NATURAL HAZARDS 2018

NATURAL HAZARDS RESEARCH PLATFORM

RESILIENCE TO NATURE'S CHALLENGES

Kia manawaroa – Ngā Ākina o Te Ao Tūroa

National SCIENCE Challenges

Front: Clockwise beginning Top, left:
A sediment core collected near Lake Grassmere. Photo: GNS Science; Road damage caused by the Kaikōura earthquake. Photo: GNS Science; Storm on the Wellington south coast. Photo: NIWA; Mt Tongariro fumarole. Photo: GNS Science.
Back: Mt Ruapehu crater lake. Photo: GNS Science.

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FOREWORD

Building damage caused by the 22 Feb 2011 Christchurch earthquake. Photo: GNS Science.

Tēna koutou kātoa.

Welcome to the final issue of 'Natural Hazards' compiled by the Natural Hazards Research Platform (NHRP). In this issue, we look back on what we've achieved together and where we go from here.

Over its 10-year life, the NHRP has worked across disciplines to increase New Zealand's resilience to natural hazards. We combined the efforts of the geophysical, engineering and social sciences to address our risks from natural hazards, while working more closely with end-users for delivery of the research outputs.

Over that time, we saw an increased number of natural hazard events. Two notable earthquakes, volcanic eruption, extreme weather causing wind, flood, and storm damage – all of these impacted on people and infrastructure.

The NHRP was the first programme of its kind in New Zealand. It could be considered the 'pilot' for the National Science Challenges, including the Resilience to Nature's Challenges, which features in this issue.

Our research has also been influential overseas. Tsunami blue lines now exist in the west coast of the USA and parts of Indonesia. And how we communicate earthquake aftershock forecasts has been received with great interest by colleagues in Japan and the USA.

So in this issue, we'll look back at the highlights of the past 10 years and activities from current research projects. If you'd like to see it all at a glance, see page 54 – our Hazards to Impact table attempts to put 10 years of work on a page (although it's not an exhaustive list).

The NHRP has not been alone on this journey. We gratefully acknowledge –

Our **end-users** for challenging us as researchers to look at a problem through multiple lenses.

To the **NHRP theme leaders, project leaders and colleagues** – thank you for your dedication to teaching, research and determination to inform others about natural hazards.

To the **Platform Management Group** comprised of Kelvin Berryman (Director; 2009-15); Terry Webb, Gill Jolly, Hannah Brackley (GNS); Murray Poulter, Sam Dean (NIWA); Jarg Pettinga, Rajesh Dhakal (UC), Michael Davies, Pierre Quenneville (UA), Peter Kemp (Massey); Ben Holland, Peter Benfell and Wendy Turvey (WSP-Opus). Your collective wisdom of the geophysical, engineering, and social sciences, the pathways towards shaping natural hazards resilience and your willingness to share that knowledge and experience has been inspiring. It was a pleasure to work with you.

To the **Strategic Advisory Group**, led by David Middleton since 2009 – thank you for the time you have given to the NHRP. During the Christchurch and Kaikōura earthquakes, your own agencies were stretched but you always made yourselves available. Your advice was hugely appreciated – Richard Smith, Sarah Stuart-Black, Roger Fairclough, Basil Chamberlain, Mike Adye, Bryce Davies, Mike Stannard, Adrian Bennett, Kieran Devine and Hilary Blake.

And lastly, to the International **Technical Advisory Group**, led by Russell Blong (Australia; 2012-15), followed by George Pankiewicz (UK) – thank you for staying in touch from a distance. Your contributions to New Zealand's natural hazards community have helped shape our work and future directions – Bill Ellsworth (USA), Bill Holmes (USA), Stephanie Chang (Canada), Michael Lindell (USA), Stephen Sparks (UK), Willy Aspinall (UK), Jim Hall (UK) and Tom O'Rourke (USA).

The NHRP's contract ends on 31 October 2019, while the second phase of the Resilience to Nature's Challenges gets underway for the next five years. Best wishes to the Resilience Challenge team as they lead us forward from here. ■

Catherine Pinal
Natural Hazards Research Platform

NATURAL HAZARDS 2018

14

THE KAIKŌURA EARTHQUAKE AND PAST FAULT RUPTURE

By Rob Langridge and Kate Clark

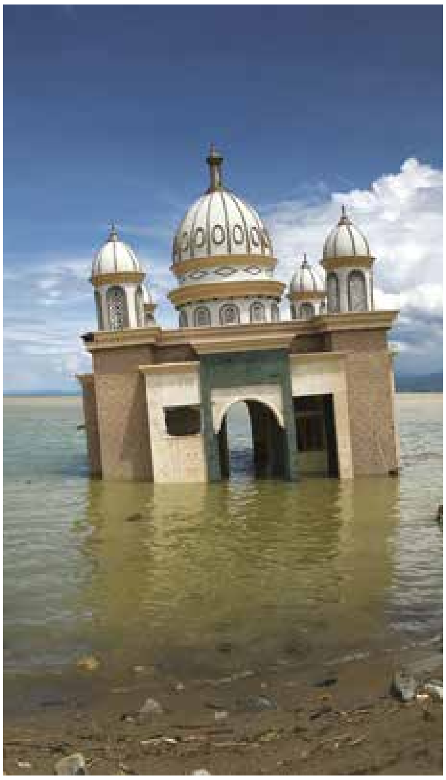
The 2016 earthquake was one of the most globally complex earthquakes to have occurred in modern times. Two research teams tell us about their field work.

20

NEW TOOLS FOR ASSESSING CLIMATE CHANGE IMPACTS ON COASTAL HAZARDS

By Giovanni Coco and Karin Bryan

Researchers have developed a free online tool to help New Zealanders understand the present and future changes in coastal hazards.

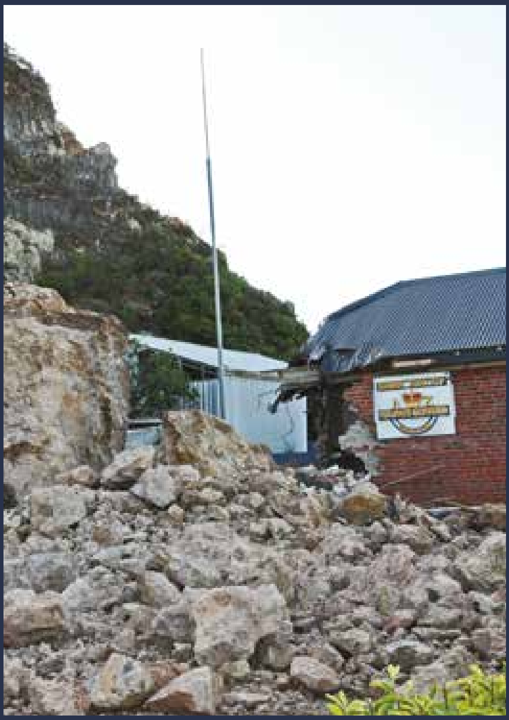


National SCIENCE Challenges

RESILIENCE TO NATURE'S CHALLENGES

Kia manawaroa – Ngā Ākina o Te Ao Tūroa

GEOLOGICAL HAZARDS



All photos GNS Science.

10 YEARS
SEISMOLOGY AND TSUNAMI SCIENCE – A DECADE OF SIGNIFICANT PROGRESS

*By **Stephen Bannister***

The Natural Hazards Research Platform was established at the beginning of a period of substantial earthquake activity in New Zealand, leading to big changes in public response mechanisms and new science capabilities.

In the 30 years between 1979 and 2009 there were only seven earthquakes beneath New Zealand that were considered large (magnitude greater than 6) and shallow (less than 40 km deep). Five of these occurred in the 1990s.

In comparison, since the inception of the Natural Hazards Research Platform (NHRP) in 2009, New Zealand has experienced 12 such large earthquakes. These include the extensive 2010-2012 Canterbury earthquake sequence, the 2013 Cook Strait earthquakes, and the 2016 Kaikōura earthquake and aftershocks.

NHRP'S KEY ROLE OVER 10 YEARS

In these last 10 years, the NHRP has played a critical role in helping coordinate the science response during natural hazard events, by organising the short-term response programmes which informed stakeholders involved in recovery work, in addition to coordinating the underpinning NHRP research already taking place.

Along the way, our science has evolved very quickly in the seismology and tsunami space. We have incorporated new large streams of data that were quite rare back in 2009, using vastly evolved techniques, and new paradigms informed by knowledge from the latest earthquakes, slow slip phenomena and tsunami. Many of the changes in our science were greatly assisted by the evolving network of GeoNet instrumentation and GeoNet data.

The 2010 magnitude 7.1 Darfield earthquake, which began the extended Canterbury earthquake sequence, involved rupture across a structurally complex fault network. As the Canterbury sequence unfolded, including the 2011 magnitude 6.3 Christchurch earthquake, the importance of the pre-existing fault network geometry, the role of earthquake stress triggering, and the influence of crust rheology were all notable.

However, what became very evident following the Canterbury sequence was the need for big changes in how we communicated earthquake aftershock forecasts and time-varying hazard to the public. In addition, there was a need to see how our science was subsequently used in setting standards and public policy.

IMPACT OF 2016 KAIKŌURA EARTHQUAKE

The 2016 magnitude 7.8 Kaikōura earthquake was unprecedented in its complexity. Involving at least 22 faults, scientists applied a range of methods – joint inversion of seismological, geodetic, fault geology, tsunami and

InSAR data. We folded in LiDAR and coastal uplift data to inform the details, along with offshore high-resolution multibeam data.

New approaches using dynamic rupture simulations were applied to help understand the multi-fault rupture. NHRP-funded projects from the 2015 contestable round – *Seismic hazard of Kekerengu Fault*, led by Tim Little (VUW), as well as *Characterisation of active faulting earthquake sources in eastern Marlborough*, led by Phil Barnes (NIWA) – were clearly prescient.

The impact from the Kaikōura earthquake on Wellington city infrastructure was larger than expected. It highlighted the increased need to understand the role of the 3-D Wellington basin structure on ground motions. There was also the need to infer future ground motion effects for future Wellington earthquakes, both crustal and on the Hikurangi megathrust, to inform revisions of Wellington building design standards. The NHRP moved to address some of these needs in its Kaikōura short-term response projects.

Most recently, there has been an evolving understanding of how slow-slip events can modify the earthquake probabilities. This has led to an increased effort in communicating the science behind slow-slip phenomena, the hazard from the Hikurangi subduction megathrust, as well as tsunami awareness, to the public and key agencies.

TSUNAMI

The period since 2009 has also been the most active for tsunami in New Zealand. The 2009 Samoa tsunami had a big impact on our South Pacific neighbours, with New Zealand scientists identifying that the tsunami was caused by not one but two near-simultaneous earthquakes.

In 2011, a magnitude 9.0 earthquake caused devastation in Japan, and flooded houses in the northern Coromandel – the first time this had occurred in New Zealand since 1960.

The 2016 Kaikōura earthquake generated a tsunami that inundated and badly damaged a cottage on Banks Peninsula, and towns south of Kaikōura experienced a near-miss as the tsunami ran-up 6-7 metres on embankments between them and the sea. New Zealand researchers were instrumental in gathering the data on this tsunami, providing the only clear picture of how far this earthquake extended offshore.

Significantly within the last 10 years, NHRP-funded research allowed us to develop the first model of tsunami hazard for all New Zealand coasts, and progress with the techniques that have enabled much of the country to have tsunami evacuation zones mapped. ■

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▲ GNS Scientist Matt Gerstenberger explains the aftershock forecasts to a crowd of 200 in the Seddon community meeting following the 2013 Cook Strait-Lake Grassmere earthquakes. Photo: Derek Flynn, Marlborough Express.

10 YEARS
LESSONS FROM NEW ZEALAND LANDSLIDES AND ROCKFALL

◀ Dislodged boulders near the RSA clubrooms following the Feb 2011 Christchurch earthquake. Photo: Margaret Low, GNS Science.

▶ Landslide dam along Hapuku River triggered by the Kaikōura Earthquake 2016. Photo: Dougal Townsend, GNS Science.

By ***Sally Dellow*** and ***Chris Massey***

The last 10 years have seen significant advancements in the way landslides, landslide hazards and landslide risk are treated in New Zealand.

The Christchurch earthquake in February 2011 was a turning point for researchers and policy makers. There were great challenges in gathering the data and expert opinion, and providing the advice necessary to the public and decision-makers.

But from this difficult period, landslide risk assessment in New Zealand came to be recognised as international best practice. Other countries learned from New Zealand's Christchurch response, and it is that continual cycle of building upon the knowledge of past events – here or overseas – that benefits us all.

WHAT WE LEARNT FROM CHRISTCHURCH

The extended Canterbury earthquake sequence provided scientists with a wealth of knowledge about rockfall, cliff collapse, and landslides and allowed us to develop a comprehensive picture of landslide hazards. Laboratory studies to characterise the properties of the rocks and soils involved in the landslides helped us better understand how these materials responded to triggering events.

Data collected from repeat surveys of cliffs in the Sumner and Red Cliffs area using a terrestrial laser scanner revealed that the amount of material shed by the cliffs was directly related to the strength of shaking, material type and slope geometry. Numerical modelling of slope behaviour and detailed slope models built from the survey data are providing insights into the future behaviour of slopes, with strong potential to identify areas of future vulnerability.

In Christchurch, we undertook extensive risk analyses to prepare detailed maps of life-safety risks. These maps were used as the basis for declaring 400 residential properties unfit for habitation. The life-safety risks were deemed unacceptable (the properties were 'red-zoned'), and the life-safety risk maps were subsequently used to update Christchurch City Council's District Plan.

LESSONS FOR KAIKŌURA

The lessons from Christchurch were put to good use following the 2016 Kaikōura Earthquake. A landslide dataset, containing nearly 30,000 individual landslides was compiled using high-resolution aerial photography, LiDAR and oblique aerial photography. Research related to the Kaikōura landslide has been used to develop new earthquake-induced landslide forecasting models using new methods not available during the Canterbury earthquake sequence, including artificial intelligence statistical techniques.

The landslide datasets also include rainfall-induced landslides, which occur frequently. A challenge has been how to acquire high-quality data to allow rainfall-induced landslide forecasting models to be developed. The arrival of ex tropical cyclones to the vulnerable Kaikōura region resulted in remobilisation of landslide debris and failure of cracked ground, causing ongoing hazards and risk to local residents.

The ability to forecast rainfall-induced landslides is critical to understanding how changes in climate will impact our landscapes. The consequent increase in hazards is likely to result in much greater risks from landslides until we are managing those risks well. ■

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10 YEARS
ADVANCES IN NEW ZEALAND VOLCANOLOGY

*By **Jonathan Procter** and the **Volcano team***

Jonathan Procter discussing the lahar deposits in coastal Taranaki. Photo: Massey University.

Mt Taranaki.
Photo: Brad Scott, GNS Science.

New Zealand volcanology has had an important coming-of-age as a result of the Natural Hazards Research Platform.

The 1995 Mt Ruapehu eruption was the last significant eruption to disrupt the everyday lives of New Zealanders. Volcanic ash closed airports, damaged hydroelectric power facilities, closed major thoroughfares, and impacted agriculture, livestock and fisheries.

The impacts from the 1995 eruption were important to shaping the purpose of the Natural Hazards Research Platform – bridging the geophysical, social, and economic dimensions of natural hazards research – but also provided the impetus for the greater collaboration needed during crises.

The 2012 Te Maari eruption, while relatively small, produced pyroclastic density currents (PDCs), a small debris avalanche, ballistic projectiles, ashfall and rock falls. Ballistic impacts heavily damaged Ketetahi Hut on the Tongariro Alpine Crossing, which fortunately was unoccupied at the time. NHRP-funded research enabled us to take a multi-disciplinary approach to explore these impacts, generate new knowledge, methodologies and produce world-leading science. The event was significant in that the greater collaboration led to the rapid development of hazard management products and strategies based on good science that enabled greater preparation and better response during the event.

Our collective research on the 2012 eruption culminated in a series of publications in the *Journal of Volcanology and Geothermal Research* in addition to a report on volcanic hazard and risk for the UN Office of Disaster Risk Reduction, Global Assessment of Risk ('GAR Reports), putting New Zealand's practice of volcanology – in a hazard and risk context – on the world stage. Since Te Maari, we have continued to make advances, including a 'NZ Inc' approach towards establishing a National Volcanic Hazard Model for New Zealand [Bebbington, NHRP Contest 2015].

We also respect the volcanoes we work on and the significant cultural connections Iwi and Māori have with them. It is a privilege to be able to explore those environments and in return share our knowledge with iwi. We now lead internationally in developing methods to exchange knowledge between western science and indigenous knowledge systems for the betterment of all (Procter – NHRP Contest 2012 '*Mātauranga Māori for volcanic hazard*'; and more recently with the Resilience Challenge '*Better Understanding and Implementation of Mātauranga Māori and Tikanga to Build Resilience*').

Meanwhile our research excellence continues to be noticed internationally. Our work on an eruption simulator for pyroclastic density currents has attracted international interest and was featured in Nature Geoscience ('*Experiments to save lives*' Nature Geoscience, 12, 309 (2019). Our research in Taranaki has also provided new directions for understanding and communicating volcanic hazard information by providing probabilities and computer simulations of future events and scenarios that better inform emergency management plans. The research is recognised internationally as the future direction of volcanic hazard analysis. ■

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COLLAPSE OR NOT? EXPLORING FLANK COLLAPSE HAZARDS OF MT RUAPEHU

*By **Gabor Kereszturi**, **Lauren Schaefer**, **Craig Miller** and **Stuart Mead***

In a first for the Southern Hemisphere, researchers from Massey University, University of Canterbury and GNS Science are applying state-of-the-art technology to understand the risk of Mt Ruapehu volcanic flank collapse.

Volcanic slopes may weaken and collapse. While less frequent than eruptions or lahars, these low probability, high-risk phenomena can trigger dangerous debris avalanches – a potentially hazardous mass flow of volcanic and non-volcanic particles.

Mt Ruapehu has produced debris avalanches over the past 200,000 years, with some travelling up to 50 km from their source. The sporadic occurrence of this high impact natural hazard poses challenges for accurately predicting the volume and location of future events.

STRONG ROCKS BECOME WEAK ROCKS

One way to address these hazards is by quantifying the hydrothermal alteration history of Mt Ruapehu. Hydrothermal alteration is a process which turns already solidified rocks into easily deformable and weak rocks.

Hydrothermal alteration occurs as infiltrating surface water and circulating groundwater are heated by the nearby stored magma bodies, such as dykes and sills. This circulating hot water becomes acidic over time which enhances its ability to dissolve volcanic rocks and form new minerals, including clay, oxide and sulfate minerals.

By changing the chemical composition of volcanic rocks, hydrothermal alteration undermines the physical strength of rocks. These weakened volcanic rocks gradually become more susceptible to failure due to gravitational, seismic and weather-related triggers, thus producing debris avalanches.

NEW GEOPHYSICAL IMAGING TECHNIQUES

Our approach is to use advanced hyperspectral imaging, photogrammetry and aeromagnetic surveys to map the surface of Mt Ruapehu and at depth below.

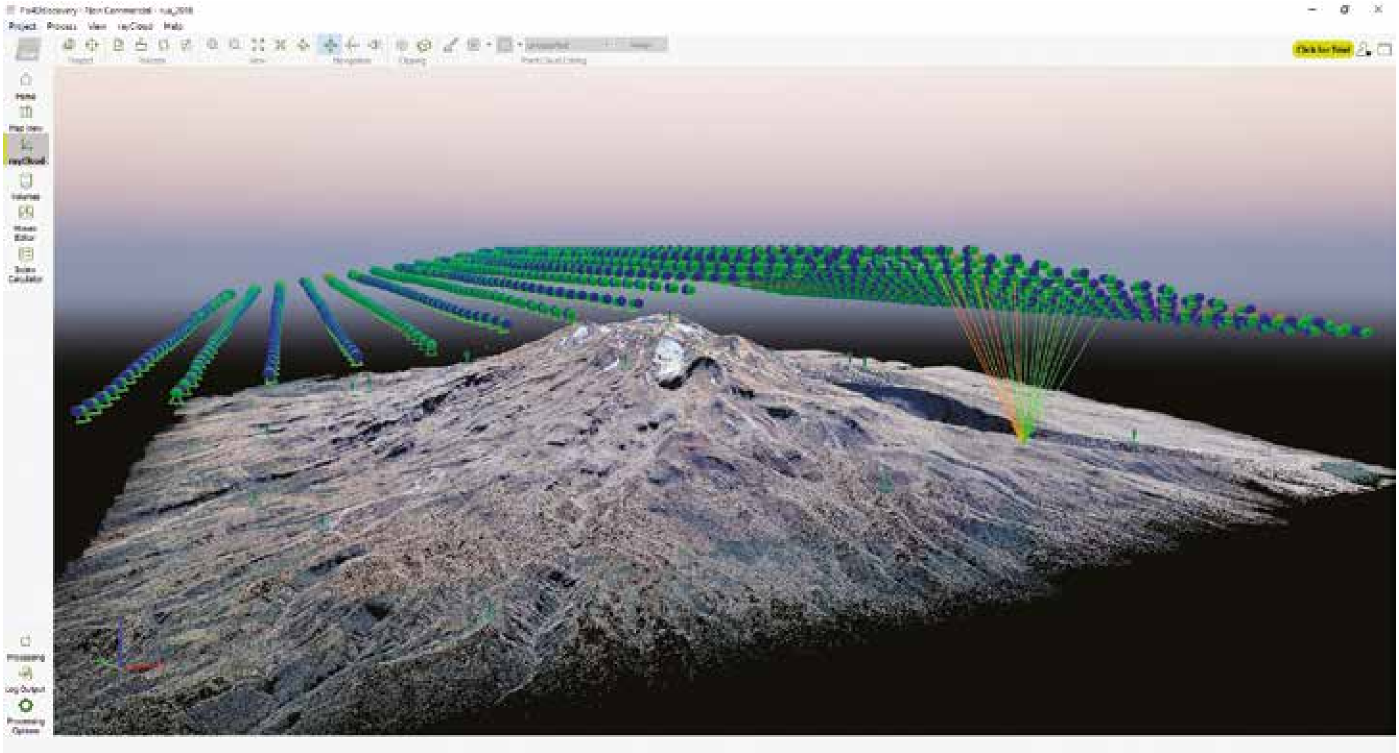
The hyperspectral imaging system is the first of its kind in New Zealand, providing new spectral datasets for mapping and modelling. On the same aerial surveys, hundreds of digital photos were taken, to depict the topography of Mt Ruapehu, providing a new high-resolution Digital Terrain Model through photogrammetry.

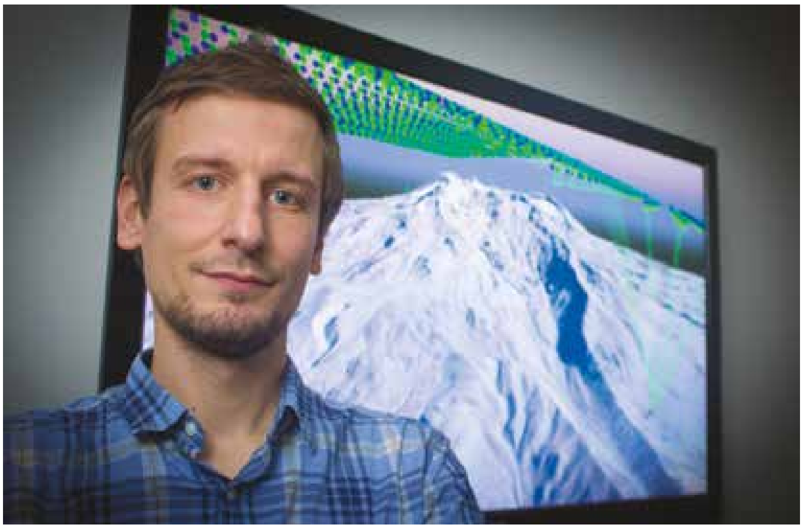
Hyperspectral imaging can measure reflected light at hundreds of wavelengths – beyond what is observable by the human eye. This extended spectral range allows quantification of surface mineral composition changes that indicate departures from strong, fresh lava rocks to hydrothermally altered weak rocks, enabling us to create a detailed geotechnical map of Mt Ruapehu. Combined with aero-magnetic surveys, a detailed picture of the sub-surface distribution of hydrothermal alteration begins to emerge.

We have collected a wide assortment of hydrothermally altered rocks. This helps quantify the rock mechanical properties, such as strength and porosity, as well as mineral-proxies that indicate the degree of alteration.

Rock strength data coupled with the surface and shallow sub-surface geophysical information will be used to create a new geotechnical model that will be incorporated into a stability assessment of Mt Ruapehu. This assessment will help us develop new numerical simulations of the likely run-out distance of future debris flows. For the first time ever, we will have a flank instability and debris avalanche hazard map of Mt Ruapehu.

This project will greatly improve our understanding of Mt Ruapehu's geological hazards and can be applied to other New Zealand volcanoes. ■





Dr Gabor Kereszturi. Photo courtesy of Massey University.

Perspective view of the new point cloud data with the location of the camera position (blue and green spheres) over Mt Ruapehu. Image: Gabor Kereszturi, Massey University.

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YouTube video: For a spectacular view of the hyperspectral and topographic survey of the Mt Tongariro volcano in New Zealand see https://www.youtube.com/watch?v=dLs97Ph7-aA

THE KAIKŌURA EARTHQUAKE AND PAST FAULT RUPTURE

By **Rob Langridge** and **Kate Clark**

The 2016 Mw 7.8 Kaikōura earthquake is one of the most globally complex earthquakes to have occurred in modern times. New research is addressing whether the multi-fault rupture observed in the Kaikōura earthquake is typical for this part of the New Zealand plate boundary. The results will help us better understand how complex fault ruptures can be better incorporated into our hazard models.

Paleoseismologists taking measurements across the main strand of the Papatea fault. The fault heads down the hill to the right and into the Clarence River valley where major river diversion was caused by the vertical movement of the fault through the valley. Photo: Kate Clark, GNS Science.

▲ GNS scientist Rob Langridge (far right, in blue) at the Papatea Fault in the Clarence Valley. Photo: GNS Science.

The Kaikōura earthquake ruptured at least 20 faults in an approximately 200 km area in the north-eastern South Island. The earthquake caused significant landscape change, such as coastal uplift, landslides, river diversion across the North Canterbury and Marlborough regions, and a localised tsunami. Scientists Rob Langridge and Kate Clark from GNS Science are leading teams of researchers from across New Zealand to understand the complex event.

INVESTIGATING THE PAPATEA FAULT

With colleagues at the University of Canterbury, University of Otago and Lincoln University, Rob Langridge is leading a project to investigate the record of past surface ruptures along the Hope-Seaward, Humps, Hundalee, and Papatea faults.

The Papatea Fault was one of the more unusual fault ruptures of the Kaikōura earthquake, with vertical offsets of up to 10 metres occurring on this fault up the Clarence River valley, along with multiple large landslides. A major challenge with the Papatea Fault was finding locations where the enormous 2016 fault offsets did not inhibit fault trenching.

In early 2019, three trenches were excavated across the main strand and two minor splay faults off the Papatea Fault. Initial results from these trenches suggest there have been two to four earthquake ruptures during the Holocene period, including the 2016 earthquake. Another way to understand the Papatea Fault's behaviour has been to investigate the record of fluvial and landscape change in the Clarence valley. Radiocarbon dating of deposits exposed by avulsion and erosion indicates the previous episode of major fluvial change in the valley occurred around 1000 or more years ago.

UNDERSTANDING PAST EARTHQUAKES

A concurrent project is using the coastal landscape record of uplifted marine terraces to understand past earthquakes along the Kaikōura – Marlborough coastline.

Many of the faults involved in the Kaikōura earthquake either crossed the coastline or were entirely offshore. Marine terraces offer a method of understanding when the coastal and offshore faults last ruptured and the relative size of those earthquakes.

This project is being led by Kate Clark in collaboration with the University of Auckland, NIWA and Victoria University of Wellington. Particular areas of focus are the Kaikōura Peninsula, Cape Campbell and the coastline near the Papatea Fault. Preliminary results show there were at least one or two earthquakes within the past 2000 years at all sites, with the most frequent coastal uplift occurring at Cape Campbell, consistent with the high slip rate of the offshore Needles Fault.

Our original view was that the 2016 Kaikōura earthquake was a very rare event as it involved faults with extremely different recurrence intervals. The research to date supports this.

Paleoseismology offers a pathway for understanding the frequency of multi-fault earthquakes, and will enable insights into future earthquake behaviour across the complex plate boundary in the northern South Island. ■

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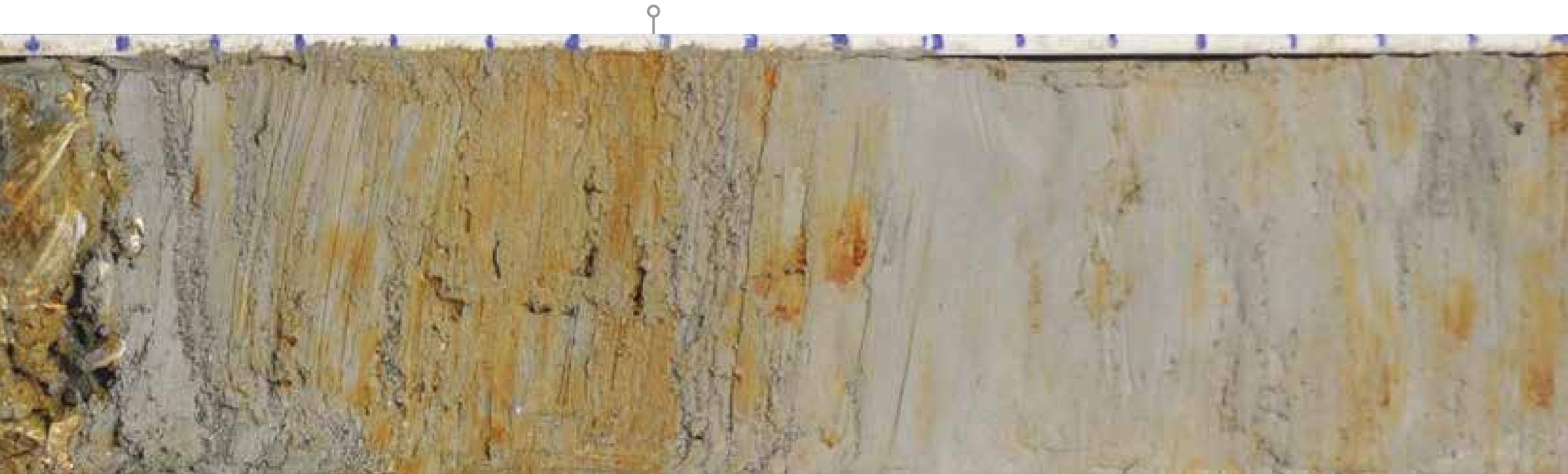
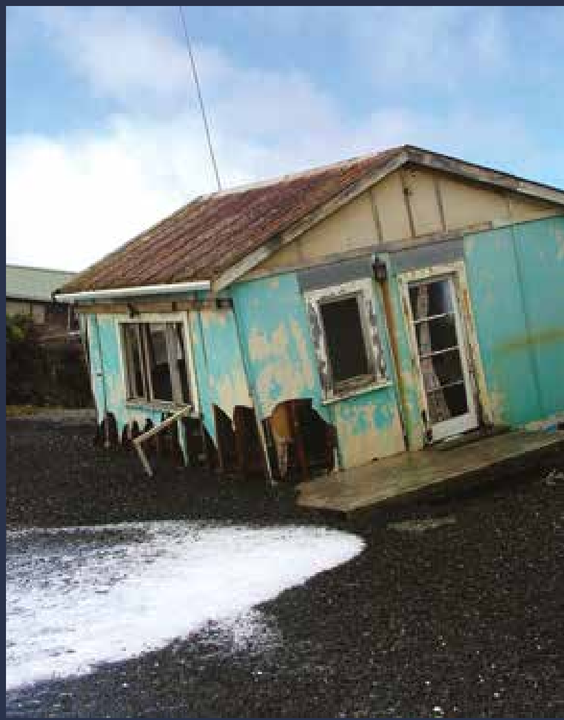
▼ A sediment core collected near Lake Grassmere, southeastern Marlborough. This core shows sudden influxes of coarse sediment that were probably deposited by past tsunamis triggered by nearby fault ruptures. The information on past offshore fault ruptures can be integrated with paleoseismic records from onshore faults to understand past earthquakes. Photo: Kate Clark, GNS Science.



WEATHER FLOOD COASTAL



Clockwise beginning Top, left: Wellington storm; Haumoana coastal erosion; Scientists at work during the 2014 Christchurch flood. Photos: NIWA; Bottom, left: 2017 Edgecumbe flood. Photo GNS Science.

10 YEARS
A DECADE OF ADVANCES IN WEATHER, FLOODS, AND COASTAL HAZARD RESEARCH

*By **Richard Turner***

Damaged irrigator in the aftermath of the 2013 Canterbury wind storm. Photo: Dave Allen, NIWA.

A ten-year milestone is a good opportunity to look in the rear-view mirror, review achievements and renew our enthusiasm for what lies ahead. Here are some highlights of research conducted within the Weather, Floods, and Coast theme of the Natural Hazards Research Platform.

The Natural Hazards Research Platform (NHRP) has been a great mechanism for encouraging and funding collaboration between weather researchers/modelers and design/structural engineers working on issues of importance to New Zealand, with stakeholder engagement encouraged and supported.

A good example of this collaboration was the WSP-OPUS led project, '*Improving New Zealand's resilience to wind storms*' (Safei Pirooz et al, this issue). This project, and earlier wind research within NHRP, has contributed to a proposed major revision of the New Zealand relevant portion of the wind loading code (AS/NZS 1170.2). It has also led to better and verified methods in calculating effects of complex terrain on design winds.

FLOOD FORECASTS FOR ALL OF NEW ZEALAND

Another exciting project nearing completion is the 2017 NHRP-funded '*Enhanced probabilistic flood forecasting…*' which will generate high-resolution, probabilistic two-day ahead flood (catchment) forecasts for all of New Zealand. The forecasts are produced by using a complex Bayesian statistical method to create an unbiased spread (or ensemble) of forecasted hourly rainfall rates at grid points over a catchment that feed into a river flow model. These unbiased ensembles are calculated on a fine spatial grid of 1.5 km and forecasts are updated every six hours and extend to 48 hours.

The development of this method will enable the production of next generation forecasts as high-resolution weather ensemble forecasts become available in New Zealand. This will allow for more realistic uncertainty (probabilistic) estimates (providing a range of outcomes) to be made in flood situations.

COASTAL INUNDATION

Climate change is a critical issue. The NHRP has supported a study led by the University of Auckland which has modelled and assessed coastal inundation due to tide, wave and storm surge conditions for current and future storms that impact New Zealand. Impressive visualisation tools have been developed that demonstrate the changing risk over the next century (Coco & Bryan, this issue).

MODELLING ATMOSPHERIC FLOWS

Over the last 10 years, NIWA's support of underpinning natural hazards research has been strategically aligned with NHRP/RNC investment. This has contributed to the advanced modelling capability for atmospheric flows, and this has benefited some very practical applications such as ashfall dispersion from the 2012 Te Maari eruption, as well as the 2017 dispersal of myrtle rust spores from Australia to New Zealand and Raoul Island. It has also been a catalyst for upgrades to the emergency plume dispersal modelling system which operates at NIWA and is designed for modelling airborne disease outbreaks.

The models and computational platforms upon which the weather, flood, and coasts hazard research depends would not be possible without the support of High Performance Computing in New Zealand that comes from the National e-Science Infrastructure. ■

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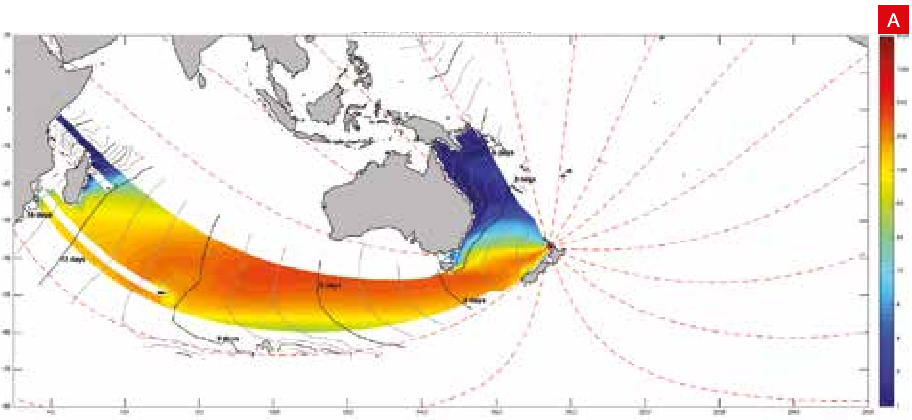
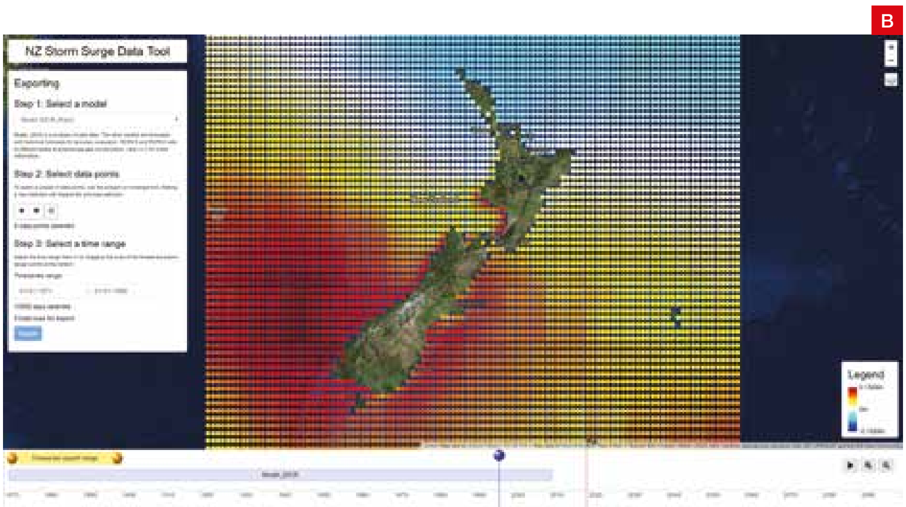
Brett Phibbs, NZ Herald.

NEW TOOLS FOR ASSESSING CLIMATE CHANGE IMPACTS ON COASTAL HAZARDS

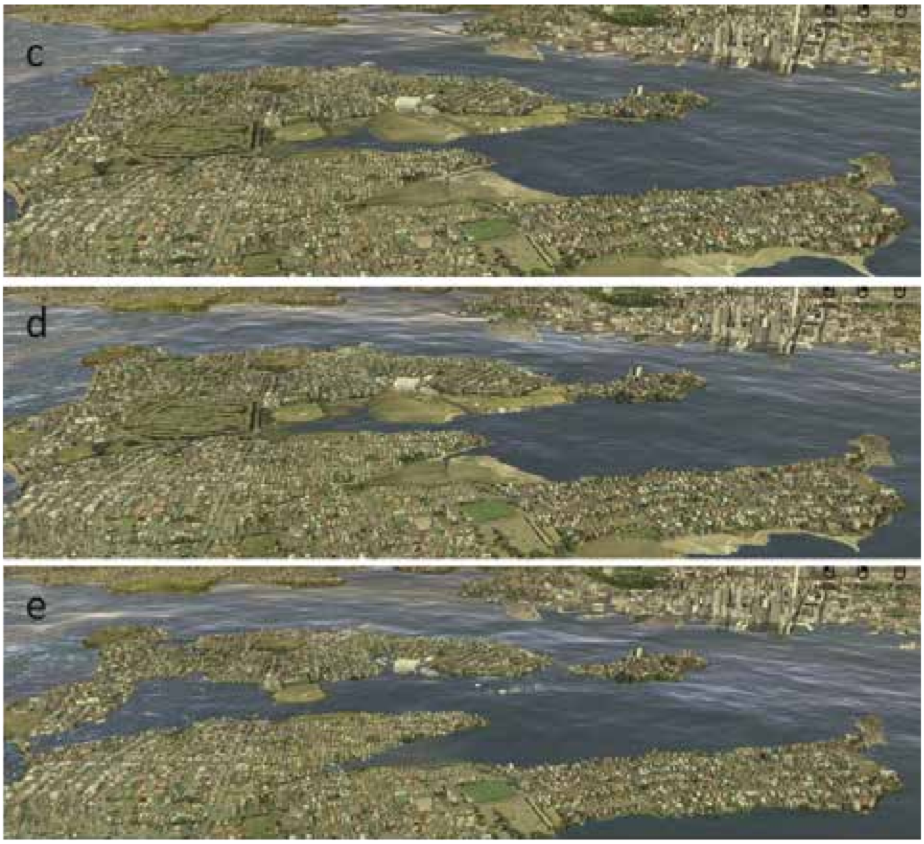




By ***Giovanni Coco*** *and* ***Karin Bryan***

In New Zealand, coastal erosion and coastal inundation are significant issues for decision-makers involved in land-use planning. There is a growing demand for robust evidence to understand both the present and future changes in coastal hazards.

(a) Map of model output showing generation region of coastal waves. Waves reaching the west coast of the New Zealand can be generated hundreds of kilometres away;
(b) Snapshot of the webpage where storm surge data can be downloaded.



(c) Mean sea level today; (d) Mean sea level in 2050; (e) Mean sea level in 2050 plus the combined effect of a large storm and king tides.

UNDERSTANDING NEW ZEALAND'S COASTAL HAZARDS

Coastal erosion and coastal inundation are generated by a combination of three key factors:

- extreme weather-related events
- how our climate has changed over time
- the systematic increases in sea level, waves and storm surge as a result of climate change.

A collaborative project by the University of Auckland, University of Waikato and NIWA is generating a nationwide set of projections of nearshore wave and storm surge conditions. The projections look at the next 80 years using state-of-the-art modelling approaches. The most recent IPCC* emission scenarios and associated climate properties are used to drive these predictions of future wave and surge processes.

Our projections of wave climate and storm surge are obtained using an innovative "multi-model" approach, which combines dynamical modelling and statistical downscaling. It incorporates weather-type classification and clustering techniques (Fig. a). The projections are calculated at a scale of 10 kilometres for the whole New Zealand coastline. And for the first time, these data are now publicly available through a free-access web-based platform (Fig. b).

The data can be downloaded at: https://coastalhub.science/storm-surge

A hindcast of wave data is also available (https://coastalhub.science/data) and in the near future, projections until the year 2100 will be made available over the same portal. This work provides unprecedented access to vital information needed to combat the future stresses caused by climate change.

Dr Tom Shand, Technical Director at Tonkin + Taylor has found the data useful: *"Thank you for making the wave and storm surge data available. As coastal practitioners, our ability to help communities is dependent on having accurate data. These wave and water level hindcasts will be extremely useful in understanding historic events allowing us to more accurately predict future hazard and to design more resilient structures."*

VISUALISING COASTAL FLOODING

Effective communication of the impacts of climate change is critical to facilitate uptake of the findings. In collaboration with the Centre of e-Research from the University of Auckland, we have developed a high-resolution coastal flooding visualisation for Auckland city, which is also available in Virtual Reality mode. Sea level rise, king tides and storm surge are the parameters available at: https://coastalhub.science/coastal-hazards

The tool allows the user to compare the present conditions and the effect of sea level rise (Fig. c; Fig. d shows the predicted sea level in 2050). Using the tool, the user can add the combined effect of sea level rise with a major storm and king tides (Fig. e). This type of visualisation is particularly relevant because it shows how the combined effect of all the possible components critically determines the severity of coastal flooding. ■

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*IPCC: Intergovernmental Panel on Climate Change

TOOLS AND KNOWLEDGE TO IMPROVE NEW ZEALAND'S LONG-TERM RESILIENCE TO WIND STORMS

By ***Amir Safaei Pirooz, Richard Flay, Richard Turner, Paul Carpenter, Peter Cenek*** *and* ***Neil Jamieson***

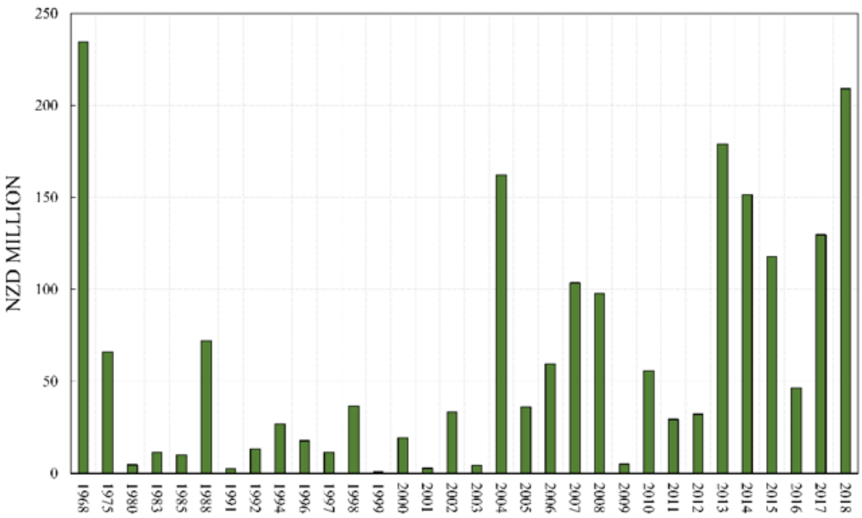

Fig. 1. Time series from 1968 to August 2018 of insured losses (inflation adjusted to 2017 NZD) related to storm events where wind damage was a major factor (i.e. not counting storm events where losses were primarily due to flood or coastal erosion) contributing to losses.

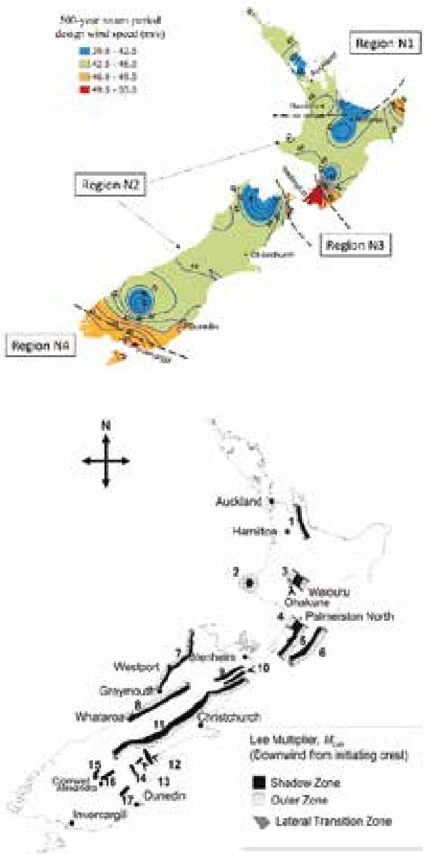

Fig. 2. (a) Design wind speed contour map and wind regions;
(b) Lee zone regions.

New Zealand's position in the 'Roaring Forties' makes it vulnerable to extreme weather and wind hazards, with many population centres and infrastructure assets located in exposed coastal or hilly areas.

Extreme wind hazards have a substantial societal and environmental impact. With climate change, it is expected that extreme weather and windstorms will occur more frequently.

When evaluated over time the insured damages and losses are considerable. In the last decade, the total insured losses for extreme wind events in New Zealand was about $1 billion NZD (Fig. 1).

All buildings and structures in New Zealand are designed to resist the effects of the wind speeds specified in the wind-loading standard AS/NZS1170.2 (2011). Much of the content of this standard has been prepared by a joint Australia/New Zealand committee. However, New Zealand's wind data have not been re-evaluated for purposes of updating the standard for the last 20 years.

Most wind loading design applications are concerned with the strongest winds expected in the lifetime of a structure. The establishment of appropriate design wind speeds is a critical first step towards the calculation of design wind loads for structures.

VARIATIONS FOR THE WIND-LOADING STANDARD

In this collaborative project involving the University of Auckland, NIWA and WSP-Opus, New Zealand's historical wind speed data over the past two years have been analysed for the purpose of revising design wind speeds, and directional and lee-zone multipliers for the next version of the wind-loading standard.

Based on our findings, several substantial changes have been proposed for AS/NZS1170.2, including adding a new region consisting of the Foveaux Strait area, refinements of wind zone boundaries, and revising all directional and lee-zone multipliers.

Fig. 2a Shows a preliminary contour map of design wind speeds for a 500-year return period, and the new wind regions. Fig. 2b Illustrates the revised lee zones proposed for the next version of wind-loading standard AS/NZS1170.2.

Currently, wind data from additional stations are being analysed to enhance the spatial resolution of the regional wind speed map. We are also using the data to investigate the possible effects of climate change on the long-term trends in extreme winds for design wind speed purposes.

Annual and seasonal trends in both the magnitudes and frequencies of the extreme winds are being evaluated. This is to determine whether or not the long-term wind gust series have changed significantly. We will also look at how these changes can be considered in the estimation of design wind speeds to ensure the safety and reliability of future structures. ■

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SOCIETAL RESILIENCE

Clockwise beginning Top: Kaikōura branch of the Red Cross preparing parcels. Photo: New Zealand Red Cross; Tsunami blue lines. Photo GNS Science. GNS scientist addresses town hall following Cook Strait-Lake Grassmere earthquake. Photo: Derek Flynn, Marlborough Express; Social scientist Julia Becker. Photo: GNS Science.

10 YEARS
SOCIETAL RESILIENCE RESEARCH AND ITS IMPACT OVER THE PAST DECADE

*By **Julia Becker** and **David Johnston***

Earthquake, tsunami and weather-related events over the last ten years have highlighted New Zealand's vulnerability to natural hazards and have prompted important societal research. The merging of social science with geophysical and engineering studies has improved how we communicate with the public about natural hazards, and provided insights into psycho-social recovery.

In a post-Canterbury and Kaikōura earthquake context, we understand more about how to effectively respond and recover, including for iwi and Māori stakeholders, communities, organisations, tourism, and from an economic perspective.

The NHRP Canterbury earthquake recovery programme contributed funding to the CERA* Wellbeing Index and Survey. This body of work assisted in understanding recovery needs over time, and how to best design interventions to increase wellbeing. In 2014, Government allocated an additional $13.5 million for psychosocial services as a result of on-going need identified by the Survey, with similar provision of services following the Cook Strait and Kaikōura earthquakes (1).

The Canterbury Wellbeing Index and Survey (as renamed in 2016) was globally leading in developing post-disaster recovery indicators, and contributed to international recovery knowledge. Following the disestablishment of CERA, the survey continued under the Canterbury District Health Board. More details can be found here: https://www.cph.co.nz/your-health/wellbeing-survey/

The Canterbury earthquakes also highlighted the pivotal role provided by Iwi and Māori stakeholders in recovery efforts, repeated during Kaikōura. Marae were operationalised as recovery assistance centres, where food and shelter were provided for those in need. Lessons learned have relevance for regional and emergency management planning across New Zealand (2).

▲ David Johnston (left) and Julia Becker (right). Photo: Catherine Pinal, GNS Science.

New Zealand research teams have also studied the actions of people during and after earthquakes which influences their risk of injury or death. Implications for assessing crowd behaviour also exist, particularly understanding the interactions between individuals such as how the actions/inactions of an individual influence the actions/ inactions of another (3).

The Ministry of Civil Defence & Emergency Management (MCDEM) '*ShakeOut*' drill has been regularly run to assist people in protecting themselves during future earthquakes. Research has investigated the effectiveness of the ShakeOut campaign. It found that it encourages participants to take protective action during an earthquake and enhances preparedness. MCDEM has also used the research findings to adjust the ShakeOut programme for greater effectiveness.

Tsunami research has highlighted challenges in the public's response to tsunami, with people undertaking slow and partial evacuation after earthquake ground shaking (4). In response to these challenges, and based on research on warning system effectiveness, we have seen several new initiatives. These include the development of new tsunami evacuation maps, the '*Long or Strong Get Gone*' public education campaign, rapid public alerting to mobile phones (Emergency Mobile Alerts, MCDEM 2017), effective short warning messages, and practical recommendations for vertical evacuation for tsunami.

Research on tsunami preparedness in schools has also revealed that not all at-risk schools are fully prepared for a tsunami, leading to the launch of the '*Tsunami Safer Schools*' project by MCDEM in 2017.

Research on risk reduction and preparedness has highlighted important lessons for individual households and communities, and for institutional and government preparedness. A key aspect of preparedness requires engaging with communities to grow their understanding of hazards and build resilience.

An example of a successful project for engaging with the community is the '*I can live with this*' research project. This project sought to elicit local perspectives in the Bay of Plenty about tolerable and intolerable risks, and build these into the land-use planning process for natural hazards. The Bay of Plenty example is being used as a case study for other local authorities to guide their land-use planning practices (5). ■

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*CERA, Canterbury Earthquake Recovery Authority (2011-16).

QUICKER, SAFER TSUNAMI EVACUATIONS

By ***Kate Boersen, Lucy Kaiser,*** *and* ***William Power***

Community workshops in Napier. Photo: Kate Boersen, ECLAB.

Community workshops in Napier. Photo: Kate Boersen, ECLAB.

Researchers from GNS Science, Massey University, East Coast LAB (Life at the Boundary), and University of Canterbury have been working with emergency managers, council staff and local communities to develop and refine computer-based tsunami evacuation models.

The models are based on simulations of the tsunami evacuation paths taken by people in the event of a long or strong earthquake. The project focuses on suburbs in Wellington, Napier and Christchurch. Validation of the model using GPS tracking of volunteers practising evacuations is also being undertaken.

Early engagement with emergency management- and council staff during the development of the project validated its usefulness and helped identify the most valuable case study locations for future civil defence emergency management planning.

This engagement has continued throughout the process, from the co-development of workshops to the refinement of the final models developed by GNS Science.

RELYING ON LOCAL KNOWLEDGE

Project Leader William Power (GNS Science) said that the research team recognised early on that they needed to incorporate information in the models that only the locals knew (such as congestion points and unmapped pathways). They decided the best way to tap into this knowledge was to hold community workshops.

The workshops were designed with the community at its centre, with day and evening hours to suit busy schedules and disability access available at chosen venues. Workshops have been held in Wellington, Napier and Christchurch.

Participants were introduced to the project before the workshop began. They helped to identify routes presented in the model that would not be accessible in real life, as well as alternative routes that could be used. Participants also identified potential solutions to make tsunami evacuations easier, safer and quicker.

Participation has varied across locations with between 10 and 115 people attending the workshops. The information that participants identify will be passed on to emergency managers and it is also intended that the final evacuation models will be shared with the civil defence emergency groups in the three case study areas. ■

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Photo: Julian Thomson, GNS Science.

ADAPTIVE AND INTERACTIVE FUTURES: A SERIOUS GAME FOR DECISION-MAKING AND COASTAL HAZARDS

By ***Paula Blackett, Kate Davies, Paula Holland, Ben Davies*** *and* ***Nick Cradock-Henry***

Computer-based 'serious games' allow players to explore complex and contested issues. In this project exploring coastal adaptation to climate change, researchers have tested the concept with the public.

In this project we are developing a 'serious game' that will empower communities and individuals with new knowledge to decide and act regarding coastal adaptation to climate change.

For the game to be relatable to the players, it needs to present a plausible and interesting scenario based on realistic adaptation options and community reactions. In this case, the player enters the game as the decision-maker for a New Zealand coastal community faced with increasing inundation and coastal erosion due to climate-driven sea level rise. Their task is to work with the community, represented by six 'non-player' characters, to enable adaptation to changing risk from sea level rise over 100 years.

Over the course of the game, coastal erosion and inundation will impact many of the elements valued by this community such as the beach, homes and local businesses. How quickly these impacts occur depends on which scenario is randomly selected at the start of the game. To simulate decision-making under deep uncertainty, no information is presented on the pace of change. It is revealed as the game evolves – much like a real-life situation!

The player has several adaptation options they can apply (e.g. beach re-nourishment, building sea-walls) provided they can afford them. Each option has advantages and disadvantages, as well as a lifespan related to sea level. This is complicated by non-player preferences for different options, and certain actions can affect the players' income (rates) and overall popularity.

Player choices influence how non-player characters behave in subsequent rounds by shifting both their satisfaction with current conditions and their trust in decision-makers. Non-player character responses are based on previous work by the research team, as well as research experiences from adaptation debates.

In November 2018, we tested a prototype game at the New Zealand Coastal Society Conference with 20 participants, including council staff, practitioners and researchers. Overall, responses to the game were positive and feedback suggested that:

- The concept of a game as an engagement tool was well received, and the players became engrossed in the game.
- Many found making choices difficult and agonised over how to balance the interests of the different characters.
- Players felt the game represented their experiences of coastal climate change adaptation, albeit with less detail, but in a more abstract and simplified setting.

Based on this feedback we are working on further character development, improving the visual experience and refining the interactions between finances and popularity. Once completed, in November 2019, the game will be freely available. It takes about 10-20 minutes to play. We thank Monica Pooley for providing the game illustrations.

If you are interested in helping test the next version of the game, please contact us. ■

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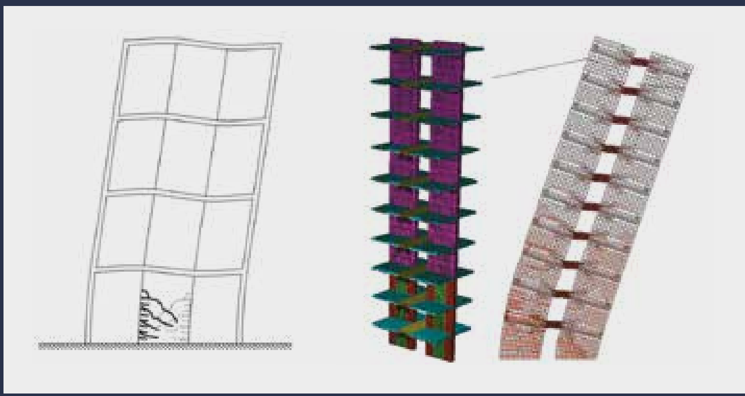
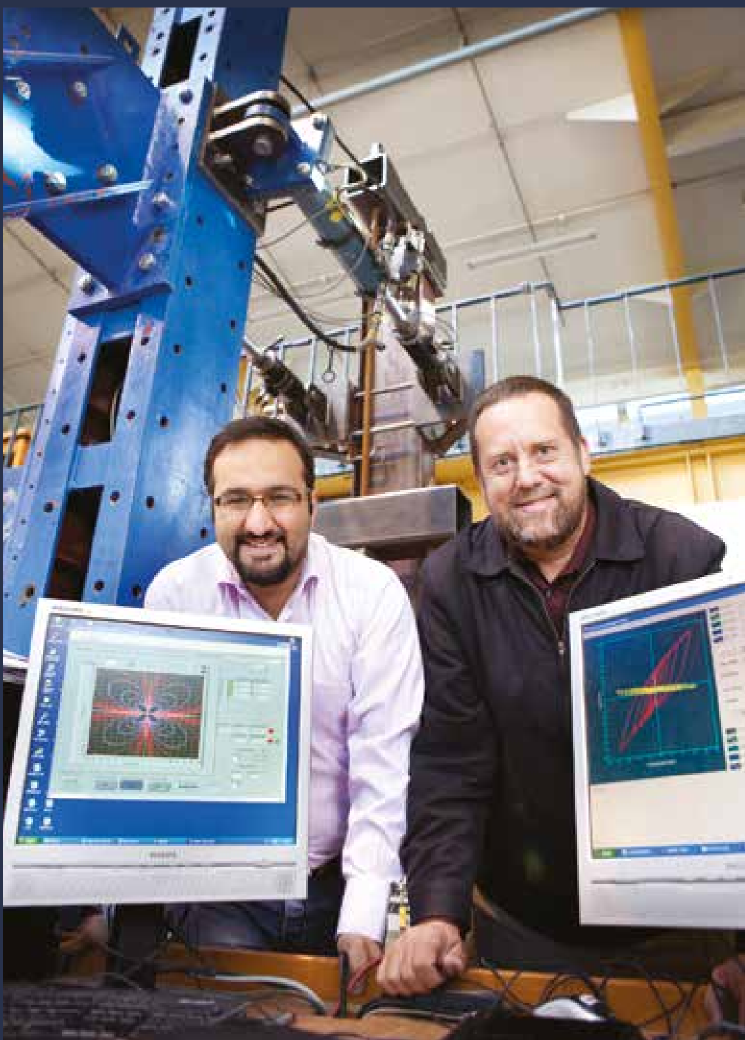
Serious game illustrations by Monica Pooley.

◀ Storm on the Wellington south coast. Photo: Dave Allen, NIWA.

▶ Fig. 1. The player begins with this community ….
Fig. 2. The community might experience damage to the park and coastal foreshore.
Fig. 3. The community might choose to build a seawall….
Fig. 4. … or relocate beach front homes and shops.

RESILIENT ENGINEERING & INFRASTRUCTURE





Clockwise beginning Top, left: Structural interactions between walls and floors; Damage to unreinforced masonry following the Christchurch earthquake. Images: University of Auckland; Damage at CentrePort; Matthew Hughes with the Liquefaction Resistance Index map; Greg MacRae (right) and PhD student Jamaledin Borzouie. Photos: University of Canterbury.

10 YEARS ENGINEERING AND INFRASTRUCTURE RESEARCH

The Canterbury earthquakes signified a turning point for the building and infrastructure sector. For engineers, it was a heightened period of research to understand performance and damage profiles. For the public, it became an evolving awareness of the building code (life safety vs immediate occupancy), infrastructure functionality, and whether this matched with expectations.

At its start, the NHRP programme supported underpinning research for ongoing studies in unreinforced masonry, low damage technologies and non-structural elements.

Following the Canterbury earthquakes, effort was quickly diverted to investigating performance of buildings (unreinforced masonry, concrete, steel), non-structural elements, infrastructure and lifelines. Extensive ground damage as a result of liquefaction and lateral spreading was a critical issue, and a research programme examining the impacts of liquefaction, soil profiles and triggering factors was initiated.

This research was an integral part of the NHRP Canterbury earthquake recovery programme, with NHRP engineers providing technical reports and expert testimony to the Royal Commission, in addition to seminars and workshops communicated with the sector.

Over the longer-term, research sought improvements to design practices and recommendations to achieve tolerable impact levels with respect to building functionality and safety at varying intensities of earthquake hazard. The geotechnical work included field data and modelling to understand soil-structure interactions, underground pipe networks, restoration times, damage costs, and impacts of mitigation measures. Research outcomes were shared with recovery agencies, government and the engineering sector.

The Canterbury programme was influential in low damage technologies being introduced into some of the new construction in Christchurch, and to some extent was mirrored in Wellington following the Cook Strait-Lake Grassmere earthquakes.

The risks related to unreinforced masonry and options for retrofit were known. On 1 July 2017, the Building (Earthquake-prone Buildings) Amendment Act 2016 came into force modifying how local councils, engineers and building owners are to carry out assessment and deal with earthquake-prone buildings. The issue remains contentious with ongoing political and economic discussion.

Researchers have contributed to standards and guidelines utilised by the engineering profession. This includes an update of the Detailed Seismic Assessment Guidelines for concrete, steel, timber and URM buildings, and development of Guidelines for Earthquake Geotechnical Engineering Practice. Much of this work was informed by the Canterbury experience.

The research team are also continuing their studies on residual capacity, which is to understand the impact of prior earthquake damage on a structure and how this affects downstream performance in subsequent events. These studies were critical in the inspection of precast concrete floors in Wellington buildings following the Kaikōura earthquakes.

IMPROVING THE DESIGN OF NEW BUILDINGS

By ***Rick Henry, Minghao Li, Chin-Long Lee, Greg MacRae,*** *and* ***Charles Clifton***

Fig. 1. ILEE-QuakeCoRE low-damage concrete building test. Photo: University of Auckland.

Fig. 2. Glulam frame BRB test. Photo: University of Canterbury.

Fig. 3. Bi-directional steel frame BRB testing. Photo: University of Canterbury.

It is critical that research into structural systems keeps up with trends in current building practices, and that design standards and guidelines are updated.

Trends in building construction are constantly evolving as engineers adopt new systems and incorporate lessons from past experience. Previously popular reinforced concrete-frame buildings with precast floors are giving way to buildings that use stiffer braced steel frames or concrete walls, composite floors, and a range of new low-damage technologies.

A coordinated research programme within the Natural Hazards Research Platform has focused on assessing the seismic performance and design of structural systems popular in new buildings. These include concrete walls, steel buckling-restrained brace (BRB) systems, composite floors, and timber LVL, CLT and glulam.* The interactions between these structural components have been considered with detailed modelling and large-scale experimental testing.

CONCRETE BUILDINGS EXAMINED

For concrete buildings, the research has focused on wall design and provisions in the Concrete Structures Standard (NZS 3101) to account for whole-of-building response. The influence of wall-to-floor interactions has been assessed using detailed numerical models.

Modelling results have shown that the inclusion of the floor stiffness and strength can significantly increase the axial and shear demands imposed on walls and columns, compared to the demands estimated from simplified models used in design. In addition, modelling of coupled wall systems has quantified the overstrength that occurs due to axial restraint from floor slabs adjacent to coupling beams.

The influence of load rate on reinforced concrete walls has been investigated with a series of tests on axially loaded prisms. The prism test results are being used to verify the dynamic load factors included in the NZS 3101 provisions for wall minimum vertical reinforcement. Lessons from the research on wall-to-floor interactions were recently included in large-scale shake-table tests of low-damage concrete wall buildings as part of the collaboration between QuakeCore and the International Joint Research Laboratory of Earthquake Engineering (ILEE) at Tongji University in China. (See Fig. 1.)

TIMBER BUILDINGS INVESTIGATED

For timber buildings, the behaviour of dowel-type connections used in new structures has been investigated with a series of large-scale tests using timber LVL and CLT.

An overstrength factor identified from these tests has now been included in the new draft of the timber design standard AS/NZS 1720.1. A separate project is investigating the use of heavy timber frames with BRBs. Two full-scale prototype glulam frames with common BRBs have been tested (See Fig. 2). These hybrid structures were designed as low-damage systems with glulam members and connections protected by capacity design and BRBs providing the source of energy dissipation. In addition, a new type of BRB is being developed using a timber casing, with initial testing providing promising results.

STEEL BUILDING RESEARCH

For steel buildings, research has focused on the interaction of BRBs, gusset plates and their supporting frames. The test rig used to subject the BRB frames to bi-directional loading demands is shown in Fig. 3. The experimental findings, and supporting numerical studies, are being developed into simple and clear analytical methods.

A separate project has focused on composite floors and specifically the interface between composite floors and steel-framed seismic resisting systems. Building demands from time history analysis, considering floor inertia forces and the forces caused by relative movement of framing systems were considered and compared with a number of proposed design methods. The capacity side has focussed on experimentally determining the strength and stiffness of common composite floor diaphragm connections. Design guidance has been developed and will be published shortly. ■

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*__LVL__, laminated veneer lumber; **CLT**, cross-laminated timber; **Glulam**, glue-laminated timber; **BRB**, buckling-restrained braces.

For more information about timbers used in New Zealand construction, see an article by Jeff Parker (2015) Timber takes on new forms, Build Magazine, Issue 149, page 50-51 (Aug/Sept 2015).


HERA
NATURAL HAZARDS

RISK

Clockwise beginning Top, left: Rockfall following the Christchurch earthquake. Photo: GNS Science; Damage in Greymouth after ex-Tropical Cyclone Ita. Photo: NIWA; Building damage caused by the Christchurch earthquake. Photo: GNS Science; Damaged irrigators following Canterbury wind storm. Photo: NIWA.

10 YEARS PROGRESS IN RISK MODELLING IN THE ERA OF THE NATURAL HAZARDS RESEARCH PLATFORM

By ***Kelvin Berryman***

When thinking about the progress in New Zealand risk modelling, it is useful to go back a few years prior to the formation of the Natural Hazards Research Platform in 2009.

You could say that a major step forward in New Zealand risk modelling began in 2004 with the start of RiskScape, taking us from a hazards-centric point of view to the world of risk.

And 'risky' it was. There was no business plan and access to key asset data, such as infrastructure and built environment, was limited or non-existent. A great deal of effort was expended in the early days to gather the fundamental data. I would suggest there was too little attention paid to user needs – the pressure was on to deliver tangible results before really understanding 'for whom, why and what'.

JOINING UP THE RESEARCH

Step forward to 2009 and the beginning of the era of the Natural Hazards Research Platform. The joining of natural hazards research with the built environment research brought together the components of the risk formulation – hazard and assets – and their fragility at varying levels of hazard severity.

There were also more players in the risk field. Catastrophe modelling in the insurance sector, and the Global Earthquake Model (GEM) initiative founded in 2009 sought to reconfigure the earthquake problem from a hazard narrative to that of risk, with consideration of consequences and impacts.

In addition, engagement between scientists and the local government sector was beginning to gather momentum with value being attached to sharing the fundamental asset data. This meant that when delivered back to the infrastructure or building owner, the added value was understood and appreciated.

RISK MODELLING ON THE RISE

Fast forward to the end of the NHRP era in 2019 and risk modelling continues to gather momentum. Multiple runs of risk models with alternative fragility attributes of the built environment can illustrate the value of retrofit in reducing future losses and disruption of communities.

Risk modelling is at the core of many science programmes and projects. However, the research and user community must continue to evolve the methods and tools. Disruptive technologies, such as machine learning, more complex numerical simulation capabilities; rapidly changing asset characteristics, such as aging infrastructure and demographic shift; and the desire to expand the range of visualisation approaches to communicate risk, all need to be addressed. ■

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RISKSCAPE 2.0 – WHAT IS COMING NEXT?

By ***Richard Woods***

The impact of the risk modelling tool RiskScape is growing, with the Earthquake Commission recently joining GNS Science and NIWA to further develop the tool for New Zealand.

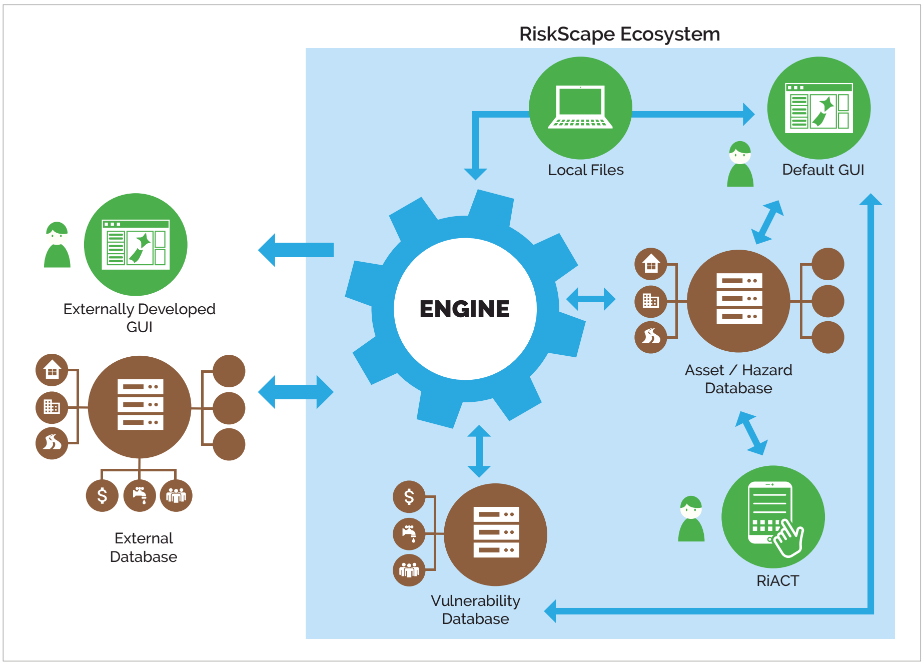
New Zealand is vulnerable to many natural hazards including floods, tsunami, volcanoes and earthquakes. Measures can be taken to reduce the risk to lives and livelihoods, but first it is necessary to understand the likely location and intensity of these hazards' impacts.

RiskScape is risk modelling software developed jointly by NIWA and GNS Science since 2004. It quantitatively estimates the impacts of natural hazard events, identifying where the highest risks to people, buildings and infrastructure damage may occur. It's a valuable tool for land-use planners, emergency managers, engineers and insurers.

A new collaboration with the Earthquake Commission (EQC) will see RiskScape 2.0 replace the Commission's current risk modelling software. It will be used to produce earthquake loss and impact estimates and will inform EQC's annual reinsurance negotiations. Our three organisations will continue to invest in the development of RiskScape 2.0, including assessing other geological and weather-related hazards.

The New Zealand Treasury and the insurance sector are also using the tool for major projects to forecast future losses and impacts. However, interest is not restricted to New Zealand shores with the World Bank Group and NASA showing keen interest in RiskScape.

RISKSCAPE VERSION 2.0



REDEVELOPING THE TOOL

From May 2018, RiskScape has been under redevelopment using open source technology to build a new modular adaptive platform. The work programme for RiskScape includes continuing to develop its core engine, with a focus on workflow functionality, optimisation and performance enhancements. Starting in late 2019, a customised user interface will be built using specific requirements from the vast array of users.

Since its initial development, RiskScape has been used domestically and overseas to learn more about natural hazards and evaluate potential mitigation options. Beginning with pilot studies in Westport, Hawkes Bay and Christchurch, RiskScape is now being used by the Samoa and Vanuatu governments, through the Pacific Risk Tool for Resilience (PARTneR) project, and in some Indonesian universities.

In New Zealand, RiskScape has underpinned loss estimates for the AF8 research programme and has evaluated the impacts of a large Wellington earthquake, in partnership with the MeRit Tool (Measuring the Economics of Resilient Infrastructure). ■

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RISKSCAPE TEAM JOINS POST-TSUNAMI SURVEY IN INDONESIA

▲ The ruins of what was previously known as the "floating mosque" of Palu. The mosque was a raised building in a body of water and supported by piles. Photo: RiskScape

By ***Ryan Paulik, James Williams, Aditya Gusman*** *and* ***Sheng-Lin Lin***

The 2018 Mw 7.5 Sulawesi earthquake and tsunami destroyed many buildings and caused more than 1700 fatalities in Palu City, Sulawesi, Indonesia. A New Zealand field team accompanied Indonesian colleagues to observe and record tsunami damage to buildings, roads and electricity infrastructure in Palu City from the event.

The field team comprised researchers from NIWA, GNS Science and the University of Canterbury.

We measured tsunami flow depths up to 3.65 metres at 371 building sites and recorded the attributes and damage levels for 463 buildings, 7.9 km of road and 455 utility poles.

We observed that non-engineered 'light timber' and 'lightly reinforced concrete' buildings were highly susceptible to non-structural component damage when tsunami flow depths exceeded 0.4 metres (for light timber) and 1 metre (for lightly reinforced concrete) above building first floor levels.

Unrepairable or complete damage was regularly observed when flow depths exceeded 1.2 metres. Only non-structural component damage was observed for engineered 'reinforced concrete' buildings.

Coastal roads were frequently damaged at culvert sites and utility poles sustained complete damage from debris impact or scouring. These observations are consistent with damage recorded by New Zealand researchers in Coquimbo, following the 2015 earthquake and tsunami in Illapel, Chile.

The information collected in Palu City contributes to an important evidence base for future tsunami hazard and risk research that informs activities to minimise damage and loss of life from future tsunami events.

With our colleagues we have published our survey activities and findings in the 2018 Sulawesi earthquake and tsunami special edition of *Pure and Applied Geophysics*.

We would like to acknowledge the StIRRRD programme – 'Strengthened Indonesian Resilience: Reducing Risk from Disasters' – which made our participation possible. ■

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RESILIENCE TO NATURE'S CHALLENGES

National Science Challenges

RESILIENCE TO NATURE'S CHALLENGES

Kia manawaroa – Ngā Ākina o Te Ao Tūroa

Clockwise beginning Top, left: Scientists Rob Bell, Ellie Kay and Wendy Saunders. Photo: GNS Science; Outreach in Kaikōura; RNC Trajectories researchers. Photo: Resilient Organisations; Haumoana, part of the 'Living on the Edge' programme. Photo: NIWA.

TOWARDS RESILIENCE SOLUTIONS FOR RURAL REGIONS

By **Nick Cradock-Henry, Joanna Fountain,** and **Tom Wilson**

From response through to recovery, researchers are working together with policy-makers and practitioners to advance resilience solutions for rural Aotearoa New Zealand.

Road damage near Clarence caused by the 2016 Kaikōura earthquake. Photo: Julian Thomson, GNS Science.

Earthquakes, floods, snowstorms, and the effects of climate change present unique challenges for the well-being of rural Aotearoa New Zealand. Preparing for and responding to these and other risks is compounded by the exposure of critical infrastructure and lifelines, and local economies dependent on the free movement of goods, services and people. Disasters however, can also be catalysts for change. By disrupting existing conditions or circumstances, disasters can create opportunities to critically evaluate risks and explore pathways to greater resilience for local communities.

Located on the east coast of the South Island, Kaikōura is small community of 2000 people, with 1500 more in the surrounding district. The local economy is dependent on primary industries and tourism. Furthermore, it is exposed to a range of hazards, including earthquake, wildfire, tsunami and landslide risks, typical of rural regions throughout Aotearoa.

Just after midnight on 14 November 2016, a magnitude 7.8 earthquake began near Culverden, south of Kaikōura, and came to a stop near Seddon, ninety kilometres north, rupturing across multiple fault lines. The two minutes of shaking raised the coastline several metres in places, tearing through road and rail networks. Along State Highway 1, thousands of landslides, slips and surface deformation cut off critical road access, while across the region, there was extensive damage to homes and buildings.

The following morning as the damage became clear, a concerted response effort was mobilised, led by Civil Defence and Emergency Management and others with contributions from the scientific community. This collaborative effort has continued to grow and develop.

The Rural Co-Creation Laboratory – part of the Resilience to Nature's Challenges National Science Challenge – has been working with stakeholders to develop applied resilience research to inform risk and opportunity assessment, operational planning, and decision-making. Co-creation refers to ways in which researchers, policy-makers and practitioners can generate new knowledge together to address societal challenges. Over the last four years, the Rural team and its co-creation partners have been working in Kaikōura with civil defence, tourism stakeholders, and local and central government agencies, exploring innovative approaches to building resilience, documenting lessons and experiences, and developing tools which can be used elsewhere.

Pre- and post-quake, the Rural team has worked to foster co-productive relationships, particularly with the Ministry for Primary Industries (MPI). By providing data and leveraging science investment, the team has been able to develop new pathways for rural resilience and extend existing research into additional projects with MPI's investment support.

The 2016 earthquake drew attention to the vulnerability of farm businesses and their role in sustainable land and biodiversity. Through MPI funding to Beef and Lamb NZ, Jo Fountain (Lincoln University) and Environment Canterbury's Michael Bennett are working with North Canterbury livestock farmers to build resilience through economic diversification and storytelling. By developing additional revenue sources, farmers may be better prepared for economic shocks, and through telling stories of people, place and provenance, create additional value and brand loyalty.

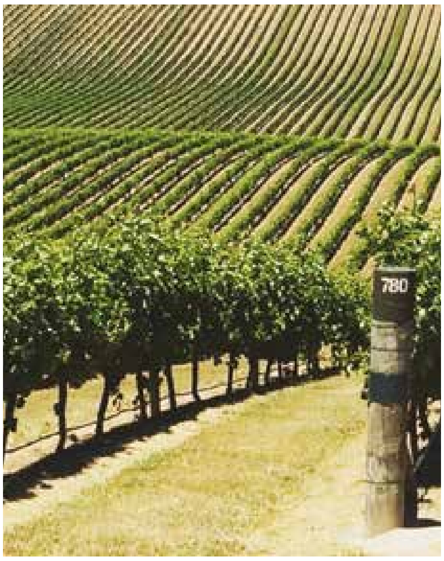
Another co-creation project funded by MPI is focusing on earthquake vulnerability and New Zealand's fast-growing wine industry, with case studies in the Waipara Valley, North Canterbury and Marlborough. The project team led by Nick Cradock-Henry (Manaaki Whenua Landcare Research) involves a diverse team of social scientists, engineers, and industry partners including Fountain, Jason Ingham (University of Auckland), and Ed Massey (NZ Winegrowers). Taking a value chain perspective, the research is focusing on

the structural, social and economic impacts of earthquakes, from the vineyard through to processing, transportation and distribution.

The engineering team has recently developed the world's largest database of impacts on wine storage tanks, and is now using data to improve tank design. A new paper* by the social-science team explores how resilience is shaped within the broader context of other risks, and influenced by size and scale of operations. The resilience framework is now being extended to work on supporting climate change adaptation in the industry.

Over the past five years the Rural programme has developed these and other aligned projects to better understand the impacts and implications of different stressors. Partnering with policy-makers and practitioners from across the primary sector and rural economy, this new mode of working together is generating useful and usable knowledge.

Looking ahead to the next five years of the Resilience Challenge, these efforts will be extended with projects aimed at strengthening agri-food and tourism networks, enhancing value-chain resilience, and exploring the effectiveness of policy interventions. The Rural programme will continue to engage and co-create new knowledge with research and industry partners to inform preparedness and recovery planning elsewhere, and generate rich examples of the ways in which disasters can create opportunities for resilient rural futures. ■



◄ Grapes growing near Seddon are essential to New Zealand's rapidly growing wine industry. Photo: Nick Cradock-Henry.

▲ Rupture on the Papatea fault through farmland and across roads following the 2016 Kaikōura earthquake. Photo: Dougal Townsend, GNS Science.

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*Cradock-Henry, N.A., Fountain, J. (2019) Characterising resilience in the wine industry: Insights and evidence from Marlborough, New Zealand. Environmental Science and Policy, 94, pp. 182-190.

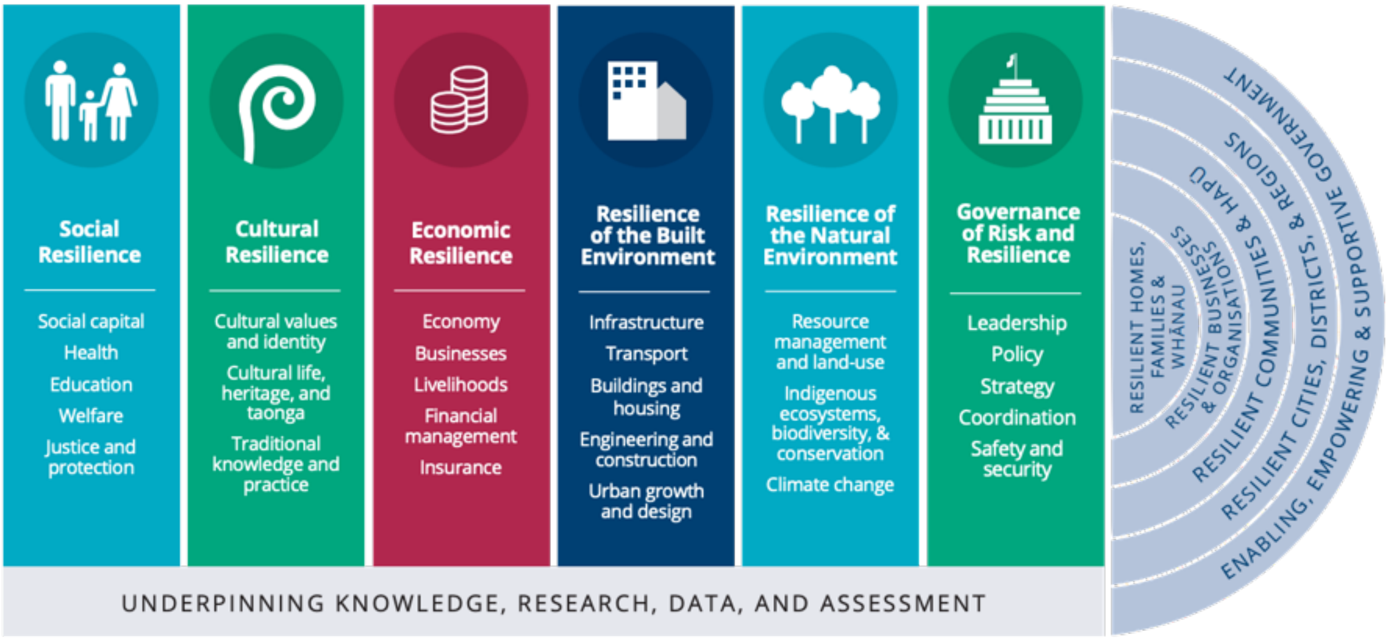
▲ Top: University of Auckland PhD student, Mohsen Yazdanian inspecting damaged wine tanks in the Marlborough following the 2016 Kaikōura earthquake. Photo: Dmytro Dizhur.

▲ Bottom: Wineries in Marlborough sustained damage to storage tanks, catwalks and piping systems. Dmytro Dizhur and team records damage data for input into models and for improving design considerations. Photo: Mohsen Yazdanian.

THE NEW ZEALAND RESILIENCE INDEX AND MEASURING RESILIENCE

By ***Ellie Kay, Chris Bowie*** *and* ***Vivienne Ivory***

Monitoring and evaluation is an important part of New Zealand's new National Disaster Resilience Strategy. But how do you measure a seemingly abstract concept like resilience?



Through the Resilience to Nature's Challenges National Science Challenge, researchers from Resilient Organisations and WSP Opus have developed the New Zealand Resilience Index (NZRI). This is a composite indicator* that assesses the resilience of the country's place-based communities over time.

The index uses the multi-capital model that underpins the National Disaster Resilience Strategy (Fig. 1). Comprised of indicators across the six capitals, the NZRI provides users with a mechanism to evaluate community resilience over time and to inform resilience intervention decision-making.

The NZRI can be used at both national and regional level. At national level, the current 13-indicator NZRI is limited to publicly available, nationally-consistent data. A further 53 resilience concepts could be added if data were routinely collected. Over time, initiatives such as the *Indicators Aotearoa* programme, will help to fill missing data gaps within the NZRI.

At regional level, there is an opportunity to apply and expand the NZRI to cover a wider range of resilience concepts. The research team worked with the Wellington Regional Emergency Management Office to identify datasets that could be repurposed to develop a localised resilience assessment for the Wellington region. For example, the locations of earthquake-prone commercial buildings were added to the index, providing additional understanding of resilience in the Built capital. By including data collected during 'business-as-usual' activities, it enabled us to align the resilience measurement with existing local and regional planning.

There are future opportunities to further our ability to measure, and therefore understand, holistic resilience. As well as augmentation of the national NZRI through increasing data availability (i.e., through programmes like *Indicators Aotearoa*) and regional augmentation of the index, there are opportunities to enhance our ability to collect primary (survey) data to better inform the index. The research team are currently exploring the development of an agile surveying tool that can assess community resilience capabilities, as well as engaging communities in resilience decision-making.

The NZRI complements the National Disaster Resilience Strategy as a method of measuring progress towards the vision of New Zealand as a disaster resilient nation. It also provides a mechanism to proactively manage risk and build resilience to improve the wellbeing and prosperity of New Zealand.

Read more about this project in our full report available at www.resorgs.org.nz: *'The Resilience Warrant of Fitness Research Programme: Towards a method for applying the New Zealand Resilience Index in a regional context.'* ■

◄ Researchers reviewing the National Disaster Resilience Strategy. Photo: Resilient Organisations.

▲ Fig. 1. The New Zealand Resilience Index uses the multi-capital framework of the National Disaster Resilience Strategy.

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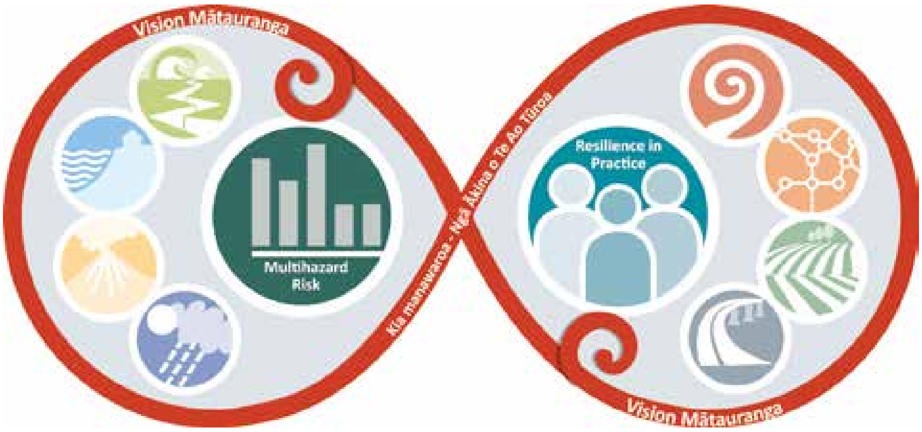
*** A composite indicator** combines multiple indicators into a single measure, allowing for the capture of the multi-dimensional nature of resilience while simultaneously simplifying a complex concept.

Indicators Aotearoa New Zealand is being developed by Statistics New Zealand as a source of measures for New Zealand's wellbeing. The set of indicators will go beyond economic measures, such as gross domestic product (GDP), to include wellbeing and sustainable development. Visit www.stats.govt.nz for more information.

RESILIENCE TO NATURE'S CHALLENGES

LOOKING AHEAD: 2019 TO 2024

*By **Richard Smith***



In November 2018, the MBIE Science Board approved the next five years of funding for the Resilience Challenge (RNC). The high-level research plan draws extensively on the successful ten years of the Natural Hazards Research Platform, and integrates the research capability and key partnerships from phase one of the RNC, into phase two (2019-24).

For the last six months we have been busy developing the research leadership team, and turning the high-level intent into more detailed research plans for the ten research themes. The shape and scope of these themes reflect the inputs and advice of stakeholders over the last 18 months, and extends many of the strong workstreams in rural, urban, Mātauranga Māori, coastal and infrastructure resilience.

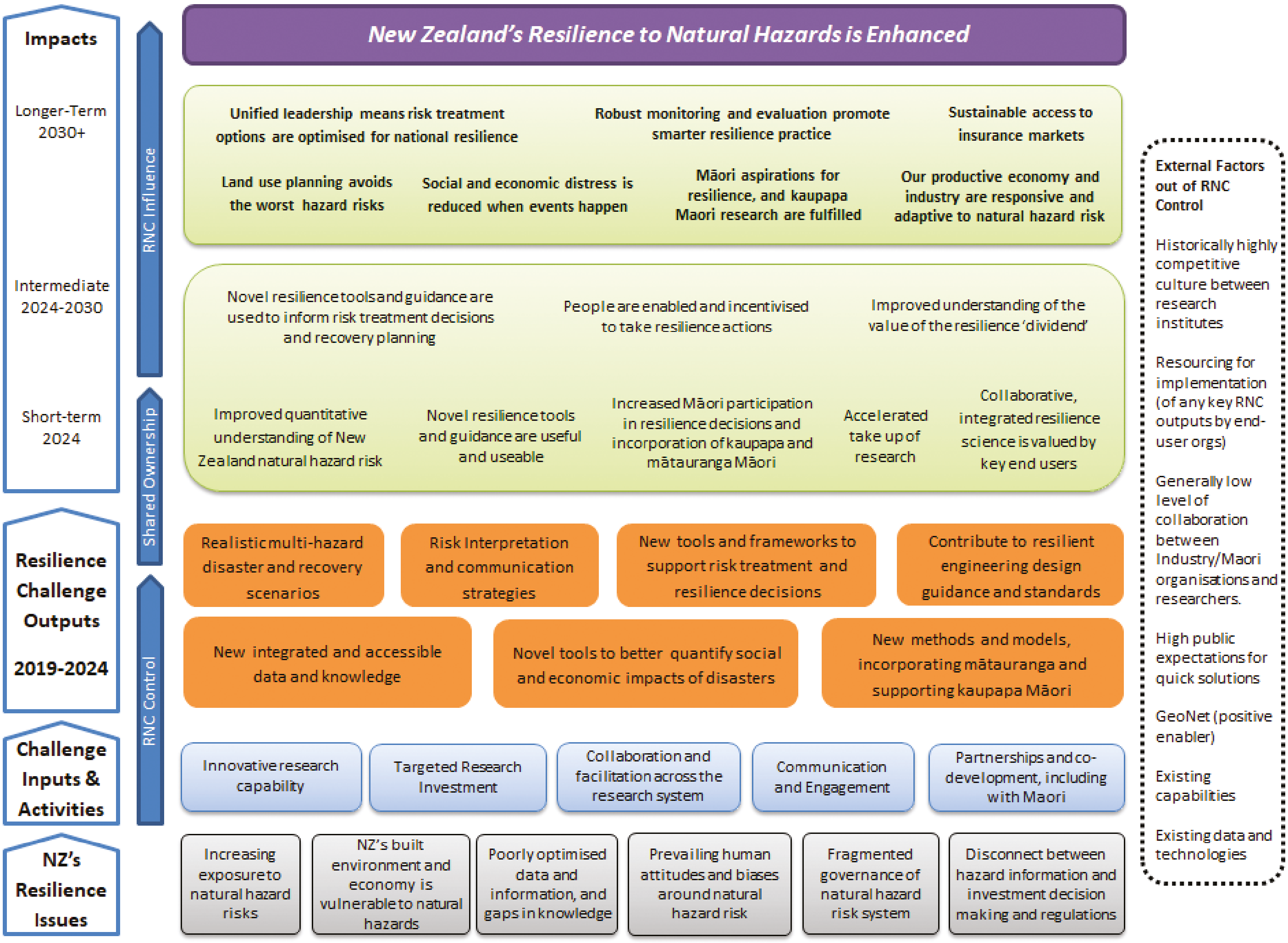
Over the next five years, these workstreams will be accompanied by exciting new research to advance our understanding of natural hazard processes such as wildfire, earthquakes, tsunami, landslides, volcanoes and high-impact weather. And it will include a strong push for developing potentially transformative *Multi-hazard Risk* methods.

This improved quantitative view of our disaster risks will be strongly paired with social, economic and cultural research to develop tools and methods to build *Resilience into Practice* (and policy) across New Zealand's public, private and built environment sectors.

This is a time of significant change in how we will work and organise ourselves, with new governance and leadership roles coming on board. We are also looking to develop a new strategic leadership team to support the Director, with responsibilities for integration of Vision Mātauranga, science linkages across the ten research themes, and coordinated approaches for research co-development and partnerships. Stand by for a call for *Expressions of Interest* in the next two months.

Key to success of the next five years will be not only excellence in science, and effective collaboration across the science system, but also how effectively we can partner with the users of the research. We need to ensure the RNC's outputs can be easily taken up and applied to influence changes in behaviour, practice and policies.

To this end, we have developed a revised Outcomes Framework which will steer our priorities and efforts.



While we have defined the overall research scope, we are still developing the approach to working on many key research questions and issues, and how best to communicate, connect, and partner to ensure successful co-production.

For some of the research themes, this will involve building on existing mechanisms that are working well. For others, new arrangements and approaches may be needed, including how we involve different groups of stakeholders at different stages of projects and at different levels of the overall Themes and Challenge. This work will be a key focus over the next 6-12 months. We look forward to working with you to make the most of this opportunity. ■

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EARTHQUAKES

In 2018, GeoNet recorded 19,472 earthquakes in New Zealand – which is around the annual average of about 20,000. Thirty of these earthquakes were magnitude 5.0 or greater, with the most significant of these being a M6.2 earthquake 207 km below Taumarunui on 30 October. There was a M6.7 earthquake just inside the New Zealand network interest in the Kermadec region on 10 September, at a depth of 126 km – this was not as widely felt as the Taumarunui earthquake.

This could be considered a quiet year for seismic activity in New Zealand, with no damaging earthquakes occurring.

TSUNAMI

2018 was a relatively quiet year for tsunami activity in the Pacific. At the start of the year on 23 January, a M7.9 earthquake in Alaska prompted the Ministry of Civil Defence and Emergency Management to issue a warning for potential strong currents and surges in New Zealand. This was later withdrawn as more data became available.

On 5 December, some small observations of tidal activity were noted on our tide gauges from a M7.6 Loyalty Islands earthquake. Scientists assessed whether the earthquake created a tsunami that could affect New Zealand, which resulted in a 'no threat' notice being issued.

HIGH TEMPERATURE

2018 was New Zealand's second-equal warmest year on record, according to NIWA's Seven Station Temperature Series which begins in 1909, while January 2018 was the hottest single month on record for New Zealand.

Alexandra reached 38.7°C on 30 January – New Zealand's 12th highest temperature on record overall and 3rd warmest January temperature on record. This was New Zealand's hottest temperature for 2018.

Overall, this was New Zealand's warmest summer on record (for the period December 2017-February 2018). This was in part due to air temperatures being warmed by the Tasman Sea marine heatwave, which lasted from November 2017 to March 2018.

NATURAL

A BRIEF SNAPSHOT OF THE

COASTAL HAZARDS

On 5-6 January 2018, a low-pressure system of subtropical origin deepened near New Zealand, generating strong north to north-east winds in the Upper North Island. The wind generated waves, which when combined with storm surge and the highest high tide of the year, led to widespread coastal flooding and damage, with severe damage to the Thames-Coromandel state highway. The storm-tide level at the Tararu gauge in the Firth of Thames reached its highest water level (2.86 m) on 5 January since the gauge was commissioned in 1990, resulting in a 3.0 m water level at the shoreline (an average recurrence interval of 100 years).

On 1-3 February, ex-tropical cyclone Fehi impacted the northern part of the South Island and the West Coast with wave overtopping and coastal flooding, with significant damage to coastal roads and housing and $45.9M insured losses. The joint probability of storm surge (0.43 m), wave setup/runup at the coast and a high perigean-spring tide produced a water level in the Nelson/Tasman area with an average recurrence interval of 110-170 years.

On 20-21 February, ex-tropical cyclone Gita approached central New Zealand from the Tasman Sea, bringing large swells to the west coast – particularly the Taranaki to Kāpiti coast, overtopping and damaging seawalls and SH1, before crossing the country and impacting the Canterbury coast. The Banks Peninsula wave buoy recorded its largest significant wave height for the year of 6.52 m (period 11.1 secs) early on 21 February, with a maximum individual wave height, of 11.4 m following slightly later. It is estimated insured losses from this event were $35.6M nationwide.

In the Southern Ocean, a wave buoy deployed by MetOcean Solutions and the New Zealand Navy near Campbell Island recorded a 23.8 m wave at 00:00 NZST on 9 May 2018. This is believed to be the largest ever wave height recorded in the Southern Hemisphere.

VOLCANIC HAZARDS

2018 was a quiet year for volcanic activity in New Zealand. Currently the Volcanic Alert Level for two of New Zealand's cones are at Level 1. These are Whakaari/White Island off the Bay of Plenty Coast, and Mt Ruapehu in the Tongariro National Park, both showing signs of volcanic unrest. All the remaining cone volcanoes and caldera volcanoes remain quiet, in addition to the Auckland Volcanic Field.

Following the eruptions in 2016, little has happened at Whakaari/White Island. However, by March a crater lake was starting to form and fill on the floor of the active crater. In 2018 the temperature of the crater lake at Ruapehu was quite variable and became 'stuck' at about 30 °C in the later portion of the year.

In July, a small hydrothermal eruption occurred at Waiotapu with no impact to people. About 5-6 cubic metres of mud was ejected.

LOW TEMPERATURE

On 10-11 April, an active front moving north across the country brought in very cold air, resulting in numerous low daily maximum temperature records for the month of April.

At the end of May, an inversion and persistent low cloud trapped cold air at the earth's surface throughout Central Otago, resulting in low daytime maximum temperatures for many locations. On 31 May, Lauder only reached a maximum temperature of -2.6°C, which was a new May record with data going back to 1924.

The lowest air temperature of 2018 was -10.4°C recorded at Mt Cook (Airport) on 3 June.

WIND & TORNADOES

The passage of two powerful ex-tropical cyclones, Fehi and Gita in February ($46 million and $36 million in insured losses, respectively) and a severe wind event hitting the Auckland region on 10 April ($75 million) were the notable New Zealand wind events of 2018.

2018 was unusual in terms of ex-tropical cyclone activity and impact on NZ in several respects, including (i) the number of events – 3 ex TC compared to the long-term average of around 0.7 for the period 1960 to 2018; (ii) the number of events crossing the South Island (2 compared to the long-term average of 0.2); (iii) intensity; Fehi ranked 3rd equal and Gita 6th in terms of central pressures, and (iv) the early dates of occurrence. Both Fehi and Gita caused damaging coastal inundation, widespread tree and building damage and power outages.

The 10 April event was noteworthy in that the for the directions experienced in this storm, West and Northwest, the average recurrence intervals (ARI) were at least 5-10 years for all wind recording sites across Auckland and greater than 20 years for around half the recording sites. Damage to trees and power distribution was extensive and power outages lasted several days in many locations.

Tornadoes were reported on 5 days with damage caused at Rahotū, Taranaki, National Park, and Auckland (Swansons Railway) on 10 April, Matamata on 18 June, New Plymouth and Ohope on 20 August, Ruakura on 29 October, and Ashburton on 18 November.

For more on damaging wind events in New Zealand in 2018, see the "Strong Winds" section of NIWA's annual climate summary: https://www.niwa.co.nz/climate/summaries/annual-climate-summary-2018.

HAZARDS

MAIN EVENTS OF 2018

LANDSLIDES

Landslides have continued to impact New Zealand communities. The landslides we know of are those that are reported in the media or are in populated areas, many others may go undetected. Much of the landslide activity in the past year was triggered by extreme rainfall events.

In 2018, we recorded 10,095 small landslides (<1,000 cubic metres), 37 medium landslides (1,000-10,000 cubic metres), and 4 large landslides (>10,000 cubic metres).

Most of the landslides were triggered in the Tasman and Kaikōura areas by ex-tropical Cyclone Gita (about 2000 landslides) in February, and by the Queen's Birthday storm that affected the Gisborne East Coast region (about 6700 landslides). The Uawa catchment experienced some of the highest rainfalls (205 mm/12 hrs) which triggered multiple debris flows in areas of recent forestry, resulting in significant amounts of wood being deposited on the beach at Tolaga Bay. We had projects that allowed us to map the landslides in the Tasman, Kaikōura and Gisborne areas. This is the reason our total number of landslides is high this year and indicates that we probably miss thousands of landslides most years because they are neither reported nor recorded.

In late February, a large landslide blocked the Mangapoike River in Wairoa, causing a landslide dam lake. There was also a large debris avalanche (about 200,000 cubic meters) off Craig Peak, near Fox Glacier in August. One person died as a result of rockfall on SH4 at Raukawa falls. There were no reports of injuries.

LOW RAIN & DROUGHT

Soil moisture levels were much lower than normal at the start of 2018. Prolonged dry conditions prompted the Ministry of Primary Industries to declare a medium scale adverse event for Grey and Buller Districts, as well as Otago and Southland in January. In 2018, several Auckland locations recorded their driest spring on record.

SNOW, HAIL & ELECTRICAL STORMS

On 6 August, a large avalanche occurred on the upper slopes of Turoa ski field on Mt Ruapehu, damaging the High Noon Express chairlift. The damage was significant enough that the chairlift was unable to be used for the remainder of the ski season.

On 17 September, a cold front moved over the South Island bringing heavy rain and snow, particularly to Central Otago and parts of Southland. Schools in Queenstown, Arrowtown, and Te Anau Basin closed for the day. Queenstown Airport cancelled more than 30 flights due to snow.

HEAVY RAIN & FLOODS

Ex-tropical cyclones Fehi and Gita caused heavy rainfall and significant flooding for parts of the South Island during February 2018. On 4-5 June, torrential rain caused flooding and slips in the Tolaga Bay area (East Cape). Debris flows containing forestry slash damaged bridges and houses.

10 YEARS NATURAL HAZARDS RESEARCH PLATFORM

IMPACT

ADVICE
Researchers provide expert testimony to the Royal Commission on the Canterbury Earthquakes

ACTION
Christchurch City Council uses NHRP research to identify Port Hills Red Zone

ADVICE
Volcanic hazards researchers provide advice to emergency managers on eruption scenarios

INTERNATIONAL
NIWA joins the Unified Model Consortium – links NZ research on weather prediction & climate simulation with global partners

INTERNATIONAL
Tsunami Blue Lines introduced in Wellington; later used in Oregon and Washington, USA

ADVICE
NHRP provides science advice to CERA

ACTION
NZ Government provides additional $13.5M for psychosocial services based on the CERA Wellbeing survey results

INTERNATIONAL
NZ is signatory to the Sendai Framework on Disaster Risk Reduction; NHRP office provides technical support to the NZ delegation

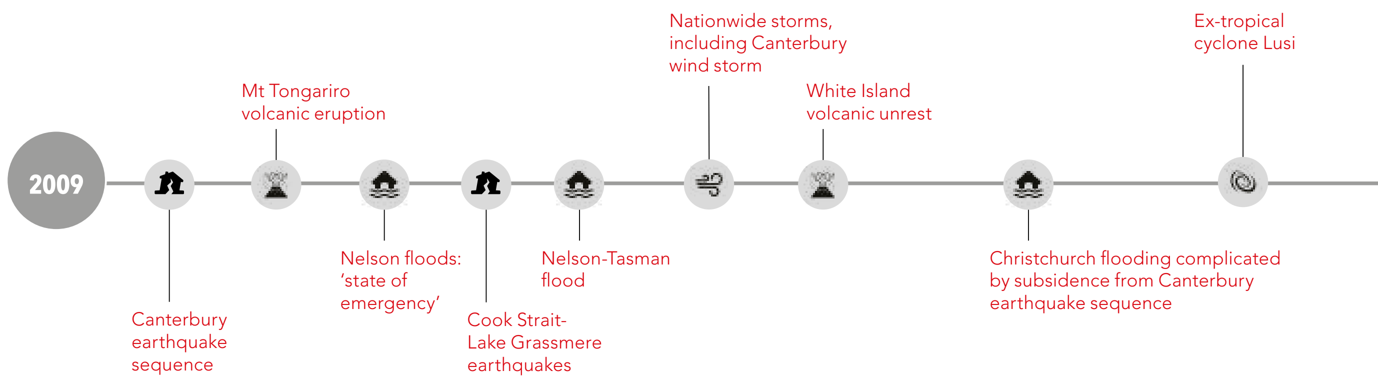
SCIENCE

- Canterbury EQ Recovery research informed by stakeholders – includes geological, geotechnical, engineering

- Recovery research contributes to CERA Wellbeing index & survey
- Canterbury research develops Liquefaction Resistance Index map

- Researchers develop National Tsunami Hazard Model for all NZ coasts
- NIWA & Scion develop the National Fire Weather System

HAZARD



ACTION
After Kaikōura, risk modeling influences amendment to the Building Act to address risk from URM and shorten repair deadlines to EQP buildings

ACTION
Engineering research contributes to Detailed Seismic Assessment Guidelines

ADVICE
Kaikōura earthquake landslide inventory completed; recognised by overseas peers as one of the best available globally

INTERNATIONAL
NZ volcanology teams provide advice to international colleagues following eruptions in Vanuatu & USA

ACTION
Wigram-Magdala Bridge is 1st NZ bridge to use low-damage technologies; Christchurch's Tūranga Library includes low damage design

ACTION
Fire services utilises NIWA modeling during the Port Hills Fires

ACTION
Resource Management Act reforms pass into law, recognises management of 'significant risks from natural hazards'

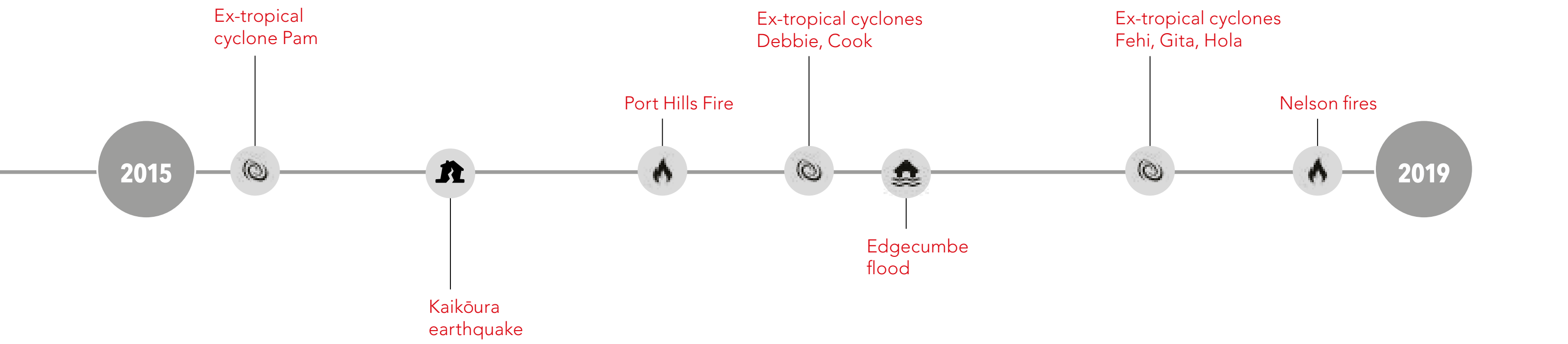
ADVICE
Tsunami vertical evacuation guidelines considered for NZ with advice from NHRP researchers

- Researchers prepare report on sea level rise for the Parliamentary Commissioner for the Environment
- Alpine Fault research refines the recurrence interval for M8 earthquakes to approx. 300 years
- Numerical weather prediction – highest national resolution at 1500m; limited cases of regional NWP at 100m

- Risk researchers & Bay of Plenty Regional Council develop award-winning framework for public engagement about risk
- Kaikōura earthquake recovery research – includes geological, geotechnical, engineering & economics
- RiskScape + MERIT modeling tools are joined to explore resilience investment

- Researchers contribute to updates of engineering guidelines & standards for wind load, structures, and geotechnical
- Research begins on a National Volcanic Hazard Model

- Following the Kaikōura EQ, slow slip events are introduced into earthquake forecasts for the first time globally
- Coastal hazard researchers develop a free storm surge & coastal hazard tool for end-users



NATURAL HAZARDS
RESEARCH PLATFORM

RESILIENCE TO NATURE'S CHALLENGES
Kia manawaroa – Ngā Ākina o Te Ao Tūroa
National SCIENCE Challenges