

An overview of the impacts of the 2010–2011 Canterbury earthquakes



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ABSTRACT

A magnitude 7.1 earthquake struck the Canterbury Region of New Zealand at 4:35 am on 4 September 2010. It was centred 11 km beneath the rural town of Darfield, on the Greendale fault, which was previously unidentified. Christchurch City lies 40 km east of Darfield, and was home to a population of approximately 370,000 at the time of the earthquake. There was extensive damage as a result of the MM9 shaking, particularly to buildings and infrastructure, but fortunately there were no deaths. The residents began the recovery process, plagued by frequent aftershocks. Then, more than five months after the mainshock, on 22 February 2011, a M6.3 aftershock occurred 5 km south-east of Christchurch at a depth of only 5 km. This earthquake struck at lunchtime on a working day, causing catastrophic damage to the city, and resulting in 185 deaths. Most of these casualties occurred as a result of the collapse of two large office buildings, with further deaths resulting from falling bricks and masonry, and rockfalls in city suburbs. The M7.1 earthquake and associated aftershocks have caused extensive impacts on the local built, economic, social, and natural environments. The on-going aftershocks have also caused a disrupted environment in which to recover. This paper will outline the nature of the Canterbury earthquakes and provide an introduction to the ongoing effects the earthquakes have had on these local environments to help frame the growing body of research coming out of the Canterbury earthquakes.

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1. Introduction

On 4 September 2010 a moment magnitude (M_w) 7.1 earthquake occurred near the small town of Darfield in the Canterbury Plains of the South Island of New Zealand ([21]; Fig. 1). While many older brick and masonry buildings were damaged and approximately 100 people were injured in this earthquake, there were no associated deaths. This is largely due to the earthquake taking place in the early hours of the morning when residents were in bed, and due to the distance of the earthquake from major urban areas. An aftershock sequence was initiated, which included a catastrophic M_w 6.3 earthquake on 22 February 2011 beneath the city of Christchurch, killing 185 people.

The Canterbury earthquake sequence caused severe and on-going impacts on the social, built, economic, and natural environments in the region. The purpose of this paper is to provide the context for this special issue on the Canterbury earthquake sequence using the initial findings from the Canterbury Earthquake Recovery Authority (CERA) Wellbeing Survey reports and

other relevant literature that has come out since the sequence. It begins with a description of the earthquakes and the social setting of the Canterbury Region. It then reviews some of the initial and ongoing impacts on the aforementioned local environments related to these events. By providing this broad overview of the local environment impacts this article will provide a means by which researchers can understand the related contextual issues linked with the recovery process as well as an overall context for understanding and the literature being written about these events and the local recovery.

1.1. Geological setting and historical earthquakes

The South Island of New Zealand lies on a zone of continental convergence, with the Pacific tectonic plate in the east subducting beneath the Australian plate in the west under the northern South Island, and the reverse happening in the southern South Island, with the Australian plate subducting beneath the Pacific plate. The right lateral strike-slip Alpine Fault is the interface of the convergence, stretching for 650 km through the Southern Alps. It has a recurrence interval of approximately 200–300 yr for major earthquakes ($M > 7.5$), and most recently ruptured in 1717 (e.g., [53,46]).

Other nearby faults have ruptured during historical times,

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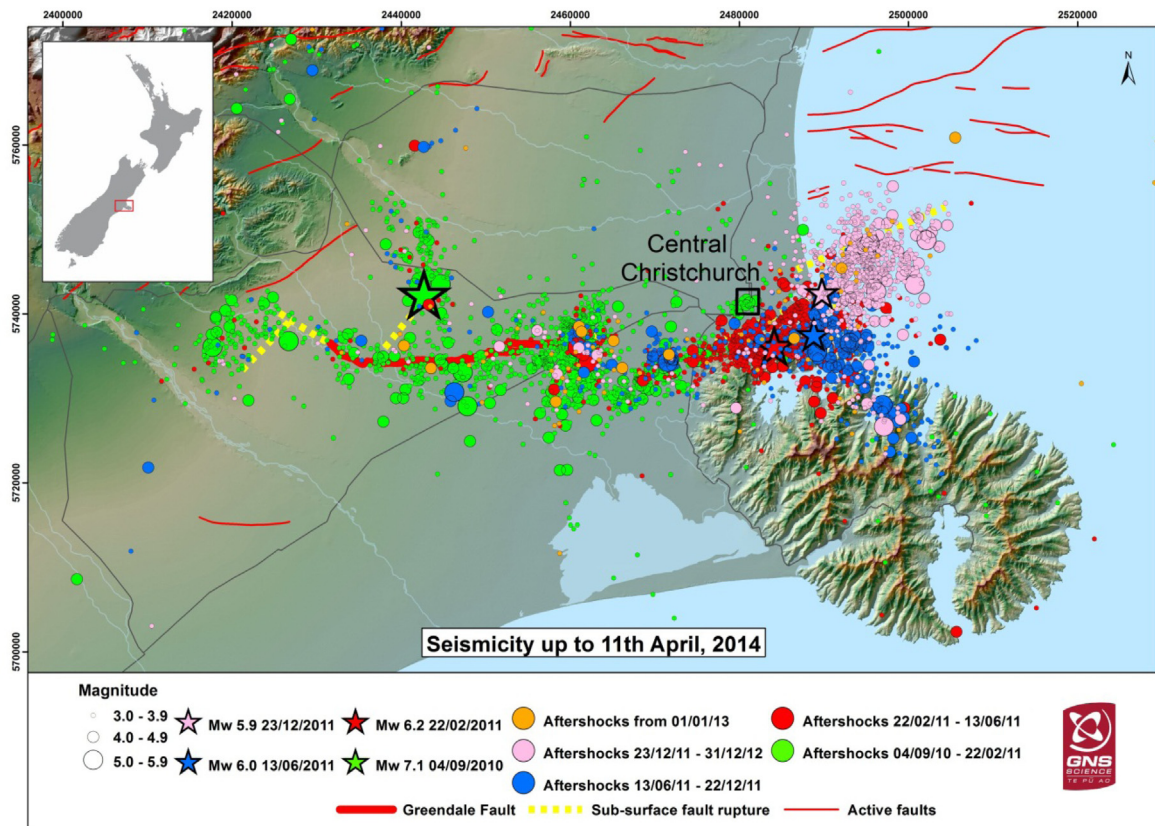


Fig. 1. Location of epicentres during the Canterbury earthquake sequence. Source: Robert Langridge, GNS Science.

causing damage in the Canterbury Region (Table 1). Nonetheless, prior to the September 2010 earthquake, there was a perception that the likelihood of a future earthquake in Canterbury was low [33]. This perception rose significantly following the Darfield earthquake. Interestingly, the perceived likelihood for an earthquake to occur in other cities also increased following the Canterbury earthquake sequence [33].

Many rivers flow eastwards from the Southern Alps towards the Pacific Ocean, depositing post-glacial alluvial gravels that have built the Canterbury Plains over time (e.g., [20]). The city of Christchurch is vulnerable to shaking and liquefaction due to the foundation of alluvial sediment. Underlying these sediments are tectonic faults, only some of which have been identified (e.g., [51,21]).

1.2. Social setting of the Canterbury Region

The population of Canterbury Region is just over 550,000 [52]. Canterbury has a strong agricultural industry built on the alluvial plains, which contributes to its economy. Additionally tourism is also an important economic contributor, with many tourists visiting Christchurch prior to the earthquakes and enjoying the scenery created by the Southern Alps. In terms of transport, road, rail, Christchurch airport, and a busy port at Lyttelton Harbour form the main links [52]. With respect to local government, the organisation Environment Canterbury (which was run by commissioners, rather than elected officials) oversaw management of the Canterbury Region prior to the earthquakes. There are ten district councils located within the region (Fig. 2) including Kai-koura, Hurunui, Waimakiriri, Selwyn, Christchurch City, Ashburton, Timaru, Mackenzie, Waimate and Waitaki.

The main city in the region is Christchurch, with approximately 370,000 people living there prior to the earthquake sequence.

Christchurch City was made up of approximately 145,000 dwellings at the time of the earthquake, with approximately 10,000 of those listed as unoccupied [49]. According to the 2006 census, 7.4% of residents living in Christchurch considered themselves of Maori descent [49]. Other notable ethnic groups included Asian (7.6%) and Pacific Island (2.7%) [49]. Median figures for age, household composition and income were close to the national figures for 2006. Christchurch was location to a number of important services that the wider community relied on including a hospital, university, art gallery and sports facilities.

2. The 2010–2011 Canterbury earthquake sequence

The Darfield earthquake occurred at 4:35 am (New Zealand Standard Time, NZST) on 4 September 2010, causing no fatalities and few injuries. It was centred 9 km southeast of the town of Darfield, 40 km west of Christchurch (all locations mentioned in the text are in Fig. 2). The movement was strike-slip, however analysis of seismograph and geodetic data indicate complex sub-surface fault movement (e.g., [3]). The earthquake occurred at a depth of 10.8 km on a previously unidentified fault, which has since been named the Greendale fault [21]. The Greendale fault had a surface rupture of 30 km, trending east-west across predominantly farmland (Fig. 1). It had a maximum displacement of approx. 5 m horizontally and 1.5 m vertically [21,44].

Aftershocks were strong and frequent (Fig. 3), including one on 26 December 2010 (M_w 4.9). However, the decay rate decreased quickly, most likely due to a lack of significant ‘afterslip’ [45]. Five and a half months after the mainshock occurred beneath the Canterbury Plains, an aftershock with a moment magnitude (M_w) of 6.3 [45] struck approximately 6 km southeast of Christchurch city at 12:51 pm. It was centred at a depth of 5 km on a previously

Table 1
Summary of the more significant historical Canterbury earthquakes and their impacts.

Date ^a	Magnitude	Location	Impacts	References
1869, 4 June	M 4.7–4.9	Near Christchurch City	MM7. Liquefaction at the Avon–Heathcote Estuary.	G. Downes, as stated in Gledhill et al. [21]
1870, 31 August	M 5.6–5.8	Near Lake Ellesmere, Selwyn District.	MM9	(G. Downes, as stated in [21])
1888, 31 August	M 7.0–7.3	Amuri District, North Canterbury; Hope Fault	MM9 near epicentre, MM7 in parts of Christchurch. Serious damage to buildings, and furniture was overturned. Upper 8 m of the Christ Church Cathedral spire collapsed. Numerous landslides and rockfalls, liquefaction and fissures.	Cowan [8], and references therein
1901, 15 November	M 6.9	Cheviot, Hurunui District	MM7. Caused liquefaction at Kaiapoi and lateral spreading. Cathedral spire damaged.	Pettinga et al. [43,23])
1922, 25 December	M 6.4	Motunau, Hurunui District	MM7. Caused liquefaction along the Pegasus Bay coast, Leithfield Beach and Waikuku.	Pettinga et al. [43] and McCahon, [32]
1929, 9 March	M _w 7.0	Arthur's Pass, Selwyn District	35 km fault rupture length. Near to the epicentre, chimneys were toppled and furniture overturned.	Doser et al. [11], and references therein
1946, 26 June	M _L 6.2	Lake Coleridge, Selwyn District	Minor structural damage to buildings and the Lake Coleridge hydro-electric power station. Numerous landslides and aftershocks.	Downes [12]
1994, 18 June	M _w 6.7	Arthur's Pass, Selwyn District	70 mapped landslides, and rockfalls blocked State Highway 73 for a week. Damage claims of US\$3.2 million, predominantly from Christchurch.	Abercrombie et al. [1], and references therein
1995, 24 November	M _w 6.2	Cass, Selwyn District	MM6 near epicentre.	Gledhill et al., [22], and references therein.

^a Dates are based on Universal Time, and as stated in Pettinga et al. [43].

unknown fault, and did not rupture the surface [25]. This after-shock caused extreme ground shaking, with accelerations of up to 2.2 g recorded [25].

Other significant aftershocks that caused disruption in Canterbury occurred on 13 June 2011 (M_w 6.0), and two offshore events on 23 December 2011 (M_w 5.8 and M_w 5.9; [45]; Fig. 3). During the June 2011 aftershock, high levels (approx. 2 g) of horizontal ground acceleration were recorded in parts of Christchurch city, and it was centred beneath the suburb of Sumner [25]. Liquefaction repeatedly occurred, causing disruption to the city and recovery effort.

3. Impacts on the local environments

This section provides an overview of the impacts that the Canterbury earthquake sequence had on the natural environment as well as the interrelated impacts on the built, social and economic environments.

3.1. Impacts on the natural environment

The Canterbury earthquakes caused a significant change to the natural environment, including liquefaction, lateral spread near waterways, land level changes, and numerous rockfalls and landslides. Air and water quality were also impacted, with water-based recreational activities halted until November 2011. The regional council, Environment Canterbury, is leading the management of the environmental recovery.

3.1.1. Liquefaction and water quality

As noted earlier, liquefaction caused significant damage to the built environment in Christchurch. A large volume of the resulting silt was ejected onto the surface. Approximately 900,000 tonnes of liquefaction silt were removed from the greater Christchurch area [16].

In addition to other waste, silt was washed into waterways, increasing the concentration of suspended sediment and causing impacts on water quality. The land level was changed in parts of Canterbury through settlement and tilting (e.g., [34,16]). Much of the underground infrastructure was damaged by the movement and liquefaction, causing lifeline failure and the discharge of untreated sewerage into waterways. The impact on water quality was reflected by the high level of bacteria (*Escherichia coli*) in lower reaches (Christchurch City Council, May 2013, cited in [16]). Stormwater quality was also impacted, as sediment, effluent, and waste from damaged properties were entrained. The waterways had low dissolved oxygen levels, high ammonia concentrations, and an accumulation of contaminants in riverbed sediments [47].

While the quality of groundwater was largely unaffected, pipes, wells and reservoirs were damaged, causing the potential for contamination of the water supply. Some of the supply was chlorinated until late 2011 [16]. Some springs stopped flowing, however many increased in rate of flow, and new springs were created.

3.1.2. Impacts on ecology and biodiversity

The deposition of silt and contaminants in waterways effected aquatic life. Decreased concentrations of dissolved oxygen, which occurred when large volumes of wastewater were discharged into the rivers, may have adversely affected sensitive fish species [47]. Habitats were smothered with silt, reducing biodiversity in some places. Liquefaction mounds covered up to 40% of the Avon–Heathcote Estuary, changing the topography of the area and reducing the level of organic material in the estuary sediment [16]. Shellfish in the estuary contained high concentrations of

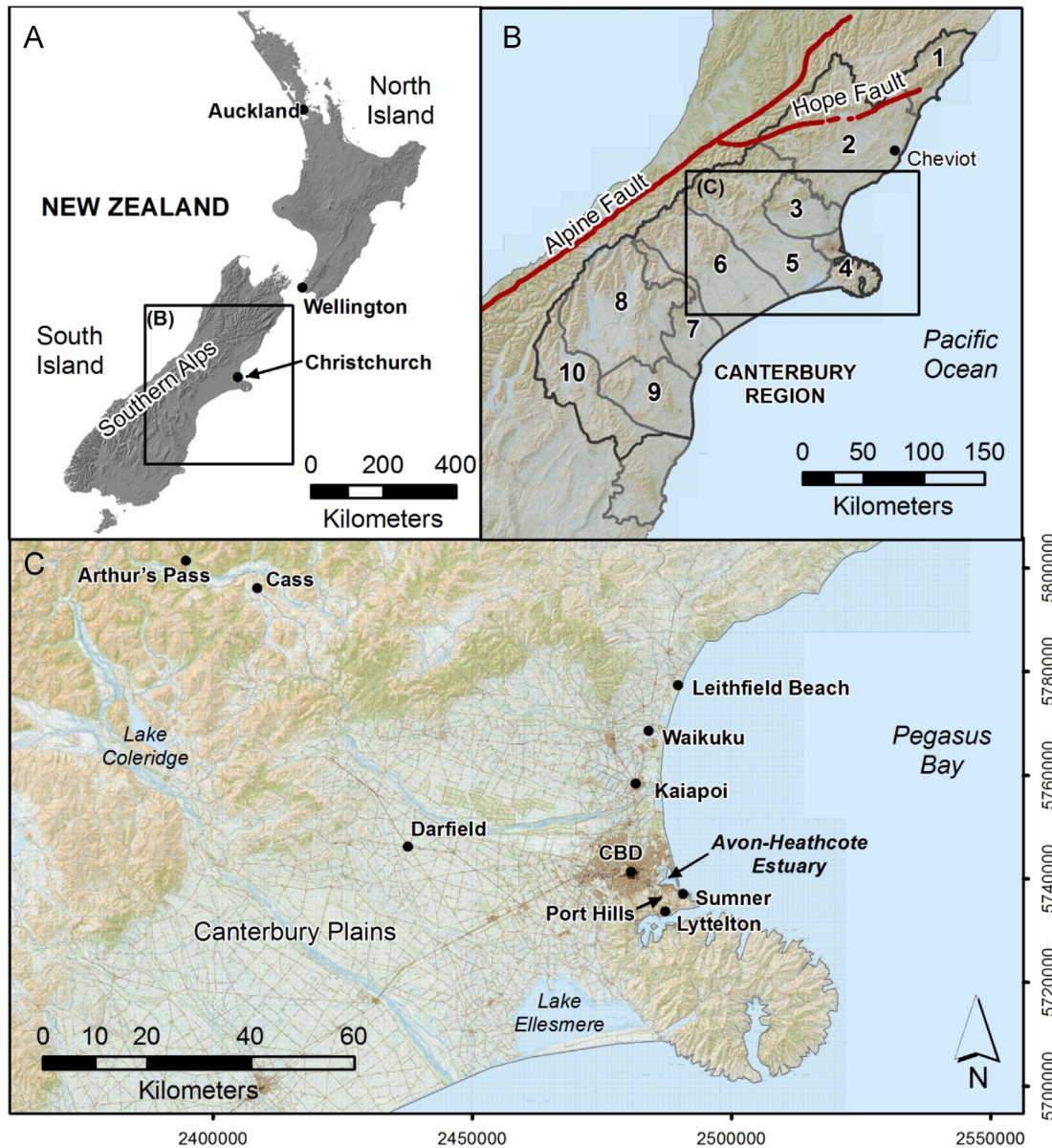


Fig. 2. Maps of the Canterbury Region, with places mentioned in this paper labelled. (A) New Zealand map with main cities labelled. (B) Canterbury Region, with districts labelled as 1) Kaikoura; 2) Hurunui; 3) Waimakariri; 4) Christchurch City; 5) Selwyn; 6) Ashburton; 7) Timaru; 8) Mackenzie; 9) Waimate; 10) Waitaki. (C) Map of the Christchurch city area and nearby towns.

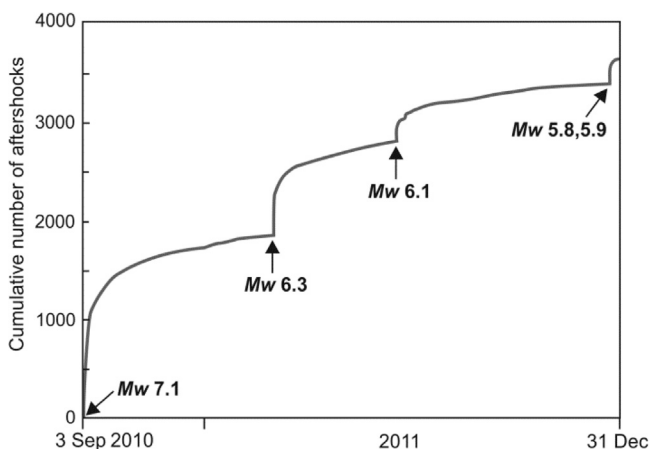


Fig. 3. Cumulative number of earthquakes in the Canterbury Region following the Darfield earthquake, until 31 December 2011. Modified from Reyners et al. [45].

micro-organisms from faecal matter [16]. The growth of nuisance algae has recently increased in the estuary. While this has been largely attributed to the diverting of discharge from the Christchurch Wastewater Treatment Plant (CWTP) away from the estuary prior to the earthquakes, and due to the addition of nutrients in the Avon and Heathcote rivers, there has also been a minor increase in algae growth due to the addition of raw effluent-derived nitrogen caused by the earthquakes [2]. Similarly, white-bait (*Galaxias maculatus*, or inanga) spawning areas were damaged, with advisories against eating them issued in 2012 [16]. It is expected that any damage caused to the rivers by siltation during the earthquakes, or sediment removal activities in lower reaches, will not have long-lasting effects on fish and invertebrates, provided mitigation measures are followed [17].

Between 2011 and 2013, birds died due to avian botulism. While the cause is uncertain, it is potentially related to a change in the biology of the CWTP treatment ponds [16].

The coastal forest in some areas has been damaged, with

changing ground conditions causing trees to die [16]. Due to the lack of access to areas in the Port Hills, the control of weeds and pest species has been reduced.

3.1.3. Increased risk of flooding

Deposition of entrained sediment in waterways, liquefaction of the river beds, and lateral spreading has altered the capacity of rivers. Lateral spreading and the destabilisation of river banks increased erosion by waterways, and narrowed river channels [16]. The subsidence of land has led to increased inundation and erosion by sea water [34]. In addition to the subsidence of land and an increase in the water table, these changes have caused flooding to become more frequent in parts of Christchurch. This in turn has led to increased mosquitos in the area [16]. In some places the land has been uplifted, causing it to remain dryer than it had previously been [34].

3.1.4. Impacts on air quality

Air quality decreased in Christchurch city in 2011, exceeding the national air quality standard on 32 days. This was partly attributed to an increase in airborne silt and dust from liquefaction deposits, as well as dust caused by earthworks and demolition (e.g., [15,16,48]). Air quality had been a problem in Canterbury towns and cities prior to the earthquakes due to domestic wood burners. As thousands of chimneys were damaged by the shaking and many new homes are being built, the types of heating devices have changed and insulation is being installed. The air will continue to be monitored by Environment Canterbury to ascertain the longer-term impacts of the earthquakes on air quality.

3.1.5. Earth movement hazards

Rockfalls, rock rolls, cliff collapse, landslides and slumps occurred in the hill areas. These disrupted the roosting/nesting areas used by birds, and the habitats of marine mammal, causing a relocation of breeding sites [16]. They also caused the closure of a number of tracks and paths that had been used by residents for recreation in the Port Hills, and alongside rivers, parks, and beaches. Due to the on-going aftershock sequence, the likelihood of further earth movements remains elevated.

3.1.6. Waste and contaminated land

The amount of waste has more than doubled since before the earthquakes due to the demolition process (Environment Canterbury, June 2012, cited in [16]). In total, around 9 million tonnes of construction and demolition waste will be produced (40 years' worth of waste). New landfill sites were created, which will require on-going monitoring of contaminants. Illegal dumping of waste has become more common. Inert demolition waste is being used to reclaim land at Lyttelton Port [16]. A number of underground fuel storage tanks were ruptured during the earthquakes, however, no significant releases of hazardous substances were observed.

3.1.7. Management of impacts on the natural environment

Further impacts on the natural environment may not become apparent for many years. Within the context of the Recovery Strategy for Greater Christchurch is the Natural Environment Recovery Programme, led by Environment Canterbury [16]. Seventeen projects that are part of this programme aim to manage repairing the damage and improve sustainability of the ecosystems. Intended outcomes include effective land-use planning for future hazards, careful management of contaminated land, enhanced weed and pest control, and improving recycling and reusability of demolition waste. The recovery process will be routinely monitored and reported using indicators [16].

3.2. Impacts on the built and social environments

Many buildings were severely damaged during the September 2010 and February 2011 earthquakes, predominantly unreinforced masonry buildings [23]. Many of these structures were damaged by ground shaking as well as ground deformation, including liquefaction, uplift, subsidence and tilting. A variety of buildings and infrastructure were affected, including residential housing, health care and schooling facilities, the central business district, iconic landmarks and heritage buildings. The impacts of the earthquakes on Canterbury communities was and still is being shaped not just by the nature and scale of the physical impacts, but also by the social environment that supports the complex and protracted processes of recovery [42]. The earthquakes have impacted individuals, whanau, social networks and communities in many complex and interrelated ways, some of which are highlighted in the following subsections in relation to the built impacts.

3.2.1. Fatalities, health and mental wellbeing

Physical health and safety were impacted upon in a number of ways by the Canterbury earthquakes. 185 people were killed in the February 2011 earthquake. The majority of these fatalities occurred due to the collapse of two multi-storey office buildings – the Canterbury Television (CTV) building (115 deaths) and the Pyne Gould Corporation (PGC) building (18 deaths; [38]). Eight people died on buses in the central city that were struck by falling masonry; 28 people died in other areas of the central city; and 12 people died in suburban locations [38].

Additionally, at least 7171 people were injured, three times as many as due to the September 2010 earthquake [24]. Injuries were mainly caused by the primary shaking, and were unavoidable. However actions taken during the shaking (such as moving or taking cover) and subsequent earthquake-related actions (particularly cleaning up from the earthquakes) also contributed to the number of reported injuries [24]. Immediately following the September 2010 earthquake, there was an increase in the number of heart attacks in the Canterbury Region (however, an increase was not seen following the February 2011 earthquake; [5]).

A number of rest homes for the elderly were damaged during the earthquakes, resulting in the temporary evacuation of over 250 residents to other regions [5]. Factors that are known to increase medical admissions were abundant during the recovery phase, including overcrowding of homes, schools and office spaces, and damaged, damp and cold homes [5]. Access to General Practitioners did not seem to be affected by the earthquakes [5].

The mental wellbeing of the population, as well as their reported quality of life was also affected by the Canterbury earthquakes [5]. Health and welfare services were highly sought after for assistance with general stress symptoms (particularly immediately following the earthquakes), hyper-vigilance and anxiety [5]. Additionally, it was reported that some people felt forgetful, preoccupied, irritable, and deprived of sleep [9].

Within the Canterbury Region, there were geographical differences in the emotional wellbeing of the population. In a comparison survey between two communities that were impacted by the September 2010 earthquake to different degrees, the community that was more impacted showed increased levels of depression and anxiety than the less impacted community [10]. Quality of life was reported to be lower in Christchurch city than in Selwyn and Waimakariri districts [5].

Over time, reported stressors reflected the secondary impacts relating to the earthquakes. In 2012, as part of a CERA Wellbeing Survey, people reported suffering moderate or major distress related to aspects such as loss of facilities (34%), on-going aftershocks (42%), dealing with insurance issues (37%) and making decisions about damage, repairs and relocation (29%) [5].

Workplace stress also increased, with 44% of CERA Wellbeing Survey respondents reporting additional work pressures as a result of the earthquakes [5].

People did also experience some positive aspects, however, including an increase in pride in their ability to cope, increased resilience, a renewed appreciation of life, and a heightened sense of community [5]. These findings suggest that although the Canterbury earthquake sequence has had an impact on people's mental and emotional wellbeing, not all of these have been negative.

3.2.2. Education

The effects on the education system continue to go beyond the initial school closures following both the 4 September 2010 and 22 February 2011 earthquakes. Following the September 2010 earthquake all schools reopened within a couple of weeks in affected areas. The 22 February 2011 caused considerably greater impacts with extensive damage at numerous schools. Within three weeks of the February 2011 aftershock, 84% of school students in the greater Christchurch area were able to attend school [5]. However, more than half of secondary schools were 'site sharing', to enable two schools to use one school facility every day. Over 12,000 school students left their school and enrolled elsewhere, including at schools outside the region [37], and may be related to the relocation stressors aforementioned.

The tertiary education sector in the Canterbury Region was also impacted, with first-year enrolments decreased by 28% compared to 2010 [5]. A similar decrease in enrolments of international students to the region was also seen. Despite an increase in reported cognitive disruption in Canterbury, academic performance of undergraduate students at Canterbury University did not suffer during the July to October 2010 semester [26]. Study withdrawal rates did not substantially increase as a result of the September 2010 earthquake in that same semester [26]. These findings suggest that although the tertiary education sector is facing some challenges around enrolment it appears to be continuing to maintain its academic performance.

3.2.3. Crime

In the year following the 2010 September earthquake, overall crime was recorded to fall from 1,073 offences per 10,000 people to 876 offences per 10,000 people [5]. A reduction in criminal behaviour in the months following a disaster is consistent with what is reported in other disasters around the world (e.g., Hurricane Katrina). In terms of type of crime, burglary rates fell in a similar way to crime overall. Family violence rates appeared to peak in the month after the September 2010 earthquake, but no peak was found after February 2011. It is possible that people's ability to report family violence may have been disrupted by the effects of the earthquake, however, and may not be an accurate record of offending [5].

3.2.4. Community connectedness, recreation and local identity

As mentioned previously, residents reported that the earthquakes helped increase sense of community, and also contributed to improving social connectedness. Following the earthquake, spontaneous volunteering occurred, as agencies and the public helped each other out both in immediate response to the earthquakes (e.g. saving people, looking after others) and in the days following the large shakes (e.g. supplying food to others, clearing liquefaction material, checking on the wellbeing of vulnerable populations). People made new connections and bonds with their neighbours as they sought to help each other through the issues caused by the earthquakes [5]. However, some community connectedness was also lost. A number of residents (26% of respondents in the Wellbeing survey) were forced to leave their

homes due to earthquake impacts.

Furthermore, some community facilities where people used to meet (e.g. cafes, libraries, marae, cultural centres, schools) were also damaged and closed down or relocated [5]. This includes the closure of a number of sport and recreational facilities due to earthquake damage. There was an increased cost to residents to travel to new venues and/or to undertake alternative forms of recreation [16]. This in turn may have restricted locals' opportunities to participate in their regular recreational and social activities.

Heritage buildings were particularly affected by the aftershocks due to the large number of unreinforced masonry structures. In a report to the Canterbury Earthquakes Royal Commission, the New Zealand Historic Places Trust summarised an assessment of the damage to 100 selected heritage buildings [39]. Of that sample, there was moderate damage to 41 of the selected buildings following the September 2010 earthquake, and one with severe damage [39]. Severe damage resulted from continued aftershocks, with the collapse of 3 buildings out of the sample of 100 during the February earthquake, and major to severe damage to a further 51 buildings, nearly all of which were required to be demolished [39]. Another 32 of the buildings were moderately damaged. The impacts of the damage to these buildings on the community and sense of local identity can be seen in the spirited local response to discussions about whether or not (and if so, how) the Christchurch Cathedral should be restored.

3.2.5. Impacts on Maori and other populations

In response to the earthquakes local Maori recovery initiatives were collaborative, effective and shaped by cultural values, including the principle 'aroha nui ki te tangata' [27]. Marae (meeting houses) opened throughout the South and North Islands to accommodate Maori refugees and provide places of support [28]. Tradespeople and nurses were sent to Canterbury, as well as Maori wardens. A recovery assistance centre was also established to field phone calls for organisations such as Housing New Zealand, the Red Cross, and Work and Income. The response and recovery of the Maori communities in Canterbury emphasised the resilience of Maori cultural values and skills [28].

Refugees that had settled in Christchurch prior to the earthquakes reported that they had generally coped well [40]. Refugee ethnic groups reported similar feelings of anxiety, hyper-vigilance and helplessness that were reported for the population as a whole [30]. Survey participants indicated that levels of anxiety was higher for females than males, and higher for couples with children and older adults than it was for individuals [40].

3.3. Impacts on the built and economic environment

The September 2010 earthquake caused an estimated repair and rebuilding cost of about NZ\$5 billion, and the financial markets were largely unaffected [41]. The cost of repairing damage caused by the aftershock sequence is significantly higher. The New Zealand Treasury estimates the capital cost of the Canterbury earthquakes to be around NZ\$40 billion, or approximately 20% of the New Zealand Gross Domestic Product (GDP; [36]). The Government, on behalf of New Zealand taxpayers, is making a significant contribution to the rebuild of around NZ\$14.9 billion (including New Zealand's Earthquake Commission, EQC; [36]).

The New Zealand dollar dropped immediately following the February 2011 earthquake, however it subsequently recovered, and share prices were little changed [41]. The overall impact on the national economy as a result of the earthquakes does not appear to be pronounced [13]. Similarly, the effect on the Canterbury regional economy has not been considerable [41]. Christchurch city accounts for 8% of the GDP [41].

3.3.1. Housing and Insurance

The Canterbury earthquake sequence damaged nearly three quarters of the housing stock in the region [41]. Approximately 9100 of these were assessed as uninhabitable [5]. Of the 150,000 homes that were damaged, about one fifth exceeded NZ\$100,000 in damage [41]. Approximately 30,000 homes that have been cleared to be repaired or rebuilt require significant structural or land remedial work [41]. In total, there is an estimated cost of 13 billion New Zealand dollars (NZ\$) to repair or replace residential property damage [41].

Thousands of unreinforced masonry chimneys collapsed or were damaged. Liquefaction caused the settlement of land, damaging even timber-framed structures. Rockfalls and mass movements in the Port Hills caused on-going impacts to housing and infrastructure.

The number of available low-cost rental houses decreased during the earthquakes due to the decision by landlords not to rebuild, or to improve the level of housing with an associated increase in rent [5]. Along with the reduction in available building sites, this means that housing availability decreased following the earthquakes, particularly for the more vulnerable parts of the community. House purchase prices also increased [31]. The number of sections sold in the Selwyn and Waimakariri Districts increased by between 88% and 115% in the year after the February 2011 earthquake compared to the year from February 2009 to February 2010 [5].

Over 750,000 insurance exposure claims were received by EQC for building, land and contents damage [19]. Of these, approximately two thirds had been closed by the time of writing (June 2014; [19]). Insured losses total over NZ\$30 billion, taking into account disruption costs and contents damage [41]. Many households and business have experienced up to five damaging earthquakes over the extended earthquake sequence resulting in complexities in the settlement processes, disrupts over apportionment of claims between the multiple events and delays due to a range of interrelated factors [35]. As an example, it took Housing New Zealand over two years to receive its insurance settlement of NZ \$320 million, only after which it could progress the repair and rebuild programme for over 5500 homes [5]. At the time of writing (June 2014), the EQC had completed repairs on 55,500 houses, with 14,500 remaining [19]. This protracted sequence and associated uncertainties has placed enormous stress on individuals, households and communities (e.g., [5]). King et al. [29] note that changes in regional seismicity during the aftershock sequence and the resulting changes in design requirements, and the need to remediate land and building platforms which have settled and been tectonically distorted have further complicated the settlement process. The EQC aims to repair all earthquake damage by the end of 2015 [18].

3.3.2. Businesses

Businesses within the Christchurch Central Business District (CBD) and surrounding areas were affected differently by the Canterbury earthquakes. The cordon around the Christchurch CBD meant that businesses inside it were closed, and could not be accessed even to collect important items that lay within the premises. In a survey of Canterbury organisations effected by the September 2010 earthquake, 64% were forced to close at least temporarily [50]. At least 1% of those businesses were closed permanently. This increased to 11% as a result of the February 2011 earthquake. The median duration of closure for organisations following the February earthquake was found to be 16 days, more than double the duration of closure experienced following the initial earthquake [50].

Christchurch's CBD experienced moderate damage in the September 2010 earthquake. Initially, 26% of buildings in the CBD

were determined to be unsafe or have restricted access [50]. Due to the extent of the damage, a cordon was placed around the city centre by local authorities, restricting access. It was reduced in size over a number of days, and removed on 10 September 2010, however cordons around individual unsafe buildings remained in place.

The damage caused by the February 2011 earthquake was more severe, and occurred during lunchtime on a week day, when many workers were in the city streets. As previously mentioned, two large multi-storey concrete office buildings collapsed, causing 133 fatalities. Within the CBD, 47% of buildings were determined to be unsafe or required restricted access (Kam et al., 2011; cited in [7]). At least 627 commercial buildings will be demolished, in addition to partial demolitions. Of the approximately 220 buildings in the CBD over five storeys high, nearly half will be demolished [7].

After the February aftershock, the cordon was reinstated around the CBD. It had halved in extent by July 2011, and subsequently slowly reduced in size until it was removed on 30 June 2013 [6]. The purpose of the cordons was to increase public safety, and to allow building assessments and demolition to take place within its boundaries unrestricted by pedestrians and traffic management [7].

Outlying towns such as Kaiapoi and Lyttelton also experienced damage to their business districts during the earthquake sequence. The estimated cost to restore damage to commercial property in Canterbury is NZ\$4 billion, and the cost to repair and replace damaged infrastructure is NZ\$3 billion [41]. The damage and disruption caused many businesses to relocate to other areas [5]. Six thousand businesses were displaced by the cordon, impacting 50,000 central city jobs [7]. Rent for commercial premises outside of the CBD increased, and longer contracts were required [7].

Christchurch city is a hub of manufacturing organisations, however most manufacturers were located outside the city centre, and therefore were less affected [41]. Severely affected business sectors included tourism, small businesses, and service industries such as retail, wholesale trade, hospitality, international education and aged care [5,50]. Sectors experiencing an increase in demand were utilities, construction, safety, healthcare, social assistance, goods exports, and manufacturing [14,41]. The agriculture sector was largely unaffected [41].

Organisations experienced a larger change in revenue following the February 2011 earthquake than they did following the September earthquake [50]. Smaller organisations (those with fewer than 20 full-time employees) were more vulnerable to a negative impact on revenue than larger organisations [50].

The most disruptive factor to businesses following the aftershocks was seen to be issues with customers, including decreased customer numbers, customers needing different services than those provided, and decreased spending [50]. The level of retail spending by the Canterbury population was well behind the national trend [14]. Businesses in the Canterbury Region were operating with a reduced income, reduced employees and higher costs on average, than they had prior to the earthquakes [50].

3.3.3. Employment

Employment in Canterbury was affected by the Canterbury earthquakes, with a particular impact on Christchurch City itself. Given that there was severe business disruption, people either lost their jobs or were forced to change their working circumstances (e.g., travel to different premises to work, etc.). There was a sharp decline in the employment rate following the two earthquakes, with the employment rate falling from 67% in September 2010 to 63% in September 2011 [5].

Larger organisations hired more staff following the earthquakes, compared to smaller organisations [50]. The retail, wholesale trade, accommodation and food service sectors were

more likely to reduce the number of staff than other sectors [50]. Conversely, the number of people employed in the construction sector increased greatly, with demand particularly high for carpenters, joiners, painters, concreters, plasterers and general labourers [5].

The aftershock sequence resulted in 32% of surveyed organisations employing staff who relocated, which may have caused a disruption to business [50]. Emotional wellbeing of staff was seen to be a disruption to recovering businesses as they struggled to balance supporting staff emotionally with maintaining their businesses [50].

Government subsidies were set up to assist employers in paying employees when they were unable to operate due to earthquake damage and disruption [5].

4. Summary

This paper provides an overview of the Canterbury earthquake sequence, including the mainshock near Darfield on 4 September 2010, and the significant aftershock sequence, in particular the event on 22 February 2011 that caused 185 fatalities. The February aftershock prompted a national state of emergency and an extraordinary recovery process [4] to be instigated which will still be on-going for many years to come. The severe impacts of the earthquakes on the natural environment as well as the social, economic and built environments collectively have been described in this article as a means of providing an initial context for understanding and interpreting the ongoing impacts and recovery. It is anticipated that there is still much to be learnt from the Canterbury earthquakes and so this article provides a snapshot of some of the impacts of the earthquakes up until the time that this article was written.

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