunami evacuation zone (shore exclusion zone e.g. beach and estuaries); these were commercial business sheds located near or on the foreshore zone. Primary and secondary roads of the Kaikōura's road network is located within the orange tsunami evacuation zone. Once the road segment was topographically corrected at each intersection junction, the results concluded 108 road segments totalling 31.8 km located in the orange tsunami evacuation zone.

Table 4.3-1: Tsunami exposure assessment for population, building assets and road network located within Kaikōura orange tsunami evacuation zone.

Tsunami exposure assessment	
Population (n)	n= 2748 (Total) in orange tsunami evacuation zone = 1941 = 70%
Buildings (n) – Orange evacuation zone	n=1056 (Total)
Emergency services Educational facilities Commercial accommodation Commercial business Residential dwellings	n=1 n=4 n=45 n=111 n=895
Buildings (n) - Red evacuation zone	n=7 (Total)

Roads (Length)	108 (n) road segments are located in the orange tsunami evacuation zone. This equates to 31.8km of road.

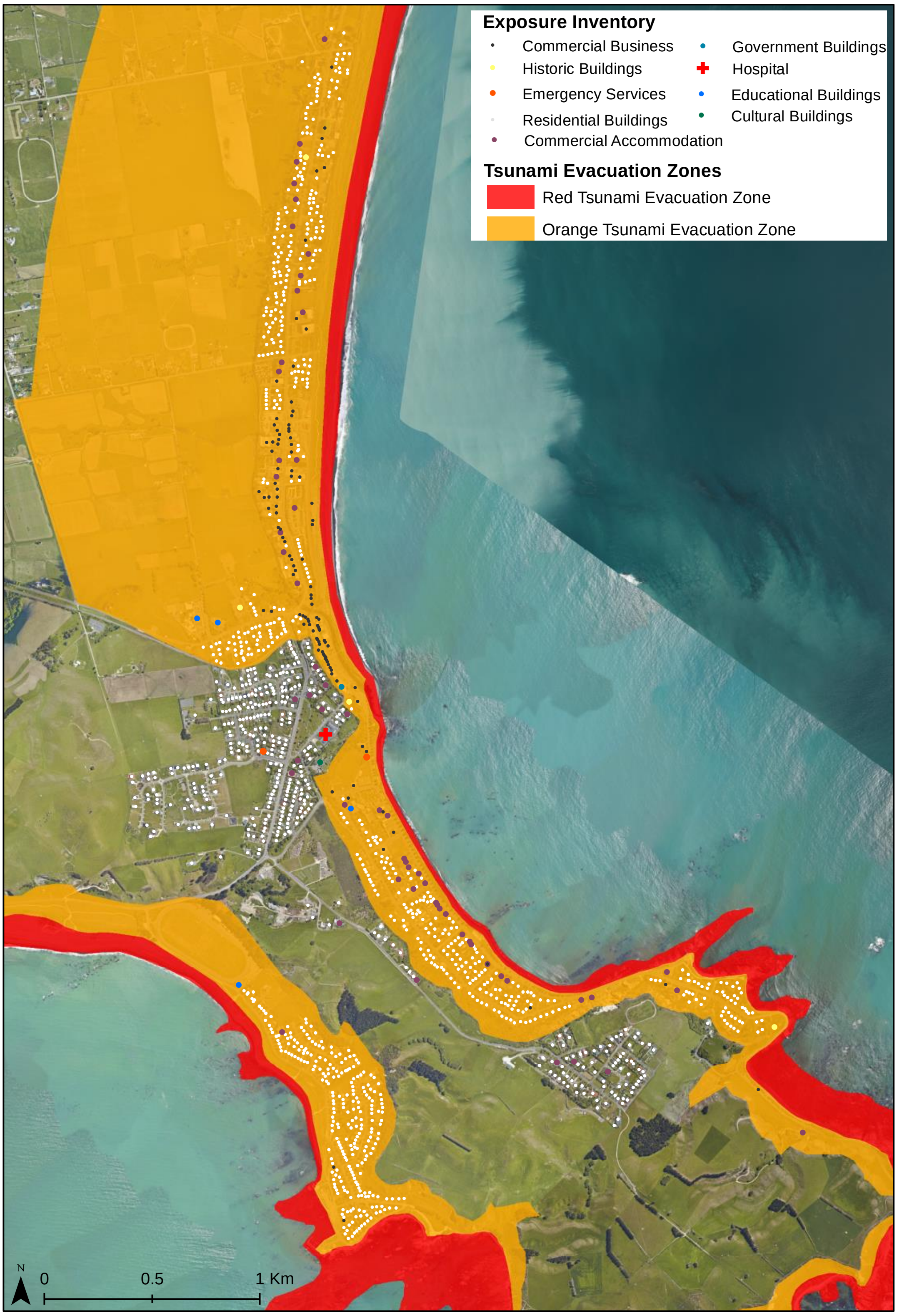

Figure 4.3-1: Exposure inventory of building assets located in Kaikōura, based on Kaikōura tsunami evacuation zones.

4.3.2 Results of the ArcCASPER vehicle evacuation model

The following section presents the results of the ArcCASPER network-based vehicle evacuation model. Results are presented by maps and descriptive qualitative data as a direct results of the evacuation modelling inputs and the ArcCASPER optimization method used for this model. The ArcCASPER evacuation model provides an estimation on destination-catchment densities (allocated evacuation route and safe zone location), evacuee road density (number of vehicles travelling along each road segment), evacuation time to travel along each road segment and evacuation time to reach safety for each household. The total evacuation time for the entire Kaikōura township to evacuate to safety under an 'ideal scenario', is estimated to 12:05 minutes.

The evacuation modelling results are presented for the four key outputs below;

Destination catchments densities

Figure 4.3-2 (pg. 100) provides a visual output (map) representing assigned evacuation routes and safe zone destinations for all households located in the Kaikōura township. The results of this map show a distinct spatial correlation between origin locations and safe zone locations; vehicles (households) were assigned to the closest safe zone location. The output shows households located in South Bay and along the northern low-lying area of Kaikōura Peninsula would evacuate to Kaikōura Cemetery (represented by green). Households in South Bay and all households along Beach Road and the northern end of Churchill Street are predicted to evacuate to Churchill Park (represented by red). Households located out of the tsunami evacuation zone (located on higher ground) were accounted for in the evacuation model. Household in the immediate proximity to Takahanga Marae, Seaview Subdivision and Kaikōura 'water towers' were assigned to the closest safe zone destination e.g. residents living proximal to Takahanga Marae was assigned to the marae as its safe zone location.

Road Density

Figure 4.3-3 (pg. 101) provides a visual output (map) representing vehicle count densities along each road segment required to evacuate the Kaikōura township to a safe zone destination. The results of this map is shown by road segment thickness (bold line represents a higher vehicle count). The results show a distinct correlation of primary roads (SH1 and Churchill Hill Street) experiencing a greater volume of evacuees. Scarborough Street (located on Kaikōura Peninsula, see Figure 4.3-3), is predicted to experience the largest volume of vehicles (greater than 600 along that road segment). Beach Road, Killarney Street, South Bay Parade and State High 1 South are key roads predicted to experience high traffic volumes (greater than 200 vehicles). Secondary roads (e.g. side streets that connect to primary roads) are predicted to experience less vehicles traveling along these particular road segments. The results indicate potential congestion pinch points along certain road segments due to high vehicle density e.g. Killarney Street, Churchill Street and Scarborough Street.

Estimated evacuation time – Road Network

Figure 4.3-4 (pg. 102) provides a visual output estimating vehicle travel time along each road segment informed by road capacity, evacuee density and congestion potential. The results of this output estimated longer evacuation times along road segments that were further away from safe zone destinations. Travel time along each road segments varied. South Bay Parade, Fyffee Quay, and northern end of Beach Road are predicted to take the longest time to travel along due to the distance from the safe zone location (2 minutes or greater). Road segments closer to safe zone locations including Seaview subdivision and Churchill Park are predicted to take less time to travel along (less than one minute). It is important to note that predicted evacuation time is based on the length of road segment.

Estimated evacuation time – Vehicles

Figure 4.3-5 (pg 103) provides a visual output estimating evacuation time per vehicle (household) assuming that every household uses one vehicle to evacuate to safety. The results of this output predicts that evacuation time varies depending on origin location (location of household). Evacuation times ranged from less than one minute to greater than five minutes. Households along the north end of Beach Road, South Bay and along Avoca Street were estimated to take the longest time to reach safety (longer than 5 minutes). Households closer to safe zone locations is predicted to take less time to evacuate (less than 2 minutes). A correlation is shown; evacuation time to safety gradually increases as households are further away from a safe zone location. This is evident for households located along the north side of Kaikōura peninsula (see Figure 4.3-5).

Evcauation flocking model

Figure 4.3-6 (pg 104) provides a visual output representing the result of the ‘flocking model’. The results of the ‘flocking model model represents vehicles (household, represented by a red dot) movements along Kaikōura’s road network captured a 6-second intervals. The results of this output show vehicle density along road segments and at safe zone locations. Safe Zone locations show the greatest number of evacuees across the total evacuation time for the Kaikōura township. Road intersections are also shown to have a greater number of vehicles. Primary roads including SH1-south, Killarney Street, Churchill Street, and Scarborugh Street are predicted to experience congestion.

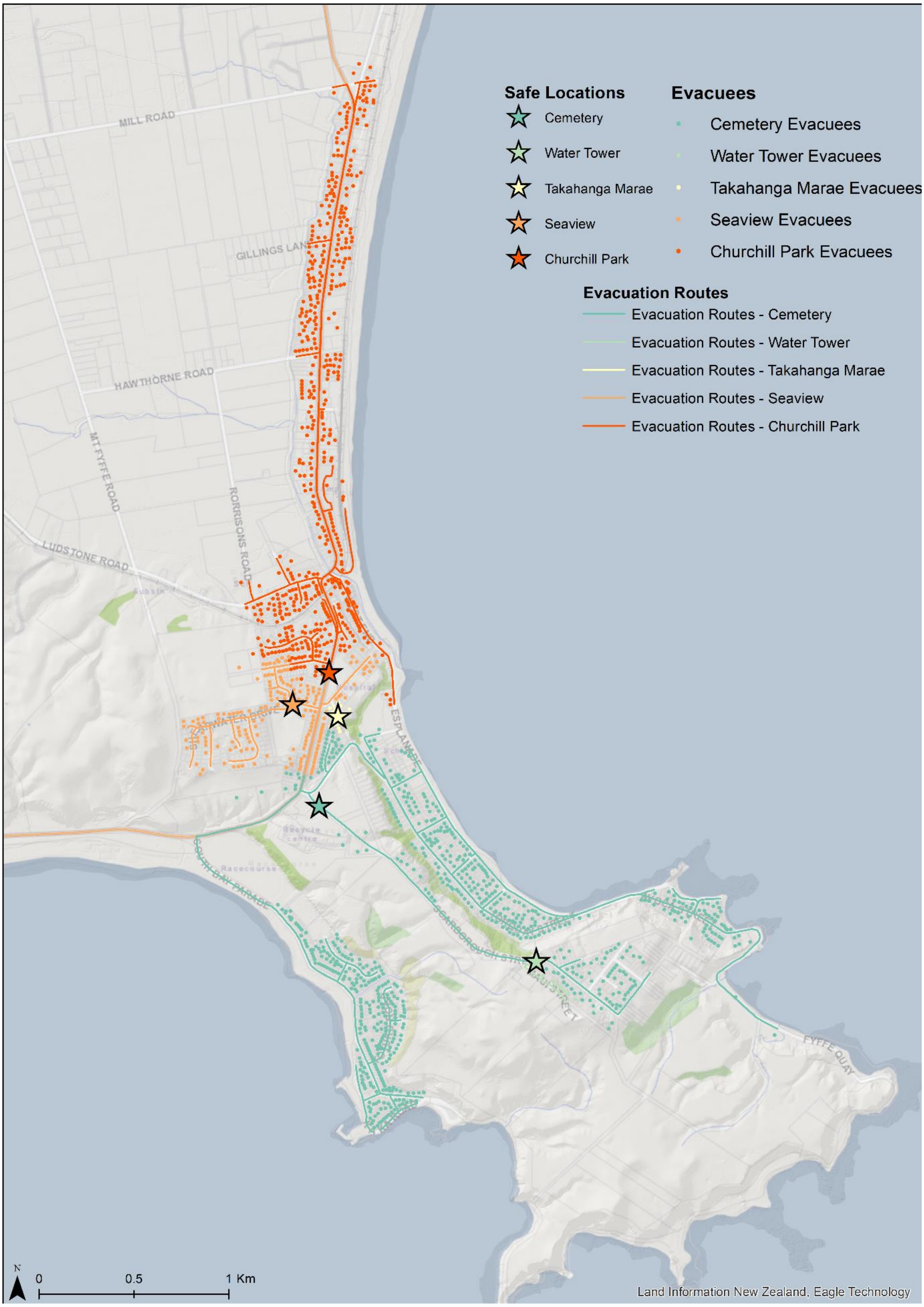

Figure 4.3-2: Map showing allocated route and evacuation zone catchment densities. Five destination zones are identified (Cemetery, Water Towers, Takahanga Marae, Seaview and Churchill Park), colours are coordinated with evacuees and allocated routes to those safe zone destinations.

Figure 4.3-3: Map showing evacuation route densities. Each road segment was assigned a weight value (line thickness) to represent vehicle count. Bold lines represent high traffic density.

Figure 4.3-4: Map displaying predicted evacuation travel time along each road segment. Red represents greater evacuation time, yellow represents quicker time to travel along road segments.

Figure 4.3-5: Map displaying predicted evacuation travel time to reach safety for every household located in the township. Dark red represents longer evacuation time, yellow represents quicker evacuation times.

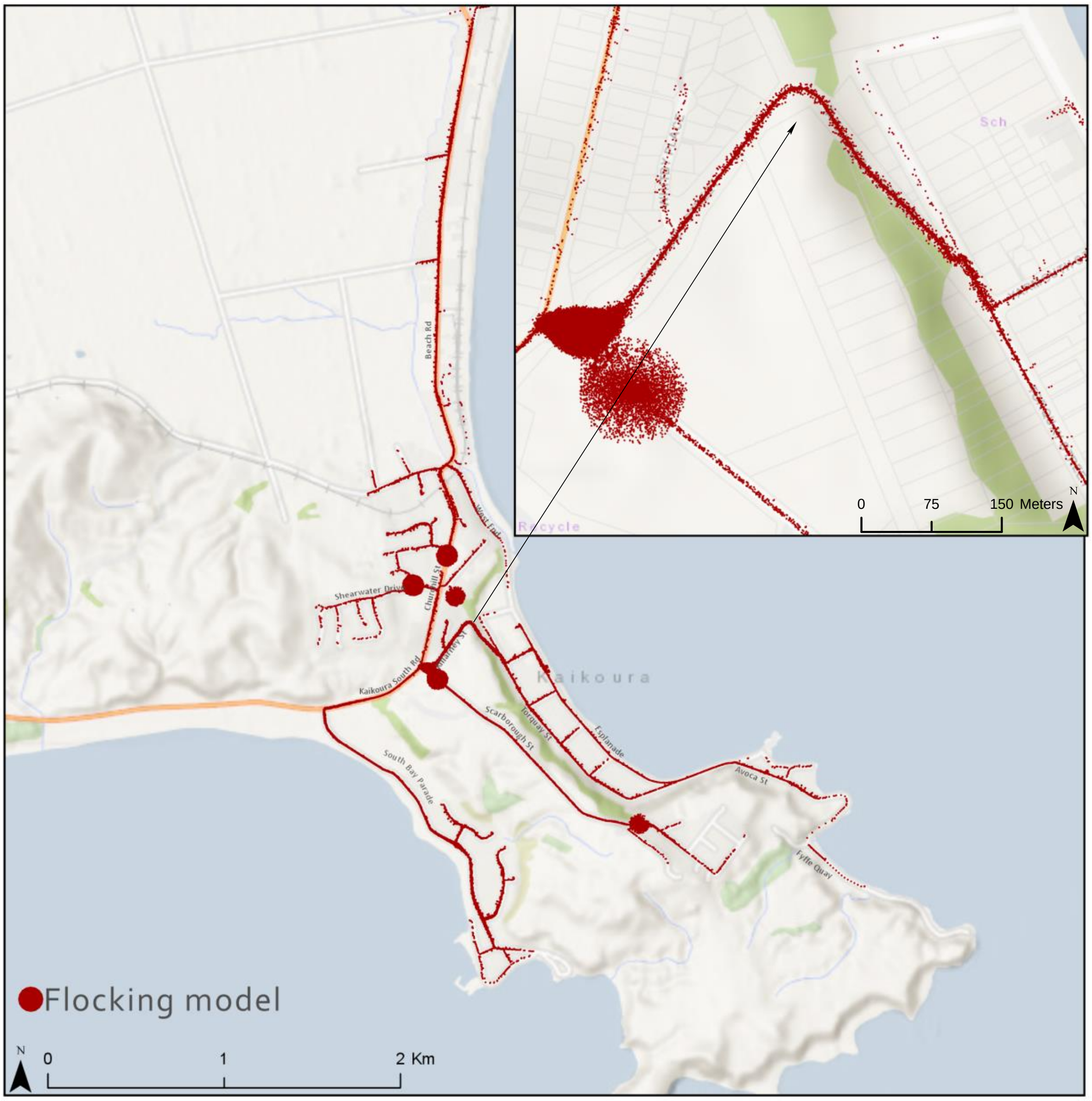

Figure 4.3-6: Map of the ArcCASPER flocking model results. An insert is presented of Killarney Street to show detailed evacuee (vehicle) points. The red dots represent simulation of vehicles along the road network of 6 second intervals.

4.4 Discussion

This sections presents a discussion on the main findings of the exposure assessment and results of the Kaikōura tsunami evacuation model. This section discusses more broadly the importance of understanding and including real event evacuation behaviour and movements and field data observations to improve evacuation planning. Although, evacuation modelling planning recommends incorporating various spatio-temporal evacuation scenarios, the purpose of this chapter was to test an evacuation modelling planning tool, with an 'ideal night time scenario' for Kaikōura township. The discussion presented below discusses results with relevance to the one-scenario test in the evacuation model.

4.4.1 Discussion on tsunami exposure assessment

As previously stated in Chapter 2, effective tsunami risk management begins with assessing tsunami risk through the process of identification, analysis, and evaluation (MCDEM, 2019). This includes understanding the characteristics of the exposed population, assets and critical infrastructure located in a hazard zone. The exposure assessment undertaken for this research aimed to identify population, assets, and critical infrastructure located in Kaikōura's evacuation zones. The exposure assessment was developed at a high level (excluding vulnerability factors e.g. demographics) primarily as the inputs required for baseline data of the network-based tsunami evacuation model. The results of the synthesised tsunami exposure inventory concludes considerable exposure of the total resident population, assets, and critical infrastructure located within Kaikōura's tsunami evacuation zones (relative to population and assets located out of tsunami evacuation zones).

Spatial population data can be an important consideration for emergency response planning as this provides an indication of where residents could be located during a potential earthquake and tsunami event. Building exposure data can also be used as an indication to determine population exposure, particularly for defining the locations of visiting populations (e.g. commercial accommodation). Statistics New Zealand 2013 Census 'usually resident' population dataset was used for this exposure inventory. This indicated a high resident population density within the vicinity of south end of Beach Road, north side of Kaikōura Peninsula and South Bay. The results of the population dataset were consistent with residential building locations. This indicates exposed residential buildings primarily located in South Bay, north side of Kaikōura peninsula and a long Beach Road (85% of total residential building are located in the orange tsunami evacuation zone; see Figure 4.3-1). Although this exposure inventory analysed residential population exposure, Fraser et al. 2014, highlighted the importance to determine the maximum exposed at risk populations. To determine this, exposure models should consider day-time, night-time, and seasonal fluctuations of residents and visitors located in a tsunami evacuation zone (e.g. peak tourist season Dec-Feb). As stated in the introduction chapter of this thesis, Kaikōura is known as one of New Zealand's most popular tourism destinations in terms of day stops for both domestic and international visitors. For future evacuation planning, considerations should therefore be given to the potential spatial distribution of 'day-stop' visitors (i.e. no commercial accommodation or residential address).

4.4.2 Discussion on ArcCASPER evacuation modelling results

The following subsections present a discussion on the key findings of Kaikōura network evacuation modelling outputs.

4.4.2.1 Total evacuation cost of Kaikōura township

Under an 'ideal' night-time scenario, evacuation times of individual evacuee origin points (households) varied from less than one minute to over five minutes. The total evacuation time cost for all households located in the Kaikōura township to evacuate to one of the designated safe zone locations (Churchill Park, Kaikōura Cemetery, Seaview subdivision, Water Towers, and Takahanga Marae; see Figure 4.3-2) is estimated to take 12.05 minutes. This evacuation time is concerning, in terms of life safety for local-source tsunami threat. As mentioned in Chapter 2, it is estimated that an earthquake generated along the Hikurangi subduction zone could arrive at some locations of New Zealand's coast within 10 minutes, including Kaikōura, for a southern fault rupture (Mueller et al. 2019). For a southern Hikurangi source tsunami, the results of the evacuation model suggest that most of Kaikōura's residents are likely to evacuate prior to the first tsunami wave arrival. Consideration should be given to evacuation delay-time, prior to evacuation, including pre-evacuation actions such as gathering life essentials and checking on family. These pre-evacuation actions were reported by respondents during the 2016 Kaikōura earthquake event. Although, an evacuation delay-cost time of one minute was applied to the evacuation model, this does not accurately represent real-world variations in evacuation delay times across individual households. A tsunami hazard with an even shorter wave arrival time is a local- Kaikōura canyon submarine landside-sourced event (Walters et al. 2006 a:b). It is estimated that wave arrival times from this potential source are within a matter of minutes event (Walters et al. 2006 a:b). This is concerning given that the evacuation model estimates a 12:05 minute evacuation time, for all households located in Kaikōura township. However, the total evacuation cost is modelled under an 'ideal night-time scenario', therefore evacuation times may exceed this estimation. Despite this, future evacuation events could see a reduction in this estimated evacuation time (12:05 minutes) if the results of this model (e.g. Figure 4.3-2) are effectively incorporated into the ongoing public education and awareness campaigns.

4.4.2.2 Kaikōura evacuation model - destination catchment results

The results of the destination catchment map (see Figure 4.3-2) shows most, if not all vehicles were assigned to the closest safe zone evacuation destination from their origin location. This is a direct result of the ArcCASPER modelling approach to assign an optimal evacuation route for individual households. The shortest path to a reported safe zone is favoured which represents an ideal evacuation response (i.e. minimum evacuation time). However, it is likely households will evacuate to additional safe zones to which those were reported during the 2016 Kaikōura earthquake (see Chapter 3). An example of this is that a number of survey respondents reported evacuating to Seaview subdivision or to Churchill Park, this contradicts the models output as ArcCASPER models all South Bay residents evacuating to Kaikōura cemetery, despite only a limited number of respondents reporting this as their specific evacuation location. Although many evacuated to the cemetery during the night of the 2016 Kaikōura earthquake, a number of residents evacuated to the other designated evacuation zones in this model. The results also indicate that households located on high ground, have been assigned a safe zone destination, however this may not reflect real-world evacuation behaviours of these households in future events. Similar results were presented in Evans (2020) and Tilley (2018), where most evacuees were assigned to the closest safe zone location.

Evacuation behaviour reported during the 2016 Kaikōura earthquake, indicated that people located out of a tsunami evacuation zone, primarily evacuated as a result of experiencing strong aftershocks. However, many reported that they only evacuated their dwelling (for earthquake safety) rather than evacuating to a safe zone (for tsunami safety).

4.4.2.3 Kaikōura evacuation model - road density results

Vehicle count density is an important indication of the potential number of evacuees travelling along a particular road segment, which can identify potential road congestion. As stated in the results section of this chapter, the vehicle count output shows a strong correlation of high vehicle counts along road segments leading to a safe zone location (Section 4.3). This is particularly evident along Churchill Street, South Bay Parade, State Highway1 South and Killarney Street (see Figure 4.3-3). Survey response data validates this correlation using reported traffic congestion observations. During the 2016 Kaikōura earthquake a number of survey respondents reported they observed many cars evacuating up Churchill Street and Seaview subdivision. This suggests, that during an evacuation, roads leading out of a tsunami evacuation zone and towards the reported safe zones will likely experience higher vehicle counts relative to other road segments. This information could be useful for emergency managers in developing future evacuation response plans and implementation of tsunami risk management strategies, including for future revisions to the tsunami evacuation zones and for the potential placement of tsunami evacuation information boards.

4.4.2.4 Kaikōura evacuation model – evacuation time (road network)

Evacuation time estimates along certain road segments provides an indication of which road segments may take longer to evacuate along. Input characterises including how evacuation 'delay cost' influences the results of this output. As stated in the results section of this chapter (Section 4.3), evacuation time estimates varied across the entire road network and evacuation time estimates were dependent on the length of the road and vehicle count density. Although Churchill Park was reported as experiencing high vehicle counts, the road segments leading to the Churchill Park estimated to have lower evacuation time than other road segments in the immediate area. Road segments including Scarborough Street, South Bay Parade and Fyffee Ave are estimated to take the longest time to evacuate along. This is likely attributed to longer road segments and higher vehicle count, relative to the surrounding area, leading to a reported safe zone location.

4.4.2.5 Kaikōura evacuation model – evacuation time (vehicles)

Evacuation time estimates along certain road segments provides an indication on how long a vehicle (household) may take to evacuate to reach safety. The results of the network evacuation model output provide estimates of varied evacuation time for individual households for the entire township (including households located on higher ground). The output shows there is an evident pattern of evacuation time increasing as the distance increases to reach safety. However, this model assigns the same evacuation delay time for all individual vehicles, therefore, this model does not represent the variation of evacuation delay time prior to evacuating (e.g. taking pre-evacuation actions).

The results of this evacuation model output can be validated using evacuation time estimates reported in the 2016 Kaikōura earthquake tsunami survey. The average time to reach a reported safe zone location was 6.6 minutes. This reflects a similar result to that of Figure 4.3-5, which estimates a large portion of households (primarily residing in a tsunami evacuation zone) taking longer than 5 minutes to evacuate. Self-reported data of the 2016 Kaikōura event, reported evacuation travel times to research safety ranged from one minute to 25 minutes, although the result shown in Figure 4.3-5 exceeded 5 minutes. This estimate could be assumed to reflect the range of evacuation times as was reported during the 2016 Kaikōura event.

Households located in South Bay, Avoca Street and the north end of Beach Road, were estimated to exceed 5 minutes to evacuate. This is likely to be a result of the distance needed to travel to safety and the potential congestion barriers that maybe experienced prior to reaching a designated safe zone location (vehicles evacuation that are closer to designated safe zone locations). This evacuation modelling output could be used to inform evacuation response planning. An example of this could be the prioritisation of tsunami evacuation boards and signs to increase awareness of optimal evacuation routes to safety for both resident and visiting populations.

4.4.2.6 Kaikōura evacuation model – flocking model

The flock simulation model allows for the identification of congestion hot spots through a more detailed analysis of evacuation routes (Trindale et al. 2017). A lower concentration of 'flocking' points means that either more fluid movement of evacuees is occurring along the road network, or there is a speed reduction, indicating potential stand still traffic and crowded locations (Trindale et al. 2017). Examining the results of the flock map, all five safe zone locations experience dense clusters (Figure 4.3-6). This indicates that stand still traffic is likely when evacuees arrive at their safe zone location (assume they stop and do not move to another location). In addition to the five key cluster points, a number of intersection along Kaikōura network shows congestion (dense point cluster), this is particularly evident for road segments leading to a designated safe zone location. An example of this is at 'Post Office Cutting' (Killarney Street) (see insert map on Figure 4.3-6). Other examples of potential congestion, as indicated on the flock map, occur at intersections connecting side roads or 'secondary roads' to primary roads to reported safe locations. This occurs at intersections in South Bay, specifically Kotuku Road and Takaha Drive intersecting South Bay Parade. Congestion reported in the 2016 Kaikōura earthquake and tsunami survey (Chapter 3) validates the results of the flocking model. There is an evident correlation between the flocking model map and reported evacuation routes taken during the 2016 Kaikōura earthquake (Section 3.3). Although assumed traffic congestion is likely to be a result of high vehicle counts along particular road segments, qualitative survey data reported traffic congestion at Post Office Cutting (Killarney Street), Churchill Street, and Seaview subdivision. The results of the flocking model and validation of the model based on survey response data, provides a realistic output that could potentially be used as a traffic planning tool for Civil Defence Emergency Management or official agencies (e.g. police), prior to or during an emergency response. This tool can provide an indication of where certain locations may need prioritisation during an emergency event.

4.4.2.7 Mode of transport and inclusion of empirical data

The ArcCASPER modelling tool was selected as it is able to model vehicle evacuation. Although this tool can model various transportation methods, including vehicle, pedestrian and bike, the evacuation algorithm built into the model is designed for evacuation and traffic modelling parameters. For this reasoning, and because the most commonly reported evacuation transport method during 2016 Kaikōura earthquake and tsunami survey was by vehicle (85% evacuated by vehicle), a vehicle evacuation mode was assigned for the model. Although the evacuation time and congestion estimates provide a degree of realism for representing a large proportion of the township evacuating by vehicle, pedestrian evacuation was also reported during the 2016 Kaikōura earthquake. The evacuation model assumed households used only one vehicle to evacuate to safety. Although it is not clear that this was reported in the survey dataset (Appendix A), it is likely that a number of households may have used more than one vehicle to evacuate. This would depend on individual household composition. A number of survey respondents also stated they needed assistance to evacuate, therefore an assumption could be that not all households used a vehicle to evacuate.

As mentioned in Chapter 2, a limited number of studies have analysed pedestrian evacuation for at risk coastal communities in New Zealand (Fraser et al. 2016; Le. 2016). However, as evacuation modelling techniques improve, it would be beneficial to incorporate the empirical datasets from the field investigations presented in this thesis (Appendix B and D). Incorporating field investigations such as observations of New Zealand's national earthquake drill (ShakeOut) and tsunami hīkoi could refine evacuation modelling outputs, for all evacuation modelling methods, including ArcCASPER. Field investigation observations presented in Appendix B provide a framework for incorporating real-world evacuation time estimates (how long it took students to evacuate from classrooms to their safe zone destination) and allocating designated route paths. This would ultimately increase the realism of pedestrian evacuation modelling outputs, particularly for day-time evacuation scenarios. Appendix B summarises methods and observations from the 2018 Kaikōura High School ShakeOut. An additional field investigation to supplement the 2018 ShakeOut observations of Kaikōura High School (Appendix B), calculated average walking speeds for walking tracks along Kaikōura peninsula using GPS Tracking (Appendix D). Findings of these field investigations present informative dataset for potential future evacuation modelling and response planning.

4.4.3 Limitations and recommendations the evacuation modelling framework

The evacuation modelling framework applied in this thesis provided a useful application to incorporate real-world tsunami evacuation behaviour input parameters. Despite this, there are several limitations that could be improved upon in future work. These include;

1) Exposure data inventory
   - Only usually resident populations were considered. Future research should consider transient populations and seasonal population variations.
   - The population exposure data was based on NZ Statistics 2013 Census meshblock dataset. When available, future work should incorporate updated census data.
   - Building-use categories were remotely sensed using satellite imagery and street-level observations (Google Earth, 2020). Future work should consider validating this asset dataset with field observations.

2) ArcCASPER modelling approach
   - Although CASPER has the ability to model optimal evacuation routes (shortest path) and estimate evacuation time for road segments and evacuees considering congestion potential, the tool has several limitations. One of these limitations is CASPER models congestion based on number of lanes to represent evacuee capacity critical density, saturation density per unit capacity, and the initial delay cost per evacuee (defined in section 4.2) which represent all roads the same way. In reality, congestion rate along certain road segments may vary depending on speed limits, and variation of household evacuation delay time. Future work should consider classifying individual road to improve the accuracy of estimated evacuation times.
   - ArcCASPER does not have the capability to incorporate more than one mode of transportation per simulation so only vehicle evacuation was considered. Future work should consider additional evacuation modes of transportation in simulations.
   - ArcCASPER tool only models people evacuating from their origin point to a safe location. The tool does not consider individual behaviours between origin and destination points that might increase or decrease evacuation estimates for that household (e.g. altering route to assist neighbours or family, or subsequent natural cues prompting an increase in evacuation speed). Future research should consider diverse evacuation speeds of the population.

3) Empirical evacuation behaviour data
    - Only self-reported safe zone destinations were included in the network evacuation model. Unreported safe zone destinations were included however there are likely additional safe zone destinations within Kaikōura township.
    - Although reduced speeds due to congestion are considered in the network evacuation model, other variation of vehicle evacuation speeds were not considered (e.g. exceeding the speed limit). Future work should consider incorporation the survey results on evacuation speed variation.
    - The model does not incorporate real-world physical barriers causing congestion (e.g. a fallen lamp post, road damage, bridge collapse). Future models should incorporate congestion barriers (empirical or simulated)

4.5 Chapter summary

This chapter addressed Objective two of this thesis: Develop an evacuation modelling framework and test by modelling likely evacuation behaviours of coastal Kaikōura residents, to ensure that it is applicable to other communities at risk from tsunami in New Zealand and international. This chapter developed and provided an evacuation planning tool framework. It then presented and discussed results of an applied evacuation modelling method (ArcCASPER) for the Kaikōura township. The results presented in the form of maps, allow identifying the optimal evacuation routes as well as the unfeasible or less desirable evacuation routes. This information could be used to inform future tsunami risk management initiatives in Kaikōura.

The ArcCASPER tool was applied within the evacuation planning tool framework to estimate evacuation time of households and time and congestion along individual road segments within Kaikōura's road network. The key findings are;

- The estimated time for the entire resident population to evacuate to safety was 12:05 minutes.
- High vehicle density counts were estimated at the following locations;
    - Churchill Street
    - Killarney Street (Post Office Cutting)
    - Scarborough Street
- High evacuation times were estimated for households located at;
    - South Bay

- Avoca Street
- North end of Beach Road

The following chapter summarises key findings of the evacuation behaviour and modelling framework presented in this thesis.

Chapter 5: Summary and recommendations

5.1 Summary and conclusions

As outlined in Section 1.2, this Masters of Science thesis had two aims. The first aim was to develop an empirical evidence-base that provides a comprehensive understanding of human evacuation behaviours and dynamics of a local-source tsunami threat. The second aim was to improve current evacuation modelling methods through the input of real-event evacuation behaviour characteristics. This involved combing scientific and local knowledge across the three risk assessment phases of the Risk Management Framework (Section 1.3-4) to help inform national and global tsunami risk management and emergency response planning (risk treatment options).

The first aim of this thesis was addressed by using the Mw 7.8 2016 Kaikōura earthquake and tsunami (local-source) as a case study to assess the immediate reactions and evacuation behaviour dynamics of residents in the coastal town of Kaikōura during and following the 2016 Kaikōura earthquake. The survey instrument used to collect self-reported evacuation response and dynamics in Chapter 3 was then used to address research aim two, by informing realistic rules and interactions for the development of a network-based vehicle evacuation model for the Kaikōura township (Chapter 4). Key findings and the methodological framework presented in this thesis contribute to the global knowledge on understanding immediate reactions and evacuation behaviours of a local source tsunami threat, and constitute real-word evidence to inform and improve evacuation modelling techniques. Findings could be used to help inform national and global tsunami evacuation preparedness and contribute to mitigating the number of casualties in future events through appropriate tsunami risk management and response initiatives. These findings are explained and discussed in more detail in the following sections.

5.1.1 Improving current understanding of immediate reactions and evacuation behaviours of a near-source tsunami threat (Chapter 3)

The tsunami generated by the 2016 Kaikōura earthquake provided a valuable opportunity to address a global tsunami research gap (outlined in Chapter 1), to assess a complete evacuation response of a near-source tsunami threat. A survey instrument was developed with disaster risk management practitioners, with a design focus on improving the understanding on of warning and evacuation decision-making, evacuation movements and associated dynamics, and risk awareness influence on evacuation response. A total of 1055 surveys were distributed in the Kaikōura township, with 131 returned (12.4% return rate). Key findings of survey results as reported in Chapter 3 include;

- Prior to the 2016 Kaikōura earthquake, respondents had a ‘good’ (44%, n=55) or ‘very good’ (25%, n=31) level of knowledge on tsunami hazard and the need to evacuate.

- Of the total survey respondents (n=131), 69% evacuated.
- A large proportion (79%, n=88) of respondents who reported that they evacuated did so due to the potential tsunami threat during and immediately after the 2016 Kaikōura earthquake.
- The vast majority (95%, n=64) of those living in the tsunami evacuation zone at the time reported that they evacuated. Almost half (45%) of respondents who were residing outside tsunami evacuation zones (n=42) evacuated, with most reporting that they did so because of 'severe shaking and aftershocks'.
- Reported congestion barriers included bridge failures, fallen lamp post, and road damage due to subsidence caused by the earthquake. These barriers slowed down evacuation time of some residents, particularly along Churchill Street and Killarney Street, adding minutes to their total evacuation time.
- More than half (55%) of respondents evacuated prior to the first tsunami wave was recorded after the earthquake (within 10 minutes). Ninety percent had reported they evacuated by the time of which the tsunami highest point was measured on the Kaikōura sea level gauge 40 minutes after the earthquake.
- The time at which respondents stayed at their evacuation point ranged from 30 minutes to 48 hours. The most common reported time respondents stayed at their evacuation point was 6 hours (18%).
- The three most commonly reported preparedness actions residents have made following the 2016 Kaikōura earthquake include; prepared an emergency kit with essential items (57%, n=70), discussed an evacuation plan with friends and family or household members (54%, n=67) and prepared a go bag containing essential items (43%, n=53).

While this section presented the summary of the survey results, the next section (section1.2-2) presents key conclusions of the application of empirical data derived from this dataset to inform evacuation modelling outputs

5.1.2 Development of a network-based based vehicle evacuation model for Kaikōura township (chapter 4)

The empirical dataset from the survey instrument (Chapter 3) provided the opportunity to inform 'real event' evacuation rules and interactions (safe zone locations, travel mode and vehicle speed) to develop a realistic network-based vehicle evacuation model for the Kaikōura township (chapter 4). Under an 'ideal night-time' scenario, where households evacuate using one vehicle, the results of the ArcCASPER network model predicted the total evacuation time of 12:05 minutes for the entire township to reach safety. The results of the model poses a great risk to the Kaikōura community given the townships close proximity to near source tsunami threats (Kaikōura Canyon and Hikurangi subduction zone). Evacuation time estimate of the entire township suggest most of Kaikōura residents will evacuate prior to the arrival of tsunami waves generated by a Hikurangi subduction zone earthquake, however the evacuation time of 12:05 minutes is a concern for the immediate risk of tsunami generated by a submarine landslide of earthquake along the Kaikōura Canyon which waves are predicted to reach the coast in a matter of minutes. In this case, modelling results of predicted evacuation times and potential congestion could be used to identify high risk areas for prioritisation of tsunami risk management initiatives. An example of this, where modelling results indicate greater evacuation time for households to reach safety include South Bay, along Avoca Street, and north end of Beach Road. The results of the network-based evacuation model can be used as an informative evacuation planning tool, particular to improve on tsunami risk management initiatives in Kaikōura such as identifying key locations for tsunami evacuation boards and signs and the development of a local level response plan.

Based on the summarised results above, the following section (1.2) provides key recommendations for applications and key recommendation for future work.

5.2 Key recommendations

This sections provides key recommendations applicable at both a local and national scale based on the conclusions drawn from the case study.

I. Implement additional tsunami risk management initiatives including public education and evacuation planning:

   Public education is a key component of tsunami risk management. Public education aims to raise awareness on tsunami risk and knowledge on how to interpret natural and official warnings and appropriate protective actions to take during an emergency response.

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   - Continue efforts on raising public awareness through the application of community preparedness workshops, promotion of national public education awareness campaigns, and evacuation planning initiatives.
   - Evacuation planning initiatives could include:
     - Implementation of tsunami information boards and evacuation signs in high risk areas vulnerable to local-source tsunami threat. Placement of signs and information boards should consider high residents and visitor population densities and potential congestion pinch-points.

- Encourage all schools, workplaces and households to participate in national and local level evacuation drills annually (ShakeOut). A recommendation would be to encourage local-level evacuation drills more frequently e.g. bi annually, to increase the level of awareness on correct protective actions and become more familiarised on planned evacuation routes.
    - Implementation of blue lines to increase public's awareness on tsunami inundation extent of a worst-case scenario.
  - Future policy and decision-making can be informed by the learnings of this thesis. Including, but not limited to; land-use planning and national guidance and technical standards on evacuation planning.

II. Improve on research methodology (see future work in section 5.3)

5.3 Key recommendations for future work

Recommendations for future work include:

1) **Conduct further evacuation modelling for Kaikōura and/or coastal communities at risk to local-source tsunami threat in New Zealand.** The ArcCASPER evacuation modelling approach used in this thesis was a useful tool to determine evacuation time estimates and potential congestion for Kaikōura. However, whilst real-event empirical data was incorporated as key inputs for the evacuation model (safe zone locations, mode of transport and evacuation speed), to inform realistic evacuation time outputs and congestion potential, the tool lacked the ability to incorporate additional survey data that would represent the complexities of human behaviour during an evacuation event. Recommendations for future work include:

    I. Model evacuation time and congestion potential outputs using other common evacuation modelling approaches. This could include agent-based modelling and/or least cost distance modelling. The outputs of these models could be used to test and compare evacuation modelling results of the Network-based evacuation model.

    II. Agent-based modelling is well recognised and an increasingly applied evacuation method for its ability to incorporate multiple characteristics of human evacuation behaviour. It is recommended to apply this modelling approach to represent vehicle and pedestrian evacuation.

    III. Model various spatio-temporal evacuation scenarios to represent population distribution across the time of day, month and seasons. This should incorporate transient population fluctuations to represent more realistic scenarios.

IV. Additional research should incorporate field investigation results of average walking speeds and evacuation response behaviour of local and national evacuation drills

2) **Conduct further evacuation behaviour research for other communities at risk to local source tsunami globally and in New Zealand.** The evacuation behaviour and modelling framework presented in this thesis provides an approach to assess immediate evacuation response to a local-source tsunami threat. This framework can be applied and improved in the future by:

I. Conducting evacuation behavioural research, using the survey instrument to assess complete evacuation responses following national and international tsunami evacuation events.

II. Coordinate a science and practioners network to conduct consistent data collection and research following future tsunami evacuation response events.

III. Refine survey instrument by including subsequent questions addressing participant experiences with emergency mobile alerts, prior to and during evacuation events.

IV. Analyse the long term (days – years) population effects in Kaikōura District following 2016 Kaikōura earthquake event.

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Appendices

Appendix A: Kaikōura earthquake tsunami evacuation survey

A1 Human Ethics Committee approval letter

This appendix provides a copy of the approval letter of the low risk application to the Human Ethics Committee. This letter confirms the review and approval to conduct the 2016 Kaikōura earthquake tsunami evacuation survey.

UC UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

HUMAN ETHICS COMMITTEE

Secretary, Rebecca Robinson
Telephone: +64 03 369 4588, Extn 94588
Email: human-ethics@canterbury.ac.nz

Ref: HEC 2018/100/LR

4 January 2019

Laura Tilley
Geological Sciences
UNIVERSITY OF CANTERBURY

Dear Laura

Thank you for submitting your low risk application to the Human Ethics Committee for the research proposal titled "Understanding Community Evacuation Dynamics Through Agent-Based Modelling in Kaikōura Following the 2016 Kaikōura Earthquake and Tsunami".

I am pleased to advise that this application has been reviewed and approved.

Please note that this approval is subject to the incorporation of the amendments you have provided in your email of 12th December 2018.

With best wishes for your project.

Yours sincerely

pp. R. Robinson

Professor Jane Maidment
Chair, Human Ethics Committee

University of Canterbury Private Bag 4800, Christchurch 8140, New Zealand. www.canterbury.ac.nz

F E S

A2 Human Ethics Committee – Low risk student application form

This appendix provides a complete copy of the Human Ethics Committee low risk student application form to conduct the 2016 Kaikōura earthquake tsunami evacuation survey.

Human Ethics Committee – Student Application

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

For Office Use Only –	**HEC Reference:**	
Date Received:	**Reviewers:**	
Date Approved:	**Approved:**	**(HEC Chair)**

HUMAN ETHICS APPLICATION COVERSHEET – STUDENT

Please remember that your audience for this application form, as well as all forms for participants, will include community members and scholars from outside your discipline and therefore must be written in everyday language. Please do not delete any part of this form.
This form should be completed after reading the *Research Involving Human Participants* issued by the Human Ethics Committee available at http://www.canterbury.ac.nz/study/ethics/

Will another ethics committee review this application?

- If a New Zealand Health and Disability Ethics Committee (HDEC) is reviewing your project, please send your HDEC application to us with this coversheet, and then the approval. You do not need to fill out the full University of Canterbury application form.
- If you have ethics approval from another institutional ethics committee (e.g. another New Zealand or Overseas University ethics committee) and you will conduct your research in the country of that ethics committee, please send this coversheet only with that application and the later approval letter, and an explanatory email. You do not, initially, need to fill out the full University of Canterbury application form.

Please ***Bold*** your answers

Project Title: Understanding community evacuation dynamics through agent-based modelling in Kaikōura following the 2016 Kaikōura earthquake and tsunami

Status of Research: Master of Science

Applicant

Name: **Laura Tilley**

University Programme/ Department: **Disaster Risk and Resilience/Geological Sciences**

Applicant's Email: **laura.tilley@pg.canterbury.ac.nz**

Primary Telephone No: **027 385 7291**

Primary Supervisor Title, given name and family name

Name: **Thomas Wilson**

University Programme/ Department: **Disaster Risk and Resilience/Geological Sciences**

Supervisor's Email: **thomas.wilson@canterbury.ac.nz**

Primary Telephone No: **+64 3 364-2987 ext 94503**

Other Supervisors

Name: **Matthew Hughes**

University Programme/ Department: **Civil and Natural Resources Engineering, University of Canterbury**

Supervisor's Email: **matthew.hughes@canterbury.ac.nz**

Primary Telephone No: **+64 3 364 2987 ext 3328**

Name: **Sarah Beaven**

University Programme/ Department: **Disaster Risk and Resilience/Geological Sciences**

Supervisor's Email: **sarah.beaven@canterbury.ac.nz**

Primary Telephone No:

RESEARCHER'S SIGNATURE

I *Laura Tilley* have considered, the various ethical issues involved in this research and have personally completed the application form; I have discussed this proposal with my supervisor(s), and I will conduct this research within the bounds of any approval given by the Human Ethics Committee of the University of Canterbury.

Signed: ____________________ Dated: 25/11/2018

Is the approval of this application a necessary pre-requisite for the Dean of Postgraduate Studies to formally accept your PhD proposal? **NO**

SENIOR SUPERVISOR'S SIGNATURE

As the primary supervisor of *Laura Tilley's* research project I, *Thomas Wilson* consider that the design and documentation are of a standard appropriate for a research project carried out in the name of the University of Canterbury.

Signed: ____ ____________ Dated: 29 November 2018

LOW RISK PROCESSES (TO BE COMPLETED BY THE PRIMARY SUPERVISOR)
The low risk process for students differs from a full application only in that it is examined solely by the Chair of the Human Ethics Committee. As a result it may be possible to reply to the applicant in 7 days. It is to be signed only by supervisor(s).

Please explain why the research is low risk, noting the information overleaf
If no explanation is provided, the application will be considered a full application.

The purpose of this research is to better understand the evacuation dynamics that occurred in Kaikōura as a result of the 14 November 2016 Kaikōura earthquake at 12.02 a.m. The intention is to derive this information from a range of sources, including media reports, official reports, social media, traffic monitoring sensors, and surveys to Kaikōura residents and accommodation providers. These data will be used to gain an understanding of the dynamics of this evacuation dynamics, and to inform agent-based modelling to develop a tsunami evacuation model for the Kaikōura community. Outputs are expected to be of particular value for emergency management personnel, and policy and hazard analysts involved in tsunami evacuation planning. The project has been initiated in response to a request that arose out of ongoing collaborative research support for the recovery effort in the Kaikōura District. In the first instance findings will help Kaikōura District Council Emergency Management personnel and Environment Canterbury hazard analysts to select optimal tsunami evacuation routes and safe zone locations for the Kaikōura community. Findings are also expected to contribute directly to more effective tsunami evacuation planning for Kaikōura and New Zealand.

Initial collection of available open source data and official reports has begun. This research is now at the stage of inviting residents and moteliers in the Kaikōura community to participate in a survey and provide information on their evacuation response. This HEC application pertains only to this survey.

The survey is expected to be low risk for both participants and researchers. The survey aims to gather information from residents and moteliers concerning remembered evacuation behaviour and responses following the 14 November 2016 Kaikōura Earthquake and Tsunami. Questions will ask about

- Evacuation origin and destination
- Modes of transportation used to evacuate
- Estimates of travel time to destination and initial response time
- Experience and locations of traffic congestion
- Use of known walkways or tracks

It is not expected that the surveys will cause cultural offence. However we are mindful that this could have been a distressing event for some people, and that the survey may remind them of this distress. To mitigate this risk the survey will include information (in the introduction and on the final page) for those wishing to access support from the Mental Health Education and Resources Centre, which includes information about a range of emotional and mental health resources (www.mherc.org.nz/seeking-help, 033655344).

Signed (Senior/Primary Supervisor only) ___ [signature] Dated: 29 November 2018

SUBMISSION INSTRUCTIONS.

Please submit ONE electronic file containing all the necessary documents in a PDF format and ONE fully signed hard copy. Exceptions may be made, but must be discussed first with the HEC Secretary. Processing of HEC applications is unable to begin until a hard copy of the application has been received by the Ethics Office.

Electronic copies should be emailed to human-ethics@canterbury.ac.nz. Hard copies should be sent to the Secretary, Human Ethics Committee (Level 5, Matariki South).

Low Risk application information:

Research may be considered low risk when it arises from

a Masters or PhD theses where the projects do not raise any issue of deception, threat, invasion of privacy, mental, physical or cultural risk or stress, and do not involve gathering personal information of a sensitive nature about or from individuals.

b Masters or PhD level supervised projects undertaken as part of specific course requirements where the projects do not raise any issue of deception, threat, invasion of privacy, mental, physical or cultural risk or stress, and do not involve gathering personal information of sensitive nature about or from individuals.

c Undergraduate and Honours class research projects which do not raise any issue of deception, threat, invasion of privacy, mental, physical or cultural risk or stress, and do not involve gathering personal information of sensitive nature about or from individuals, but do not have blanket approval as specified in Section 4 of the Principles and Guidelines.

3. No research can be counted as low risk if it involves:

(i) invasive physical procedures or potential for physical harm
(ii) procedures which might cause mental/emotional stress or distress, moral or cultural offence
(iii) personal or sensitive issues
(iv) vulnerable groups
(v) Tangata Whenua (if in doubt please see the comments under question 12 on the application form)
(vi) cross cultural research
(vii) investigation of illegal behaviour(s)
(viii) invasion of privacy
(ix) collection of information that might be disadvantageous to the participant
(x) use of information already collected that is not in the public arena which might be disadvantageous to the participant
(xi) use of information already collected which was collected under agreement of confidentiality
(xii) participants who are unable to give informed consent
(xiii) conflict of interest e.g. the researcher is also the lecturer, teacher, treatment-provider, colleague or employer of the research participants, or there is any other power relationship between the researcher and the research participants.
(xiv) deception
(xv) audio or visual recording without consent
(xvi) withholding benefits from "control" groups
(xvii) inducements (over a nominal amount of $20, for example to recompense travel costs)
(xviii) risks to the researcher

This list is not definitive but is intended to sensitise the researcher to the types of issues to be considered. Low risk research would involve the same risk as might be encountered in normal daily life.

DESCRIPTION OF THE PROJECT

1. What does the project seek to do?

This project seeks to:

- **Gain an understanding of evacuation dynamics (origin, route, destination, timing and mode of transport of evacuation) in Kaikōura following the 14 November 2016 Kaikōura earthquake and tsunami.**
- **Use the results of the surveys e.g. evacuation times, evacuation routes, origin and destination evacuation points to inform agent-based evacuation modelling.**
- **To use the results of the agent-based tsunami evacuation model and surveys to better inform tsunami evacuation planning in Kaikoura and New Zealand.**

2. What is the research question or hypothesis of this project?

The research questions are:

- **What were the evacuation dynamics in Kaikōura following the 2016 Kaikōura earthquake and tsunami?**
- **How can these findings be used to inform agent-based tsunami evacuation modelling in order to improve future tsunami evacuation planning?**

3. Describe how this project arose i.e., please explain the academic area or issue etc. which generated the question(s) to be examined – this is to allow lay members of the committee some context for the research.

The topic arose out of discussions in 2017 involving the supervision team (Thomas Wilson and Matthew Hughes), hazard analyst Helen Jack from Environment Canterbury, and Kaikōura District Council Emergency Management officer Kd Scattergood. Both these practitioners were concerned about evacuation as a result of the 2016 Kaikōura earthquake and tsunami, yet were unsure exactly what happened – with only anecdotal accounts available to inform future evacuation planning. They therefore requested that this project be carried out as part of on-going collaborative research supporting recovery efforts in the Kaikōura District.

This research also aligns with a two-year project called 'Quicker Safer Tsunami Evacuations' funded by the Natural Hazard Research Platform involving GNS Science, University of Canterbury, Massey University and East Coast LAB; and is funded as part of the National Science Challenge 'Resilience to Natures Challenges' Rural co-creation laboratory

4. How will you go about answering the research question?

A survey will be used to answer the research questions by collecting responses from community members (residents and accommodation providers) who evacuated. This primary data, which is rare in global disaster evacuation knowledge, will contributing to a more detailed picture of the evacuation dynamics undertaken by the Kaikōura community as a result of the 14 November 2016 Kaikōura earthquake and tsunami. This data will be supplemented and informed by analysis of additional data sources:

1. Official media reports and social media platforms
2. Field data collected by the researchers e.g. average walking speeds along tracks in Kaikōura
3. Evacuee data collected by GNS Science (will be shared on the basis of prior collaboration agreement within the NHRP research programme) to compare with and inform an agent-based tsunami evacuation model for Kaikōura

The survey data will be analysed, and will contribute to data input for a bespoke agent-based tsunami evacuation model for Kaikoura.

Information about the Participants

5. Who are the participants and why have they been chosen to be asked to participate?

   Participants will be members of the Kaikōura community who were living or present in Kaikōura at the time of the Kaikōura earthquake and tsunami on 14 November 2016. The focus is on residents and motel/hotel owners, since this earthquake occurred at 12.02 a.m. when other businesses were closed.

6. How many participants will be involved (of each category where relevant)? Please include statistical justification where necessary.

   The aim is to collect as many survey responses as possible from residents and motel/hotel owners present or living in Kaikōura during the 14 November 2016 earthquake and tsunami. Hardcopies of the survey will be letter-box dropped in the coastal township, inviting all residents (the township population is approximately 2,080) to complete the survey (Statistics New Zealand, 2013). We would like to give all households the opportunity to participate in this study, however a high participation rate is unlikely given the geographic scale of the research area, seasonal visitor trends, and high numbers of holiday homes in the township. 50 survey responses would be a satisfactory response.

   Statistics New Zealand. (2013). 2013 Census QuickStats about a place: Kaikōura District. Retrieved from http://archive.stats.govt.nz/Census/2013-census/profile-and-summary-reports/quickstats-about-a-place.aspx?url=/Census/2013-census/profile-and-summary-reports/quickstats-about-a-place.aspx&request_value=14704&reportid=10&tabname

7. What selection criteria and/or exclusion criteria will you use? i.e., randomly, by age, gender, ethnic origin, other – please give details. What plans do you have if the recruitment phase is too successful, or does not recruit enough participants?

Selection will be on an opt-in basis, based on availability, willingness to participate, and whether or not potential respondents were present or living in Kaikōura at the time of the 2016 earthquake event.

8. Describe how potential participants will be identified and recruited?

The researcher (LT) will undertake a letter drop to all/most houses and motels/hotels in the Kaikōura Township. Kaikōura Township including South Bay (NZ Statistics 2017 Area Unit) is the key focus of this research (Figure 1). If and when possible the researcher (LT) will also hand out hard copies of the surveys in Kaikōura's town centre (along West End) during a pre-planned field trip in February. An online version of the survey link will also be available to selected online community groups e.g. Facebook Kaikōura Notice Board and Kaikōura District Council Facebook Page, where members will be invited to participate and share the survey link.

9. Does the project involve recruitment through advertising? **YES**

This research (online survey link) will be posted on Kaikōura's community Facebook page which is called 'Kaikōura Notice Board'. Laura requested permission to join the page, in which she mentioned she is not a local but carrying out research in Kaikōura. The administrators accepted her request on 10/11/2018, making her a member of this Facebook page. Administrators will be messaged directly and asked for consent to post the online survey link on this page. If they believe their platform is not suitable to post the online survey link it will not be posted.

The Kaikōura District Council Emergency Management officer (part of the research team) has also offered her connections to advertise this research and encourage interested residents to participate in the survey. The Kaikoura District Council Emergency Management Officer has offered to put the survey link on the Kaikoura District Council website and to write a story on this research for the council newsletter this will include the survey link (see attached email).
The survey will also be advertised on:

- **Kaikōura District Council Facebook Page**
- **Kaikoura District Council Newsletter**
- **Kaikoura Notice Board (community Facebook page)**

10. How much time are participants asked to contribute to the research?

Approximately 15 - 20 minutes

11. Is any form of inducement to be offered? **NO**

12. How will the participants be treated?

Participants will receive a letter in their letterbox inviting them to participate, and giving them two options. If they choose to complete a hard-copy survey they can use the prepaid addressed envelope to return the completed survey, or alternatively photograph the completed pages and email them to laura.tilley@pg.canterbury.ac.nz

Alternatively, participants can use a link that take them to the online survey. This link will be provided on the hard-copy survey. It will also be made available on relevant social media platforms, that will allow participants can access the survey through a shareable link https://bit.ly/2FLSozu

The survey is comprised of a series of questions and check-box style answers, with directions to select one response only. Some questions include a drop-down option where the respondent can use additional text to answer in more detail, or otherwise comment in response to the question. In the hard-copy survey, participants that evacuated will also be asked to draw their evacuation route on a map. For the online survey, there will be a text box where participants will be asked to explain their evacuation route in detail.

13. Will forms for participants need to be translated? **NO**

14. Will the project require engagement and consultation with iwi Māori? **NO** (delete inapplicable)
• Will the design, implementation or outcomes of the project have implications for iwi Māori?
• Will there be significant Māori content, use of culturally sensitive material or knowledge?
• Will the research require access to Māori sites, or sampling of flora/fauna?
• Will there be Māori participants or subjects?
• Will the ethnicity of participants be recorded and likely to result in different treatment for Māori participants during the study or result in statements specifically about Māori in the results?

If the answer is yes to any of the questions above, you should contact your College's Māori research advisors. Contact details for the Maori advisors in your College and other important information and advice regarding engaging with Māori are available at
http://www.research.canterbury.ac.nz/maoriresearch/ntceg.shtml
The advisor will be able to help you assess whether you need to seek further consultation and engagement, and whether you need to contact the Kaiārahi Maori research in order to access the Ngāi Tahu Consultation and Engagement Group. Should you have already organised a Māori steering group/senior Māori advisor to work with you on your project, please check with them on the need for consultation.

OTHER PARTIES WITH AN INTEREST IN THE RESEARCH

15. Does the project require permission of an organisation, other people, to access participants or information? **Yes – as mentioned above, permission/consent will be asked of social media platform administrators to provide a shareable link to the survey on relevant Facebook Pages, and the Kaikōura Gets Ready webpage. It is expected that those who manage or own motels or hotels will have the authority to respond to the survey without requiring permission from other parties.**

16. Will the project require Community consultation? **NO**

17. Is the project funded externally? **NO** (delete inapplicable). If yes, please provide details and discuss any conflict of interest issues that may arise.

18. Is the project commissioned by or carried out on behalf of an external organisation(s)? **NO**

19. Is the project to be part of the CEISMIC digital archive? **NO**

DATA COLLECTION

20. Does the project involve a questionnaire? **YES**

(a) Explain how and why the questionnaire(s) will be anonymous or confidential

Confidential: Survey responses will not include names, but will include gender and street addresses, and so will not be strictly anonymous. Raw data will be kept confidential to the researcher and her supervisors. Data will be otherwise anonymised, so that identifying details will not be discernible in any material that enters the public domain.

(b) Explain how the questionnaire will be distributed and collected.

The survey will be distributed in two ways. Access to an online survey will be provided as a shareable link on Facebook community pages. A letter box drop of a hard-copy

survey will include all or most residential properties and motel/hotel complexes in the Kaikōura Township. The researcher has a pre-planned field trip (1 week) in February 2019 to distribute the surveys. She will also spend a couple of hours standing along West End and handing out surveys to residents if necessary. The researchers are mindful that this is a tourist destination, and that many of the properties receiving the survey are likely to be holiday homes. Upon completion of the form, participants will either email photos of the forms to laura.tilley@pg.canterbury.ac.nz or post them to Laura Tilley at UC in a pre-paid envelope (which will be provided with the letter drop).

21. Does the project involve a structured or semi-structured interview? **NO** (delete inapplicable). If yes, please list the topics or the specific questions to be covered.

22. Does the project involve an unstructured interview? **NO**

23. Does the project involve focus groups? **NO**

24. Does the project involve recording of Audio, Video or Images? **NO**

25. Will participants will be given the opportunity to check the transcript and/or notes of their interview/focus group? **N/A**

Informed and Voluntary Consent

Please note: The HEC recommends that participants receive an information sheet, which they must be able to retain, unless there are good reasons for not adopting such a procedure. The information sheet(s) and the consent form(s) should be separate. Projects which **only** involve an anonymous questionnaire may not necessarily require a separate information sheet, provided that the questionnaire includes your name and contact number as well as the other points contained in the information and consent templates available on the HEC website. *Please note: so that participants can retain a copy of the information sheets, the information sheet(s) and the consent form(s) should be separate.*

26. By whom and how will information be given to potential participants?

A hard copy information sheet will be provided to participants along with the survey form. A written consent form will also be provided as the first page of the hard copy survey. If this form has not been completed the relevant responses will not be included in the survey results.

The online survey will open onto an information sheet and a consent form. Participants will be asked to provide consent before proceeding to the survey.

When appropriate or if requested, the researcher (Laura) will meet with community members to discuss the survey form, and clarify any issues people might have. Laura

(and possibly a research assistant) has a week-long field trip scheduled for early –mid February 2019, in order to distribute hard-copy surveys. Both will also be available to meet with residents and answer questions over this time. The information sheet will also encourage respondents to get in contact with Laura or the supervision team by phone or email if they have any questions or concerns. It will be clear that the participant can say no or withdraw from completing the survey at any point (see 'Information Sheet' attached to this application).

27. Are all participants competent to give consent on their own behalf? **YES**

If no, please explain,

(a) why they are not competent to give informed consent on their behalf?

(b) how consent will be obtained in the absence of that competency?

(c) if applicable, how will assent to participate be gained?

Privacy and Confidentiality

28. Will information pertaining to or about the participants be obtained from any source other than the participant? **NO**

(a) the identity of the third party or parties.

(b) why such information is needed.

(c) how will you obtain consent from the participant and the third party/parties) to gather that data.

(d) the processes you will use to obtain that data.

29. Is information that identifies participants to be given to any person outside the research team, or if identification of or attribution of comments by participants is sought, please explain how and why. **NO**

30. Please explain how confidentiality of the participants' identities will be maintained in the treatment and use of the data.

Survey results will be stored in a separate password-protected folder on the researcher's UC computer and on a geology drive (Cougar), behind a password protected folder. All data will be backed up on the UC server (geology Cougar drive is automatically backed up). Hard copies of completed surveys will be stored in a locked draw in the researcher's (Laura) office. Non-identifying data will be managed by using codes that are assigned to a participant on the consent form. Identifiable details, such as street addresses, will only be used to analyse evacuation routes and times, and to geocode data in evacuation models.

31. Is an institution (e.g., school, business, etc.) to which participants belong to be named or be able to be identified in the publication or presentation of this project? **NO**

32. Where will the project be conducted?

Hard-copy surveys will be handed out to all residential properties in the Kaikōura Township (see map above). It is expected that residents will complete the survey at their leisure in a venue of their choosing.

Since the focus of the survey is evacuation, commercial accommodation providers are the only businesses included in the letter box drop. With the exception of accommodation providers, commercial businesses will be excluded from this research, since the 14 November 2016 Kaikōura earthquake occurred at 12.02 a.m. a time when most commercial premises are unoccupied.

RISK

33. Is there any risk to physical well-being? **NO**

34. Could participation involve mental stress or emotional distress? **YES**

We are mindful that this could have been a distressing event for some people, and that the survey may remind them of this distress. We are also aware that Kaikōura communities are still in the recovery phase, when after-effects including secondary stressors (such as dealing with insurers, financial hardship and other impacts) often increase the stress of residents and communities. To mitigate these risks the survey and information sheet are designed to make it very clear that participation is voluntary, and to foreground information (in the introductory and final pages) for those wishing to access support from the Mental Health Education and Resources Centre, which includes information about a range of emotional and mental health resources (www.mherc.org.nz/seeking-help, 033655344). Researchers will also advise participants that there is no obligation to engage in the research process if psychological distress is a possibility.

35. Is there a possibility of causing moral or cultural offence, inadvertently or otherwise? **NO**

36. Is deception involved at any stage of the project? **NO**

DATA STORAGE AND FUTURE USE

37. Please provide details of how the data will be securely stored, and how you will separate identifying and non-identifying data.

Returned hard-copy surveys will be stored in a locked cabinet in the researcher's office. Results of the hard-copy surveys will be transcribed into an excel format which will stored on a password-protected file on the researchers computer as well as an external hard-drive.

Identifying data (e.g. the consent form) and non-identifying data will be specifically coded and stored in separate files.

38. Who, apart from the researcher and their supervisor (where applicable) will have authorised access to the data?

    No one

39. What will happen to the raw data at the end of the project?

    The data will be stored on the researcher's UC computer on a geology drive (Cougar), behind a password protected folder a password-protected file, this will be stored within the Department of Geological Sciences for 5 years, and then destroyed. Hard-copy surveys will be stored in the researcher's draw until this MSc is completed, then they will be destroyed.

40. What plans do you have for the publication of the data?

    The data collected from the surveys is expected to contribute significantly to the development of an agent-based tsunami evacuation model for Kaikōura. The results will contribute to an MSc thesis, and additional published findings in the form of at least one paper submitted to a relevant peer-reviewed journal in the field of tsunami evacuation research.

41. Please describe plans for future use of the data beyond those already described above.

    The MSc (including survey responses to inform data into the evacuation model) will be shared with emergency management personnel to inform tsunami evacuation planning in Kaikōura.

A3 Kaikōura earthquake and tsunami information sheet and survey

This appendix provides a copy of the information sheet and 2016 Kaikōura earthquake tsunami survey booklet.

Understanding Kaikōura evacuation dynamics following the 2016 Kaikōura Earthquake

Information Sheet

February – March 2019

UC University of Canterbury Te Whare Wānanga o Waitaha

Environment Canterbury Regional Council Kaunihera Taiao ki Waitaha

Kaikōura District Council

GNS Science

Natural Hazards Research Platform

Resilience to Nature's Challenges

National Science Challenges

Department: Disaster Risk and Resilience/Geological Sciences
Telephone: +64 7 385 7291
Email: laura.tilley@pg.canterbury.ac.nz
February - March 2019

Understanding Kaikōura evacuation dynamics following the 2016 Kaikōura earthquake and tsunami

Information Sheet for Participant

Kia ora my name is Laura Tilley and I am a student at the University of Canterbury studying towards a Master of Science in Disaster Risk and Resilience. This research will contribute to my thesis.

About the research

The evacuation of the Kaikōura community following the 14th November 2016 Kaikōura earthquake provides a valuable learning opportunity to understand evacuation behaviour to better inform planning for future tsunami event. We invite you to participate in this survey which aims to understanding Kaikōura evacuation dynamics following the 2016 Kaikōura earthquake and tsunami. Responses from this survey will be used to help develop a better tsunami evacuation plan for the Kaikōura community, which is exposed to tsunamis from both close to shore and across the Pacific Ocean. This research has been requested by Kaikōura District Council Civil Defence & Emergency Management and Environment Canterbury as part of on-going collaborative research supporting recovery in the Kaikōura District. It is funded through Resilience to Nature's Challenge – a National Science Challenge funded by the Ministry of Business Innovation and Employment.

Aims of the research

This research project seeks to increase understanding of the evacuation dynamics following the 2016 Kaikōura earthquake, including factors such as how many people evacuated, where they evacuated from and to and how, and how long it took. As well as surveying Kaikoura residents we will also evaluate official reports and reviews, and information on social media.

The results of this evaluation will inform an evacuation model being developed for the Kaikōura community. Survey data of actual human behaviour during an evacuation will be used to test, refine and validate the model. Findings of this research will help with future evacuation planning and increase community readiness and response for future earthquakes and tsunamis.

This research will be undertaken by University of Canterbury researchers Laura Tilley, Associate Professor Thomas Wilson, Dr Matthew Hughes and Dr Sarah Beaven, in collaboration with Environment Canterbury, Kaikōura District Council Civil Defence & Emergency Management and GNS Science.

What will the research be used for?

The findings will be shared with Environment Canterbury, Kaikōura District Council Civil Defence & Emergency Management and GNS Science to help inform tsunami evacuation planning.

Your involvement in the study

You are being invited to take part in this research. If you choose to do so, your involvement will consist of providing information about what you did immediately after the November 2016 Kaikōura earthquake. The survey will ask if you evacuated or not, and if so, where to, what routes you used, how long it took to get there, and so on. If you evacuated your home following the initial earthquake shaking, you will be invited to draw your evacuation route on an enlarged map of Kaikōura. We estimate completing the survey will take approximately 15 - 20 minutes.

The survey can be completed in this hard-copy booklet, or if you prefer you can access an online version of exactly the same survey at **https://bit.ly/2FLSozu**. To return the hard-copy booklet, please either return it in the pre-paid envelope included in this package, or take a photo of the survey pages and the consent form and email to laura.tilley@pg.canterbury.ac.nz.

Participation is voluntary and you have the right to withdraw at any stage without penalty. Closing the internet browser will withdraw you from the online survey. You will have the option to amend/change/remove any information you provide on the survey form.

We do not anticipate that completing the survey will pose significant risks to you. However it may trigger distressing memories of the earthquake and related events. If so, there is no obligation to engage with this research, or to continue to do so. You may withdraw at any time, and please note that support is available at the Mental Health Education and Resource Centre (www.mherc.org.nz/seeking-help, 033655344).

Once you have completed the survey, you may contact the research team and ask for your survey data to be returned to you or destroyed at any point before 15th March 2019. If you choose to withdraw, we will remove information relating to you. However, once analysis of data starts it will become more difficult to reduce the influence of your data on the results; data analysis will be finalised by the 1st April 2019, which will include your results.

The data gathered in this investigation will be kept strictly confidential to the University of Canterbury researcher Laura Tilley, and her supervisory team, Associate Professor Thomas Wilson, Dr Matthew Hughes, and Dr Sarah Beaven. All details about survey participants will remain strictly confidential, and no details that could identify you (such as street address) will be included in publications that result from the information that you provide in the survey. No one else will have access to this information, which will be stored in locked and secure facilities and in password-protected electronic form. Any data you have provided will be destroyed after five years.

Please indicate on the consent form if you would like to receive a copy of the summary of results of the project. We would be really glad to share this with you.

Laura Tilley is leading this project, and she can be contacted at laura.tilley@pg.canterbury.ac.nz or 027 385 7291. She is happy to discuss any concerns you may have about participation. You can also contact Thomas Wilson at thomas.wilson@canterbury.ac.nz or 03 369 4503 ext. 94503 or Matthew Hughes at matthew.hughes@canterbury.ac.nz or 03 364 2987 ext. 94599.

This project has been reviewed and approved by the University of Canterbury Human Ethics Committee, and participants should address any complaints to The Chair, Human Ethics Committee, University of Canterbury, Private Bag 4800, Christchurch (human-ethics@canterbury.ac.nz).

If you agree to participate in the study, you are asked to complete the consent form before filling out the survey.

Department: Disaster Risk and Resilience/Geological Sciences
Cell phone: 027 385 7291
Email: laura.tilley@pg.canterbury.ac.nz
February - March 2019

UC UNIVERSITY OF CANTERBURY Te Whare Wānanga o Waitaha CHRISTCHURCH NEW ZEALAND

Understanding Kaikōura Evacuation Dynamics that occurred following the 2016 Kaikōura earthquake and tsunami

Consent Form for Participants

Confidentiality

- ☐ I understand there are no significant risks anticipated with taking part in this research.
- ☐ I have been given a full explanation of this project and have had the opportunity to ask questions.
- ☐ I understand what is required of me if I agree to take part in the research.
- ☐ I understand that participation is voluntary and I may withdraw at any time. Withdrawal of participation will also include the withdrawal of any information I have provided should this remain practically achievable (before 15th March, 2019).
- ☐ I understand that any information or opinions I provide will be kept confidential to the researcher and the researcher's supervisor and that any published or reported results will not identify the participants.
- ☐ I understand that all data collected for the study will be kept in locked and secure facilities and in password protected electronic form and will be destroyed after five years.
- ☐ I understand that I can contact the lead researcher Laura Tilley on 027 385 7291 or laura.tilley@pg.canterbury.ac.nz or research supervisor's Thomas Wilson on +64 3 369 4503 Ext 94503 or thomas.wilson@canterbury.ac.nz or Matthew Hughes matthew.hughes@canterbury.ac.nz for further information. If I have any complaints, I can contact the Chair of the University of Canterbury Human Ethics Committee, Private Bag 4800, Christchurch (human-ethics@canterbury.ac.nz)
- ☐ I would like a summary of the results of the project.
- ☐ By signing below, I agree to participate in this project.

Name:____________________________Signed:___________________________Date:

Email address (if would like a summary of findings):

If you require any support services, please contact research supervisor Thomas Wilson on +64 3 369 4503 Ext 94503 or thomas.wilson@canterbury.

UC UNIVERSITY OF CANTERBURY Te Whare Wānanga o Waitaha CHRISTCHURCH NEW ZEALAND · Environment Canterbury Regional Council Kaunihera Taiao ki Waitaha · KAIKŌURA DISTRICT COUNCIL · GNS SCIENCE TE PŪ AO · NATURAL HAZARDS RESEARCH PLATFORM · RESILIENCE TO NATURE'S CHALLENGES · National SCIENCE Challenges

Evacuation response to the 14th November 2016 Earthquake – Kaikōura

TO RETURN THIS SURVEY: EMAIL THIS BOOKLET (consent form and survey) TO laura.tilley@pg.canterbury.ac.nz OR RETURN IN THE PRE-PAID ENVELOPE. ALTERNATIVELY USE THIS LINK TO ACCESS THE SURVEY ONLINE: https://bit.ly/2FLSozu

Q1. Did the earthquake on Monday 14th November 2016 at 12.02 a.m. wake you up? (Tick only **one**)

☐1 Yes ☐2 No
☐3 Not applicable (I was already awake)

Q2. How strong did the earthquake feel to you? (Tick only one)

☐1 Not felt ☐2 Heard but not felt
☐3 Gentle, hardly recognised as an earthquake (like light trucks passing) ☐4 A jolt or mild, but unmistakably an earthquake (like heavy traffic passing)
☐5 Moderate (could still stand up) ☐6 Strong/powerful (hard to stand up)
☐7 Violent/severe

Q3. For how long did you feel the earthquake shaking? ________ seconds (as **best** you can estimate) **OR**

☐1 Don't know ☐2 Not felt

Comments:

____

Q4. How much damage did the earthquake do to your home? (Tick only **one**)

☐1 None ☐2 Slight
☐3 Moderate ☐4 Severe
☐5 Totally destroyed ☐6 Not applicable

Comments:

____

Q5. What did you do after the earthquake shaking stopped? (Please give details)

____
____

Q6. Where were you when the earthquake occurred? (Please be **very specific**, e.g. give the address, nearest street corner or landmark)

____

Q7. Did you evacuate? (Tick only **one**) ☐1 Yes (skip to Q9) ☐2 No

Comments:

____
____

Q8. If you did not evacuate, why not? (Please give details)

____
____

Q9. Did you evacuate more than once? (Tick only **one**) ☐1 Yes ☐2 No

If yes, why?

____
____

Q10. Where did you evacuate to? (Please be **very specific**, e.g. give the address, nearest street corner or landmark)

____
____

Q11. Please draw your evacuation route on the map below OR if you prefer, please describe your evacuation route in as much detail as possible in the text box below e.g. roads, waking tracks, path behind property etc.

If you evacuated more than once, please draw/describe all evacuation routes you took

Describe your evacuation route:

____

Q12. If you did evacuate, was it because of a possible tsunami? (Tick only **one**) ☐1 Yes (skip to Q14) ☐2 No

Q13. If not because of a possible tsunami, why did you evacuate? (Please give details)

____

____

Q14. What warned you of a possible tsunami coming? (Tick **all** that apply)

- ☐1 The earthquake (natural warning)
- ☐2 Other household/family members
- ☐3 Other community members
- ☐4 Emergency services (e.g. Police, Fire Service)
- ☐5 Official warning from Civil Defence (on social media, radio, TV...)
- ☐6 Tsunami sirens
- ☐7 Other (please describe) ____________________
- ☐8 I never thought/ have never been aware there could be a tsunami

Comments:

____

____

Q15. What sources of information did you use to decide to evacuate? (Tick **all** that apply)

- ☐1 The earthquake (natural warning)
- ☐2 Other household/family members
- ☐3 Other community members
- ☐4 Emergency services
- ☐5 Official warning from Civil Defence (on social media, radio, TV...)
- ☐6 GeoNet
- ☐7 Other (please describe) ____________________

Comments:

____

____

Q16. What was the MAIN reason that made you decide to evacuate? (Tick only **one**)

- ☐1 The earthquake (natural warning)
- ☐2 Other household/family members
- ☐3 Other community members
- ☐4 Emergency services
- ☐5 Official warning from Civil Defence (on social media, radio, TV...)
- ☐6 GeoNet
- ☐7 Other (please describe) ____________________

Comments:

____

____

Q17. What did you do before evacuating? (Tick **all** that apply)

- ☐1 Nothing (evacuated immediately)
- ☐2 Gathered family/household members
- ☐3 Gathered life essentials (food, water…)
- ☐4 Collected valuables (jewellery, money etc.)
- ☐5 Called family or friends
- ☐6 Assisted others in evacuation (e.g. friends or neighbours)
- ☐7 Sought further official information (from radio, TV, internet, GeoNet)
- ☐8 Discussed action plan with family/other community members
- ☐9 Gathered my pets
- ☐10 Other (please describe) ____________________
- ☐11 Not applicable

Comments:
____
____

Q18. How long did all of these actions take before you actually started evacuating? (Tick only **one**)

- ☐1 One minute or less
- ☐2 1-5 minutes
- ☐3 5 - 10 minutes
- ☐4 10 - 20 minutes
- ☐5 20 - 30 minutes
- ☐6 30 minutes – 1 hour
- ☐7 One hour or more
- ☐8 Not applicable

Comments:
____
____

Q19. What time did you evacuate?
____

Q20. Once you started evacuating, how long did it take to reach your destination? _______ minutes (as **best** you can estimate)
Comments:
____
____

Q21. Did you evacuate individually or with others? If with others, please describe:
____
____
____

Q22. How did you travel to your evacuation destination? (Tick only **one**)

- ☐1 Car
- ☐2 Run
- ☐3 Walk
- ☐4 Bicycle or similar
- ☐5 Other (please describe): ____________________

Comments:
____
____

Q23. Did you encounter any traffic congestion or were you aware of congestion problems? ☐1 Yes ☐2 No (skip to Q27)
Comments:
____
____

Q24. If yes, which roads or areas were congested? Please indicate these roads and areas on the map
____
____
____
____

Q25. On average, how slow do you think traffic was moving in these congested areas? __________ km/h (as **best** you can estimate)

Q26. How long were these roads or areas congested for? From __________a.m. until ______ a.m. (as **best** you can estimate).
Comments:

____
____

Q27. Did you observe stages/surges of evacuation traffic? At what times did these occur?

____
____
____
____

Q28. Did you need help to evacuate? (Tick only **one**)

☐1 Yes (please describe) ____

☐2 No (skip to Q30)

☐3 Waited for a relative to arrive

Q29. If yes, how did this affect the evacuation process? (Tick only **one**)

☐1 I received the support I needed

☐2 It delayed the evacuation, but I evacuated anyway

☐3 It was a barrier so I did not evacuate

Comments:

____
____

Q30. How long did you stay at your evacuation point? ________ hours _______ minutes (as **best** you can estimate)

Q31. Why did you decide to return from your evacuation point? (Tick **all** that apply)

☐1 When I felt it was safe (after seeing evidence that there was no danger)

☐2 After discussing with others

☐3 After a reasonable time

☐4 When I received an official 'All Clear' message

☐5 Other (please describe) ____

☐6 Sunrise

Q32. Do you have any other comments about the evacuation?

Q33. Following your evacuation response to the 2016 Kaikōura earthquake, would you consider a different evacuation route?

- ☐1 Yes
- ☐2 No
- ☐3 Not applicable

If yes, please draw your planned evacuation route on the map below (next page) OR describe your planned evacuation route in the text box below:

____

Q34. What is your gender? (Tick only **one**)

- ☐1 Male
- ☐2 Female
- ☐3 Gender diverse
- ☐4 Prefer not to disclose

Q35. How old are you?

- ☐1 Under 15 Years
- ☐2 15 – 64 Years
- ☐3 65 years and Over
- ☐4 Prefer not to disclose

Q36. Which best describes the situation you are living in? (Tick only **one**)

- ☐1 Family with children
- ☐2 Family without children
- ☐3 Alone
- ☐4 With non-family
- ☐5 Prefer not to disclose

Q37. Prior to the Monday 14th November 2016 Earthquake, how would you describe your knowledge of tsunamis and the need to evacuate? (Tick only **one**)

- ☐1 Non-existent
- ☐2 Very poor
- ☐3 Poor
- ☐4 Fair
- ☐5 Good
- ☐6 Very good

Q38. If you were aware prior to the 14th November 2016 Earthquake of tsunamis and the need to evacuate, what were your information sources? (Tick **all** that apply)

- ☐1 I was not aware of tsunamis and the need to evacuate
- ☐2 Civil Defence information (e.g. back of phone book, pamphlets)
- ☐3 Formal education – primary/intermediate school
- ☐4 Formal education – secondary school
- ☐5 Formal education – tertiary education (university/polytechnic)
- ☐6 Media coverage of previous tsunamis (e.g. 2004 Indonesia Boxing Day Tsunami, 2011 Tohoku Tsunami)
- ☐7 Documentaries (television or movies)
- ☐8 Books, or articles in magazines/newspapers
- ☐9 Community meetings - Civil Defence
- ☐10 Community meetings - Other
- ☐11 Discussions with Civil Defence Staff
- ☐12 Discussions with family and friends
- ☐13 Other (please describe)

____

Q39. How did your prior awareness of tsunamis influence your behaviour BEFORE the 14th November 2016 Earthquake? (Tick **all** that apply)

- ☐1 I had discussed/prepared an evacuation plan for my family/household
- ☐2 I had prepared a go-bag
- ☐3 I had arranged to check on my neighbours
- ☐4 I had prepared an emergency kit
- ☐5 It did not influence my behaviour
- ☐6 Other (please describe)

____

Q40. How did your prior awareness of tsunamis influence your behaviour IMMEDAITELY AFTER the 14th November 2016 Earthquake? (Tick **all** that apply)

- ☐1 I had prior awareness but it did not influence my behaviour
- ☐2 Moved to higher ground
- ☐3 Moved inland/away from beach
- ☐4 Gathered essential items before evacuating
- ☐5 Alerted or check on family/friends/neighbours
- ☐6 Listened to radio for further information
- ☐7 Monitored websites (e.g. GeoNet, Civil Defence, Council) for further information
- ☐8 Monitored social media (e.g. Facebook, Twitter) for further information
- ☐9 Other (please describe)

____

Q41. Following the 14th November 2016 Earthquake, how would you describe your CURRENT knowledge of tsunamis and the need to evacuate? (Tick only **one**)

- ☐1 Non-existent
- ☐2 Very poor
- ☐3 Poor
- ☐4 Fair
- ☐5 Good
- ☐6 Very good

Q42. Which of the following preparations have you made in case of another significant earthquake and tsunami evacuation? (Tick **all** that apply)

- ☐1 I have made no preparations
- ☐2 Discussed evacuation plan with family/household members
- ☐3 Arranged to check on neighbours to ensure they are aware of evacuation
- ☐4 Prepared a go-bag containing essential items
- ☐5 Identified evacuation routes/destinations
- ☐6 Made yourself aware of evacuation zone information (e.g. Canterbury Maps Evacuation Zones)
- ☐7 Ensured easy access to online information updates (e.g. bookmarked Civil Defence website on your phone)
- ☐8 Prepared an emergency kit with essential supplies (e.g. food and water for 3 days)
- ☐9 Other (please describe)

____

Thank you for your participation, it is greatly appreciated.

TO RETURN THIS SURVEY: EMAIL THIS BOOKLET (consent form and survey) TO laura.tilley@pg.canterbury.ac.nz OR RETURN IN THE PRE-PAID ENVELOPE.

Front cover image retrieved from: https://www.christchurchnz.com/destinations/kaikoura/

A4 Tabulated results of the 2016 Kaikōura earthquake tsunami evacuation survey

This appendix provides tabulated results on all questions provided in the 2016 Kaikoura earthquake tsunami survey booklet (A3).

Q1. **Did the earthquake wake you up?**

Did the earthquake wake you up?	Count (n)	% of respondents
Yes	103	82
No	3	2
N/A	20	16
Total	**126**	**100**

Q2. **How strong did the earthquake feel to you? (on Monday 14th November 2016 at 12.02 a.m.) (Tick only one)**

How strong did the earthquake feel to you? (On Monday 14th November 2016 at 12.02 a.m.) (Tick only one)	Count (n)	% of respondents
Not felt	1	1
Heard but not felt	1	1
Gentle, hardly recognised as an earthquake	0	0
A jolt or mild, but unmistakably an earthquake	1	1
Moderate	6	5
Strong/powerful (hard to stand up)	49	38
Violent/severe	73	57
Total	**131**	**103**

Q3. **For how long did you feel the earthquake shaking? - _____ seconds (as best can estimate)**

For how long did you feel the earthquake shaking? - _____ seconds (as best can estimate)	Count (n)	% of respondents
< 60 seconds	12	10
60 seconds	14	12
60 - 120 seconds	25	22
120 seconds	31	27
> 120 seconds	14	12
Don't know	19	16
Not felt	1	1
Total	**116**	**100**

Q4. **How much damage did the earthquake do to your home?**

How much damage did the earthquake do to your home?	Count (n)	% of respondents
None	3	2
Slight	46	39
Moderate	50	42
Severe	18	15
Totally destroyed	1	1
N/A	1	1

Total	**119**	**100**

Q5. **Q5 What did you do after the earthquake stopped?**

Common actions people said they did after the initial earthquake shaking stopped were:

- Many respondents jumped out of bed (with family) and evacuated to outside their property or on the road.
- Many residents said the evacuated immediately and drove to higher ground
- Many said they grabbed essential item e.g. evacuation kit, blankets, warm clothes, handbag, keys
- A few people said the turned off the hot water cylinder before evacuating, others checked for damage to property
- A number of respondents said they went to go check on the neighbours
- People experienced difficulty getting their cars out of the garage due to power being cut off so garage door wold not open

Q6. **Survey respondent's location on the night of the 2016 Kaikōura earthquake**

Q7. **Did you evacuate? - Selected Choice**

Did you evacuate? - Selected Choice	Count (n)	% of respondents
Yes	88	69
No	39	31
Total	**127**	**100**

Q8. **If you did not evacuate, why not?**

If you did not evacuate, why not?	Count (n)	% of respondents
No need (high ground or inland)	27	62
Felt safe in home	8	19
Couldn't evacuate e.g. disability/impassable roads	5	12
Other	3	7
Total	**43**	**100**

Q9. **Did you evacuate more than once? - If yes, why?**

Did you evacuate more than once? - If yes, why?	Count (n)	% of respondents
Yes	19	17
No	91	83
Total	**110**	**100**

Q10. **Where did you evacuate to?** (see map in results section of Chapter 3)

Q11. **Evacuation routes** (see map in results section of Chapter 3).

Q12. **If you did evacuate, was it because of a possible tsunami?**

If you did evacuate, was it because of a possible tsunami?	Count (n)	%
Yes	68	79
No	18	21
Total	**86**	**100**

Q13. **If not because of a possible tsunami, why did you evacuate? (please give details)**

If not because of a possible tsunami, why did you evacuate? (please give details)	Count (n)	% of respondents
Didn't feel safe in house	10	45
Wanted to be with others	4	18
Instructed to do so	2	9
Did not evacuate	3	14
Other	3	14
Total	**22**	**100**

Q14. **What warned you of a possible tsunami coming? (Tick all that apply)**

What warned you of a possible tsunami coming? (Tick all that apply)	Count (n)	% of respondents
The earthquake	82	75
Other household/family members	16	15
Other community members	14	13
Emergency services	4	4
Official warning from CD	13	12
Tsunami sirens	1	1
Other	10	9
I never thought/have been aware there could be a tsunami	2	2
Comments	4	4

Q15. What sources of information did you use to decide to evacuate?

What sources of information did you use to decide to evacuate?	Count (n)	% of respondents
The earthquake	67	74
Other household/family members	17	19
Other community members	11	12
Emergency services	6	7
Official warning CD	6	7
GeoNet	2	2
Other	1	1

Q16. **What was the MAIN reason that made you decide to evacuate? (Tick only one)**

What was the MAIN reason that made you decide to evacuate? (Tick only one)	Count (n)	% of respondents
The earthquake	62	71
Other household/family members	9	10
Other community members	6	7
Emergency services	4	4
Official warning from CD	2	2
GeoNet	0	0
Other	5	6

Q17. **What did you do before evacuating? (Tick all that apply)**

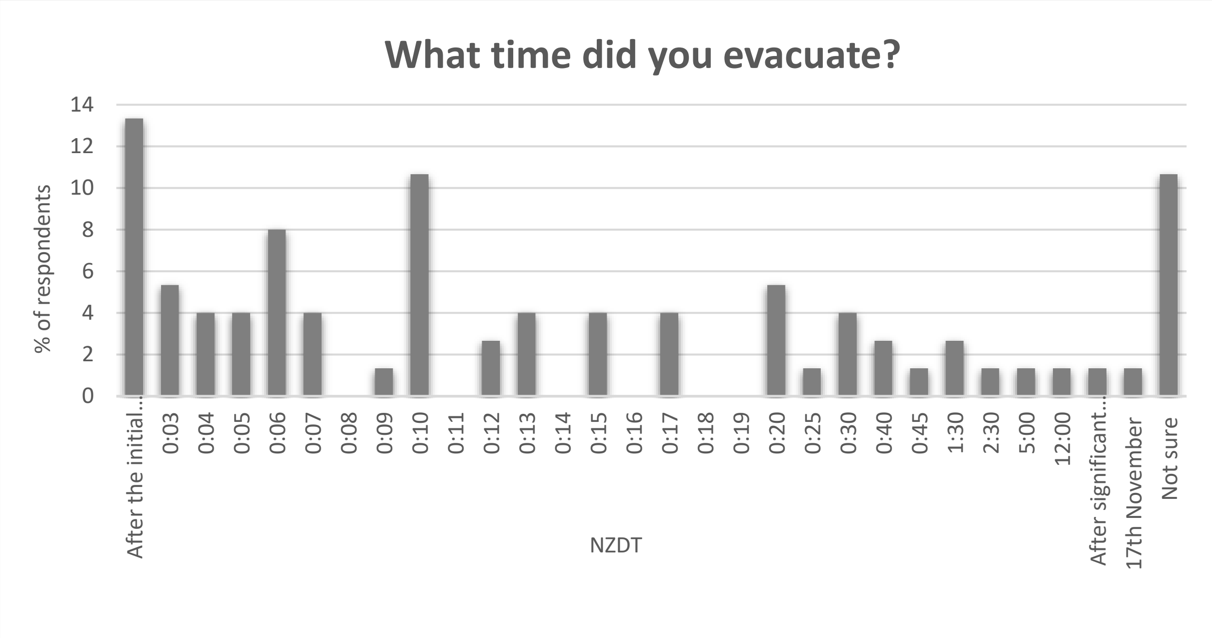
What did you do before evacuating? (Tick all that apply)	Count (n)	% of respondents
Nothing (evacuated immediately)	36	35
Gathered family/household members	33	32
Gathered life essentials	21	20
Collected valuables	2	2
Called family or friends	3	3
Assisted others in evacuation	17	17
Sought further information	2	2
Discussed action plan with family/other community members	9	9
Gathered my pets	14	14
Other	7	7

Q18. **How long did all of these actions take before you actually started evacuating? (Tick only one)**

How long did all of these actions take before you actually started evacuating? (Tick only one)	Count (n)	% of respondents
>1 min	19	21
1-5 mins	24	27
5-10 mins	20	22
10-20mins	11	12
20-30 mins	3	3
30 mins -1hour	3	3
One hour or more	2	2

N/A	5	6

Q19. **What time did you evacuate?**



Q20. **Once you started evacuating, how long did it take to reach your destination?**

- Average = 6.6 minutes
- Range = 1-25 minutes

Q21. **Did you evacuate individually or with others? if with others, please describe:**

Did you evacuate individually or with others? if with others, please describe:	Count (n)	% of respondents
Alone	9	11
With partner	25	30
Family/Flatmate(s)	26	31
Neighbours/others	24	29

Q22. **How did you travel to your evacuation destination? (Tick only one)**

How did you travel to your evacuation destination? (Tick only one)	Count (n)	% of respondents
Car	72	85
Run	4	5
Walk	9	10
Bike	0	0

23. **Did you encounter any traffic congestion or were you aware of congestion problems?**

Did you encounter any traffic congestion or were you aware of congestion problems?	Count (n)	% of respondents
Yes	36	40
No	54	60

Total	90	100

Q24. **If yes, which roads or areas were congested? Please indicate these roads and areas on the map above**

- Killarney Street
- Churchill Park
- Kaikōura Cemetery

See map presented in Chapter 3 for high vehicle counts along Kaikōura road network

25. **On average, how slow do you think traffic was moving in these congested areas**

- Average = 18.23 minutes
- Range = 0km/hr – 60km/hr

Q26. **How long were these roads or areas congested for? From _____ a.m. until _____ a.m. (as best you can estimate)**

- Average = 3.3 hours

Q27. **Did you observe stages/surges of evacuation traffic? at what times did these occur?**

Areas reported that experienced/observed traffic congestion:

- Churchill Park area
- Post Office Cutting (Killarney St)
- Kaikōura Flat heading to Mt Fyffe

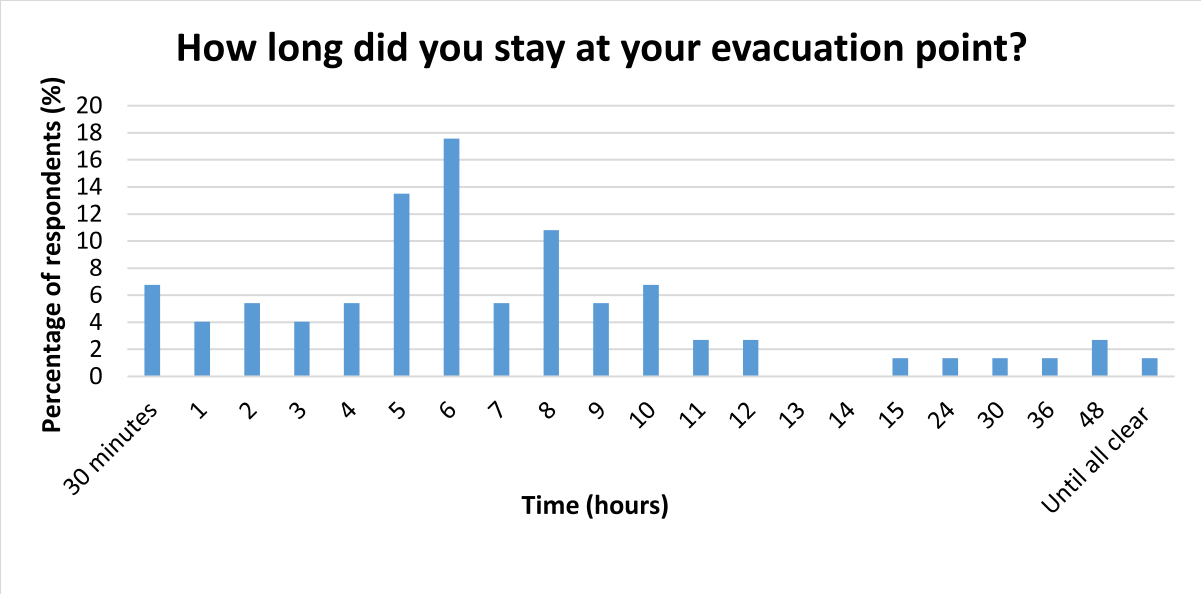
Q28. **Were you in need of any assistance for evacuating? (Tick only one)**

Were you in need of any assistance for evacuating? (Tick only one)	**Count (n)**	**% of respondents**
Yes	10	11
No	81	89
Waited for a relative to arrive	2	2

Q29. **If yes, how did this affect the evacuation process? (Tick only one)**

If yes, how did this affect the evacuation process? (Tick only one)	Count (n)	% of respondents
I received the support I needed	11	91
It delayed the evacuation, but I evacuated anyway		
It was a barrier, so I did not evacuate		

Q30. **How long did you stay at your evacuation point? _____hours______minutes (as best you can estimate)**



Q31. **Why did you decide to return from your evacuation point? (Tick all that apply)**

Why did you decide to return from your evacuation point? (Tick all that apply)	Count (n)	% of respondents
When I felt it was safe	45	52
After discussing it with others	21	24
After a reasonable time	17	20
When I received an official 'all clear' message	11	13
Sunrise	17	20
Other	19	22

Q32. **Do you have any other comments about evacuation?**

Q33. **Following your evacuation response to the 2016 Earthquake, would you consider a different evacuation route?**

Following your evacuation response to the 2016 Earthquake, would you consider a different evacuation route?	Count (n)	% of respondents
Yes	11	12
No	67	76
N/A	11	12

Q34. **What is your gender?**

What is your gender?	Count (n)	% of respondents
Male	46	36
Female	81	64
Gender diverse	0	0
Prefer not to disclose	0	0

Q35. **How old are you?**

How old are you?	Count (n)	% of respondents
Under 15 years	0	0
15-64 years	61	49
65 years and over	62	50

Prefer not to disclose	1	1

Q36. **Which best describes the situation you are living in?**

Which best describes the situation you are living in?	Count (n)	% of respondents
Family with children	26	20
Family without children	60	47
Alone	36	28
With non-family	4	3
Prefer not disclose	2	2

Q37. **Prior to the Monday 14th November Earthquake, how would you describe your knowledge of tsunami hazard and the need to evacuate?**

Prior to the Monday 14th November Earthquake, how would you describe your knowledge of tsunami hazard and the need to evacuate?	Count (n)	% of respondents
Non-existence	3	2
Very poor	3	2
Poor	8	6
Fair	26	21
Good	55	44
Very good	31	25

Q38. **If you were aware prior to the 14th November 2016 Earthquake of tsunami hazard and the need to evacuate, what were your information sources? (Tick all that apply)**

If you were aware prior to the 14th November 2016 Earthquake of tsunami hazard and the need to evacuate, what were your information sources? (Tick all that apply)	Count (n)	% of respondents
I was not aware of tsunami and the need to evacuate	7	6
CD information	62	50
Formal education-primary	24	19
Formal education- Secondary	19	15
Formal education-tertiary	11	9
Media coverage of previous events	69	56
Documentaries	54	44
Books, articles, magazines	39	31
Community meetings-CD	16	13
Community meetings - other	6	5
Discussion with CD staff	14	11
Discussion with family and friends	51	41
Other	26	21

Q39. **How did your prior awareness of tsunami hazards influence you behaviour BEFORE the 14th November 2016 Earthquake (Tick all that apply)**

How did your prior awareness of tsunami hazards influence you behaviour BEFORE the 14th November 2016 Earthquake (Tick all that apply)	Count (n)	% of respondents
I had discussed/prepared an evacuation plan for my family/household	42	35
i had prepared a go-bag	22	18
I had arranged to check on my neighbours	12	10
I had prepared an emergency kit	37	31
It did not influence my behaviour	45	38
Other	18	15

Q40. **How did your prior awareness of tsunami hazards influence your behaviour IMMEDIATELY AFTER the 14th November 2016 Earthquake (Tick all that apply)**

How did your prior awareness of tsunami hazards influence your behaviour IMMEDIATELY AFTER the 14th November 2016 Earthquake (Tick all that apply)	Count (n)	% of respondents
I had prior awareness but did not influence my behaviour	26	21
Moved to higher ground	68	56
Moved inland/away from beach	24	20
Gathered essential items before evacuating	21	17
Alerted or check on family/friends/neighbours	34	28
Listened to radio for further information	49	40
Monitored websites	12	10
Monitored social media	6	5
Other	15	12

Q41. **Following the 14th November 2016 Earthquake, how would you describe your CURRENT knowledge of tsunami hazard and the need to evacuate (Tick only one)**

Following the 14th November 2016 Earthquake, how would you describe your CURRENT knowledge of tsunami hazard and the need to evacuate (Tick only one)	Count (n)	% of respondents
Non-existent	1	1
Very poor	0	0
Poor	2	2
Fair	15	12
Good	57	46
Very good	49	40

Q42. **Which of the following preparations have you made in case of another significant earthquake and tsunami evacuation? (Tick all that apply)**

Which of the following preparations have you made in case of another significant earthquake and tsunami evacuation? (Tick all that apply)	Count (n)	% of respondents
I have made no preparations	17	14
Discussed evacuation plan with family/household	67	54
Arranged to check on neighbours to ensure they are aware of evacuation	24	20

Prepared a go-bag containing essential items	53	43
Identified evacuation routes/destinations	46	37
Made yourself aware of evacuation zone information	21	17
Ensured easy access to online information updates	9	7
Prepared an emergency kit with essential supplies	70	57

This appendix provides a copy of the approval letter of the low risk application to the Human Ethics Committee. This letter confirms the review and approval to conduct the 2016 Kaikōura earthquake tsunami evacuation survey.

Appendix B: Kaikōura High School 2018 ShakeOut observations

B1 Human Ethics Committee approval letter

This appendix provides a copy of the approval letter of the low risk application to the Human Ethics Committee. This letter confirms the review and approval to observe Kaikōura High School 2018 ShakeOut earthquake drill.

UC UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

HUMAN ETHICS COMMITTEE

Secretary, Rebecca Robinson
Telephone: +64 03 369 4588, Extn 94588
Email: human-ethics@canterbury.ac.nz

Ref: 2018/06/ERHEC-LR

27 September 2018

Laura Tilley
Geological Sciences
UNIVERSITY OF CANTERBURY

Dear Laura

Thank you for submitting your low risk application to the Educational Research Human Ethics Committee for your research proposal titled "Understanding Community Evacuation Dynamics in Kaikōura Through Agent-Based Modelling Following the 2016 Kaikōura Earthquake".

I am pleased to advise that this application has been reviewed and I confirm support of the School's approval for this project.

With best wishes for your project.

Yours sincerely

pp R. Robinson

Dr Patrick Shepherd
Chair
Educational Research Human Ethics Committee

Please note that ethical approval relates only to the ethical elements of the relationship between the researcher, research participants and other stakeholders. The granting of approval by the Educational Research Human Ethics Committee should not be interpreted as comment on the methodology, legality, value or any other matters relating to this research.

F E S

B2 Human Ethics Committee - low risk student application form

This appendix provides a complete copy of the Human Ethics Committee low risk student application form to observe 2018 Kaikoura High School ShakeOut earthquake drill.

UC UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Low Risk Application Form

Ethical approval of low risk research involving human participants reviewed by departments or schools in the College of Education

PLEASE read the important notes appended to this form before completing the sections below

Researcher's Name:	Laura Tilley
Name of Department or School:	Geological Sciences/Disaster Risk and Resilience
Email Address:	lrt33@uclive.ac.nz
Title of Project:	Understanding community evacuation dynamics in Kaikōura through agent-based modelling following the 2016 Kaikōura earthquake
Projected Start Date of Project:	17/08/2018
Staff member/supervisor responsible for project:	Thomas Wilson, Matthew Hughes and Sarah Beaven
Names of other participating staff and students:	NONE
Status of Research: (e.g. Thesis)	MSc Thesis
Brief description of the project: Please give a brief summary (approx. 300 words) of the nature of the proposal in lay language, including the aims/objectives/hypotheses of the project, rationale, participant description, and procedures/methods of the project:-	

(Version April 2012) Page 1 of 7

The objective of this MSc thesis is to develop an agent-based tsunami evacuation model for the Kaikōura community. This research has been requested by Kaikōura District Council and Environment Canterbury, as part of on-going collaborative applied research supporting recovery in the Kaikōura district. Findings will be used to help Kaikōura District Council emergency mangers and Environment Canterbury hazard analysts to select optimal tsunami evacuation routes and destinations for the Kaikōura community, including Kaikōura High School.

To make the evacuation model as accurate as possible it is important to capture realistic human behaviour data during evacuations to input into this model. The study proposes to gather data to inform the agent-based evacuation model in two ways:

a) surveying Kaikōura populations about their actions during the 2016 Kaikōura earthquake tsunami, when many people evacuated
b) observing evacuation performance during the 2018 NZ ShakeOut earthquake drill and tsunami hikoi.

This ethics application concerns only the proposed observation of Kaikōura High School's participation in the 2018 NZ ShakeOut.

NZ ShakeOut is New Zealand's annual earthquake drill and tsunami hikoi, which will take place on the 18th October 2018. Kaikōura High School is one of two high schools registered to participate in NZ ShakeOut this year. The purpose is for the school to better prepare and practice their response procedures if a future earthquake and tsunami event were to occur. In evacuation modelling, specifically tsunami evacuation modelling it is difficult to capture realistic evacuation behaviour to input into agent-based modelling (simulation of individuals evacuating from a start location to end location). ShakeOut provides a unique opportunity to observe Kaikōura High School's evacuation procedures if a future earthquake and tsunami were to occur during school hours. Capturing this data also helps with validating evacuation modelling approaches.

The research proposes to record the duration and dynamics of the evacuation of the school population to their 'safe zone' location. Specifically, this will include recording how long the school takes to

- Begin evacuating, following the initial warning
- Fully evacuate the school grounds
- Arrive at and fully pass identified features along the route
- Complete the evacuation hikoi by arriving at the safe zone location

The researcher will also gather data concerning the evacuation route taken by the school and factors that have influenced the time it takes.

Observing Kaikōura High School evacuation performance during ShakeOut will begin outside the school on Thursday 18th at 9.30am. The researcher has arranged with the school that she will approach one of the staff members to let them know that

- the observation has begun, and that the researcher will observe the exercise from outside the school grounds (with the exception of this initial contact).

The times taken for the school to begin evacuating, to leave the school grounds, pass identified features and complete the evacuation will be measured using the stopwatch feature on a cell phone, with individual times recorded on paper. A paper map extracted from the internet (Google Earth) will allow the researcher to draw the schools evacuation route, including estimated times at main features e.g. evacuation over a bridge. This will also help identify barriers that might influence evacuation performance such as rivers, buildings, and factors that limit access for children with disabilities. The researcher will walk 100m behind the evacuating body and record evacuation routes and time estimates on the map until they reach their 'safe zone' location. The researcher will stop recording information when they school has finished NZ ShakeOut and have completed their evacuation hikoi. Evacuation routes and time estimates will be manually uploaded into modelling software (ArcGIS) to represent a Kaikōura High School evacuation scenario. The results will provide information on average walking speeds and evacuation routes, and identify barriers students and staff may have had to overcome.

Why is this a low risk application?

Description should include issues raised in the Low Risk Checklist (see below).
Please give details of any ethical issues which were identified during the consideration of the proposal and the way in which these issues were dealt with or resolved.

This research application is low risk to the students and staff members involved in NZ ShakeOut.

The researcher proposes to remain at a distance of approximately 100 metres from evacuating staff and students in order to observe their evacuation movements during a simulated evacuation. Participants (students and staff) will not be asked to do anything, and there will no communication and/or interaction with the student body. No students or staff members will be identified in this research.

Initial interaction with one of the staff members will occur before NZ ShakeOut begins to ensure that they are aware of the researcher's presence and activities. The researcher will remain outside school grounds, and once the last group of students has left the school grounds, follow the evacuation hikoi at a distance of 100 meters for the duration of the evacuation.

The researcher has asked for consent to gather data from the school principal, who has confirmed that the school gives consent for the proposed data gathering. This followed an initial phone call (on Monday 17th September 2018) with a staff member to inform Kaikōura High School of the proposed research and to ask for permission to observe the school's evacuation performance during NZ ShakeOut. The staff member confirmed that the school in principle was likely to agree to the proposed data collection, on the grounds that the risk was minimal since what is proposed involves only observation from a distance. A subsequent email exchange with the principal of Kaikōura High School, John Tait, resulted in an email from him confirming that the school consents to the proposed data gathering.

The researcher has confirmed with the school staff member that

- no student or staff member will be identified either during the observation of the ShakeOut or in any subsequent data analysis or research outcomes.
- Communication between the school and the researcher on the day will be limited to initial contact to ensure that staff are aware that the researcher is in place, and will be observing proceedings as agreed.
- Subsequent to the Shake Out Exercise, the principal of the school will be asked if the school wishes to be acknowledged or otherwise named in any publication or other research outcomes.
- There will be no mention of the school by name other than at the express wishes of the principal. The school has the researcher's contact details, if for any reason they wish to clarify aspects of the project (including changes in their current intention to participate in NZ ShakeOut).

Evacuation times will be recorded and stored in GIS modelling software on a password-protected file on an external hard drive stored with the department of Geological Sciences. This will be stored with the department for up to 5 years and then destroyed.

Given the recent Kaikōura earthquakes, we are mindful that the students may feel emotional or distressed during this practice drill. Since the researcher will not be interacting with students or staff members, however, providing support to distressed students or staff members during the ShakeOut exercise will remain the responsibility of the school.

This MSc thesis project is being conducted in collaboration with the emergency management officer at Kaikōura District Council, who is aware and supportive of the proposed research observing the students during ShakeOut (face to face conversation).

Applicant's Name:	Laura Tilley		
Signature:		Date:	21/09/2018

LOW RISK CHECKLIST – *PLEASE ALSO REFER TO THE NOTES AT THE BACK OF THIS DOCUMENT*

Please check that your application / summary has discussed:

- procedures for voluntary, informed consent
- privacy & confidentiality
- how much anonymity can be offered and how it will be maintained
- risk to participants
- obligations under the Treaty of Waitangi
- needs of dependent persons
- conflict of interest
- permission for access to participants from other individuals or bodies

- inducements
- dissemination of research findings
- storage and subsequent destruction of data

Please ensure that Sections A, B and C below are all completed

A SUPERVISOR DECLARATION:

1. I have made the applicant fully aware of the need for and requirement of seeking ERHEC approval for research involving human participants.
2. I have ensured the applicant is conversant with the procedures involved in making such an application.
3. The applicant has individually filled in this Low Risk application form which has been reviewed by me.

Signed (Supervisor):	Thomas Wilson [signature]	Date:	23 Sept 2018

B Supported by the Departmental/School Research Committee:

Name:	Ben Kennedy	Signature:	[signature]	Date:	26/09/2018

C Supported by the Head of Department/School:

Name:		Signature:		Date:	

Please attach copies of any Information Sheets, Consent Forms and/or Questionnaires as appropriate.
Forward **one hard copy and one electronic copy to**:

The Secretary
Educational Research Human Ethics Committee
Level 5 Matariki South (human-ethics@canterbury.ac.nz)

All queries will be forwarded to the applicant within 10 working days of receipt of the application by the Secretary of the committee.
Please include a copy of this form as an appendix in your thesis or course work

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Action taken by Educational Research Human Ethics Committee

☐	Added to Low Risk Reporting Database	☐	Referred to full ERHEC
☐	Referred to another Ethics Committee - Please specify:		
Approved by:		Date:	

NOTES CONCERNING LOW RISK APPLICATIONS

1. ***Procedures:***

This **Low Risk** application form should **only be used** for proposals which are **Low Risk** as defined in the University of Canterbury Educational Research Human Ethics Committee Principles and Guidelines policy document.

In consultation with the ERHEC, Departments or Schools will develop a process for review and approval. Departments or Schools will advise ERHEC if there are any subsequent changes to the process.

The staff making application must sign a declaration that students:

- undertaking those research projects are being made fully aware of the need for and the requirement of seeking ERHEC approval for all research involving human participants,
- are conversant with the procedures involved in making such an application,
- have individually filled in the required applications submitted to the concerned staff.

A low risk notification form should be filled out and forwarded to the secretary of the ERHEC. Attachments should include a sample of the information and consent forms that will be used.

2. Low risk applications would involve the same risk as might be encountered in normal daily life. For example,

a. Master's theses where the projects do not raise any issue of deception, threat, invasion of privacy, mental, physical or cultural risk or stress, and do not involve gathering personal information of a sensitive nature about or from individuals.

b. Master's level supervised projects undertaken as part of specific course requirements where the projects do not raise any issue of deception, threat, invasion of privacy, mental, physical or cultural risk or stress, and do not involve gathering personal information of a sensitive nature about or from individuals.

c. Undergraduate and Honours class research projects which do not raise any issue of deception, threat, invasion of privacy, mental, physical or cultural risk or stress, and do not involve gathering personal information of a sensitive nature about or from individuals, but do not have blanket approval as specified in Section 4 below.

3. No project, regardless of level, may be considered as low risk if it involves any of the following.:

a. invasive physical procedures or potential for physical harm
b. procedures which might cause mental/emotional stress or distress, moral or cultural offence
c. personal or sensitive issues
d. vulnerable groups
e. Tangata Whenua
f. cross cultural research
g. investigation of illegal behaviour(s)
h. invasion of privacy
i. collection of information that might be disadvantageous to the participant
j. use of information already collected that is not in the public arena which might be disadvantageous to the participant
k. use of information already collected which was collected under agreement of confidentiality
l. participants who are unable to give informed consent, including children
m. conflict of interest e.g. the researcher is also the lecturer, teacher, treatment-provider, colleague or employer of the research participants, or there is any other power relationship between the researcher and the research participants
n. deception
o. audio or visual recording without consent
p. withholding benefits from "control" groups
q. inducements
r. risks to the researcher

The only exception to this is that research with children and young people in educational settings may be included in applications made within blanket approval category, *provided the skills and strategies being learned are those that would be expected to be part of normal teaching practice on completion of the qualification.*

This list is not definitive but is intended to sensitise the researcher to the types of issues to be considered. Low risk research would involve the same risk as might be encountered in normal daily life.

In some circumstances research that appears to meet low risk criteria may need to be reviewed by the ERHEC. This might be because of requirements of:

- The publisher of the research
- An organisation which is providing funding resources, existing data, access to participant, etc.
- Research which meets the criteria for a review by a Health and Disability Ethics Committee (see HRC website).

4. A separate low risk form should be completed for each teaching or research proposal which involves human participants and for which ethical approval has been considered or given at Departmental or School level.
5. The completed form, **together copies of any Information Sheet or Consent Form**, should be returned to the Secretary, Educational Research Human Ethics Committee, Level 5 Matariki South, and by electronic copy, **as soon as the proposal has been considered at departmental or school level**.
6. The Information Sheet and Consent Form should NOT include the statement "This proposal has been reviewed and approved by the University of Canterbury Educational Research Human Ethics Committee" as this is inappropriate for low risk proposals. A statement such as "This proposal has been reviewed and approved by the Department/School of ….. University of Canterbury" must, however, be used.
7. Please ensure the Consent Form and the Information Sheet has been carefully proofread; the institution as a whole is likely to be judged by them.
8. ERHEC aims to notify applicants for low risk approval within ten working days of receiving the application from the Head of Department/School.
9. The research must be consistent with the UC ERHEC Principles and Guidelines. Refer to the appendices of the UC ERHEC Principles and Guidelines for guidance on information sheets and consent forms.
10. Please note that if the nature, procedures, location or personnel of the research project changes after departmental/school approval has been given in such a way that the research no longer meets the conditions laid out in Section 5 of the Principles and Guidelines, a full application to the ERHEC must be submitted.
11. Ensure that the reference is made to the ERHEC complaints procedure which should be included in the body of the information as follows: Complaints may be addressed to The Chair, Educational Research Human Ethics Committee, University of Canterbury, Private Bag 4800, Christchurch, Email: human-ethics@canterbury.ac.nz.
12. This form is available electronically at the following web address: http://www.canterbury.ac.nz/humanethics/erhec/apply.shtml
13. **Responsibility:**

    Supervisors are responsible for:

    a. Theses where the projects do not raise any issues listed.
    b. Masters level supervised projects undertaken as part of specific course requirements where the projects do not raise any issues listed.
    c. Undergraduate and Honours class research projects which do not raise any issues listed but do not have blanket approval as specified in the Principles and Guidelines.

    HODs are responsible for:

    a. Giving departmental or school approval in principle for the low risk application.
    b. Ensuring a copy of all applications is kept on file in the Department/School.
    c. Ensuring one hard copy and one electronic copy of the application are sent to the secretary of the ERHEC.
    d. Advising the applicant that the project may not commence before the Secretary of the ERHEC has advised final approval (see item 8 above).

The Educational Research Human Ethics Committee is happy to give advice on the appropriateness of research for low risk review.

B3 Kaikōura High School ShakeOut Observations – Summarised report

This appendix provides a summarised report on Kaikōura High School 2018 ShakeOut observations. The summarise report includes an introduction on why this field research took place, methods and results.

Introduction

NZ ShakeOut is New Zealand's annual earthquake drill and tsunami hikoi (walk).In 2018, Kaikōura High School was one of two high schools registered to participate in NZ ShakeOut. The purpose is for the school to better prepare and practice their response procedures if a future earthquake and tsunami event were to occur. In evacuation modelling, specifically tsunami evacuation modelling it is difficult to capture realistic evacuation behaviour to input into agent-based modelling (simulation of individuals evacuating from a start location to end location). ShakeOut provided a unique opportunity to observe Kaikōura High School's evacuation procedures if a future earthquake and tsunami were to occur during school hours. Capturing this data also helps with validating evacuation modelling approaches. This research aimed to record the duration and dynamics of the evacuation of the school population to their 'safe zone' location. Specifically, this will include recording how long the school takes to:

- Begin evacuating, following the initial warning
- Fully evacuate the school grounds
- Arrive at and fully pass identified features along the route
- Complete the evacuation hikoi (walk) by arriving at the safe zone location

Method

Two members of the University of Canterbury tsunami research group drove to Kaikōura High School on the 18th October 2018. Observations of Kaikōura High School evacuation performance began outside the school on Thursday 18th at 9.30am. The times taken for the school to begin evacuating, and to evacuate to the school hall was measured using the stopwatch feature on a cell phone, with individual times recorded on a paper map. Both researchers noted down earthquake response actions and hīkoi procedures of pupils recorded at a distance of 100m from any pupil or staff member. Evacuation routes and time estimates was manually digitised in ArcGIS to represent th2 2018 Kaikōura High School ShakeOut and earthquake procedures (see Appendix B2 for a detailed overview of the aims, methods and ethical considerations to conduct this field investigation).

Results

On the day of the national earthquake drill ShakeOut, pupils evacuated from their classrooms to the school hall as a result of wet weather. However, Kaikōura High School's official evacuation safe point is located on the hill directly behind the school grounds. Evacuation times presented below represent Kaikōura High School evacuation response to the School hall.

Evacuation times recorded:

- It took 32 seconds after the hypothetical 'earthquake shaking' before researchers observed pupils evacuating classrooms
- The total evacuation time for Kaikōura High School to complete their evacuation hikoi to the school hall was 5:02 minutes.

Evacuation procedures of the 2018 Shakeout are presented on the geospatial map in Figure B3-2. This map compares the evacuation procedures recorded in 2018 to the evacuation procedures pupils should take in the case of a future event. Further observations of Kaikōura High School shakeout procedures are presented in Figure B3-1

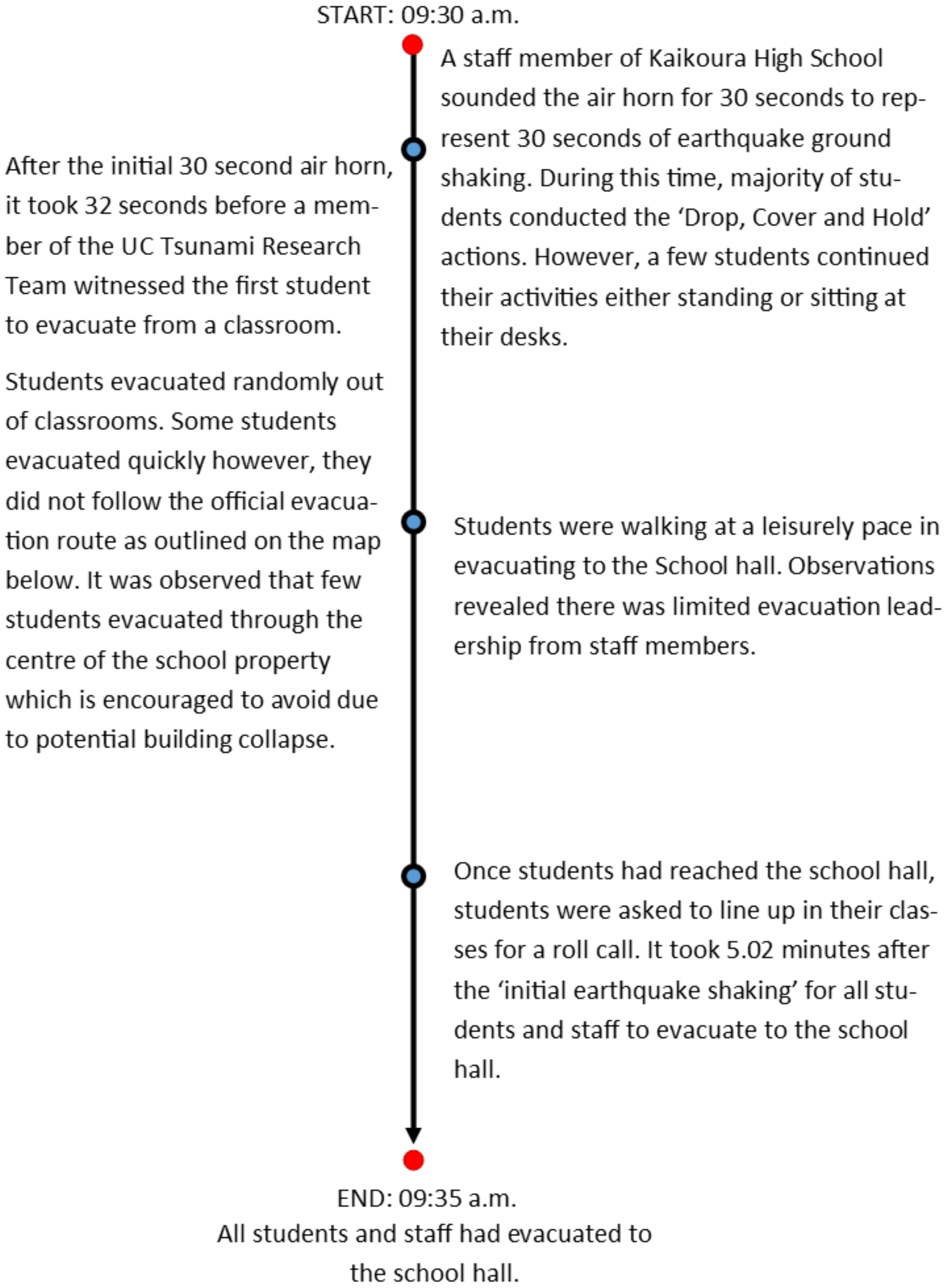

Figure B3-1: Kaikōura High School ShakeOut observations. Observations presented in this figure represent the immediate reactions to the hypothetical earthquake warning till the time all staff and students evacuated to Kaikōura School Hall.

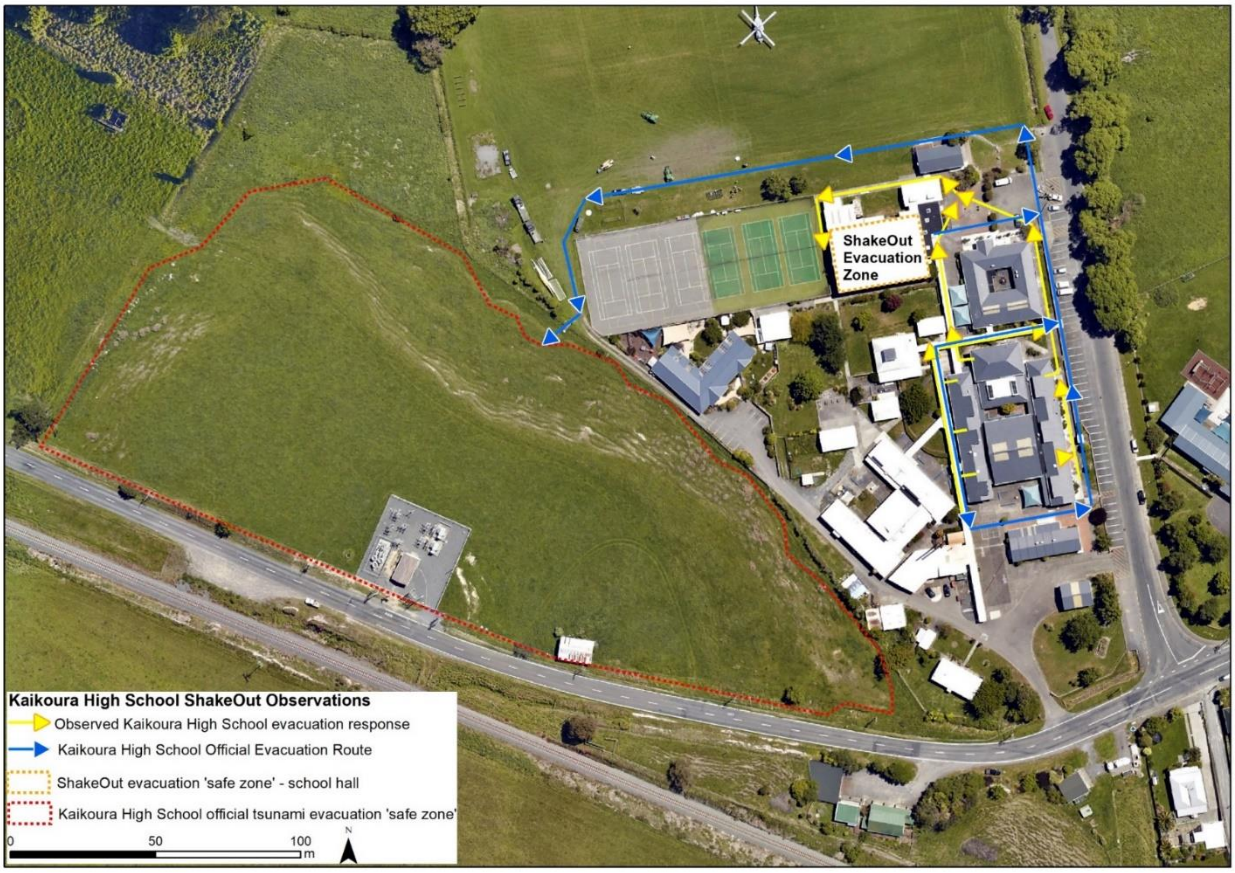

Figure B3-2: Map representing observed 2018 ShakeOut and tsunami hīkoi procedures (yellow) compared with the evacuation procedures encouraged to take during an official response (blue). Red dotted line represents Kaikōura High School safe zone location.

Additional observations and considerations from Kaikōura High School Staff members:

- Staff members were surprised at the time taken for the school to complete the earthquake drill and tsunami hikoi. They recognised more urgency is required, however mentioned it is difficult to encourage urgency from students as it perceived as a 'practice drill'. In a real event, there would be a higher level of urgency, especially among senior students who were in Kaikōura at the time of the earthquake.
- Staff members advised that the school will practice their tsunami hikoi the following week when the weather is clear. The school was planning on running the tsunami hikoi with individual classes and then practice a whole school evacuation.
- Staff members informed members of the UC tsunami research team of the Kaikōura High School official tsunami evacuation zone, which is located on the hill behind the school grounds (Figure B3-2). They acknowledged that there is a step that students and staff will need to climb over to evacuate up to the hill. This could be a potential delay evacuation time when the whole

school is needing to evacuate to safety. Staff members mentioned the school used to evacuate to a shed further up the road however, their priority is to evacuate to the hill and once evacuated safely, they would consider evacuating further inland. During previous evacuation drills to the hill, the school completed their hikoi in around two minutes.

- The schools evacuation plan is relatively similar to the school's fire drill that they practice once every term (they evacuate to the back of the tennis courts), so pupils should be somewhat familiar with the evacuation routes.
- Staff members raised the point that new staff (9 staff members) started following the 2016 Kaikōura earthquake and subsequent tsunami. It was highlighted that these staff members may not be familiar with the tsunami hikoi procedures. This was also recognised for new students, particularly new entrants.
- Considerations were discussed, specifically children with injuries (a student was on crutches during shakeout) suggesting that there is the possibility of injured students in a future event and acknowledged they may need assistance. Other considerations raised were unsure of future earthquake shaking duration and time taken for a tsunami wave to reach the coast and the potential severity of damage an earthquake could cause to the school property (e.g. building collapse).

Appendix C: 2016 Kaikōura earthquake and tsunami official Civil Defence Emergency Management official responses.

#	Time	Media	Agency	Post
1	12.40 a.m.	Website Kardos (2016)	**MCDEM**	"National Advisory: **No Tsunami Threat** to New Zealand No:01" advising "the Pacific Tsunami Warning Centre (PTWC) has issued a Tsunami Information Statement in response to the earthquake. Only messages issued by MCDEM represent the official warning status for NZ. MCDEM has assessed the information with the assistance of scientific advisors. Based on the current information, the initial assessment is that the earthquake is unlikely to have caused a tsunami that will pose a threat to NZ".
2	01.00 a.m.	Website Kardos (2016)	**MCDEM**	"National Warning: **Tsunami Threat** No:01 tsunami warning for all southern coastal areas of NZ. A tsunami is possible. The first wave activity may not be the most significant. Tsunami activity will continue for several hours and the threat must be regarded as real until this warning is cancelled. MDCEM is still assessing the threat and will provide more information within the next hour. Meanwhile, people in **coastal areas should: stay out of the water, stay off beaches, do not go sightseeing, follow instructions of local civil defence authorities**. Warning will remain in effect until a cancellation message is issued by MCDEM".
3	01.02 a.m.	Facebook	CDEM Canterbury	Hi Everyone, As you know we are experiencing a whole lot of large aftershocks in and around Kaikoura. If you live near the coast, and you feel a long earthquake, or it is so strong you can't stand up, move to higher ground. **LONG OR STRONG BE GONE. Don't wait for CDEM or anyone else to tell you.** Jessica
4	01.11 a.m.	Online Bulletin	RNZ	Civil Defence now saying anyone near the east coast of the South Island should **move to higher ground** where possible. That adapts the earlier advice.
5	01.12 a.m.	Online Bulletin	RNZ	Civil Defence saying there has been a shift in the tidal level based on measurements near Kaikoura.
6	01.19 a.m.	Online Bulletin	RNZ	Here's the full Civil Defence warning: **People near the eastern coast of the south island should immediately move to high ground or inland as far as possible.** Take your getaway kit with you if possible. Do not travel into the areas at risk to get your kit or belongings. Take your pets with you if you can do so safely. **Move immediately to the nearest higher ground, or as far inland as you can**. If evacuation maps are present, follow the routes shown. Walk or bike if possible and drive only if essential. If driving, keep going once you are well outside the evacuation zone to allow room for others behind you. **If you cannot escape the tsunami, go to an upper storey of a sturdy building or climb onto a roof or up a tree, or grab a floating object and hang on until help arrives**. Boats are usually safer in water deeper than 20 metres than if they are on the shore. Move boats out to sea only if there is time and it is safe to do so. Never go to the shore to watch for a tsunami. Stay away from at-risk areas until the official all-clear is given. **Listen to your local radio stations** as emergency management officials will be broadcasting the most appropriate advice for your community and situation.
7	01.21 a.m.	Facebook	CHCH CDEM	Hi everyone, the Ministry of Civil Defence & Emergency Management have issued a tsunami threat message for the eastern coast of the South Island. **People are advised to stay off beaches, and out of the water.** We will continue to monitor and update you as we know more.
8	01.29 a.m.	Website Kardos (2016)	**MCDEM**	"National Warning: Tsunami Threat No 2" advising "MCDEM has issued a tsunami warning for Eastern coast of North and South Island including the Chatham Islands. It may arrive in the Eastern Coast of the North Island shortly. **Move inland or to higher ground immediately.** A tsunami is possible. The first wave activity may not be the most significant. Tsunami activity will continue for several hours and the threat must be regarded as real until this warning is cancelled. MDCEM is still assessing the threat and will provide more information within the next hour. People in coastal areas should: **stay out of the water, stay off beaches, do not go sightseeing, follow instructions of local civil defence authorities.** Warning will remain in effect until a cancellation message is issued by MCDEM".
9	01.35 a.m.	kardos (2016)	CHCH CDEM	UPDATE **No evacuations have been issued at this stage** and we are continuing to seek further clarification from the Ministry of Civil Defence Emergency Management. **Stay out of the water (sea, rivers and estuaries, including boating activities), stay off beaches and shore areas. Do not go sightseeing.**
10	1:37 a.m.	kardos (2016)	NZ POLICE	Telephone to (District Operations Manager, Chch Police) at 02.07 a.m. to request that the Police activate the "Coastal Evacuation Plan" because CCC is setting off the tsunami sirens. Informed by Police that the Police had started evacuating approximately half an hour before on the direction of the District Commander. The District Commander had been directed to activate the Coastal Evacuation Plan by the Deputy Commissioner of National Operations of Police based in Wellington.
11	01.38 a.m.	Facebook	CDEM Canterbury	Hi Everyone, We have reports that the tide gauge at Kaikoura has risen by two metres. Jessica
12	01.44am	Online Bulletin	RNZ	To repeat, Civil Defence is warning a **"destructive tsunami"** is possible as a result of this morning's quake. It is asking people in low-lying areas on the east coast of **both the North and South Island to move to higher ground immediately.**
13	02.01 a.m.	Website Kardos (2016)	**MCDEM**	National Warning: Tsunami Threat #3 HAMNER SPRINGS EARTHQUAKE AND TSUNAMI No:03 MARINE AND **LAND THREAT"** advising "MCDEM has issued a tsunami warning for all of the eastern coast of the North Island and all of the east coast of the South Island including the Chatham Islands. Confirmation has been received that a tsunami was generated. Waves have been detected on the Geonet Tsunami Gauges. The first tsunami wave activity has been detected in the areas around Kaikoura and Wellington. The first wave activity may not be the most significant. Tsunami activity will continue for several hours and the threat must be regarded as real until this warning is cancelled. People in coastal areas should: stay out of the water, stay off beaches, do not go sightseeing, follow instructions of local civil defence authorities. Warning will remain in effect until a cancellation message is issued by MCDEM".
14	02.05 a.m.	kardos (2016)		Telephone to (Canterbury CDEM Group Team Leader) to check that MCDEM were directing CDEM to activate the sirens. confirmed yes, at the direction of the National Controller, CDEM must activate the sirens.
15	02.11 a.m.	Facebook	CHCH CDEM	NEW INFORMATION: We are **evacuating low lying areas of Christchurch**, including around the estuary. This is a precaution as we are **not expecting large waves or substantial damage on land in Christchurch.**
	02.15 a.m.	Online	**MCDEM**	National Warning: Tsunami #4 – Threat to Marine and Land Areas. No: 04. Issued 0215 hours NZDT 14 Nov 2016 The Ministry of Civil Defence & Emergency Management (MCDEM) has issued a tsunami warning land threat from the East Cape to Southland including Wellington and the Chatham Islands. There is a beach and marine threat for the remainder of New Zealand. More Detail Areas under 'Marine and Beach Threat' can expect unusually strong currents and unpredictable water flows near the shore. This means a threat to beach, harbour, estuary and small boat activities. The severity of currents and changing water flows will vary within a particular coastal area and over the period this warning is in effect. Areas under 'Marine and Land Threat' can also expect a threat of coastal inundation to land areas near the shore. Current assessments indicate that wave amplitudes of up to 2 m can be expected in some areas. Tsunami wave activity has been detected. The first wave activity may not be the most significant. Tsunami activity will continue for several hours and the threat must be regarded as real until this warning is cancelled. People in the above coastal areas should: 1. Stay out of the water (sea, rivers and estuaries, including boating activities) 2. Stay off beaches and shore areas 3. Do not go sightseeing 4. Share this information with family, neighbours and friends 5. Listen to the radio and/or TV for updates 6. Follow instructions of local civil defence authorities 7. If a land threat is forecasted for your area, take appropriate evasive action (see 'Marine and Land Threat' below) This warning will remain in effect until a cancellation message is issued by MCDEM. Only messages issued by MCDEM represent the official warning status for New Zealand. We note the Pacific Tsunami Warning Centre (PTWC) has issued a Tsunami Information Statement for this event. PTWC messages do not represent the official warning status for New Zealand. Local civil defence authorities will interpret this information for their areas and advise public action.
16	02.19 a.m.	Facebook	CDEM Canterbury	As a precautionary measure **all residents on coastal areas evacuate to high ground** #eqnz
17	02.24 a.m.	Facebook	CHCH CDEM	UPDATE: If you live on low lying ground within **one kilometre of the Christchurch coastline you are advised to evacuate inland or to higher ground.** This is a precaution as we are n**ot expecting substantial waves or damage on land**. For more information of low-lying areas go to: http://canterburymaps.govt.nz/.../Tsunami_Canterbury.html
18	03.07 a.m.	Facebook	CDEM Canterbury	UPDATE: Search for your property in the address search bar to see Canterbury's **tsunami evacuation zones**.
19	03.15 a.m.	Facebook	CHCH CDEM	UPDATE: Linwood College has been set up as a **evacuation point** for people who have left their home. The address is 85 Aldwins Road, Phillipstown. The centre is just getting set up now and will be operational from about 4.15am. Akaroa School Hall is also open as an evacuation centre. We will be opening further centres as required.
20	03.20 a.m.	Website Kardos (2016)	**MCDEM**	"National Warning#5: Tsunami – Threat to Marine and **Land Areas**" advising "MCDEM has issued a tsunami warning (marine and land threat) from East Cape to Southland, including Wellington (which also includes the Cook Straight area), Marlborough Sounds/ Tasman Bay and the Chatham Islands, and a marine threat for all other New Zealand coastal areas. See the map attached for affected areas. Areas under "Marine and Land Threat' can also expect a threat to coastal inundation to land areas near the shore. Current assessments indicate that **wave amplitudes of up to 3-5 meters along the coastlines** closest to the earthquake epicenter (estimated from Blenheim to Banks Peninsula, and also including the Chatham Islands) can be expected in some areas (see attached map). People in coastal areas should: stay out of the water, stay off beaches, do not go sightseeing, follow instructions of local civil defence authorities. Warning will remain in effect until a cancellation message is issued by MCDEM. Local civil defence authorities will interpret this information for their areas and advise public action." **Map attached highlights Christchurch and Banks Peninsula as subject to a tsunami threat at a level of 3-5m.**
21	03.49 a.m.	Online Bulletin	RNZ	Sarah Stuart-Black, the national director of civil defence says not to return home until they have given the all clear.
22	03.56 a.m.	Facebook	CHCH CDEM	3.56AM - LATEST UPDATE Christchurch Civil Defence and Emergency Management has activated its Emergency Operations Centre and is currently responding to the earthquake. Civil Defence Controller John Mackie says people in low-lying coastal areas within one kilometre of the Canterbury coast are instructed to evacuate inland or head to higher ground. Tsunami sirens have been sounding for some time and there operation may be intermittent but the precautionary **evacuation order remains in place**. "**We are expecting wave heights of between three and five metres from Blenheim to Banks Peninsula. Waves may arrive over the next few hours.**" An evacuation centre is being set up at Linwood College. It is expected to be operational from about 4am. Mr Mackie encouraged people to try to find friends and family to stay with if they can. "Akaroa School Hall is also open for people who need somewhere to go in the Peninsula." Other centres will be opened in the city as required. There are two rest homes in areas affected by the evacuation order. One has been evacuated and the other is progressing with moving residents out. Civil Defence is also in contact with the port and has advised that large moored vessels are safer out at sea. Police have road blocks in place to prevent access to the coastal areas that may be affected by a tsunami. Residents will be advised when it is safe to return. General advice: - Expect aftershocks. Each time you feel one, drop, cover, and hold on. - Help those around you if you can. - Report injuries or fires to the emergency services (dial 111). - Put out small fires. Evacuate your building if fires cannot be controlled. - Do not go sightseeing and stay out of damaged buildings. - It will take some time for emergency services to determine priorities and to respond accordingly. You may be on your own for some time. - Listen to your radio for updates. - Check out Facebook, Twitter or the website for updates. As the situation evolves, more information will be available.
23	04.24 a.m.	Website Kardos (2016)	**MCDEM**	"National Warning: NO CHANGE Tsunami – Threat to Marine and Land Areas No 6" advising "MCDEM has issued a tsunami warning (marine and land threat) from East Cape to Southland, including Wellington (which also includes the Cook Straight area), Marlborough Sounds/Tasman Bay and the Chatham Islands, and a marine threat for all other New Zealand coastal areas. See the map attached for affected areas. Areas under "Marine and Land Threat' can also expect a threat to coastal inundation to land areas near the shore. Current assessments indicate that wave amplitudes of up to 3-5 meters along the coastlines closest to the earthquake epicenter (estimated from Blenheim to Banks Peninsula, and also including the Chatham Islands) can be expected in some areas (see attached map). People in coastal areas should: stay out of the water, stay off beaches, do not go sightseeing, follow instructions of local civil defence authorities, if a land threat is forecasted for your area, take appropriate evasive action. Warning will remain in effect until a cancellation message is issued by MCDEM. Local civil defence authorities will interpret this information for their areas and advise public action. Local authorities will determine the implication of the expected wave heights for their areas and will decide on appropriate response actions (e.g. evacuations). Listenor check for this information from your local authority."
24	04.38 a.m.	Online Bulletin	RNZ	Civil Defence director Sarah Stuart-Black says tsunami are expected to continue for hours. People should expect to experience aftershocks.
25	04.46 a.m.	Facebook	CHCH CDEM	4.46am UPDATE: Mairehau High School has been opened as an evacuation point for those needing a place to go. You may wish to also go to family and friends located inland areas
26	05.00 a.m.	Facebook	CHCH CDEM	UPDATE: 5am: **Three evacuation centres** are open in Christchurch city after this morning's earthquake and tsunami alert. They are at Akaroa School Hall, Linwood College and Mairehau School, although Christchurch Civil Defence Controller John Mackie encouraged people to consider staying with family and friends located inland areas if possible. As at 5am there were 230 people at Linwood and 50 at Mairehau. Civil Defence has released maps showing the city-wide evacuation zone (refer attached). "The Ministry of Civil Defence and Emergency Management is advising that the threat level remains the same while there is still a risk of **aftershocks so we are still advising people in those low-lying coastal areas within a kilometre of the Canterbury coast to head inland or get to higher ground."** Tsunami sirens continue to sound although this may be intermittent. Mr Mackie explained that while the earthquake was centred inland, the fault line extended offshore for a considerable distance. That meant that seismic activity could cause movement out at sea, leading to a tsunami. Christchurch Airport is open and operational
27	05.44 a.m.	Website Kardos (2016)	**MCDEM**	National Warning#7: Tsunami – Threat to Marine and Beach Areas" advising "MCDEM has issued a tsunami warning (marine and beach threat) for the East Coast of New Zealand, from East Cape to Southland, and also the Kapiti Coast and Tasman Bay/Marlborough Sounds. See the attached map for affected areas. The Chatham Islands and the region between Blenheim and **Banks Peninsula is still prone to a marine and land threat,** and future maximum wave amplitude of approx. **1-3 meters can still possibly be expected to occur**. Areas under "Marine and Beach Threat' can expect unusually strong currents and unpredictable water flows near the shore. This means a threat to beach, harbor, estuary and small boat activities. The severity of currents and changing water flows will vary within a particular coastal area and over the period this warning is in effect. Current assessments indicate that coastal inundation (flooding of land areas near the shore) is not expected but this assessment may change. People in coastal areas should: stay out of the water, stay off beaches, do not go sightseeing, follow instructions of local civil defence authorities, if beach threat is forecasted for your area, take evasive action. Warning will remain in effect until a cancellation message is issued by MCDEM. Local civil defence authorities will interpret this information for their areas and advise public action. Map attached highlights Christchurch and Banks Peninsula as subject to a tsunami threat at a level of 3-5m.
28	06.15 a.m.	Facebook	CHCH CDEM	UPDATE 6.15am People living in the **white areas shown below may return home**, provided they **do not need to pass through a cordon area**. For example if you live in New Brighton and your house is in the white area but you need to pass through a cordon to get home then you are not able to return. Properties located within the **gray zone must remain evacuated.** We will continue to keep you updated.
29	06.56 a.m.	Website Kardos (2016)	**MCDEM**	"National Warning: Tsunami – **Threat to Marine, Beach and Land Areas** No 8" advising "MCDEM has issued a tsunami warning (marine, beach and land threat) for the East Coast of New Zealand, from East Cape to Southland, and also the Kapiti Coast and Tasman Bay/Marlborough Sounds. The Chatham Islands and the coastal areas between Blenheim and **Banks Peninsula are still prone to a marine and land threat,** and future maximum wave amplitude of approx. 1-3 meters can still possibly be expected to occur. Areas under "Marine and Beach Threat' can expect unusually strong currents and unpredictable water flows near the shore. This means a threat to beach, harbour, estuary and small boat activities. The severity of currents and changing water flows will vary within a particular coastal area and over the period this warning is in effect. A land threat still exists and these areas may result in coastal inundation to land areas near the shore. Current assessments indicate that wave amplitudes of up to 2m can be expected in some areas (Chatham Islands and the coastal areas between Blenheim and Banks Peninsula). People in coastal areas should: stay out of the water, stay off beaches, do not go sightseeing, follow instructions of local civil defence authorities, if beach threat is forecasted for your area, take appropriate evasive action. Warning will remain in effect until a cancellation message is issued by MCDEM. Local civil defence authorities will interpret this information for their areas and advise public action.
30	7.00 a.m.	Facebook	CHCH CDEM	UPDATE 7am: Christchurch Civil Defence and Emergency Management is advising people who live **outside the evacuation areas in the city who have left their homes that they can now begin to make their way home.** Christchurch Civil Defence Controller John Mackie said it is important to note that this applies only to those outside the evacuation areas. **People inside those areas should still go inland or head to higher ground.** "Anyone outside the evacuation areas who is going home can only do so if they don't have to pass through an area that is at risk. For example, in the maps available online if you live in New Brighton and you need to pass through a cordon to get home, you should not be trying to return." The three evacuation centres open in Christchurch at Akaroa School Hall, Linwood College and Mairehau School remain busy. Mr Mackie encouraged people to consider staying with family and friends located inland areas if possible. As at 6.30am there were 300 people at Linwood and 50 at Mairehau and 25 at Akaroa. There are about 100 people at Mt Pleasant Hall and a number of people in cars on site as well. They are not requiring Civil Defence assistance at this time. Tsunami sirens have been sounding during the night and morning and a decision has been made to only sound these on the passing of each hour to indicate the evacuation advice remains in force. A number of schools are closed and people should check with their local school for details. Metro buses services and a number of school runs would be operating a limited service. Check the Metroinfo website for updates. Building owners and or occupants who are entering buildings after this morning's earthquake sequence, are advised to get the building checked to establish if any damage has occurred. If this assessment raises any concern, the building should be checked by a professional engineer. The Council staff will be checking its own buildings. Building owners have a responsibility to check their own buildings to make sure they are safe to occupy. If residential home owners are concerned the need to engage a suitably qualified person to assess their property. There is more information on the Council website. https://www.ccc.govt.nz/.../what-building-owners-should-do-a.../
31	08.00 a.m.	Website Kardos (2016)	**MCDEM**	"National Warning#9: Tsunami – Threat to **Marine and Beach Areas"** advising "MCDEM has issued a tsunami warning (marine and beach threat) from Napier to north Dunedin, Cook Straight coastal areas and The Chatham Islands. Please see map attached for affected areas. The threat for all other regions has been lifted. All previous threat regions will experience unusually strong currents for some time. Areas under "Marine and Beach Threat' can expect unusually strong currents and unpredictable water flows near the shore. This means a threat to beach, harbour, estuary and small boat activities. The severity of currents and changing water flows will vary within a particular coastal area and over the period this warning is in effect. Current assessments indicate that coastal inundation (flooding in land areas near the shore) is not expected but this assessment may change. People in Napier to north Dunedin, Cook Straight coastal areas and The Chatham Islands should: stay out of the water, stay off beaches, do not go sightseeing, follow instructions of local civil defence authorities, if beach threat is forecasted for your area, take appropriate evasive action. Warning will remain in effect until a cancellation message is issued by MCDEM. Local civil defence authorities will interpret this information for their areas and advise public action. Map attached highlights Christchurch and Banks Peninsula as subject to a tsunami threat at a level of 0.2 -1m tsunami threat levels.
32	08.10 a.m.	Facebook	CHCH CDEM	8.10am UPDATE: **People who were evacuated due to this morning's earthquake are now able to go home,** Christchurch Civil Defence and Emergency Management says. Christchurch Civil Defence Controller John Mackie said the Ministry of Civil Defence and Emergency Management had advised the risk to land had been downgraded, although there was a threat in the marine and beach environment. That would mean that people staying in camping grounds or freedom camping near waterways could still be at risk and people are still advised to stay away from beaches for the time being. "After a difficult night, people will be relieved to be able to get home. However, we are asking for people to be patient. There will be thousands of people looking to go home just as a lot of others will be going to work for the day. It's important people are patient and make allowances for other people while travelling." The evacuation centres are still open and people there would be advised they can go home. The centres would likely remain open until lunchtime for people who didn't feel comfortable going home. Checks on stopbanks along Ōtākaro / Avon River have revealed no visible signs of damage from today's earthquake.

Appendix D: Field Investigations GPS tracking

Using real-time GPS tracking data is a technique to quantify the effects of slope and terrain on walking speed data inputs for pedestrian evacuation models (Power et al. 2020). The Apple mobile phone GPS tracking app 'MyTracks' was used in this research to generate GPS routes and time estimates for established walking tracks along Kaikōura Peninsula and the Esplanade. In August 2018, the mobile app was used to test 'slow walk speed' to represent evacuation of elderly or disabled population, 'medium walk speed' to represent evacuation speeds of an average walking pace such as the pace at which someone walks to work or could represent a family evacuating with children, and 'run speed' which represented evacuating with urgency. The GPS app and various walking speeds were tested for the following Kaikōura walkways:

- Peninsula Walkway
- Dempsey Track
- South Bay Track (North side of Kaikōura Peninsula)
- South Bay Track (South side of Kaikōura Peninsula)
- St Pauls Track
- Anne Boyd Walkway
- Ward Street Track
- Esplanade

These tracks were tested to represent elevation variation, to see if this would impact GPS tracking speeds. The results of the GPS tracking data were provided as the outputs shown in Figure 4.2-4. The GPS tracking data were uploaded as a KML file into ArcMap to produce a map output to represent evacuation tracks for various speeds. Microsoft Excel was used to analyse the results and calculate average walking speeds.

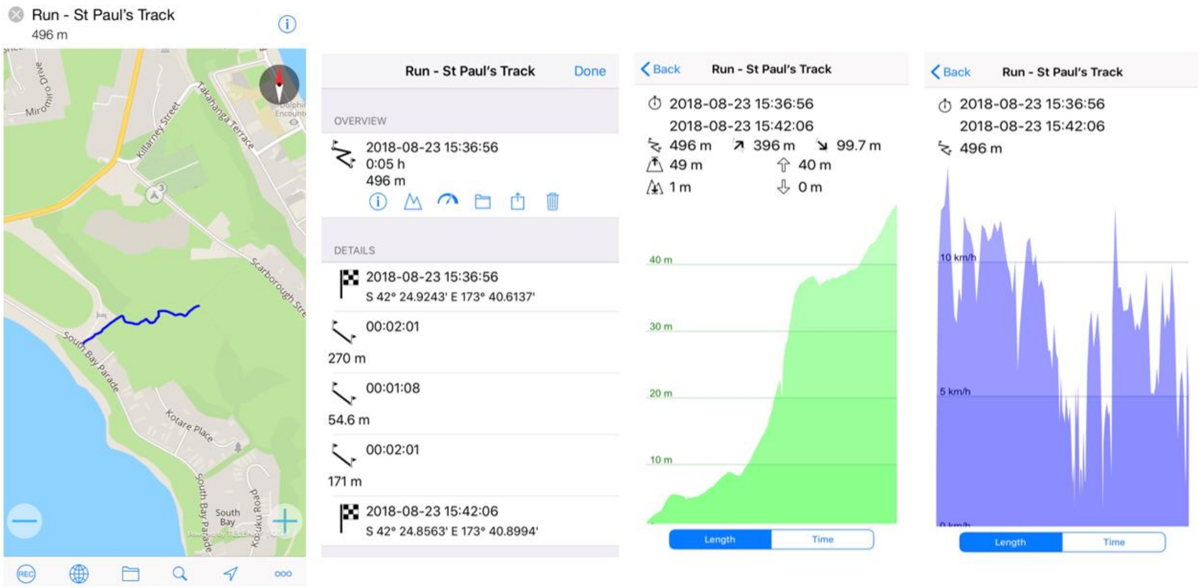

Figure D1-1: GPS Tracking mobile app 'MyTracks' outputs used to determine evacuation walking speeds. This figure represents the example for St Pauls Track. Left, represents the spatial location of the walking track, second panel from the left represents the time and elevation data to walk segments of the track, followed by elevation variation of the tracks, the right panel represents the variation in speed.

The results of the 'real-time' GPS tracking data vary depending on topography of the evacuation route. Figure D1-2 provides a geospatial visualisation of the 8 walking tracks along Kaikōura Peninsula and Kaikōura Esplanade tested in this study. The effects of various walking speeds and terrain were evident from the results of the GPS tracking times. The results conclude that evacuation speeds for medium walking speeds ranged from 4 km/her to 6km/hr. Slow walking speeds ranged around 2km/hr and 'run' speed concluded a range of 7 -10km/hr. Figure D1-2 provides a detailed breakdown of calculated walking speeds for each tested walking path.

Figure D1-2: GPS tracking data captures for 8 walking tracks along Kaikōura Peninsula and Kaikōura Esplanade. Coloured lines represent varying walking speeds (red=run, orange=medium walk, yellow=slow walk).

MyTracks Data -- Kaikōura Field Trip		
	Average time (min/sec)	**Average time (km/hr)**
Peninsula Walkway		
Slow walk	**30.76m/min**	**1.8**
Medium Walk	**93m/min**	**5.6**
Run	**175m/min**	**10.5**
Dempsy Track		
Slow walk	**33.94m/min**	**2.0**
Medium walk	**70.16m/min**	**4.2**
Run	**115m/min**	**6.9**
South Bay Track (North side of Peninsula)		
Slow walk	**35m/min**	**2.1**
Medium walk	**74.96m/min**	**4.5**
Run	**121.63m/min**	**7.3**
South Bay Track (top of Peninsula)		
Medium walk	**96.86m/min**	**5.8**

South Bay Track (South side of Peninsula)		
Medium walk	**85.28m/min**	**5.1**
St Pauls Track		
Slow walk	**32.74m/min**	**2.0**
Medium walk	**76.06m/min**	**4.6**
Run	**120.97m/min**	**7.3**
Side Loop (medium walk)	**73.39m/min**	**4.4**
Anne Boyd Walkway		
Medium walk	**57.95m/min**	**3.5**
Ward Street Track		
Medium Walk	**71.5m/min**	**4.3**
Esplanade		
Run - Brighton Street	**165m/min**	**9.9**
Run - Esplanade	**151m/min**	**9.1**
Medium walk - Torquay	**85.9m/min**	**5.2**
South Bay Parade		
Medium walk (1)	**95.86m/min**	**5.8**
Medium walk (2)	**91.84m/min**	**5.5**
Run (1)	**166.97m/min**	**10.0**
Run (2)	**140.70m/min**	**8.4**