Design and development of realistic exercise scenarios: a case study of the 2013 Civil Defence Exercise Te Ripahapa

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ABSTRACT

Emergency management exercises are regularly undertaken by both government and non-government bodies in an attempt to practise responding to a crisis. The scenarios involved in these exercises range from natural hazards to pandemics to terrorist attacks. Their foremost purpose is to test the resilience of the involved parties and to identify preparedness issues that can be modified pre-event. As such it is vital that the scenarios involved are both probable and scientifically realistic.

Herein, we propose a Scenario Development framework (SDf) for the design and development of future scenarios used in emergency management exercises. We detail the key steps of the SDf and provide examples throughout. We then present the recent South Island CDEM Tier 3 Exercise Te Ripahapa as an illustrative example of the use of SDf’s, and include detailed discussions of the various steps within the SDf that led to Te Ripahapa’s creation.

We conclude that the process of developing an exercise must be split into four stages: 1) Exercise Design; 2) Hazard Scenario; 3) Impact Scenario; and 4) Exercise Control. Each of these stages must be completed in succession because each stage is directly influenced by the previous stage. Furthermore, we demonstrate that both the Hazard and Impact Scenarios must achieve four main aims to be sufficient for an exercise. These are to be:

1. Scientifically realistic and consistent with current knowledge;
2. Of sufficient size to generate consequences applicable to the scale of the exercise;
3. Likely enough not to be dismissed as rare or extreme; and

In order for these to be achieved, the hazard involved must be well understood and thus a significant amount of scientific literature must be available on the topic. In the case of natural hazards this typically requires that a similar event has occurred historically. Finally, we demonstrate that validation of the scenario, via a process of Peer Review, is encouraged and required before the results can be incorporated into an exercise. This ensures that the scenario achieves the four aims stated above as well as the precise exercise requirements and adds a level of credibility.

KEYWORDS

Scenario Development framework; Emergency management; Exercise Design; Hazard Scenarios; Impact Scenarios
1.0 INTRODUCTION

The use of exercises is a popular tool for training and development and is applied in many fields from healthcare to emergency management. The purpose of an exercise is to prepare the participant(s) for particular situations which they are likely to encounter, and as such must be as realistic as is practicably possible (Alexander, 2000). Within the healthcare system, exercises have been shown to increase safety, decrease errors, improve judgement, and be useful for teaching and evaluating specific skills (Bearnson and Wiker, 2005). Further, those that undertake exercises typically score higher in self-confidence and perceived confidence than those not participating (Scherer et al, 2007). In highly stressful occupations, such increases in self-confidence can be critical as they determine whether coping strategies are initiated, how much effort is applied, and how long this effort is sustained when experiencing difficulties (Harder, 2010).

The key concept of exercises is the scenario around which they are based. Alexander (1999) suggests that, in emergency management, scenarios can be designed and incorporated to form three different types of exercise: the traditional linear approach which progresses from cause to impact to response and allows participants to plan procedures in each of these phases (discussion type); a secondary approach where the scenario functions to clarify key emergency management concepts and functions such as resource management (table-top type); and a simulation approach which allows participants to respond to a ‘real’ situation (simulation type). Each of Alexander’s (1999) types of exercises are used regularly around the world in training for a large number of possible scenarios including: epidemics (e.g. Bates et al, 2003), terrorist attacks (e.g. Rose et al, 2007), and natural disasters (e.g. Jones et al., 2008). Globally, natural disasters are increasing in number and severity as a consequence of population increase, climate change, concentration of assets, and marginalisation of communities into hazardous locations amongst others. As such, they are a popular focus for exercises around the world. Nevertheless, natural disasters are extremely complex and in many instances unpredictable. Thus, designing a scenario for a natural disaster is complex and is often simplified as a result.

Following the 2010-11 Canterbury earthquake sequence, there has been a heightened focus throughout New Zealand to increase resilience to future disastrous events. As a result in late 2012, the Canterbury Civil Defence and Emergency Management Group (CDEM) initiated the development of a South Island-wide simulation-type exercise to be held in mid-2013. This exercise was known as ‘Te Ripahapa’ and its aim was to test inter- and intra-dependencies between all South Island CDEM Groups and other major stakeholders (emergency services, lifelines, District Health Boards (DHBs) etc.) in the event of a major natural disaster. The exercise involved the scenario of a magnitude (M) 8.0 earthquake on the Alpine Fault on the West Coast of New Zealand’s South Island. The scenario was intended to present one of the most realistic earthquake simulations attempted globally and included a full earthquake scenario together with likely secondary effects and the impacts to the critical infrastructure of the South Island.

This report summarises the methods undertaken in the creation of the Te Ripahapa scenario. It is intended to serve as an outline for the creation of future realistic scenarios within New Zealand and further afield. First we present an outline of the New Zealand CDEM structure, then we summarise previous international examples of exercise scenarios, and finally we present a conceptual framework for the design and development of simulation-type exercise scenarios established during the creation of the Te Ripahapa scenario.
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2.0 NEW ZEALAND CIVIL DEFENCE AND EMERGENCY MANAGEMENT

2.1 CDEM STRUCTURE

New Zealand’s Civil Defence and Emergency Management structure is, in general, broken down into 3 main levels (Figure 1): National – which consists of the Ministry of Civil Defence and Emergency Management (MCDEM) and National Crisis Management Centre (NCMC); Group – which comprises the 16 regional CDEM Authorities; and Local – containing each of the local councils within the 16 Groups although some local variations do occur. Figure 2 shows the 16 CDEM Group Authorities and the local councils associated with each. The main aim of the CDEM is to create a ‘Resilient New Zealand’ and this is intended to be achieved by local and regional cooperation and coordination (MCDEM, 2013). Each of the levels shown in Figure 1 are independently run and organised but are coordinated by the level above and thus this can be considered a command chain.

Figure 1 New Zealand Civil Defence hierarchy and associated exercise tier levels.

Figure 2 The CDEM Groups and their associated Local Councils (www.civildefence.govt.nz).
2.2 CDEM Exercises

New Zealand has 4 levels of exercise that can be undertaken ranging from very small, local level to large, nationwide level. Each level of exercise is known by a Tier number designating the level of participation and organisation and is an effective measure of the scale of the exercise (Figure 1). These tiers are:

- Tier 1 - Local
  - Local council organisation & participation
  - Rarely involve other councils
- Tier 2 – Intra-Group
  - Organisation by CDEM Group
  - Participation from CDEM Group and all/most local councils
- Tier 3 – Inter-Group
  - Organisation by one of more CDEM Group(s)
  - Participation from several CDEM Groups and associated councils
  - MCDEM and NCMC may be involved
- Tier 4 – National
  - Organised by MCDEM
  - Participation from all/most CDEM Groups, MCDEM, NCMC and central government

Multiple exercises of various tiers are undertaken each year, for instance seven are due to take place throughout 2013 (including Te Ripahapa) with a further nine planned for 2014 (MCDEM, 2013). Most commonly these exercises are Tier 2 or 3 with Tier 4 exercises only taking place every few years. Tier 1 exercises are typically more informal and usually involve public participation. These exercises are most often based on the occurrence of some natural disaster given New Zealand’s propensity for and diversity of natural hazards. Previously these exercises have included: earthquakes, tsunamis, volcanic eruptions, pandemics, and extreme weather events (MCDEM, 2013). Partner agencies typically representing emergency services and/or critical lifelines are often involved to some degree (more typically in higher Tier exercises), but rarely are all such agencies included.

Previous earthquake exercises have been undertaken by a number of regions including Wellington, Canterbury, and the West Coast. Whilst these involved realistic earthquake scenarios (such as Canterbury’s 2007 Exercise Pandora for an Alpine Fault earthquake and Wellington’s 2012 Exercise Phoenix for a Wellington Fault earthquake), to date a detailed geomorphic effects scenario has never been tested.
2.3 Exercise Te Ripahapa

The scenario for Exercise Te Ripahapa was written by Tom Robinson, Tom Wilson, and Tim Davies, of the University of Canterbury, and Caroline Orchiston of the University of Otago at the request of James Thompson from the Canterbury CDEM Group who led the development and implementation of the exercise.

The exercise was Tier 3, involving all of the South Island Regional CDEM Groups and their local councils, MCDEM, NCMC, as well as the South Island Lifelines groups. The requirements for the scenario writers were to design and develop a ‘maximum credible event’ for an Alpine Fault earthquake occurring in May that was seismically and geomorphically realistic. The resulting impact scenario from this event was to include the impacts to the:

- State Highway network,
- Regional rail network,
- Major international and domestic airports/airfields,
- Major ports,
- Hydroelectric power (HEP) generation,
- Power transmission,
- Telecommunications network (landline telephone, mobile telephone, and internet), and
- Buildings (residential and public)

An estimate of the number and locations of casualties (fatalities and injuries) was also required.

The exercise occurred over a 12 hour period on 29 May 2013 and commenced 6 hours after the occurrence of the earthquake. It was run in ‘real-time’ with information being injected into the exercise via email and telephone at specific times to model the flow of information in a real event. Any events that occurred within the first 6 hours were outlined in a pre-exercise information pack that was given to participants to read immediately before the exercise.
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3.0 EXAMPLES OF PREVIOUS EXERCISES

Numerous exercises for natural disasters have been undertaken globally because of their proven record in increasing education, awareness, general ability, and preparedness. Some of the largest and most successful of these have been undertaken by the United States in conjunction with other countries. Analysis of the scenario development in each of these previous exercises highlights successes and strengths that should be incorporated in to future scenario development, as well as failures and weaknesses to be avoided. Below are three examples of recent exercises outlining, where possible, the design and development of the scenarios, the scenarios themselves, and the merits and disadvantages of each.

3.1 HURRICANE PAM, 2004

In 2004 the United States Federal Emergency Management Agency (FEMA) contracted the private contractor Innovative Emergency Management (IEM) to design and run a planning exercise for a catastrophic hurricane scenario in Southeast Louisiana. The aim of the project was to develop a functional, scenario-based exercise simulating a catastrophic hurricane response that would result in the writing of Incident Action Plans (IEM, 2013).

Known as "Hurricane Pam" the exercise involved more than 300 participants from over 15 federal departments/agencies, the Louisiana Office of Homeland Security and Emergency Preparedness, the States of Mississippi and Arkansas, and FEMA Headquarters (IEM, 2013). The exercise was designed to replicate the occurrence of a major hurricane impacting the city of New Orleans and the surrounding parishes. The scenario involved was developed using advanced computer modelling by leading Louisiana State University (LSU) hurricane researcher Ivor Van Heerden.

The scenario involved a slow moving category 3 hurricane resulting in sustained winds of 120mph (193kph), up to 20in (50cm) of rain, and a storm surge that topped the levees in New Orleans (FEMA, 2004). The resulting impacts and humanitarian crisis included the destruction of 500,000 to 600,000 buildings and the evacuation of more than one million residents (FEMA, 2004). The scenario used realistic weather data and damage information developed in conjunction with the National Weather Service, the U.S. Army Corps of Engineers, and the LSU Hurricane Centre. Such a scenario was considered to be a likely worst-case scenario and FEMA ranked it first out of 25 proposed disaster scenarios based on priority of risk for its country-wide initiative for catastrophic disaster planning (US House of Representatives, 2006).

The scenario was designed specifically to demonstrate to participants the possibility of an almost entirely flooded New Orleans; a scenario which previously had not been considered by FEMA or any of the other participants (US House of Representatives, 2006). Indeed the scenario turned out to be prescient. In August 2005, a slow moving category 3 hurricane named Katrina made landfall close to New Orleans bringing with it 125mph (200kph) winds, over 10in (25cm) of accumulated rainfall, and a storm surge which topped levees and flooded 80% of New Orleans (Waple, 2005). Participants involved in the 2004 exercise were notably struck by the similarities between the proposed scenario and the actual events of Hurricane Katrina (US House of Representatives, 2006).

Several key participants noted that the realism of the Hurricane Pam scenario was vital to the response following Hurricane Katrina. For example, medical officials were highlighted to the
issues of evacuating New Orleans hospitals and the Superdome’s special needs centre. They also realised the importance of post-landfall care and evacuation procedures and were in the process of implementing a contingency plan when Hurricane Katrina occurred. Despite this plan not being complete it proved invaluable in the response effort (US House of Representatives, 2006).

Despite this, the emergency response to Hurricane Katrina was insufficient and has been widely criticised by practitioners and researchers (e.g. US Senate 2006; US House of Representatives, 2006). Over 1,500 people were killed and 1.7 million people were left without power or clean drinking water for several weeks (Waple, 2005). A US Senate Report after the disaster found that all levels of the US government failed to ‘plan, prepare for, and respond aggressively to the storm’ (US Senate, 2006). Nevertheless, the detail and reality of the scenario utilised in Hurricane Pam was noted and praised by the report. Instead, the failures were a result of the lessons learnt being ignored or inadequately applied, while the few successes resulted from officials implementing concepts and drafts that resulted from Hurricane Pam (US Senate, 2006).

Prior to 2004, FEMA, as well as the other exercise participants, had not considered the possibility of an almost entirely flooded New Orleans. Such a scenario was only foreseen by involving leading researchers using the most up-to-date scientific information and modelling techniques. Without such a detailed and realistic scenario, it is unlikely that the few concepts that were successfully implemented would have been developed.


Exercise 24 (X24) is a virtual (i.e. online) humanitarian assistance and disaster relief (HADR) exercise that uses crowdsourcing from social media (e.g. Facebook, Twitter etc.) to aid emergency management in the response to a crisis (Bressler et al., 2012). It uses a comprehensive, science-based, holistic approach to test international civilian-military collaboration during a real-time crisis (Howe, 2010). The exercise is open-invitation; that is to say it was available to anyone, anywhere in the world. To date it has consisted of three separate exercises run in 2010, 2011, and 2012 that involved scenarios in Southern California, Eastern Europe, and central Mexico respectively (Howe, 2010; Bressler et al., 2012).

The first of these, X24, involved >12,700 people from 79 nations and 90 US government, non-government, and public organisations (Bressler et al., 2012). The scenario involved a large earthquake off the coast of Southern California which generated a tsunami and catastrophic oil spill in Baja, Mexico, followed by a series of strong inland aftershocks (Howe, 2010). The main purpose of the exercise was to demonstrate the feasibility of the use of crowdsourcing in crisis response and to foster greater collaborative partnerships between Mexico, the United States, and San Diego county (Bressler et al., 2012). Such a scenario is plausible as many active offshore faults are found in the region and a large earthquake nearby in 1902 also resulted in a large tsunami (Bressler et al., 2012). A series of inland aftershocks, away from the main epicentre is considered rare as the aftershocks cluster away from the main epicentre; however, migration of aftershocks has been noted elsewhere (e.g. Bannister and Gledhill, 2012). The involvement of a tsunami was requested by the Commanding Admiral for Mexico’s Second Naval Region in order to demonstrate to consequences of an offshore earthquake as well as test the Navy’s capability to respond (Bressler et al., 2012).
The second, X24 Europe, involved >49,000 participants from 92 nations, 78% of which were from Croatia, Macedonia, and Bosnia-Herzegovina (Bressler et al., 2012). The scenario involved was complex and involved a large offshore earthquake which generated a tsunami in the Adriatic Sea that impacted five Balkan countries (Bosnia-Herzegovina, Croatia, Kosovo, Montenegro, and Macedonia) (Bressler et al., 2012). This region is prone to large earthquakes associated with the onshore active faults in Italy which caused the devastating L’Aquila disaster. A major earthquake on an offshore thrust/reverse fault in the Adriatic Sea could generate a large tsunami that would impact all nations along the Balkan coast as well as Italy and possibly Greece and North Africa.

The latest version, X24 Mexico, involved >1,300 participants from >40 nations and included government and non-government agencies including the US Department of Health and Services, US Customs and Border Protection, Mexican Army and Navy, National Defence University, and the Red Cross. The scenario involved an earthquake on the Middle America Trench offshore of Central Mexico which resulted in a moderate eruption of the Popocatepetl volcano near Mexico City (Bressler et al., 2012). The fault involved is known to have produced large earthquakes historically including a M8.2 in 1902. The earthquake was designed to produce high levels of shaking across a large, populated area of central Mexico and was coincidentally similar to an earthquake which occurred in the region a month after the exercise (Figure 3). The exercise developers highlighted that the eruption of a volcano immediately after an earthquake is considered rare. Nevertheless, they demonstrated several instances of such events occurring, including the 1902 M8.2 earthquake which was immediately followed by the eruption of volcanoes in the Caribbean, Guatemala, and Mexico (Bressler et al., 2012). Despite its rarity, evidence of other similar events globally as well as an historical event in the same region demonstrates this as a realistic, worst-case scenario.

![Figure 3](modified_mercalli_intensity_shake_map_of_the_2012_m7_4_oaxaca_mexico_earthquake_from_usgs_of_which_the_x24_mexico_earthquake_scenario_was_coincidentally_similar.png)
To date X24 has been an excellent education tool for both officials and members of the public. Each of the exercises has facilitated collaboration between various nations which is especially notable in X24 Europe, which achieved this in a region which is historically volatile and has, at best, strained relations between the affected nations. Furthermore, the lessons learnt from X24 and X24 Mexico were later applied by both Mexican and US officials in the response to the 2011 Japan earthquake, tsunami, and radiation leak (Bressler et al., 2012).

To effectively include and facilitate discussion amongst organisations from multiple nations, this worst-case scenario must be realistic. Even ‘friendly’ nations are unlikely to contribute to exercises if they are deemed to be unrealistic. Further, this highlights the need for the collaboration between hazard researchers and emergency managers. Emergency managers are able to design and build an exercise involving their national and international partners, while hazard researchers add legitimacy to the scenario involved encouraging the various participants that the scenario is both realistic and pertinent.

Finally, the X24 scenarios demonstrate the vital need for the inclusion of numerous secondary, cascading hazards. The example of the first X24 scenario, which involved an earthquake, tsunami, and oil spill, is markedly similar to the 2011 Japan earthquake, tsunami and radiation leak. The idea of a tsunami following a large offshore earthquake is well known; however, the idea of such a scenario resulting in a dangerous chemical spill/leak as well has rarely been addressed. This is most likely because such a scenario has previously been dismissed as ‘over-the-top’ or ‘scaremongering’. As such, the officials that participated in the first X24 were well placed to deal with the 2011 scenario in Japan, despite the Japanese being well versed in earthquake and tsunami hazard. Hazard researchers therefore need to incorporate these secondary, cascading hazards, whether natural or man-made, into worst-case scenarios.

### 3.3 Southern California ShakeOut, 2008

California is one of the world’s leaders in earthquake exercises, and has regularly undertaken emergency response and preparedness exercises for the occurrence of large earthquakes. One of the most detailed of these was the 2008 Southern California ShakeOut exercise prepared and conducted by the USGS and California Geological Survey (CGS) (Jones et al, 2008; Porter et al., 2011). This exercise was designed to simulate the response to a large earthquake occurring on the southern segment of the San Andreas Fault. The aim of the exercise was to identify the physical, social, and economic effects of such an earthquake and enable exercise participants to identify effective changes that could be implemented pre-event (Jones et al., 2008).

ShakeOut 2008 had one of the highest participation rates worldwide, with over 5.5 million people taking part (Porter et al., 2011). The majority of these were members of the public who practiced the ‘drop, cover, hold’ method globally recommended in the event of an earthquake. Other participants included the Bank of America which trialled its Emergency Notification and Associate Communication Tool; the Los Angeles Unified School District which trialled a rapid method for visual screening of earthquake prone buildings; and the California Governor’s Office of Emergency Services which ran its first ever exercise for infrastructure recovery and debris removal (Porter et al., 2011). The ShakeOut concept has been so successful it is now an annual event, with numbers increasing, and has been implemented by several other nations in the Pacific replicating the exercise in their own communities. This includes New Zealand which held its own version in 2012, which and achieved up to 1 million participants, ~25% of the population (MCDEM, 2013).
The scenario for the 2008 ShakeOut was developed by over 300 practitioners, researchers, and technical experts from over 50 organisations utilising a number of different methods from computer modelling to expert elicitation (Jones et al., 2008; Porter et al., 2011). The proposed scenario had to achieve a number of specified goals which included being:

1. Scientifically realistic and consistent with current knowledge;
2. Large enough to generate regional, long-term consequences;
3. Likely enough not to be dismissed as rare or extreme; and

The finalised scenario involved a M7.8 earthquake with rupture length in excess of 300km on the southern segment of the San Andreas Fault (Figure 4). This section of the Fault is known to have produced similar earthquakes historically, with a 16% probability of such an event occurring in the next 30 years (Weldon et al., 2005; Field et al., 2007). Secondary hazards such as landslides and liquefaction severed several key lifelines and specific examples and locations of these were included (Treiman et al., 2008). Other effects included:

- 1,800 fatalities and 53,000 emergency room injuries;
- Temporary (days-to-weeks) power loss for the entire region;
- Collapse of 55 buildings, 5 of which are high rise buildings;
- Damage to three dams; and
- Four hazardous material releases (Porter et al., 2011).

As a result, it was one of the largest and most detailed natural disaster exercises ever undertaken globally. Two of its major successes were the level of detail and scientific data included in the scenario, and the large numbers of participants. The scenario achieved all of its stated goals and represents an entirely realistic and believable scenario for a future earthquake on the San Andreas Fault.
The scenario also highlighted several key issues that would result from such an event including significant fires, disruption to transport and power, and the damage to several dams. Attempting to manage an emergency response while incorporating these effects, provided a major challenge to participants and highlighted the complexities of a major natural disaster.

Another noted success was the way the ShakeOut developers and various local and state users interacted in the development and distribution of the exercise (Porter et al., 2011). Such cooperation and interaction highlighted California’s status as a world leader in earthquake preparation and further demonstrated the need for continued efforts in California and globally. Despite decades of earthquake preparations and building strengthening by state and federal authorities, the proposed scenario still identified a number of areas for continued improvement, most notably in fire and dam safety.

A possible negative of ShakeOut 2008 was that it was primarily a scientific exercise, being run and coordinated by two scientific bodies (the USGS and CGS). This meant that much of the work was scientifically relevant and interesting, but not necessarily so for emergency managers. For example, Figure 4 shows the detailed rupture and shaking analysis developed from various calculations using supercomputer software at the Southern California Earthquake Centre (SCEC). Such data has significantly advanced the field of seismology and our understanding of seismic wave propagation. However, such detailed seismic information lacks relevance for emergency managers and would rarely be available in the immediate (hours-to-days) post-event response. Nevertheless, the use of such advanced modelling techniques is not to be discouraged; however it should be applied in a manner more appropriate for emergency managers. This further highlights the need for collaboration between researchers and emergency managers in the design and development of exercise scenarios.

The involvement of >300 leading researchers, all of whom were specialists in their various subjects, resulted in ShakeOut 2008 becoming a leading example in the level of detail and realism possible for emergency management exercises. The large participation rates and the global replication of its format are testament to its success. Similar levels of detail and realism are possible globally and do not necessarily require the inclusion of expensive modelling techniques, as we show below. It should therefore be the aim of all major exercises globally to achieve similar standards of detail and realism to ShakeOut 2008. The four stated scenario goals for ShakeOut 2008 are applicable to all exercise and we suggest these as the foundation in scenario development for emergency management exercises.
3.4 SUMMARY

Each of the examples above has demonstrated the need for detailed, realistic scenarios during emergency management exercises. Such a practice has been widely established in other fields such as civil aviation (e.g. Weiner et al., 1993) and healthcare (e.g. Dausey et al., 2007) with much success. Alexander (2000) noted that for natural disasters the scenario employed should represent a 'reference event'. A reference event effectively provides emergency managers with an example of what is expected to happen in the future, often based on previous events. Nevertheless, Alexander (2000) notes that simply recreating real, historic scenarios can limit emergency response. Participants are inclined to rely on hindsight and de facto 'solutions' rather than considering the scenario as a new event. Instead, Alexander (2000) suggests the best practice is to loosely base scenarios on historic events which ensures the scenario's realism but removes the presence of any 'solutions'. The need for realism was also noted by Preuss and Godfrey (2006) who developed a series of guidelines for developing an earthquake scenario. They noted that in order to actively engage the community in preparation, the scenario must represent a credible and plausible event and detail the specific impacts that result. Preuss and Godfrey (2006) further note that such a scenario should build on current knowledge and incorporate local characteristics which suggests the need for the involvement of local, subject specific researchers.

Hurricane Pam is an excellent example of the development of a reference event. In this case, despite the numerous failings in the response to Hurricane Katrina, the few successes that did result can be directly attributed to the realism of the scenario proposed in Hurricane Pam. Without the Hurricane Pam exercise, emergency managers and government organisations responding to Hurricane Katrina would not have considered the possibility of an entirely flooded New Orleans and the catastrophe could conceivably have been worse as a result. Alexander (2000) also noted the need for the inclusion of realistic secondary consequences in scenarios and both X24 and ShakeOut 2008 have demonstrated to value of including these.

A secondary point noted from each of these examples that is a vital aspect in emergency management exercises is collaboration between the scenario developers (i.e. researchers) and emergency managers. This point was noted by both Alexander (1993) and Perry and Lindell (2003), who suggested that emergency planners and policy makers contact researchers once they have established their knowledge on a particular threat is lacking. However, it is vital that the knowledge transfer from researchers to emergency managers is appropriate and this requires continued collaboration between the two parties.

The failings during Hurricane Katrina can be attributed to failings in this collaboration. X24 on the other hand has demonstrated the huge benefits that can be achieved when this collaboration is successful. The various exercises have led to large steps forward in hazard awareness and education in both the public and government officials, especially in Mexico. It has also led to greater communication between nations threatened by a single hazard (i.e. a tsunami) and a drive towards better integrated response plans. Finally, ShakeOut 2008 has shown that the information that can be produced by researchers in search of a detailed and realistic scenario is not always relevant to emergency managers. Greater collaboration between these two parties can ensure that such information is used and included in a context that better suits emergency manager's needs, whilst also ensuring the vital information they require is present.
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4.0 CONCEPTUAL FRAMEWORK

There are numerous available frameworks for the development of emergency management exercises, each specialised to a specific exercise type (e.g. table-top, discussion etc.) (Figure 5). Nevertheless, detailed information on the design and development of the scenarios involved is relatively sparse. Preuss and Godfrey (2006) produced a noteworthy example; however, they did not provide a strict framework. In New Zealand, MCDEM have comprehensive guidelines on the development of exercises which include instructions on what a scenario should include, however they also do not provide a strict framework (MCDEM, 2013). Consequently, despite numerous frameworks for exercise design, there is currently no definitive framework for the specific creation of scenarios. As part of Te Ripahapa therefore, a conceptual framework for the design and development of CDEM exercise scenarios was established (Figure 6). This Scenario Development framework (SDF) is designed to provide an accepted process by which all future scenarios, regardless of hazard type, exercise tier, or location, can be generated, and which can easily be implemented into the various existing exercise frameworks. The following section outlines the details of the SDF, using examples to illustrate key points.

Figure 5 Conceptual framework for the design and development of discussion based exercises. From Smith et al. (1999).
Emergency management exercises are multifaceted as they attempt to replicate the complex sequence of events that can result during large-scale emergencies. As such there are several steps that need to be undertaken in the design and development of any exercise. Preuss and Godfrey (2006) split the process into four general categories: launching the exercise; organising the planning effort; constructing the scenario and presentation. Smith et al. (1999) suggested a similar process; first developing an exercise design team, then developing the scenario and finishing with the exercise process (Figure 5). Based upon these outlines we suggest that the development of an exercise can effectively be disseminated into four general steps (Figure 6):

1. Exercise Design
2. Hazard Scenario
3. Impact Scenario
4. Exercise Control

Here, contrary to Preuss and Godfrey (2006) and Smith et al. (1999), we have split the scenario into two separate steps: Hazard and Impact. This is because the development of these two scenarios is very different, often involving different methods and/or different personnel (e.g. geoscientists and engineers). This fits with the work of Alexander (2000) who noted that the impacts should be a distinct aspect and outcome of the exercise. Below is a description of each of the steps above with reference to the outlines of Smith et al. (1999) and Preuss and Godfrey (2006) where applicable.

**Exercise Design** – This corresponds to the ‘launching the exercise’ and ‘organising the planning effort’ categories of Preuss and Godfrey (2006) and the ‘exercise design team’ step of Smith et al. (1999). It is the first and most important stage in the development of the exercise. During this phase a development team is selected who determine the hazard type, scale, duration, aims and objectives, and requirements of the exercise, as well as announcing the exercise and establishing a list of participants.

**Hazard Scenario** – This is the first part of the ‘constructing/developing the scenario’ step. During this stage the physical effects that comprise the natural scenario are determined including any natural consequential secondary effects.

**Impact Scenario** – This is the second part of the ‘constructing/developing the scenario’ step. This stage evaluates the effects of the **Hazard Scenario** on the built environment.

**Exercise Control** – This corresponds to the ‘presentation’ category of Preuss and Godfrey (2006) and the ‘exercise process’ of Smith et al. (1999). During this phase the details included in the Hazard and Impact Scenarios are compiled into a series of ‘injects’, as suggested by Alexander (2000), upon which the exercise will be based, culminating in the exercise itself.

During the development of the Te Ripahapa scenario, it was noted that the various processes being undertaken could be broadly incorporated into three separate groups (Figure 6):

1. Procedure
2. External Factors
3. Credibility
These groups linked the various stages by combining them based on their contribution to the scenario. The *procedure* group consists of the series of step-by-step processes which build the scenario. The *external factors* group contains optional elements that may alter the scenario and thus the exercise. They are not the direct result of any aspect of the scenario(s) but may be utilised to achieve any specific exercise requirements set down in the *Exercise Design* stage. The *credibility* group comprise external assessments of the various steps undertaken in the *procedure* group to test the feasibility of the scenario(s) and ensure it meets the *Exercise Design* requirements.

The principal purpose of exercises is to increase levels of societal preparedness for a disaster; however, it is also possible that such exercises can contribute to furthering scientific knowledge (e.g. ShakeOut 2008; Jones et al., 2008). As shown by the examples discussed above, this requires collaboration between researchers and emergency managers which helps to focus current research on hazard science issues that are of particular importance to emergency managers, lifelines groups, and local communities. Given that emergency managers are well practised in exercises and most knowledgeable about their own internal exercise processes, it is recommended that the *Exercise Design* and *Exercise Control* stages are coordinated by emergency managers. The *Hazard and Impact Scenarios* on the other hand can be science led, allowing them to contain the most advanced scientific knowledge available, whilst ensuring the information included is pertinent to users (i.e. those participating in the exercise). This approach is likely to yield dramatic advantages in increasing awareness, knowledge, and resilience throughout the community, whilst also helping to direct scientific research objectives on important social issues.

Consequently, this report focuses on the *Hazard and Impact Scenario* stages of exercise development. Figure 6 presents the SDF for the specific development of a natural disaster scenario in the context of each of the four main stages described above. This SDF utilises both recent global examples of scenario development and the lessons learned from the May 2013 Te Ripahapa exercise to produce the most up to date and complete conceptual model available for scenario design and implementation. It is hoped that the SDF may be used to inform and guide future exercise scenarios both by researchers and emergency management practitioners.
Figure 6  Conceptual Scenario Development framework (SDf) for the design and development of emergency management scenarios.
4.1 **EXERCISE DESIGN STAGES**

4.1.1 Exercise Requirements

Preuss and Godfrey (2006) and Smith et al. (1999) note that during this stage the emergency managers developing the exercise establish its scale (i.e. national, regional, local etc.), the intended participants, and the overall aims/desired outcomes. The latter of these can be multiple and range from the development of Incident Action Plans (e.g. Hurricane Pam) to increasing public awareness (e.g. ShakeOut 2008) to testing new (or current) technology (e.g. X24). It is the desired outcomes that lead to any particular exercise requirements. These requirements dictate various aspects of the scenario(s) and ensure the aims and desired outcomes are achieved. The specific requirements can be hugely varied but may include: testing a distinct selection of participants’ responses to a specific event; modelling the impacts to a single asset; practising response with limited resources etc. These requirements can be thought of as the ‘ground rules’ and ‘logistical factors’ that Alexander (2000) highlighted as part of the building blocks of any scenario.

4.1.2 Hazard Selection

As demonstrated by ShakeOut 2008, the Hazard Scenario must achieve four main aims:

1. Be scientifically realistic and consistent with current knowledge;
2. Be of sufficient size to generate consequences applicable to the scale of the exercise;
3. Be likely enough not to be dismissed as rare or extreme; and

Alexander (2000) showed that the most successful scenarios are those that included events that have occurred historically (and are likely to reoccur) and that are sufficiently well understood. This therefore requires a large repository of scientific literature from which the scenario and its likelihood can be based. In the absence of such a repository, first-hand research into the hazard in question can be undertaken provided there is sufficient time. The latter has significant risk associated however, as exercising for a hazard that is not sufficiently understood is strongly discouraged.

Consideration of hazards used in recent exercises is also encouraged. High impact events such as large earthquakes are rare (low frequency), while low impact events such as storms are more common (high frequency). In regions that experience multiple types of hazard (e.g. New Zealand) there is therefore a need to ensure emergency managers are equally prepared for the more frequent, low impact events, which they already regularly respond to, as well as the less frequent, high impact events, which they may only experience once.
4.2 HAZARD SCENARIO

4.2.1 Primary Process(es)

The primary process(es) for a scenario are those from which all subsequent consequences and impacts originate (whether natural or infrastructural). For instance, an exercise may be based around a heavy rainstorm that generates flooding. However, before the extent of flooding can be determined, the amount and location of rain needs to be established. In this case, it is the weather scenario (particularly the rainfall) that is the primary process. The details of the primary process(es) will dictate the entire scenario. For example, a rainstorm scenario requires:

- A total rainfall amount;
- Location of rainfall;
- Duration of rainfall; and
- Rainfall intensity

The scenario can then be developed in accordance with these details. In most instances the primary process(es) will be a single event (e.g. an earthquake) however, for some hazards there may be many different processes occurring simultaneously in different locations (e.g. an extreme weather event). In the case of the latter the whole set of processes must be determined before the secondary processes can be established.

Data built into a scenario is likely to include some uncertainty because all hazards have some unknown element(s). It is important that this uncertainty is explicitly stated and scenario developers should ensure that the exercise participants fully understand them. In analysing rock fall hazard, Straub and Schubert (2008) discussed two different types of uncertainty; epistemic and aleatory. Epistemic uncertainties are a function of our incomplete knowledge of the process in question (often due to limited data); aleatory uncertainties are random uncertainties, inherent to any modelling process invoked (Straub and Schubert, 2008).
It is vital that both of these uncertainties are accounted for and accurately described within the scenario. It should be made apparent that despite the final scenario representing a realistic, reference event, it may potentially over- or underestimate the hazard. Nonetheless, this uncertainty can also be utilised within the exercise itself to force participants to make decisions based upon uncertain data as they would in a real-life emergency (Alexander, 2000).

4.2.2 Moderating Factors

Moderating factors are those which occur independently of the primary process(es) and are not hazardous, but will influence the magnitude and/or distribution of the primary and/or secondary processes. For example, an exercise based around a volcanic eruption may consider the amount of snow on the volcano summit which will affect any subsequent lahars. Alexander (2000) included ‘complicating factors’ as one of the critical building blocks in scenario development and our moderating factors can be considered similar. These factors are opportunities to influence the primary and secondary processes in accordance with any particular exercise requirements. For instance, if the exercise requires ash fall from a volcanic eruption to affect a particular area, scenario developers can use wind as a moderating factor to ensure ash falls in accordance.

Not all hazard scenarios will have moderating factors. Moderators can take a number of different forms, with a different range and scale of impact on secondary processes. Moderators are specific to the particular hazard and region involved in the exercise. They can be used to either increase or decrease the effects of a particular hazard depending on the particular requirements of the exercise. For example, an earthquake scenario could include a heavy rainfall event to exacerbate the secondary processes (Robinson and Davies, 2013) in order to develop a more challenging exercise for those participants.

4.2.3 Secondary Processes

Secondary processes occur as a direct consequence of the primary process(es), and may or may not be affected by moderating factors. All hazard scenarios, regardless of hazard type, involve secondary processes and thus they must be considered and included in every scenario (Alexander, 2000). Their consequences may be relatively minor and have very limited effects, or be as large as, or larger than, the primary process(es). For instance, secondary processes in a severe weather exercise may include flooding and debris flows that may have greater direct impact on built infrastructure than the primary rainfall and wind gust hazards.

The fourth scenario aim (producing a single, specific scenario) is the most challenging with respect to secondary processes. Many of the hazards that are used in exercises have large unknown elements and some are unpredictable (i.e. earthquakes). Understanding the complex processes that result from these events is often challenging and in some cases impossible. For example, it is possible to theorise a single, specific earthquake event however, it is currently not possible to accurately know the exact locations of the consequential landslides. In these instances, the susceptibility from the primary process must be established and a specific scenario determined from this analysis, usually at random.

Secondary processes can also be utilised to suit specific exercise requirements. This can often be at the expense of the scenarios realism but if applied correctly they can be beneficial. Examples of such a practice may include: to more fully exercise a location that would otherwise be relatively unaffected; to focus a team within the exercise to a specific event; or to include an additional level of uncertainty a factor suggested by Alexander (2000).
4.2.4 Peer Review

When completed, it is vital that the Hazard Scenario be subjected to a formal system of peer review. This ensures that the scenario being exercised has achieved all of its aims and adds a level of credibility that emergency managers require from exercises. It is suggested that this validation process take the style of academic peer review.

It is preferable that this validation be undertaken by an individual or group that is not participating in the exercise and has not been involved in scenario development. The scenario may be reviewed as a whole, or in parts by separate reviewers however, each reviewer should be knowledgeable in the relevant fields. Any specific exercise requirements that have influenced the Hazard Scenario must be submitted to the reviewer(s). It is the task of the reviewer(s) to judge whether the scenario meets to four main scenario aims as well as the specific exercise requirements. If the scenario fails in any of these factors it must be adapted before being reconsidered.

4.3 Impact Scenario

Following the Hazard Scenario, the consequential effects for the built environment must be determined. This is known as the Impact Scenario (Figure 6 and Figure 8). The first step is to establish which ‘assets’ are to be included in the exercise. In this instance, ‘assets’ includes any vital part of society that is exposed to the hazard. These can include the critical lifelines facilities (transport, power, water, telecommunications etc.), key building infrastructure (hospitals, fire stations etc.), population (i.e. casualties), social health and wellbeing etc. Exercises may include just one specific asset (i.e. road network), or detail impacts to numerous assets (i.e. road network, power network, and casualties). For the latter it is vital to include the interdependencies between the various assets (see below). For example, casualties from the immediate hazard are likely to increase if the transport network has also been damaged resulting in injured people becoming isolated.

4.3.1 Asset Groups

Mullin (1989) noted that in the case of well-defined problems, an expert’s conceptualisation of the issues and solution process far exceeds that of a non-expert. Therefore, given a well-defined Hazard Scenario, it is recommended that any relevant asset groups/industries (‘experts’) are actively included in the design and development of the Impact Scenario. There are a range of possible methods for including asset groups into the scenario design. In ShakeOut 2008, experts were utilised to develop their own Impact Scenario from the given Hazard Scenario (Jones et al., 2008). This allowed the various groups to actively model the response of their asset and produce a detailed analysis of its response (e.g. Dam response to shaking by structural engineers and dam operators; Jones et al., 2008). Nevertheless, it requires that those involved fully understand the hazards the asset is exposed to and can potentially result in asset interactions being ignored/forgotten. A further issue may be asset groups (particularly private companies) moderating results so as to appear more resilient to a given hazard to prevent any public reprisal.
Alternatively, Mullin (1989) suggested that actually it is an expert’s solution processes and judgements that are important rather than their underlying knowledge. Mullin (1989) therefore suggested a method whereby an expert’s judgement and processes are coded and a solution is found by computer modelling. This was shown to work well for routine problems but poorly for more complex situations with large uncertainties (Mullin, 1989). Such a process is therefore not applicable to natural hazard scenario development. A further method involves the use of an Integrated Design Team (IDT). Reitman (1989) applied this method to the development of expert systems processes; however, it can be suitably adapted for emergency management exercises. An IDT allows numerous experts from various fields to collaborate and share both knowledge and solution processes. It essentially uses group discussion and expert elicitation to derive the most likely solution. This method effectively deals with the issue of pragmatic knowledge (Reitman, 1989), whereby the desired output is actually a function of the experts’ knowledge of their assets, the emergency managers’ requirements for the exercise, and the scenario developers’ knowledge of the Hazard Scenario. Reitman (1989) also noted that this method allowed emergency managers to have
an advocate on the design team, and expedited development by focussing the various experts on their particular value. Negatives included substantial organisation time, potential personality clashes between participants, and professional pride (Reitman, 1989).

We therefore suggest the best use of these groups is a process of expert elicitation via an IDT. In this manner the Hazard Scenario developers can interact with the various groups in order to ascertain the likely consequences, while assuring that the requirements of the emergency managers is also met. This process also acts as a form of validation and adds significant legitimacy to the scenario outputs as well as ensuring continued collaboration between researchers and emergency managers (and experts).

4.3.2 Asset Exposure/Fragility

The first stage in developing the Impact Scenario is determining the exposure of each asset to the Hazard Scenario. Determining the likely impacts and/or functionality of each asset will be the direct result of its hazard exposure, combined with its fragility. Geographical Information System (GIS) software is recommended because it has the capability for developing multiple layers to be included on a single map. This allows for a determination of risk as well as highlighting the specific hazards that may impact various locations. An asset’s fragility determines how it responds to the hazard(s) it is exposed to. For instance, this can include construction materials which determine how buildings respond to ground shaking in an earthquake or floor heights, which determine the extent of flooding.

It is important to consider at this stage that some of this information may already be known and understood, particularly by the various asset groups who may have carried out previous risk assessments or contingency planning (e.g. NZTA, 2010). For instance, the Transport group are likely to have already carried out risk assessments of their network and identified locations that are particularly susceptible to landslides from previous experience, computer modelling etc. As a result, there may already be mitigation measures in place that would limit the effect to the asset. It is therefore important to include existing mitigation measures and highlights the value of including asset organisations at this stage in the scenario development.

4.3.3 Impacts/Functionality

Once the asset exposure and fragility have been determined, it is necessary to establish the consequential impacts to, or functionality of, each asset. For those assets which provide a service (i.e. the Transport network, power network etc.) it is preferable to determine their functionality (e.g. how serviceable it is) although in some instances simply detailing the impacts is sufficient. For instance, when analysing runways, scenario developers may not be aware of the specific capabilities of military aircraft that may be utilised during the exercise. In this instance stating the functionality of the runway may result in confusion as military aircraft can typically use runways unavailable to commercial aircraft. For those assets that do not provide a service it is the direct impacts that are required. For instance, it is not possible to determine the functionality of the population however it is possible to determine the impacts to the population (i.e. casualties).

Determining the specific impacts to/functionality of each asset is usually obvious, for instance, a landslide across a road results in either a complete or partial blockage of the road. Where possible it is advantageous to make use of historical occurrences of similar events.
4.3.4 Pre-existing Conditions

Pre-existing conditions are similar to the moderating factors in the Hazard Scenario. Like the moderating factors, these can be considered as another aspect of the ‘complicating factors’ identified as vital by Alexander (2000). They are conditions of particular assets prior to the occurrence of the scenario, but are not a direct consequence of the scenario. For example, a particular road may be impeded or closed due to maintenance prior to the exercise. Depending on the requirements of the exercise pre-existing conditions may or may not be included.

Pre-existing conditions are opportunities to influence the impacts to/functionality of various assets in accordance with any exercise requirements. For instance, an exercise might require that a specific region loses power, so a pre-existing condition might be included stating that powerline maintenance was taking place at the time of the scenario causing power loss. These can include real conditions that have actually occurred in the build-up to the exercise, or alternatively they can be replica conditions included for a particular requirement. When creating replica conditions, it is vital that these are realistic in nature and location.

4.3.5 Asset Interactions

The direct effects of the Hazard Scenario on each individual asset must be known. For exercises containing more than one asset, it is important to consider the interdependencies between them because decreased functionality of one asset typically has consequences for the functionality of other assets (Martí et al., 2008). For instance, the number of fatalities immediately resulting from the Hazard Scenario are likely to increase due to impacts to the transport network (which prevents vital access) and critical facilities such as hospitals.

Martí et al. (2008) demonstrated a full systems analysis method designed specifically for modelling interdependencies between assets during large scale emergencies. Their method allowed each asset group to model their own immediate impacts before interdependencies are modelled externally. This has the advantage of including multiple infrastructures in a single model without the internal details of each system being revealed to the other groups. This removes any issues with competition between private companies and security issues for public institutions (Martí et al., 2008). Nevertheless, such a method requires advanced computer simulations and can be financially expensive and time consuming. An alternative method is the IDT expert elicitation process highlighted in Reitman (1989) and herein suggested as the best method for developing the Impact Scenario. This method has the obvious advantage of involving all the relevant parties in discussions. Nevertheless, this does not prevent the issue of competition between private companies, and security issues for public institutions. Both of these methods, as well as the numerous other methods available, have significant flaws and thus it is for the scenario and exercise developers to decide exactly which method to apply. They will need to consider the available time, funds, and any potential competition/security issues which may affect the modelling.

At this stage scenario developers can then reassess the functionality of each asset and apply any secondary, interdependency related impacts. Developers should also be aware that some assets may be unaffected by the Hazard Scenario but will be affected by asset interactions.
4.3.6 Resource/Information Requests

As noted by Alexander (2000), many exercises do not replicate ‘real-time’. Instead they incorporate either large time steps, in order to advance the exercise and conceptualise the outcomes of particular decisions, or time pauses, in order to halt the scenario at a particular point to allow participants time to discuss solutions to a particular issue. Alexander (2000) notes that this is practical for teaching and analysing specific decisions, but is not realistic and thus often not suitable, for large-scale emergency management exercises. Such a practice has historically been incorporated into the majority of New Zealand CDEM exercises primarily for asset and information requests. For instance, participants wishing to utilise helicopters for aerial reconnaissance have traditionally received the relevant information immediately; however, this is not realistic. In a real event such a request would not provide any information for perhaps several hours as helicopters require a significant set-up time (i.e. fuelling, safety checks etc.) as well as the associated flight time.

To avoid such issues it is suggested that asset and information requests are incorporated into any exercise in real-time. Thus when requesting aerial reconnaissance for instance, the relevant information cannot be injected into the exercise until the appropriate amount of time has passed. Determining the amount of time appropriate for such requests could involve estimates from previous experience or alternatively involving an expert from the particular resource group. It is also important that emergency managers have an inventory of the various available resources (helicopters, excavators etc.) and that this inventory is incorporated into the exercise. Requests for more resources than are available is likely in emergency situations and this forces participants to prioritise the use of the assets available.

4.3.7 Peer Review

Similar to the Hazard Scenario (section 4.1), the Damage Scenario must be validated before being finalised for the exercise. In this instance, a two-step verification process is recommended. Firstly, each individual lifeline group (if they did not develop the scenario themselves) should review their specific section. This ensures that the lifeline groups are satisfied that the Damage Scenario accurately reflects the capacities of their networks. Each lifeline group should be encouraged to highlight any areas where the Damage Scenario underestimates the impacts. Lifelines groups should use such exercises as an opportunity to assess and test their network and apply the relevant outcomes.

Secondly, peer review should be undertaken in the same manner as the Hazard Scenario. External reviewers should be utilised to ensure that the exercise is of a sufficient degree of complexity. Again, any specific exercise requirements must be made known to the reviewers whose job it is to ensure such requirements are met in the most realistic manner (i.e. those experienced in loss modelling).
4.4 Exercise Control

4.4.1 Injects

Once both scenarios have been finalised, the last step before actively exercising is to form the scenarios into a series of ‘injects’ as suggested by Alexander (2000). These injects enable the information determined in the scenarios to be introduced during the exercise. Depending on the exercise type (discussion, table-top, simulation) these injects can take various forms: from scenario updates in the form of a prose narrative moving the scenario forward (see Alexander (2000) for an example), to replicating realistic reports such as emergency service calls. This process should involve both emergency managers, who can ensure the injects are appropriately and realistically introduced to the exercise, and researchers, who can include the technical data of the scenario.
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5.0 EXERCISE TE RIPAHAPA

This section details the example of Exercise Te Ripahapa to demonstrate the capability and use of the SDf. For each of the stages discussed we first present an Executive Summary which outlines the details of the various stages that were used in the exercise. For the complete copies of the reports that were generated for Exercise Te Ripahapa, see Appendices. We then provide brief points of discussion for the various steps in each stage showing decisions that were made during development and the reasons for these.

5.1 EXERCISE DESIGN

5.1.1 Exercise Requirements

Te Ripahapa was a Tier 3 exercise in the New Zealand CDEM Exercise scale (Figure 1) and required involvement of all the South Island CDEM Groups. One of the exercise requirements was the inclusion of a scenario that had either significant natural effects or infrastructural impacts for each region. Another requirement was that the exercise accurately represented a natural disaster occurring at the same time of year as the exercise: May. This included the number of tourists—which fluctuates between the winter and summer months—and any weather effects (i.e. moderating factors). Lastly, the exercise required the occurrence of a maximum credible event, and the Impact Scenario needed to reflect this. This required the interactions between the critical lifelines (the assets involved in the exercise) to represent a possible worst-case scenario.

5.1.2 Hazard Selection

To generate natural effects and infrastructural impacts across the entire South Island required the use of a high impact (low frequency) event that would affect a large area. There were several options:

- An extreme weather event;
- A large tsunami; or
- A large earthquake

Given the recent Canterbury earthquake events it was decided that a large earthquake exercise would generate the most benefit for CDEM groups. Several Fault Systems within the South Island are capable of generating a sufficiently large earthquake including the Puysegur Trench, one of the Marlborough Faults, and the Alpine Fault. The Alpine Fault was chosen because it is able to generate M8 earthquakes (Sutherland et al., 2007), and is late in its seismic cycle (Berryman et al., 2012). It is currently considered to be the most severe seismic threat to the South Island (Robinson and Davies, 2013).
5.2 HAZARD SCENARIO

5.2.1 Executive Summary

At 0300 hours on 29 May 2013 an M8 earthquake occurs on the Alpine Fault with epicentre in the Fox Glacier region. During the following 18 hours, four aftershocks with magnitude >5.5 also occur. The most significant of these is an M6.1 on the Akatore Fault at 1140 hours which generates MM8 (Heavily Damaging) intensity shaking in Dunedin City. Following the main earthquake, liquefaction occurs in various locations across the South Island, most notably Westport, Greymouth, and Christchurch. Fault rupture breaks the Waiho stopbank causing the Waiho River to change course and flood a large area of land south of Canavans Knob. Landsliding is widespread throughout the Southern Alps and completely blocks the Alpine passes removing access to the West Coast. Landslides also fall into and block many of the major South Island rivers, most notably the Waimakariri, Buller, and Hokitika rivers. None of these dams break within the first 18 hours; however, a landslide into the Young River landslide dammed lake causes the dam to be overtopped resulting in catastrophic failure of the dam. No heavy rain falls across the South Island during the exercise and as a result debris flows only occur in the Mt Cook and Franz Josef regions which are particularly susceptible. The Hermitage Hotel at Mt Cook is partially buried by a debris flow. A landslide from the NW face of Mt Te Kinga enters Lake Brunner and generates a tsunami with runups of up to 25m. A rockfall into Milford Sound also generates a substantial tsunami which impacts the township.
This scenario was split into 2 sections for validation: the geological scenario and the weather scenario (moderating factors). They were reviewed by GNS Science researchers Dr Phaedra Upton and Dr Mike Page respectively. The full Natural Hazards report is included in Appendix 1 and the Weather Report (moderating factors) in Appendix 2.

5.2.2 Discussion Points

5.2.2.1 Primary Process(es)

This scenario was primarily designed and developed through a detailed analysis of the available literature on New Zealand and international earthquakes. Fortunately, given New Zealand’s propensity for seismic hazards there is a large amount of literature available on the subject. With regards to the Alpine Fault, extensive research has been carried out by New Zealand’s major universities and Crown Research Institutes (GNS Science) over the past several decades. Determining the necessary details of an earthquake on this Fault was therefore a matter of reviewing this material.

Nevertheless, very little research on the geomorphic (secondary) consequences of an earthquake currently exists. These effects result from ground shaking, and include: for example, landsliding, liquefaction, and tsunami (Robinson and Davies, 2013). Current understanding of secondary effects remains insufficient; more specifically, while individual hazards (e.g. landslides) are well understood, very little research exists detailing the cascading effects resulting from an earthquake. The scenario developers therefore attempted a detailed review of New Zealand and global literature assessing the individual geomorphic consequences of analogous historic earthquakes. These included the 2008 Wenchuan earthquake, 1855 Wairarapa earthquake, and 1999 Chi-Chi earthquake amongst others. This culminated in a study which built on previous work (e.g. Hancox et al., 1997; Hancox, 2005) and brought all of the current research together into a single paper outlining the geomorphic consequences of a large earthquake (Robinson and Davies, 2013). It was from this work that a single, specific geomorphic scenario was developed.

5.2.2.2 Moderating Factors

For Te Ripahapa the major moderating factor was the weather. Variations in the particular weather scenario can have significant consequences for the secondary geomorphic effects. For instance, if a heavy rainstorm immediately follows the earthquake, landslide debris deposited in river valleys can be remobilised as debris flows. Alternatively, a major snowfall immediately before the earthquake can result in large snow avalanches during the earthquake.

Part of the exercise requirements were that the scenario should reflect a realistic event occurring in May. As such, the scenario developers analysed climate data from the National Institute of Water and Atmospheric Research (NIWA) from each of the South Island’s weather stations for May since 2008. This enabled determination of the average temperature, rainfall, and cloud levels across the entire island and determined the weather scenario for the exercise (Appendix 2).

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1 There have been 20 significant earthquakes affecting the South Island since European settlement began around 1840 (Robinson and Davies, 2013).
5.2.2.3 Secondary Processes

In Te Ripahapa several large aftershocks were included at various times throughout the exercise in order to make the scenario realistic. The exercise coordinators requested a damaging aftershock that would significantly impact the city of Dunedin to test the local and regional response to such an event. There are several Faults capable of generating an earthquake/aftershock with significant impacts in Dunedin (Figure 10) however, the majority of these are at substantial distance from the Alpine fault. An M8 earthquake on the Alpine Fault would likely change the tectonic stress field throughout the South Island significantly, thus making all seismogenic faults within the South Island potential aftershock generators. This fits with observations following the 2008 M8 Wenchuan earthquake which found that faults up to 400 km from the epicentre had an increased probability of sustaining an earthquake (Toda et al., 2008). Nevertheless, Faults at large distances from the Alpine fault will experience less of a stress alteration than more proximal Faults and are therefore less likely to generate large aftershocks. The aftershock sequence following an Alpine Fault earthquake would therefore likely involve aftershocks primarily focussed along the Alpine Fault and the most proximal seismogenic faults. An aftershock significantly affecting Dunedin is therefore not unrealistic, but inherently unlikely. Without the specific request for such an event, it is unlikely that the scenario developers would have included such an aftershock.

This example also provides another interesting point of discussion. During consultations with the exercise coordinators, it was suggested that the aftershock scenario put forward for Dunedin was too improbable and an alternative was suggested. This scenario involved the occurrence of a much larger aftershock (M7.0) on the Dunstan North fault in Central Otago, rather than the proposed M6.1 on the Akatore Fault (Figure 10). A larger aftershock was needed to generate sufficiently damaging shaking intensities in Dunedin. However, the suggested event would also result in significant impacts for the local area, which would require a focussed CDEM response. As a result Dunedin CDEM activities would not be high enough priority. Once this had been established and demonstrated to the exercise coordinators it was agreed to continue with the original M6.1 Akatore Fault aftershock scenario for Dunedin. This point further highlights the need for collaboration between researchers and emergency managers.

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2 Aftershock sequences are unique to each earthquake however, and while it is possible to determine a most likely sequence, it is impossible to make accurate predictions. The 2010 Darfield earthquake was followed by an aftershock sequence in which the location of aftershocks gradually progressed eastwards, away from the original epicentre (Bannister and Gledhill, 2012). Such a sequence is rare but not unique.
Figure 10  Comparison of the proposed Dunedin aftershock scenarios. a) The Akatore Fault scenario used in Te Ripahapa; b) The Dunstan North Fault alternative scenario suggested by exercise coordinators.
5.3 \textbf{IMPACT SCENARIO}

5.3.1 Executive Summary

The State Highway network is extensively damaged, especially in West Coast Region and the Alpine passes making West Coast District completely isolated by road. Mt Cook Village, Milford Sound, and Queenstown are also without road access and only limited access is available to the surrounding areas. The rail network is similarly affected with no access along the West Coast or through Arthur’s Pass. All the international airports are undamaged following the main earthquake; however, the land on which Dunedin airport is built is heavily liquefied during the Akatore Fault aftershock. Most of the airfields within the Southern Alps and along the West Coast are severely damaged in the initial earthquake.

Power is immediately lost to the West Coast Region, Queenstown-Lakes District, and Arthur’s Pass. There remains no power in any of these areas for the duration of the exercise and it is expected that power will not be restored for several days, possibly weeks. The rest of the South Island loses power as well but this is able to be restored in stages. The system requires ‘rebuilding’, starting in the south at Manapouri and progressing northwards, connecting circuits between substations. Power is steadily returned to the eastern areas throughout the morning and by midday power is fully restored in all areas except West Coast, Queenstown-Lakes and Arthur’s Pass.

The telecommunications network is heavily damaged. Internet and landline telephone connection is immediately lost to West Coast Region and Queenstown-Lakes District. This may take several weeks to fully restore. In the foothills of the Southern Alps, internet and landline connections survive but are unreliable and cut out randomly. The entire South Island and lower North Island are affected by losses of mobile telephone reception. Generally this lasts for short periods of time but reoccurs throughout the exercise related to aftershocks and the reinstatement of power.

Unreinforced masonry (URM) and reinforced concrete (RC) buildings are the most susceptible to damage. In the epicentral region strong shaking results in all exposed buildings being damaged to some extent; in total shaking damages 75% of buildings within West Coast Region. Any unreinforced chimneys experiencing >MM7 are damaged. Typical damage includes failure of parapets and walls, some weaker buildings partially collapse but generally total collapse of buildings is unexpected. All South Island buildings situated on liquefiable material are damaged as foundations subside and building frames are twisted.

The Te Ripahapa Damage Scenario was reviewed by the various lifelines groups highlighted below as well as GNS Science researchers Kim Wright and Dr Jim Cousins. The full report is included in Appendix 4.
5.3.2 Discussion Points

5.3.2.1 Asset Groups

Te Ripahapa involved the modelling of impacts to the critical lifelines networks, population (i.e. casualties), as well as social impacts. The latter was developed individually by the various local councils and thus was not considered in the scenario development. The critical lifelines (transport, hydroelectric power, and telecommunications networks) and casualties were however. Those members of the various asset groups involved in the design and development of the Impact Scenario were:

- Peter Connors: New Zealand Transport Agency – Operations Manager
- John Reynolds: New Zealand Transport Agency – Principal Structures Engineer
- Neil Campbell: Kiwi Rail – Southern Regional Manager
- Andy Lester: Christchurch International Airport – Chief Operating Officer
- Paul Lloyd: Meridian Energy – Network Performance Manager
- Adam Henderson: Transpower – Regional Services Manager, South Island/HVDC
- Rob Ruiter: Chorus – National Manager for Network Protection
- Ray Norton: Telecom – Network Performance
- Lawrence Watson: Telecom – Network Performance

5.3.2.2 Asset exposure

In order to develop a single, specific landslide scenario, the exposure of the lifelines networks was first compared to a coseismic susceptibility map. This map was developed externally to the scenario development and at the time of writing is still in the development phase hence it is not included. Nevertheless, the susceptibility has been estimated from observations of coseismic landsliding in the 2008 Wenchuan, 1999 Chi-Chi, and 1994 Northridge earthquakes and is considered robust (T. Kritikos, personal communication, 2012). From this the locations of individual landslides were then selected to reflect the exposure of each of the included networks. For instance, if a long section of the road network was exposed to high or very high coseismic landslide susceptibility, one or more landslides was chosen at random to occur in this area.

This method allows for a scenario to be established that reflects the most likely impacts to the critical lifelines. It also allows for the scenario to only include those landslides that will require an immediate response from emergency managers. A landslide occurring in an area with no population or lifelines only presents an immediate hazard if it blocks a river with up-or downstream infrastructure. In the South Island, the central Southern Alps are virtually unpopulated and have almost no infrastructure. Therefore very few landslides in this area will require an immediate response during the scenario (or real event). Developing a specific landslide scenario from the susceptibility map without first analysing the locations of the various lifelines networks, would undoubtedly have included several locations that did not require a response. In terms of the exercise these would have been surplus to requirements and would not have elicited a response. Again, this further highlights the need for collaboration between emergency managers and researchers.
5.3.2.3 Pre-existing conditions

No pre-existing conditions were used in Te Ripahapa. Nevertheless, the opportunity to include such a condition did arise. Shortly before the exercise was scheduled to commence, SH94 (Te Anau-Milford Road) was closed due to a large rockfall blocking its path. After discussion with exercise coordinators, this pre-existing condition was not included because the proposed scenario was already sufficiently complex. Its inclusion would have affected the number of people present in Milford township during the exercise, which consequentially would have affected the number of casualties resulting from the planned rockfall tsunami included in the scenario (see Appendix 1).

5.3.3 Impacts/Functionality

In Te Ripahapa the impacts to communication links were a major concern for the exercise. It was established that landline telephone and internet connections were likely to be lost for the entire duration of the exercise over a large area. Mobile and satellite telephone connections would also be lost across much of the country, temporarily and sporadically throughout the exercise. This presented a major issue for exercise coordinators as the desire was for a realistic exercise. However, a loss of so many communication links, to such a large area, at often crucial times presented a key issue for sharing information and effectively running the exercise. It was therefore decided that communications impacts would only be partially included. During times when it was necessary to the exercise for communications to be available (e.g. national situation-report teleconferences) the realistic impacts would be ignored. Temporary periods of realistic communications would then be included at various, pre-determined times throughout the exercise. In this way the exercise was able to proceed effectively whilst also being able to include realistic communications issues.

5.3.4 Asset Interactions

Due to financial and time constraints, an advanced, full systems modelling approach was not possible for establishing the various effects of asset interactions. Instead the process of IDT expert elicitation was utilised. Figure 11 shows the interdependencies between the transport, power, and telecommunications networks in New Zealand that resulted from this process.

![Interdependencies between three of the major critical lifelines networks. Arrows point to dependent network; thick line – strong dependence; thin line – weak dependence; medium line – moderate dependence.](image-url)
Figure 11 shows that the Transport network is dominant in each of its interdependencies. Without access it is often impossible to begin repairs and reinstallations. It is therefore the Transport network that plays a dominant role in the emergency response and recovery. For instance, consider the case of an isolated power line only accessible by a single road (not uncommon in the South Island). If it takes 2 days to repair the power line, but 6 months to repair the road, the total time to repair the power line is 6 months and 2 days as repairs cannot begin until the road has been reinstated. Communications is interlinked with both Transport and Power networks however, it has a much weaker connection. Repairs and reinstallations will be considerably hindered with a lack of reliable communication methods however, unlike with the Transport network, they will still be able to proceed.

5.3.5 Resource/Information Requests

Te Ripahapa was one of New Zealand’s largest CDEM exercises to include real-time resource and information requests. This required those involved in the Exercise Design (not Scenario Design) to establish inventories of the critical resources available (helicopters, excavators etc). During the exercise a number of resource requests were made, particularly for aerial reconnaissance in order to establish information from areas that had lost communication. For instance, one request at 0930hrs asked for aerial reconnaissance of the Waimakariri gorge and Arthur’s Pass areas. Once the request had been filed, the exercise controllers estimated the preparation and flight time required. In this instance, preparation and flight time would last approximately 2 ½ hours and thus the relevant information was not injected back into the exercise until 1200hrs.

Another unique part of Te Ripahapa was the utilisation of example photographs to represent information received during reconnaissance missions. Previous exercises had not included such information preferring instead to simply provide a written report of what the reconnaissance team ‘witnessed’. Using example photographs such as Figure 12 for hazards such as landslides, landslide dams, and rockfalls added a level of realism not seen before in CDEM exercises.
5.3.6 Casualties

5.3.6.1 Executive Summary

In total, we estimate 455 people are killed and 7,432 injured (Table 1).

Table 1 Summary of casualties for earthquake and landslide tsunami as well as the worst affected Districts.

<table>
<thead>
<tr>
<th>Cause</th>
<th>Fatalities</th>
<th>% of total</th>
<th>Injuries</th>
<th>% of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earthquake</td>
<td>293</td>
<td>64%</td>
<td>7,366</td>
<td>&gt;99%</td>
</tr>
<tr>
<td>Landslide Tsunami</td>
<td>162</td>
<td>36%</td>
<td>66</td>
<td>&lt;1%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>455</strong></td>
<td></td>
<td><strong>7,432</strong></td>
<td></td>
</tr>
</tbody>
</table>

Worst Affected Districts

<table>
<thead>
<tr>
<th>District</th>
<th>Fatalities</th>
<th>% of total</th>
<th>Injuries</th>
<th>% of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grey</td>
<td>218</td>
<td>48%</td>
<td>2,863</td>
<td>39%</td>
</tr>
<tr>
<td>Westland</td>
<td>95</td>
<td>21%</td>
<td>2,376</td>
<td>32%</td>
</tr>
<tr>
<td>Queenstown-Lakes</td>
<td>30</td>
<td>7%</td>
<td>763</td>
<td>10%</td>
</tr>
<tr>
<td>Buller</td>
<td>16</td>
<td>3%</td>
<td>401</td>
<td>5%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>359</strong></td>
<td><strong>79%</strong></td>
<td><strong>6403</strong></td>
<td><strong>86%</strong></td>
</tr>
</tbody>
</table>
Immediate death tolls from building collapse related to high intensity shaking number 293. Grey District is the worst affected with 113 deaths, 77 of which occur in Greymouth. Westland District is similarly affected with 95 deaths; 12 in Hokitika. Queenstown-Lakes District is also significantly affected with a total of 30 deaths, 17 of these in Queenstown and Wanaka. Total injuries occurring are 7,366. These are distributed geographically similarly to the fatalities. Nearly 75% of injuries are defined as soft tissue injuries (5,524). A further 12% (884) are lacerations/punctures and 5% (368) fractures and dislocations.

Landslide generated tsunamis with runups of ~15m at Milford Sound and Lake Brunner cause numerous deaths. In total these tsunamis cause 162 deaths, ~35% of the total death toll from the earthquake. A total of 95 people, the majority of which (75) are staff members, are staying in the backpackers, campgrounds, and the lodge at Milford Sound; 57 are killed and a further 23 are injured; only 15 escape unhurt. At the time of the earthquake 453 people are staying in the area immediately surrounding Lake Brunner, 177 of them are affected by the tsunami. In total 105 people are killed and 43 are injured; 29 escape unhurt.

This model was independently reviewed by GNS researcher Dr Jim Cousins. He concluded that this model produced numbers that were probably higher than that expected for a real event but were suitable for the purposes of an exercise. The full report is included in Appendix 3.

5.3.6.2 Discussion Points

All of the South Island District Health Boards, as well as the Department of Health and St John participated in Te Ripahapa. As a result a casualty model was required. There were several models available to estimate the number of casualties likely to result from this scenario. The most complex and detailed of these require knowledge of the infrastructure and building damage resulting from the scenario, and therefore need to be undertaken after the Impact Scenario. Nevertheless, these models also require that the region have experienced four fatal earthquakes since 1970 for calibration. New Zealand has only experienced one fatal earthquake in this time: the 22 February 2011 Christchurch earthquake. These models were therefore not applicable. The method adopted for Te Ripahapa therefore relied solely on the intensity of shaking and the population density of each district. The values associated with each shaking intensity and population density were determined from historical, global examples within the available literature. Given that no New Zealand example was included in this data, the scenario developers compared this method to the casualty rates generated by the 4 September 2010 (0 fatalities) and 22 February 2011 (185 fatalities) Canterbury earthquakes.

It should be noted that this model is not a prediction. Instead, the purpose of this model was to produce an order of magnitude estimate, acknowledged as being realistic by reviewers, and that had a realistic geographical spread (i.e. majority of casualties on the West Coast, with numbers decreasing east of the Southern Alps).
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6.0 CONCLUSIONS

The purpose of emergency management exercises is to increase community and emergency management preparedness and resilience to the various hazards that threaten a region. The scenarios involved in such exercises are complex and multifaceted because the events they attempt to replicate are also complex. Nevertheless, in order to be successful the scenario involved must be as realistic as possible. This has been demonstrated in numerous exercises globally but most notably in the Louisiana Hurricane Pam exercise in 2004 and the Southern California ShakeOut exercise in 2008. The latter was one of the most detailed and participated exercises to have been developed anywhere in the world and highlights California’s earthquake resilience efforts. This concept has been adopted in a number of other nations globally, including New Zealand with great success.

New Zealand, and particularly the South Island, is currently attempting to increase its preparedness and resilience to large earthquakes. As a result, a Tier 3 CDEM earthquake exercise was held on 29 May 2013 and involved all South Island CDEM groups, MCDEM, NCMC, and other key stakeholders. This exercise was known as Exercise Te Ripahapa and details of the scenario are included in this report.

As part of the construction of the scenario, a conceptual Scenario Development framework (SDf) for the design and development of scenarios for future CDEM exercises was developed. This SDf involves a series of step-by-step procedures that apply to any level (tier) of exercise or natural hazard scenario and, when followed, ensure the development of a realistic and scientifically rigorous hazard scenario.

We present the SDf herein in the hope that it may serve as a guideline for future development of CDEM exercises in New Zealand and globally. In presenting the framework we have included various examples and discussions for illustration purposes, and we also include a detailed discussion of the various steps taken in the creation of Te Ripahapa. The Appendices contain the scenario reports developed for the exercise.
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7.0 ACKNOWLEDGEMENTS

We would like to thank the various lifelines groups who gave their time in the creation of Exercise Te Ripahapa as well as GNS Science and the researchers who reviewed all of its various parts. We also thank all those involved in Exercise Te Ripahapa, whether in the design and development of the exercise or as participants. Finally a special thanks goes to the Canterbury CDEM Group who hosted design meetings as well as sharing their facilities with us during the development of the scenarios.

8.0 REFERENCES CITED


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APPENDICES
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APPENDIX 1: NATURAL HAZARDS SCENARIO FOR EXERCISE TE RIPAHAPA

This report is part 1 of a 4 part series which designs a scenario of an M8 Alpine fault earthquake affecting the South Island of New Zealand at 0300hrs on 29 May 2013. This scenario will be used as part of South Island Civil Defence and Emergency Management 2013 Tier 3 exercise (Te Ripahapa) at the request of the Canterbury CDEM Group.

A1.1 EXECUTIVE SUMMARY

At 0300 hours on 29 May 2013 an M8 earthquake occurs on the Alpine fault with epicentre in the Fox Glacier region. During the following 18 hours, four aftershocks with magnitude >5.5 also occur. The largest of these is an M6.1 on the Akatore fault at 1140 hours which generates MMVIII (Heavily Damaging) intensity shaking in Dunedin City. Following the main earthquake, liquefaction occurs in various locations across the South Island, most notable Westport, Greymouth, and Christchurch. Fault rupture breaks the Waiho stopbank causing the Waiho River to change course and flood a large area of land south of Canavans Knob. Landsliding is widespread throughout the Southern Alps and completely blocks the Alpine passes removing access to the West Coast. Landslides also fall into and block many of the major South Island rivers, most notably the Waimakariri, Buller, and Hokitika rivers. None of these dams break within the first 18 hours, however, a landslide into the Young River landslide dammed lake causes the dam to be overtopped resulting in catastrophic failure of the dam. No heavy rain falls across the South Island during the exercise and as a result debris flows only occur in the Mt Cook and Franz Josef regions which are particularly susceptible. The Hermitage Hotel at Mt Cook is partially buried by a debris flow. A landslide from the NW face of Mt Te Kinga enters Lake Brunner and generates a tsunami with runups of up to 25m. A rockfall into Milford Sound also generates a substantial tsunami which impacts the township.

A1.2 METHODOLOGY

The descriptions of events herein are primarily determined from the work of Robinson and Davies (2013) which at the time of writing is in final review for publication. Their work focusses primarily on a detailed literature review of the current knowledge of a likely Alpine fault earthquake, as well as estimates of the geomorphic effects resulting from such an event. They have used quantitative data where possible, primarily in investigating aftershock and landslide processes. They have also established the locations of previous events such as landslide dams, dambreak floods, liquefaction etc. We have therefore deduced a likely scenario for an event from their descriptions and assigned locations to particular hazards where possible. In some instance our own critical judgement of what is most likely has been implemented as Robinson and Davies (2013) did not comment on specific locations due to lack of available sources. This has primarily occurred in our landslides section. Robinson and Davies (2013) were able to come to conclusions on the amount of landslides, area affected by landslides, and volume of landslide material but were unable to definitively determine locations of coseismically generated landslides. This problem is not reserved to Robinson and Davies' work as accurately anticipating the locations of earthquake derived landslides is a globally unanswered problem. We have therefore attributed landslides to the most likely locations based on the occurrence of previous landslides, and where the terrain appears particularly susceptible. For a detailed overview of all the hazards described herein we direct the reader to the work of Robinson and Davies (2013).
A1.3 ALPINE FAULT EARTHQUAKE

At 0300 hours on Wed 29th May 2013 a large earthquake occurs on the West Coast that causes strong shaking to be felt across the entire South Island and lower North Island. No warnings (i.e. Foreshocks) precede the event and its occurrence is completely unpredicted. Figure A 1 shows the Modified Mercalli Intensity (MMI) felt across the South Island. Table A 1 in the appendix describes the various MMI units. Shaking lasts for ~70 seconds and is reported as violent, side-to-side shaking on the West Coast and in central regions. East Coast reports the shaking as strong and rolling in nature.

Immediate reports from GNS identify this as a high M7, low M8 earthquake somewhere on the central section of the Alpine Fault. At 0330hrs GNS and USGS confirm a M8.0 earthquake has occurred on the Alpine fault. Its epicentre is confirmed as being directly beneath Fox Glacier at a depth of 10km. GNS receives ‘felt reports’ from all locations in New Zealand, including Auckland and Whangarei. The event is also felt by several people in Sydney and Hobart in Australia.

Immediate reports focus on casualty numbers, building and lifelines damage, and large-scale landslides. Some reports from the epicentral region suggest seeing surface rupture with horizontal displacements of ~10m and vertical displacements of ~2m. Reports along the rupture zone but further afield suggest smaller displacements of <5m horizontal and ~1m vertical. It is likely that mean horizontal displacement is ~7m while mean vertical displacement is ~1m.

A1.4 AFTERSHOCKS

Aftershocks start to occur within minutes of the main event. Hundreds of small (<M5.0) aftershocks occur within the first 24 hours. These mainly occur on the Alpine Fault but some occur on subsidiary faults in the region. Several larger magnitude aftershocks occur within the first 24 hours. These are listed in Table A 2 along with their magnitude, causative Fault, and MMI. Figure A 2 shows a map of the known active Faults in the South Island with the locations of the main shock and aftershocks listed in Table A 2.

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3 An inaccurate version of this map will likely be produced by GNS and/or USGS within the first few hours and gradually be refined to an accurate version days-to-weeks after the event.

4 It is important to note local ground conditions (soil/rock type/depth, topography etc.) have not been accounted for. Consequently, local conditions may increase the MMI shown at any location by up to 1.5MM units.

5 It is unlikely there will be felt reports from much of the South Island as communications and internet connections are lost – see Critical Lifelines Report (Part 4).
Figure A 1  Damaging isoseismals for the 29th May 0300hrs M8.0 Alpine fault main event earthquake.

Table A 1  The Modified Mercalli Intensity Scale from Wood and Neumann, 1931.

<table>
<thead>
<tr>
<th>Intensity</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>I</td>
<td>Imperceptible</td>
</tr>
<tr>
<td>II</td>
<td>Scarcely felt</td>
</tr>
<tr>
<td>III</td>
<td>Weak</td>
</tr>
<tr>
<td>IV</td>
<td>Largely observed</td>
</tr>
<tr>
<td>V</td>
<td>Strong</td>
</tr>
<tr>
<td>VI</td>
<td>Slightly damaging</td>
</tr>
<tr>
<td>VII</td>
<td>Damaging</td>
</tr>
<tr>
<td>VIII</td>
<td>Heavily damaging</td>
</tr>
<tr>
<td>IX</td>
<td>Destructive</td>
</tr>
<tr>
<td>X</td>
<td>Very destructive</td>
</tr>
<tr>
<td>XI</td>
<td>Devastating</td>
</tr>
<tr>
<td>XII</td>
<td>Very devastating</td>
</tr>
</tbody>
</table>
Figure A 2  Aftershock map showing location of the major (>M5.5) aftershocks during the exercise.

Table A 2  Aftershocks >M5.0, causative fault, and a summary of their Modified Mercalli Shaking Intensities.

<table>
<thead>
<tr>
<th>Time</th>
<th>Magnitude</th>
<th>Causative Fault</th>
<th>MMI</th>
</tr>
</thead>
</table>
| 0930 | 6.0       | Alpine Fault    | VII – Ross, Harihari  
VI – Whataroa, Franz Josef, Hokitika |
| 1140 | 6.1       | Akatore Fault   | VIII – Mosgiel, Dunedin Airport  
VII – Dunedin City, Balclutha  
VI – Palmerston |
| 1325 | 5.6       | Alpine Fault    | VII – Haast  
VI – Jacksons Bay |
| 1615 | 5.7       | Hope Fault      | VII – Arthurs Pass  
VI - Hokitika |
| 1920 | 6.3       | Alpine Fault    | VIII – Franz Josef, Fox Glacier  
VII – Okarito, Whataroa  
VI – Ross, Mt Cook Village |

The Akatore Fault lies within the Coloumb stress field for an Alpine Fault earthquake. Dynamic stress changes resulting from a large magnitude earthquake are often sufficient to initiate earthquakes on faults within the Coloumb stress field. This is the likely cause of the 22 Feb Christchurch earthquake. Such earthquakes can occur seconds to years after the main earthquake. An aftershock on the Akatore Fault occurring at any time in the aftershock sequence is therefore considered realistic.
A1.5 LIQUEFACTION

Liquefaction is reported in regions of sandy and silty soils typically close to rivers, on floodplains, at river estuaries, and lagoons (Figure A 3). Lateral spreading resulting in small-scale flooding is also reported along river banks. Such locations include:

- Westport
- Greymouth
- Hokitika
- Okarito
- Gore
- Christchurch
- Kaiapoi

Reclaimed land in Dunedin, particularly in Port Chalmers, the city’s industrial area on the waterfront, and South Dunedin, experiences minor liquefaction and lateral spreading in the main earthquake. Very little damage occurs and all affected areas remain inhabitable and useable. During the Akatere fault aftershock however, large areas of Port Chalmers and South Dunedin report liquefaction and lateral spreading. Reports suggest this is on a scale similar to that seen in Christchurch resulting from the 2010/2011 earthquake sequence. Further liquefaction also occurs at Okarito as a result of the Alpine fault aftershock occurring at 1920hrs and Hokitika during both the Alpine Fault aftershock at 0930hrs and the Hope fault aftershock.

A1.6 FLOODING

Horizontal displacement during the main earthquake alters many of the West Coast rivers flow directions. Those with deeply incised channels are relatively unaffected and continue to flow along their original path. However, the Waiho River is significantly affected. Surface rupture severely damages the Waiho stop banks and combined with horizontal displacement along the fault, the Waiho changes flow path. The new path is reported to go through the site of the Glacier Gateway Motel and south of Canavans Knob. Further reports suggest this has resulted in widespread flooding on the Waiho flats.

A1.7 LANDSLIDING

The entire Southern Alps are affected by landsliding to some degree. Immediate reports suggest that thousands of landslides have occurred. Most are small slips with limited runout distances. The Western Range front of the Southern Alps is particularly badly affected. Many of these are significant landslides and several are later found to be larger than 1km³. Most of the landsliding occurs in isolated, inaccessible regions and isn't discovered for several days after the earthquake. However, several substantial landslides occur at the following locations:

- Otira Gorge
- Haast Pass
- Lewis Pass
- Buller Gorge
- Milford Road
- Mt Cook
- Kingston Road
While these landslides are not the largest to occur in the Southern Alps, they are the most significant to critical lifelines, infrastructure, and people. Damaging rockfall events also occur in:

- Port Hills, Christchurch
- Seaward Kaikoura Ranges (North and South of Kaikoura, along SH1)
- Paparoa National Park (Along SH6)
- Lake Wanaka (Eastern lake edge, along SH6)
- Crown Range
- Nevis Bluff
- Glenorchy

Figure A 3 shows the location of the above listed events. Both M6.0+ aftershocks on the Alpine Fault cause no new significant landslides but reactivate and enlarge many of the landslides generated by the main earthquake. Following the Akatore Fault aftershock there are no reports of substantial landslides in the affected area. Small slips do however damage and partially block SH1 north of Dunedin and damaging rockfalls occur in the Port Chalmers area, and along SH88 connecting Dunedin and Port Chalmers.

**A1.8 LANDSLIDE DAMS**

Throughout the exercise reduced river levels and dirty water in several rivers are reported. This is inferred to have been caused by landslide dams upstream. Pilots flying over the Southern Alps report seeing large landslides that have blocked corresponding rivers, however most of these landslides remain unidentified due to their remote locations and low cloud across the Southern Alps. The following rivers have reports of reduced flow:

- Buller
- Karamea
- Mokihinui
- Matakitaki
- Maruia
- Ahaura
- Crooked
- Kokatahi
- Hokitika
- Waitaha
- Waimakariri
- Poerua
- Hooker
- Tartare
- Callery
- Cook
- Haast
No upstream flooding is witnessed as a result of these dams due to their remote locations within the Southern Alps. Figure A 3 shows the rivers (and upstream tributaries7) affected. Following the initial main earthquake, there are reports of reduced flow and muddy water in the Waimakariri River at the road bridge near Bexley.

**A1.9  DAMBREAK FLOODS**

During the main earthquake, a landslide into the Young River landslide dammed lake in Mt Aspiring National Park8 causes the lake to overtop the dam. This results in the dam failing catastrophically ((Figure A 3). A powerful flood wave is reported coming out of the Young Valley and dispersing across the Makaroa River flood plain. This raises the level of the Makaroa River downstream of the Young River confluence significantly. There are reports of turbid flow in the Makaroa River and flooding in Makaroa township.

The 1615hrs Hope Fault aftershock (Figure A 2; Table A 2) generates a small landslide that falls into the partially filled Waimakariri landslide dam lake. The dam partially fails and a substantial amount of water overtops the dam and rushes down stream towards Christchurch (Figure A 3).

**A1.10  DEBRIS FLOWS**

Very few debris flows are reported on the day of the exercise due to the lack of long duration, heavy rainfall for much of the South Island in the days before or during the earthquakes. They are expected to occur where loose landslide material remains in steep, narrow valleys during the first heavy rainstorm.

Reports of damaging, long runout debris flows for the Mt Cook and Franz Josef areas in the mid-afternoon were received as heavy rain fell steadily in the area for several hours (Figure A 3). First reports suggest two landslides in the Mt Cook region have been reactivated as debris flows. One of these has heavily damaged Mt Cook Village and reports suggest the Hermitage Hotel is partially buried. The other reportedly occurred in Glentanner and has damaged SH80 and Glentanner airport. Reports from Franz Josef describe a substantial debris flow from Stony Creek which has completely buried several buildings and caused severe damage to SH6.

**A1.11  LANDSLIDE TSUNAMIS**

During the main earthquake a large landslide from the north-western face of Mt Te Kinga impacts Lake Brunner and generates a tsunami (Figure A 3; Figure A 4). As the earthquake occurred at night there are no reports of anyone witnessing the tsunami. Moana township is severely affected as well as lake front houses in Cashmere Bay. The tsunami reportedly generated runups of ~15m at both these locations. Trees were observed to have been ripped up from Carew, Bain, and Dobson Bays immediately opposite the landslide at a height of ~25m. Reports also suggest the tsunami travelled some way up the Arnold River toward the power station, ripping trees and vegetation from the river banks. No damage is reported at the power station but the Arnold Valley road is significantly damaged.

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7 Some of these rivers are unlikely to have blockages in the named river, but rather in one or more of their upstream tributaries.

8 This formed in 2007 and has been stable since despite overtopping soon after the formation of the dam. The impounded lake has an estimated volume of 23 million cubic metres.
A large rockfall event is also reported to have generated a tsunami in Milford Sound (Figure A 3; Figure A 5). Again this wave was not witnessed. Damage to vegetation along the Sound walls suggest the wave was substantial, reaching heights similar to that at Lake Brunner. Milford Sound airport has been completely destroyed as well as the dock and several boats moored there. The campground and hotel are severely flooded. The tsunami wave appears to have travelled up the Cleddau River to the confluence with the Tutoko River. It has also travelled up the Arthur River and may have reached Lake Ada.

There are no reports of a tsunami in the Tasman Sea, however liquefaction and subsidence at Okarito Lagoon may have resulted in a local tsunami as there are reports the sea has flooded the spit and caused the lagoon level to rise by up to 1m.

**A1.12 SEICHES**

No seiches\(^9\) reportedly occurred anywhere in the South Island however, analysis of tide gauges after the exercise shows that small seiche waves (<20cm) did occur in Otago Harbour (Port Chalmers) and Lyttleton Harbour. There are however, reports from the North Island of seiches in Wellington Harbour, Lake Taupo, and Napier. These waves have not caused any damage due to their small wave height (<1-2cm) and are only noticed by keen observers.

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\(^9\) A seiche is a standing wave in an enclosed, or partially enclosed, body of water.
Figure A 4  Lake Brunner landslide generated tsunami runup zones. Inset – detailed view of the tsunami runup at Moana township.

Figure A 5  Milford Sound rockfall generated tsunami runup zones. Inset – detailed view of the tsunami runup at Milford Sound township.
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APPENDIX 2: WEATHER SCENARIO FOR EXERCISE TE RIPAHAPA

This report is part 2 of a 4 part series which designs a scenario of an M8 Alpine fault earthquake affecting the South Island of New Zealand at 0300hrs on 29 May 2013. This scenario will be used as part of South Island Civil Defence and Emergency Management 2013 Tier 3 exercise (Te Ripahapa) at the request of the Canterbury CDEM Group.

A2.1 EXECUTIVE SUMMARY

Two days before the earthquake occurs on 29 May 2013 a small storm has blown over the South Island causing heavy rain for much of the island. Southland is the worst affected area receiving >26mm in places. The day before the earthquake this storm clears the island but a front that was forming behind and slightly south of the storm makes landfall. While most of the island is dry, rain continues in Southland. On the day of the earthquake the front has slowly advanced across the island bringing continued rain to Southland. By mid-afternoon rain is also falling in Westland and Grey Districts and isolated showers have formed in the central Southern Alps. The north and eastern areas remain dry throughout the day. Temperatures are cold across the whole island and snow is possible in the high country. Forecasts for the three days following the earthquake suggest the front will continue to move SE. Rain will continue in Southland for at least the next two days, while the rest of the island will remain dry. Temperatures stay cold throughout and night-time temperatures drop below 0 everywhere. Day-time temperatures reach the low teens.

A2.2 METHODOLOGY

The following weather report for 29 May 2013 is considered to be average weather conditions for any given day in May. This is a 5-year-average calculated for the years 2008-2012 using NIWA’s online\(^{10}\) monthly climate summaries. It primarily discusses temperatures and rainfall as this data is available in hourly reports and is the most influential for emergency response and secondary hazards. The Excel spreadsheet used to determine this average is available as supplementary material. The basic method has involved compiling the number of days in May from 2008 to 2012 that each weather station determined as a ‘rain day’ (defined as any day where >0.1mm of rain falls across the region monitored by the weather station). This has then been averaged for each station to determine the likelihood of rain on any given day in any given year in May for each station. From here we have distributed the total amount of rain for each station in May of the 5 years researched over the total number of rain days to determine the average amount of rainfall on any given rain day. This assumes that historical rain has fallen evenly over all rain days which is unlikely to be correct, however, it provides us with a reasonable average. From this data we have been able to determine which stations are most likely to receive rain on any given day in May and the amount likely to fall. It is from this that we have determined where rain will occur throughout the exercise and the strength of that rain. Temperatures have similarly been averaged over the 5 years for each weather station by comparing the average maximum and average minimum temperatures throughout each May provided by NIWA.

\(^{10}\) [http://www.niwa.co.nz/climate/summaries/monthly](http://www.niwa.co.nz/climate/summaries/monthly)
The weather data described herein is then a combination of actual historical data collated from NIWA’s CliFlo online database\(^{11}\). A search of the database determined that no one day in the last 5 years comprised the exact average conditions as was expected. In order to achieve average island-wide weather conditions therefore we have had to combine data from 29 May 2009 and 29 May 2011. We have used data from 29 May to best represent the conditions at the end of May. Data from the 29 May 2012 provided rain over Southland, while data from 29 May 2009 provided rain over Westland and the central Southern Alps. An Excel spreadsheet of this data is provided as an Appendix. Included as well is a summary of the weather for the previous two days before the exercise and a weather forecast for the three days following the exercise. These have also been determined using collated data from NIWA’s CliFlo, and are taken for the actual weather conditions before and after the dates specified above.

It should be noted that the weather conditions described herein are relatively benign. While storms and heavy rain are possible for the South Island at this time of year, the weather conditions described herein are an average and therefore do not include a strong storm. As a result the natural hazards pertaining to the earthquake discussed in Part 1 of this series of reports will not be exacerbated by the weather conditions. In the event that this earthquake should occur during a particularly bad weather scenario, such as that experience by the South Island during the 2012-2013 New Year period, the natural hazards in Part 1 are likely to be intensified. In any case, Part 1 still relates to a worst-case scenario of natural hazards but it should be kept in mind that the exact weather conditions at the time of the earthquake may play a major role in determining the secondary hazards.

### A2.3 Results

#### A2.3.1 May 27\(^{th}\)

A Cold Front came in from the Tasman Sea on a westerly wind crossing the South Island throughout the day. As a result the whole island experienced periods of heavy rain with >26mm being recorded in Bluff and >15mm recorded in Karamea. The South experienced the worst of the storm with heavy downpours lasting all day from Haast to Invercargill. Only Christchurch escaped the rain but recorded strong wind gusts for most of the afternoon. Temperatures were fairly warm, but wind chill added a cold feel to the day for most of the island.

#### A2.3.2 May 28\(^{th}\)

The previous day’s Cold Front cleared the island and made its way out to sea. Another front forming behind and slightly to the South meant rain continued in the South but at a much lower intensity. The North was dry with clear skies while Christchurch received some showers throughout the day as the last of the front lingered. The temperature was much colder across the whole island and a light frost formed in many rural areas over night.

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\(^{11}\) [http://cliflo.niwa.co.nz/](http://cliflo.niwa.co.nz/)
A2.4 **EXERCISE DAY (MAY 29TH)**

A2.4.1 Overview

- Eastern areas mainly dry throughout the day with a chance of short isolated showers in some locations.
- Rain in Fiordland all day which may turn heavy for parts of the day.
- West Coast begins mainly dry with some showers around Haast but by midday rain has settled over Westland and Grey districts turning heavy by mid-afternoon. May dry up by late evening.
- Cold across the entire South Island.
- Single figures at night across the whole Island with frost and possible snow in high country where temperatures will drop below freezing.
- Eastern areas will warm up to around 15C by early afternoon but Southland and the West Coast will remain in single figures for most of the day.

A2.4.2 Regional

A2.4.2.1 Canterbury

- Dry across most of the region throughout the day.
- Some short, light showers possible in the Christchurch/Banks Peninsular area during the early morning.
- Light showers forming in Mt Cook National Park, Lake Pukaki, and Twizel around midday, likely lasting until early evening.
- Overcast in the morning clearing to scattered clouds by early afternoon.
- Temperatures in single figures throughout the region until around midday.
- Warming to a high of 16C in the Lake Aviemore region by around 15:00.
- High country regions will remain in single figures throughout the day with some areas below freezing in the early morning and evening.
- Snow possible in Arthurs Pass and Mt Cook National Park.

Christchurch City

- Early morning showers possible on Banks Peninsular.
- Dry for rest of the day.
- Scattered clouds for most of the day.
- High of 15C at Akaroa, 14C in town.
- Low of 0C in town during early morning.

A2.4.2.2 Marlborough

- Dry all day throughout the region.
- Scattered clouds early, clearing by afternoon.
- Temperatures in single figures throughout the region until around midday.
- High of 14C in Blenheim; Low of 2C during the early morning in Blenheim.
A2.4.2.3 Nelson and Tasman
- Dry throughout the region.
- Showers possible in Nelson Lakes National Park around midday.
- Further showers possible in the Murchison area by early evening.
- Overcast in the morning, clearing to scattered clouds in the North by mid-afternoon but remaining overcast in the South and West.
- Cold for most of the day with temperatures in single figures across the region.
- High of 16C in Golden Bay around 14:00, Low of -3C in Nelson Lakes in early morning.

Nelson City
- Dry throughout the day.
- Overcast early, clearing to scattered clouds by mid-afternoon.
- High of 16C; Low of 1C.

A2.4.2.4 West Coast
- Starts off dry and overcast for most of the region with early morning showers in Haast.
- Rain by mid-morning/afternoon for Westland and Grey districts but remaining dry in Buller district.
- Rain may turn heavy in Franz Josef region during the early afternoon.
- Overcast with patches of low cloud throughout the day.
- Temperatures cold across entire region, barely getting out of single figures.
- High of 12C in Greymouth; Low of 1C in Franz Josef.

Westport
- Dry throughout the day.
- Overcast all day, with patches of low cloud at times.
- Temperatures remain cold all day with a high of 11C and a low of 3C.

Greymouth
- Starts off dry with showers occurring by early afternoon continuing into early evening.
- Overcast all day, with patches of low cloud at times.
- Cold for most of the day with only the early afternoon above single figures.
- High of 12C; Low of 4C.

Haast
- Showers throughout the day, starting to get heavy by early afternoon.
- May dry out in the evening.
- Low cloud in the morning remains for most of the day but may clear by evening.
- High of 9C; Low of 4C.
A2.4.2.5 Otago

- Dry across most of the region throughout the day.
- Some short, light showers possible in Dunedin area in the early morning and in Albert Burn near Lake Wanaka in the late evening.
- Scattered clouds for the day in the east but overcast in Central Otago and the Queenstown Lakes districts.
- Temperatures start off low, in single figures until mid-morning but warm up throughout the day.
- Central and Eastern regions likely to have temperatures in the mid-teens.
- High of 16C in Oamaru area; Low of -2C in the high country around Lake Wanaka.

Dunedin City

- Dry for most of the day with some scattered showers to the South around mid-morning.
- Scattered clouds throughout the day, with periods of clear sky.
- Temperatures in the single figures for the morning but warming during the afternoon.
- High of 13C; Low of 4C.

Queenstown

- Dry throughout the day, very little chance of rain.
- Scattered clouds throughout the morning clearing by afternoon.
- Cold until mid-morning but warming during the afternoon.
- High of 16C; Low of 4C.

A2.4.2.6 Southland

- Dry in the East but rain throughout the day in the West.
- Steady rain falls constantly across Fiordland with little signs of stopping.
- Heavy bursts likely in Manapouri, Te Anau, and Milford Sound in the late afternoon.
- Overcast throughout the day with low cloud in the afternoon and evening.
- Fairly cold throughout the day with temperatures not getting out of single figures for most of Fiordland.
- High of 13C; Low of -5C in the highlands.

Invercargill City

- Dry throughout the day.
- Overcast for much of the day with periods of low cloud in the evening.
- Temperatures in single figures for much of the morning but reaching low teens by mid-afternoon and remaining there for the rest of the day.
- High of 13C; Low of 8C.
Milford Sound

- Rain all day, generally light but may include heavy bursts in the late afternoon.
- Overcast all day with low cloud forming in the afternoon and remaining into the evening.
- Remains cold all day not getting out of single figures.
- High of 8C; Low of 3C.

A2.5 3 Day Weather Forecast

A2.5.1 May 30th

- Continued rain throughout Fiordland turns heavy as the new front pushes inland and begins to turn South.
- West Coast turns dry although scattered showers are expected in Haast and Hokitika throughout the morning and afternoon.
- Continued light rain in the Mt Cook region.
- Rest of the island remains dry but overcast.
- Temperatures are generally in the mid-to-low teens.
- High of 20C in Oamaru; low of 0C in Christchurch.

A2.5.2 May 31st

- Rain continues in Fiordland but begins to ease.
- Front moves south-east over much of Southland and the Catlins bringing rain for Invercargill, Gore, and Balclutha.
- Continued showers around Haast but generally dry for the rest of the island.
- Isolated showers in Central Otago and the Mt Cook region possible.
- Temperatures remain in the mid-to-low teens.
- High of 19C in Balclutha; low of -5C in Twizel.

A2.5.3 June 1st

- Rain finally clearing from Fiordland as the front progresses to the south-east.
- Continued showers in the South around Invercargill, Gore, and Stewart Island.
- Dry elsewhere around the island. Clouds clearing to patchy skies.
- Temperatures relatively unchanged from previous days.
- High of 18C in Motueka; low of -4C in Mt Cook.
APPENDIX 3: CASUALTIES SCENARIO FOR EXERCISE TE RIPAHAPA

This report is part 3 of a 4 part series which designs a scenario of an M8 Alpine Fault earthquake affecting the South Island of New Zealand at 0300hrs on 29 May 2013. This scenario will be used as part of South Island Civil Defence and Emergency Management 2013 Tier 3 exercise (Te Ripahapa) at the request of the Canterbury CDEM Group.

A3.1 EXECUTIVE SUMMARY

In total, we estimate 455 people are killed and 7,432 injured (Figure A 6 and Figure A 7).

<table>
<thead>
<tr>
<th>Cause</th>
<th>Fatalities</th>
<th>% of total</th>
<th>Injuries</th>
<th>% of total</th>
</tr>
</thead>
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<td>Earthquake</td>
<td>293</td>
<td>64%</td>
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<tr>
<td>Landslide Tsunami</td>
<td>162</td>
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<table>
<thead>
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<th>Worst Affected Districts</th>
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<th>% of total</th>
<th>Injuries</th>
<th>% of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grey</td>
<td>218</td>
<td>48%</td>
<td>2,863</td>
<td>39%</td>
</tr>
<tr>
<td>Westland</td>
<td>95</td>
<td>21%</td>
<td>2,376</td>
<td>32%</td>
</tr>
<tr>
<td>Queenstown-Lakes</td>
<td>30</td>
<td>7%</td>
<td>763</td>
<td>10%</td>
</tr>
<tr>
<td>Buller</td>
<td>16</td>
<td>3%</td>
<td>401</td>
<td>5%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>359</strong></td>
<td>79%</td>
<td><strong>6403</strong></td>
<td>86%</td>
</tr>
</tbody>
</table>

Immediate death tolls from building collapse related to high intensity shaking number 293. Grey District is the worst affected with 113 deaths, 77 of which occur in Greymouth. Westland District is similarly affected with 95 deaths; 12 in Hokitika. Queenstown-Lakes District is also significantly affected with a total of 30 deaths, 17 of these in Queenstown and Wanaka. Total injuries occurring are 7,366. These are spread out geographically similarly to the fatalities. Nearly 75% of injuries are defined as soft tissue injuries (5,524). A further 12% (884) are lacerations/punctures and 5% (368) fractures and dislocations.

Landslide generated tsunamis with runups of ~15m at Milford Sound and Lake Brunner cause numerous deaths. In total these tsunamis cause 162 deaths, ~35% of the total death toll from the earthquake. A total of 95 people are staying in the backpackers, campgrounds, and lodge at Milford Sound, the majority (75) are staff members; 57 are killed and a further 23 are injured; only 15 escape unhurt. At the time of the earthquake 453 people are staying in the area immediately surrounding Lake Brunner, 177 of them are affected by the tsunami. In total 105 people are killed and 43 are injured; 29 escape unhurt.

These numbers have been derived from empirical formulae developed from observations of earthquakes globally. Using the night resident population (NZ census data 2006) we have determined the population density for various urban and rural regions. Using global coefficients that we show to be applicable to New Zealand we then calculate the numbers of fatalities likely to occur for each population density. By applying modified weightings to the various shaking intensities we are able to determine the zones that are most likely to experience the highest fatalities. We have then distributed these fatalities by comparing the population affected with the total population and distributed fatalities accordingly.
Nevertheless, this method struggles to resolve low population densities and it has therefore not been possible to determine precise locations of rural fatalities, only urban ones. It also does not consider the fragility of individual buildings which may increase or decrease casualty numbers.

A3.2 REPORT STRUCTURE

In the following report we begin by describing the methodology. Here we begin with a description of the data that was available to us, its strengths and weaknesses, why we have chosen the particular data, any adaptations, and the reasons for these, we have made to the available data. We then describe the possible methods that currently exist for determining the numbers of casualties resulting from an earthquake. Here we describe both the benefits and limitations of each method and why we consider them unreliable methods for New Zealand. We then move on to describe the basic principles of the model we have chosen to use and why this is a better choice than other methods. Within this section we also describe the various adaptions we have made to this model, our reasons for this, and any limitations that exist within the model. Next we describe our methods for determining the numbers of injuries resulting from the earthquake before we describe how landslide tsunami casualties are calculated. Next we discuss the results that we have achieved and separate these into sections on earthquake casualties and landslide tsunami casualties.

![Number of Fatalities resulting from shaking per District](image)

**Figure A 6** Total number of fatalities per district generated by building collapse due to high intensity shaking and landslide/rockfall induced tsunami.
Figure A7  Total number of injuries per district generated by building damage due to high intensity shaking and landslide/rockfall induced tsunami.

A3.3 METHODOLOGY

The number of fatalities occurring during the exercise has been split into those killed by building collapse due to high intensity shaking, and those killed by tsunamis at Milford Sound and Lake Brunner. Fatalities resulting from other secondary effects, such as landslides and aftershocks, have not been calculated.

In order to produce these estimates we have used an empirical model developed from observations of earthquakes globally since 1900. Using the night resident population (NZ census data 2006) we have determined the population density for various urban and rural regions. Using global coefficients that we show to be applicable to New Zealand we then calculate the numbers of fatalities likely to occur for each population density. By applying modified weightings to the various shaking intensities we are able to determine the zones that are most likely to experience the highest fatalities. We have then distributed these fatalities by comparing the population affected with the total population and distributed fatalities accordingly. Below we discuss this method in more detail, as well as the various other methods that can be used and their limitations.
A3.4 Data

Population data used to determine the population exposure has been taken from the 2006 New Zealand Census\textsuperscript{12}. Where possible we have used the Night Resident Population (NRP) in our analysis to account for the time of the main earthquake (0300hrs). It should be noted that data for the NRP in the 2006 Census corresponds to the number of people in a meshblock on the night of the census (7 March 2006). The NRP is therefore occasionally different to the Usually Resident Population (URP). We have assumed that this is due to tourist numbers. Some meshblocks see dramatic increases between URP and NRP, and sensitivity checks have confirmed these correspond to the most popular tourist destinations. For instance one of the meshblocks corresponding to Franz Josef has a URP of 54 but a NRP of 303. Tourist numbers will vary throughout the year and the timing of the exercise (in May) corresponds to New Zealand’s tourism low season. It is therefore likely that some NRP’s will be smaller than those used in this study. As a result we have attempted to use data that corresponds to the populations during the tourism low season where appropriate. We have only completed this for Milford Sound as this location witnesses a tsunami and therefore exact numbers of population are necessary. Elsewhere we have used data from the 2006 Census as this likely corresponds to a reasonable average between the tourism high and low seasons.

Data on earthquake prone buildings has not been used in this report. The timing of the main earthquake used in this scenario is 0300 hours. At this time of day the large majority of the population will be at home in their place of residence; very few will be at work or in public use buildings. Data provided by the various Local Authorities however, represents only the public use buildings. Even significant damage and collapse of one of these buildings is unlikely to yield many casualties at 0300hrs. The observation of a correlation between earthquake fatalities and timing of the earthquake is well known and is often a consequence of the general population’s location when the earthquake occurs (see Lomnitz (1970) for discussion). Data provided by the Local Authorities has therefore been included in the Lifelines Report (Part 4) of this series instead.

A3.5 Methods for estimating earthquake fatalities

Various models for estimating the likely number of casualties from an earthquake exist within the literature. Each requires a large input of very specific and detailed data in order to calculate a complex problem. Some of the most powerful models require computer modelling and are able to evaluate the likelihood of various states of damage to buildings, lifelines, and other components of the built environment, and estimate the direct and indirect financial losses resulting from this damage. Examples of these are HAZUS (Kircher et al., 2006) and QLARM (Trendafiloski et al., 2011) and for New Zealand, RiskScape (King et al, 2008). These models however require vast amounts of detailed data that were not available for this study. One of the primary data needs is an accurate database of the region’s building stock. While data on earthquake prone public use buildings has been provided by the various Local Authorities, data on the residential buildings was not available to us. We are therefore not able to use any of the available computer models in this study. Nevertheless several empirical models are available that do not require knowledge of the building stock and we detail these herein.

A3.6 PAGER MODEL

This method was originally detailed by Jaiswal et al (2009) and is used by the USGS’s Prompt Assessment of Global Earthquakes for Response (PAGER) system. This is primarily used post-earthquake to identify if a particular event has caused significant casualties. One of the key strengths of this method is that it has developed models for specific countries and regions. Unfortunately in order to generate a country-specific model to accurately represent the conditions, that country must have experienced at least 4 deadly earthquakes since 1978. As a result New Zealand has had to be integrated into a ‘region’ which consists of a number of countries with similar vulnerability levels. The factors which contribute to this are: Human Development Index, building inventory, geography, climate, and a collection of other socio-economic factors thought to influence vulnerability. Taking this into consideration New Zealand is grouped with California (California is considered separately from the rest of the United States as it has notably more stringent building codes, seismically resistant buildings, and a population experienced in earthquakes).

The fatality rate, \( \nu \), which is a function of shaking intensity, \( S \), is then computed from:

\[
\nu(S) = \Phi \left[ \frac{1}{\beta} \ln \left( \frac{S}{\theta} \right) \right] \tag{Equation A 1}
\]

where \( \Phi \) is the standard normal cumulative distribution function, \( S \) is the shaking intensity bounded between MMI V and MMI X and increases in increments of 0.5 (i.e. 5.0, 5.5, 6.0, 6.5, 7.0), and \( \theta \) and \( \beta \) are parameters of the distribution. If \( P_i(S) \) is the population exposed to shaking intensity \( j \) for an event, \( I \), then the expected number of fatalities, \( E_i \), is:

\[
E_i \approx \sum_j \nu_i(S_j) \cdot P_i(S_j) \text{ where } j = 5.0, 5.5, 6.0 \tag{Equation A 2}
\]

Jaiswal et al (2009) have calculated the free parameters \( \theta \) and \( \beta \) for 213 countries globally. For New Zealand \( \theta \) and \( \beta \) are 38.33 and 0.36 respectively. This results in a fatality rate of about 1 in 30,000 for MM VIII shaking.

The 22 February 2011 Christchurch earthquake does not fit these data however. From 2006 New Zealand Census data we note that 284,625 people were exposed to MM VIII shaking in the February earthquake. Using the PAGER model suggests ~10 people would have died in the event. The actual death toll was 185 but Ingham (2011) has estimated that had the 4 September 2010 earthquake not occurred, damage to Unreinforced Masonry Buildings (URM’s) would have killed a further 294, bringing the final death toll to 479. This is much higher than the 10 predicted by Jaiswal et al (2009)’s model. Furthermore, if we expand the view to a M8 earthquake on the Alpine fault we note that between 25,000 and 30,000 people are exposed to MM VIII or greater shaking, with between 5,000 and 10,000 exposed to MM IX or greater. According the above method this would only result in 1 or 2 deaths. While we cannot say for sure this is incorrect, it seems unrealistic and is a further reason we do not follow this method in our casualty models.
Several models exist which consider the population density of the affected area when estimating likely fatalities. A basic method was suggested by Christoskov and Samardjieva (1984) and assumed the fatalities were mainly a function of the earthquake magnitude, $M$, and the population density, $D$, of the affected area. They determined that for earthquakes with a focal depth of <60km the number of fatalities, $N_k$, could be determined by:

$$ \log N_k(D) = a(D) + b(D)M $$  

Equation A 3

where the coefficients $a$ and $b$ are regression parameters depending on the average population density. Samardjieva and Badal (2002) used a large catalogue of deadly earthquakes occurring between 1901 and 1999 to show that these coefficients varied in time as overall vulnerability generally decreased with increasing awareness and resilience. This is shown in Table A 4. The deadly earthquakes they selected had to correspond to a number of parameters, namely:

- an onshore epicentre,
- an epicentre not under a major city,
- no extremely high populations in the affected area,
- no extremely low populations in the affected area
- an epicentre depth <60km,
- an estimate of magnitude, and
- average, or above average, building conditions.

New Zealand and the earthquake being used in this scenario correspond to all these factors and we therefore deem these regression parameters to be applicable. A further caveat was that population densities for the affected had to be not <1 person per square kilometre and not >>200 persons per square kilometre.

Table A 4  Regression coefficients for the periods 1900-1950 and 1951-1999 for the different population density groups as determined by Samardjieva and Badal (2002).

<table>
<thead>
<tr>
<th>Population Density (people/km$^2$)</th>
<th>1900-1950</th>
<th>1951-1999</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$a$</td>
<td>$b$</td>
</tr>
<tr>
<td>$D &lt; 25$</td>
<td>-3.41</td>
<td>0.66</td>
</tr>
<tr>
<td>$D = 25-50$</td>
<td>-3.00</td>
<td>0.71</td>
</tr>
<tr>
<td>$D = 50-100$</td>
<td>-2.60</td>
<td>0.75</td>
</tr>
<tr>
<td>$D = 100-200$</td>
<td>-2.17</td>
<td>0.77</td>
</tr>
<tr>
<td>$D &gt; 200$</td>
<td>-2.09</td>
<td>0.86</td>
</tr>
</tbody>
</table>

The average population density of the South Island is 6.95 people per square kilometre. Using Equation A 3 this suggests 178 total fatalities. While this figure may immediately appear low for a M8 earthquake on the Alpine fault, it should be considered that only 185 people were killed in the 22 February Christchurch earthquake despite 385,965 people being exposed to MM VII or greater shaking. Accounting for Ingham (2011)’s observation that this would have been 479 had the 4 September 2010 earthquake not happened gives a fatality ratio of 1 death for every 800 people. Only 95,537 people are likely to be exposed to MM VII or greater shaking in a M8 Alpine fault earthquake. Using the same ratio as above suggests that ~120 deaths would occur. This method therefore appears feasible. Nevertheless, this model can only determine the total fatalities providing no way of identifying where these fatalities will occur.
A3.8 Christoskov et al. (1990) Model

Christoskov et al. (1990) adapted the model of Christoskov and Samardjieva (1984) by assuming that the number of casualties decreases proportionally with the square of the epicentral distance, \( R \), similar to the attenuation of seismic energy. A weighting factor, \( W_i \), depending on the radii, \( R_i \), of the area of shaking intensity, \( i \), was introduced. Christoskov et al. (1990) suggested that this worked for intensities > MM VI, highlighting that fatalities globally appear to only occur in shaking zones > MM VI. They determined the weights can be calculated by:

\[
W_i = 1 / \left[ R_i^2 \sum_j \left( \frac{1}{R_j^2} \right) \right], \quad j = \text{VII, VIII, IX} 
\]

Equation A 4

The number of fatalities within an area of shaking intensity, \( i \), then becomes:

\[
N_k^{(i)} = W_i \cdot N_k(D_i) 
\]

Equation A 5

\( N_k(D_i) \) is estimated from Equation A 3 for the population density, \( D \), of the affected area of intensity, \( i \), and total fatalities, \( N_k \), is the sum of \( N_k^{(i)} \). In this instance it becomes possible to determine how many fatalities will occur in each intensity zone.

In the area affected by the Alpine fault earthquake scenario average population density for each shaking intensity is < 25 due to the largely rural nature of the area. The epicentral radii for MM zones VII, VIII, and IX+\(^\text{13} \) are 182.96km, 118.81km, and 74.74km respectively. Using Equation A 3, Equation A 4, and Equation A 5 results in total fatalities of 178 (the same as the original method due to the similar population densities). These are dispersed using the weighting factors with 19 in the MM VII zone, 45 in MM VIII, and 114 in MM IX+. This therefore allows us to better visualise where the numbers of fatalities are likely to occur. Nevertheless, due to the magnitude and rupture length of this earthquake these areas are still very large and it would be beneficial to be able to further identify the locations within each intensity zone where fatalities are likely to occur. We have therefore adapted the method of Christoskov et al. (1990) in order to better identify where fatalities may occur.

Given the available empirical models, it is the latter model of Christoskov et al. (1990) that we deem to be the most relevant and applicable to this scenario. Nonetheless, their model made several assumptions that are not applicable to the scenario being used for this exercise. We therefore have further adapted this model to fit the exercises specific needs. We discuss these adaptions next.

\(^{13}\) The MM X zone occupies a small area surrounding the epicentre in this scenario and so contains a varying population depending on where the epicentre is located. We therefore use a MM IX+ category to produce an estimate for a full rupture of the Alpine fault, rather than for a specific epicentre.
A3.9  **The Earthquake Fatalities Model**

Despite adapting the model of Christoskov et al. (1990), Equation A 3 and Equation A 5 remain the same. Nevertheless, the weighting method (Equation A 4) requires adaption to be relevant to an Alpine Fault earthquake.

### A3.9.1 Weighting Adaption

The model of Christoskov et al. (1990), which applies weightings to fatalities caused by different shaking intensities, assumes that the number of fatalities decreases proportionally with the square of the epicentral distance. This relates to circular or quasi-circular isoseismals whereby it is the distance from the point of shaking (epicentre) that is most important. In the Alpine fault earthquake used in this scenario however, this is not the case. Surface rupture occurs that results in the isoseismals stretching out to surround the fault rupture. In this instance it is still the distance from the source of shaking which is important, however, the source of shaking is no longer the epicentre but instead the fault rupture itself. For an Alpine fault earthquake the isoseismals are therefore quasi-elliptical/quasi-rectangular (Figure A 8) and can be modelled by rectangles. The number of fatalities in this case decreases proportionally with distance away from the fault, $N \sim 1/(0.5a)$. Figure A 8 demonstrates the comparison between Christoskov et al (1990)’s method and our adaption.

The weightings are therefore determined by:

$$W_i = 1/\left[\left(0.5a_i\right)\sum_j (1/(0.5a_j))\right], \ j = VII,VIII,IX...$$  

Equation A 6

Table A 5 shows the new weights as designated by Equation A 3 compared to those that would have been used in by Christoskov at el (1990).

---

**Figure A 8**  a) Circular isoseismals in which fatalities decrease proportionally with distance from the epicentre, $R$, $N \sim 1/R^2$; b) Quasi-rectangular isoseismals where fatalities decrease proportionally with distance away from the fault rupture, $0.5a$, $N \sim 1/(0.5a)$. 

---

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Comparison between calculated weights using the original Christoskov et al (1990) method and our adapted version.

<table>
<thead>
<tr>
<th>MMI Zone</th>
<th>Weight (W)</th>
<th>Christoskov et al (1990)</th>
<th>This Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>0.1068</td>
<td>0.1775</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>0.2532</td>
<td>0.3437</td>
<td></td>
</tr>
<tr>
<td>9+</td>
<td>0.64</td>
<td>0.4786</td>
<td></td>
</tr>
</tbody>
</table>

A3.9.2 Urban Rural Index Adaption

The original Christoskov et al. (1990) model calculates fatalities related to the average population density for each shaking intensity zone. For the Alpine fault earthquake used in this scenario the majority of the area affected is rural and so has a very low population density (<1 person per square kilometre). This has a large effect on the model since places like Queenstown, Greymouth, and Westport are considered to have the same population density as the surrounding rural areas. We have therefore used New Zealand’s Urban Rural Index (URI; see Table A 6) to better estimate the number of fatalities and their location within in each intensity zone.

Table A 6 The Urban Rural Index for New Zealand with example locations for each index.

<table>
<thead>
<tr>
<th>URI</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Major Urban (Christchurch)</td>
</tr>
<tr>
<td>2</td>
<td>Secondary Urban (Greymouth)</td>
</tr>
<tr>
<td>3</td>
<td>Minor Urban (Queenstown)</td>
</tr>
<tr>
<td>4</td>
<td>Rural Centre (Franz Josef)</td>
</tr>
<tr>
<td>5</td>
<td>Rural (Hari Hari)</td>
</tr>
<tr>
<td>6</td>
<td>Other (Lakes, Rivers, Waterways etc.)</td>
</tr>
</tbody>
</table>

From this we have taken into account the percentage of the intensity zone’s area occupied by each URI. This was required because the model assumes that the population density calculated for each URI is actually the average density for the entire intensity zone. In this way we can account for the variations in population density within one intensity zone. Nevertheless, URI 5 still occupies the majority of the land affected and so has a population density <1. URI 6 occupies a far smaller area but has a far smaller population, resulting in a population density also <1. To counter for this we combined URIs 4, 5, and 6 to create a ‘rural combination’ URI which has a population density of ~1. This is due to the much higher (~20x) population densities in URI 4 than in URIs 5 and 6. The consequence of this is that we can no longer discern where deaths occur in the rural combination however, it now allows us to use this method for calculating rural casualties by creating an area with a population density that corresponds to the working parameters of this model (i.e. not <1 per square kilometre).

We are now able to distribute our fatalities resulting from shaking (293 in total) geographically by analysing the area of each District affected by shaking intensity, i, and how much of this area corresponds to the various URIs. By calculating the percentage of the population living in each of these zones we are then able to distribute the fatalities assuming that these are directly related to the population numbers. For instance, ~42% of the rural population exposed to MM VIII shaking live in Westland District. We therefore assign 42% of
the rural, MM VIII fatalities (25 of 61) to the area in Westland experiencing MM VIII. Buller District has ~11% of the population living in URI 3 exposed to MM VII shaking. It is therefore expected to get 11% of the fatalities associated with URI 3 in the MM VII shaking zone (3).

This method has resulted in more casualties than the original model of Christoskov et al. (1990) estimated. This is due to our method taking into account variations in population density within each shaking intensity zone. Table A 7 shows the various estimates of casualties corresponding to each of the methods described herein as well as their associated advantages and disadvantages.

Table A 7 Comparison between the casualty estimates of each of the methods described and the advantages and disadvantages associated with each.

<table>
<thead>
<tr>
<th>Model</th>
<th>Estimated Casualties</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>USGS PAGER</td>
<td>1-10</td>
<td>Considers building stock and socio-economic indicators</td>
<td>Limited data available for NZ</td>
</tr>
<tr>
<td>Christoskov and Samardjieva (1984)</td>
<td>178</td>
<td>Uses population density</td>
<td>Variations in shaking intensity not considered</td>
</tr>
<tr>
<td>Christoskov et al. (1990)</td>
<td>178</td>
<td>Accounts for variations in shaking intensity</td>
<td>Assumes circular or quasi-circular isoseismals</td>
</tr>
<tr>
<td>This Study</td>
<td>293</td>
<td>Accounts for variations in population density; uses adapted isoseismals model</td>
<td>Difficulties resolving low population densities</td>
</tr>
</tbody>
</table>

A3.10 Earthquake Injuries

Injuries have been calculated using a simple death to injuries ratio adapted from Wyss and Trendafiloski (2011) and observations of the 4 September Darfield and 22 February Christchurch earthquakes.

Wyss and Trendafiloski (2011) showed that the fatalities to injuries ratio varies globally, typically with levels of industrialisation. As a fully industrialised nation New Zealand corresponds to their statistics that for every person killed, 11 are injured. Nevertheless, analysis of the 22 February Christchurch earthquake shows that this was not the case for this event. In total 185 were killed and 7,171 were injured. This corresponds to a ratio of 39 injuries for every death, much higher than Wyss and Trendafiloski (2011) suggest. No fatalities resulted from the 4 September Darfield event and it is therefore not possible to determine a fatalities to injuries ratio. We contend that the increased casualties ratio from the Christchurch earthquake was due to a) better than average reporting of injuries due to New Zealand’s ACC medical system; and b) a relatively low death toll due to many earthquake prone buildings which may have killed people being demolished after the Darfield earthquake (Ingham, 2011).

We have therefore attempted two methods to scale our deaths to injuries ratio to account for first assigned rural (4, 5, 6) and minor urban (3) URIs to the industrialised nations averaged ratio from Wyss and Trendafiloski (1:11) and the Christchurch ratio to major urban URIs (1). Secondary urban URIs (2) are then assigned the average of these 2 ratios (1:25). In order to determine the number of injuries for each district, we have analysed the percentage of survivors in each district and distributed the injuries in accordance with these percentages in a similar way to the method used for distributed fatalities (see above).
This scaling method nevertheless suggests ~4,000 people will be injured, similar to the Darfield earthquake. Despite the Darfield earthquake exposing ~260,000 people to MMI VII+ shaking while the Alpine fault earthquake exposes ~150,000 we contend that number of injuries likely to be suffered from the latter event should be larger. We suggest this because the Darfield earthquake sustained very short period (<30 seconds) shaking, while the Alpine fault earthquake in this scenario is likely to sustain shaking for a far longer period (>70 seconds). This is therefore likely to generate more injuries due to the extended period of shaking that the population is exposed to. We therefore suggest that the rural regions should also be assigned a ratio of 25 injuries to every fatality; the same as for secondary urban areas. No major urban areas are contained within the MM VII+ shaking zones and so the ratio here need not be considered in this study. It should be noted that this produces >7,000 injuries, ~5% of the population exposed which we suggest is a much more likely number given the duration of shaking likely to be experienced in an Alpine fault earthquake.

One of the flaws with this method is that it can only link numbers of injuries to shaking intensities where fatalities occur. As a result we have no injuries in the MM VI or lower shake zones. Whilst there are likely to be a number of injuries in the MM VI zone, we suggest that these may actually be minor injuries, many of which will not need medical attention, and so are inconsequential for purposes of the exercise. Nevertheless, our method of distributing injuries amongst districts by the percentage of total survivors at each location does allow for injuries to occur in districts where no deaths have occurred. This is not possible by calculating injuries per district with ratios as those districts with 0 deaths will result in 0 injuries.

### A3.11 Tsunami Casualties

To model tsunami casualties we have used a simple method based on observations of historical tsunami by Berryman (2005), Saunders (2006), Cousins et al. (2007), and Reese et al. (2007). This states that the fatality rate, \( \nu \), of the exposed population is directly proportional to water depth, \( W_d \), in metres by:

\[
\nu = 4W_d \tag{A7}
\]

The injury rate, \( IR \), (among survivors, i.e. the total population minus the number of fatalities) is similarly related to water depth by:

\[
IR = 4W_d \tag{A8}
\]

In order to determine the exposed population, we have analysed the locations of buildings in the exposed meshblocks to determine the number that are affected by the tsunami runup. We have then assumed that the population of each meshblock is evenly distributed through the total number of dwellings within the corresponding meshblock. The population affected is then a simple multiplication of population per dwelling and buildings affected. Data on the population and number of dwellings is taken from the 2006 New Zealand census. The location of buildings is provided by Land Information New Zealand (LINZ). In some instances the number of buildings affected in a meshblock was larger than the total number of dwellings in the same meshblock. This is most likely because LINZ does not distinguish between dwellings and other types of buildings. Where the total number of buildings exceeds the total dwellings we have ignored the excess in order to account for uninhabited buildings. Table A 8 and Table A 9 show the results of this analysis for the Lake Brunner and Milford Sound tsunamis respectively.
As both the tsunamis analysed here are generated by landslides/rockfalls which occur during the shaking it is assumed that the tsunami wave will impact these areas either while shaking is still continuing or immediately after shaking stops. As a consequence, there will be no time for the population to evacuate or implement avoidance measures. Thus we do not include an evacuation factor in our estimates.

Table A.8 Data and results of casualty estimates for a 15m tsunami runup at Lake Brunner.

<table>
<thead>
<tr>
<th>Meshblock</th>
<th>Total dwellings</th>
<th>Buildings affected</th>
<th>Population</th>
<th>Population per dwelling</th>
<th>Affected population</th>
<th>Fatalities</th>
<th>Injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td>2400902</td>
<td>6</td>
<td>0</td>
<td>15</td>
<td>2.5</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2401000</td>
<td>45</td>
<td>0</td>
<td>138</td>
<td>3.1</td>
<td>18</td>
<td>11</td>
<td>4</td>
</tr>
<tr>
<td>2401101</td>
<td>24</td>
<td>7</td>
<td>63</td>
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<tr>
<td>2401201</td>
<td>9</td>
<td>4</td>
<td>39</td>
<td>4.3</td>
<td>18</td>
<td>11</td>
<td>4</td>
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<tr>
<td>2401202</td>
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<td>1</td>
<td>12</td>
<td>2.0</td>
<td>2</td>
<td>1</td>
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<tr>
<td>2401206</td>
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<td>18</td>
<td>3.0</td>
<td>18</td>
<td>11</td>
<td>4</td>
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<tr>
<td>2401207</td>
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<td>9</td>
<td>3.0</td>
<td>9</td>
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<tr>
<td>2401208</td>
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<td>42</td>
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<td>2401500</td>
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<td>2</td>
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<tr>
<td>2414700</td>
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<td>6</td>
<td>18</td>
<td>3.0</td>
<td>18</td>
<td>11</td>
<td>4</td>
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<tr>
<td><strong>Total</strong></td>
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<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Table A.9 Data and results of casualty estimates for a tsunami at Milford Sound. *Population data provided by the Milford Development Authority and Emergency Management Southland to account for the variation in overnight population between the time of the census (March) and the time of the exercise (May). †This meshblock represent the Milford Track and its huts/shelters. Population will vary on any given day and the population may well not be evenly distributed through the buildings.

<table>
<thead>
<tr>
<th>Meshblock</th>
<th>Total dwellings</th>
<th>Buildings affected</th>
<th>Population</th>
<th>Population per dwelling</th>
<th>Affected population</th>
<th>Fatalities</th>
<th>Injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td>3174800</td>
<td>2</td>
<td>0</td>
<td>6</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3174900</td>
<td>13</td>
<td>13</td>
<td>95*</td>
<td>7.3</td>
<td>95</td>
<td>57</td>
<td>23</td>
</tr>
<tr>
<td>3175000†</td>
<td>10</td>
<td>1</td>
<td>186</td>
<td>18.6</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3175200</td>
<td>0</td>
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<td>-</td>
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<td>-</td>
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<tr>
<td><strong>Total</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>23</strong></td>
<td></td>
</tr>
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</table>
A3.12  **Results**

The following estimates of casualties relate primarily to the earthquake scenario put forward in Part 1 of this series of reports. Figure A.1 shows the extent of the isoseismals this M8 Alpine fault earthquake generates and which have been used in modelling casualty numbers. Total fatalities are 455 with 293 resulting from building collapse due to shaking and 162 from landslide/rockfall induced tsunami (Figure A.6). Buller, Grey, Westland, and Queenstown-Lakes Districts are worst effected by high intensity shaking (Figure A.6). The majority of fatalities occurring in Southland District are the direct consequence of the tsunami in Milford Sound (Figure A.6).

A3.12.1 **Ground Shaking**

Total fatalities resulting from building collapse due to high intensity shaking are 293. Total injuries from the same process are 7,366. Table A.10 details the total numbers by district; Figure A.6 and Figure A.7 respectively show the distribution of these across the South Island.

<table>
<thead>
<tr>
<th>District</th>
<th>Fatalities</th>
<th>Injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nelson City</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Tasman District</td>
<td>1</td>
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</tr>
<tr>
<td>Marlborough District</td>
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<td>0</td>
</tr>
<tr>
<td>Kaikoura District</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Hurunui District</td>
<td>7</td>
<td>180</td>
</tr>
<tr>
<td>Waimakariri District</td>
<td>5</td>
<td>136</td>
</tr>
<tr>
<td>Christchurch City</td>
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<td>Selwyn District</td>
<td>7</td>
<td>167</td>
</tr>
<tr>
<td>Ashburton District</td>
<td>5</td>
<td>119</td>
</tr>
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<td>Timaru District</td>
<td>0</td>
<td>9</td>
</tr>
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<td>Mackenzie District</td>
<td>8</td>
<td>210</td>
</tr>
<tr>
<td>Waimate District</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Buller District</td>
<td>16</td>
<td>401</td>
</tr>
<tr>
<td>Grey District</td>
<td>113</td>
<td>2,820</td>
</tr>
<tr>
<td>Westland District</td>
<td>95</td>
<td>2,376</td>
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<tr>
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<td>2</td>
<td>37</td>
</tr>
<tr>
<td>Central Otago District</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>Queenstown-Lakes District</td>
<td>30</td>
<td>763</td>
</tr>
<tr>
<td>Dunedin City</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Clutha District</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Gore District</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Southland District</td>
<td>4</td>
<td>105</td>
</tr>
<tr>
<td>Invercargill City</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
The worst affected location is **Greymouth**, where **77 deaths** and **1,936 injuries** occur. Other badly affected locations are:

- Hokitika – 12 Deaths, 296 Injuries
- Queenstown – 10 Deaths, 260 Injuries
- Wanaka – 7 Deaths, 172 Injuries
- Reefton – 3 Deaths, 66 Injuries
- Westport – 3 Deaths, 78 Injuries

### A3.12.2 Tsunami

A rockfall generated tsunami at **Milford Sound** results in **57 fatalities** and **23 injuries**. All buildings, the main road and the airfield are completely destroyed. It is not possible to say exactly where within the affected meshblocks the fatalities and injuries will occur.

A landslide from Mt Te Kinga generates a tsunami in **Lake Brunner** with runups averaging 15m (a maximum of 25m is recorded immediately opposite the landslide). This causes **105 deaths** and **43 injuries**. Many of the affected buildings are completely destroyed and several key roads for the area are badly damaged. Table A 11 shows the likely locations of deaths and injuries.

**Table A 11**

<table>
<thead>
<tr>
<th>Ward</th>
<th>Fatalities</th>
<th>Injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lake Brunner</td>
<td>91</td>
<td>37</td>
</tr>
<tr>
<td>Arnold Valley</td>
<td>11</td>
<td>4</td>
</tr>
<tr>
<td>Marsden-Hohonu</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>
A3.13 REFERENCES


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APPENDIX 4: IMPACT SCENARIO FOR EXERCISE TE RIPAHAPA

This report is part 4 of a 4 part series which designs a scenario of an M8 Alpine Fault earthquake affecting the South Island of New Zealand at 0300hrs on 29 May 2013. This scenario will be used as part of South Island Civil Defence and Emergency Management 2013 Tier 3 exercise (Te Ripahapa) at the request of the Canterbury CDEM Group.

A4.1 EXECUTIVE SUMMARY

The following report has focused on the functionality of critical lifelines for the South Island following an M8 Alpine Fault earthquake. These include the transport, power, and telecommunications networks as well as analysing the anticipated extent of damage to buildings. The State Highway network is extensively damaged, especially in West Coast Region and the Alpine passes making West Coast District completely isolated by road. Mt Cook Village, Milford Sound, and Queenstown are also without road access and only limited access is available to the surrounding areas. The rail network is similarly affected with no access along the West Coast or through Arthur’s Pass. All the international airports are undamaged following the main earthquake; however, the land on which Dunedin airport is built is heavily liquefied during the Akatore Fault aftershock. Most of the airfields within the Southern Alps and along the West Coast are severely damaged in the initial earthquake.

Power is immediately lost to the West Coast Region, Queenstown-Lakes District, and Arthur’s Pass. There remains no power in any of these areas for the duration of the exercise and it is expected that power will not be restored for several days, possibly weeks. The rest of the South Island loses power as well but this is able to be restored in stages. The system requires ‘rebuilding’, starting in the South at Manapouri and progressing northwards, connecting circuits between substations. Power is steadily returned to the eastern areas throughout the morning and by midday power is fully restored in all areas except West Coast, Queenstown-Lakes and Arthur’s Pass.

The telecommunications network is heavily damaged. Internet and landline telephone connection is immediately lost to West Coast Region and Queenstown-Lakes District. This may take several weeks to fully restore. In the foothills of the Southern Alps internet and landline connections survive but are unreliable and cut out randomly. The whole South Island and lower North Island are affected by losses in mobile telephone reception. Generally this lasts for short periods of time but reoccurs throughout the exercises related to aftershocks and the reinstatement of power.

A4.2 REPORT STRUCTURE

The following report discusses the various disruptions to the most critical lifelines for the South Island. In order to achieve this we have entered into discussions with key stakeholders from each of the lifelines organisations involved. These were:

- Peter Connors, New Zealand Transport Agency – Operations Manager
- John Reynolds, New Zealand Transport Agency – Principal Structures Engineer
- Paul Lloyd, Meridian Energy – Network Performance Manager
- Adam Henderson, Transpower – Regional Services Manager, South Island/HVDC
- Rob Ruiter, Chorus – National Manager for Network Protection
- Ray Norton, Telecom – Network Performance
- Lawrence Watson, Telecom – Network Performance
Our analysis has been derived from detailed discussions with these stakeholders as to the relevant response of each lifeline to the various hazards which they are exposed. Our discussions have focussed on:

- The location/distribution of the network
- Redundancies within the network
- Network functionality
- Interdependencies between the networks
- Response of the network to recent events (e.g. Darfield and Christchurch earthquakes)
- Expected damage from known hazards
- Effect on network functionality
- Network reinstatement process
- Network reinstatement timescales

We have chosen to focus our analysis on the functionality of each network as it is this, rather than the damaged sustained, that is most important to emergency responders. From the discussions we have been able to determine the functionality for sections of each network based on the location of each section. For instance, sections of a particular network which are located in Arthur’s Pass are expected to be affected by surface rupture and landslide/rockfall and thus have been assigned functionalities in this area reflecting their expected response to these hazards. From these functionality maps we have then been able to determine the response of the network as a whole whilst also considering the effect to other dependant networks. For instance, the mobile telephone network is dependent on both the telecommunications cable network and the power network. Thus the condition of these networks will also influence the condition of the mobile telephone network. By analysing the interconnectivities between the networks as well as the associated network reinstatement timelines we have also be able to estimate the duration of effects to each network. This has allowed us to estimate timings for disruption to and reinstatement of particular networks.

### A4.2.1 Transport Network

#### A4.2.1.1 Road

First, in Part A, we discuss the Transport Network, where we focus on the State Highway network, the rail network, key airports and airfields and ports. First we describe effects to the roads as well as the conditions of the bridges along these roads. Road damage is discussed generally and only occasionally do we refer to specific locations. In this way regional stakeholders/authorities can analyse the overview results we provide and assign location-specific effects that fit with our results.

#### A4.2.1.2 Rail

Secondly in Part A we discuss the impacts on the rail network. Here, our results have been determined by examining the exposure of the rail network and comparing it with the final functionality states of the State Highway network. Unlike the roads, railway lines are either passable or impassable and we therefore describe these routes appropriately.
A4.2.1.3 Airports

Thirdly we discuss the response of key airports, airfields, and airstrips. The South Island has a large number of airstrips (>1100) most of which are grass and only suitable for light aircraft. It is therefore not necessary to determine the effects on each of these. We have focussed on vital airstrips and airports distributed around the South Island. These include the international airports, domestic airports, and vital airfields with asphalt runways of greater than 800m length. In total we have studied 15 airports/airfields:

- Christchurch International Airport
- Queenstown International Airport
- Dunedin International Airport
- Woodbourne Airport (Blenheim)
- Nelson Airport
- Westport Airport
- Greymouth Airport
- Hokitika Airport
- Timaru Airport
- Wanaka Airport
- Invercargill Airport
- Franz Josef Airfield
- Mt Cook Airfield
- Milford Sound Airfield
- Manapouri Airfield

It should be noted that in an emergency situation such as that following an M8 Alpine Fault earthquake, sections of State Highway may be utilised for landing such aircraft. We have not identified locations where this may be possible as this will need to be assessed on a case-by-case basis during the exercise. We therefore refer the reader to the State Highways section when planning to use these roads as emergency runways. We also note that when analysing the airports/airfields we have referred to damage states rather than functionality. This is because the functionality of each runway is dependent on the aircraft using the runway. Military aircraft for instance, are able to land on ground that is typically unsuitable for non-military aircraft.

A4.2.1.4 Ports

Finally we assess the largest Ports in the South Island, namely: Lyttleton, Port Chalmers, Nelson, Westport and Greymouth. Here we have analysed the response of Lyttleton Port during the 22 February earthquake in order to determine the likely response of the other ports around the Island to the various shaking intensities they are expected to be subjected to.

A4.2.2 Power Network

Next, in Part B, we discuss the Power Network. Here we have focussed only on the hydroelectric power (HEP) stations as they account for 98% of the South Island’s power supply. Within this section we first discuss the status of the major hydroelectric power stations around the South Island and determine the status of power supply throughout the island following the main earthquake. Next we investigate the impacts on the transmission
network. For this we have investigated the exposure of the high voltage (50/66kV, 110kV, 220kV, and 350kV) transmission lines and their associated substations.

When assessing the HEP network there are two possible scenarios dependant on the direction in which power is being fed along the 350kV Inter-Island connection. We have focussed our analysis on a worst-case scenario in similar fashion to the natural hazards (see Part 1 – Natural Hazards). The alternative scenario which we have not presented involves either transfer of power from the South Island to the North Island, or not at all. In the latter case a sufficient number of dams remain functioning to continue providing power to regions with undamaged transmission lines. In the former the same is true however, parts of the North Island may lose power if their demand for electricity is particularly high. A South-to-North transfer occurs when the North Island is producing less power than it is consuming, thus if the power lose is long-term (i.e. damage to the Inter-Island transfer line) the North Island is likely to experience widespread, rolling power cuts.

Firstly, we have determined which HEP stations are likely to remain operational immediately after the earthquake. This is independent of the electricity transfer direction between the islands. Then we have evaluated the response of the transmission lines and the various substations. In this way we can determine where power outages are likely to occur, and how long they are likely to last for.

It should be noted that in our results we have estimated times that electricity will start to return in specific areas. This has taken into account functionality of the road network (see Part A) and assumes that both Meridian and Transpower will be using helicopters to distribute their engineers to key locations.

A4.2.3 Telecommunications Network

In Part C we discuss the response of the Telecommunication network focusing on fibre-optic cables, which provide internet and landline telephone connections, as well as the response of the mobile telephone network. For the internet and landline telephone network we have focussed on the response of the Chorus Ltd network as this is likely to affect intra- and inter-Island communication, and we do not consider local communication in detail. Here forth we refer to this as the ‘Telecommunications Cable Network’.

Telecom New Zealand Ltd and Vodafone New Zealand Ltd are the largest mobile telephone network providers with roughly 85% of the market share. Their networks are distributed across the entire South Island in approximately equal manner and thus provide mobile telephone reception to the majority of the Island. For this reason we have focussed on the response of the Telecom and Vodafone networks. Here forth we refer to this as the ‘Mobile Network’.

When estimating the response of the cable network we have been unable to collect and publish information on the exact location and distribution of cables within the South Island. This information is commercially sensitive and has therefore only been roughly described to us for analysis. Nevertheless, Chorus have been able to provide detailed descriptions of the general locations and conditions of their cable network and their expected response. This corresponds broadly with the transport network (see Part 4a – Transport Network) as cables following existing routes and use road bridges to cross obstructing features.

Analysis of the mobile network focuses primarily on the availability of mobile telephone reception and the ability of the network to transmit. This is influenced by three factors: power,
connectivity, and congestion. Cell towers require power to be able to transmit and are included in the main power network (see Part 4b – HEP Network) while also having back-up generators that can provide emergency power when necessary. Cell towers are also connected by fibre optic cables and so are linked to the telecommunications cable network. These cables are required in order for the cell towers to be able to transmit. The mobile network has a finite carrying capacity that is able to handle typical loads; however, during a disaster usage is expected to increase well above normal network operating capacity. In this instance the network becomes congested and cannot cope. As a result people are unable to make telephone calls and SMS messages (‘texts’) can be significantly delayed. This is typically a temporary affect that only occurs within the first few hours of the event.

A4.3  PART A – TRANSPORT NETWORK

A4.3.1 Road Network

The South Island State Highway network is distributed in a corridor nature with very little redundancy available. Only three routes cross the Southern Alps and connect West Coast Region with the rest of the Island. These are the Alpine Passes which are highly susceptible to blockage. Furthermore many of the State Highways pass through steep, narrow gorges, and some are located on liquefiable sediments. There are a number of bridges on each State Highway due to the large number of rivers the roads must cross. Many of these are single lane Bailey bridges and are highly susceptible to damage from high intensity shaking, liquefaction and lateral spreading. We have therefore summarised the conditions of the roads into three categories:

- **Impassable**
  - Road has been significantly damaged and completely blocked at certain locations.
  - Many bridges have experienced catastrophic damage and are unusable by all vehicles.
  - No vehicle access along any of the road.

- **Disrupted**
  - Roads have suffered some damage and are partially blocked in places.
  - Some bridges are damaged but are useable by light vehicles on a single-lane, one at a time.
  - Only useable by emergency vehicles and travel times are greatly increased.

- **Passable**
  - Road is relatively undamaged and clear although some cracking may have occurred.
  - Bridges are undamaged however some may have settled at particularly susceptible locations.
  - Able to withstand normal traffic loads although travel times may be increased.

A4.3.1.1 Shaking Exposure

The State Highway network is exposed to high levels of shaking with close to 40% of the network experiencing shaking >MM 7 (Damaging) (Table A 12). The Alpine Passes (Haast, Lewis, and Arthur’s) and SH6 experience the highest levels of shaking.
Table A 12  
Length and percentage of length of each State Highway exposed to various levels of shaking intensity.

<table>
<thead>
<tr>
<th>State Highway Total length (km)</th>
<th>Length exposed to MMI (km)</th>
<th>% exposed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td>6</td>
</tr>
<tr>
<td>1  969.3</td>
<td>431.8</td>
<td>504.6</td>
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</tbody>
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A4.3.1.2 Network Functionality

Figure A 9 Condition of State Highway network following an M8 Alpine Fault earthquake.
Table A 13  Summary of the affected State Highways detailing segments classified into each of the 3 functionality conditions.

<table>
<thead>
<tr>
<th>State Highway</th>
<th>Passable</th>
<th>Disrupted</th>
<th>Impassable</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Picton to Ward; Cheviot to Invercargill</td>
<td>North and South of Kaikoura</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>Blenheim to Kawatiri; Lumsden to Invercargill</td>
<td>Kawatiri to Murchison; Hawea to Cromwell; Kingston to Lumsden</td>
<td>Murchison to Hawea; Cromwell to Kingston</td>
</tr>
<tr>
<td>6A</td>
<td>-</td>
<td>-</td>
<td>Whole Route</td>
</tr>
<tr>
<td>7</td>
<td>Waipara to Culverden</td>
<td>Culverden to Hanmer Springs</td>
<td>Hanmer Springs to Greymouth</td>
</tr>
<tr>
<td>7A</td>
<td>-</td>
<td>Whole Route</td>
<td>-</td>
</tr>
<tr>
<td>8</td>
<td>Timaru to Fairlie; Clyde to Milton</td>
<td>Fairlie to Cromwell</td>
<td>Cromwell to Clyde</td>
</tr>
<tr>
<td>8A</td>
<td>-</td>
<td>Whole Route</td>
<td>-</td>
</tr>
<tr>
<td>8B</td>
<td>-</td>
<td>Whole Route</td>
<td>-</td>
</tr>
<tr>
<td>65</td>
<td>-</td>
<td>-</td>
<td>Whole Route</td>
</tr>
<tr>
<td>67</td>
<td>-</td>
<td>Birchfield to Waimarie</td>
<td>SH6 Junction to Westport</td>
</tr>
<tr>
<td>67A</td>
<td>-</td>
<td>-</td>
<td>Whole Route</td>
</tr>
<tr>
<td>69</td>
<td>-</td>
<td>-</td>
<td>Whole Route</td>
</tr>
<tr>
<td>73</td>
<td>Christchurch to Springfield</td>
<td>Springfield to Porters Pass</td>
<td>Porters Pass to Kumara Junction</td>
</tr>
<tr>
<td>80</td>
<td>-</td>
<td>-</td>
<td>Whole Route</td>
</tr>
<tr>
<td>83</td>
<td>Kurow to Pukeuri</td>
<td>Kurow to Omarama</td>
<td>-</td>
</tr>
<tr>
<td>84</td>
<td>-</td>
<td>Whole Route</td>
<td>-</td>
</tr>
<tr>
<td>94</td>
<td>Gore to Te Anau</td>
<td>Te Anau to Eglinton Flats</td>
<td>Eglinton Flats to Milford Sound</td>
</tr>
</tbody>
</table>

State Highway 6 – Blenheim to Invercargill via Buller Gorge, West Coast, & Haast Pass

SH6 is the most severely affected. Surface rupture displaces the road at numerous locations throughout Westland District where the road crosses the fault. Most notably this occurs north of the Whataroa bridge, at the Wanganui bridge, at Franz Josef township, and SE of Haast as the road enters the Southern Alps at the western edge of the Haast Pass. Surface rupture displaces the road vertically by up to 2m and horizontally by up to 8m making it completely impassable.

Landslides block the road along the eastern edge of Lake Wakatipu, throughout Haast Pass (most notably at the Gates of Haast), between Fox Glacier township and Franz Josef township, at Mt Hercules, and throughout the Lower and Upper Buller Gorges. Further rockfalls significantly block the road through the Kawarau Gorge, along the eastern edge of Lake Wanaka, and between Greymouth and Westport along the Punakaiki coast.

A short section of SH6 south of the Waiho Bridge is destroyed by flooding when the Waiho stopbanks fail due to fault rupture causing the river to change its course south of Canavans Knob. Failures of small road cuts as well as isolated cases of minor debris flows also impact the road throughout West Coast District.
Almost all of SH6’s bridges in West Coast District suffer some form of damage. NZTA have estimated that 10% of bridges are likely to suffer catastrophic damage and either completely collapse or be unfit for vehicle use. Some bridges may survive with relatively minor damage but be unusable by heavy vehicles.

There is no access along SH6 from Murchison in Tasman District to Wanaka in Queenstown-Lakes District, and from Cromwell in Queenstown-Lakes District to Lumsden in Southland District. All towns including Westport, Greymouth, and Queenstown are completely isolated from each other and the rest of the Island (Figure A 9).

**State Highway 7 (Lewis Pass) – Waipara to Greymouth via Hanmer Springs & Reefton**

SH7 is significantly affected. Surface rupture displaces the road east of Springs Junction with the road displaced by up to 1m vertically and 2-3m horizontally making it impassable. Landslides completely block the road at numerous locations between Reefton and Hanmer Springs. Rockfall partially blocks the road as it enters Greymouth from the north, and south of Reefton. Severe liquefaction also affects the road between Reefton and Greymouth although it remains traversable for most high clearance vehicles. Nevertheless, at some locations severe lateral spreading has occurred and the road has been completely destroyed making it impassable.

A large proportion of SH7’s bridges are likely to suffer some damage. Similar to SH6, around 10% are likely to suffer catastrophic damage and be impassable for all vehicles. Some bridges remain intact but are significantly damaged. Many are destroyed by landslides and rockfalls.

There is no access along SH7 from Hanmer Springs in Hurunui District to Greymouth in Grey District (Figure A 9). Some access between Reefton and Greymouth may be possible for off road or emergency vehicles but not for road vehicles. Any travel between Reefton and Greymouth will be extremely difficult and is expected to take several hours.

**State Highway 73 (Arthur’s Pass) – Christchurch to Kumara Junction via Otira Gorge**

SH73 is significantly affected. Surface rupture displaces the road at several locations along the Taramakau River south of Lake Poerua. The road is displaced by up to 2m vertically and up to 6m horizontally making it completely impassable from Rocky Point to Wainihinihi. Landslides completely block the road at numerous locations between the Waimakariri River bridge and Otira. A large landslide occurs at the Otira Viaduct (which survived the initial shaking). The viaduct remains standing but is significantly damaged and unable to withstand any heavy vehicles.

Rockfalls partially block the road from Rocky Point near Inchbonnie to Otira, along the southern side of the Waimakariri River, and throughout Porters Pass. A small debris flow at Lake Pearson completely buries that section of the road.

A large proportion of bridges between Porters Pass and Kumara Junction are damaged. Some suffer catastrophic damage and are unable to be used by any vehicles. Several are completely destroyed by rockfalls and landslides.

There is no access along SH73 from Springfield in Selwyn District to Kumara Junction in Westland District (Figure A 9). All townships throughout the pass including Otira and Arthur’s Pass are completely isolated from each other and the rest of the island.
State Highway 65 – Springs Junction to the Upper Buller Gorge via the Maruia River valley

The road section at Springs Junction, where SH65 meets SH7, is completely destroyed by surface rupture and high intensity shaking. The road here is displaced 1m vertically and 2-3m horizontally making it impassable to all vehicles. SH65 liquefies north of Springs Junction where it runs along the banks of the Maruia River. Sections of the road fall into the river as a result of lateral spreading. Rockfalls block the road at several locations within Tasman District.

The SH65 bridge near Springs Junction crossing the Maruia River collapses or is severely damaged and cannot be used by any vehicles. Other small bridges along the road survive but suffer severe damage and can only be used by light vehicles.

There is no access along the entirety of SH65 severing the key link between SH6 in the Upper Buller Gorge and SH7 (Lewis Pass) (Figure A 9).

State Highway 69 – Reefton to Inangahua Junction via the Inangahua River valley

SH69 is unaffected by surface rupture and remains relatively free from blockages from landslides and rockfalls, although landslides in the Inangahua River valley threaten the road at some locations. The road is heavily liquefied however, and parts of the road have completely collapsed due to lateral spreading. Sections of the road that have liquefied are traversable by high clearance, off-road vehicles only however, lateral spreading completely severs the road at several locations making it impassable to all vehicles.

Most of SH69’s bridges suffer some form of damage. Many are unusable by heavy vehicles. The bridge at Inangahua Landing is severely damaged making it completely impassable. Only small, light, off-road vehicles may cross some of the least damaged bridges.

SH69 remains partly traversable for off-road vehicles however; some locations are completely impassable to all vehicles. Travel along sections of the road may be possible but the full route is impossible. There is no continuous access between Reefton and Inangahua (Figure A 9).

State Highway 80 – Twizel to Mt Cook via Glentanner

Landslides, rockfalls and (later) debris flows block SH80 at numerous locations. A long runout debris flow at Glentanner has completely blocked the road here. A debris flow in Mt Cook Village has also significantly affected the route out of the village.

Bridges at the southern end of SH80 have survived but show visible signs of damage. They are unable to support heavy vehicles or more than one light vehicle at a time. Several bridges north of Glentanner have suffered catastrophic damage and are completely impassable by all vehicles.

There is no access along the entirety of SH80 between Twizel to Mt Cook Village (Figure A 9). The only route into and out of Mt Cook Village is severed and the village is completely isolated.
State Highway 8 – Timaru to Milton via Fairlie, Twizel, the Lindis Pass, Cromwell, and Alexandra

SH8 survives the earthquake relatively intact. Rockfalls completely block the road in places through the Cromwell Gorge and at some locations here the road has fallen away into the Clutha River. Along the rest of SH8 isolated rockfalls partially block the route, particularly through the Lindis Pass and between Lake Tekapo and Fairlie, but a through route is still possible. Between Lake Tekapo and the Lindis Pass SH8 has very little damage and both lanes are clear and open.

Some bridges have settled but suffer no significant damage allowing all forms of traffic across albeit at a reduced rate in some instances. South of Alexandra and south of Fairlie the road is unaffected. There is no access between Cromwell and Clyde. Between Cromwell and Fairlie the road is disrupted but remains open to small flows of traffic but often with only a single lane available (Figure A 9).

State Highway 94 – Gore to Milford Sound via Te Anau and the Homer Tunnel

SH94 is significantly affected in parts. Multiple landslides and rockfalls completely block the road north of Eglinton Flats. Rockfalls block both entrances to the Homer Tunnel and the tunnel entrances themselves show visible signs of damage. Some small avalanches have occurred but these haven't impacted the road due to the snow cover being light at this time of year.

Many of the bridges north of Eglinton Flats have suffered damage but none completely collapse. Light vehicles may be able to use the least damaged bridges but several are too badly damaged to withstand any vehicles.

SH94 remains unaffected between Gore and Te Anau and is able to cope with normal traffic flows. Between Te Anau and Eglinton Flats the road is heavily disrupted in places by small rockfalls and bridge damage but a single lane at least is open for the whole of this route. Journey times are greatly increased. There is no access between Eglinton Flats and Milford Sound. SH94 is the only route into and out of Milford Sound and the area is therefore completely isolated from the rest of the island.

State Highway 1 – Picton to Invercargill via Christchurch, Timaru, and Dunedin

SH1 is relatively unaffected. Only small rockfalls partially block the road north and south of Kaikoura where the road follows the coastline. All bridges survive undamaged although the Rakaia Bridge shows visible signs of settling and cracking. It remains open to traffic but requires monitoring. Access to Kaikoura is limited but remains open with single lane routes available past rockfall zones. The rest of SH1 is unaffected and capable of dealing with typical traffic flows.

Other State Highways

All other State Highways remain open and unaffected. No bridge damage is reported on any other route and all lanes are open and available for traffic at normal loads. Nevertheless, journey times are greatly increased due to the increased traffic resulting from disruption to other routes.
Other Roads

This report has not dealt with roads other than State Highways. It is expected however, that sealed roads will perform in a similar manner to the State Highway(s) in their vicinity. Each District can therefore determine the condition of their sealed roads by examining the condition of the various applicable State Highway sections discussed above. For instance, the Crown Ranges road between Wanaka and Queenstown is expected to have impacts similar to SH6 and SH8 in that vicinity as the road is of similar condition and runs through similar terrain. It is therefore expected to be completely blocked by rockfalls and landslides and impassable to all vehicles. This confirms that there is no passable route into or out of Queenstown by road.

Unsealed roads are expected to suffer significantly more damage than their sealed counterparts. These roads are often only available to off road vehicles under normal circumstances and it is expected that all but a few of these will be impassable to all traffic following an M8 Alpine Fault earthquake. Those that are furthest from the fault rupture, namely those in the Catlins, Abel Tasman National Park, and Marlborough Sounds regions, may remain open and useable to appropriate vehicles. Furthermore, those that are primarily flat and do not pass close to rivers may also survive relatively intact. Nevertheless, any unsealed road within the MM6 or greater shaking zones is anticipated to be significantly damaged.

Akatore Fault Aftershock – 1140hrs M6.1

At 1140hrs an M6.1 aftershock occurs on the Akatore Fault south of Dunedin. This event generates up to MM8 shaking at the epicentre but does not initiate any major landslides or rockfalls. Some minor rockfalls occur in the Port Chalmers area along SH88 which block sections of the road leaving no access to the port via this route. In some places SH88 completely falls into the harbour.

Liquefaction and lateral spreading occur in large areas of South Dunedin severely damaging roads in the vicinity including sections of SH1. Nevertheless these roads remain passable albeit in a disrupted manner.

SH1 is also severely disrupted north of Dunedin where small slips have occurred which partially block the road in places. To the south of Dunedin many of the SH1 bridge abutments have settled and some of the bridges show visible signs of structural damage. Nevertheless, no bridge completely fails and the majority remain open to light vehicles on a single lane basis.
A4.3.2 Rail Network

In order to determine the condition of the rail network we have calculated the length of railway exposed to each level of shaking intensity, where railways cross the fault rupture, and likely locations for landslides and rockfalls. We have compared the shaking exposure of the rail network with that of the road network discussed above in order to determine the likely response of the railways. We have summarised the conditions of the railways into two categories:

- Impassable
  - Railway has been significantly damaged and completely blocked at certain locations.
  - Many bridges are damaged and several have experienced catastrophic damage; all are unusable.

- Passable
  - Railway is undamaged and clear.
  - Bridges are undamaged however some may have settled at particularly susceptible locations.
  - Able to withstand normal rail loads.

We no longer consider a disrupted category due to the working parameters of railway lines. Any damage or blockage, no matter how minor, renders a railway line completely unusable.

A4.3.2.1 Shaking Exposure

The rail network is far less exposed to high intensity shaking than the road network primarily because the majority (73%) of the railway network is situated on the east coast of the South Island, the maximum possible distance from the fault rupture. Furthermore, only the Midland Line, which travels through the Waimakariri Gorge and Arthur’s Pass, crosses the Southern Alps connecting the West Coast District with the rest of the island. Just 15% of the rail network experiences ≥MM8 shaking while 38% is exposed to MM6 shaking (Table A 14).
Table A 14  Comparison of the length and percentage of length of each railway line exposed to various levels of shaking intensity. Note – no railway line is exposed to MM10 shaking and so this intensity has not been included.

<table>
<thead>
<tr>
<th>Line</th>
<th>Total length (km)</th>
<th>Length exposed to MMI (km)</th>
<th>% exposed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total length</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Bluff Industrial Line</td>
<td>27.5</td>
<td>27.5</td>
<td></td>
</tr>
<tr>
<td>Ferrymead Railway</td>
<td>0.9</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>Finegand Industrial Siding</td>
<td>2.4</td>
<td>2.3</td>
<td></td>
</tr>
<tr>
<td>Hokitika Industrial Line</td>
<td>40.3</td>
<td>40.2</td>
<td></td>
</tr>
<tr>
<td>Hornby Industrial Line</td>
<td>4.8</td>
<td>4.8</td>
<td></td>
</tr>
<tr>
<td>Kingston Branch</td>
<td>13.8</td>
<td>13.8</td>
<td></td>
</tr>
<tr>
<td>Main North Line</td>
<td>348.3</td>
<td>108.5</td>
<td>196.1</td>
</tr>
<tr>
<td>Main South Line</td>
<td>600.7</td>
<td>298.4</td>
<td>302.3</td>
</tr>
<tr>
<td>Midland Line</td>
<td>210.6</td>
<td>23.4</td>
<td>60.3</td>
</tr>
<tr>
<td>Ocean Beach Railway</td>
<td>0.6</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>Ohai Industrial Line</td>
<td>79.9</td>
<td>36.0</td>
<td>43.8</td>
</tr>
<tr>
<td>Plains Historical Railway</td>
<td>3.1</td>
<td>3.1</td>
<td></td>
</tr>
<tr>
<td>Pleasant Point Railway</td>
<td>1.9</td>
<td>1.9</td>
<td></td>
</tr>
<tr>
<td>Port Chalmers Industrial Line</td>
<td>1.7</td>
<td>1.7</td>
<td></td>
</tr>
<tr>
<td>Rapahoe Industrial Line</td>
<td>9.5</td>
<td>1.3</td>
<td>8.2</td>
</tr>
<tr>
<td>Stillwater-Westport Line</td>
<td>167.1</td>
<td>5.3</td>
<td>98.7</td>
</tr>
<tr>
<td>Taieri Branch</td>
<td>4.3</td>
<td>4.3</td>
<td></td>
</tr>
<tr>
<td>Taieri Gorge Railway</td>
<td>60.0</td>
<td>48.8</td>
<td>11.3</td>
</tr>
<tr>
<td>Weka Pass Railway</td>
<td>12.7</td>
<td>12.7</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1590.0</strong></td>
<td><strong>528.3</strong></td>
<td><strong>606.6</strong></td>
</tr>
</tbody>
</table>
A4.3.2.2 Network Functionality

Midland Line – Christchurch to Greymouth via Waimakariri Gorge and Arthur’s Pass

The Midland Line is the most severely affected. Surface rupture breaks the line in several places at Inchbonnie and along the eastern-side of Lake Poerua. The rails are twisted and broken, showing total displacement of about 2m vertically and 8m horizontally. A tsunami generated in Lake Brunner completely destroys the rails affecting a 12km section of the line from Te Kinga township to Kaimata township.

Rockfalls damage and block the line as it enters Greymouth, and between Otira and Rocky Point near Inchbonnie. The tunnel entrance at Otira is badly damaged and blocked by rockfall there. Further landslides and rockfalls in the Waimakariri Gorge and throughout Arthur’s Pass have damaged and blocked the line here also.

Substantial liquefaction and lateral spreading has also damaged the line where it follows the Arnold River north of Lake Brunner. Rail bridges along the line fare similarly to the road bridges, with many suffering significant damage.

There is no access along the Midland Line between Springfield in Selwyn District and Greymouth in Grey District. Access between Christchurch and Springfield is still possible as the line and bridges here survive relatively intact (Figure A 10).

Stillwater-Westport Line – Stillwater to Westport via Reefton and Inangahua

The Stillwater-Westport Line is not cut by fault rupture. Nevertheless, it experiences liquefaction and lateral spreading where it follows the Grey River between Stillwater and Reefton, and rockfalls south of Reefton block the line completely. Further liquefaction and lateral spreading affects the line north of Reefton where it follows the Inangahua River. The bridge at Inagahua Landing does not collapse like the road bridge, but it is visibly damaged.

Numerous landslides and rockfalls throughout the Lower Buller Gorge damage and block the line completely. The line is again liquefied in Westport township and sections that run alongside the Buller River here fall away into the river. Bridges along the line remain standing but are damaged an unable to withstand any use, especially where they have been affected by liquefaction.

There is no access along any of the Stillwater-Westport Line.

Hokitika Industrial Line – Greymouth to Hokitika via Kumara Junction

The Hokitika Industrial Line is primarily affected by liquefaction and lateral spreading. No surface rupture, landslides, or rockfalls affect the line. South of Greymouth the line experiences liquefaction and lateral spreading where it runs close to the coastline and the New River at Gladstone. The bridges across the Taramakua and Arahura Rivers remain standing but are damaged and unable to withstand any use.

There is no access along any of the Hokitika Industrial Line (Figure A 10).
Rapahoe Industrial Line – Greymouth to Rapahoe via Runanga

Rockfall damages and blocks the line as the Rapahoe Industrial Line enters Greymouth. Damage to the bridge over the Grey River also prevents travel along the line. Nevertheless, north of the Grey River the line remains intact, as do its bridges, and a lack of rockfalls, landslides, and liquefaction means access between Rapahoe and Runanga may be possible.

There is no access between Runanga and Greymouth (Figure A 10) but access between Runanga and Rapahoe remains.

Main North Line – Picton to Christchurch via Blenheim and Kaikoura

Most of this line is unaffected. Nevertheless, the same rockfalls that partially block SH1 north and south of Kaikoura render the Main North Railway line completely impassable. Rockfalls have significantly damaged the line and block isolated sections and tunnels along the route.

There is no access along the Main North Line between Goose Bay in Kaikoura District and Mirza in Marlborough District. The rest of the line remains passable and open (Figure A 10).
Other Railway lines

Other than the Kingston Branch between Kingston and Garston which is affected by small rockfalls just north of Garston the remaining lines remain open and unaffected. Normal usage of these lines is possible (Figure A 10).

A4.3.3 Airports and Airfields

To evaluate the condition of the airports/airfields following an M8 Alpine Fault earthquake we have focussed on the effect of shaking on the runways. We have not assigned airports/airfields into functionality categories as we have for State Highways and Railways. Instead, we have determined the various damage states that each runway is likely to experience. We do this in order to allow decisions to be made during the exercise on the final functionality of each runway on a case-by-case basis. In this way more expert judgement on their functionality can be sought at the appropriate time possibly allowing runways that have only suffered minor damage to be available for particular aircraft.

The likely damage states that we have investigated are:
- Runway cracking due to high intensity shaking
- Liquefaction and lateral spreading
- Landslide-triggered tsunami impacts
- Flooding
- Long runout debris flows

None of the runways in the South Island are likely to be affected by landslides or rockfalls due to their location of flat terrain, large distances from potential source zones. In order to determine the likely damage each runway is expected to incur we have investigated their shaking exposure, the soil type they are built on, and the various hazards that result in their vicinity.

A4.3.3.1 Shaking Exposure

Of the 15 runways investigated, 9 are subjected to MM7 or greater shaking intensity (Table A 15). Only 1 (Queenstown International Airport) of the 3 international airports is amongst these, as well as 4 domestic airports (Westport, Greymouth, Hokitika, and Wanaka). Of the airfields, only Manapouri is outside of the MM7 or greater shaking zone. Furthermore, 5 of these airports/airfields are situated on liquefiable soils (Table A 15).
Table A 15 Vital statistics and shaking exposure of key airports/airfields for the South Island to an M8 Alpine Fault earthquake. During the main Alpine Fault earthquake Dunedin International Airport experiences MM5 however, an M6.1 aftershock on the Akatore Fault at 1140hrs exposes the airport to MM8 shaking.

<table>
<thead>
<tr>
<th>Airport/Airfield</th>
<th>Runway Length (m)</th>
<th>Max. MMI exposure</th>
<th>Liquefiable Soil? (Y – Yes, N – No)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Christchurch International</td>
<td>1700 &amp; 3300</td>
<td>6</td>
<td>N</td>
</tr>
<tr>
<td>Queenstown International</td>
<td>1900</td>
<td>7</td>
<td>N</td>
</tr>
<tr>
<td>Dunedin International</td>
<td>1900</td>
<td>8†</td>
<td>Y – Holocene lake sediments</td>
</tr>
<tr>
<td>Nelson</td>
<td>1350</td>
<td>6</td>
<td>N</td>
</tr>
<tr>
<td>Woodbourne (Blenheim)</td>
<td>1400</td>
<td>5</td>
<td>N</td>
</tr>
<tr>
<td>Westport</td>
<td>1250</td>
<td>7</td>
<td>Y – Holocene river sediments</td>
</tr>
<tr>
<td>Greymouth</td>
<td>1100</td>
<td>8</td>
<td>Y – Holocene river sediments</td>
</tr>
<tr>
<td>Hokitika</td>
<td>1300 &amp; 1150</td>
<td>8</td>
<td>N</td>
</tr>
<tr>
<td>Timaru</td>
<td>1300</td>
<td>6</td>
<td>N</td>
</tr>
<tr>
<td>Wanaka</td>
<td>1200</td>
<td>7</td>
<td>N</td>
</tr>
<tr>
<td>Invercargill</td>
<td>2200</td>
<td>5</td>
<td>N</td>
</tr>
<tr>
<td>Franz Josef</td>
<td>800</td>
<td>9</td>
<td>N</td>
</tr>
<tr>
<td>Mt Cook</td>
<td>1500</td>
<td>8</td>
<td>Y – Active river plain</td>
</tr>
<tr>
<td>Milford Sound</td>
<td>800</td>
<td>9</td>
<td>Y – Holocene sediments</td>
</tr>
<tr>
<td>Manapouri</td>
<td>1600</td>
<td>6</td>
<td>N</td>
</tr>
</tbody>
</table>

A4.3.3.2 Network Damage

Liquefied Runways

During the initial earthquake the runways at Westport and Greymouth experience severe liquefaction and lateral spreading. Both runways suffer extensive damage, are briefly flooded, and covered in fine sediments and silts. Sections of both runways suffer lateral spreading and slump towards the sea. Neither runway remains level as sections subside by varying degrees causing the runways to undulate along their entire lengths (Figure A 10).

The runway at Mt Cook suffers widespread damage. Despite being situated on gravels which do not liquefy, the runway is built on an active alluvial plain and substantial lateral spreading occurs. The runway no longer remains level, undulating substantially for its entire length. Parts of the runway are washed away or fall away into the rivers due to lateral spreading.

During the initial Alpine Fault earthquake the runway at Dunedin International Airport remains intact. Although there is very minor subsidence at either end of the runway, the runway itself remains level and clear. At 1140hrs an M6.1 aftershock occurs on the Akatore Fault and the runway experiences liquefaction and lateral spreading. The entire runway is affected; becoming briefly flooded, and covered in fine sediments and silts. The runway breaks apart in places due to lateral spreading while intact sections subside by varying degrees bending and deforming the runway (Figure A 10).
**Cracked Runways**

Both runways at Hokitika are built on non-liquefiable sediments and so are unaffected by either liquefaction or lateral spreading. Nevertheless, the runways are exposed to at least MM8 shaking. This causes long (>5m), wide (>5cm) cracks to form in both runways. They remain intact, clear, and level but are cracked along most of their length (Figure A 10).

Queenstown International Airport and Wanaka Airport are similarly located away from liquefiable sediments and are therefore unaffected by liquefaction or lateral spreading. However, both runways are subjected to MM7 shaking. This results in small sections of the runways cracking. Wanaka is affected worst, with short (<2m), narrow (<0.5cm) cracks forming along large sections of the runway. Despite this the runway remains intact and level. Queenstown International Airport is less affected with only very small sections of the runway experiencing minor cracks (<1m long and ~1mm wide). The majority of the runway appears unaffected and it remains level along its entire length.

**Other Damage**

The airfield at Franz Josef experiences the highest levels of shaking (MM9) being the closest runway to the epicentre. The runway therefore experiences severe cracking, far worse than at Hokitika Airport. Nevertheless, this is not the worst damage the runway experiences. During the earthquake, stopbanks controlling the Waiho River north of the airfield are catastrophically damaged and collapse, allowing the Waiho River to partially change course south of Canavans Knob, flooding the surrounding area. The runway is situated almost 5km away from this and therefore escapes the worst of the damage. Nonetheless, the runway is still extensively flooded and there is little to no access to the airfield. The heliport at Franz Josef is also extensively damaged and experiences severe lateral spreading as well as cracking due to high intensity shaking. It is unlikely to remain functional for helicopter use.

The airfield at Milford Sound experiences MM9 shaking and as a result suffers some cracking. However, a rockfall generated tsunami in Milford Sound with runups of ~15m causes the most damage. The airfield is situated on the edge of the fiord and is within 1m of the fiord level. The airfield is completely destroyed by the tsunami. The runway is severely damaged with large sections being completely washed away while remaining sections are covered in debris.

**A4.3.4 Ports**

To evaluate the condition of the major South Island ports following an M8 Alpine Fault earthquake we have analysed the response of the Lyttleton Port near Christchurch to the 22 February 2011 earthquake. Despite suffering significant damage to the port and the surrounding area, the port was able to remain operational. Lyttleton Port appears to have experienced MM8 to MM9 shaking and was almost directly above the epicentre of the 22 February earthquake. Only the port at Greymouth experiences similar levels of shaking and thus we propose that the major ports will be able to remain operational after an M8 Alpine Fault earthquake despite several being damaged (Table A 16). Nevertheless, the duration of shaking from an Alpine Fault earthquake is expected to be significantly longer than that experienced during the 22 February earthquake (>70secs vs. <15secs). We therefore suggest that the worst affected ports at Greymouth and Westport will remain operational but at reduced capacity. Table A 16 summarises the condition of the major ports following an M8 Alpine Fault earthquake.
Table A 16  
Condition of major South Island ports following an M8 Alpine Fault earthquake.

<table>
<thead>
<tr>
<th>Port</th>
<th>District</th>
<th>Damage</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lyttleton</td>
<td>Canterbury</td>
<td>-</td>
<td>Fully Operational</td>
</tr>
<tr>
<td>Port Chalmers</td>
<td>Otago</td>
<td>Liquefaction, Rockfall</td>
<td>Fully Operational</td>
</tr>
<tr>
<td>Port Nelson</td>
<td>Nelson City</td>
<td>-</td>
<td>Fully Operational</td>
</tr>
<tr>
<td>Westport</td>
<td>Buller</td>
<td>Liquefaction</td>
<td>Reduced Capacity</td>
</tr>
<tr>
<td>Greymouth</td>
<td>Grey</td>
<td>Liquefaction, Lateral spreading</td>
<td>Reduced Capacity</td>
</tr>
</tbody>
</table>

A4.4  PART B – HYDROELECTRIC POWER NETWORK

A4.4.1  Hydroelectric Power Network

The South Island Hydroelectric Power (HEP) network is similar to the State Highway network in that it is of corridor nature; however there are a number of redundancies in place in order to keep the electricity supply working. These include back-up transformers at all sites that are able to replace any damaged or faulty transformers, redundant generators which are able to sustain power generation should there be a problem with the primary source, and self-starting HEP stations such as Manapouri and Benmore which are able to restart after shutting down without drawing power from the remaining network. As well as this, Meridian Energy and Transpower are well rehearsed in emergency response, and have international agreements in place allowing them to focus engineering efforts on repairing damage to allow power to be restored in relatively quick time. This is reflected in the recent Darfield and Christchurch earthquakes where power was restored to the vast majority of the affected area within hours of the earthquake.

Nevertheless, there are a number of high-risk zones where a severed link would cause widespread power outages for long-periods of time. The highest risk location is Queenstown, in in-land Otago, where one set of towers carries twin power lines to and from the town (Figure A 11). These lines also run through the steep-sided Kawarau Gorge which is susceptible to rockfall and landslide. The West Coast Region is also at high risk. Only two lines connect the West Coast with the rest of the island (Figure A 11) and these run through Arthur’s Pass and the Upper Buller Gorge, which are susceptible to rockfall and landslide. Damage to the Arthur’s Pass line is likely to be of minor consequence to the West Coast due to the low voltages (66kV) that are used. However, damage to the 110kV and/or 220kV lines between Murchison and Inangahua in the Upper Buller Gorge would likely result in long-term power outage for the entire West Coast region.

A4.4.1.1  Power Station Response

Following an M8 Alpine Fault earthquake, none of the major HEP stations shown suffer any form of structural damage. All are built to withstand high intensity shaking and their ability to cope with such levels is demonstrated by the response of the Manapouri station to the recent M7.8 Dusky Sound earthquake. No damage occurred at the station despite shaking intensities of ~ MM9 and the station was able to remain operational throughout the earthquake.
Despite no damage occurring, MM7 or greater shaking is sufficient to cause transformers at the power stations to bounce at which point an automatic sensor will step in and cause the circuit to trip. This causes the affected power stations to shut down, requiring a manual restart. Figure A 12 shows the locations of the major HEP stations separated into those which will shut-down during shaking and those that will remain operational. Those expected to shut-down are:

- Kumara
- Coleridge
- Tekapo A
- Tekapo B
- Ohau A
- Ohau B
- Ohau C
- Benmore

Despite Benmore being outside the MM7 zone, it is very close to the MM6-MM7 border and we suggest in order to exercise a worst-case scenario that Benmore should also be anticipated to shut-down.
Restarting these stations will first require an inspection of the dam and the relevant transformers. This cannot occur until it is light enough for visible inspection. Sunrise on 29 May 2013 is expected at 0750hrs, nearly 5 hours after the main earthquake. Given that Meridian Energy and Transpower both have agreements in place to fly engineers into affected zones it is assumed that this will be sufficient time for engineers to arrive on site. The restart process is therefore expected to start at around 0900hrs once inspections have been completed. The restart procedure will begin with Benmore, which can self-start and will therefore not require placing extra strain on the already weakened system. Once this has been completed the rest of the Waitaki dams can begin their restart procedures feeding off Benmore. It is expected that all of these dams will be restarted and generating electricity by 1300hrs, less than 12 hours after the initial earthquake.

A4.4.1.2 Transmission Network Response

The transmission network we have focussed on includes the high voltage (50/66kV, 110kV, 220kV, and 350kV) power lines which transfer electricity around the country, and the large substations which transfer electricity from these long-distance transmission lines to more local distribution networks (Figure A11). In this way we are able to resolve on a large scale the effect on the network allowing us to focus on a more national outlook.

These substations and transmission lines (which are supported by steel towers) were recently tested by the Darfield and Christchurch earthquakes and were shown to perform remarkably well. Following the Christchurch earthquake no substation or tower was significantly damaged as a result of shaking; only the Bexley substation and two towers suffered minor damage due to liquefaction. Rockfalls and landslides are also a major hazard to these systems but none of the local substations or towers in the Christchurch area was impacted by these events. Nevertheless, following an M8 Alpine Fault earthquake, landslides and rockfalls are anticipated to occur at a numerous locations throughout the Southern Alps including Arthur’s Pass and the Upper Buller Gorge where the West Coast transmission lines are located. There is therefore a high probability of towers in these zones being impacted by landslide and/or rockfall. It is consequently expected that both the Arthur’s Pass and Upper Buller Gorge transmission routes will suffer tower damage (Figure A12).

Furthermore, substations in Westport, Greymouth, the Grey Valley, and Hokitika are expected to suffer extensive liquefaction, while substations at Otira and Arthur’s Pass are likely to be damaged by a combination of rockfall/landslide and high intensity shaking (Figure A12).

This will result in power being lost to an area south of the Murchison substation, and south-east of the Castle Hill substation. This includes the whole West Coast Region as well as Arthur’s Pass in eastern Selwyn District (Figure A12). This power loss will last for the duration of the exercise. Replacement towers are available in limited numbers and can be installed relatively quickly. Nevertheless, there will be no road access to the affected areas (see Part A) and continuing aftershocks may result in further damage and provide a significant risk to engineers repairing towers. The installation time is 2-3 days per tower meaning damage to a number of towers may take a week or more to resolve however, this time does not account for delays due to access issues and it should therefore be expected to be significantly longer. Furthermore, only around 20 temporary towers are immediately available; damage to more than this will require prioritising where these towers are needed. In low priority zones power from the main network may be lost for several weeks to months.
Damage is also expected to occur to the transmission lines between Cromwell and Queenstown where the line passes through the Kawarau Gorge. Rockfalls and landslides are likely through this area and there is therefore a high likelihood that towers within this region will be affected. There is not expected to be any damage to the substations at Frankton or Cromwell, which are situated on non-liquefiable soils and set back from any possible landslides or rockfalls.

This will cause **power to be lost to the whole Queenstown-Lakes District** as this local grid is supplied by the Frankton substation (Figure A 12). This includes the major towns of Wanaka and Queenstown, which will also be isolated by road (see Part A).

![Figure A 12](image)

*Figure A 12*  Shutdown and working powerstations, damaged substations, damaged transmission lines and long-term power outage region.
A4.4.1.3 Effect to the Network

A large-scale drop in frequency is generated in the whole network as power is lost to the West Coast, Queenstown-Lakes, and Arthur’s Pass areas at the same time as most of the Waitaki HEP stations shut-down. This causes the whole network to trip. **The entire South Island immediately loses power**, and the Inter-Island direct current (DC) transmission line fails causing the North Island to switch to its back-up generator. **At no point does the North Island lose power.**

In order to restart the network, generation will need to be resumed at the HEP stations. This will begin with Manapouri as it is able to self-start. Once this is completed the grid will be turned on as each network and substation is checked and reset, starting in the south and progressing northwards. In this way segments of the system will open up between substations, returning power to the areas they feed. These checks however, cannot be performed until daylight, which will not occur until 0750hrs on the day of the exercise. **The whole South Island is therefore expected to be without power from 0300hrs until 0800hrs** (Table A 17) when power is restored to the southern part of the Island. **Power will not be restored to the whole island until around 1200hrs** on the same day when the north of the island is able to be brought back into the network (Table A 17).

Power transfer to the North Island along the DC connection can be restarted once power has been restored to the Benmore HEP station (1000hrs; Table A 17). Given that large areas will be without power in any case (see above) the load on the system will be lower than that before the earthquake and power transfer will therefore not add strain to the system.

**Table A 17** Timings for power returning to key locations around the South Island. Note: these timings are estimates only. Transpower and Meridian Energy should be consulted for the exact times.

<table>
<thead>
<tr>
<th>Location</th>
<th>Est. Power Return</th>
</tr>
</thead>
<tbody>
<tr>
<td>Invercargill</td>
<td>08:00</td>
</tr>
<tr>
<td>Gore</td>
<td>08:30</td>
</tr>
<tr>
<td>Dunedin</td>
<td>08:45</td>
</tr>
<tr>
<td>Cromwell</td>
<td>08:45</td>
</tr>
<tr>
<td>Queenstown</td>
<td>-</td>
</tr>
<tr>
<td>Oamaru</td>
<td>09:15</td>
</tr>
<tr>
<td>Twizel</td>
<td>09:30</td>
</tr>
<tr>
<td>Timaru</td>
<td>09:45</td>
</tr>
<tr>
<td>Greymouth</td>
<td>-</td>
</tr>
<tr>
<td>Christchurch</td>
<td>10:30</td>
</tr>
<tr>
<td>Westport</td>
<td>-</td>
</tr>
<tr>
<td>Kaikoura</td>
<td>11:15</td>
</tr>
<tr>
<td>Nelson</td>
<td>11:30</td>
</tr>
<tr>
<td>Blenheim</td>
<td>11:45</td>
</tr>
</tbody>
</table>
A4.4.1.4 Notes

It should be noted that throughout the exercise a number of aftershocks occur. These aftershocks (including the 1140hrs M6.1 Akatore Fault aftershock) will only affect the local power transmission and distribution networks. They have therefore not been considered in this section. It is likely that power will be lost in the affected regions for a short period of time. We recommend that the appropriate Local Authorities determine their own scenario for these based on their own needs and the recommendations of the local energy companies participating in the exercise.

A4.5 Part C – Telecommunications Network

A4.5.1 Telecommunications cable network

Fibre optic cables that provide internet and landline telephone access for the South Island largely follow the road network. These cables are primarily underground but have to travel above ground along road bridges in order to cross obstacles such as rivers. This makes the telecommunications cable network especially vulnerable as damage to bridges also results in damage to the cables. Any damage to cables results in loss of communication along that cable. As it is not possible to access data on the exact locations of the telecommunications cable network we have assumed that all cables follow the major State Highways (see Part A). Both Chorus and Telecom have confirmed that this is a reasonable assumption. We therefore (re)present our results for damage to the State Highway network as also showing likely damage to the telecommunications cable network (Figure A 9). We have re-categorised our conditions from the road network to accurately represent the conditions of the telecommunications cable network. Below is a summary of the network condition.

A4.5.1.1 West Coast Region

The connection between West Coast Region and the rest of the South Island takes 2 routes: Arthur’s Pass and the Grey Valley. The road network in both these areas suffers catastrophic damage and is completely impassable (see Part A). The main damage to the telecommunications cable network in Arthur’s Pass is caused by surface rupture around Inchbonnie which breaks the cable while bridge damage throughout the pass also severely stretches, and in some places breaks, the cable. In the Grey Valley several bridges are affected by liquefaction and lateral spreading and thus settle and some instances collapse. This results in the cable being severely stretched and damaged, and in some instances the cable breaks. As a result, there is no landline telephone communication into or out of West Coast Region. This damage may take several days to repair once access to the region has been achieved and thus it is likely that this may last several weeks to months.

Within the West Coast Region the telecommunications cable network primarily follows SH6. This is the worst affected road and is completely impassable for its entire length (see Part A). Surface rupture breaks the cable at several locations including north of the Whataroa bridge, at the Wanganui bridge, and at Franz Josef township.

Furthermore, almost all the bridges suffer catastrophic damage and many completely collapse severing the cable in many locations and significantly damaging it at numerous others. The result is that no landline telephone communication is available in the entire West Coast Region. Landline calls may still be possible within the large townships such as Greymouth, Westport, and Hokitika, but communication between the townships will not be possible. Internet access is also lost to the entire region.
A4.5.1.2 Alpine Regions

East of the main divide the telecommunications cable network is expected to fare better than that to the West. Nevertheless, there are several state highways that suffer significant damage and it is expected that the telecommunications cable network here will also suffer significant damage in these locations.

Landslides and rockfalls are frequent in Arthur’s Pass and several of the bridges in here suffer catastrophic damage. This causes multiple breaks in the telecommunications cable network. As a result there is no internet or landline telephone connection for any of the communities within Arthur’s Pass and this is likely to last for weeks to months.

West of Springs Junction the telecommunications cable network follows SH7 through Lewis Pass, SH63, SH65, and SH6 through the Upper Buller Gorge. All these roads are heavily damaged by landslides, rockfalls and liquefaction. Many of the bridges are severely damaged and this causes multiple breaks in the cables. As a result no internet or landline telephone connection is available for any of the communities in these areas including Murchison and Reefton.

The route to Mt Cook village also suffers significant damage from landslides, rockfalls, and (later) debris flows. As a result several bridges north of Glentanner suffer catastrophic damage and completely collapse, breaking cables. South of Glentanner bridges remain intact but still show visible signs of damage and settling. No breakages in cables occur but several are stretched and may be damaged. Internet and landline telephone connection is lost between Glentanner and Mt Cook village. South of Glentanner internet and landline connections may remain intact but they are likely to be disrupted and unreliable.

East of Queenstown the telecommunications cable network passes through the Kawarua Gorge. Numerous rockfalls occur here and several bridges collapse resulting in breakages in the cables. South of Queentown the telecommunications cable network follows SH6 and passes along the eastern bank of Lake Wakatipu. The road here is severely affected by landslides and rockfalls and in places the road completely falls away into the lake. The cables are broken numerous times as a result. Queenstown is left without internet connection and no landline telephone connection into or out of the town.

The rest of the Alpine region performs reasonably well. Bridges built on liquefiable soils settle and subside stretching cables and possibly causing some damage. There are no more breaks in the telecommunications cable network however. As a result, internet and landline telephone connection is disrupted and unreliable in some areas but connection remains for the majority of the region. Connections between some towns may be unavailable but overall connection remains; no township is completely cut off from communication.

A4.5.1.3 Other Regions

Away from the Southern Alps connection is relatively unaffected as bridges remain intact and cables remain relatively undamaged. Tasman loses connection in the far south around Murchison but the rest of the region is unaffected. Marlborough, Eastern Canterbury, Otago and Southland are unaffected; internet and landline telephone connection between these areas remains intact. However, network congestion may result in some local outages.
A4.5.2 Mobile Network

When analysing the mobile network we have had to consider three separate factors all of which influence the network in varying ways:

- Connectivity – each cell tower must be connected to the main fibre optic telecommunications cable network,
- Power – cell sites require power, and
- Congestion – the system struggles to cope with larger than normal loads.

Below we discuss each of these factors separately before combining their results to determine the overall condition of the mobile network.

A4.5.2.1 Connectivity

Each cell tower must be connected to the main telecommunications cable network in order to be able to transmit calls and messages. Damage to these cables therefore not only affects internet and landline telephone communication, but also mobile telephone communication in the vicinity. As a result, all regions described above as being without landline telephone connection will also be without mobile telephone connection. Those regions where landline telephone connections are unreliable and disrupted are likely to have only intermittent mobile network coverage with low signal strengths even when connection is available.

A4.5.2.2 Power

Power is essential for the mobile network. As a result, each cell site has a back-up power generator that is able to take over and continue supplying power in the event of a network power outage. Nevertheless, these generators can only function for a finite amount of time. Given the widespread power outages expected (see Part B), as well as the extensive road network damage (see Part A), it is expected that the large majority of these sites will run out of fuel before they can be resupplied.

In order to determine where reception will be lost as a result of power outages, we must compare the longevity of the back-up generators to the time the affected area is expected to be without power (see Part B). The exact longevities of each generator is unknown; however, Telecom has been able to provide average generator endurances based upon their knowledge of the network. Urban locations comprise the majority of the network usage and so have far longer lasting generators to account for their importance to the network. These are expected to last for up to eight hours. In Christchurch, which is the main mobile network node, this may be even longer, possibly extending to 10 hours. In rural areas, which cover a larger area but have lower usage, these generators are expected to last for just four hours. Minor urban areas and rural centres likely have generators somewhere between these extremities; possibly around six hours.

We have therefore used the Urban Rural Index (URI) to determine the longevity of mobile reception for all areas of the Island (Figure A 13). We have then been able to compare this longevity map with the power outage map provided in Part b. This allows us to determine which areas are likely to be without power longer than the back-up power generators can continue running. We are therefore able to determine the areas where mobile reception will be lost, when this is likely to occur, and how long this is likely to last. Table A 18 shows our results.
Several caveats should be noted however. Firstly in rural areas, local farmers are permitted and encouraged to refill back-up generators and attach their own generators in order to extend the longevity of the local areas mobile reception. Nevertheless, it is not possible to predict where this might happen, and by how much this will extend the lifespan and we have therefore not been able to include it in our results. Lastly, reception loss to a location means that calls and SMS messages cannot be made or received. Calls and messages can be sent across the area however, as long as the sending and receiving locations have reception. For instance, cell reception may be lost in the region between Dunedin and Oamaru but reception is still available in the two towns. It is therefore possible to make calls and send messages between Dunedin and Oamaru, however regions in between are unable to send or receive calls and messages from either.

**Figure A 13** Estimated longevity of mobile telephone reception in the event of Island-wide power loss.
Table A 18  Estimated timings and durations for loss of mobile telephone reception for each district as a direct result of network power loss.

<table>
<thead>
<tr>
<th>District</th>
<th>Urban/Rural Description</th>
<th>Max Generatory Longevity (hrs)</th>
<th>Time Reception Lost</th>
<th>Loss Duration (hrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tasman</td>
<td>Urban</td>
<td>8</td>
<td>1100</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Minor Urban</td>
<td>6</td>
<td>0900</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Rural</td>
<td>4</td>
<td>0700</td>
<td>5</td>
</tr>
<tr>
<td>Nelson City</td>
<td>Urban</td>
<td>8</td>
<td>1100</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Rural</td>
<td>4</td>
<td>0700</td>
<td>5</td>
</tr>
<tr>
<td>Marlborough</td>
<td>Urban</td>
<td>8</td>
<td>1100</td>
<td>1</td>
</tr>
<tr>
<td></td>
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<td>6</td>
<td>0900</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Rural</td>
<td>4</td>
<td>0700</td>
<td>5</td>
</tr>
<tr>
<td>Buller</td>
<td>Minor Urban</td>
<td>6</td>
<td>0900</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Rural</td>
<td>4</td>
<td>0700</td>
<td>4</td>
</tr>
<tr>
<td>Grey</td>
<td>Urban</td>
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<td>-</td>
<td>-</td>
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<tr>
<td></td>
<td>Minor Urban</td>
<td>6</td>
<td>0900</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Rural</td>
<td>4</td>
<td>0700</td>
<td>4</td>
</tr>
<tr>
<td>Westland</td>
<td>Minor Urban</td>
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<td>2</td>
</tr>
<tr>
<td></td>
<td>Rural</td>
<td>4</td>
<td>0700</td>
<td>4</td>
</tr>
<tr>
<td>Kaikoura</td>
<td>Rural</td>
<td>4</td>
<td>0700</td>
<td>5</td>
</tr>
<tr>
<td>Hurunui</td>
<td>Minor Urban</td>
<td>6</td>
<td>0900</td>
<td>3</td>
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<td></td>
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<td>0700</td>
<td>5</td>
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<tr>
<td>Waimakariri</td>
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<td></td>
<td>Rural</td>
<td>4</td>
<td>0700</td>
<td>4</td>
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<td>Christchurch City</td>
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<td>Selwyn</td>
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</tr>
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<td></td>
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<td>0700</td>
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<td>6</td>
<td>0900</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Rural</td>
<td>4</td>
<td>0700</td>
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<tr>
<td>Timaru</td>
<td>Urban</td>
<td>8</td>
<td>-</td>
<td>-</td>
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<td></td>
<td>Minor Urban</td>
<td>6</td>
<td>0900</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Rural</td>
<td>4</td>
<td>0700</td>
<td>3</td>
</tr>
<tr>
<td>Mackenzie</td>
<td>Minor Urban</td>
<td>6</td>
<td>0900</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Rural</td>
<td>4</td>
<td>1000</td>
<td>3</td>
</tr>
<tr>
<td>Waimate</td>
<td>Minor Urban</td>
<td>6</td>
<td>0900</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Rural</td>
<td>4</td>
<td>0700</td>
<td>3</td>
</tr>
<tr>
<td>Waitaki</td>
<td>Urban</td>
<td>8</td>
<td>-</td>
<td>-</td>
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Our results show that due to network power loss, all rural areas lose mobile telephone reception for some duration from around 0700hrs. In the far south this lasts for two hours while in the north it lasts for up to five hours. Minor urban areas south of Waitaki District do not lose reception; however, north of Waitaki these areas suffer losses in reception around 0900hrs and lasting between one and three hours. The northern major urban areas (Blenheim and Nelson) lose reception at around 1100hrs and this lasts for about one hour.

### A4.5.2.3 Congestion

All networks, regardless of type, have a maximum load. When this load is exceeded the network becomes congested causing disruption often to the entire network. The same is true for the mobile network. When the mobile network load is exceeding it no longer becomes possible to make calls to or from a mobile telephone while SMS messages become significantly delayed. This effect has been seen in multiple disasters whereby a large proportion of the affected population, as well as those connected with the affected population (e.g. family), attempt to contact each other, congesting the system. This effect is temporary and is expected to last for up to two hours following an M8 Alpine Fault earthquake. After this period loads will begin to normalise and the network will return. It should be noted that this accounts for half the time that rural back-up generators are likely to last.

The region likely to be affected by this loss due to congestion typically extends beyond the area worst affected by the earthquake. For New Zealand, Christchurch is the main node of the mobile network for all locations south of Taupo in the North Island. Congestion in the network will therefore result in the whole South Island and bottom half of the North Island (which includes Wellington, Palmerston North, and Napier) being without mobile telephone reception for up to two hours after the earthquake. Given that the earthquake occurs at 0300hrs Telecom expects there to be a delay between the earthquake occurring and the network exceeding its capacity load, as many people in the lowest shaking intensities are likely to remain asleep, while those in the highest shaking intensities deal with immediate priorities before attempting to make contact. We therefore expect **mobile reception to be lost to the entire area south of Taupo from 0330hrs to 0530hrs**. Further outages due to congestion are also expected to occur immediately after aftershocks and will affect the same area.
A4.5.3 Mobile Telephone Reception

Mobile telephone reception for the duration of the exercise will therefore depend on a combination of all of the effects described above. We have therefore combined the results for each effect in order to determine the total response of the network. Table A 19 details our results and show locations and timings/durations for outages. It should be noted that following the Alpine Fault and Hope Fault aftershocks we have not included loss of the mobile network. This is because the areas that experience the most intense shaking (primarily West Coast Region) will be without mobile reception for the duration of the exercise and will therefore be unable to congest the system. The shaking generated in regions with mobile reception from these aftershocks is unlikely to be large enough to cause congestion on the network.

We note that High Frequency radio and satellite telephone communications are unlikely to be affected by an Alpine Fault earthquake. It is therefore likely that these will comprise the main forms of communication following the event. Nevertheless, it should be noted that the satellite telephone network can also suffer from congestion and immediately after the main earthquake as well as the Akatore Fault aftershock this network may suffer disruption and be unavailable for short periods of time.
Table A 19  Timings and causes for losses to mobile telephone reception for urban, minor urban, and rural areas of the Lower North Island (south of Taupo) and the South Island Districts.

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