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Policy Adaption Following Cascading Natural Hazards: Case Study of Christchurch, New Zealand

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Abstract: The complexity of cascading hazard events create discontinuities for public policy makers. This is especially true in cities where the urban services may be operated by different government agencies. This paper provides a case study of an urban region, Christchurch, New Zealand, experiencing cascading events: earthquakes and floods, and how the national and local policy adapted to future risk and recovery challenges. This main variables examined are: the process of information collection, transfer, and utilization in policy adaptation to the hazard events. In this case, the national government made quick decisions based on geoscience information, while local government chose incremental adjustments based on geotechnical and hydrological information.

Key words Flood recovery; Cascading events; Earthquake; Recovery policy.

1. INTRODUCTION

When cascading hazard events occur there are often discontinuities in how public policy addresses the risks and challenges arising from the impacts of the event. This is especially true in cities where the urban services (transport, utilities, communications, land use regulation, etc.) may be operated by different government agencies (Alesch and Siembieda 2012). This paper examines a cascading set of natural hazards and examines how information inputs to policy are developed to create an integrated risk governance response (Shi et al. 2013). Of particular interest is increasing our understanding of the process of information collection, transfer, and the outcomes of information utilization in policy adjustments. Examined here are: how the geotechnical, civil infrastructure, hydrologic, and seismic information emerges to inform decision makers. The main question addressed is how rapidly civil infrastructure, geotechnical, and seismic information can be adapted in the development of recovery policy after a cascading set of major hazard events.

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In this paper, a single case is used to establish the informational inputs to policy from natural hazard data. This case is the seismic and flood events that occurred in the Canterbury region of New Zealand. These events cover a 42-month period, resulting in physical changes to the landform, water table, drainage, and watercourses. The major seismic events (from September 2010 through December 2011) were instrumental in the extents of the flooding event (March 2014). Physical geotechnical and civil infrastructure information were assembled from the published reports and interviews from private companies contracted to produce the studies and on-site field studies and interviews after the March 2014 floods (Allen et al. 2014). In this paper, Christchurch's history with flooding is examined, followed by a discussion of the Canterbury earthquake sequence and subsequent government actions taken after these events based on information collected in each event.

2. CHRISTCHURCH

Christchurch, home to over 430,000 residents, is located on New Zealand's South Island (Statistics New Zealand 2013). For over 100 years, the Greater Christchurch area has been subject to major flooding and earthquakes. The local and national government and private insurers have provided mechanisms for dealing with occasional damage related to these hazards. Beginning with the 2010 Darfield earthquake (30 km west of the central city), changes to the landform (an uplift in part of the estuary and subsidence in eastern settled areas) induced changes to the city's built and natural drainage systems. The communities on the broad floodplain in the eastern suburbs are now subject to a combination of new physical hazards as a result of the Canterbury Earthquake Sequence (CES) including areas with subsidence of the ground surface, rising of land surface in other areas, increased flooding and a high (near ground surface) groundwater table.

While each set of cascading events creates its own set of policy challenges the main ones in this case are: allowing as many people as possible to safely continue living in the eastern neighbourhoods, how to address the new stormwater management issues that could result from a major storm especially in the face of climate change and sea level rise and; finally, how to fund the long term costs by different government levels..

In the Canterbury region there are three levels of government at work with respect to civil infrastructure: the national, the local and the regional. The national government (hereafter referred to as "government") has a direct presence in Christchurch and Canterbury region through a series of agencies and ministries. Prior to the earthquake these agencies were, and remain, the Earthquake Commission (EQC) and the New Zealand Transportation Agency. The Earthquake Commission (EQC), a national (crown) agency, formed in 1993 through the Earthquake Commission Act 1993 insures residential property against natural hazards and the New Zealand Transport Agency (NZTA) is a major funding agency for roads (Figure 1). At the regional level of government dealing with drainage and flooding issues is the regional council, Environment Canterbury (ECAN) and at the city level dealing with stormwater management and civil infrastructure is the Christchurch City Council (CCC) (Figure 1). Throughout this paper, the role and development of new policies of these agencies following the cascading hazards will be developed and discussed (Figure 1 depicts these agencies in relation to the hazards timeframe).

3.1 Historical Flooding

Europeans first settled in Christchurch in the mid-1800s. The Europeans located the main part of the city in a largely low-lying, flat area characterized by poorly draining soils and a high water table. To drain the city and make it habitable, the Christchurch Drainage Board was established in 1875 by the Provincial

Government and city authorities (Wilson 1989). Located in the floodplain of the Waimakariri River to the north, the soils in the floodplain are mostly deposits of the alluvial fan of the river. The Waimakariri River poses the largest flooding hazard to the City and is contained by a series of primary and secondary stopbanks (levees) to control flooding.

Figure 1. National and Regional Government Changes in Response to Cascading Events

The last time the Waimakariri River flooded the city was 1957 and the Waimakariri was not an issue for flooding in the city following the CES, even though there was significant damage to the stopbanks following the Darfield earthquake (Green et al. 2011). The other important rivers are the Avon River and the Heathcote River. The Avon meanders through the central city district and residential areas to the estuary that empties into the sea. The Heathcote River in the southeast flows through residential areas before flowing into the estuary (Figure 2).

Figure 2. Map of Christchurch Central Business District and Eastern Suburbs (Google 2015).

3.2 Historical Policy Related to Flood Management

There are many government entities engaged in flooding hazards related policy in the Canterbury region (this includes Christchurch, Selwyn, Kaikōura, and Waimakariri). The Christchurch City Council (CCC) is the city government and is owner of several enterprises including the airport, the port, the water distribution system, the stormwater system, and the wastewater treatment system. The regional authority is the Environment Canterbury (ECAN), formed in 1989 to manage the region's air, water and land. ECAN implements provisions of the national Resources Management Act (RMA 1991), and has a separate board of director's from that of the city. While ECAN establishes the regional water plan it relies on the CCC to implement and manage the regional stormwater management facilities within the municipal boundaries. The operation and maintenance of the conveyance system are the CCC responsibility. Separating the implementation responsibilities of CCC from the regional water planning (ECAN) itself creates a lag between how data related to geotechnical information and civil infrastructure is collected and used decision making related to planning.

The Resource Management Act (RMA) guides environmental management of natural and physical resources, including land use development and permitting processes. The Local Government Act (New Zealand Parliament 2002) defines the authorities, responsibilities and powers conferred from Government upon local territorial authorities. ECAN has a major role related to land use, flooding, and stormwater management in the region through its water management plan. Christchurch has a statutory obligation under the RMA to address floodplain management and has done so through Operative Variation 48 Management of Flood Hazard in Christchurch (Christchurch City Council 2011) that addresses new construction requirements.

The Christchurch District Plan provides the guidance for land use, environmental protection, and subdivision of land within the district. One of the most important Plan chapters is Natural Hazards, where the Flood Management Area (FMA) boundaries are established and associated regulations for granting consents (permission to build) are stated. To address flooding the Christchurch City Council created maps of Flood Management Areas throughout the city as part of Operative Variation 48 to inform the District Plan for minimum floor levels for new buildings to avoid flooding. The FMA are areas that hydrologic modeling has shown (Figure 3) to experience occasional flooding or are prone to tidal flooding. The FMA maps were created through models utilizing a 50 year return period rainfall event (occurrence probability of 1%) and a 16% buffer to account for a 2 degree temperature rise and a 0.5 m Sea Level Rise (SLR) by the end of the century (Allen et al. 2014). Until 2011, these levels were sufficient to provide protection for new residential construction in the City. In the 200-year flood event areas no residential consents are issued without proper mitigation measures being installed (Hansen 2015).

Figure 3. Christchurch Flood Management Area Map (Christchurch City Council 2010)

3.3 Historical Earthquakes

Since European settlement in the mid-1800s, the city of Christchurch has experienced minor damage as a result of multiple earthquakes (Pettinga et al. 2001). The June 4, 1869 earthquake likely occurred

within the current city limits eastern extents, and was the most destructive earthquake prior to the CES. Chimney damage was evident in Christchurch and Lyttelton during the August 31, 1870 earthquake centered approximately 50 km south of the city, and the M6.2-6.3 December 5, 1881, 80 km west of Christchurch. Northern and eastern suburbs were damaged during the 1 September 1888 North Canterbury earthquake (M 7.0-7.3), along with partial collapse of the Christchurch Cathedral Spire. The spire was again damaged and replaced during the November 16, 1901 Cheviot earthquake (M 6.5-7), with evidence of liquefaction in the town of Kaiapoi (Berrill et al. 1994).

3.4 Historical Earthquake Policy

In New Zealand, all new buildings are required to be constructed to the current national seismic and building code standard. As required under the Local Government Act of 2002, councils however, adopt their own policy towards what to do with existing buildings that are earthquake prone. In 2010, after the September quake, the Christchurch council amended its policy to have nonresidential buildings that do not meet 33% of the current Building Code requirements engage in strengthening. Depending on the type of building function the owners will have 15-30 years to conduct the seismic upgrades. The Christchurch 33% standard is in line with other large cities in New Zealand, such as Wellington. A more stringent policy is that of the Gisborne District Council, that requires buildings damaged in an earthquake to be strengthened to at least 67% of current building code requirements. The city of Gisborne has a population of 35,000 (Statistics New Zealand 2013).

3. RECENT NATURAL HAZARDS

3.1 Canterbury Earthquake Sequence

Prior to 2010, flooding and earthquakes were treated as separate issues. The following section describes the Canterbury Earthquake Sequence (CES) and associated geotechnical and residential damage. The damage from the CES led to an increase in flooding risk in parts of the city and the increased flooding and subsequent policy related to the coupled events are described here. This sequence occurred over many months, and provided new opportunities to collect, and report on geotechnical data and to understand areas wide changes in land formation. The five major earthquakes events, covering a period of 15 months are presented below. These five quakes ranged between Mw 7.1 and Mw 5.8. Nearly 10,000 quakes were recorded, and this led to expanding the damages to property and people's daily life. More than 100,000 of the region's 160,000 houses suffered damages, with 15,000 being beyond repair. Eleven hundred of the Central Business District's 2,000 buildings were damaged and eventually demolished. In terms of infrastructure 600 of 1,700 km of wastewater pipes, 79 km of stormwater pipes, 86 km of potable water supply pipes, over 1.8 million square meters of roads, and 151 bridges and culverts required repair (Siembieda and Johnson 2015).

4 September 2010 Darfield Earthquake

The Canterbury Earthquake Sequence began at 4:35 am local time on the 4th September 2010 with the Mw 7.1 Darfield earthquake. This occurred on a previously unknown fault approximately 30 km from the city of Christchurch (Gledhill et al. 2011). Ground motions of up to 0.25g were recorded in the Christchurch Central Business District (CBD) (GNS Science 2014; Cousins and McVerry 2010).

While there was significant damage, there were no fatalities. Modern buildings performed well, with shaking damage mainly confined to unreinforced masonry buildings (Dizhur et al. 2010). Large areas along the Avon River in the eastern suburbs of Christchurch experienced significant liquefaction, with subsidence and lateral spreading damaging residential buildings, bridges, roads and buried infrastructure (Allen et al. 2010).

Following this event, the Earthquake Commission (EQC) commissioned an extensive geotechnical investigation across the residential areas affected by liquefaction, primarily for the design of ground improvement works in the area (Tonkin & Taylor 2012).

22nd February 2011 Christchurch earthquake

The second significant earthquake in the CES was the 22 February 2011 Mw 6.2 Christchurch earthquake. This event occurred on an unknown blind fault in the southeastern edge of the city (Beaven et al. 2011). As this event occurred closer to the urban area of Christchurch, ground motions were significantly higher than the Darfield earthquake, with up to 0.67g horizontal peak ground accelerations recorded in the flat areas of the city away from the Port Hills (GNS Science 2014; Bradley & Cubrinovski 2011).

This event was the most damaging of all the earthquakes in the CES, with significant damage due to ground shaking and liquefaction, and resulted in 185 casualties. Severe liquefaction was evident across a large portion of the urban area of Christchurch, resulting in significant damage to the built environment (Cubrinovski et al. 2011). The extent and severity of liquefaction and damage to the built environment was greater than that observed following the Darfield earthquake. Some areas along the Avon River experienced subsidence causing houses to sink and other areas, including the estuary, experienced uplift causing water pipes to be lifted. This caused major disruption in both the water and sewer services. Many areas that experienced liquefaction in the Darfield earthquake experienced repeat liquefaction in the Christchurch earthquakes, further degrading the horizontal infrastructure in these locations. In addition to the liquefaction, there was extensive lateral spreading along the rivers throughout the city causing decreased carrying capacity as the cross sections of the rivers decreased in size.

As a result of the increased the liquefaction, a wider geotechnical investigation plan was implemented by EQC for the affected residential areas and by Christchurch City Council for the CBD (Tonkin & Taylor 2012). This geotechnical information was quickly used to classify the land into four zone types (Red, Green White and Orange) according to a number of categories related to reconstruction potential. For example in the Green zone there are three technical categories TC1, TC2, and TC3 graded low to high according to expected future liquefaction damage (Rogers et al. 2014). This strong technical approach was then applied to building consents in terms of where reconstruction could occur. The zones however, were not applied to flood prone regions at the time. Thus within two years of the event, geotechnical information had a direct impact on land use policy and building policy. A set of procedures accompany each technical category to assure that proper mitigation measures are taken to lower risk to land and buildings in future seismic events. The ability to link of risk reduction actions to property rights is an important regulatory tool for disaster risk management.

Other Major 2011 Earthquakes

There were two events in 2011 that lead to further widespread liquefaction in Christchurch, both of which were preceded a few hours earlier by smaller but still significant earthquakes. Both affected areas where liquefaction had occurred previously.

At 2.20 pm local time on the 13th June 2011 an Mw 6.0 earthquake occurred, which was preceded at 1:01 pm by a Mw 5.6 earthquake (GNS Science 2014). Both occurred on a previously unknown blind fault on the south eastern edge of the city, approximately 10 km from the Christchurch CBD. Peak ground accelerations in the city were higher than the Darfield earthquake, but less than the Christchurch earthquake. Liquefaction in this event affected an area similar to that affected during the Darfield earthquake (Tonkin & Taylor 2012).

On the 23rd December 2011 a Mw 5.8 earthquake occurred at 1.58 pm local time, and was shortly followed by a Mw 5.9 earthquake at 3:18 pm (GNS Science 2014). These events occurred on an unknown fault to the east of the city. Peak ground accelerations were less than the 13th June 2011 event, however liquefaction still occurred across the eastern suburbs of the city, with significant liquefaction in the

northeastern suburbs.

3.2 Post - Earthquake Flooding

During the Canterbury earthquake sequence (CES) up to 10 earthquakes induced liquefaction within the city limits (Quigley et al. 2013). There was progression of damage across the city after each major event, including subsidence, and lateral spreading that reduced channel capacity and resulted in increased susceptibility to flooding in certain areas of the city. These events, in and of themselves, could be considered as cascading due to the long sequence time period, and the linked impacts on soils, landforms, and the built environment.

In the winter of 2013 a precipitation event occurred that caused localized flooding, particularly in the eastern suburbs. The city council acknowledged that earthquakes had played a role in the flooding through sedimentation of the channels and filling of storm sewers from liquefaction ejecta, physical damage to the pipes of the storm sewers (Canterbury Earthquake Recovery Act 2013). In 2014, larger flood events occurred that highlighted the further flood susceptibility from land subsidence and channel cross-section changes from lateral spreading in the earthquakes. The large floods of 2014 pushed the central government to examine how much the earthquake may have increased flooding in the city and to re-examine policies related to insurance as discussed in the next section. The CCC however, did not adjust its flooding policy framework. Changes to flood management will be discussed further in section 3.3.

3.3 Post - Earthquake Regulatory Framework

Following the CES, a new governmental agency, the Canterbury Earthquake Recovery Agency (CERA) formed through special emergency legislation passed in 2011 to direct the reconstruction phase of the recovery (see Figure 1) (New Zealand Parliament 2011). CERA has emergency operational authority related to all built environment aspects of recovery. The existing Earthquake Commission (EQC) was funding major repairs following the Canterbury earthquakes.¹ This is the main revenue source for residential damages to buildings, land, and contents. The New Zealand Transport Agency (NZTA) is a major funding agency for road reconstruction and an owner partner of the Stronger Christchurch Infrastructure Rebuild Team (SCIRT) (see Figure 1).

The Canterbury Earthquake Recovery (CER) Act of 2011 has given powers to the Government appointed Minister for Earthquake Recovery to suspend or make exemptions to almost any New Zealand law including parts of the RMA 1991, and LGA 2002. This legislation will remain in effect at least until 2016 when it is set to sunset, at which time CERA would also cease operations in its present form (CER Act 2011). As of 21 February 2014, CERA provided the Christchurch City Council 2230 Detailed Engineering Reports (DEEs) from (CERA). Some of these buildings are listed as earthquake prone and have been put on the Council's Earthquake prone buildings register. Over the next few years, an additional 11,000 DEEs will be completed, and this will establish a complete inventory of non-residential building conditions. This database of seismic engineering assessments is a direct science input for reconstruction and regulatory policy. This database did not exist prior to the CES, and CCC now has a science based tool for informing building consent decisions.

Following the cascading events, the CCC commissioned additional modeling. Preliminary modeling to determine Increased Flooding Vulnerability results from 2014 showed that 309 homes showed potential for increased flooding vulnerability due to earthquake damage (SCIRT 2014). Additionally, CCC has updated its Flood Management Area (FMA) maps utilizing new Lidar data that includes the land subsidence and uplift in the City. The FMA was also updated using a 200 year return period (probability of 0.5%) with an additional 400 mm of freeboard to account for sea level rise (CCC 2014). The 200 year

return period flood mapping, provide technical information based on physical data and provided a boundary to impose stricter building consent regulations at the city level.

4. RISK MANAGEMENT ACTIONS BY GOVERNMENT

This section describes the changes to insurance and summarizes the changes presented previously to agencies in Christchurch following the CES. These changes and organizations highlight how the region has had to adapt following the physical changes induced by the natural hazards outlined in the previous sections. New Zealand has recognized the need to address these coupled natural hazards and has created these policies for adaptation in the changing physical setting.

4.1 Insurance

Insurance is a risk-transfer instrument and can be configured and priced in many ways. There are unique aspects of New Zealand's insurance system that has direct impact on the CES recovery process and the March 2014 flooding. The EQC provides natural disaster insurance for all residential property (contents, dwellings and some coverage for land), against loss or damage from earthquakes, volcanic eruptions, hydrothermal activity, tsunamis, natural disaster fires and natural landslips (New Zealand Parliament 1993). Private insurers provide commercial coverage. There is also a local authority protection insurance fund that provides funds for matching central government assistance.ⁱⁱ

The Earthquake Commission Act (1993) specifies that land damage caused by the specified natural disasters will be remediated as part of the insurance settlement process. The land on which the residential building is situated and all land within 8 meters of the horizontal building line is covered. New Zealand is the only country in the world that provides such coverage from the national government.

In April 2014, the EQC established an Increased Flooding Vulnerability (IFV) provision to their general policy to establish a type of land damage that may be covered by EQC for some houses now at risk of flooding where previously they were not and for some that are now at a greater risk of flooding. Due to subsidence, the CES events have created additional areas vulnerable to flooding, and in December 2014 the New Zealand High Court ruled that land damage coverage applies to such areas (New Zealand Law Society 2014). Under this ruling, EQC is now able to provide payments to these homeowners. Payments can cover on-site flood mitigation work to make a house less flood prone, through complete buy-out of the property under a diminished value procedure. Legally, seismic and flooding are now linked and thus create additional liability/

4.2 CERA

The Canterbury Earthquake Recovery Authority (CERA) was established by Government to lead and coordinate the ongoing recovery effort following the devastating earthquakes. CERA reports to the Minister for Canterbury Earthquake Recovery, who is responsible for coordinating the planning, spending, and actual rebuilding work needed for the recovery. Special powers have been vested in the Minister for Canterbury Earthquake Recovery and CERA in order to enable an effective, timely and coordinated rebuilding and recovery effort. CERA has a voice in the reconstruction of the horizontal infrastructure networks, and in this way has an interest in flooding.

Between 2011 and 2013, the Government, through CERA, acquired some 7,300 properties in the mostly flat areas of Christchurch in what is called the Residential Red Zone (RRZ). Most of these are adjacent to the Avon River, which is where water from the Dudley Creek flood area is conveyed. So, part of the policy solution was to retreat from the area primarily located along the Avon River in the eastern communities, and in Kaiapoi to the north.

Being zoned red means that the land has been so badly damaged during the Canterbury Earthquake Series, it is unlikely that it can be rebuilt on for a prolonged period and that success of engineering solutions may be uncertain given the ongoing seismic activity (<http://cera.govt.nz/land-information/red-zone>). The gap between the size of the problem (the uncertain cost of repairs, the time required and the long term exposure to liability) and solutions at hand made acquisition of these lands an acceptable strategy for the central government.

5. GAPS IN THE PRESENT SYSTEM

Christchurch is addressing a long-term flooding problem exacerbated by the CES. Based on field observations and technical studies (e.g. Tonkin and Taylor 2013) the problem has a series of parts. Improvement of the present stormwater system performance is needed. Second, based on the March and April 2014 flooding, there is a need to determine if the design parameters of the flood models are considering larger storm impacts. The higher than pre-CES water table and the rapidly saturating soils demonstrate a gap between the present models and what is now needed, or desired. That is, does the city want the capacity to convey, for example, twice the volume of water as was in the March 2014 storm without flooding? Third, are the proposed Flood Management Areas (FMAs) in the city's district plan hazard's chapter large enough to address future flood risk? Fourth, while sea level rise adjustments have been incorporated into local hazard policy, no mention of other climate change adaptations are addressed.

The policy inputs examined in this case study focus on how new geotechnical information emerges to inform decision makers, and how government decision makers use this information in their policy formation process, and how the nature of the hazard themselves are understood. The main question addressed in this example is how rapidly can geotechnical information be collected and interpreted in the development of recovery policy after a major cascading event.

6. ELEMENTS OF AN ADAPTIVE POLICY FRAMEWORK

The hydrologic and geotechnical data establishes the need to quickly convey stormwater away from the eastern areas. Water can be pumped and conveyed to channels with capacity to move this stormwater, however, pumping is expensive and consumes energy and the largest available conveyance channel in the area is the Avon River. The optimum conveyance points are through lands now held by the NZ national government, in the area known as the Residential Red Zone along the Avon River. Use of this area for flood relief requires identification of RRZ areas that are most appropriate for this use and a discussion with the Government on acquiring the easements and conditions of use (e.g. how much water, for detention time, and how stormwater is conveyed to the estuary or other outlet). See the RRZ Map, Figure 4. Although the Christchurch City Council is charged with the operations of the stormwater system, it has not considered, in its public documents and statements, the impact of more extreme precipitation events on the eastern suburbs.

Figure 4. Residential Red Zone- Areas in Red. Source: CERA website, land maps.

6.1 Collective Improvement Areas.

In areas where land alterations and water table changes have altered the flow characteristics and thus exacerbating flood risk, then localized collective agreements on conveyance improvements are necessary. These collective agreements would involve the CCC and the neighbourhoods only, and not require national government participation.

6.2 Regulation of Flood Management Areas.

In New Zealand, cities develop and adopt a District Plan (a comprehensive plan) that meets the national Resource Management Act requirements. This is the public policy regulatory component. The 2014, CCC amended the District Plan and increased, by 30% the size of the Flood Management Areas and raised the floor level building requirements to account for sea level rise and higher flood levels. The CCC uses a 200 year return period rainfall event, plus a one metre sea level rise and a 20 year high tide event to establish its freeboard requirement for new construction (Hansen et al. 2015). This allows the CCC to require new buildings to be above the predicated flood levels prior to obtaining a building consent. The FMA's however do not adequately account for new geotechnical information on water table levels. The higher the water tables, the less water that may be absorbed in a storm and the more need for greater conveyance and storage capacity. Geotechnical modeling of water table impacts would provide additional policy inputs. Additionally, the damaged stormwater pipe system rebuild was done on a "like for like" basis with no new added capacity. The "like-for-like" decision was taken to establish a rebuild cost estimate and did not take into account any risk reduction benefits that could be derived from increased capacity. Here hydrologic science appears not to be an important consideration as a policy input.

6.3 Collaboration and Adaptation.

One policy input is how the nature of the hazard is understood in terms of geotechnical information. In the Canterbury region there are three main policy actors: Environment Canterbury, the regional authority; the Christchurch City Council; and the national government. These actors have not agreed on a common set of geotechnical indicators to use in policy formation. Without such agreement their actions will lack the coordination needed for overall risk reduction.

7. DISCUSSION

The main question addressed in this paper is how rapidly can geotechnical information be adapted in the development of recovery policy after a major cascading event? For the CES case the results are mixed. The national government invested the time and the money to acquire geotechnical information needed to address the liquefaction and landform issues before making its main reconstruction decisions: which were to acquire 7,500 at risk properties and eliminate future risk to life and property, and to rebuild the downtown as a compact and pedestrian friendly central business district (Siembieda and Johnson 2015). The CCC has integrated a 1 meter sea level rise estimate to establish its 400mm freeboard standard for new construction, and also choose to limit building consents in areas subject to 200 year storm events (Hansen et al. 2015). The CCC has not however chosen to support collective solutions for neighbourhoods whose landforms and flooding have changed due to the earthquakes. The CCC continues its established storm system modelling approach to high flood areas, but does so without a spatial planning component related to extreme storm conveyance needs or a climate change adaptation approach. The CCC behaviour is that of incremental governance, small steps that call into question its overall resilience approach. The cascading seismic and flood events have created a “new condition” for Christchurch. Given that Christchurch faces a \$400-\$500 million infrastructure funding shortage in 2014 it is not surprising that an incremental approach appears to be the policy of choice. At the local government level, geotechnical information is slow to influence risk reduction policy, which is heavily influenced by technical and engineering stakeholders. At the national level the government has shown willingness, even a necessity, to use geotechnical information to guide decisions and to shape its risk reduction and risk exposure policy.

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REFERENCES

- Allen J., Ashford S., Bowman E., Bradley B., Cox B., Cubrinovski M., Green R., Hutchinson T., Kavazanjian E., Orense R., Pender M., Quigley M., and Wotherspoon L. (2010) Geotechnical Reconnaissance of the 2010 Darfield (Canterbury) Earthquake. *Bulletin of the New Zealand Society for Earthquake Engineering*, 43 (4): 243-320.
- Allen, J., T. Cochrane, C. Davis, B. Deam, G. De Pascale, S. Giovinazzi, D. Hart, M. Hicks, D. Holland, M. Hughes, L. Johnson, S. Young Ko, R. Measures, M. Quigley, G. Rix W. Siembieda N. Stark, R. Teasley, L. Wotherspoon, S. van Ballegooy (2014) “ Geotechnical & Flooding Reconnaissance of the 2014 March Flood Event Post 2010-2011 Canterbury Earthquake Sequence, New Zealand.” National Science Foundation Geo-Extreme Event Reconnaissance GEER Association Report No. GEER-035. 19 June 2014

- Alesch, D. and W. Siembieda (2012) The role of the built environment in the recovery of cities and communities from extreme events. *International Journal of Mass Emergencies and Disasters*, 32(2): 197-211.
- Beavan, J., Fielding, E., Motagh, M., Samsonov, S., & Donnelly, N. (2011). Fault location and slip distribution of the 22 February 2011 Mw 6.2 Christchurch, New Zealand, earthquake from geodetic data. *Seismological Research Letters*, 82(6): 789-799.
- Berrill, J.B., Mulqueen, P.C. and Ooi, E.T.C. (1994) Liquefaction at Kaiapoi in the 1901 Cheviot, New Zealand, Earthquake. *Bulletin of the New Zealand Society for Earthquake Engineering*, 27(3): 178-189.
- Bradley B.A. and Cubrinovski M. (2011) Near-source Strong Ground Motions Observed in the 22 February 2011 Christchurch Earthquake, *Seismological Research Letters*, 82, 853-865.
- Canterbury Earthquake Recovery Agency (2013) Land Use Recovery Plan. December 2013. <http://cera.govt.nz/recovery-strategy/built-environment/land-use-recovery-plan>
- Canterbury Earthquake Recovery Agency (2014) Greater Christchurch Recovery Update. Issue 31 (April)
- Christchurch City Council (2010) Flood Management Areas Map (Variation 48). <http://resources.ccc.govt.nz/files/MapofAreasCoveredByVariation48.pdf>
- Christchurch City Council. (2011) Management of Flood Hazard in Christchurch. Operative Variation 48, Resources Management Act 1991. City Plan Amendment. <http://resources.ccc.govt.nz/files/Variation48-OperativeDocument.pdf>
- Christchurch City Council. 2014. Draft Natural Hazards Chapter, District Plan Review (March).
- Cousins J. and McVerry G. (2010) Overview of strong motion data from the Darfield Earthquake, *Bulletin of the New Zealand Society for Earthquake Engineering*, 43(4): 222-227.
- Cubrinovski M., Bradley B., Wotherspoon L., Green R., Bray J., Wood C., Pender M., Allen J., Bradshaw A., Rix G., Taylor M., Robinson K., Henderson D., Giorgini S., Ma K., Winkley A., Zupan J., O'Rourke T., DePascale G., and Wells D. (2011) Geotechnical aspects of the 22 February 2011 Christchurch earthquake, *Bulletin of the New Zealand Society for Earthquake Engineering*, 43(4): 205-226.
- Dizhur D., Ismail N., Knox, C., Lumantarna R. and Ingham J. (2010) Performance of unreinforced and retrofitted masonry buildings during the 2010 Darfield earthquake. *Bulletin of the New Zealand Society for Earthquake Engineering*, 43(1): 321-339.
- Gledhill K., Ristau J., Reyners M., Fry B. and Holden C. (2011) The Darfield (Canterbury, New Zealand) Mw 7.1 Earthquake of September 2010: A Preliminary Seismological Report. *Seismological Research Letters*, 82(3): 378-386.
- GNS Science (2014). GeoNet <http://www.geonet.org.nz> (accessed December 15, 2014).
- Green, R. A., Allen, J., Wotherspoon, L., Cubrinovski, M., Bradley, B., Bradshaw, A., Cox, B. and Algie, T. (2011) Performance of Levees (Stopbanks) during the 4 September 2010 Mw7.0 Darfield and 22 February 2011, Mw6.1 Christchurch, New Zealand earthquakes, *Seismological Research Letters*, 82 (6): 898-908.
- Hansen, J., Mitchell, P., Dawson, S. and J. Huria. (2015) Independent Hearings Panel. Christchurch Replacement District Plan: Decision 6, Natural Hazards Part. (July 17).
- New Zealand Law Society (2014) Accessed December 20,2014 <http://my.lawsociety.org.nz/news/high-court-rules-on-earthquake-damage>

- New Zealand Parliament. Public Act (1991) No. 69. Resource Management Act 1991. Parliament Counsel Office: Wellington, New Zealand.
- New Zealand Parliament. Public Act (1993) No. 84. Earthquake Commission Act. Parliament Counsel Office: Wellington, New Zealand.
- New Zealand Parliament. Public Act (2002) No. 84. Local Government Act 2002. Parliament Counsel Office: Wellington, New Zealand.
- New Zealand Parliament. Public Act (2011) No. 12. Canterbury Earthquake Recovery Act. Parliament Counsel Office: Wellington, New Zealand.
- Pettinga, J. R., Yetton, M. D., Van Dissen, R. J. and Downes, G. (2001) Earthquake source identification and characterization for the Canterbury region, South Island, New Zealand, *Bulletin of the New Zealand Society for Earthquake Engineering*, 34 (4): 282-317.
- Quigley M.C., Bastin S., and Bradley B.A. (2013) Recurrent Liquefaction in Christchurch, New Zealand, during the Canterbury Earthquake Sequence, *Geology*, 41(4): 419-422.
- Rogers, N., Williams, K., Jacka, M., Wallace, S. and Leeves, J. (2014) Geotechnical aspects of disaster recovery planning in residential Christchurch and surrounding districts affected by liquefaction, *Earthquake Spectra*, 30 (1): 493-512.
- SCIRT (2014) <http://www.rebuildchristchurch.co.nz/blog/2014/5/land-with-an-increased-risk-of-flooding>
- Shi, P., Jaeger, C., and Ye, Q. (Eds.) (2013) *Integrated risk governance: Science plan and case studies of large-scale disasters*. Beijing Normal University Press and Springer.
- Siembieda, W. and Johnson, L. (2015) Christchurch recovers: In New Zealand, collaboration is the key. *Planning*, 81 (5): 37-41.
- Statistics New Zealand (2013) 2013 Census QuickStats about greater Christchurch. <http://www.stats.govt.nz/Census/2013-census/profile-and-summary-reports/quickstats-about-greater-chch/population-change.aspx> (accessed December 9, 2014).
- Tonkin & Taylor (2012) Liquefaction vulnerability study. Report prepared for the Earthquake Commission by Tonkin & Taylor.
- Tonkin & Taylor Ltd (2013) Liquefaction vulnerability study. Earthquake Commission. T&T Ref: 52020.0200/v1.0
- Wilson, J. (1989) *Christchurch: swamp to city: a short history of the Christchurch Drainage Board, 1875-1989*. Te Waihora Press for the Christchurch Drainage Board.

ⁱ The Canterbury Earthquake Recovery Act 2011 (CER Act) defines recovery in this way: "Recovery includes restoration and enhancement." Land Use Recovery Plan (2013, p9). Therefore there is statutory language to enhance the storm drainage system if so determined.

ⁱⁱ New Zealand's government has the potential obligation to contribute 60% of the restoration costs for essential local infrastructure after a natural disaster, with local authorities contributing 40% (MCDEM 2005, New Zealand Office of the Auditor General 2012). This includes local roads, potable water and wastewater systems, and stop banks. In 1993, local authorities created a Local Authority Protection Programme (LAPP) fund and make annual contributions to the fund to meet their 40% share (New Zealand Office of the Auditor General 2012). The LAPP provided the local match for Waikimakiri's infrastructure repair.