1. INTRODUCTION

The city of Christchurch is the second largest city in New Zealand located on the South Island in the Canterbury Plain. The city is located in a low-lying and low-gradient coastal flood plain. Portions of Christchurch were historically characterized by marshy, poorly draining land that has been drained to make the land inhabitable. As a result, Christchurch is naturally prone to flooding from several rivers passing through and around the city, high artesian groundwater, and coastal influences. Numerous inundation protection measures have been implemented to control drainage and flooding, which have proven effective over the past several decades for controlling design level flooding.

Christchurch was struck by a sequence of strike-slip and thrust earthquakes in 2010 and 2011; the most significant earthquakes were: M_w 7.1 on September 4, 2010); M_w 6.2 on February 22, 2011, M_w 6.0 June 13, 2011, M_w 5.8 and M_w 5.9 on December 23, 2011. The 2010 earthquake epicenter was located 45 km west of Christchurch while the 2011 earthquakes were about 6 to 10 km from the city center. The 4 September 2010 earthquake is referred to herein as the Darfield earthquake, the 22 February 2014 earthquake is referred to herein as the Christchurch earthquake, and collectively all these earthquakes are referred to as the Canterbury earthquake sequence. There were significant seismic-induced geotechnical mechanisms important to increasing the flood susceptibility in Christchurch, including vertical tectonic movements, liquefaction induced settlement, and lateral spreading. Liquefaction and lateral spreading, in addition to sedimentation, were significant in reducing river channel capacity. The local geomorphology and ecological systems have been modified from these geotechnical earthquake effects and influence the flood risks. Additional non-geotechnical mechanisms significantly effected overland and river channel flow including earthquake-induced damage to existing flood protection and drainage infrastructures, the stormwater drainage system, and other key infrastructures conveying water including the surface roads.

On March 4th to 5^{th,} 2014, a 992 hPa tropical depression sat east of the Canterbury coast for several days, providing heavy and sustained rainfall over Christchurch. This was the heaviest rainfall in the city since the 1970s. At the same time coastal water levels were also high; a high tide meeting a 20 to 50% annual exceedance probability level existed at the time of the storm event, which was compounded by a storm surge associated with the low-pressure weather system. This combination of heavy sustained rainfall, high tide, and storm surge resulted in flooding. Although, Christchurch is susceptible to flooding from this type of event, the above-described earthquake impacts, along with post-earthquake construction activities creating obstructions in the watercourses, were found to contribute to the documented flooding. In some areas flooding occurred mostly as a result of the earthquake induced impacts, while other locations were pre-exposed to flooding in this event but the earthquake impacts contributed to increase the inundation depth and area.

This report presents an overview of the earthquake-induced changes that were observed to have affected the city's response to flood events. Following this Chapter 1 introduction, the second chapter presents a historical perspective of flooding and threats to Christchurch and an overview of the 5 March, 2014 flood event. Chapter 3 describes land deformations resulting from the Canterbury earthquake sequence and descriptions on how these deformations related to increased flood risk in The detailed effects of the 2010-2011 Canterbury earthquake sequence were presented in two previous GEER reports:

http://www.geerassociation.org/GEER_Post%20EQ%20Reports/Christchurch_2011/Index_Christchurch_2011.html

http://www.geerassociation.org/GEER_Post%20EQ%20Reports/Darfield%20New%20Zealand_2010/Cover_Darfield_2010.html

Flood modelling for pre- and post-earthquake sequence conditions are examined and compared in Chapter 4 and correlated with actual flood conditions. The effects of earthquake-induced damages are described in Chapter 5. Chapter 6 describes the post-flood geotechnical field investigations and observations and Chapter 7 describes the post-flood impacts on lifeline systems. The flood impacts on the built environment are summarized in Chapter 8. Finally, the role of government entities and future flood management policies are considered in Chapter 9.

Shortly after the Canterbury earthquake sequence the University of Canterbury (UC) worked with the American Society of Civil Engineers Technical Council on Lifeline Earthquake Engineering (TCLEE) to develop an earthquake-flood multihazard project to investigate the increased flood risk to Christchurch. The UC-TCLEE international collaboration project on "Earthquake-Flood Multihazard Impacts to Lifeline Systems" was formalized in 2012. UC students and advisors were working with the Christchurch lifeline organizations and community when the 5^{th} March 2014 floods occurred. The GEER team mobilized to investigate and document the flood events, in support of initiatives such as the UC-TCLEE on-going earthquake-flood multihazard investigation efforts.

The flood events occurring after the 2010-2011 Canterbury earthquake sequence present a unique opportunity to investigate multihazard events and their impacts on lifelines in a real-time reconstruction setting. Following the March 5^{th} flood event, the GEER team was mobilized to assist ongoing research at UC by conducting a geotechnical reconnaissance through a joint USA-NZ team, with the main funding for the USA contingent coming from GEER. The majority of the observations presented in this report resulted from reconnaissance efforts over a period of four days (18-21 March 2014). However, members of the NZ contingent and one member of the USA contingent have also been working on data collection related to multihazard events in Christchurch for several years following the Canterbury earthquake sequence.

The team for the 5th March 2014 flood event reconnaissance included the following members:

- **Mr. John Allen** – (TRI/Environmental, Inc., Austin, TX, USA)
- **Dr**. **Sarah Beaven** – (University of Canterbury, Christchurch, New Zealand)
- **Dr. Tom Cochrane** – (University of Canterbury, Christchurch, New Zealand)
- **Dr**. **Craig Davis** – (City of Los Angeles Department of Water and Power, Los Angeles, CA, USA)
- **Dr. Bruce Deam** – (Tonkin & Taylor Ltd., Christchurch, New Zealand)
- **Dr. Gregory De Pascale** – (Fugro Geotechnical, Christchurch, New Zealand)
- **Dr. Marion Gadsby** – (Environment Canterbury Christchurch, New Zealand)
- **Dr. Sonia Giovinazzi** – (University of Canterbury, Christchurch, New Zealand)
- **Dr. Deirdre Hart** – (University of Canterbury, Christchurch, New Zealand)
- **Dr**. **Murray Hicks** – (NIWA, Christchurch, New Zealand)
- **Dr**. **Matthew Hughes** – (University of Canterbury, Christchurch, New Zealand)
- **Mr. David Holland** – (University of Canterbury, Christchurch, New Zealand)
- **Dr. Laurie Johnson** – (Laurie Johnson Consulting, San Francisco, California, USA)
- **Ms. Su Young Ko** – (University of Canterbury, Christchurch, New Zealand)
- **Mr. Richard Measures** – (NIWA, Christchurch, New Zealand)
- **Dr. Mark Quigley** – (University of Canterbury, Christchurch, New Zealand)
- **Dr**. **Glenn Rix** – (Geosyntec Consultants, Altanta, Georgia, USA)
- **Dr**. **William Siembieda** – (Cal Poly, San Luis Obispo, California, USA)
- **Dr. Nina Stark** – (Virginia Tech, Blacksburg, Virginia, USA)
- **Dr. Rebecca Teasley**– (University of Minnesota Duluth, Duluth, Minnesota, USA)
- **Dr**. **Thomas Wilson -** – (University of Canterbury, Christchurch, New Zealand)
- **Dr. Liam Wotherspoon** – (University of Auckland, Auckland, New Zealand)

The USA GEER and New Zealand members worked as one team, sharing resources, information and logistics in order to conduct a thorough and efficient reconnaissance covering large areas of the wider Christchurch city over a limited time period. The results of this effort are intended to feed into the on-going efforts to reduce the post-earthquake flood risks in Christchurch, New Zealand, at the same time as elucidating the reality of multihazard risks that communities worldwide may be exposed to flowing significant earthquake events. This report summarizes the key evidence and findings from the reconnaissance efforts. Any opinions, findings, and conclusions or recommendations expressed in this report are those of the individual or collective authors and editors, and do not necessarily reflect the views of the associated organizations and funding agencies.

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