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Emergency Management Response to Landslide Dams following the 2016 Kaikoura Earthquake

A thesis presented in partial fulfilment of the
requirement for the degree of

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Abstract

This research examines the response and emergency management of the Kaikoura earthquake landslide dams formed on the 14th November 2016 by a M 7.8 earthquake which caused extensive damage across Hurunui, Kaikoura and Marlborough. The Kaikoura earthquake caused tens of thousands of landslides and over 200 of those generated dams that blocked rivers. The widespread damage and number of landslide dams was unusual and required a significant response. This involved many agencies and organisations undertaking different aspects of the response.

Following the Kaikoura event, the scientific community responded, identifying the dams before carrying out risk assessments of those dams posing a threat to people and infrastructure. As the scale of the event was discovered the response involved other agencies such as district and regional councils, transport agencies, Civil Defence and Emergency Management and geotechnical consultants.

To evaluate the emergency response and management of the dams, semi structured interviews were carried out with 18 personnel from ten different agencies and organisations involved in the response. The interviews covered seven topic areas which were developed through the literature and news article review. Analysis of the interview data using content analysis involved transcribing each interview before sorting and coding the transcripts.

The analysis highlighted nine main themes. These are: roles and responsibilities; communication; co-ordination; resources; previous experience; community involvement; information and data; relationships; and long-term management. A review and discussion of those themes emphasised the need for improvements in preparedness for future events.

The recommendations developed from the analysis are: clarification of responsibilities; planning of response procedures; hazard modelling; creation of a panel agreement for work-sharing; development of geographic sectors; workshops; training; public communication; resources; development of a database; and information sharing.

The learnings from Kaikoura can be used to improve future responses for both landslide dams and multi-hazard events across large geographical areas. It is predicted that an earthquake generated by the Alpine Fault could cause severe land damage across a vast geographical area. The Kaikoura earthquake has highlighted the need to focus on landslide dams as a significant hazard to communities, infrastructure and transport links.

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Chapter 1 – Introduction

1.1 Context

On the 14th November 2016, Northern Canterbury and Marlborough were struck by a magnitude 7.8 earthquake which caused significant land damage across an extensive area. There was major uplift and surface rupture of multiple faults as well as tens of thousands of earthquake induced landslides (Woods, et al., 2017). A unique feature of this earthquake was the large number of landslides which blocked rivers known as landslide dams. With over 200 landslide dams, and a dozen identified as hazardous, they became a major concern in the emergency response (Dellow, et al., 2017). The main concern being the potential for dam break floods affecting downstream infrastructure including roads, railways and bridges, buildings and people and upstream inundation of infrastructure.

Whilst landslide dams are not a new hazard in New Zealand or internationally, the sheer scale of the event across such a large area with so many dams occurring concurrently was unusual. This required a significant response from multiple organisations and agencies across two regional council and three district council boundaries. This response was complicated by the major disruption from other earthquake related damage making many areas inaccessible with communities cut off for long periods (Woods et al., 2017).

Landslide dams occur all over the world but some countries are more susceptible to them than others due to the terrain, seismic activity and rainfall amounts. These countries include Japan, China, Taiwan, Italy and Nepal. There is a huge variation in both landslide dam characteristics and the impact they can have on land and infrastructure. Hazards from a landslide dam can be ongoing for a significant time after the initial event with risk of flooding both downstream and upstream and they have previously been responsible for many deaths (Wu, Chen, & Feng, 2014).

In 2008 the Wenchuan Earthquake in the Sichuan Province, China generated 32 landslide dams that blocked rivers. The landslide dam lakes became the most dangerous post-earthquake hazard as they threatened a million inhabitants as well as inundating inhabited areas upstream from the dams (Cui, et al., 2011). This example demonstrates that multiple landslide dams induced by an earthquake can require risk assessment and management simultaneously.

Landslide dams created by the Kaikoura earthquake was a unique event in New Zealand and the emergency response was successfully managed by multiple agencies with no loss of life or

major damage to infrastructure. The main areas of focus for this research are: the processes and procedures used in the response; the co-ordination across a multi-agency response; the impact on the response of the multi-hazard Kaikoura earthquake event, the long-term management of the dams; lessons learnt and preparedness for future events.

To undertake this research several methodologies were used including a literature review of New Zealand and international case studies, as well as an analysis of the media coverage around the time of the response to the landslide dams. Following the literature review, 18 semi-structured (Braun & Clarke, 2013) interviews were undertaken with people involved in the response from different agencies and organisations. The data from these interviews was then transcribed and coded before a content analysis was undertaken (Patton, 2015).

Reviewed literature of landslide dam events, both in New Zealand and around the world, has indicated that each response to these events has been carried out differently. Every event is unique and clarity is needed around the present knowledge on landslide dams to help develop new assessment methods as well as information integration through databases (Korup, 2002). Simple matters of responsibility can cause confusion resulting in time delays in response and the potential for a dam break flood to occur before the landslide dam is even identified.

There is a strong likelihood of events similar to the Kaikoura Earthquake in magnitude and impact occurring in the future on an even larger scale e.g. an earthquake generated from the Alpine Fault. This could produce more landslide dams in even more inaccessible areas, affecting greater numbers of people and infrastructure. The Kaikoura earthquakes have highlighted that landslide dams are a significant hazard in New Zealand. Observation of the emergency response to the Kaikoura landslide dams should help identify any fundamental issues that hindered the overall response and provide useful learnings in dealing with future events.

1.2 Research Objectives

The aim of this research is to observe and document the emergency response and management of the Kaikoura landslide dams, to review previous New Zealand and international case-studies and compare the response in Kaikoura to those case-studies. These learnings could be helpful when planning response processes and increasing preparedness for future events which could be on a larger scale.

The objectives for this research are to:

- Examine emergency responses to previous landslide dam events that lead to dam break flooding events in New Zealand and internationally to baseline similarities and differences in response processes;
- Study the emergency response and management of the landslide dams created by the 2016 Kaikoura earthquakes including the procedures and processes undertaken and co-ordination between agencies;
- Examine the impact of a multi-hazard event on the emergency response and how long-term management is integrated as a part of that response and;
- Develop recommendations based on lessons learnt from the Kaikoura earthquake to inform future landslide dam response planning and increase preparedness for future events, whether that be a single landslide dam or multiple occurrences.

1.3 Research Methodology

The research methodology used in this thesis is a mixed method research approach comprising four main stages:

1. A literature review of previous landslide dam events both in New Zealand and internationally, as well as emergency response practices and procedures. This resulted in a greater understanding of the methods used in responding to landslide dams and dam breach flood events, the assessment tools used by both the scientific organisations and government agencies involved, and the differences worldwide. This also comprised a newspaper article review of the Kaikoura landslide dams and how they were portrayed in the media. The literature review helped to determine the main areas of interest for this research and the formulation of the interview questions.
2. The main form of data collection was a series of interviews with professionals from organisations, agencies and consultancies involved with the emergency response to the landslide dams following the 2016 Kaikoura earthquake. The interview participants were selected based on their involvement in the event to gather a varied assortment of emergency response roles across an extensive region impacted by the earthquake. The interviews were semi-structured around seven main topic areas which consisted of nearly thirty questions used in a flexible way depending on the interviewee.
3. Analysis of the interview data was undertaken to categorise the key themes and sub-themes through coding of the interview transcripts. This allowed for the data collected to

be understood and allowed for similarities and differences to be seen in the emergency response from the agencies involved.

4. Discussions and recommendations have been developed from the analysis of interview data. This analysis could be beneficial in informing future planning and preparedness for events such as an Alpine Fault earthquake with multiple landslide dams, as well as responding to one off landslide dam events occurring from a heavy rainfall event.

The research methodology is discussed in more detail in the following chapter.

1.4 The Kaikoura Earthquake Sequence (Background)

The Kaikoura Earthquake occurred at 12.02am on 14th November 2016 with a magnitude 7.8 earthquake (M_w). This was a shallow earthquake at only 15km deep with the epicentre located near Waiau in North Canterbury (Dellow et al., 2017). The location of the main earthquake is shown in Figure 1.1 below by the red dot and the following aftershocks shown by the orange and yellow dots. The Kaikoura earthquake was unusually complex. It covered over 150 kilometres of land from Canterbury through to Marlborough and involved at least 21 different faults rupturing in a single earthquake (Woods, et al., 2017).

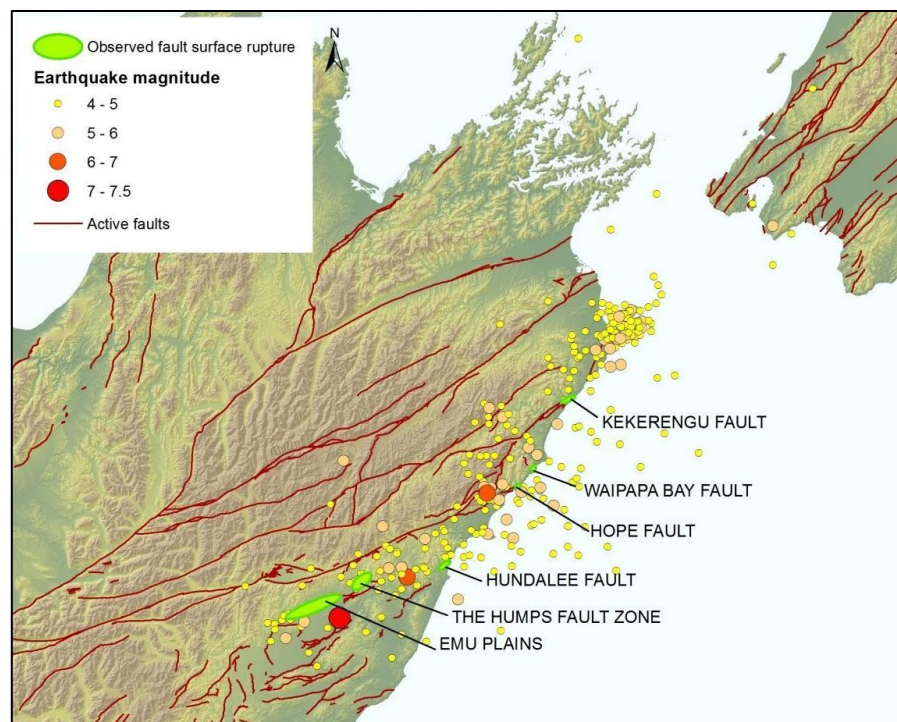


Figure 1.1 -Map showing the epicentre (red dot) at Waiau as well as aftershocks since the 14th November 2016 (BBC News, 2016).

The strength of the earthquake resulted in widespread damage to both buildings and infrastructure, as well as major land damage, with thousands of landslides and widespread surface fault ruptures with large displacements (Dellow, et al., 2017). With the large numbers of faults that ruptured and the scale of the event across such an extensive area the earthquake broke many records not only in New Zealand but across the world. It required a significant emergency response impacting as far away as Wellington where buildings and infrastructure were deemed unsafe (MCDEM, 2017).

There were two fatalities and 56 injuries in the Kaikoura and Hurunui districts, 150 households were displaced during the event and State Highway 1 was closed due to land damage. Access was cut off to many areas including Kaikoura, until an emergency route was set up on the inland route (MCDEM, 2017). Kaikoura, with a population of approximately 3,500 people, was particularly badly affected with all access routes impacted by landslides (Kaiser, et al., 2017). Due to the widespread damage, Civil Defence Emergency Management (CDEM) Groups were activated in Canterbury, Marlborough, Nelson-Tasman and Wellington. Emergency Coordination Centres (ECC's) and Local Emergency Operations Centres (EOC's) were set up in the affected areas as bases for the Civil Defence response. The level of damage in both Hurunui and Kaikoura resulted in local states of emergencies being declared followed by the Canterbury CDEM Group declaring a Group-wide state of emergency superseding the local declarations (MCDEM, 2017).

The State of Emergency officially ended on the 9th December 2016 after being extended. Although the main emergency was under control there were some remaining situations which might have required the level of control that the declaration allowed for. The CDEM Groups then began the transition into the recovery phase with the use of new legislation including the Hurunui/Kaikoura Earthquakes Emergency Relief Act 2016 and the Earthquakes Recovery Act 2016 (MCDEM, 2017).

The Kaikoura earthquake generated a large number of fault ruptures from a single earthquake event. Surface rupture has been identified on at least 13 faults and this number could still increase. The surface rupture length was unusually long at approximately 180km and with surface displacements of up to 10 – 12m horizontally and up to 5 -6m vertically (Kaiser, et al., 2017). Both horizontal and vertical peak ground accelerations (PGAs) over 1g were recorded at both ends of the faulting rupture, with 125km between them (Kaiser, et al., 2017).

Figure 1.2 shows the recorded PGAs as well as the mapped landslides in the pink shaded area, illustrating the correlation between landslides and the high levels of vertical and horizontal PGAs across the region.

Figure 1.2- Map showing the PGA levels recorded by GeoNet strong motion stations and the epicentre shown by the yellow star (Kaiser, et al., 2017).

The strong ground motion from the earthquake and the mountainous terrain of the area resulted in land damage across the region. One of the main types of land damage were the tens of thousands of landslides across an area of about 10,000km² (Kaiser, et al., 2017), concentrated in an area of about 3,500km². This distribution was accounted for by the complexity of the earthquake, where the larger landslides occurred closer to the faults that had surface rupture. Fortunately, the landslides only affected a few homes, but still caused significant disruption to main road and rail links through the South Island (Dellow, et al., 2017).

1.4.1 Geological Context of Region

The land damage caused by the Kaikoura earthquake covered a substantial area, from the epicentre at Waiau in North Canterbury through to Marlborough, as shown in Figure 1.1 above. The area is dominated by high mountains, plains, gravel braided rivers, and coastal landforms with extensive uplift from many active faults in a highly tectonic area (Rattenbury, Townsend, & Johnston, 2006).

The topography of the area is varied. The Main Divide ranges include mostly north-trending mountains with some peaking over 2000m running east along the Alpine Fault. The Kaikoura ranges include the northeast-trending Inland and Seaward Kaikoura ranges. This area contains several major faults and the mountain peaks again are over 2000m. The Hanmer Basin is a topographic depression enclosed by mountains up to 1500m. This area contains active traces of the Hope Fault and several large rivers (Rattenbury et al., 2006).

The North Canterbury basins and ranges which are south of the Hope Fault have lower mountain ranges and are less steep. A lot of the coastal land is dominated by steep cliffs with many slope failures caused by erosion. Several large rivers cross Kaikoura and the surrounding regions and many of the river courses have been influenced by active fault movement. Within the mountainous areas the rivers have cut down through the sediment to create steep sided gorges which fan out to braided channels as they reach the coastal area (Rattenbury et al., 2006).

The Kaikoura region, including Marlborough and North Canterbury, consist of a wide range of rock types. The basement rock is largely sandstones and mudstones known as greywacke and argillite with some layers of volcanics (Triassic to Early Cretaceous) which are approximately 100 to 250 million years old. This is overlain by younger cover rock approximately 1 to 85 million years old (Cretaceous and Cenozoic) sedimentary rock which includes mudstones, limestones, sands and gravelly conglomerates with some coal measures (Barrell, 2015).

The youngest deposit which is approximately 1 million years old through to present day (Quaternary) is made up of gravel deposits with sand and silt. This material has been deposited through erosion of the mountains and uplift, but much of the cover rock has been eroded away exposing the bedrock. Glacial till deposits and outwash gravels have been deposited across the plains and basins forming terraces and flood plains (Barrell, 2015; Rattenbury et al., 2006).

The Kaikoura Hurunui region lies across a tectonically complex area with many active faults. It marks the transition area from the Hikurangi subduction zone to the continental convergence

and is known as the Marlborough Fault System (Barrell, 2015). These active faults are shown in Figure 1.1 by the red lines. This area comprises four large southwest-northeast strike slip faults with the highest rates of movement on the Hope fault at 25mm per year. There is a significant thrust component to these faults striking in a north-south direction (Kaiser, et al., 2017).

This complex and active geology results in widespread slope instability due to the large number of active faults and steep sided slopes of the mountainous terrain. The majority of failures are earthquake induced although some are attributed to rainfall. Landslides are prevalent in the Cretaceous and Cenozoic rocks where weak material is undercut by rivers including many failures in the Waima River area (Rattenbury et al., 2006). Other hazards in the area include earthquakes, tsunamis, flooding and coastal erosion.

The landslides which occurred during the Kaikoura earthquake were found to be in two distinct geological materials. In the Neogene sedimentary rocks around the Hurunui District, and in Marlborough, the main landslide categories were rock block slides as well as first-time and reactivated rock slides. In the Kaikoura Ranges, with the basement greywacke rock, the main category was first-time rock and debris avalanches (Dellow et al., 2017).

1.4.2 Earthquake Induced Land Damage Impacts

The impacts of the Kaikoura Earthquake were widespread with significant damage to land, buildings and infrastructure. The land damage was seen from Waiau, the epicentre of the earthquake, right up to Marlborough over 150km away. This land damage included, landslides, landslide dams, surface fault rupture, coastal uplift and tsunamis.

1.4.2.1 Landslides

A significant number of the landslides produced by the Kaikoura earthquake occurred along the coastal cliffs. The main concentration of coastal landslides was in an area of approximately 3,500km² both south and north of Kaikoura. State Highway 1 was closed in both directions from Kaikoura with the northern route still closed a year later (Kaiser et al., 2017).

As can be seen in Figure 1.3 and Figure 1.4, the large landslides along the coast have had a huge impact on the road and rail system. The distribution of those landslides followed the elongated area of fault rupture instead of being centred around the epicentre in Waiau (Dellow et al., 2017).

Figure 1.3 - Ohau Point landslides covering State Highway 1 north of Kaikoura (Petley, 2016).

Figure 1.4 - Landslides impacting State Highway 1 south of Kaikoura at the Paratatahi Tunnels (Dellow et al., 2017).

1.4.2.2 Landslide Dams

As well as tens of thousands of landslides, one unusual outcome of the Kaikoura earthquakes was the number of landslide dams that were created with over 200 dotted across the landscape (Dellow et al., 2017). Figure 1.5 and Figure 1.6 below show two of the largest landslide dams across the Leader and Hapuku Rivers.

Figure 1.5 - Leader 220 landslide dam after breaching (Petley, 2017).



Figure 1.6 - Hapuku River landslide dam (GeoNet, 2016).

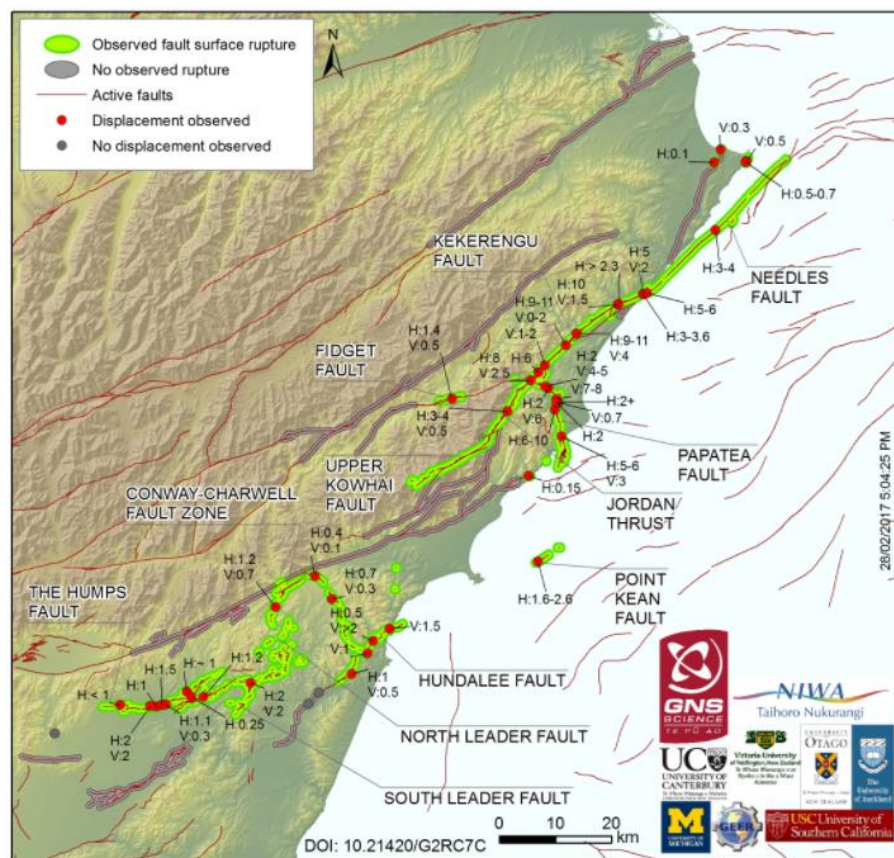
Landslide dams blocked rivers of various sizes and for different lengths of time, some dams breached the day of the earthquake whilst others were still intact months later. The main concern with landslide dams is if they breach catastrophically there is potential for a flood wave of debris to flow down the river valley and affect downstream infrastructure and buildings. There is also a risk upstream of the dam with inundation flooding of land and infrastructure. Landslide dams require extensive assessment and monitoring to ensure safety and in inaccessible mountainous terrain, they can often go unidentified for some time.

1.4.2.3 Surface Fault Rupture

Surface rupture was seen on at least 13 faults on land as well as on submarine faults. Some of these faults were not previously known as active faults (Kaiser et al., 2017). As can be seen in Figure 1.7 and Figure 1.8, the land damage is extensive and has damaged agricultural land, buildings and infrastructure with offset distances of over 10 metres at some sites.

Figure 1.7 - Surface fault scarp created near Waiau by the Kaikoura earthquake (Daly, 2016).

The observed fault surface ruptures can be seen on Figure 1.9 with the green areas being those observed and the red dots showing the displacement observed. As can be seen the Kaikoura event exhibited extensive surface rupture causing significant land damage, including coastal uplift.



1.4.2.4 Coastal Uplift

The offshore faulting which ruptured during the earthquake resulted in coastal land being uplifted which was previously underwater. There was uplift from Oaro in North Canterbury right through to Lake Grassmere near Seddon which is approximately 110km away. The uplift varied from around 1m near the Kaikoura Peninsula up to 5m on the Papatea Fault north of Waipapa Bay (Clark, 2017). Examples of this coastal uplift can be seen in Figure 1.10 and 1.11 below.



Figure 1.10 - Photo showing seabed rise from coastal uplift during the Kaikoura earthquake (BBC News, 2016).



Figure 1.11 - An aerial shot of Kaikoura's uplifted coast and seabed (BBC News, 2016).

This form of land damage has caused problems for local residents, fishermen and the tourism industry in Kaikoura as well as having a significant impact on the marine environment with the coastal margin being lifted clear of the water (Clark, 2017).

1.4.2.5 Tsunami

Several of the faults to rupture were submarine faults and the movement of the sea floor generated a tsunami along the east coast. This was unusual due to the epicentre being on land. The tsunami waves arrived only 10 minutes after the earthquake in Goose Bay south of Kaikoura with a 6.9m run-up recorded, and it travelled over 200m up the Te Moto Moto stream in Oaro as can be seen in Figure 1.12 from the debris left behind (GeoNet, n.d).



Figure 1.12 - Seaweed left high and dry by the tsunami at Oaro. Photo: D N King (GeoNet, n.d).

There was little damage to infrastructure or buildings from the tsunami along the Kaikoura coast. However, 150km south, an hour and a half after the earthquake, Little Pigeon Bay on Banks Peninsula experienced tsunami waves which lifted a historic cottage off its foundations. The water reached 140m inland (GeoNet, n.d) as can be seen in Figure 1.13 of the cottage. The coastal uplift that occurred from the earthquake actually helped to reduce the impact of the tsunami along the Kaikoura coastline (Kaiser et al., 2017).



Figure 1.13 - Tsunami damage to the cottage at Little Pigeon Bay. The red area and lines are where the veranda and poles were (GeoNet, n.d).

1.5 Landslide Dams Overview

Whilst the Kaikoura Earthquake produced many natural hazards, the focus of this research are the landslide dams that blocked major rivers and created an ongoing hazard, with the risk of dam breach floods and inundation affecting both downstream and upstream areas.

Landslide dams are the result of a landslide occurring within a valley where the landslide material blocks a river channel, thereby blocking the flow of water. They can cause loss of life and major damage to infrastructure both upstream from flooding and downstream if the dam breaches and the area becomes inundated with water and debris (Korup, 2002). Landslide dams generally form for two main reasons. Either heavy rainfall with an excessive amount of water in the ground causing slope failure, or from earthquakes. These two causes explain around 90 percent of landslide dams with other failures due to volcanic eruptions, and erosion from processes such as deforestation and river bank undercutting (Costa & Schuster, 1988).

Landslide dams are not an unusual phenomenon, they most commonly arise in narrow steep sided valleys within mountainous regions which are earthquake prone (Costa & Schuster, 1988). There are five main influences which characterise the distribution of landslide dams. These are: seismic intensity; steep slope gradients; lithology and weathering properties as well as groundwater saturation levels (Schuster, Wieczorek, & Hope, 1998).

As with the Kaikoura landslide dams, it is common for multiple landslide dams to occur during one event, whether caused by rainfall or earthquakes. Examples are the 1929 Buller earthquake in New Zealand which produced 11 landslide dam lakes, and in 1889 when a heavy rainfall event in Totsu River basin in Japan caused 53 landslide dams (Costa & Schuster, 1988).

Once landslide dams are formed and the water level behind the dam starts to increase it is only a matter of time before the dam lake level becomes too high. Most of them fail simply by overtopping when the water level gets high enough to run over the top of the dam. More rarely they fail from internal seepage (piping) or slope failure of the dam (Korup, 2002).

The length of time it takes for a dam to fail can vary greatly. They can fail in several minutes or last several thousand years. Their longevity depends on three main factors:

1. the volume and rate of water inflow to the area behind the dam;
2. the size and shape of the dam; and
3. the composition of the dam material (Costa & Schuster, 1988).

The study carried out by Costa & Schuster (1998) showed that out of 73 documented landslide dam failures, 27% failed less than one day after forming and around 50% failed within 10 days of forming. Dams tend to fail quicker in a rain event due to higher levels of water in the catchment area flowing down into the newly formed lake. This is compounded by the high-water content in the landslide dam material (Wu et al., 2014).

While many dams do fail within a year of formation others can be long-lived and become permanent features in the landscape. This usually occurs with large landslide dams such as the Young River dam near Wanaka in New Zealand which was created in August 2007 and remains in place even though the lake has overtopped the dam (GeoNet, 2016).

Whatever shape, size, cause, and longevity of the landslide dam, there are going to be effects on the area which it impacts both in the short and long term. These impacts can include:

- flooding upstream due to the dam lake forming;
- flooding downstream due to dam breach failure;
- increase in sediment throughout the river system (aggradation); and
- erosion through the river system (scour) (Zhang, Zhang, Lacasse, & Nadim, 2016).

Short-term impacts from landslide dams are related to flooding. Both upstream caused by the lake forming behind the dam, and downstream if the dam breaches. Such flooding is possibly the highest risk to be anticipated from landslide dams (Korup, 2002). In particular, downstream

flooding can be unexpected when failure of the dam occurs rapidly sending high velocity water and debris rushing down a river bed and over-flowing the river channel. Upstream flooding occurs more gradually and can be monitored allowing for evacuation in time to avoid hazard to life (Schuster et al., 1998).

In New Zealand, landslide dams have caused substantial structural damage from dam breach and downstream flooding on at least ten occasions since the 1929 Murchison earthquake. The two most significant impacts were the 1929 Mokihinui River dam caused by the Murchison earthquake and the 1957 Otira River dam, both of which caused damage to buildings and transport links (Benn, 2005).

The major long-term impact from landslide dams is extra sediment in the river system which leads to aggradation as well as scouring. The landslide dam material which accumulates in the river system can be redistributed by flood waters and debris flows both during a dam breach and rainfall event (Korup, 2002). This can lead to erosion and scour of river beds and hard infrastructure such as bridges. Large amounts of sediment in the river system (aggradation) can significantly affect channel morphology and stability (Korup, 2002) and can impact bridges and flood protection systems (Dellow et al, 2017).

Such long-term impacts can lay unnoticed for several years until there is a heavy rain event and the river course may suddenly change. Flood plains can become covered in sediment, transport infrastructure such as bridges, road and rail can be damaged and buildings destroyed. After dam breaches, there can still be a significant hazard to those downstream of the original dam. A disruption to the river system from a blockage can also have flow-on effects with deterioration in water quality which in turn impacts the river's ecological system and poses a risk to wildlife environments (Schuster et al., 1998). These impacts are often ignored in the assessment of risk from landslide dams (Korup, 2002).

As explained, landslide dams can cause a significant risk to people and property or infrastructure, both upstream and downstream. These risks need to be managed which can be difficult with such an unpredictable hazard in often inaccessible areas. It has been suggested that a database of geologic, morphometric, hydrologic and geotechnical parameters needs to be developed to assist in assessing stability of dams and the probability of dam breach (Korup, 2002). However, this is only one aspect of the emergency response required for landslide dam events.

1.6 Thesis Outline

This thesis has been arranged into seven chapters, outlined below:

Chapter One gives a summary of the research objectives that will be explored together with an overview of the methodologies used. An outline of the Kaikoura Earthquake, the geological context of the area and a basic summary of the landslide dams themselves including likely impacts and risk management of them.

Chapter Two details the methodologies used to undertake the research. This covers the data collection process comprising the literature review and interviews followed by the data analysis including transcribing and coding the interviews and sorting the data.

Chapter Three discusses the theoretical background to the research. This includes an examination of historical case studies both in New Zealand and internationally as well as general emergency response procedures and processes.

The case study events, comprise:

- Wenchuan earthquake, China 2008
- Sunkoshi River Landslide Dam, Nepal 2014
- Ram Creek Landslide Dam, New Zealand 1981
- Mount Adams Landslide Dam, New Zealand 1999
- Mount Ruapehu Out-burst flood, New Zealand 2007
- Young River Landslide Dam, New Zealand 2007
- Kashmir Earthquake, Pakistan 2005
- Chi-Chi earthquake, Taiwan 1999

Chapter Four looks at the emergency response to the landslide dams during the Kaikoura Earthquake. It covers the seismic hazards in the region, a timeline of events, the involvement of organisations in the response and the interactions between those organisations. This chapter is based on the literature review and news article review.

Chapter Five gives an overview of the Landslide Dams emergency response processes actually undertaken. This is followed by a discussion of the main themes emerging from the review of historic case studies and the information collected through the interviews.

The main themes discussed, are:

- Roles and responsibilities
- Communication
- Co-ordination
- Resources
- Previous experience
- Community involvement
- Information and data
- Relationships
- Long-term management

Chapter Six discusses the emergency response to future landslide dams including: requirements around pre-event planning; training; responsibilities; a panel agreement; information sharing systems and a country-wide database. The aim of this analysis is to offer suggestions to improve future responses to landslide dam events, such as an Alpine Fault earthquake.

Chapter Seven brings together the conclusions from the research as well as suggesting recommendations for future research for response to an Alpine Fault scale event.

Chapter 2 - Research Methodology

2.1 Introduction

This chapter deals with the methods of data collection and analysis undertaken for this research on the emergency response and management of the Kaikoura landslide dams. Lessons learned from this research could be used to enhance response processes and increase the level of preparedness for future events which could be on an even larger scale in New Zealand.

This research involved the use of a mixed method approach comprising four stages. These stages are discussed in detail through this chapter, and the ethical approval is also considered. The four stages are:

1. A literature review of historic landslide dam events in New Zealand and internationally and emergency response practices and procedures. This also included a news article review of the Kaikoura landslide dams;
2. Interviews were conducted as the main form of data collection. The interviewees were professionals from an array of organisations, agencies and consultancies who were involved with the response to the Kaikoura landslide dams;
3. Content analysis of the interview records was undertaken to categorise the key themes through coding of the interview transcripts; and
4. Discussions and recommendations have been developed from the literature review, newspaper article review, and the analysis of that interview data.

A combination of methods were used to carry out this research which strengthens the results of the research. As stated by Lune & Berg (2017) “The use of multiple research design strategies and theories increases the depth of understanding an investigation can yield” (p. 15). This use of multiple methods is known as triangulation. It combines different methods to strengthen the research.

There are four basic types of triangulation identified by Patton (2015), they are:

1. *Data triangulation – the use of a variety of data sources in a study,*
2. *Investigator triangulation – the use of several different evaluators or social scientists,*
3. *Theory triangulation – the use of multiple perspectives to interpret a single set of data, and*
4. *Methodological triangulation – the use of multiple methods to study a single problem or program (p. 316).*

This research methodology employs both data triangulation and methodological triangulation. Data triangulation is achieved through interviewing different people from an array of agencies and organisations in diverse roles to gain a variety of perspectives. Methodological triangulation is achieved by combining: literature review; news article reviews; interviews and content analysis.

As the research aims to use the learnings from the Kaikoura landslide dams to increase preparedness for future events through planning and processes it was considered that the methods detailed above (literature review, news article review, interviews and data analysis) were the most suitable and relevant approaches to employ.

2.2 Literature Review

The purpose of the literature review is to provide a comprehensive overview of existing research relevant to both emergency response procedures and landslide dams. Literature reviews can be used to provide a means of validation for the research and the necessity to undertake the study. It can create direction for new research as well as support new findings which will be a new input into the area of research (Berg, 2007). A literature review is good at focusing the research on what is known or unknown at the time. However, there is a risk of creating a bias in the researchers thinking which can reduce openness of the researcher (Patton, 2002).

The literature review was undertaken to examine previous landslide dam events both in New Zealand and internationally with specific reference to the emergency response to these events. This allowed for comparisons to be made between the Kaikoura earthquake landslide dams and other case studies around the world which in turn could identify improvements to current procedures in place for emergency response and management. The literature review

also aided in the development of the interview topic areas as well as the questions for the data collection component of this research.

For each area of interest, literature was identified using an extensive search through the Massey University Library and databases such as Google Scholar. These searches were carried out using keywords relating to landslide dam emergency response and management, general emergency response processes and key authors in the field of research. Types of documents reviewed included textbooks, reports, journal articles and conference papers as well as newspaper articles.

Once the relevant literature was found it was logged, read, and reported on. This allowed for an understanding to be developed on the current research and knowledge around the landslide dams especially the response to them post-event. The knowledge gained through the literature review allowed gaps to be found in the research and the scope for new research to be developed for this thesis. The results from the literature review are reported in Chapter Three.

2.3 Kaikoura Landslide Dams Interviews

An interview is a conversation with the purpose of gathering information (Berg, 2007). The interviews aimed to allow the participant to talk openly about their own experiences and perspectives on the research area. It allows the interviewer to capture the interviewees' way of expressing those experiences (Braun & Clarke, 2013). The interviews were undertaken in a semi-structured format which is the dominant form for qualitative interviews. This form of interview uses a pre-prepared set of questions or interview guide but these questions do not have to be rigidly adhered to (Braun & Clarke, 2013).

The aim of the interviews was to establish the participants' roles and responsibilities during the response to the landslide dams. This included the processes and procedures that they undertook and lessons learnt for future events. Finally, participants were asked about other important areas of the response they wished to discuss. Semi-structured interviews allowed for flexibility in the conversation and were considered an ideal tool for this research.

2.3.1 Interviewee Selection

The interviewees were selected for this research based on their involvement with the emergency response to the landslide dams and resultant hazards to roads, rail, infrastructure and people. Interviewees represented both local and national government agencies as well as private companies and organisations.

The organisations and agencies selected for the interviews are listed below. They were selected to provide informed perspectives and contribute useful information about the response to the Kaikoura landslide dams. Whilst there were many people involved in the response, the interviewees had a greater level of involvement, and were often recommended through others involved in the response. Organisations and agencies that interview participants represented were:

- Institute of Geological and Nuclear Sciences Limited (GNS Science)
- Civil Defence Emergency Management Canterbury
- Environment Canterbury Regional Council (ECAN)
- Christchurch City Council
- New Zealand Transport Agency (NZTA)
- KiwiRail
- Hurunui District Council
- Kaikoura District Council
- Marlborough District Council
- Aurecon Engineering Consultants

The main form of sampling used for selecting the interview participants is known as purposive sampling which is common in qualitative research (Braun & Clarke, 2013). This method aims to produce in-depth understanding of the research area. This is done by selecting data cases (participants) knowing that they will be able to offer information-rich data (Patton, 2002).

A second sampling method was also used known as snowball sampling. This method utilises those people already selected for interviews by asking them for referrals to other relevant participants, (Berg, 2007) who they may have worked alongside in the response. In the interviews, multiple interviewees suggested people who they thought would have valuable input to the research area and would be worth interviewing. Several of those suggested people were indeed contacted and interviewed.

The original aim was to interview between 10 and 20 participants to gain a broad range of perspectives and different roles in the response to the landslide dams. For a qualitative study, a sample size of between 15 and 30 interviews is common in research trying to identify patterns in the data (Braun & Clarke, 2013). In total 18 interviews were undertaken through both purposive and snowball sampling, providing sufficient data to be analysed.

2.3.2 Interview Questions

The interview questions were developed from the literature review, news article review and advice from researchers with experience in interviewing. The interviews were conducted using a semi-structured format. This allowed for flexibility and versatility throughout the interviews. This flexibility allows the interview to be more conversational in style and provide understanding of lived experiences while maintaining the focus on the research area that has been predetermined by the interview guide (Galletta, 2013; Patton, 2015). The semi-structured interview allows for substantial reciprocity between the participant and the interviewer giving the interviewer the chance to probe the response of the participant for clarification (Galletta, 2013).

Primary questions were developed for all participants using the semi-structured interview methodology. Since participants' roles in the response varied greatly, not all were asked the same questions.

The interview questions were developed around seven main topic areas as follows:

1. Roles and responsibilities during the Kaikoura landslide dam response;
2. Processes and procedures used through the Kaikoura landslide dam response;
3. Co-ordination across a multi-agency response;
4. Multi-hazard event (i.e. ongoing aftershocks, rainfall, multiple landslide dams);
5. Long term management and impacts from the landslide dams;
6. Lessons learnt from the landslide dams response and management; and
7. Preparedness for future events.

The interviews began by asking participants to state their name, the organisation that they represented and their title during the response to the landslide dams. This allowed the interviewer to identify questions which may not be meaningful for them to answer. The order of the questions was carefully developed to allow for flow through the interview and encourage the interview to follow the event as it unfolded. The full list of questions is attached

in Appendix A. In total there were around 30 questions. The questions provided a useful checklist to ensure that the information required from each participant was gathered.

2.3.3 Ethics Approval

Before the research began an application to the Massey University Human Ethics Committee was submitted to ensure that the research was carried out in accordance with their guidelines. The application included details on the aims of the research, methodology of data collection including minimising risk and stress to participants involved in the research.

An information sheet and consent form were created according to the guidelines provided by Massey University's Ethics Committee. These were to inform interview participants about the research aims and outline the ethics procedures around confidentiality of the voice recordings and data collected. The information sheet and consent form were approved as part of the ethics application procedures.

The consent form and information sheet were emailed to all participants the week before the scheduled interview to allow time to read them and ask any questions. All the interviews began by checking that the participants understood and agreed to everything outlined on both documents before signing the consent form to accept their involvement in the research. For the face to face interviews, the consent forms were signed at the start of the interview and for the telephone and Skype interviews the signed consent forms were sent back via email before commencing the interview. The information sheet and consent form are shown in Appendix B and Appendix C respectively.

2.3.4 Data Collection

2.3.4.1 *Contacting Participants*

The potential interview participants were firstly contacted by email to explain to them the research aims and ask if they would be willing to contribute. On some occasions, the email was followed up with a phone call to confirm any questions around the research or the interview. After it was confirmed that they were willing to participate, a date, time and location for the interview was agreed.

The participants were emailed to confirm the details agreed upon together with the information sheet and consent form. These documents provided them with more detail on the

research, the topics the interview would cover, the ethical considerations and the confidentiality arrangements. Most of the people who were contacted about the interviews accepted and wanted to be involved with the research.

2.3.4.2 Interview Location

The participants mainly dictated the location of the interview. This was usually a meeting room at the participants' work place. It was important to make sure that the participant felt comfortable in the location chosen (Braun & Clarke, 2013) as well as making it as convenient as possible for them to attend the interview. It was important when deciding on an interview location to make sure that the space would be quiet with little distraction.

Some participants were not easily accessible to the interviewer as they were located across New Zealand. Those interviews which could not be carried out in person were interviewed via Skype or telephone. Travel to Kaikoura and Hurunui was undertaken for those interviews as it was considered important that these particular interviews be undertaken in person.

2.3.4.3 Interview Method

In total, 18 interviews were undertaken to collect the data required for this research. The interviews were conducted in two different ways: face-to-face and over Skype or telephone. The majority of the interviews were carried out face-to-face, with only four via Skype and one over the telephone.

In this study face-to-face interviews were the preferred method of interviewing. Face-to-face interviews engender a more natural conversation especially with people unfamiliar to the interviewer and are generally thought to gather better quality data (Sturges & Hanrahan, 2004). It was important in this research to carry out as many face to face interviews as possible.

The use of Skype or phone interviews are no longer regarded as a poor substitute for the face to face interviews, they are simply a different method (Braun & Clarke, 2013). The use of Skype for interviews was much like a face to face interview with the use of a camera.

Telephone interviews are still a good method of collecting quality data and enable the researcher to reach people who would otherwise be difficult to access, and not ignore the perspective of people due to their location (Sturges & Hanrahan, 2004). However, it must be

remembered that phone interviews can have limitations that other methods do not face. These include not being able to read body language between the interviewer and interviewee where visual communication can be an important factor (Berg, 2007).

All the interviews were voice recorded using a digital voice recorder including, the face-to-face, Skype and telephone interviews. Voice recording interviews is the best way to achieve an accurate and precise record of the interview as well as the interviewer not getting distracted writing notes whilst listening to the participant (Braun & Clarke, 2013). Voice recording interviews is essential for gaining the best data from the interview process and provides the most complete record possible when it comes to data interpretation and analysis. The purpose of the data collection stage is to record the perspective of the participant as fully and fairly as possible which cannot be achieved through note taking alone (Patton, 2015).

As a part of the ethical guidelines from Massey University the interview participants could choose not to be voice recorded or at any point ask for the voice recorder to be turned off during the interview. The participants could also request a copy of the interview voice recording or transcript if they wanted, although only one participant asked for a copy of their interview transcript. These details were laid out in the consent form which participants read and signed before the interview started, shown in Appendix C. The identity of the interview participants and the data collected was kept securely throughout the research.

Two digital voice recorders were used throughout the interviews for redundancy. The voice recorders were always placed near to the participant to gain the best recording possible. Interview locations were selected to be quiet enough and free of interruptions for a good recording result (Patton, 2015).

The participants were informed beforehand that the interview would take approximately one hour. However, the length of the interview was very much determined by the participant. Interviews varied from 35 minutes to over two hours.

2.4 Interview Data Analysis

To understand the emergency response and management of the Kaikoura earthquake landslide dams, data analysis was undertaken of the interview data collected through June and July 2017.

This analysis included:

- Transcription of the interview voice recordings;
- Coding of the interview transcriptions; and
- Content analysis of the interview transcriptions.

As identified by Berg (2007), content analysis is, “systematic, examination and interpretation of a particular body of material in an effort to identify patterns, themes, biases and meanings” (pp. 303-304). This type of analysis is usually used for analysing text like interview transcripts, documents, or diaries so is well suited for analysing the transcripts from this research. It is used to find themes and patterns in the data (Patton, 2015) which can then be used to discuss findings from the Kaikoura response. Content analysis was selected for this research being best suited to the research aims as well as the type of data being collected.

2.4.1 Transcription

Transcription of all 18 interviews was undertaken by the researcher (myself). None of the transcribing was outsourced to an external person or business. An orthographic style transcription was used as it focuses on spoken words in the voice recording without considering how it was said (Braun & Clarke, 2013). For the aims of this research an orthographic transcription was sufficient to gather what was needed from the data.

The researcher elected to carry out all the transcription as it allows for evolution between the data collection through interviewing and the content analysis. It also provided the chance to be immersed in the data which can allow for useful understandings to emerge before starting the analysis (Patton, 2002).

Following transcription, the files were stored securely and only accessible to the researcher. This transcription process allowed for the analysis to be undertaken as well as extracting quotes from the dialogue which demonstrated key themes on the response to the Kaikoura landslide dams.

2.4.2 Data Coding

Once the interview transcripts were complete the first step of the content analysis was to develop a system of classifications and coding to simplify and make sense of the data. This involved identifying, coding, categorising, and classifying the patterns and themes in the data (Patton, 2015). Each of the interview transcripts were coded looking for key words, phrases,

topic areas, ideas, experiences and concepts around the response and management of the Kaikoura landslide dams. Following this, the transcripts were read through systematically to identify categories and sort the data into topics or themes. This process led to the development of coding categories before the formal coding commenced.

A method of coding described by Berg (2007) as open coding was used to keep the inquiry as open as possible to allow questions and answers to emerge through the coding process. Four guidelines were followed whilst coding:

- (1) Ask the data a specific and consistent set of questions;*
- (2) Analyse the data minutely;*
- (3) Frequently interrupt the coding to write a theoretical note; and*
- (4) Never assume the analytic relevance of any traditional variable until the data shows it to be relevant (Berg, 2007, p. 317).*

The open coding approach was used for this research as it allowed for exploration of all areas of the data. It allowed for both expected and unexpected codes to arise whereas some other coding methods are restricting from the start. The analysis was undertaken thoroughly to make certain that concepts were not missed.

At the end of the analysis, the key themes found through coding were revised. This was done to eliminate duplication of themes that were similar but had been coded differently. There were many similar themes as well as learnings and suggestions from the response to the landslide dams which reoccurred through the coding process. These had a strong significance and became key themes. At this point the key themes from the data were compared to the literature reviewed earlier in the research to look for links in previous events, both in New Zealand and globally.

2.5 Results interpretation and development of recommendations

The interpretation of results was undertaken in several ways. The news article review and some of the recent literature allowed a timeline of events to be constructed of the response following the Kaikoura earthquake. This timeline represents the response following the earthquake focused on the landslide dams, including when they were identified, evacuations, ongoing risks, warnings to the public and the significant dam breaches. This timeline gives an understanding of the emergency response and clarifies results from the interviews.

Important themes were identified through the content analysis of the interviews. Each of the themes were examined to identify how the response was carried out and the learnings from these responses.

The interview results were compared with historical landslide dam events both in New Zealand and around the world, as well as general emergency response literature for New Zealand. Reviewing historical events confirmed that the recommendations identified from the Kaikoura response are credible and consistent. This gives confidence that the recommendations can help inform response to future events and increase preparedness for future landslide dams.

The recommendations in Chapter Six were developed from the literature review, the news article review and the data analysis of the interviews on the response to the Kaikoura landslide dams. The recommendations are intended as a discussion document to illustrate ideas, techniques, process, procedures and methods for response and management of future landslide dam events and more specifically multiple landslide dams occurring from one event such as earthquakes or rainfall. This could assist responders at all levels, such as the science community, Civil Defence, emergency responders, government organisations, district and regional councils and consultants.

2.5.1 Limitations to Research Methodology

As with all types of qualitative data collection methods, semi-structured interviews have limitations. These differ between face to face interviews compared with telephone or Skype interviews. Some of these limitations include (Qu & Dumay, 2011; Roulston, 2014; Sewell, n.d):

- Providing inconsistent, opposing information or imprecise recollections;
- Not understanding the question posed;
- Context of the interview being negatively influenced by emotional states;
- Interpersonal dynamics between the interviewer and the interviewee as well as personalities and mood on the day;
- Results from an interview are dependent on the skill and experience of the interviewer; and
- There is a limit on the number of people that can be reached through interviews, therefore limiting the sample size.

These problems can twist or bias the information provided by the participants and reduce the effectiveness of the interview process for collecting objective data relating to the response to the landslide dams.

There are also limitations with the data analysis part of the research. Analysis of qualitative interviews is very time consuming especially transcribing the voice recordings (Sewell, n.d; Braun & Clarke, 2013). The other difficult part of a qualitative data analysis is making sense of large amounts of non-quantifiable data, again this can be a time-consuming process (Patton, 2002).

Although there are limitations in the data collection and analysis phase of the research, they can be minimised through pre-planning and research design prior to the interview stage commencing. This research focused on people working closely on the response and purposely did not include any participants who might have an emotional response to the interview process. Whilst the interviewer (myself) had very little prior interviewing experience, advice was sought from experts beforehand. The interviews were carried out six months after the event which minimised the concern of participants struggling to recollect their experiences.

2.6 Summary

This chapter has outlined the methodologies employed for this research. Two main methods have been utilised. Firstly, a literature review of both New Zealand and international case studies of landslide dam responses together with a review of news articles from the time of the Kaikoura earthquake landslide dams. This provided an understanding of the sequence of events at the time which is further detailed in Chapter Four.

Secondly, data was collected through 18 interviews with key personnel from a variety of agencies and organisations. These interviews were recorded and transcribed to assist in providing a deeper understanding of the data. A qualitative content analysis was carried out to gain meaning from the data and subsequently generate recommendations for future events. The findings from this data analysis are discussed in Chapter Five.

Chapter 3 - Literature Review

3.1 Introduction

This chapter presents the context and theoretical foundation for this research into the response and management of the Kaikoura earthquake landslide dams. The purpose of this chapter is to review literature detailing general information around landslide dams, specific case studies of landslide dam events, as well as emergency management and response procedures. Case studies will be discussed both from New Zealand and from around the world. These case studies comprise:

- Wenchuan earthquake, China 2008
- Sunkoshi River Landslide Dam, Nepal 2014
- Ram Creek Landslide Dam, New Zealand 1981
- Mount Adams Landslide Dam, New Zealand 1999
- Mount Ruapehu Out-burst flood, New Zealand 2007
- Young River Landslide Dam, New Zealand 2007
- Kashmir Earthquake, Pakistan 2005
- Chi-Chi earthquake, Taiwan 1999

There are several key themes that will be explored through the literature review. These include: multi-agency response and responsibilities; management of the event and rapid response; methods of risk assessment; warnings and evacuation procedures; mitigation and monitoring; community involvement; and long-term impacts from the landslide dams.

Emergency response techniques from the reviewed case studies will inform a comparison of the response to the Kaikoura earthquake landslide dams through the data collected from interviews with key personnel. The literature review provides a theoretical context for why the response and emergency management of the Kaikoura landslide dams requires exploration.

3.2 New Zealand Based Case Studies

Landslide dams are a common feature of New Zealand's mountainous terrain but often go unnoticed as they only impact small catchments and occur in inaccessible areas. Historically there have been many landslide dams, but there are likely many more that have never being recorded or reported (Korup, 2004).

There is now a recently developed nationwide database to keep track of known landslide dams. This has identified 130 locations of landslide dam activity around New Zealand (Korup, 2002). For this literature review four New Zealand case studies will be discussed to gain an understanding of previous events and the response to them.

3.2.1 Mount Adams Landslide Dam 1999

On the 6th of October 1999 a landslide occurred on the slopes of Mount Adams which blocked the Poerua River. A landslide dam was created which was approximately 120m high and a large lake formed behind the dam. The lake volume was estimated as five to seven million cubic meters. It is unknown why the landslide occurred as it was not from either an earthquake or heavy rainfall. The dam was located only 11km upstream from a road bridge across the river on State Highway 6 which is the main road along the West Coast of the South Island (Hancox, McSaveney, Manville & Davies, 2005; Hancox, McSaveney, Davies & Hodgson, 1999).

The landslide blocking the Poerua River overtopped only a day after forming on the 7th of October, but the dam remained intact even after overtopping. It was not until six days later on the 12th of October that the dam breached inundating the river flats in the upper valley. The breach itself caused only slight damage. However, it did deposit considerable amounts of gravel and other debris downstream of the dam. Most of the debris was confined to the flood plains but it did overwhelm some farmland in the upper valley (Becker et al., 2007).

The initial recognition of a problem upstream came from the residents who heard the noise of falling rock, and then noted there was a lack of water in the river. The residents notified the West Coast Regional Council (WCRC), Westland District Council (WDC) and the Police. A helicopter inspection was organised and it was confirmed that a landslide dam had occurred and a lake was forming. An emergency response plan was developed which included monitoring the dam, a phone tree system for residents, evacuation of people in the valley mouth, set up of monitoring at the State Highway 6 bridge, set up of evacuation points, and closure of Department of Conservation (DOC) tracks in the area (Becker et al., 2007).

In the days following the landslide, hazard assessments were undertaken by a GNS field team and residents were kept informed through public meetings. The dam was assessed as stable in the short-term so evacuated residents could return home. It was determined that moderate to heavy rainfall would significantly increase the risk of a dam breach and therefore residents should be evacuated in a substantial rainfall event. Only a few days later there was a heavy

rain warning for the area with 80mm of rain expected. However, no monitoring systems had been established by this time (Becker et al., 2007; Hancox et al., 1999).

Following the heavy rain warning, GNS Science recommended to the WCRC and WDC to evacuate residents overnight as a precaution. This recommendation was communicated over the phone and in writing through an email. This message was not read by the WCRC or WDC until the next day when the dam had already breached (Becker et al., 2007). Once the dam had breached on the 12th of October, the Poerua River valley residents were evacuated and a State of Emergency was declared. Due to the weather improving and the lack of damage in the valley, the State of Emergency ended by midday the same day (Hancox et al., 1999).

Although there was no major damage from the dam break flood event in the Poerua valley, the response raised several issues. Becker et al. (2007) discussed the main issues to the response which included:

- Concern by residents about the delayed response by the councils and police. The nature of the hazard means it can have a sudden onset of failure and therefore flooding.
- The agencies involved in the response had very little professional contact. The event emphasised the need for co-ordinated decision making and information sharing.
- Communication breakdown regarding the message to evacuate residents prior to the breach. The email was not received so other forms of communication are required to confirm the information has been received.
- Decision making procedures needed to be clearer so that scientific advice or information is received, understood, and acted on.
- Confusion among the agencies and organisations involved with respect to roles, responsibilities, and contacts for the appropriate person for difficulties. It was not clear who oversaw actions. This resulted in certain actions not being carried out.
- Inaccessibility of the landslide dam created problems with monitoring and anticipating the potential impact downstream from a breach event (Becker et al., 2007).

3.2.2 Mount Ruapehu Out-burst flood 2007

Between 1995 and 1996 Mount Ruapehu experienced a sequence of volcanic eruptions (Johnston, Houghton, Neall, Ronan, & Paton, 2000). These eruptions formed a barrier along the edge of the Crater Lake in the head of the Whangaehu Valley. This tephra barrier acted very much like a landslide dam in a river as the lake level rose behind the barrier over time. It was predicted that the lake volume could reach between seven and nine million cubic meters. This meant that if the dam breached it would result in a dam-break lahar which could impact people and infrastructure (Becker et al., 2017).

With previous eruption events causing dam-break lahars from Ruapehu, including the 1953 Tangiwai disaster, it was considered necessary to implement precautions to reduce the risk further down the valley (Massey et al., 2010).

Due to the likelihood of a dam breach, the location of the dam, the potential magnitude of the breach, and the timeframe of the lake level rising, the emergency response could be well planned. By the end of 2001 it was decided that a warning system known as the Eastern Ruapehu Lahar Alarm and Warning System (ERLAWS) would be put in place. Emergency management response and contingency plans would be established by those agencies involved.

As well as warning systems and plans, some structural mitigation measures were executed. These included, raising and strengthening road bridges, installation of warning lights and signals on at-risk roads, and constructing an embankment along the mouth of the gorge to reduce the lahar material reaching State Highway 1 (Becker, Manville, Leonard & Saunders, 2008).

Part of the preparation was to hold training exercises which meant that all agencies could practice responding and working together. This not only allowed for testing of the technical aspects of the response procedures, but also for relationships to be built between agencies with ongoing communication.

On the 18th March 2007, after a long period of rainfall, the dam breached and the lahar flowed down the Whangaehu Valley. Figure 3.1 shows images from the GNS Science dam cam before and after the dam breach, at only an hour apart. This footage, along with many other data sources collected during the dam breach, helps scientists and other agencies understand future events and increase preparedness.

Figure 3.1 - Images from the GNS Science installed dam cam near the summit of Mt Ruapehu, left side shows the dam intact at 11am on 18th March and the right side shows an hour later with a fully formed breach and water pouring through (GNS Science, 2010a).

The ERLAWS sensors were triggered as the lahar travelled down the valley. The alarm was sent to those agencies involved in the response, as well as initiating the automatic barrier arms and signals on the State Highway (Becker et al., 2017). Although the response to the dam-breach event went well, there were a few minor communication issues which included:

- The need to develop greater public information about the lahar prior to the event.
- Communication levels were different during the actual event compared with the exercises. Due to a much greater increase in contact some participants had trouble getting through busy communication lines.
- Personal relationships affected the response structure as people sidestepped the plan, resulting in a communication breakdown (Becker et al., 2017).

The planning, mitigation measures, ERLAWS sensors and practices over 11 years prior to the lahar meant that the event occurred with very little damage to infrastructure and no injuries or loss of life (Massey et al., 2010).

3.2.3 Ram Creek Landslide Dam 1981

The Inangahua earthquake on 23 May 1968 caused a landslide which blocked Ram Creek on the West Coast of the South Island. The dam height was approximately 40m above the valley floor. The lake dimensions were approximately 450m long, 350m wide and 40m deep with an estimated water volume of just over one million cubic meters (Nash, Bell, Davies & Nathan, 2008).

The dam was assessed for stability using the impoundment index, blockage index and the dimensionless blockage index (Nash et al., 2008). These indices are commonly used to quantitatively predict and assess the stability of landslide dams. This forms a part of the risk assessment (Korup, 2004). The three indices all determined that the dam was stable for at least the short-term. Unfortunately, this was not the case and the dam breached after overtopping 13 years later (Nash et al., 2008; Nash, 2003).

On 29 April 1981 the dam breached unexpectedly after an intense rainfall event. During failure the entire lake volume was released which generated a wave of water and debris. This caused significant damage to roads, bridges, infrastructure and farmland downstream (Nash et al., 2008). Some of the damage to the downstream bridge and road can be seen in Figure 3.2 below at Dee Creek. The debris from the flood covered the road and washed away the bridge. Two people in a car on the bridge were nearly swept away (Nash, 2003).

Figure 3.2 – Debris from dam-breach flood in 1981, 5km downstream of the landslide dam at Dee Creek (Nash et al., 2008).

The maximum flood height observed was around two metres by the Dee Creek bridge and sediment from the dam breach was deposited up to 5.5km downstream. In some places farmland was buried up to two metres deep with both rock and large pieces of wood debris (Harrison, Dunning, Woodward & Davies, 2015). Approximately 120,000m² of farmland was impacted by the dam breach flood (Nash, 2003).

The Ram Creek dam was assessed through statistical analysis as being stable in the short term but two supplementary parameters in this case influenced the dam stability. Those two parameters were the rainfall intensity and the material make-up of the dam itself (Nash et al., 2008). Nash et al. (2008) have stated that:

The breakout of this dam was unexpected and would not have been predicted even today as well as it is impossible to predict when a sufficiently intense event will cause failure of a landslide dam; it is conceivable that the Ram Creek dam could have remained intact for many more decades if the 1981 storm had been a little less intense or centred a few kilometres farther away (p.192).

This shows how unpredictable landslide dams can be as a hazard and that relying on a statistical assessment alone is not enough for the emergency response to the potential dam break flood event.

3.2.4 Young River Landslide Dam 2007

In September 2007 a landslide blocked the Young River forming a landslide dammed lake. The lake level rose and on the 5th October 2007 water began to flow over a section of the dam crest (Palmer, 2007). Most of the dam remains in place today and there is still potential for a significant dam-break flood from a breach.

The dam was only discovered on the 26th September by a helicopter pilot who then reported it to DOC before the Otago Regional Council (ORC) became aware of it (Palmer, 2007). There was no identified trigger for the landslide from either heavy rainfall or an earthquake event and the trigger is still unknown today. The landslide itself generated seismic shaking which was recorded on the GeoNet seismic network three weeks prior to its discovery (Massey, McSaveney, Palmer, Manville & Hancox, n.d).

The lake which formed behind the dam has an approximate volume of 23 million cubic meters at full height, with the dam height being approximately 70m on the downstream side (Massey et al., n.d). Figure 3.3 shows the extent of the landslide dam and the lake which has formed behind it with an arrow indicating the distance across the lake at 500m.

With this volume of water behind the dam, a breach could cause a significant impact.

Downstream of the landslide dam are several vulnerable pieces of infrastructure and areas where people are likely to be.

Figure 3.3 - Young River landslide dam looking north west (Massey et al., n.d).

There are tramping tracks in the Young River valley as well as a DOC shelter (The Forks), and the Makarora River flats are used by anglers and trampers which the Young River feeds into. There are also two sections of State Highway 6 which are particularly low and could be impacted by debris (Palmer, 2007).

Due to the ongoing potential for a dam breach failure, the ORC, the Queenstown Lakes District Council, and DOC have worked together to manage the risk. This has also involved the community in the Makarora valley. The emergency management response has included:

- Closing access to the lower area of the Young River and installing warning signage in the local angler's areas.
- Installing monitoring equipment on the dam, through a radio system, web cams and pressure sensors.
- Involving experts from GNS Science and Universities to provide information on both the dam itself, risk assessment of the dam, and monitoring.

- Assisting the Makarora community to develop their own response plan around actions to be undertaken in the case of a dam breach (Massey et al., n.d; Palmer, 2007).

The Young River landslide dam is still in place today and could continue that way for many more years to come. The local and regional councils thought it was imperative to have plans and procedures in place due to the ongoing risk and this is indicative of how longer-term planning is important.

3.3 International Based Case Studies

Landslide dams and the breaching of these dams are a common hazard around the world, especially in mountainous regions which have high rainfall levels or are seismically active. Dam breach events have caused many fatalities (Korup & Tweed, 2007).

Events such as the 1786 landslide dam breach in Sichuan, China which killed approximately 100,000 people (Korup & Tweed, 2007) shows the importance of understanding landslide dams and improving the emergency response processes to deal with them. Another example, the Raikhot dam on the Indus River in Pakistan in 1841, was considered the largest damming and slope failure event in the world (Korup, 2002).

For this literature review four case studies from around the world will be explored to gain further understanding of historical events and the emergency response process and procedures used and the outcome of the landslide dam. These were selected based on their differences in the nature of the event occurring and the response to the dams.

3.3.1 Wenchuan Earthquake, China 2008

On the 12th May 2008 the area of Sichuan, China was shaken by the M 8.0 Wenchuan Earthquake. The earthquake, in a populated mountainous region, generated many landslides, rock avalanches, and debris flows. This impacted infrastructure such as railways and bridges, electrical and telecommunications services, and caused multiple casualties throughout the region (Xu, Fan, Huang & Westen, 2009). The earthquake triggered over 60,000 landslides with 828 of those being recorded as landslide dams, and 501 landslide dams completely blocking rivers (Fan, Westen, Xu, Gorum & Dai, 2012).

The initial identification of the landslide dams was undertaken through a review of 52 prior and post-earthquake satellite images as well as aerial photographs. Those identified were then

field checked in areas which were accessible. A serious limitation of this approach was that dams less than 200m² could not be identified due to the resolution of the image quality (Fan et al., 2012).

Following the identification of the landslide dams, risk assessment was undertaken with a rapid empirical approach. With so many landslides a quick method of assessment was required. Three parameters were used for the hazard assessment (Xu et al., 2009):

1. Dam height.
2. Material.
3. Maximum lake capacity behind the dam.

These parameters allowed for a classification of risk to be determined and a focus on the mitigation measures to begin.

Of the assessed dams, 32 required mitigation works using engineering measures. The most common method being the construction of spillways with both machinery and explosives (Peng, Zhang, Chang, & Shi, 2014). The Chinese Army created spillways on the landslide dams to reduce the potential risk of dam-breach floods by lowering the lake capacity (Peng et al., 2014). These types of mitigation works can be seen in Figure 3.4 below.

Figure 3.4 – Two different mitigation techniques being demonstrated, one enlarging an overflow spillway with excavators and the other with blasting (Peng et al., 2014).

The Tangjiashan dam was the largest landslide dam blockage event, and is located 3.2km upstream from the town of Beichuan in the Jian River. The landslide dam threatened over a million people in the city of Mianyang downstream of the dam. Upstream populations were also at risk as the dam lake submerged an area over 8.9km² reaching a town 23km upstream from the dam (Cui et al., 2011).

After a risk assessment was undertaken of the Tangjiashan landslide dam it was determined that between 0.2 and 1.2 million people were at risk of the predicted floods. The Chinese government decided to reduce the dam breach potential by excavating a diversion spillway. The mitigation works were carried out and a 12m deep spillway was constructed which lowered the capacity of the lake. As well as the engineering works, around a quarter of a million people were evacuated from the area downstream (Peng et al., 2014).

The lake overtopped the spillway on the 7th of June 2008 but the flow was low, so to accelerate the process, blasting was undertaken to assist with loosening the dam material. This caused the dam to breach on the 10th of June. The breach flood severely impacted the town of Beichuan, but no people were affected as the town was evacuated two weeks beforehand (Peng et al., 2014).

One month after the Wenchuan earthquake, 215 out of the 501 landslide dams remained intact. However, four months later during a heavy rainfall event, 72 debris flows were activated in the region. This led to significant amounts of sediment being deposited into the rivers with one dam causing inundation of a relocated town (Fan et al., 2012). It is anticipated that the post-earthquake hazards produced during the 2008 earthquake, such as the debris flows from the landslide dams, could be ongoing for up to 20 years (Cui et al., 2011).

3.3.2 Kashmir Earthquake, Pakistan 2005

On the 8th of October 2005, a M 7.6 earthquake struck the Kashmir region in Pakistan, triggering thousands of landslides (Harp & Crone, 2006). The Kashmir earthquake was the deadliest earthquake in South Asia's recent history. There were over 86,000 deaths, 69,000 injuries and four million people left without homes (Owen et al., 2008).

One of the largest landslides known as the Hattian Bala was so vast that it buried an entire village causing around a thousand deaths (Harp & Crone, 2006). The landslide blocked two valleys in the Jhelum River system and two lakes formed which were around 400m and 800m long. With a downstream population only 2.8kms away and a high risk of a dam breach failure, a risk assessment was required. The downstream population was particularly vulnerable with some people living in tents (Harp & Crone, 2006) with no defence to a flood full of debris from the landslide.

The at-risk landslide dams were inspected by Geotechnical Engineers and Hydraulic Engineers from the Pakistan military. Following those inspections mitigation measures were decided on

for those dams deemed to cause a risk. The main concern was the Hattian Bala landslide, where mitigation included the Pakistan military excavating spillways across the dams. This allowed for the lakes to overtop the dam before it filled up to maximum capacity. This was carried out with the expectation that flooding downstream from a breach would be less damaging with less water in the lake (Harp & Crone, 2006; Owen et al., 2008).

On the 9th of February 2010, the Hattian Bala landslide dam breached following a heavy rainfall event. The dam breach caused water to inundate low-lying land along the river beds of both the Karli and Jehlum Rivers. The flooding destroyed over 20 homes and caused the death of one child (Kiyota et al., 2011).

The residents downstream of the Hattian Bala landslide dam had been informed of the potential risk of a dam breach event occurring as a part of the mitigation measures. This was just as well because a loud sound of rock movement was heard up the valley, causing the residents to self-evacuate the area. Shortly afterwards the dam breached (Kiyota et al., 2011).

Monitoring of the Hattian Bala dam lakes and the landslide dam itself have been conducted ever since 2008, as the dam has been considered a significant threat to those living downstream. The landslide dam had been showing signs of deterioration through erosion from the excavation of the spillway. It is understood that a lakefront landslide possibly contributed to the dam breach with the lake level rising. The Hattian Bala landslide dam requires ongoing attention as masses of soil and rock continue to detach from the surrounding slopes which could block channels and change the river flows (Konagai & Sattar, 2012).

3.3.3 Sunkoshi River Landslide Dam, Nepal 2014

On the 2nd of August 2014 a huge landslide blocked the Sunkoshi River and created a landslide dam near the village of Jure in Nepal. The cause of the landslide is still unknown as there was no significant rainfall in the area or seismic activity. The landslide itself was highly damaging to the Jure village where it destroyed over 20 houses, as well as killing 156 people and injuring 27 (Champati & Chatteraj, 2014; Shrestha & Nakagawa, 2016).

The landslide dam was large, at approximately 300m long and 52m high. The lake behind the dam contained approximately 11 million cubic metres. The lake level rose over time and inundated several houses and buildings in the upstream catchment, including the Sanima Hydropower Company powerhouse as well as part of a road (Shrestha & Nakagawa, 2016).

The landslide occurred around two o'clock in the morning on the 2nd of August and by two o'clock in the afternoon the Nepal Army had created an outlet spillway in the dam. Another spillway was created on the 30th of August by excavation and blasting by the Nepal Army. This process continued on the 6th of September to widen the spillway to 52m (Shrestha & Nakagawa, 2016).

On the 6th of September there was heavy rainfall in the area and on the morning of the 7th of September 2014 the dam breached. The dam lasted a total of 37 days before breaching. The flooding resulting from the breach caused some damage to houses but no deaths were reported (Shrestha & Nakagawa, 2016). It was reported that those people downstream of the dam heard the swollen river and self-evacuated to safer ground higher up the valley (The Kathmandu Post, 2014).

The main damage extended six kilometres downstream but there were impacts from the flood as far away as 30km downstream (Shrestha & Nakagawa, 2016). The lake level behind the dam dropped by 18m after the breach (The Kathmandu Post, 2014) which significantly reduced the ongoing risk to the downstream populations.

It is believed that the damage downstream from the breach flood was much less than it could have been due to the widening of the spillway and a disaster had been avoided (The Kathmandu Post, 2014). Some people suspect that the blasting undertaken by the Nepal Army weakened the dam causing it to breach after heavy rainfall as the failure point was close to the spillway where blasting had been undertaken (The Kathmandu Post, 2014). However, on the positive side, without mitigation measures being undertaken, the lake level would have been higher and therefore the flood could have had an even more catastrophic effect.

3.3.4 Chi-Chi Earthquake, Taiwan 1999

A M 7.6 earthquake struck on the 21st of September 1999 near the town of Chi-Chi in central Taiwan. This earthquake was one of the most destructive events seen in Taiwan in recent times, killing more than 2,450 people (Chen et al., 2006).

The earthquake resulted in 9,272 landslides being generated in an area covering 128km² (Chen et al., 2006). Many of landslides blocked rivers producing landslide dams. There was flooding upstream from the lakes and a strong threat to downstream populations from dam breach flooding (Chan et al., 2006).

Landslides are common in Taiwan due to the extensive mountainous terrain, frequent earthquake activity, and heavy rainfall in typhoon season (July to September). As the earthquake occurred in September after heavy rainfall this contributed to a large number of dams being triggered (Chen et al., 2006). The landslide dams were identified early in the response to the earthquake as a high risk due to the likelihood of them breaching causing further loss of life. Each landslide dam was analysed for the potential of inundation which included assessment of rainfall run-off upstream of the dam to quantify the risk to people downstream of the dam (Hung, 2000).

The Tsaoling landslide is one of the largest landslide areas in Taiwan. It has sequentially had five large landslides since 1862 moving upslope retrogressively. During the Chi-Chi earthquake the area slid again resulting in a 125 million cubic metre landslide blocking the river. The previous landslide dam which formed in 1942 had breached many years prior to the new landslide dam in 1999 (Chigira, Wang, Furuya & Kamai, 2003).

When the Tsaoling landslide occurred in the Chi-Chi earthquake it resulted in significant damage with houses being carried away and everything in its path being devastated (Chan et al., 2006). The landslide killed 39 people as well as blocking the Chingshui River with a 150m high (downstream) landslide dam (Chen et al., 2006).

To reduce the risk from flooding, an emergency spillway was constructed by excavation through the dam. This was to allow for the water to flow over in a controlled manner and to reduce the potential lake capacity. On the 22nd of December 1999 the lake level overflowed the dam. While there was no damage to the dam when the water overflowed, severe erosion of the downstream side of the dam has occurred over time. Some man-made dams were constructed on the Chingshui River downstream of the landslide dam to mitigate the effects of a dam breach flood and debris flow (Chen et al., 2006; Hung, 2000).

Previous experience in responding to similar events appears to have assisted greatly in responding quickly and efficiently to the Chi-Chi earthquake landslide dams. The use of a GIS database early in the response became an essential tool for managing key information and data throughout the whole response (Hung, 2000).

3.4 Key Themes

From the review of the case studies, eight key themes have emerged on the emergency response and management of landslide dam events. Although the response and management of each landslide dam varied depending on local conditions, there are similarities in the processes and procedures undertaken to reduce the risk to life safety and infrastructure.

The eight key themes identified were used to assist in drafting the interview questions and to build an understanding and comparison to the Kaikoura earthquake landslide dams. Much can be learnt from past events to inform preparedness for future events. Whilst these are separate identifiable themes, they are also all interlinked with each other.

3.4.1 Multi-agency response and responsibilities

In several of the case studies reviewed, there is a common theme relating to the roles and responsibilities of the agencies and organisations involved. Often in landslide dam events multiple agencies are required to work together on a response. Generally, the staff from these agencies have had limited contact with each other under normal working environments which can cause problems when suddenly required to work cohesively and in an emergency (Becker et al., 2007). These issues have also been noted following the response to other New Zealand hazard events (Paton, Johnston, & Houghton, 1998).

A good example of the problems of multiple agencies working together was the Mount Adams landslide dam. There was confusion around responsibilities and who the appropriate agency was to contact regarding certain issues. There was also confusion around who was responsible for evacuation of the community, resulting in a dam breach occurring before residents were evacuated. It was also found that after public or civil defence meetings, agencies were unclear on who was responsible for following up actions (Becker et al., 2007). This led to tasks not being carried out in a timely manner and key parts of the response being missed.

It has been suggested by Becker et al. (2007) that there is “a need for developing integrated operating procedures capable of allowing them to operate under unexpected and urgent circumstances” (p. 40). One way of assisting multiple agencies working together on a response is to develop action plans for the response which are agreed upon by all involved at an early stage. This includes setting out individual and collective responsibilities and actions for each agency. Planning in the early stages of a response confirms, inter alia, responsibilities around information sharing, community advice, and information to the media and other agencies (Palmer, 2007).

3.4.2 Management and response

Earthquakes commonly result in multiple simultaneous landslide dams, which creates problems for emergency management as resources are frequently stretched. Often a local response will be pushed beyond capacity. Assistance from outside is needed to cope with the sheer extent of an affected area. When multiple dams occur during one event, it can take weeks if not months to find and assess all the landslide dams, by which time many of them could have already failed and impacted infrastructure or people (Crozier, 2005).

Planning the response to a major landslide dam episode must consider that a rapid and significant breach could occur with little warning. Therefore, plans must cover the worst scenario and mitigation organised to reduce the risk as much and as quickly as possible (Palmer, 2007).

3.4.3 Methods of risk assessment

There are many different methods to assess landslide dam risk from upstream inundation and downstream flooding from a breach. Undertaking a hazard assessment of a newly formed landslide is essential to assist with emergency planning and management. The results from the risk assessment help to determine suitable mitigation strategies as well as organise evacuation of people at risk (Xu et al., 2009).

The risk assessment of a landslide dam may differ with each dam but in general it will depend on the geomorphology of the area and the dam characteristics. When undertaking flood hazard assessments there are many uncertainties involved. It is therefore best to plan for a worst-case scenario if it is still realistic (Hancox et al., 2005).

Korup, (2005) discusses how “Hazard and risk analysis of landslide dams thus cannot rely on a single methodology, but must consider all available site-specific field and model data in an integrative approach to encompass both initial and consequential geomorphic effects” (p. 187).

Problems arise when trying to determine the probability of dam break flood as it is a function of dam stability, which is subject to temporal variability. The situation can rapidly change due to lake volume increasing, seismic ground shaking from aftershocks or displacement waves from landslides impacting the already formed lake. It is important that site specific field work is carried out as part of the assessment of the dam to consider the condition of the dam and the susceptibility of failure (Korup, 2005).

3.4.4 Warnings and evacuation procedures

Once a landslide dam has been identified as posing a risk to an upstream or downstream population it is important that the appropriate warnings are given and if necessary evacuations are undertaken. In the case of landslide dams, flood risk is directly connected to warning times and evacuation, therefore evacuation decisions are critical.

Emergency management of landslide dams and dam breach flooding is aimed to reduce the consequences by using non-structural measures such as evacuation (Peng & Zhang, 2013). A decision to evacuate a population can be very expensive, so it is not something that should be taken lightly. Of course, when human lives are at risk it is important to get people away from the area in time. Prior planning to an event can assist, especially if there are procedures in place or guidelines around evacuation. This can reduce uncertainty and can reduce the decisions required before opting to either warn or evacuate a community (Becker et al., 2007).

A part of the response to landslide dams is collecting information about the dam to reduce uncertainty around dam stability and failure time. Collecting data can take time and possibly delay the decision to evacuate but reliable information can reduce the cost of an evacuation by getting a greater understanding of the risk beforehand. The concurrent problem with delaying the evacuation decision to gain more clarity is that you risk losing more lives if the dam breaches in the meantime (Peng & Zhang, 2013).

3.4.5 Mitigation and monitoring

Many different types of mitigation measures can be used for reducing the risk from a landslide dam to the downstream population. The most common method for stabilising a dam is through construction of a spillway (Costa & Schuster, 1988). The option to breach the dam manually by excavating a spillway may be desirable but can be impractical due to site accessibility. Another option to breach the dam is through blasting with explosives (Hancox et al., 2005). Depending on the dam structure, this can work but is not always successful in stopping dam failure and may even precipitate it. Sometimes when a spillway is created the outflowing water erodes the dam rapidly causing failure (Costa & Schuster, 1988; Hancox et al., 2005).

If physical mitigation measures are not feasible, then the hazard is treated as a flood event downstream. A longer-term solution may be accomplished by building protection measures to reduce the impact of a dam break flood. This can include raising bridges or moving communication and power lines (Massey et al., 2010).

When physical mitigation measures are not viable, monitoring can be set up, evacuation can be carried out, and planning can be put in place to reduce the risk (Hancox et al., 2005).

Warning systems can be installed to monitor the dam and the downstream area. If a breach is to occur then warnings will be transmitted to downstream populations as well as warning lights or barriers on bridges being activated (Massey et al., 2010).

A study of potential landslide dams near Franz Josef village in New Zealand, concluded that mitigation in the form of physical protection with river controls would not be feasible. The force of a flood full of debris would be too strong for the protection measures and it would be a very expensive solution. Warning systems were also deemed unfeasible as they would not allow enough time for people to evacuate the high-risk area. Therefore, the suggested solution is to relocate buildings within the area deemed to be at risk should a landslide dam occur (Davies, 2002).

3.4.6 Community involvement

When responding to landslide dams, involvement in the response from the local community is essential. This is because they have local knowledge of the area and are often in the best place to issue warnings and know who needs to be warned. Working together with the community can increase community resilience and make them more accepting of the risk (Becker et al., 2007). In the case of the Young River landslide dam, the local community developed response plans under the direction of the local Council and Civil Defence. The response plans outlined the actions which should be undertaken in a dam breach event (Palmer, 2007).

Due to landslide dams being characterised by rapid onset, it is important that residents are included in training exercises and networking with other residents. If residents can be better networked it allows them to advise others in the community about a problem (Becker et al., 2007). Involving the community in this process gives them a greater understanding of the plans and risks rather than simply being told what to do by the authorities (Palmer, 2007).

Public meetings or briefings seem to be a common approach to informing the local community about the risks from landslide dams. Often meetings are held daily or as information is

gathered. Keeping local communities informed is an essential process in the response to the dams. Another way of involving the community is having the agencies involved with the response based in the local area. This can facilitate direct contact with the local community. This facilitates immediate responses to the community and the community can provide feedback directly to those agencies on their concerns or the situation (Palmer, 2007).

3.4.7 Long-term impacts

The hazard and impact from landslide dams can be ongoing and not just because a dam has not breached in the immediate aftermath of its formation. Landslide dams can create adverse long-term effects well after they have breached. These effects include backwater inundation and aggradation which promotes channel instability, both upstream and downstream of the dam (Korup, 2004). Longer-term effects from landslide dams receive far less attention as these generally do not pose a life risk or cause a high-risk situation to populations downstream. However, the long-term impacts of a landslide dam can be highly damaging (Nash, 2003).

Long-term impacts can include: agricultural land being inundated with extra sediment, flooding patterns can change with higher levels of sediment in the river bed, increased erosion of river banks, impacts on infrastructure such as bridges and roads damaged due to excess sediment. This is especially bad during heavy rainfall events (Korup, 2004).

Since the long-term impacts can have such devastating effects, these need to be included as part of the risk assessment and response process to landslide dams. Such risks need to be accounted for as consequential hazards (Korup, 2005).

3.4.8 Future research

Learning from previous landslide dam events is essential if improvements are to be made responding to future events. Through the reviewed literature, several ideas have emerged for increasing preparedness for future events and refining response procedures. Planning for future events is required to reduce the loss of life and the impacts of the dams on the environment.

Two areas for development in responding to events are improving control and communication during a response and monitoring sites for longer to consider the long-term impacts from a landslide dam on a river valley (Hancox et al., 1999). Communication can be an issue in response to any disaster and there is always room to improve communication throughout a

response. Ideas such as a Science Liaison and building relationships can provide improvements in communication (Becker et al., 2007; Woods et al., 2017).

Another option for increasing preparedness is the identification of past landslide dam sites as well as undertaking hazard mapping. This would identify those areas at risk and promote awareness around landslide dams as an earthquake hazard (Hancox et al., 1999). Recognising areas at risk from landslide dams prior to an earthquake or rainfall event would not stop the dam occurring but may reduce the risk from a landslide dam. Mitigation measures could be undertaken prior to an event occurring in areas where the risk is thought to be very high. This includes relocating threatened infrastructure and people, for example in Franz Josef, New Zealand (Hancox et al., 2005).

Finally, as landslide dams can have a short-term life before failure or breaching it is important that future research looks at developing and refining rapid assessment methodologies for predicting the impact from a dam breach and identifying when people need to be evacuated (Korup, 2002).

3.5 Summary

This chapter discusses information relating to four international and four New Zealand historical landslide dam events. This is followed by any response activities regarding mitigation measures, evacuation of communities, and the consequences, if any, of a dam breach. Several key themes were evidenced in most of the case studies. These key themes related directly to the response activities following a landslide dam event.

The comparison between the case studies and the discussion around the key themes can be used to contextualise the emergency response to the landslide dams created during the Kaikoura earthquake. The theory detailed through this chapter will be discussed further in Chapter Five and Chapter Six in terms of the Kaikoura earthquake landslide dams and the response to them.

Chapter 4 - Response to Landslide Dams during the Kaikoura Earthquake

4.1 Introduction

The Kaikoura earthquake landslide dams present a New Zealand case study of the emergency response and management of landslide dams by multiple agencies and organisations. This chapter describes the background to the Kaikoura earthquake landslide dams event. This will give an appreciation of the response and management of the dams and will support interpretation and the interview analysis in Chapter Five.

This chapter summarises the landslide dam response as reported in the media, through the news article review, together with the literature review of articles written shortly after the Kaikoura earthquake. This information is presented as a timeline of events from the day of the earthquake (14 November 2016) through to May 2017. Finally, this chapter discusses the involvement of organisations and agencies in the response and their roles and responsibilities in respect of the landslide dams.

4.2 Seismic Hazard in the Region

To understand the causes of the landslide dams it is important to examine the seismic history of Kaikoura and surrounding region before the earthquake on the 14th November 2016. This allows for an understanding of the historical events in the region and how the known seismic hazards affected the response and management of the landslide dams.

The Kaikoura region sits across a highly active seismic area with many active faults both onshore and offshore. This results in a high occurrence of large but shallow earthquakes. According to Rattenbury et al. (2006),

“Since written records of earthquakes have been kept in New Zealand (from about 1840), eight shallow magnitude 6.0 or greater earthquakes have originated within the Kaikoura map area. Two of these earthquakes, the 1848 Marlborough and 1888 North Canterbury earthquakes, had magnitudes over 7.0.” (p.56).

Earthquake events of significance can be seen on Figure 4.1 below, with five recorded earthquakes over magnitude 7 affecting the region. This historic seismic activity is significant in understanding the 2016 Kaikoura earthquake.

Figure 4.1 - Major historical earthquakes within the Kaikoura region (Rattenbury et al., 2006).

The 1848 Marlborough earthquake and 1888 North Canterbury earthquake both caused land cracking with associated liquefaction (Rattenbury et al., 2006; Yetton & McCahon, 2009). In 1901 the Cheviot earthquake caused damage near the Cheviot epicentre and cracks opened along the Hundalee Road (Yetton & McCahon, 2009).

The magnitude 7.7 Buller earthquake in 1929 occurred in a lightly populated area but was responsible for the deaths of 15 people, mainly from landslides. The Kaikoura region suffered structural and land damage including severe landslides. Landslide dams were a key feature of the Buller earthquake causing significant infrastructure damage and flooding. There was also a magnitude 7 earthquake in Arthurs Pass in 1929 which caused little damage (Rattenbury et al., 2006). Most recently, in 1968 the magnitude 7.1 Inangahua earthquake caused significant damage, with three deaths and others injured. Again, there was land damage including landslides, with one large landslide dam blocking the Buller River which caused major concern. The entire population of Inangahua was evacuated for a month due to the risk of a dam break flood (GNS Science, 2010b).

Since 1929 there have been no earthquakes over a magnitude seven in the region and the earthquake shaking over the last 150 years has been moderate but not great (Yetton &

McCahon, 2009). In 2009 when Environment Canterbury undertook an earthquake hazard assessment of the Kaikoura District they determined that “historically Kaikoura District has not experienced the level of earthquake shaking that is expected given the geological and seismic setting of the district” (Yetton & McCahon, 2009, p. 20).

The Kaikoura earthquake in 2016 was not unexpected in geological and historical terms but the scale of the event and the severity of damage to infrastructure and land across such a large geographical area had not been experienced in recent times in New Zealand. The vast number of landslide dams with over 200 of them generated through the earthquake was unique. The landslide dams quickly became one of the highest risk hazards and the response to them required significant numbers of people and resources.

4.3 Emergency Response to the Landslide Dams

Following the devastating Kaikoura earthquake and the extensive levels of land damage including the landslide dams, there was an urgent need for a rapid and systematic response. Much of the response was focused towards the landslide dams and involved a range of agencies, organisations and councils. This came with many challenges to those involved throughout New Zealand.

One of the main challenges for the response was the complexity of the earthquake, with a large geographical area being impacted, over 21 faults rupturing causing landslides, tsunami, subsidence, and uplift together with other hazards. The restricted access and isolation of areas cut off by the damage added another challenge, as well as co-ordinating the response across not only regional and district boundaries, but also across multiple agencies and organisations (Woods et al., 2017). Figure 4.2 below shows the regional and district boundaries of the different councils involved in the response and demonstrates the scale of the area affected by the landslide dams. Land damage encompassed an area right through the Hurunui District, the Kaikoura District and up into Marlborough District.

A local state of emergency was declared by both Kaikoura and Hurunui Districts on the 14th November 2016. This was followed by Canterbury declaring a regional state of emergency the following day. The purpose of the regional declaration was to bring further assistance and support to those local districts with limited resources. The regional state of emergency remained in place until the 6th December 2016, and the Kaikoura District local state of

emergency ended shortly after on the 9th December 2016 after being extended due to ongoing difficulties.



Figure 4.2 - Map showing Regional and District Boundaries (Local Government New Zealand, 2017).

Response to the Kaikoura earthquake landslide dams was a high priority due to the risks to both people and infrastructure. The response required agencies to work individually on certain areas, but also to co-ordinate between each other. They needed to share information collected and understand the needs of each discipline. Due to the scale of the event, co-ordination between all those responding was a particular challenge (Woods et al., 2017). With prior experience from other events, systems and processes were developed swiftly to assist in a co-ordinated response. Just one day after the earthquake, meetings were being held and staff tasked to transfer information collected in the field to local emergency responders in the form of a Science Liaison team. With recent experience from the Canterbury earthquakes in 2010 and 2011, teams of knowledgeable people were able to form rapidly with a prior understanding of the need for a co-ordinated working environment (Woods et al., 2017).

The response to the landslide dams began with a GeoNet response determining the area that required systematic searching for the dams. After the area had been defined, searching began in the areas most affected by the earthquake shaking. Another priority were areas with property and lives at risk from dam break floods, particularly the higher populated areas closest to rivers.

message to stay away from rivers. This image was made public on the 17 November 2016, three days after the earthquake.

Figure 4.4 - Hapuku landslide dam, 17 November 2016 (BBC News, 2016).

These same communication techniques were used for the response and management of the Goose Bay Ote Makura River landslide dam which led to the evacuation of the downstream community. Figure 4.5 shows an annotated photo of the landslide dam of concern.

Figure 4.5 - Ote Makura River landslide dam above Goose Bay, 25 November 2016 (Telfer, 2016).

The Goose Bay landslide dam on the Ote Makura River was the dam that required the highest level of management and resulted in an evacuation of the whole community downstream of the dam nine days after the Kaikoura earthquake. This required involvement of Civil Defence, the Kaikoura District Council as well as scientific advisors from GNS Science and ECAN. All were involved in the risk assessment and modelling as well as multiple community meetings and the development of long-term management plans. These plans allowed the community to return to their homes and follow self-evacuation procedures in case of a dam break flood event. This was an excellent example of how different agencies and organisations worked together in the response.

Further detail on the daily events of the response and management of the landslide dams is presented in the next section using a timeline of events. This shows how the response developed throughout an ever-changing situation.

4.3.1 Timeline of Events

Table 4.1 shows key details of the events and responses to the Kaikoura landslide dams following the earthquake on the 14th November 2016. These details and timings were outlined by Woods et al. (2017), Dellow et al. (2017) and sourced from the newspaper article review. The main sources of news articles were online media sources, Civil Defence Emergency Management (CDEM) Updates, Environment Canterbury Regional Council (ECAN) Updates, Newshub and TVNZ News. This timeline details the response to the landslide dams, and provides an understanding of what participants in this research were dealing with in their different roles.

Table 4.1 - Timeline of events to the response of the Kaikoura landslide dams.

Date	Time	Key Details
14 Nov 2016	12.02am	M7.8 earthquake occurs. Known as the Kaikoura earthquake it tore through 150km of land from North Canterbury to Marlborough.
	12.08am	GeoNet confirmed a preliminary earthquake and magnitude at M7.5 at 15km deep with the epicentre located 15km north-east of Culverden.
	6.00am	GeoNet deployed a team of landslide specialists to undertake a field reconnaissance of the damaged areas.
	15.00pm	Kaikoura and Hurunui districts declared local states of emergency

Date	Time	Key Details
14 Nov 2016		GeoNet landslide teams had observed and reported widespread slope failures including landslide dams in the Clarence and Conway Rivers.
		Police contacting residents downstream of the Clarence River dam to advise them of the risk of dam breach.
	16.40pm	Clarence River landslide dam breached sending a wall of water downstream. CDEM provided warning for residents to evacuate to higher ground.
15 Nov 2016		GeoNet landslide reconnaissance ongoing. Indications from reconnaissance flights was that there were around 100,000 landslides.
		Canterbury declared a regional state of emergency to support the wider area of damage and assist the local areas of Hurunui and Kaikoura.
16 Nov 2016	12.00pm	An online clearinghouse was established and accessible to all interested parties to store and share their data and findings.
		GeoNet officially upgraded the earthquake to a M7.8
		Seven more landslide dams were found on the south-east of the Seaward Kaikoura mountain range.
17 Nov 2016		Field observations confirmed as many as 50 landslide dams. Particularly concerning was the Hapuku River.
		GNS Science established a risk assessment process for determining risk to people from dam failure.
	3.00pm	ECAN released a river flood warning advising people to stay out of rivers due to the landslide dams. The warning also listed six of the major dams the Hapuku River, Kowhai River, Kahutara River, Clarence River, Conway River and the Leader River.
		CDEM also put out a warning around the Hapuku River, warning people to stay away. This included an illustrated photo of the dam shown in Figure 4.4 and identified concerns over the Waima River in Marlborough.
17 Nov 2016		Police worked to identify residents and campers in the Hapuku River area, evacuating anyone in harm’s way if the dam breached.
18 Nov 2016		The DOC Puhi Puhi campground in river valley was evacuated due to downstream risks from dams.
		Residents near the Waima River were told to evacuate by mid-morning due to the risk of the dam breaching.
		Risk of Hapuku Dam breaching lowered released in statement by Civil Defence.

Date	Time	Key Details
22 Nov 2016		Towy River dam at imminent danger of overtopping and breaching.
		CDEM warning people to stay away from Conway River as the Towy River is dammed and flows into it.
23 Nov 2016		Goose Bay residents evacuated due to risk from upstream landslide dam on the Ote Makura River. Dam at risk of breaching.
		Urgent public meeting held advising residents to evacuate immediately and that they could be away for 10 days whilst monitoring continues on the landslide dam.
	2.30pm	35 homes in Goose Bay evacuated.
24 Nov 2016		Ote Makura River dam being closely monitored by Geotechnical Engineers as well as risk modelling ongoing.
		Goose Bay residents not allowed back to homes with rain forecast for the coming days increasing the risk of dam breach.
		Goose Bay residents annoyed to have been evacuated, especially those that live 100m uphill from the creek.
25 Nov 2016		One Goose Bay resident made an official apology after he questioned the decision of CDEM to evacuate the area. He was shown the landslide dam by helicopter and was then in full agreement that evacuation was the right decision.
2 Dec 2016		Linton Creek dam was identified as a low risk to nearby school with 13 pupils. The school was informed and an evacuation plan was put in place.
		In Goose Bay, 17 households remained evacuated but 12 households had been allowed to return home.
6 Dec 2016		Canterbury regional state of emergency ended.
8 Dec 2016		Still nine landslide dams posing a significant risk to people and infrastructure.
8 Dec 2016		ECAN regularly monitoring those dams still posing a significant risk. This is at a cost of around \$10,000 a week due to accessibility only via helicopter.
9 Dec 2016		Kaikoura local state of emergency ends after being extended once for a week due to some concerns around houses which had not been inspected due to accessibility issues.
		Ote Makura River dam water now flowing through steadily at the base of the dam.
		Another eight Goose Bay properties deemed safe for residents to return to their homes based on the research undertaken by

Date	Time	Key Details
9 Dec 2016		geotechnical engineers. There were now 20 out of 28 properties reoccupied in the area.
14 Feb 2017		Leader River dam overtopped and partially breached, the lake level dropped by 4m.
6 April 2017	2.00am	Hapuku Dam overtopped, it partially breached with erosion and seepage points on the dam face.
8 April 2017		Many of the remaining landslide dams breached during flooding flows from heavy rainfall from Cyclone Cook and Cyclone Debbie.
		Water level on the Hapuku dam dropped by 2m after it overtopped, a natural spillway had been created as water cut down the dam.
		Risk posed by the dams now significantly lower as most breached following the Cyclones.
		Reassessment of the risk from the dams to be undertaken by ECAN in the following weeks.
12 May 2017		Only one large dam remains in place and that is the Hapuku, even though it has overtopped already the dam itself remains.

4.3.2 Involvement of Organisations in Response

Many agencies and organisations were involved in the overall response to the Kaikoura earthquake and the response to the landslide dams was no different. The National Civil Defence Emergency Management Plan recognises over 60 agencies or organisations who have responsibilities for civil defence emergency management in an event (LGNZ, 2014). While not all 60 were involved in the response to the landslide dams, for this research ten different agencies, organisations and consultancies were identified as having had significant roles. Interview participants were selected from the following organisations and agencies:

- Institute of Geological and Nuclear Sciences Limited (GNS Science)
- Civil Defence Emergency Management Canterbury
- Environment Canterbury Regional Council (ECAN)
- Christchurch City Council
- New Zealand Transport Agency (NZTA)
- KiwiRail
- Hurunui District Council
- Kaikoura District Council
- Marlborough District Council
- Aurecon Engineering Consultants

Each of these organisations and their involvement in the response to the Kaikoura landslide dams are considered in the following sections.

4.3.2.1 Civil Defence Emergency Management Group

In an emergency the Civil Defence Emergency Management (CDEM) group's role is to respond and manage emergencies in their region. Their main function is to identify and assess risk, communicate those risks, and identify as well as implement risk reduction in a cost-effective manner (LGNZ, 2014). The Canterbury regional CDEM group became involved in the Kaikoura earthquake response early on with the establishment of the Emergency Coordination Centre (ECC) to support local Emergency Operation Centres (EOC's).

The main role in the landslide dam response for the Canterbury ECC was to coordinate agencies who were assessing the event at a regional scale, and support the local response if required. One key part of the CDEM group was Science Liaison. This role was crucial in the coordination of the response by facilitating communication between scientists and geotechnical engineers in the field and the CDEM group. This ensured that information collected in the field could be utilised quickly to inform decisions being made by the CDEM regional and local groups.

4.3.2.2 District Councils

Hurunui, Kaikoura and Marlborough District Councils were all involved in the response to the landslide dams. Some more so than others but all three had to consider the risk from the dams as all districts contained dams which posed a potential hazard to the residents in their district.

All three of the District Councils were included in the response to the landslide dams through their inclusion in the local CDEM and by providing staff for the EOC's. Although District Councils were not directly involved in assessing the landslide dams, the information gathered was fed back through the CDEM structure. In the case of Goose Bay, the Kaikoura District Council did become heavily involved as it became an ongoing issue beyond the state of emergency.

The involvement of all three District Councils continued well beyond the response phase to the landslide dams into the recovery phase. Working with other agencies and experts, District Councils will be developing plans and mitigation measures to lessen the risk to residents and infrastructure from the remaining dams.

4.3.2.3 GNS Science (CRIs)

GeoNet, which is run by GNS Science, and funded by the Earthquake Commission (EQC) is required to respond to significant landslide events within an established set of criteria. When a state of emergency is declared, GNS Science can provide specialist resources (staff and equipment) who can provide advice to other agencies. Those agencies have the authority to implement risk reduction resources such as evacuation (Dellow et al., 2017) or mitigation using physical barriers.

During the response to the landslide dams, GNS Science was responsible for providing information to the other response agencies making decisions around risk to life or property. GNS Science also liaised with, and reported to, the affected councils and stakeholders, and answered their questions concerning the collected scientific information. Additionally, GNS Science ensured that the data being captured during the response phase would be helpful in making decisions going forward.

4.3.2.4 Environment Canterbury

Environment Canterbury Regional Council (ECAN) is the government agency in charge of managing floods and mitigating flood risk in Canterbury rivers as well as having many other responsibilities (LGNZ, 2014). Therefore, ECAN became responsible for warning residents and the public about the landslide dams and the risk of dam break floods. The first example of this was the Clarence River dam where the risk was identified by GNS Science staff who reported that information to ECAN allowing them to issue warnings to residents (Dellow et al., 2017).

ECAN's response to the landslide dams, was to treat them in the same way as they would a large rainfall event posing a flood risk. ECAN took the lead in communicating the information gathered by GNS Science and others to the public. This was done through alerts on the ECAN website prior to an online GIS system being developed. The online GIS system was accessible to the public at large, and is still available at the time of writing (see link below)

(<http://ecan.maps.arcgis.com/apps/Cascade/index.html?appid=50f00d42e29c46b1a61b848440c5295a>).

Updates were constantly added to the GIS system, listing the current status of the high-risk dams and showing their exact location. ECAN also assisted GNS Science in searching for the dams and assessing their risk levels.

4.3.2.5 Transport (NZTA & KiwiRail)

The New Zealand Transport Agency (NZTA) and KiwiRail were both involved in the response to the landslide dams given the potential for dam break floods to impact their infrastructure. There was a risk to both the public and their staff who were assessing and repairing roading, bridges and railway lines. NZTA has a responsibility to assess and inform decision making around risk to road users, and should take appropriate steps to reduce the risk if necessary. NZTA, unlike other agencies, also has the resources to implement mitigation or warning systems or to remove a hazard (Dellow et al., 2017) to reduce risk.

In the case of the Kaikoura earthquake landslide dams, NZTA and KiwiRail worked together and shared information. The areas at risk from the dam break floods would impact both of their assets that are in close proximity. NZTA contracted geotechnical consultants to undertake the assessment of risk to their own and KiwiRail's assets, as NZTA's in-house resources were stretched and lacked prior experience in this field. They used that information to decide on mitigation and risk reduction measures, including live monitoring on certain dams and warning systems on the downstream bridges. In early January 2017 when the Northern Canterbury Transport Infrastructure Recovery (NCTIR) alliance was established NZTA handed over their responsibilities around the landslide dams to NCTIR.

4.3.2.6 Geotechnical Consultants

Geotechnical consultants from the local area and from centres outside the damaged area were involved in the response to the landslide dams. Many of the consultants involved were from Christchurch, bringing with them experience from the Canterbury earthquakes of 2010 and 2011. The consultants were bought into the response through different paths, some through the CDEM systems, and others through transport agencies such as NZTA.

The main role for the geotechnical consultants was assessing life safety risk, building safety risk and risk to lifelines from the failure of the landslide dams resulting in a dam break flood. This research includes a participation from Aurecon engineering consultants who were contracted by NZTA to assess the risk to the lifelines and infrastructure.

4.4 Summary

This chapter has provided an overview of the Kaikoura earthquake landslide dam events and the response to those events, and in doing so has provided a context and summary for this research. The timeline of events presented in this chapter gives a summary overview of the response to the landslide dams.

Finally, the organisations and agencies involved in the response were considered including their key responsibilities and roles. The events detailed within this chapter will be discussed further in Chapter Five through the results of the interviews and the interpretation of those results.

Chapter 5 - Results from the Landslide Dam Response Interviews

5.1 Introduction

This chapter examines the response and emergency management of the Kaikoura earthquake landslide dams. It presents the results and observations from the data gathered through key informant interviews. The aims and objectives of this research are to:

- Study the emergency response and management of the landslide dams produced by the 2016 Kaikoura earthquakes including the procedures and processes undertaken and the co-ordination between agencies.
- Examine the effects of a multi-hazard event on the emergency response and how long-term management is considered as a part of the response.

While a great deal of data was collected during the interview process, nine key themes have been identified. These themes were identified as being of greatest interest to the research and cited by the majority of interviewees. The key themes selected are:

1. Roles and responsibilities
2. Communication
3. Co-ordination
4. Resources
5. Previous experience
6. Community involvement
7. Information and data
8. Relationships
9. Post-event/Long-term management

The themes were identified as being a significant part of the response to the landslide dams and relevant to improved preparedness for future events and the response to them. Many of the key themes intertwine and intersect with each other and similarities may be seen in some of the discussions around different themes. The discussion of the key themes often refers to the Kaikoura event details outlined in Chapter Four rather than repeating the specifics in this chapter.

5.2 Roles and Responsibilities

It is imperative that roles and responsibilities of people and agencies responding to any type of natural disaster are understood early in the response. The emergency response unfolds smoothly and systematically when the agencies and organisations involved have agreed roles and responsibilities from the outset of the event (Coppola, 2015). If these roles and responsibilities are clear then other aspects of the response run efficiently, e.g. sharing of information, co-ordination and communication (Paton et al., 1998).

Responsibility misunderstanding can cost time and money as well as risk an area of the response being overlooked if no one realises it is their responsibility. In the response to the Kaikoura landslide dams one of the most common themes identified in the interviews was confusion around responsibilities of the different agencies. It was felt by the majority of interviewees that greater understanding of those responsibilities could have significantly improved the response, especially in the early stages.

Interviewee F:

“It was a little bit tricky to try and work out where our role started and finished and I think other organisations were similar. Or they did have quite a strong idea what their role was which helped us to kind of figure out what our role should be.”

Whilst many interviewees felt confused around responsibilities, some individuals were very clear on their role and what activities they were required to undertake in the response. The latter benefitted from previous experience in responding to similar events and understanding the need to prioritise rapid assessments, as the dams could breach at any time.

Interviewee J:

“I wasn’t aware of the confusion because I was very clear on what I was doing and I probably stood on a few toes, but I knew what I wanted to do and I knew what I wanted to achieve”.

For this interviewee, who was a GNS Science employee, clarity came from understanding the statutory responsibilities during a response. GNS Science through GeoNet have a statutory responsibility to respond to these events with expertise in landslides. They have skilled resources and knowledge of their responsibility. Other agencies also had statutory responsibilities to respond but were not aware of these at the outset of the response. This resulted in a delayed response from those agencies and other agencies having to inform them of their role.

Interviewee A:

"I think one of the key things that we helped Environment Canterbury understand was their responsibilities. They actually had statutory responsibilities under legislation for the management of the landslide dams."

It was clear from the interviews that understanding individual responsibility and that of the agency individuals were representing was not sufficient. A knowledge of other agencies' roles and responsibilities would have reduced repetition of work and made for clearer paths when sharing responsibilities. Communication at the beginning of the response would have helped to define roles, but in the case of Kaikoura this was all but impossible due to the physical isolation during the initial response.

Interviewee F:

"As an organisation understanding what our roles and responsibilities would be in that type of situation, and what other organisations would be responsible for and how we kind of all fitted together."

Interviewee I:

"It would be nice to have it better defined of where we do actually fit in the structure so that as soon as we are activated we know what we are doing."

As a response of this scale to landslide dams had not occurred in New Zealand for quite some time, there were no official systems defining responsibilities of different agencies to this type of hazard. Many interview participants felt that the response was ad hoc and without formal instructions or procedures and it was hard to know what was expected from each agency.

Interviewee F:

"Was possibly a little bit ad hoc but again with the scale of the event and the number of people involved, I don't think it would be perfect. I guess there is a bit of room to clarify those roles a bit better."

As there were no formal systems or procedures many of the agencies adapted systems they already had in place to suit the landslide dams event. For example, ECAN are familiar with responding to flood events so they adapted their normal flooding procedures and established systems for communicating landslide dams risk instead.

GNS Science through the GeoNet response have a duty to provide information on the risk posed by the landslide dams to response agencies like Civil Defence Emergency Management (CDEM). CDEM then make decisions on evacuations and warnings based on that information. While GNS Science are clear on their role, confusion was caused by local Geotechnical Engineers responding in the Kaikoura region deciding that Goose Bay needed to be evacuated but without full information or reasoning behind it.

Interviewee M:

“In discussion with the science sector although the science sector don’t want to make the decisions was my observation, which is fine. They say well this is it, they provide good information and then we would say OK and make those decisions.”

Due to the scale of the event, and limited resources with experience, some responsibilities became shared. For example, GNS Science assisted ECAN who did not have the technical experience to observe the landslide dams and assess life safety risk to downstream communities.

Interviewee B:

“Trying to help out ECAN because it was essentially their responsibility but they had essentially asked for assistance and passed that over to us. So, we were keeping ECAN informed we had them on board with us.”

The Clarence River landslide dam caused damage to some infrastructure downstream when it breached. Although it is within the Kaikoura District, access was cut off to that area, and local resources were dealing with other earthquake related damage. Marlborough District Council took on responsibility for that dam until Kaikoura could cope with it again. The declared state of emergency allowed Marlborough to take on the duty with no formal arrangement around finances or agreements.

The response to the landslide dams changed over time and with that so did the responsibilities of each agency involved. As the response phase moved into a recovery phase the responsibilities had to transition and responsible agencies needed to focus on long-term management. This included collection of data and information throughout the response as well as mitigation and future planning. There can be uncertainty about when to hand responsibilities over, this was managed by setting a date. In the case of Kaikoura this transition period went through to the 8th March (Woods et al., 2017).

Interviewee I:

“At what point does the GeoNet response and monitoring stop and hand over to ECAN who have the ongoing responsibility for those dams. There was a date that was agreed that GNS would be handing over to ECAN.”

Making sure that agencies who will be responsible in the future have a person present and involved in decisions during the response is a key part of the transition. Involvement with the community from response to recovery provides continuity through the process.

Additional quotes from interviews which relate to the theme of roles and responsibilities are summarised in Table 5.1 below.

5.2.1 Key Research Findings

The results of this research around roles and responsibilities in the response to the Kaikoura landslide dam event identifies several key outcomes:

- The main concern raised in the interviews was confusion around responsibilities for most agencies during the initial response to the landslide dams.
- There is a need to understand responsibilities of different agencies better to improve the response, reduce misunderstandings and avoid doubling up on work.
- As there were no formal systems in place for duties in responding to landslide dams, systems were adapted throughout the response to suit the event.
- The response to the landslide dams covered a large area so the responsibilities had to be shared across several agencies before the responsibilities transitioned on to others as the response moved into a recovery phase.

5.2.2 Additional Interview Quotes

Table 5.1 - Quotes from interviews about the roles and responsibilities in the response to the landslide dams in Kaikoura

Sub-theme	Interview	Quote
Confusion	F	<i>"It took us a little while to get our heads around what our role actually was, I guess it wasn't something that we had thought too much about before."</i>
	N	<i>"In my perspective with the landslide dams specifically, no one really seemed to know who was responsible for them or in control of them in the early stages."</i>
	M	<i>"It was a wee bit confusing for people in the Emergency Operation Centre, who am I actually going to."</i>
Statutory	A	<i>"GNS Science through the GeoNet programme have a statutory responsibility to deploy landslide specialists to events."</i>
Define roles	B	<i>"There was no formal instruction as to how that should be done or what we were supposed to do or what was expected, there were no procedures there."</i>
	I	<i>"For us it was important to know where we sit in that structure and who needs the advice and how to go about things. So that we can have the best input possible."</i>
Adapting systems	E	<i>"Sort of worked out a system for how can we. We have got all this information and we needed to work out the ones we were most concerned about and come up with a process for keeping that up to date and make sure you have got the required information from GNS at the time."</i>
Provide information not decisions	C	<i>"We provide information to the response agencies so we don't make decisions based on what houses are at risk or that type of thing. Our purpose is to provide information to the people that make the decisions."</i>
Sharing responsibilities	J	<i>"We were working with ECAN quite early in the piece and we certainly had ECAN on the flights with us during the search week so there is always an attempt to involve other people."</i>
Transition of responsibilities	A	<i>"This is what we are doing but it's going to transition to you guys so you need to be thinking about the long-term management of these things."</i>
	M	<i>"My recommendation would be where we can if you have got others coming in on behalf of the organisation that organisation does have someone as their contact going forward and their face is at the front as well."</i>

5.3 Communication

Communication in any emergency response is a critical factor in the facilitation of a successful response. If communication is carried out well it can significantly improve a response (Paton et al., 1998). During the response to the Kaikoura earthquake landslide dams there were aspects of communication which enhanced or obstructed the response.

A major problem with communication during the response was that Kaikoura was cut off geographically but also there was very limited communication due to power outages and poor radio signal. A couple of interviewees mentioned that the community felt isolated due to being cut off and there was very little awareness of what was, and was not, being done to identify the hazards or assess the risks. The lack of communications into Kaikoura meant that gaps in the response opened-up. Agencies in other locations did not realise just how little was known in Kaikoura about the landslide dams.

This isolation caused the local Geotechnical Engineers in Kaikoura to think they were required to take control of assessing the landslide dams. They were not aware that GNS Science were already undertaking the assessment of them.

Interviewee J:

“Difficulty in communication, so Kaikoura is reasonably isolated and the local Geotech’s thought they had to take on the landslide dam work. The Geotech’s were doing work on the dams but they never contacted GNS to find out what we knew. I know X [name removed] got very upset and sent through a very grumpy email to the Geotech’s and a few noses got put out of joint. But the confusion came from a lack of ability to communicate into Kaikoura.”

Another challenge in communication during the response was consistency in response staff. Keeping the lines of communication open and consistent are very important throughout any response. In some instances, staff were swapping over every day or two, especially in the Emergency Operation Centres (EOC). This meant talking with different people every day and messages getting lost or people not understanding the importance of the information being passed on.

Interviewee H:

“The communication wasn’t really received, you might be talking to one person one day and another on another day and it might not be being passed around.”

The agencies with previous experience in these types of events knew the importance of consistent communication and therefore had procedures in place with one main point of contact co-ordinating the communication streams.

Interviewee J:

“We had to keep the lines of communication open, if I suddenly went into the field that line of communication shuts down. Having one main point of contact for everyone.”

One form of communication that was found to be effective by most agencies and allowed for communication between agencies was daily meetings. These meetings allowed everyone to come together and share what they were working on, what was being planned, and any major concerns. This allowed for consistent messaging across the board.

Interviewee Q:

“We had a briefing every morning and we always had somebody from the science cell giving us an update. Meaning that all the staff in our ECC were aware of what was going on particularly operations and welfare. We would have a daily telephone conference in Kaikoura and Hurunui and we were all able to talk about if there was anything relevant for the landslide dams.”

The meetings would normally be followed up with daily reporting which would confirm what was discussed as well as include further details on some of the science information being collected in the field. It was found that face to face communication was most effective through the response.

The communication of science information to other responding agencies was critical as agencies were making their decisions based on information from the science investigations. The information being captured in the field was needed to inform the response immediately but also had to be understood easily by non-science people. An important part of passing on science information was to answer questions about the data and find out what was still required.

Interviewee C:

“To report and liaise with the various councils and other stakeholders of what the data might mean for them and to answer their questions as much as I could.”

Interviewee J:

"I have tried to be a conduit, I am passing on information from our field teams and also receiving information in from other organisations and passing that on to those involved. I was reading the news every day and if I could answer some questions or had information that would be useful to another project I was contacting those people and passing it on."

Part of the reason for communicating science information is to increase understanding of the risks and the potential hazard. From previous experience of dealing with landslide events it has been found that it is better to increase people's knowledge as this increases their understanding of the impacts. Giving people the scientific information and not dumbing the information down means that the information is not sensationalised but is equally not underplayed. As decisions around evacuations and warnings are based on the scientific data it is important that data is communicated clearly.

A significant part of any response is communicating information and messages to the public and affected communities. In the response to the landslide dams, agencies were trying to get information out to the public but this was not necessarily carried out in an appropriate way. ECAN treated their communication with the public very much in the same way as a flood event. This comprised placing information on the ECAN website and creating a GIS system for the public to view where the dams were and information on them. Several interviewees commented that public information channels should have been more proactive to access those communities who would or could not look at a website.

Interviewee H:

"I think that the way that the public messaging was managed could have been done better as well. I think our guys tended to just put things up on the ECAN webpage which is what they do when there are floods. But this is different and different people are affected here. I think we should have been much more proactive pushing information out particularly to farmers and people like that to stay out of the river bed messaging could have put stuff on the radio about it."

Communication to the public was used as a mitigation measure for exposure to risk, warning people to stay away from dangerous areas and reducing the number of people in harm's way if a dam was to breach.

Interviewee A:

“The risk was largely mitigated by communications, and that is stay out of river channels at the moment. Then that communication was increased and pushed further when there was potential severe weather.”

Agencies less directly involved in dam assessment found their role was to be a conduit of information to inform the public of the situation and risks. This included a recovery update by the District Councils which went out once a fortnight by post and email and had simple messaging to stay out of rivers and catchments.

Interviewee N:

“We just thought the advice notes going out regularly would be sufficient to manage the risk.”

Many participants thought that this level of communication to the public was not enough and that it should have been more proactive to reduce the number of people at risk and increase the public’s understanding of the dams. For example, extra community meetings could have assisted in communicating messages about the landslide dams earlier on.

One procedural problem was identified by several interviewees, and that was not having contact details of those people involved in the response. It became a problem for those who had not been involved in response situations before and did not know who to contact. For example, District Council staff were aware that assessments were underway early in the response but did not have contact information to follow up and obtain data relevant to their needs. While some delays were caused trying to locate contact details it did not heavily impact the response itself.

Interviewee D:

“Once we had the contact information there was no hesitation of calling anyone or asking questions. It was hard trying to track someone’s number down or get hold of someone but once that’s organised it was all good.”

Additional quotes from interviews which relate to the theme of communication are summarised in Table 5.2 below.

5.3.1 Key Research Findings

The results of this research into communication in the response to the Kaikoura landslide dam event identifies several key learnings:

- Communication was cut off to Kaikoura early on creating a lack of understanding about the work which was being carried out around the landslide dams.
- Consistency in communication was important. Staff would change over, sometimes daily, and information that had previously been passed through to someone else would get lost.
- Communicating the science information to all those interested and involved in the response allows for greater understanding and co-operation.
- Communication with public and recreational users was a form of mitigation with warning messages being used to stop people entering at-risk locations.

5.3.2 Additional Interview Quotes

Table 5.2 – Quotes from interviews about communication in the response to the landslide dams in Kaikoura.

Sub-theme	Interview	Quote
Kaikoura cut-off	H	<i>"There were gaps that opened up and it was partly because Kaikoura was cut off, that was huge and I don't think that the people down here realised just how little they knew up there of what was going on even in their own patch."</i>
	M	<i>"I would say as an area of improvement is I don't think Kaikoura always got the reports because we would hear afterwards that there had been a number of reports done and we didn't actually see those."</i>
Daily Meetings	I	<i>"Everyone is aware of what is happening and have the same consistent messages."</i> <i>"We were sitting in on teleconferences between all the local controllers to provide advice like when Goose Bay occurred we were providing advice to the Civil Defence controllers".</i>
Communication of science information	A	<i>"We identified that we really want to ensure the science being captured right away was being used to inform the emergency response straight away as well. To take that information and explain it to people in a manner that they can understand."</i>
	C	<i>"From experience in other landslide events it is better to produce technical information and allow people to ask you questions. So that they understand it and that went down as well as it can be expected, so we didn't dumb anything down."</i> <i>"I think knowledge is really important that it is passed on but in a measured way so you are not sensationalising things and also not underplaying it either."</i>
Public messaging	N	<i>"We were just there as the conduit of information and to inform our rate payers of the situation and risks."</i> <i>"We had a recovery update which used to go out once a fortnight regularly and it was just a message in there saying stay away from river catchments."</i>
	G	<i>"Through everything we were trying to be the communication channel to the public, we felt that no one else was doing that to a great extent, through the online system we set up."</i>
Mitigation through communication	H	<i>"More proactive messaging, community meetings earlier, education. People aren't stupid, they get it, they just don't understand the language and nobody thinks there are subtleties to it until you are in the situation."</i>
Contact Details	N	<i>"It really would have helped to have contacts, I have spent so much time over the last 6 months just trying to ring organisations and get key contacts in different areas. That's been tough."</i>

5.4 Co-ordination

Co-ordination in a multi-agency response is vital, due to the number of agencies and organisations involved in responding. It is imperative that co-ordination is seen as an essential element during the response and the extent of the co-ordination can have significant impacts on the quality of the response. The difficulty in co-ordination increases with the scale of the event as the greater the geographical area, the more people are involved, and often the greater the damage (Curnin, Owen, Paton & Brooks, 2015).

Co-ordination of a disaster can improve efficiency and quality of the response by allowing communication, management of resources, and information sharing between different agencies (Coppola, 2015). The response to the Kaikoura landslide dams required high levels of co-ordination as the damage was widespread and the response involved many agencies working together.

Due to the number of landslide dams, the response was dynamic and constantly changing by the day or hour. This made co-ordinating the response challenging as plans constantly changed and the responders needed to remain flexible throughout.

Interviewee C:

“Flexible, yeah you have to be very flexible and a lot of people don’t like that flexibility. It has to be dynamic in every way. On one day you can’t get into the most critical ones because there is low cloud where the other one you could so there are lots of different variations.”

The situation had to be constantly reassessed before making plans or decisions on what to do next. Decisions on the next steps were based around what was seen in the field the day before.

Interviewee F:

“Yes you can plan to an extent but you have to remain a bit flexible. It’s a bit of a trap to think you can plan too much because there is always peculiarities in events.”

“We had received some information but then we know they are up there now gathering more data and it is out of date before you can actually do something with it.”

The hazard being dealt with was constantly changing and therefore the response to it needed to keep up. Changes in the weather meaning that dams could not be accessed or another

landslide dam being reported could completely change plans for the day. A new dam would change the focus to assessing the risk to a downstream population, or a dam could breach and all resources were required there.

A triage system was used for identifying the dams and assessing the risk from them. The initial assessment would rank the dams in order by relative hazard. Then the high-risk dams would be assessed first, or the ones which had the potential to cause the greatest damage or consequence to a nearby community. There were so many dams and with limited resources they could not all be investigated simultaneously.

Interviewee C:

“We had a triage system and most of them the 190 didn’t affect anybody if they were to fail, so we really homed in on those dams that if they were to fail there is a potential risk.”

“You have only got so many resources so you have got to triage them in some way and so you have to work out which are the important ones to deal with and then tackle them and that importance might actually be logistical and have nothing to do with the risk.”

The identification process took about a week but there was great uncertainty around the dams as there was no guarantee that all of them had been found or located correctly. It was hard to co-ordinate the response in constantly changing environments.

Two challenges that appeared through the response and hindered co-ordination efforts were inconsistency in staff and having too many people involved at once. Often people would come into the response for two or three days and then go again. This meant that new people constantly required briefing on their role and what was happening. This takes up time in an emergency situation. It was also found that at some stages there were too many people involved in the response. Managing people rather than the event itself became an issue and this took too much time away from people who need to be fronting in the response.

As the response to the landslide dams developed over time the co-ordination of the response evolved. It took time to know who was involved and what their roles were. After ten days there was more understanding around the response it was very much a collaborative effort between all the agencies involved.

Interviewee G:

“As we learnt who we needed to co-ordinate with the co-ordination improved before that it wasn't great. There was an element of people doing the same work which isn't necessarily a bad thing as people pick up on different things.”

Part of the co-ordination involved communication between different agencies which as previously discussed was problematic during some of the response. Whilst communication was occurring between the agencies to better their co-ordination, it sometimes took significant time which meant time spent away from responding to the dams themselves.

Interviewee E:

“We were doing a lot of liaising with GNS and ECAN and at some points I felt like I was between all three organisations just passing comments between the three. It just made life difficult so that was a big aspect of not knowing who was doing what and just making sure we weren't doubling up on work but equally making sure something wasn't being missed.”

Interviewee J:

“There were people we were working with to collect the information and analyse it and there were people we were providing information to for them to keep track of their areas of interest. I had to focus on what I needed to do which was informing the key people and then they could distribute the message further.”

It was felt by the majority of participants that the agencies involved were under-prepared for the landslide dams. The dams did not get included in the overall response to the Kaikoura earthquake damage initially, until the number and size of them were discovered. The landslide dams were not considered to the same degree as other hazards which were more visible such as landslides, coastal uplift and damage to infrastructure.

Interviewee J:

“The critical thing for me is working out what is not being done, it is much harder to sit back and work out what is not being done. It became obvious very quickly that no one in Kaikoura was systematically looking at landslide dams.”

Interviewee Q:

“You have got to have resources early on and monitor early and just being on to it as soon as possible. That is something that if this happened again I would be a lot more onto landslide dams. It was there but it just took a while to come into our consciousness, wow this is bigger than we thought.”

Several interviewees commented that the landslide dams should have been included as part of the overall co-ordination of the response from the early stages. The dams were not considered by many of the interviewees as their attention was on other land damage. On the day of the Kaikoura earthquake the Clarence River dam breached. This was a large dam and it was lucky that no one was injured or killed by the breach but at this point the risk from dams was very much unknown.

Additional quotes from interviews which relate to the theme of co-ordination are summarised in Table 5.3 below.

5.4.1 Key Research Findings

The results of this research around co-ordination in the response to the Kaikoura landslide dam event identified several key outcomes:

- Interviewees involved in the response felt that they were under prepared. The risk of landslide dams occurring had not been a hazard they were thinking of.
- The co-ordination of the response to the dams had to be flexible as it was a dynamic situation which was constantly changing.
- Having consistency in staff is important to allow for a smooth co-ordination and an efficient response.
- As the response developed, the co-ordination evolved and improved. After ten days more information came to light, and greater understanding of the risk from the dams was gained, the co-ordination became smoother.

5.4.2 Additional Interview Quotes

Table 5.3 – Quotes from interviews about the co-ordination in the response to the landslide dams in Kaikoura.

Sub-theme	Interview	Quote
Dynamic Situation	F	<i>"We always based our decision about when to go again on what we had seen in the previous flight, instead of going right we will go once every week for the next three months. So we sort of reassessed it each time."</i>
Triage system	J	<i>"From the initial assessment we could start to rank the relative hazard and from the hazard start looking at the risk and then identify the dams we wanted to go and look at in more detail. The initial evaluation took about a week."</i>
	I	<i>"The uncertainty around the dams made it very hard to deal with. You provide a map of where they all are but there is no guarantee that all of them have been found yet or correctly located. The maps changed constantly and created pressure to what we could say with any certainty."</i>
Staffing	M	<i>"Some were only coming up for two or three days which don't get them into the role, and then they are gone. So the longer you can go up there in an emergency the better off I think you get to know what is going on."</i>
	M	<i>"At one stage we were feeling that there were too many people being sent up to Kaikoura so all of a sudden you are managing people rather than manage the event. It just takes your focus away a bit if you have got too many people being thrown at you."</i>
Co-ordination evolved	G	<i>"The next stage was working with GNS a bit more, GNS started to undertake the more comprehensive identification of the dams. We were helping with the analysis of those dams with what does this mean and how big of a hazard is it. That was very much a collaborative effort between us and GNS and consultants."</i>
Under-prepared	P	<i>"The scariest thing that happened with the slip dams was the one in the Clarence, and that one failed before we were even prepared for it, before we had put anything in place."</i>

5.5 Resources

In a response to disasters sufficient resources are imperative. The availability of resources whether people, equipment, food, or money can vastly change the outcome of a response. The greater the level of damage and destruction from a natural disaster the more resources will be required.

When a community experiences extensive damage from a natural hazard often local resources cannot manage the response alone and external resources have to be brought in to assist (Coppola, 2015). In the case of the Kaikoura landslide dams' response, the resources which were highlighted through interviews included: people, specific skills and experience, equipment, technology and financial assistance.

Due to the scale of the event that caused both landslide dams and other earthquake damage through the region, resources became stretched. The three district councils involved in the response were all small with limited numbers of staff with the capacity to respond to the landslide dams as well as undertake their everyday functions. Several interviewees felt under heavy pressure with the constant requirement to provide staff to attend to the landslide dam response.

As well as the district councils finding themselves under-resourced, other agencies had the same experience and needed to bring in external resources to cover the work. This meant subcontracting in companies who could offer skills such as Geotechnical Engineers to fill those roles.

Interviewee K:

"We would use our normal Geotech's but if they quickly became stretched we would just start calling in others or basically a sub-contractor arrangement and they would come in from the outside."

With resources being stretched additional assistance was required, but it was important that the people coming in had previous experience to assess the risks from landslide dams. Many of the external people brought in had experience in responding to natural hazards from the Canterbury Earthquakes in 2010 and 2011 but not necessarily landslide dams.

Interviewee M:

"Because Kaikoura only have a staff of 20 and the Kaikoura District when it comes to Police and Fire again very limited because of the size of the district up there so yes it

was a case of bringing in a lot of external people who had never worked with each other but they all know what their role is.”

One challenge with bringing in external staff highlighted by several interviewees was that they had no local knowledge. This became an issue with locating people and places being reported in via external communications, and caused confusion, resulting in sending resources to help in the wrong places. This was identified as a problem during the response and it was suggested by one interviewee to combine local staff with external resources so that someone local is available.

Some participants felt that by bringing in external staff the response was taken away from the locals. The local responders felt displaced when senior CDEM responders came into their area and took over. This created upset as the local responders felt left out of the response and knew that at some point they would be left to pick it all back up again when the external staff disappeared after the initial response.

Interviewee I:

“Tension around what is led out of the local government versus regional co-ordination centres and then national, I think the phrase was locally led and nationally supported but there are real tensions there which came up with the Goose Bay landslide dam.”

The local staff had links into the community and knowledge about how the communities worked, the relationships were already there. A few participants found that those relationships and links were not used during the response. Therefore, the external staff were starting from scratch with the community.

The role of the Science Liaison was found to be a useful resource. Their role was to transfer the information collected in the field into useful and meaningful information for the agencies making decisions regarding evacuations and warnings.

Interviewee I:

“GNS's role is as a science advisor to the Ministry. We tend to put staff into the EOC's and ECCs to be that Science Liaison, providing a better way to get the science knowledge into the response and recovery process. Feeding the daily science information into the situation reports for the Group each morning.”

Whilst there was a Science Liaison based in the Christchurch Emergency Co-ordination Centre (ECC), and for a short while the Marlborough EOC, there was not a Liaison in the Kaikoura EOC

which was a downfall in the response. The Kaikoura EOC greatly missed having a Science Liaison present. Many interviewees commented that the role was missing and it would have saved much confusion with agencies getting involved with each other's work. The Science Liaison role has a part in the co-ordination of the response so their involvement in key locations is important.

Interviewee H:

"I think if we had somebody who was linked in better so perhaps a X [name removed] or a X [name removed] sitting up there it would have made a difference. They could have been communicating more about what their guys were doing and stopping people panicking."

Interviewee I:

"We didn't have someone based at the Kaikoura EOC and I think that was a real gap that should have been recognised sooner and addressed. We did come across issues within the Kaikoura area which could have been better managed if we had someone there."

Unfortunately, GNS Science did not have enough staff with the right experience to deploy to all EOCs and ECCs. There is a need to increase capacity in the role which involves building up knowledge and experience. It is not only a case of not having enough staff to be at all EOCs/ECCs but also to facilitate centres operating 24 hours a day with staff who can work in shifts (Woods et al., 2017).

Due to the scale of the event, a lack of staff able to respond in some agencies and long days in stressful situations, fatigue and safety became a problem that required attention for health and safety reasons. It has been suggested by several interviewees that there is a need for more staff to be involved from the outset of the event. This would allow for redundancy throughout the response as people can very often become exhausted rapidly as the work itself is taxing.

Interviewee J:

"First week was 12 hours a day and then tried to reduce down to 8 hours a day because you just can't sustain that. And part of my role was watching who had been working too much and pulling them out and telling them to take a break for two or three days."

An important part of the emergency management response was to manage the staff who were responding. Plans were set up to work out how much time people were spending on the

response. After a certain number of hours, they would be swapped over with another person so that they could get rest time.

For other agencies such as the transport networks who had staff out in the field assessing roads, railway lines and bridges there was a safety issue. Staff were working in areas at risk from many hazards including landslide dams. At the beginning of the response the risks were unknown so those agencies had to make sure their staff would not be in harm's way after they found out about the risks related to the dams.

Interviewee L:

"In the initial asset assessment stage of getting people out to check the bridges and then having to say to them no you can't go and check that bridge because there's a warning of the potential of a dam burst with stuff coming down the river so not checking some bridges until we were sure that it was safe."

Mainly people had the technological tools and resources that were required to respond. Small improvements with better cameras and cameras with GPS in them would have speeded up the process of transferring data when back in the office from field assessments and having higher quality images.

One resource which would significantly help the response by saving time, money, and people is the use of modelling. This could give a quick overview of potential damage sites given the number and severity of landslides. It could be used before field work begins to home in on areas to check first but the technology needs to be developed further.

Interviewee C:

"We don't have at the moment any tools that help us really home in on what the problems are and what I mean by that is we have the technology and models and I use them all the time for my work in risk assessment for example if an earthquake occurs with certain parameters and it occurs in this type of hill slope setting we can using our models that we already have get some idea of the number and severity of landslides where they are likely to occur."

After the assessments were completed and monitoring was recommended with instrumentation set-up on the dams and lakes, it was found that obtaining that equipment took too long. Monitoring could have been set-up earlier if equipment had been available.

Interviewee J:

“Another thing that didn't work well was getting instruments we were very slow off the mark there because we didn't have stuff sitting on the shelves.”

There is always the difficulty of determining who is paying for what, which is always going to be a problem during a response. The inaccessibility of the landslide dams meant that the identification and assessment stage was very expensive as helicopters were used extensively. The high cost of the response highlighted problems of who is responsible for paying for what. Because three districts were affected, and many people involved, this problem was escalated.

Interviewee C:

“The cost of having a look in the field is huge and so with an area like that, at the end of the first week we hadn't flown the whole area. Spending hundreds and thousands of dollars doing that. It's much more cost effective to have some model first that we can then go out.”

Additional quotes from interviews which relate to the theme of resources are summarised in Table 5.4 below.

5.5.1 Key Research Findings

The results of this research about resources in the response to the Kaikoura landslide dam event identifies several key outcomes:

- Local resources were stretched and a lack of expertise locally meant that external staff had to be bought in.
- One resource which was not utilised well in the response to the landslide dams was local knowledge, there was a lack of local resources used when dealing with local communities.
- A resource which was missing in Kaikoura and caused unnecessary confusion around what assessments were being undertaken was the Science Liaison.
- People working on the response are one of the most used resources, staff safety and fatigue became an issue and had to be closely monitored.
- Use of technology in the response was lacking, it has been suggested that computer modelling would have been a great advantage.

5.5.2 Additional Interview Quotes

Table 5.4 - Quotes from interviews about the resources in the response to the landslide dams in Kaikoura.

Sub-theme	Interview	Quote
Resources stretched	N	<i>"With councils this size and Kaikoura even more so, we don't have the resource and we are expected to carry on our everyday functions as well as Civil Defence work so it is very tough having the constant pressure."</i>
External staff	N	<i>"Our EOC was often staffed by people who had come in from the bottom of the South Island or the North Island so we didn't really have that local knowledge. This is something that we've identified as an issue and in future events we will stagger our local people through the rosters."</i>
Local knowledge not used	O	<i>"I think there were a few people that felt a bit displaced because more senior Civil Defence staff came in and took over at the team management level. I think there was a bit of a feeling there."</i>
	H	<i>"They weren't using the local knowledge so when they were dealing with that community the Emergency Manager has got fantastic links into that community and was not included in the loop at all."</i>
Science Liaison required in Kaikoura	I	<i>"An obvious gap is having more staff that we can deploy into the EOC's and ECC's. There are only a few of us that have had that experience."</i>
	I	<i>"Not being formally recognised in the structure is a bit of a barrier for Science Liaisons."</i> <i>"The ECC's run 24 hours and as Science Advisors we will often just have one person there working 12 hour days and it can be quite stressful with high demands."</i>
	M	<i>"Would have helped with the issue that they had with the Geotechs sometimes getting involved in what GNS were doing."</i>
	H	<i>"I'd told GNS that I thought they need to put a Liaison in there as well and they didn't think they needed to."</i> <i>"But if GNS had a presence in there then they could have co-ordinated the thing from there."</i>
Staff fatigue	G	<i>"It was quite taxing on us being the ones involved all the way through. By day three I was sleeping in the helicopter on the way home."</i>
	J	<i>"You need to set up clear structures around how much time people are spending working on the response."</i>
Technology	O	<i>"Obviously having no computers sort of the first break down but we got over that pretty quick."</i>
New Technology	B	<i>"Now I have got a \$12 programme TopoMap Pro does it all for you beautifully"</i>

5.6 Previous Experience

Previous experience in responding to large scale natural disasters gives responders the ability to undertake challenging roles in often highly stressful or high-risk situations (Coppola, 2015). Due to the nature of the hazard of multiple landslide dams not being overly common in New Zealand, there are limited numbers of people with previous experience.

The identification and risk assessment of the dams required skilled people who knew what they were dealing with and understood the scale of the event. Previous experience is essential for the assessment of landslide dams to know exactly what conditions and criteria are required to gain a full understanding and therefore provide the right information to make decisions on life safety and risk to infrastructure. In response to the landslide dams the initial assessment and emergency management was critically dependent on those skilled people who had previous experience.

Having previous experience meant those people responding were well prepared and ready to go. The experience gained from other landslide events could be transitioned into the Kaikoura response at a moment's notice which meant that the response commenced very shortly after the Kaikoura earthquake occurring.

Interviewee D:

"We are an established group that are ready to go, have emergency response experience and training and have responded to a number of significant earthquakes and aftershocks."

Interviewee J:

"We have got the equipment and the people with experience to respond to these events so that was a natural fit for us to assess it. We took ownership of collecting the data and making it available to everyone."

Having previous experience also means that minor parts of responding such as having the right equipment to respond quickly works smoothly and that no time is wasted trying to locate gear. GNS Science in particular, based much of their response and assessment of the landslide dams on previous events both within New Zealand and internationally. Each event allows for further learning for the next one.

Interviewee J:

“Learning from previous events allows us to assess these ones better and know a bit more and things like if it will fail or not and how long that might take. It is good to be able to inform people with more accuracy.”

Interviewee A:

“Everything that we were providing in terms of advice and information on predictive development going forward in that first week was based on our experience, our knowledge of historical events.”

Many learnings have been taken from the Canterbury earthquakes in 2010 and 2011 and utilised in the response to the landslide dams. Although the hazard type itself was different, the emergency response procedures and thinking about what is required is similar enough that the experience can be drawn on.

In the case of the landslide dams, lack of experience became problematic as there were not enough experienced resources to respond. That meant people were making decisions with a “gung-ho” attitude instead of relying on technical knowledge and experience. This caused problems relating to people being evacuated unnecessarily or not following procedures to undertake evacuations in the right manner.

Interviewee C:

“Some people have a bit of a gung-ho attitude you know it will be fine and they have no technical basis for that. For example, I made it very clear to them when I was asked what I thought whether or not the dams will fail, I cannot tell you and I think you have to assume that they will until we know otherwise.”

It was suggested by some participants that a lack of experience changed perception of risk from people who had not previously been involved in an emergency response. Not having the knowledge or experience meant that people making decisions were risk averse. In Kaikoura, the Chief Executive of the district council had been in the area for less than 12 months and was anxious about decisions and the outcomes those decisions could have.

Interviewee A:

“Making the initial risk to life assessment for Goose Bay in particular was undertaken by on-site geotechnical engineers not necessarily informed by, well they weren’t

informed by GNS Science. So, the call to evacuate the residents from Goose Bay was made by someone on site based on their perception of risk."

The lack of experience was not purely around the technicalities of landslide dams themselves but around emergency management response processes and procedures when working alongside CDEM. There is a need to understand CDEM's requirements as well as their way of thinking and communicating, without previous experience it can become difficult to know what the requirements are.

Interviewee H:

"These guys just aren't used to a response, they are used to doing everyday stuff and this big response stuff is completely new to them and that importance of public messaging."

"Our river engineers are not really understanding how the whole Civil Defence thing works and the importance of the information with communication."

The lack of experience in landslide dams formed by earthquakes also meant that the scale of the event and the task at hand was underestimated. The understanding of the scale of the event came with time during the response and as the dams were identified. It took time to appreciate the scale of the event and the possible impacts of the dams on the downstream communities which is why it took time before the Goose Bay residents were evacuated.

Interviewee K:

"We probably underestimated the scale of the problem to start with, that became pretty clear when we got this report done and realised the very real risks that were up there and then I guess that would be the only thing we should have anticipated better and we would know for next time to focus on that really early."

It was felt by several interviewees that upskilling during a response was important to increase the number of people with experience for the next event. For example, the team in ECAN very much felt that they were learning as they were going and much of that learning was coming from GNS Science. GNS Science had the expertise to not only deal with the landslide dams but to also train others through the process. Upskilling was also carried out in the CDEM area where experienced people were mixed in with less experienced people to undertake the work and train people up at the same time.

Interviewee M:

“You surround yourself with some really good experienced people and then you can feed in other teams with less experience to help do the work. So as long as you have got good leadership and give clear directions people are pretty good and you mentor them along on the role.”

Additional quotes from interviews which relate to the theme of previous experience are summarised in Table 5.5 below.

5.6.1 Key Research Findings

The results of this research around previous experience of responders in the Kaikoura landslide dam event identifies several key outcomes:

- The response required skilled people with previous experience. Some responders had experience from previous events which allowed them to be well prepared, and undertake rapid response with clear direction.
- In some instances, a lack of previous experience of landslide dams and knowledge around emergency management response lead to misunderstandings, hasty decisions and lack of communication.
- Due to a lack of experience the scale of the event was underestimated by many people in the first few days following the earthquake when their focus was on other damage caused by the earthquake.

5.6.2 Additional Interview Quotes

Table 5.5 - Quotes from interviews about the previous experience in the response to the landslide dams in Kaikoura.

Sub-theme	Interview	Quote
Skilled people	B	<i>"It really came down to having people that knew what they were up against and knew what they were trying to do"</i> <i>"It was very strongly dependent on the fact we had skilled people that had done it before, we knew what we were up against."</i>
Well Prepared	D	<i>"With that resource that made it quite easy to transition to the Kaikoura response purely for the fact we had a team with all the right PPE and the right gear packed in a bag ready to go at a moment's notice."</i>
NZ Experience	D	<i>"We were helping different organisations with all different things but using our expertise's we have from the geohazards environment in Christchurch."</i>
	I	<i>"Certainly, we did a whole lot better than after Christchurch, a key thing we did a lot better was staff welfare. Organising food and accommodation was much better."</i>
Lack of Experience	P	<i>"We didn't have the expertise and we didn't have the capacity and I don't know, in that first couple of days it is kind of a blur."</i>
Risk Perception	M	<i>"You do this and we are fine, the mayor was fine with it but the chief executive had only been in the area less than 12 months so was a bit more nervous and that comes back to how risk averse you want to be."</i>
Scale of event	G	<i>"I don't think we realised how big this task was going to be in those first couple of days. It wasn't until the second flight when we saw some of the bigger dams and realised the scale of it."</i>
	M	<i>"There have been various cases in New Zealand where landslides go into the rivers but just the sheer scale and then trying to work out if that bursts what is the impact downstream if you have got any small settlements and of course the Goose Bay one immediately there."</i>
Upskilling during response	B	<i>"It is good to have that third place available in the helicopter to be upskilling people if we can. And so, it is the trade-off between how much do other agencies need to see in order to understand the hazards versus us to go and do it and just be telling them and be upskilling our own people for the next"</i>
	F	<i>"Not a lot of experience and we were just learning the stuff as we were going along from GNS largely. But I was very impressed with the expertise that they had to deal with it and they were kind of quite clear about what they had to do and getting on with it."</i>

5.7 Community Involvement

Several interviewees commented on the importance of involving the community in the response wherever possible. This can give them greater understanding of the risks they face and also make use of their knowledge of the local area. Having the community involved with evacuation and response plans gives them ownership of the plan and undertaking exercises with them gives them a clearer understanding of the risks (Palmer, 2007).

In the case of the Kaikoura landslide dams it was important to involve the community in the response. It was mentioned by several participants that if the community were kept informed about the risks then they would be more accepting of whatever must be carried out. This involved communicating the situation to them, what is known about the situation, what is unknown about the situation and what is being done about it. If these issues can be communicated in a simple way then people know what is being done and can understand the reasons for being evacuated, this method was used in Goose Bay.

Interviewee C:

"I think that's really important that you go there with the information, you disseminate the information, you get feedback on the information, you help people understand it but it's not as good as getting them to discuss it amongst themselves."

Interviewee J:

"I went down to Goose Bay early on to discuss with them the risks, I knew the community would appreciate someone turning up and giving them information because most of the time they don't know what is happening."

It was important in the response to the landslide dams to increase the communities' understanding of the hazard threatening them and the risk associated with those hazards. In Goose Bay some of the residents did not think that the landslide dam was a great hazard to them. GNS Science took some residents up to the dam by helicopter to show them the concerns around the dam which quickly changed their minds. Those residents were then able to feed that back into their community which was a powerful persuasion tool.

This was a technique that had not been used before to increase the understanding of the community and it would not always be feasible. It did work well as the residents then went back into their community and shared what they had seen for themselves instead of everything coming from officials parachuted into the area. Allowing the community to discuss the information between themselves can also really help their understanding.

During the Kaikoura event in Goose Bay the residents agreed to work alongside the District Council and scientists to develop plans for self-evacuation. They were very much involved. An alarm system was set up and if the alarm was triggered the whole community needed to evacuate to a location uphill of the river valley.

Interviewee O:

“They had to agree to the evacuation plan and what we put in place. So, yes that was very much community involvement. There’s quite a cohesive community down at Goose Bay.”

Involving the community in the planning and development of evacuation procedures put the responsibility back on the them to look after themselves in the event of a breach, flood or another earthquake event. They needed to know the risks, the hazards and what to do in the event if they want to reoccupy their houses. The Goose Bay community wanted this form of mitigation, it was their preference to take on that responsibility.

A way of keeping the community involved in the response to the landslide dams was holding community meetings in their local area. This meant they did not have to travel to meetings which could mean missing out on receiving imperative information.

Interviewee M:

“We had quite good turnout there sort of about 40 or 50 people at the second meeting at Goose Bay and the first one would have been a similar number there but going to them because it was a bit harder for them to get to Kaikoura.”

Many roads were closed off around the Kaikoura region due to landslides and other land damage so a team of scientists, CDEM staff and council staff would fly down to Goose Bay by helicopter to reach the community.

Additional quotes from interviews which relate to the theme of community involvement are summarised in Table 5.6 below.

5.7.1 Key Research Findings

The results of this research around community involvement in the response to the Kaikoura landslide dam event shows several key outcomes, they are:

- Involving the community in making sure they understand the hazard and risk behind the decisions being made and are not just told they have to evacuate. The greater their understanding the more co-operative they become. It is important to share information but also get feedback from them.
- Holding community meetings as close to the local area as possible worked well in Goose Bay as access through to Kaikoura was difficult. This meant more people could be involved in the meetings.
- The residents in Goose Bay were heavily involved in the response and wanted to have that direct involvement in developing self-evacuation plans. The community was given the responsibility for evacuation as that was their own preference.

5.7.2 Additional Interview Quotes

Table 5.6 - Quotes from interviews about the community involvement in the response to the landslide dams in Kaikoura.

Sub-theme	Interview	Quote
Involved in science	A	<i>"At that point when GeoNet got involved is when the community became increasingly involved in the conversation about risk."</i>
	J	<i>"If I can go and talk to that community and keep them informed, I know they are under stress. This is the situation, this is what we know, this is what we don't know and this is what we are doing. It is simple but people know what is being done and the reason why I am not in my home."</i>
Understanding	C	<i>"There was a couple of the locals who were quite vocal in Goose Bay because they didn't think the size of the dam was particularly large. So I actually flew them up to the dam and took them up on the dam and they changed their minds within seconds and that was really helpful."</i>
Evacuation	O	<i>"Either they could stay out of their houses or they could agree to self-evacuate if the alarm went off and put a plan in place. They were very much involved in that one."</i>
Responsibility	M	<i>"Really putting it back to the community to look after themselves, then the same with the earthquake, if you got another strong earthquake the residents didn't need to go far to get out of harm's way to the upper terrace. They wanted it, that's what their preference."</i>

5.8 Information and Data

During a response there is a need for field and scientific information about what is happening and the risks that are present. When there are many different agencies involved in a response there is a need to share information with others so that work is not repeated and limited resources are prioritised. Without information, judgements around risk and decisions around life safety cannot be made. It is vital that the information being collected is distributed as quickly and accurately as possible (Paton et al., 1998)

Almost without exception it was felt by participants that the sharing of information was carried out well during the response and there was an openness to share information with each other. There were no barriers or walls in place to stop people seeing and using other organisations' information if it was going to assist with another area of the response. The focus was on everyone pulling together in the response to gain the best results possible.

Interviewee G:

"We got close to GNS and Aurecon doing very similar work but I don't think it happened and we managed to make sure all the models and photos were shared."

One way in which information was shared not just across agencies but also to the public was through a GIS based cataloguing database. This system was used to catalogue all the photos and data collected during the helicopter flights, each dam was named by river name followed by altitude to give every dam a unique tag.

Interviewee J:

"We needed to build a database, including information on size, volumes of water, where they were and naming them which turned out to be absolutely critical."

Once the database was set up and running, new information was constantly being added to the system and could be used to generate maps and data points. These could be sent out in reports to inform other agencies. There was limited public access to the database which was used to inform them of the risks. This was a great database for people working on the response but was not used by the public as much as was anticipated.

Interviewee H:

"One of the things that I want to see happen from here on in is how science information gets bought into EOCs. There is just so much information and GNS and

some of the others were really good at giving us information but it's no good if they just dump it all on you."

Whilst information sharing worked well it was sometimes felt that information needed to be sorted before being passed on so that it was more relevant to operational needs. As information was being shared between agencies often people were relying on data from other agencies to be able to carry out their part of the response work. Being able to rely and use other agencies' data and information reduced the amount of work that had to be doubled up or redone. But using other's data means that it needs to be trusted and that there is consistency in the assessments and results of those investigations.

Interviewee E:

"Using GNS dataset and what they had categorised as the high priority dams and went with their classification and then looked at how the dams impacted infrastructure for NZTA. We were relying quite heavily on their views."

Other than relying on other agencies for information, some agencies also called on the public to pass on any information about the rivers or dams to the District Councils who would then pass that on to GNS Science and ECAN. This local knowledge about differences they were spotting was beneficial. Relying on other's information and data also meant that some organisations had to adapt their methods or tools to work with the data which was being provided instead of trying to adapt the data to suit their methods.

Interviewee D:

"We built our risk assessment based on the information we had been provided because that is what we knew was available rather than having something in place that we were trying to then make everything fit to. We built something that would fit the information we received."

One problem identified when having an open sharing of information and data is the control and use of that data. An example of this was when GNS Science were sharing their data with ECAN who were setting up the GIS database. One person renamed one of the landslide dams together with the photos associated with that dam. This was incorrect as many other people were still using the original dam name and it would have completely confused everything by changing the name.

Interviewee B:

“So, the potential there for who is in charge of the database and what are the rules around doing it would be quite nice to sort of tidy up people’s understanding of why you don’t fiddle with these things in the middle of a response.”

Those people and agencies who are using other’s data and information need to be aware of controls and use of that data so that they know not to change names or location markers or any of the details which could cause confusion later.

Additional quotes from interviews which relate to the theme of information and data are summarised in Table 5.7 below.

5.8.1 Key Research Findings

The results of this research around information and data use in the response to the Kaikoura landslide dam event identifies several key outcomes:

- The sharing of information worked well in the response to the landslide dams with an openness that allowed access to anyone who needed the information. There was very much an attitude of working together on the response.
- Often agencies or organisations were relying on other agencies for information before they could undertake their role in the response. This meant having to adapt systems or process to the data that was provided to them.
- A database for the information was built relatively quickly following the initial identification of the dams, this GIS based system was critical in the response.

5.8.2 Additional Interview Quotes

Table 5.7 - Quotes from interviews about the information and data in the response to the landslide dams in Kaikoura.

Sub-theme	Interview	Quote
Sharing information	K	<i>"Everyone had their own area of responsibility but there was complete openness to share that information, which is absolutely what you need. And those operational meetings that we had in the morning we had people from KiwiRail, GNS when we needed them to come in. Really just do what you have got to do, so there were no walls put up or no barriers in place to stop us doing that, everyone was really just focused on pulling together."</i>
Database	B	<i>"Catalogue all the photos that we had taken we had developed this method of giving them a river name and an altitude as a name so it took a long time to basically located them into the database getting the location of everything."</i>
	B	<i>"We had a database that was starting to generate maps and things like that as we were going and we were sending out reports for the southern dams."</i>
Relying on others	C	<i>"One of the things that was really helpful was locals were passing their knowledge to the councils who were passing it to us so the data flow is going two ways."</i>
Control over data	B	<i>"He was tempted to correct it that was totally the wrong thing to do, and we had to get him to back track and say we have got a whole lot of other things that are happening in the background."</i>

5.9 Relationships

Relationships both within agencies and across different agencies and organisations are critical in responding to an event in a collaborative and co-ordinated way. Having pre-established working relationships with other people and organisations allows responders to better deal with an event as people are familiar with each other and used to working together (Curnin & Owen, 2014; Paton et al., 1998). If relationships are nurtured and maintained then the roles, responsibilities and expectations of each person or agency can be understood prior to the emergency response (Curnin, Owen & Trist, 2014).

Throughout the Kaikoura response it was thought by most participants that pre-established relationships assisted. Those relationships prior to the event helped in knowing what the other people do and their experience prior to this response. Many of the responders had worked together before on the response to the Canterbury earthquakes in 2010 and 2011. The relationships built up through that event proved to be priceless in the landslide dam response.

Interviewee H:

“Those consultants have worked together before makes a massive difference and I knew a lot of them as well and it is just huge. I could get on the phone to X [name removed] and say what are you doing and you can’t beat those relationships.”

It was found that those pre-established relationships improved simple tasks like knowing who to contact, having their contact details to hand, being more confident in that person and their ability to respond. Having pre-existing relationships also allowed for response processes to proceed more quickly. Although those pre-established relationships do help they are not necessarily essential as the New Zealand Coordinated Incident Management System (CIMS) framework is set up to work whether people are known to each other beforehand or not.

Interviewee A:

“The way the emergency management framework is structured it doesn’t really matter if you have those pre-established relationships but it really does help.”

Whilst there were many pre-established relationships from previous events responding to the landslide dams there were also new relationships. It is important to be able to converse effectively with different stakeholders, it is imperative in establishing good working relationships with people through a response (Curnin & Owen, 2014). CDEM work hard to develop relationships with different agencies and often an event is the best place to develop them as working together builds those connections. To build new relationships it is important to put effort in and work harder to build trust with those people you don’t know.

Interviewee M:

“You always want to be reliant on those relationships that you develop, if it is new then you’ve just got to work at those harder but people there are for the community good.”

“Where I put the effort in because I had never met the chief executive before, I had met the mayor a couple of times so putting the relationship into the council’s chief executive was the key thing.”

A challenge in building relationships in an event like the Kaikoura landslide dams was found to be the rotation of staff. This meant having to build relationships with several people filling a single role.

Additional quotes from interviews which relate to the theme of relationships are summarised in Table 5.8 below.

5.9.1 Key Research Findings

The results of this research around relationships in the response to the Kaikoura landslide dam event clearly identifies several key outcomes:

- Overall most interviewees believed that pre-established relationships with other people and agencies helped in the response by having a better understanding of what other people can do and will bring to the response.
- Although those pre-established relationships help they are not essential but not having them can slow down the work flow. New relationships can be built through a response with a little extra effort and be used for the next event.

5.9.2 Additional Interview Quotes

Table 5.8 - Quotes from interviews about the relationships in the response to the landslide dams in Kaikoura.

Sub-theme	Interview	Quote
Pre-established relationships help	F	<i>"Probably would have helped just to have the understanding of what they do and know this has happened let's get on the phone to this person."</i>
	Q	<i>"They understand us better which is useful, and certainly, every after-action report that we ever read says the importance of relationships and to me it reconfirmed it."</i>
Relationships not essential	Q	<i>"There were people I met for the first time and I was confident they would do what they needed to do but having that relationship just speeds it up I think."</i>
Build relationships	Q	<i>"We do work at developing relationships with them and thinking about how, or talk about how we are going to do things so yes that worked ok."</i>
	I	<i>"When staff are rotating that is another challenge you are actually needing to get to know several people filling that role not just the one person."</i>

5.10 Post-event/Long-term Management

Even during the response phase, it is important that the long-term management of a hazard is considered. Landslide dams are a long-term hazard even if they have breached and the lake level lowers. Long-term monitoring and assessment can continue for many years and the financial cost of this on-going work can heavily impact small districts with limited resources (Korup, 2005).

At the time of the interviews, most of the dams had breached to a greater or lesser extent. It was understood by several of the responders that the on-going hazard is not from the dam itself but the high levels of sediment supply in the river systems. The sediment can flow downstream in strong flood events causing problems downstream. Also, due to the poor stability of the slopes around the landslide dams, further landslides should be assumed.

Interviewee B:

“There is going to be strange flooding behaviour you are going to have all sorts of surging type things and sediment cascades that come down through. There will be effects on the highways and having to lift bridges and there will be more rockfall and stranger flows during floods for some time.”

These on-going hazards have to be considered during the response and for the most part they were. The data collection methods used in the response needed to make sure that data being collected would help to inform future planning and mitigation of the hazards present in the river system.

Interviewee C:

“We are answering or getting data that we can answer the questions that are being asked of us and secondly that we are capturing data that is going to help inform future decisions.”

Due to the on-going hazard from sediment, researchers working on the response are aware of the need to look at how the sediment is sitting in the landscape, how it might move and what that might impact downstream.

Interviewee J:

“Long-term management of the sediment as it will impact on flood protection schemes, it will impact on assets, low lying farm land. The impacts aren't over and will probably continue for decades. We need to understand the long-term effects of that sediment.”

Interviewee C:

“Our role is not just to deal with the emergency in your face although that is what it kind of was initially it is to also think about that future planning.”

Responders from the science sector involved in the response are also involved in the recovery phase. Those researchers are looking to the future and how the landscape might play out in the next 100 years.

Whilst still in the response phase, and before any official systems had been set-up around warnings or monitoring of the dams, the District Councils worked with ECAN. This included evacuating residents downstream of the Hapuku River and in Goose Bay before periods of heavy rainfall. For example, residents in the Hapuku valley were evacuated before Cyclone Debbie and Cyclone Cook as a precautionary measure.

The long-term management of the landslide dams included setting up monitoring systems on the dams with the highest risk to people and infrastructure. The Hapuku landslide dam and the Linton landslide dam pose a risk to State Highway 1. Harvest Electronics were contracted to put together a monitoring and alarm system. An alarm also triggers warning lights on the State Highways to warn people not to cross the bridges.

Figure 5.1 - Warning signage on the Hapuku Bridge with upstream monitoring to stop vehicles crossing the bridge when lights flash (credit Erwin van Drunen).

Figure 5.1 above shows a photo of the warning signage and lights approaching the Hapuku Bridge north of Kaikoura.

In the longer term it is hoped that the information gathered during the response and the ongoing monitoring will feed into regulatory restrictions around land development. It also should be considered how the landslide dams will change district plans and hazard maps.

Due to the small size of the district councils (Kaikoura) with areas affected by landslide dams funding for ongoing work and investigation around the landslide dams can be challenging. This can mean that long-term management can go by the way-side. However, in Kaikoura plans are in place to provide funding through research into the long-term impacts from the landslide dams.

Interviewee C:

“There are plans by the councils to try to assess the longer-term hazards posed by these things but that is very much dependent on funding. It is not something they have got current funding for.”

Interviewee O:

“So hopefully there are a couple of science research applications in to do some work in that area. Otherwise it will fall to ECAN and us to do the hazard analyst work and it’s not something we can really afford at the moment. That longer-term effects of aggradation and that sort of thing yes we are waiting for funding for.”

As well as district councils having concerns over funding for long-term management the transport agencies also have funding struggles. They have been considering upgrading culverts along sections of road and rail that could be affected by high sediment levels. The aim is to future proof against the long-term impacts of aggradation on bridges which has already been a problem in several areas around Kaikoura.

It appeared to some of the responders that the recovery phase was too ad-hoc and further thought should go into long-term management of an on-going hazard which has the potential to cause further damage from sediment supply and flooding.

Additional quotes from interviews which relate to the theme of long-term management are summarised in Table 5.9 below.

5.10.1 Key Research Findings

The results of this research around post-event and long-term management in the response to the Kaikoura landslide dam event clearly identifies several key outcomes:

- Part of the response to the formation of the dams needs to include recommendations for the future and how the data being collected during the response can be used later.
- Landslide dams are an on-going hazard and awareness around their management is required to make sure that they do not get forgotten.
- In a small district like Kaikoura funding for long-term management of the dams can be difficult to find even though the risk of further impacts is high. Support from external agencies appears to be lacking when moving into the recovery phase.

5.10.2 Additional Interview Quotes

Table 5.9 - Quotes from interviews about the long-term management in the response to the landslide dams in Kaikoura

Sub-theme	Interview	Quote
On-going hazard	F	<i>"I don't see that there is likely to be any long-term issues with the dams themselves but it will be more the sediment supply."</i>
	C	<i>"Sediment starts to pulse downstream and travel to the sea it will start causing problems as it goes down but also there's so much debris still up in those source areas that further landslides should be assumed."</i>
Awareness	J	<i>"People are thinking about it and we are putting it into our research proposals of how the sediment is sitting in the landscape and how that might be transferred."</i>
Funding	L	<i>"We have looked at upgrading culverts through sections but we just haven't had the funding to future proof against some of this longer-term plan. KiwiRail have done a bit of thinking on it and not too sure because one of the things is funding to upgrade for aggradation on bridges."</i>
Monitoring	G	<i>"Quite conscious of trying to get the information to the public in the weeks after the event. They are still there and are still filling up and they are really becoming more and more of a risk."</i>
	O	<i>"We investigated the sites and decided that a monitoring system was the best way to go forward and we used Harvest Electronics, they put together a monitoring and alarm system."</i>
Support lacking	O	<i>"It was very much GNS and NIWA advice straight to the controller and I guess recovery wasn't fully set up then but it would have been good for the Geotechs to be involved like the people that were involved going forward."</i>

5.11 Summary

This chapter has discussed the results and observations from the data gathered through key informant interviews. Nine key themes were discussed through the chapter, those themes are: roles and responsibilities; communication; co-ordination; resources; previous experience; community involvement; information and data; relationships; and long-term management. The themes were identified as being a significant part of the response to the landslide dams and applicable to improving preparedness for future events.

The analysis presented in this chapter indicates that there are improvements that can be made for landslide dam event planning processes and procedures. The following chapter will discuss recommendations for increasing preparedness for future landslide dam events and suggestions for improving response procedures if an event occurs. The recommendations are based on the learnings described throughout this chapter.

Chapter 6 - Recommendations

6.1 Introduction

This chapter presents a discussion around recommendations for future responses to landslide dams. This will fulfil one of the objectives of this research which is:

- Develop recommendations based on lessons learnt from the Kaikoura earthquake to inform future landslide dam response planning and increase preparedness for future events, whether that be a single landslide dam or multiple.

The investigation of the response to the Kaikoura earthquake landslide dams has highlighted areas which can be improved as well as identifying new concepts to create a more effective response. Both difficulties and successes identified through interview data analysis provided the substance for these recommendations. The recommendations presented in this chapter will facilitate improvements for future events and increase overall preparedness from both responders and the public.

Response preparation for future landslide dam events will need to remain adaptable to a variety of situations, hazards and applications. Procedures or recommendations developed for a response must be flexible to deal with unexpected circumstances. That way they can effectively transfer to any landslide dam event be it a singular dam from a rainfall event or over 200 dams from a strong earthquake. Changes made to response procedures or preparations need to be well documented so that new methodologies can be communicated between all agencies involved in a response.

As the response to the landslide dams in Kaikoura is fresh in people's minds, it is important to capture the experience gained through the response. Response experiences need to be documented so that the knowledge can be integrated into policies, plans, procedures and guidelines. If the personnel involved in the Kaikoura event are not available, or have left an organisation by the time the next event occurs, then their experience and learnings should still be available to be used and built on.

Whilst the recommendations are based around responding to a landslide dam event, many of them could be transferable to other types of natural hazard response.

6.2 Clarify Responsibilities

One of the most challenging parts of the Kaikoura response was confusion around responsibilities. The majority of interviewees commented on the need for clarity of responsibilities. It is imperative to an effective response that individuals and agencies clarify their responsibilities and roles during a response prior to the event. Appropriate planning before an event can ensure that there is little uncertainty around responsibilities.

There are several ways in which understanding about responsibilities can be clarified. These include response plans, meetings or workshops, education and event exercises. Such initiatives can increase communication and interaction between people which means they are integrating and discussing roles prior to an event (Becker et al., 2017).

It was suggested by several interview participants that there is a necessity to educate agencies involved in emergency response around the responsibilities of each agency or organisation. This training would need to include the level of responsibility for different agencies. For example, providing clear designations between local, regional and national levels within the CDEM structure. Increasing clarity around roles prior to an event reduces time wasted during a response.

As well as educating responders it would be beneficial to have emergency action plans that set out both individual and organisational responsibilities. These types of plans were developed in the response to the Young River dam (Palmer, 2007) as discussed in Chapter Three. It would be preferable to set these out prior to events to increase preparedness through planning. These plans should be shared across agencies to allow for understanding between agencies of each other's responsibilities and include clear lines of responsibility that are easy to follow in an often-stressful situation.

6.3 Response Procedures

The Kaikoura event demonstrated that there were limited formal response procedures in place to deal with the landslide dams. Most of the response was led by people who had previous experience responding to them. As landslide dams are a constantly changing hazard, response plans which are established prior to an event need to have flexibility. Every event will be different and will require a modified response.

Planning should consider several essential questions, which are:

- What are the main hazards?
- Which communities are at risk?
- What are the likely consequences on that community
- What can be done to mitigate the risk?

Response planning prior to an event needs to include all agencies so that a response is co-ordinated and there is consistency in how the response is undertaken. Ideally teams of people with experience should be assigned to tasks prior to an event so that when they occur there is no delay in response or confusion around responsibilities.

Several interviewees made suggestions related to response planning, these included:

- Develop standard operating procedures which outline the response for landslide dams and are placed in the EOC and ECC;
- Use the worst-case scenario for planning as it is easier to scale back a response from the plans than to scale up a response;
- Develop some form of checklist which defines important tasks or responsibilities to help guide the response and can be referred to at the start of a response;
- Include in the response plans a list of emergency contact information with details on the role of each person; and
- Create paper copies of any types of plans, checklists or guidelines which are produced, so that in the case of power failure, internet or, phone signal outages everything is still accessible.

Although planning prior to an event could increase preparedness and clarify many areas of confusion before an event it can be hard to know quite what will occur in an event and if the plans will be applicable. Planning can involve spending time and money on something that when it eventuates is very different from what the plan covers.

The response to the Ruapehu lahar dam break flood event in 2007 demonstrated the benefits of planning prior to the event taking place as the response was carried out successfully with no deaths or significant damage. This was a unique case in that there were defined parameters to plan around (Becker et al., 2008), with far less uncertainty than planning for landslide dams created by an earthquake or rainfall. However, the principles of planning for the Ruapehu event could be used for future dam break flood events.

6.4 Hazard Modelling

Hazard modelling prior to an event can vary greatly. It might be no more than a simple process of identifying rivers of likely concern due to downstream populations or historic evidence of previous events in a catchment. Or, it can be more technical using computer based modelling to forecast dam formation based on the data input to the modelling software. The methods used for hazard modelling may vary depending on the technical resources, the potential risk from landslide dams, the terrain, seismicity levels, rainfall and history of landslide dams.

Several interviewees suggested that the use of hazard modelling for future events could be a valuable tool to provide greater knowledge of where landslide dams might occur. This would enable attention and resources to be focused on locations where people or infrastructure could be at risk from upstream inundation or downstream dam break floods. Examining at-risk catchments prior to future events would allow for those catchments to be prioritised for assessment immediately after an event, before full scale reconnaissance starts.

Hazard modelling could be carried out as a simple desktop study with a Geographical Information System (GIS) to determine which riparian slopes are susceptible to instability and could potentially cause a dam across a river. Such a model could incorporate various earthquake intensity levels, different weather events, ground saturation and many other components such as ground material and river flows. Hazard modelling could initially focus on areas where communities could be affected as it would help to know where evacuations may be needed in the future before considering risk to infrastructure.

If a computer based model could predict a pre-event estimation of landslide dam locations and numbers, depending on magnitude of an earthquake, it would allow for responders to know where dams could be expected and what sort of issues could be anticipated. A hazard modelling tool to forecast dam formation would be a useful instrument for decision making processes and management of emergency events. Dal Sasso et al. (2014) examined the use of computer based modelling for predicting the occurrence of landslide dams on a case study in Basilicata, Italy. It was found that while it is possible to forecast the likelihood of a landslide dam the accuracy depended on the data that was available (Dal Sasso et al., 2014).

The development of a semi-automated forecasting tool could be a valuable instrument not just prior to the event but also after an event has occurred. When an event occurs a modelling system could swiftly model the potential landslide dams based on actual event data such as magnitude of earthquake, epicentre location and recent rainfall data. If such a tool could be developed it would reduce how much time had to be spent in the field in the initial response

trying to identify the landslide dams. Potentially when the Alpine Fault ruptures a very large area will be affected and a hazard modelling tool would be immensely helpful for the immediate response to know where to look first.

6.5 Panel Agreement

Following the response to the Kaikoura landslide dams several interviewees commented on the possible development of a panel agreement for future events. The concept behind a panel agreement is to pre-establish a group of organisations and consultancies with experience and knowledge of responding to landslide dams who can respond to a large-scale event at short notice.

Having a panel agreement in place would mean there will be resources quickly available who are known to the councils or CDEM and have the required skills and experience. A panel agreement means that assistance is always on call with a significant number of back-ups in the case of a large-scale event. Having a panel agreement in place pre-event, eradicates problems around contracts and liabilities that otherwise take time to set-up and discuss. If those mandatory processes are set-up in advance then those personnel required for the response can respond immediately given an instruction to do so.

The development of the Port Hills Geotechnical Group (PHGG) following the Canterbury earthquakes is a useful example of how a panel agreement can be of great value in a response. The PHGG was contracted by the Christchurch City Council (CCC) and included eight local geotechnical consultancies in the Christchurch region and was supported by GNS Science (Gibbons & Kingsbury, 2013). It meant that the Christchurch City Council had a group of experienced consultants on hand to respond to post-earthquake emergency events such as large aftershocks and flooding events.

The PHGG panel agreement was a very successful part of the response to earthquake land damage in the Port Hills. The formation of the group led to excellent working relationships both internally and externally as well as working collaboratively with key stakeholders (Macfarlane & Yetton, 2013).

Based on the success of the PHGG, the Christchurch City Council created a formal panel agreement with the Slope Stability Engineering Panel (SSEP) using six geotechnical consultancies. There are several key components to the SSEP panel which make it a useful model for an emergency response.

These components include:

- Consultancies committing key personnel with experience to emergency response operations;
- A 24/7 roster with SSEP geotechnical consultants on call;
- Alignment with emergency services and other emergency response groups to activate the SSEP to assist in any response (which occurred during the Kaikoura earthquake) (Wright, 2015).

When a panel agreement is in place everyone on that panel is working cohesively and with a final goal in mind. Often there can be a competitive atmosphere between consultancies working on the same project but when everyone is put together under the same contract it removes some of that competitive nature.

A regional CDEM led panel agreement would be of value in setting up an agreement pre-event. This would ensure that established contracts are in place and would allow for extra resources to be pulled into a response without any time delay for contractual negotiations. If councils or CDEM had panel agreements established prior to an event, then agreement could be reached in advance on the issues to be focused on in the event of landslide dams.

6.6 Geographical Sectors Planning

The development of geographical sectors alongside a panel agreement structure could be a successful way of co-ordinating a response across a large geographic area. Geographical sectors were used after the Christchurch earthquake in the Port Hills with the PHGG and continued with the change over to the SSEP. Division of the area potentially affected by landslide dams into sectors would be useful in assisting with co-ordination and deployment of resources. It would also help in prioritising assessments as well as helping to avoid duplication of work being undertaken.

Whilst it would take time to determine how to split areas up based on potential hazards, hazard modelling could assist with developing geographical sectors. Some areas are more prone to natural hazards than others. Areas more prone to dams may need to be split up into smaller sectors, otherwise the work load in one sector could be overwhelming compared to others. Factors which can influence the number of sectors required include: the severity of the event; the extent of landslide dams; location of infrastructure vulnerable to the hazard; and availability of response resources.

For areas or regions predicted to be at risk from landslide dams, such as the Alpine Fault in the South Island, it would be useful to split the area into sectors prior to a potential event. If sectors are established pre-event they would need to remain flexible so that they can be adjusted to the damaged areas. The use of computer based hazard modelling, as already discussed, could be used to help define sectors across a region based on potential hazards. Geographical sectors could be included as part of a CDEM response plan and whilst it could be beneficial long-term for many hazard types it would take time and work to establish those sectors.

6.7 Workshops

Running workshops focussed on responding to landslide dam events could be beneficial for: developing pre-event planning processes; building relationships; clarifying responsibilities; running event exercises; and training and improving communication. An annual workshop could bring responders together from all different agencies and organisations to improve awareness around the hazard, understand everybody's capabilities and develop and practice ways of co-ordinating together for a response, as well as getting to know each other. Building trust through person to person contact should not be underestimated.

Workshops would allow for understanding to be gained about the capabilities and responsibilities of each organisation in a response. Many interviewees could not outline what each organisation could do, the skills they have, the equipment, resources and services they could provide. Such workshops would be useful for linking up what the science sector and the consultancies can each bring to the response.

Workshops are already occurring within the Project AF8, which is a CDEM-led response initiative, planning for a future Alpine Fault earthquake (Orchiston et al., 2016). Personnel involved in responding to natural hazard events are gaining an understanding of potential hazards from an Alpine Fault event through the information given during the workshops. Several workshops for multi-agency earthquake response planning have been held throughout the last year and include participants from a range of backgrounds including, emergency managers, earthquake scientists, government agencies, emergency services, infrastructure providers and iwi/runanga groups (Project AF8, 2015).

The Project AF8 workshops are a valuable opportunity to discuss the implications of landslide dams. However, they also need to be considered outside of Project AF8 as dams occur not just

from earthquakes, but from heavy rainfall as well as idiopathically and outside the region that the AF8 is focused on.

It was found from the Kaikoura response that pre-existing relationships were beneficial and it would therefore be recommended to build on those relationships as well as develop new relationships prior to future events. Running workshops and meetings can be valuable in building relationships as they are a chance for people to meet others who could be involved in a future response.

An idea that was suggested from the interviews was for science sector representatives such as GNS Science talking with councils likely to be impacted by landslide dams to discuss the hazard with them. This could give councils an overview of the hazard, the processes around responding to them, key information that is required for risk assessment, the methodology of collecting data and their responsibilities. This approach might achieve better involvement from the councils if someone is prepared to go to them. It would take less time and money than them having to attend a remote workshop.

6.8 Training

It became clear from the interviews that many of the responders to the Kaikoura landslide dams lacked understanding in one area or another. Whether it was their own responsibilities, the responsibilities of others, communication techniques, general CDEM procedures or technical understanding around the risk from landslide dams. To remedy these deficiencies, it is recommended that education is provided before the next event to increase preparedness and inform responders of best practice. To keep training consistent across different agencies the development of standard operating procedures or response plans would assist with educating responders.

Whilst consistency in educating responders is important, training also needs to be targeted to certain agencies. For example, for regional councils there are specialist interest groups which meet a couple of times a year. These meetings could be used to hold presentations and have targeted sessions around landslide dams, to discuss ideas such as the long-term management of the hazard and the best practice approach for engagement with communities.

Simple training in CDEM response procedures would be valuable for individuals, agencies and organisations not familiar with responding to events alongside CDEM. This would be helpful for personnel to understand their role within the emergency management system and increase

their knowledge around the New Zealand Co-ordinated Incident Management System (CIMS). By increasing this knowledge, a greater understanding could be developed around responsibilities in the response and communication requirements during the response both to CDEM and the public.

One aspect that was highlighted through the Kaikoura response was the need for training for some agencies in public communication. Training prior to the event around public communication would be beneficial to provide clear, concise and consistent messaging to affected residents, the general public and recreational users. Training would need to include the best methods of messaging as many people as possible as well as message content.

It was felt by many participants that the best form of training is practical, hands on experience but that is hard to do during an event as people do not have time to train others. A good substitute would be to have simulated events with neighbouring councils. This type of practice would facilitate the enhancing of relationships, gaining an understanding of who people are and what people are meant to be doing. Planning for the response to the Ruapehu lahar event included running exercises to practice response procedures. This was found to help address issues that arose through practicing as well as building relationships (Becker et al., 2008). The next stage of the Project AF8 which is currently being developed and will present an opportunity for training for such events.

6.9 Public Education

To increase preparedness for a landslide dam event in the future it is important to educate the public about potential risks. This will allow affected populations to have a better understanding of what is happening when it occurs. As landslide dams were not a well-known hazard in New Zealand before the Kaikoura earthquake there was a lack of understanding around the dams by the public. During the response it was found hard to convince people how serious the risk from the dams could be because there wasn't much publicity about them. Increasing understanding prior to the next event would have advantages in the response.

There is a statutory requirement to communicate risk to the public and it was thought by several interviewees that the responsibility to do that is taken too lightly. The public should be aware that landslide dams are something that can happen very quickly and that they can cause problems to people residing in certain areas. It is recommended that there should be a better

public education program in New Zealand about natural hazards and the landslide dams should be a part of that.

Educating the public on what to look out for and what to do if they see something of concern, means they can be useful in an event. The public are likely to know their local area better than officials and will often spot differences in the landscape or river flows before an external responder. It is therefore important that the public are educated on reporting dams, or symptoms that may indicate a dam, to the appropriate authority (normally their regional council) who then have the ability to request experts to assess the risks.

Some pre- prepared fact sheets could be developed that cover what can occur, what the risk looks like in the short term, what it means, key things that people need to be aware of and some key messages about dams. It was found during the readiness phase of the Ruapehu lahar event that a greater effort should have been made to provide information to the public prior to the event (Becker et al., 2017). In summary it is a short message, if the stream flows change then there is a potential dam upstream and you should notify somebody.

As well as educating the public before an event to increase their preparedness, messaging could be prepared in advance to be used during a response. With the potential for an Alpine Fault earthquake it would make the response more organised if messaging for the public, affected communities and recreational users were to be planned in advance.

6.10 Resources

Several interviewees commented on various resources which would be helpful to have in future events. By arranging them prior to a future event the response could track effortlessly and not be held up by a lack of equipment or tools.

LiDAR mapping of the whole of New Zealand would be an extremely useful and practical tool for multiple agencies. Gathering LiDAR data regularly would mean that post-event a new LiDAR run would easily identify areas of damage which could allow resources to be prioritised to those areas sooner. This process must be carried out before an event so that the data is up to date. The use of LiDAR could be valuable to a multitude of different hazard types including most forms of land damage.

It was suggested that an Engineering Meteorologist would be valuable in the response, if immediately available after the formation of the dams. Having someone who has an understanding and experience of New Zealand weather patterns and how to model really

localised forecasts. This would mean being able to better understand what could be encountered in the field but also forecasting how the weather will impact landslide dams with lake levels rising from rainfall.

Finally, organising landslide dam kits would mean that equipment could be rapidly deployed. The landslide dam kits could include cameras for monitoring, lake level recorders, trip wires and rain gauges as well as other essential equipment. The landslide dam kits would only need to contain basic monitoring equipment until a more permanent solution could be installed. This would allow for monitoring in the immediate response without needing to rely on suppliers to deliver monitoring equipment at short notice.

6.11 Database

During the response to the Kaikoura landslide dams the development of the online GIS database created by Environment Canterbury Regional Council (ECAN) worked well for assembling data which was being collected in the field. This system could be developed further to become a data management system accessible to all agencies responding in the EOCs and ECCs as well as those out in the field. Such a system or database could help to inform emergency management decisions and provide real time data as it is collected in the field straight into the database.

A similar system was developed after the Canterbury earthquakes for data collection and later hazard modelling in the Port Hills. Whilst this database was set-up after the earthquake occurred it could be used as a case study to build a database prior to another event. The GIS database developed for the Christchurch City Council enabled efficient and reliable data management and allowed for a rapid initial indication of the extent of land damage. This system automatically included information such as GPS co-ordinates and was found to significantly reduce time taken in the field to input data (Gibbons & Kingsbury, 2013).

This type of GIS system could easily be transferred for the response to landslide dams and it would give a faster and better understanding of the scale of damage. Having one database for everyone to work from would mean that all information could be stored in one place and responders could pick and choose what they need for their part of the response, whilst still being able to access other parts of the data that might influence their role.

There is a lot of technology available now with smart phones and tablets that responders can use out in the field. With a GIS database information could be available to responders

anywhere at any time. This would enhance efficiency out in the field collecting data and enable people to use that data immediately to make decisions.

A database may be developed in the aftermath of an event, but the systems to set-up such a database need to be planned prior. This would require obtaining and updating information from local and regional authorities. But it would allow for immediate establishment of a tool to be used in the field.

6.12 Information Sharing

Information sharing through the response to landslide dams in the Kaikoura region worked well overall as the data collected was open to those who needed it. However, improvements could be made to the methods of sharing that information. Part of the reason for developing a database system during a response is that it gives a way of information sharing between agencies when everyone has access to the same database.

It is recommended that a common GIS database system is developed which all agencies can feed information into but also take information out of. It is something that could be set-up pre-event but would need to be activated with the right information and layers based on the event and the location.

A database system would facilitate inter-agency information sharing allowing for quicker analysis and creating new information for other agencies to benefit from and support an effective response. The development of information sharing platforms has been successfully undertaken by national governments around the world (Coppola, 2015). Once established in New Zealand the same systems of information sharing could be utilised for response to any form of disaster.

6.13 Summary

This chapter has outlined several recommendations for increasing preparedness for landslide dam events and improving response activities if an event occurs. These recommendations have come from the learnings of the response to the Kaikoura landslide dams as well as reviewed literature.

The analysis of the Kaikoura landslide dams event indicates that there are improvements to be made to both pre-event planning processes and procedures as well as post-event response

techniques. Such improvements can result in the response being more efficient and enhance co-ordination and communication as well as general understanding of the responders. The following chapter summarises the research which has been undertaken throughout this thesis before discussing some thoughts around future research which could improve responses to landslide dams.

Chapter 7 - Conclusions

7.1 Introduction

The purpose of this research was to examine the emergency response to and management of the landslide dams created by the Kaikoura earthquake to inform planning and preparedness for response to future landslide dam events. The objectives of this research were to:

- Examine emergency responses in previous landslide dam events leading to dam break floods in New Zealand and internationally to baseline similarities and differences in response processes through a literature review.
- Study the emergency response and management of the landslide dams created by the 2016 Kaikoura earthquakes including the procedures and processes undertaken and co-ordination between agencies.
- Examine the effects of a multi-hazard event on the emergency response and how long-term management is considered as a part of the response.
- Based on lessons learnt from the Kaikoura earthquake, develop recommendations to inform future landslide dam response planning and increase preparedness for future events, whether that be a single landslide dam or multiple.

Chapter One provides the background for this research including an overview of the Kaikoura earthquake event, the geological context of the area, and the impacts and associated risks from landslide dams. Chapter Two sets out the methodology of the research. It examines how the interviews were conducted and the analysis of data was undertaken. Chapter Three discusses the theoretical background for the research looking at historical case studies and general emergency response procedures.

Chapter Four gives an overview of the emergency response to the landslide dams from the Kaikoura earthquake based on literature and news article review, including a timeline of events. Chapter Five compiles the results from the interviews and discusses the nine themes selected from the data. Chapter Six discusses recommendations based on the findings of the interview data, including: planning; hazard modelling; training; a panel agreement and a country wide database. This chapter provides conclusions on the research outcomes and recommendations from the findings before suggesting subjects for future research.

7.2 Conclusions

The Kaikoura earthquake on the 14th November 2016 resulted in significant land damage across a large geographical area including over 200 landslide dams. The landslide dams caused damage to infrastructure downstream and buildings upstream but fortunately caused no injuries or deaths. Due to the scale of the event and the potential risk to people and property the emergency response was considered a high priority in the context of the overall response to all earthquake related damage.

Landslide dams are not an uncommon event in New Zealand with several case studies explored through the literature review. The number of landslide dams and the scale of the Kaikoura event was unusual and required an extensive response. The scale of damage was not expected by many of those responding to the landslide dams. The response to the landslide dams involved many agencies working together in a co-ordinated way as well as individually working on separate parts of the response. For this research responders from ten different agencies and organisations were interviewed to appreciate the widest range of roles in the response.

Investigation of the response to the Kaikoura landslide dams indicated that there were several challenges as well as successes. The challenges included communication and co-ordination, a lack of understanding about roles and responsibilities both within and across agencies, lack of experienced staff available to respond and a lack of local staff engaged in the response. These challenges, as well as several others, caused problems in the response. Although the response was successful and no one was injured or killed from a landslide dam breach event, it is important to identify problems that occurred to improve future responses.

There was a significant lack of understanding about roles and responsibilities within agencies as well as between agencies. This created confusion and slowed down the response whilst working out who was dealing with which parts. Also, responsibilities kept transitioning between agencies which did not help. Those people who did understand their responsibilities had previous event experience. This assisted greatly in knowing who should be doing what and keeping clearly defined roles within their agency. Formal systems for the response would help to define the different roles and responsibilities of each agency before the event occurs.

Good communication was imperative throughout the response and overall worked well. There were some problems with Kaikoura being isolated and a lack of consistency in staff meant that sometimes there was a lack of knowledge. The use of communication as a mitigation tool was important but there was certainly room for improvement, on how information was being translated for public consumption.

The co-ordination of the response had to be flexible as the situation was dynamic due to the type of hazard and this was compounded by the large number of landslide dams. As the response developed the co-ordination improved due to a greater understanding of the risks and the roles of different agencies.

Other than the use of helicopters for field inspections the main resource required in the response was people. External staff had to be bought in as local resources were stretched. This meant local knowledge was not utilised to its full potential especially when working with affected communities. As people were the main resource used in the response it was critical that they were well managed. Fatigue and safety were closely monitored through the response which was learnt as a necessity from the Canterbury earthquakes.

The potential impact of the landslide dams was initially underestimated, perhaps due to a lack of experience about the hazard they presented. Initially the focus was much more on other earthquake related damage. It was not only a lack of knowledge about landslide dams which caused problems, but a lack of knowledge about emergency response procedures lead to misunderstandings and a deficiency in communication to the public.

It was found that having pre-existing relationships helped during the response but were not essential in making sure the response a success. Many of those relationships came from the Canterbury earthquakes six years earlier, and that brought greater clarity to the response as people had an understanding of others' skills and role in the response. Having those pre-existing relationships made the response more efficient by removing the need to get to know and trust other responders.

A notable success of the response was how involved the affected communities were. It was seen as an important task to keep them involved through the process, by sharing information with them and helping them to understand the risks that they faced. Also involving them in the evacuation planning and mitigation meant that they took ownership of these aspects.

The importance of sharing information was realised early in the response and worked effectively with the development of a GIS based database. This was used to keep track of the dams and collect all the ongoing information on them. As so many agencies were working on the response having one source of information for all work meant that there was consistency and an openness with the data. This reduced work being repeated unnecessarily.

Whilst the investigation of the response has shown up several challenges and areas for improvement it also highlighted successes based on learning over time and from previous

events. This event has demonstrated that lessons have been learnt from other emergency responses such as the Canterbury earthquakes and indicates that the lessons from Kaikoura can be used to improve a future response.

New Zealand has a history of earthquake and rainfall induced landslide dams. However, the Kaikoura event demonstrated the large number of dams that can occur at once and the impact those dams can have on the landscape and built environment. Many other areas within New Zealand are situated within mountainous terrain with large active fault lines through them. There is thus the potential for similar if not larger landslide damming events to occur so it is necessary to increase preparedness for these types of events. To inform further enhancement of response processes and procedures for emergency management response to landslide dams a series of recommendations have been developed.

Recommendations for responding to future landslide dam events have been based on the review of historical events, review of media articles following the Kaikoura earthquake and the analysis of interviews conducted with responders to the landslide dams. The recommendations are detailed in Chapter Six, the most significant are:

- Clarification of responsibilities
- Hazard computer modelling
- Panel agreement and geographical sector planning
- Workshopping and building relationships
- Training
- Development of a database and information sharing

Based on the recommendations, further work and research will provide greater understanding of the impacts those recommendations could have on improving a response and increasing preparedness.

The value of this research is that it has captured many components of the response to the landslide dams covering a broad range of topics within emergency management. This research has identified several areas which can be improved for future events with lessons learnt from Kaikoura throughout all the agencies involved. This research has contributed useful discussions and recommendations which could be developed further for a future Alpine Fault earthquake research to develop best practice in New Zealand.

7.3 Future Research

This research has provided initial understanding about the emergency response and management of landslide dam events following the Kaikoura earthquake with a broad overview of the whole response. The aim of this was to inform development of planning procedures for response to future events and to use the data gathered to increase preparedness for both the responding agencies, the public and at-risk communities. To support these intentions further research would be valuable to gain additional knowledge. This research could include:

- Further research regarding the response processes and procedures relating to the long-term hazards that landslide dams pose if they have breached or not. Responding to flooding events, extra sediment in the system or breaches of the dam if still in place. Such research should consider who is responsible for that response and what planning is in place for responding to those on-going hazards.
- Further research into the use of computer based hazard modelling. Modelling could significantly reduce time spent in the field searching for landslide dams allowing resources to be prioritised to the highest risk areas. It would be interesting to research to what extent the modelling results could improve the emergency response and reduce impacts on communities.
- Further research in how to retain and encapsulate the experience and knowledge gained through the group of agencies working together on the emergency management response. This is known as institutional memory and will enable the learnings from previous events to be used, even if it is not the same group of people responding. Often individuals will change work places and their learnings go with them. The development of an appropriate knowledge management tool could be used to capture and preserve experiences for future use.
- Further research to undertake a proof of concept for the development of a panel agreement as discussed in Chapter Six. This could include examining the methods behind a panel agreement as well as the concept of geographical sectors for responding to an Alpine Fault earthquake event.

The research results from this thesis and further research could help to develop a clearer understanding of processes and procedures for responding to landslide dams. Improvements can be derived from the lessons of the Kaikoura event leading to an increase in preparedness of responders from different agencies and communities prior to the next event such as an Alpine Fault earthquake.

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Appendix A. – Interview Questions

Interview Questions for Masters Research

Emergency Management Response to the Kaikoura Landslide Dams Following the 14 November 2016 Earthquake Event

Introductory preamble

- Provide the interviewee with the structure of the interview
- Get their name, organisation(s), position(s) and 'title/role(s)' in the respect of the response.
- Ask their views generally on the response, and any issues that they have regarding the response, multiple groups involved, types of decisions, time frames.

NB: Need to find out:

- how do they know that?
- Why do they say that?
- What evidence can they provide to support their observations in respect to the response?

Topic Areas

1. Roles and responsibilities of individuals and organisations
2. Processes and procedures
3. Coordination across a multi-agency response
4. Multi- hazard event (i.e. ongoing aftershocks, rainfall and multiple landslide dams)
5. Long-term management and impacts
6. Lessons learnt
7. Preparedness for future events

Topic 1 – Roles and responsibilities

Q1. What was the role of your organisation in the emergency management response to the landslide dams?

Q2. What was your individual role in the emergency management response to the landslide dams?

Q3. Was the chain of command planned? And if so how did the process work from your perspective? (within your own organisation, and for the response in general)?

Q4. Were there other resources involved in the emergency management response by your organisation (human resource, equipment and supplies)?

Topic 2 – Processes and Procedures

Q5. Can you tell me how the emergency management response to the landslide dams unfolded for you (the story from your perspective)?

- 5a. At what stage in the response did you become involved?
- 5b. Outline the key processes that you personally undertook in the response (include examples)?
- 5c. How well did the systems that your organisation already had in place work for this response?
- 5d. Have the affected communities been involved in the response and if so in what ways?

Q6. Can you explain the post event planning put in place for potential landslide dam failures (assessment, monitoring, mitigation and evacuation etc.)?

Topic 3 – Co-ordination across a multi-agency response

Q7. How was the response co-ordinated?

- 7a. Did you work with personnel from other agencies and to what extent? In a coordinated fashion? (was your role dependant on relationships with others)?
- 7b. What methods were used between the multiple agencies and organisations involved (meetings, conference calls, emails)?

Q8. Can you please explain the processes around communication between the agencies, including:

- Method(s)
- Expectations regarding speed, timing and level/type of content
- Responsibilities
- Personal contacts/relationships and the lines of communication with any/all of these others

Q9. How well has the co-ordination between multiple agencies worked (scale 1-5) and can you give some examples?

- 1. Extremely well

- 2.Better than expected
- 3.As expected
- 4.Worse than expected
- 5.Poorly

Q10. From your experience with the emergency management response can you suggest ways in which coordination between agencies can be improved?

Topic 4 – Multi-hazard event

Q11. Do you think the emergency management response to the hazards posed was modified by the existence of multiple high risk dams compared to a single dam?

Q12. Are there ways in which you think the response could have been improved to cope with the multiple occurrence of landslide dams?

Topic 5 – Long-term management and impacts

Q13. Do you anticipate that there will be long-term effects arising from the landslide dams which will require emergency management responses and what would these be likely to be?

Q14. Since the event, have emergency management response plans been developed for the long-term and if so can you describe their main components?

Topic 6 – Lessons Learnt

Q15. Within your organisation was there any pre-event planning around emergency management of landslide dams? If so was this useful in this event?

Q16. What lessons have you learnt from this emergency response?

- 16a. About your/your agency's systems and processes?
- 16b. About your training or development needs (personal and organisational)?
- 16c. Will your experience lead to further development of your emergency response capability?
- 16d. Are there any other areas in the response that you think could be improved for a future event (and if so what)?

Topic 7 – Preparedness for future events

Q17. How do you think you could be better prepared for a similar future event?

- 17a. What sources of information do you feel could be developed to promote better preparedness should such an event occur again (e.g. community awareness, land use planning)?
- 17b. Can you think of any other resources (organisations, people, equipment or systems) which would have assisted in the response that you did not have access to?
- 17c. Do you have any thoughts about future education/training/simulations or tools which could help in future events?
- 17d. Do you have any other suggestions for improvements towards greater preparedness?

Further comments or areas of interest

Any further issues or comments which haven't already arisen

Appendix B. – Interview Information Sheet

Kaikoura Landslide Dams Emergency Management Response Research Interview Information Sheet

The M7.8 Kaikoura earthquake on Monday 14th November resulted in multiple landslide dams forming across the Canterbury and Marlborough regions and the Hurunui, Kaikoura and Marlborough districts. This research will explore the emergency response to and management of the landslide dams and the ongoing risk of dam break floods from the Kaikoura earthquake.

The key areas of interest for this research are:

- Roles and responsibilities of individuals and organisations
- Processes and procedures
- Coordination across a multi-agency response
- Multi- hazard event (e.g. ongoing aftershocks, rainfall and multiple landslide dams)
- Long-term management and impacts
- Lessons learnt
- Preparedness for future events

The outcomes of this research will use experience from the Kaikoura event to help plan for future large scale events and increase levels of preparedness in New Zealand.

To collect information on the emergency management response to the Kaikoura landslide dams, interviews will be carried out with key personnel from a range of organisations and agencies involved in the response. Your participation in the interview will help ensure that we can learn from an important event and increase preparedness for future events.

Participation in the interview is entirely voluntary and you may refuse to answer any question in the interview or choose to withdraw from the study at any time. Although the interview will require recording some personal details these will not be used in any way during reporting. All information will be kept confidential and only general trends will be reported on. As a result, there is no way in which your responses will be identifiable in any research outputs.

This project has been evaluated by peer review and judged to be low risk. Consequently, it has not been reviewed by one of the University's Human Ethics Committees. The researcher(s) named in this document are responsible for the ethical conduct of this research. If you have any concerns about the conduct of this research that you want to raise with someone other than the researcher(s), please contact Dr Brian Finch, Director (Research Ethics), email humanethics@massey.ac.nz

Should you wish to find out any additional information regarding this study, please do not hesitate to contact myself Luci Swatton or the Massey University supervisor of this research David Johnston.

For further information, please contact Luci Swatton at:

[REDACTED]

Or Dr David Johnston at:

Phone 04 570 1444 or Email david.johnston@gns.cri.nz

Appendix C. – Interview Consent Form



Emergency Management Response to landslide dam-break flooding following the 2016 Kaikoura earthquakes

Participant Consent Form - Individual

I have read the Information Sheet and have had the details of the study explained to me. My questions have been answered to my satisfaction, and I understand that I may ask further questions at any time.

- I agree/do not agree to the interview being sound recorded.
- I wish/do not wish to have my recordings returned to me.
- I agree to participate in this study under the conditions set out in the Information Sheet.

Signature:

Date:

.....

Full Name - printed

.....