Summary

Fund information

Summary information

Investment area: 2017 Endeavour Fund - Research Programmes

Contracting organisation: Institute of Geological & Nuclear Sciences Limited - Trading as GNS Science

Year 1 funding requested:

$1,638,423.00 GST excl. amount	$245,763.45 GST amount	$1,884,186.45 Total amount

Total funding requested:

$8,192,115.00 GST excl. amount	$1,228,817.25 GST amount	$9,420,932.25 Total amount

Short title:
Earthquake-induced Landscape Dynamics

Descriptive title:
Earthquake-induced landslides and landscape dynamics: planning for, and avoiding landslide hazard and risk

Investment mechanism:
Research Programmes

Number of years' funding requested:
5

Fund objective:
- (●) Economic
- ( ) Environmental
- ( ) Social

Key information

Eligibility

Is the research solely for the benefit of your organisation?

No

Are you a department of the public service as listed in Schedule 1 of the State Sector Act 1988?

No

Will the majority of research be undertaken overseas?

No

If you answered 'Yes' to any of the above questions, please explain why.

Science abstract (280 words)

The M_W 7.8 Kaikoura Earthquake generated thousands of landslides, hundreds of significant landslide dams and damaged hillslopes that are now susceptible to failure during rainstorms and aftershocks. This debris, when mobilised, will create new hazards, including further landslides, dams, rapid aggradation and formation of alluvial fans and floodplains, and increased river channel instability, as the debris cascades from hillslope to sea. These hazards can persist for decades, requiring active management by the impacted communities and stakeholders.

Hypothesis: Over what time scales do landscapes heal after major earthquakes? The Kaikoura Earthquake provides a laboratory to quantify post-earthquake landscape dynamics. Earthquake- and post-earthquake landslide risk can be effectively managed using an integrated set of predictive tools guided by an evidence-based decision making framework. The goal is to use novel and innovative methods to avoid and manage earthquake and post-earthquake landslide risk.

We will integrate perishable data obtained from state-of-the-art geophysical methods, mapping, ground profiling, field monitoring, laboratory testing, and numerical modelling to determine how the hillslopes and rivers will respond to future forcing events, focusing on:

- Forecasting landslide severity at different magnitudes of ground shaking and rain;
- Quantifying post-earthquake landslide triggering and reactivation thresholds from ground shaking, rain and time;
- Evaluating landslide dam longevity;
- Determining how far landslide debris volumes travel downslope, once triggered;
- Modelling how sediment cascades from hillslope to sea; and
- Assessing the performance of earthworks infrastructure subject to landsliding.

From our results we will develop a decision making framework and set of tools that will immediately inform landslide risk and residual risk-management methods and practices for stakeholders affected by the Kaikoura Earthquake. Moreover, our findings are equally applicable to the effects of future earthquakes in New Zealand and overseas.

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Keywords

- landslide
- Hazard
- Sediment flux
- Earthquake
- Landslide dam
- Numerical modelling
- Risk
- Rock mechanics
- Laboratory testing
- Earthworks
- Resilience
- Field monitoring
- Landslide reactivation
- Earth-surface dynamics
- Road infrastructure

Glossary

Proposal Glossary

Word/acronym/ abbreviation/te reo Māori	*Full description/translation*
aggradation	The increase in land elevation, typically in a river system, due to the deposition of sediment. Aggradation occurs in areas in which the supply of sediment is greater than the amount of material that the system is able to transport
DBPSB	Dynamic Back-pressured Shear-box
DOC	Department of Conservation
DPRI	Disaster Prevention Research Institute, Kyoto University
ECAN	Environment Canterbury
EQC	The Earthquake Commission
GIS	Geographic Information Systems
kaitiakitanga	(noun) guardianship, stewardship, trusteeship, trustee
kotahitanga	(noun) unity, togetherness, solidarity, collective action
LIDAR	Light Detection and Ranging, is a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth
MBIE	Ministry of Business Innovation and Employment
MCDEM	Ministry of Civil Defence and Emergency Management
M_W	A measure of earthquake magnitude that characterises the relative size of an earthquake
NCTIR	The North Canterbury Transport Infrastructure Recovery is an alliance representing the NZ Transport Agency and KiwiRail on behalf of government, to repair by the end of 2017 the road and rail networks between Picton and Christchurch following the November 2016 Kaikoura earthquake
NZTA	New Zealand Transport Agency
SH1	State Highway One
SH3	State Highway Three
SSIF	Strategic Science Investment Fund; MBIE administered
Tools	Defined for this work as reports, papers, tables, databases, graphs, presentations, case studies and web-based interactive applications that help stakeholders to manage and plan for landslide related risks
whenua	(noun) country, land, nation, state

Statements

Executive summary

Executive summary (560 words)

The Problem

The M_W 7.8 Kaikoura Earthquake generated tens of thousands of landslides over a total area of ~10,000 km^2, with the majority of them concentrated in a smaller area of ~3,500 km^2. A large number of landslides occurred on the steep coastal cliffs north of Christchurch, which led to the closure of the state highway. More than 200 significant valley-blocking landslides were generated, partly due to the steep and confined slopes in areas of strong ground shaking; the largest had a volume of ~12(±2) million m^3, with the debris travelling nearly three kilometres down slope to dam the Hapuku River. Although only a few homes were impacted and there were no recorded deaths due to landslides, the closure of SH1 and the main trunk rail line has severely impacted the town of Kaikoura. The long-term stability of the cracked slopes, remobilisation of landslide debris in rain events and the performance of the valley-blocking landslide dams in future strong earthquakes and significant rain events are an ongoing concern to government agencies responsible for rebuilding homes and infrastructure. Of particular concern is the debris flood and flow hazards that will result should some of the landslide dams breach catastrophically, or if landslide debris currently held on the slopes reactivates, forming debris flows. Several of these dams are located upstream from people and critical infrastructure, such as road bridges, which are at significant risk if an event were to occur. The longer-term effects of sediment aggradation, as the debris moves downstream from the steeper in-land slopes to the sea, is another cascading hazard that will pose a risk to agriculture, aquaculture and infrastructure. These hazards will persist for years, and possibly decades, and represent a prolonged risk that must be understood and managed by the impacted communities and stakeholders.

The Solution

We will develop a landslide risk management framework and tools to collectively and effectively manage the risks to people and infrastructure from landslide and sediment hazards caused by the Kaikoura earthquake. We will use this knowledge, combined with legacy data, to inform our understanding of how other regions of steep topography in New Zealand, such as Wellington, may be affected by earthquake-induced and post-earthquake slope hazards.

Our programme will comprise six interconnected Research Aims that will inform new modelling approaches to better monitor and predict how the hillslopes and rivers will be impacted, and the risk such processes pose to people and infrastructure:

1. Landslide/fault interaction and landslide severity;
2. Landslide reactivation during aftershocks and rainstorms;
3. Landslide dam longevity;
4. Landslide runout;
5. Sediment cascades; and
6. Performance of earthworks.

The data will be collected and analysed by a world-class team of scientists and engineers.

The seventh Research Aim (*Tools for managing landside hazards and risks*) will deliver tools to better inform risk avoidance (planning) and residual risk management practices for future earthquakes in New Zealand and overseas. In the interests of kotahitanga and kaitiakitanga, stakeholders will be engaged and involved in the development of options, maps and tools, including interactive web-based applications, for managing landslide and sediment hazards and risk. These co-creation of tools will begin at the outset of the programme, to ensure that any findings are useful, useable, and used.

Impact criteria

Benefit/s to New Zealand

Benefit/s to New Zealand (1120 words)
The Problem

New Zealand is subjected to frequent large earthquakes, which destabilise our steep topography, and produce many landslides. Coupled with high rainfall, the risks from falling rocks and landslides to people and infrastructure are high, and the costs to the New Zealand economy is substantial.

Five deaths occurred in the Christchurch Port Hills when steep slopes collapsed as a result of the February 2011 Canterbury earthquakes. In the landslide risk zones, 475 (out of 1,200 in the area) insured homes were offered a Government buyout, at a cost of ~$330m[1] In Wellington, more than 8,000 buildings are located on slopes. Recent research by EQC and GNS Science suggests that residential losses from landslides triggered by Wellington Fault or Hikurangi subduction zone earthquakes in central Wellington alone, could be in the order of $1b[2], excluding infrastructure reinstatement costs. Estimates of the cost to rebuild SH1 (see Figure 1), after the Kaikoura Earthquake, are up to $2b[3], excluding costs of clearing ongoing landslides and flooding, or the indirect costs of the road being closed due to landslides and flooding. Post-event functionality of infrastructure was problematic following the 1929 Murchison and the 1968 Inangahua earthquakes[4], and was still problematic in Christchurch six years after the start of the 2010/11 Canterbury earthquake sequence[5]. In Christchurch, a large landslide severely impacted the fuel storage facility at Lyttelton several years afterwards. This landslide was triggered by high rainfall and earthquake-damaged storm pipes on a slope that had been cracked by the earthquakes[6].

Figure 1. Landslide debris generated by the Kaikoura earthquake, blocking SH1

Benefits

The main benefit to New Zealand from this research will be improved resilience of New Zealand's homes and infrastructure through cutting-edge internationally leveraged science, leading to the ability to avoid costs and trauma from prolonged landscape instability. This new knowledge will be combined with ongoing research to develop a landslide risk management framework and suite of tools to allow the risks to people and infrastructure from landslide and sediment hazards to be effectively managed. This research will not just benefit those affected by the Kaikoura earthquake, it will be of benefit to those living in other seismically-prone hilly areas of New Zealand and overseas.

Scale of the Potential Benefits

Landslides cost New Zealand an average of $300m pa, but a minimum of $250m pa[7]. Individual landslide hazard events from rainstorms range from large events costing ~$350m (e.g. Cyclone Bola) to small events of ~$3.5m[7]. For earthquake-induced landslides, the residential losses in the Port Hills were estimated to be $330m[1].

Information relating to the Kaikoura rebuild suggests that:

- Rebuilding SH1 and the main trunk rail line will cost ~ $2b;
- Tourism revenue of ~$100m pa over the next few years could now be lost[8];
- A permanent loss of through traffic would severely undermine the sustainability of the town and its tourism sector; and
- Freight costs will be pushed up by the diversion of Picton-Christchurch traffic via Murchison and the Lewis Pass[8].

To estimate possible timelines for the rebuilding of the road and railway, the 2011 Manawatu Gorge slip is a useful frame of reference. This slip saw SH3 closed for about a year, with work to clear the slip and stabilise the hillside taking 15 months[9]. Traffic was re-routed via minor roads, adding several hours onto the normal journey time. There are many landslides and cracked slopes along the Kaikoura road and rail corridor, and many are larger than the Manawatu Gorge slip. It is estimated that it could take 4-5 years to reinstate the South Island's road and railway[9].

Given that many slopes in the area are now damaged, the frequency of landsliding will increase – adding ongoing reinstatement costs to the cost of rebuilding the road and rail lines. Although our research relates specifically to Kaikoura region, the risk-based framework and tools will be directly transferable to other regions of New Zealand, and can be used to further develop current region-specific research projects, such as the Alpine Fault Magnitude 8 project[10].

Our research will allow New Zealand to foresee the consequences of earthquake-induced landsliding, thus guiding infrastructure route selection and resilience, land use planning, and emergency response. Internationally, where investment has been made in improving slope practices, cost-benefit calculations demonstrate that this has been a cost-effective approach[7]. In Hong Kong, improved slope management practices have reduced landslide risk by around 50% between 1977 and 2000[11]. In New Zealand, landslides observed after the 14 February 2016 M_W 5.7 Christchurch Earthquake were contained within the government's and local Councils "red zoned" hazard areas and thus affected nobody[5].

Research that is Beyond Business as Usual

For more resilient infrastructure and land-use practices regarding the hazards and risk posed by landslides, a risk management framework containing a definitive suit of tools is the essential step-change that will shift the current "ambulance at the bottom of the hill" landslide management to proactive, preventative management. Research following the Christchurch earthquakes[12] has demonstrated that robust state-of-the-art quantitative hazard and risk assessment methods are required to allow the potential impacts of hazards to be factored into stakeholder's infrastructure resilience frameworks, and remediation approaches to be utilised effectively. The lack of knowledge of hill slope behaviour prevents the upfront consideration in planning and management, and is thus beyond the capability of existing business practice and individual stakeholders.

Implementation pathway/s

Implementation pathway/s (1120 words)
Who's Problem Is It?

Landslide risk is an issue for all New Zealanders (Figure 2), but specifically to the following: government departments such as the Ministry for Business, Innovation and Employment (MBIE, Building and Housing), Earthquake Commission (EQC), the Ministry for Civil Defence and Emergency Management (MCDEM), and the New Zealand Transport Agency (NZTA); local government entities such as ECAN; Lifelines; engineering consultants; communities, including homeowners and iwi; and the scientific community. We have included representatives from key stakeholder groups and the international research community to either be part of the research or in steering teams. In agreeing to be involved, they acknowledge that research is needed to improve management of their infrastructure networks. They further recognise that to reduce landslide-related costs of ~$300m pa, a much more substantial level of research is needed.

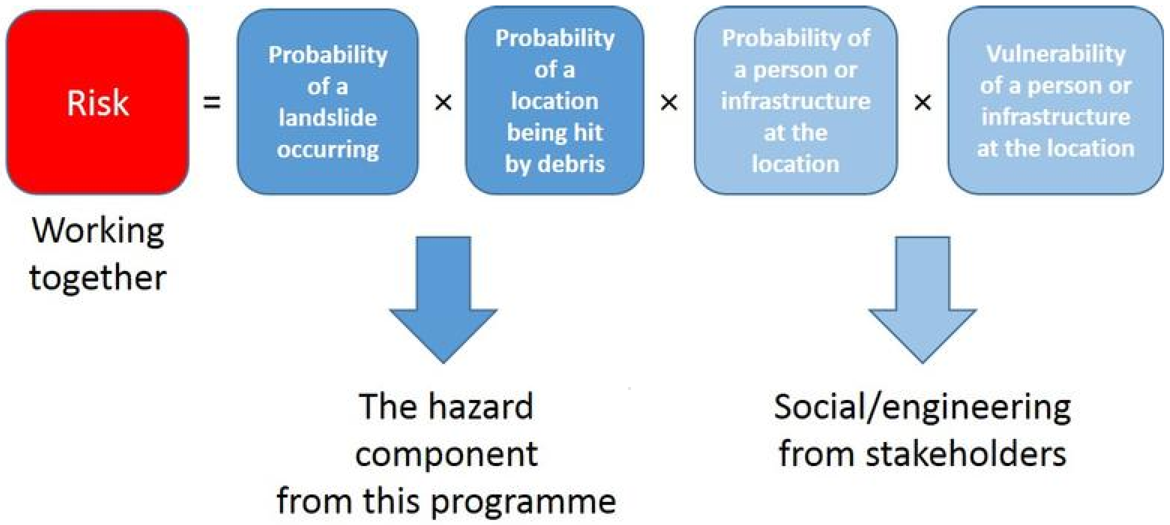

Figure 2. The landslide risk assessment framework[13]

Engagement with Stakeholders

Our research team have proven track records of quality engagement with end-users. The programme will build on the success of large projects undertaken during the rebuilding of Christchurch following the 2010/11 Canterbury earthquakes, Wellington's Transmission Gully project, and the MBIE 'Anthropogenic Slope Hazards' programme. All of these projects involved close working relationships with stakeholders to ensure that robust and defendable science supports the development of policy and creates resilient infrastructure/communities.

We will establish a technical end user steering group, comprising international technical experts and representatives from stakeholder organisations. The steering group will provide independent review at stages throughout the programme, ensuring that methods and results are fit-for-purpose and scientifically rigorous. We will hold regular technical and user workshops, and share data and results as they are generated. This on-going interaction with the international experts will be critical to our scientific success. We will establish broader stakeholder engagement to aid implementation of results to other areas of New Zealand.

Uptake

To ensure widespread and immediate uptake of our findings, we will hold technical seminars with local geotechnical consultants and local government officers, and host public workshops within communities and iwi. Research Aim 1.7 integrates the other six research aims and is the "tool" that transfers scientific knowledge to decision making stakeholders, such as local government. It will be ready for use on Kaikoura remediation work, and a proactive tool for hillslope infrastructure planning in other areas. This will lead to improved delivery of services to communities in their districts and ultimately to lower costs. Iwi will be able to apply sustainable land-use management practices and decision making to their whenua.

Implementation Barriers

The main barriers to uptake and implementation is lack of stakeholder engagement with the research team, possibly due to a reluctance to progress from the status quo approach to risk and remediation. Human psychology prefers to deal with tangible problems (clearing landslides and dams) than investing upfront, if there is a chance that the event may not happen during their lifetimes or in their district. We will address these barriers via a *stakeholder engagement plan*, which follows the “Overview of best practice approach for engagement with Māori” (Figure 3). We see this approach as applicable to all stakeholders; for many of those involved in the proposal, we are already following these steps in the plan, and will continue to do so throughout. We will also follow the plan in our engagement with other stakeholders with whom we have yet to make contact.

The GNS Science team has met with several stakeholders including MCDEM; NZ Lifelines Committee; NZTA; KiwiRail; Transpower; NCTIR, ECAN, DOC, Ngāi Tahu, and the local councils in the earthquake affected area.

Each stakeholder will have a particular interest relevant to their asset(s). However, there is also a certain amount of interdependence between the various assets and stakeholders, with many areas of mutual interest. Therefore, our engagement plan allows for meetings with individual stakeholders and cross-stakeholder meetings and workshops. Face-to-face meetings are very important to us, as they allow us to tease out particularly relevant information from experts about specific asset types at key locations. We will capture this information for use in the project.

Our cross-stakeholder meetings will either be regular short meetings on progress, or workshops (intensive discussions focused on a particular aspect of the programme). The group meetings will comprise stakeholders listed above, many of whom have already agreed to provide in-kind funding to allow their staff time to prepare and/or attend the programme meetings (about two to three meetings per year with each meeting lasting approximately half a day), contribute to the programme workshops (about one per year with each lasting a day or two), and peer-review the findings as and when needed (see *Co-funding*). We plan to hold four programme workshops to coincide with our key initiatives, and to deliver outputs at regular intervals throughout the programme to ensure end-users receive data and findings in a timely fashion for prompt uptake (see *Research Plan*).

Transferring and Implementing Results

Our team comprises engineering practitioners with a proven track record in disseminating results of research and consulting to asset owners, councils and designers via collaboration with professional institutions. From the Christchurch rebuild projects, some successful examples of quality engagement with end-users by the project team include:

- Canterbury Earthquake Recovery Authority and Christchurch City Council developing policies based on the results of research produced by the team, e.g. Residential Red Zone policy, and the Slope Hazards section of their proposed replacement District Plan.
- Engineering consultants use the methodologies and results established from Christchurch research in their consulting work; e.g. the methods and results from Christchurch are being used to update the peak ground accelerations for the Transmission Gully Project in Wellington.
- MBIE (Building and Housing) are using Christchurch research results in their Rockfall Protection Design Guide (of which Dr Massey was a panel member).

In the interests of Kotahitanga, training of iwi in the use of the framework and tools will be carried out. Improvement in the development and transfer of knowledge between scientists and iwi will facilitated through meaningful engagement with iwi, including iwi representation on steering and working groups, and having an iwi liaison position within the programme team and a Ngāi Tahu representative on the Steering Group.

Figure 3. Best Practice Guidelines for Engagement with Maori. 2014 (Te Runanga Ruanui Trust); the term “Cultural Issues” in the Step 7 may be replaced with “Particular Stakeholder Issues”.

Post-contract outcomes for New Zealand

Post-contract outcomes for New Zealand (280 words)

Within Programme

We will ensure prompt communication of results, especially where they are relevant to rebuilding efforts of infrastructure affected by the Kaikoura Earthquake. In general, findings will be delivered to key stakeholders for use in ongoing policy development and decision making via workshops and publicly available (web-based) information.

Two Years After Completion

Inventories in digital Geographical Information System (GIS) map format, and interactive applications will be made available to be incorporated into asset owner's GIS systems. New hazard maps and risk maps developed for infrastructure-critical slopes assessed will be delivered to asset managers to help them develop their emergency management plans. New methodologies, approaches and tools for assessing hazard and risk posed by slopes and landslides, and remediation approaches, will be implemented into infrastructure resilience frameworks across the country. Similar approaches are starting to be developed for other regions.

Five Years After Completion

GIS map inventories will be built on and enhanced by various stakeholders across the country. The new framework and tools for assessing hazard and risk posed by landslides, and slope risk remediation approaches, will be implemented by engineering consultants in their work for private and government clients, and will be used to underpin recommendations developed by MBIE. Findings will be disseminated to asset owners, councils and designers through collaboration with professional institutions, so they can be applied in current infrastructure project(s) as best practice case-study recommendations

Ten Years After Completion

There will be online tools, and policy changes in district plans that reflect the dynamic nature of landslide hazards. Sustainable land management and decision making policy will be in place nationwide, regulating the design, construction and accountability of slopes, natural and engineered in New Zealand.

Excellence criteria

Science

Science (1120 words)

Science Issue

Following major earthquakes, landslides create unstable hillslopes for many years[14]. Slope stability is determined by hill-slope properties (e.g. slope angle, material and damage state, groundwater, vegetation) and external forcing from shaking and weather. Thus, predicting hill slope behaviour is an exceedingly complex issue, where the influence of the individual variables is still not fully understood[15], let alone the interplay between them before and after slope collapse.

Hypothesis

Over what time scales do landscapes heal after major earthquakes? The Kaikoura Earthquake provides a laboratory to quantify post-earthquake landscape dynamics (Figure 4).

Expected Impact

The tools and framework generated by this research are being used by stakeholders for landslide risk avoidance and mitigation, and to enhance residual risk-management methods and practices in New Zealand and overseas.

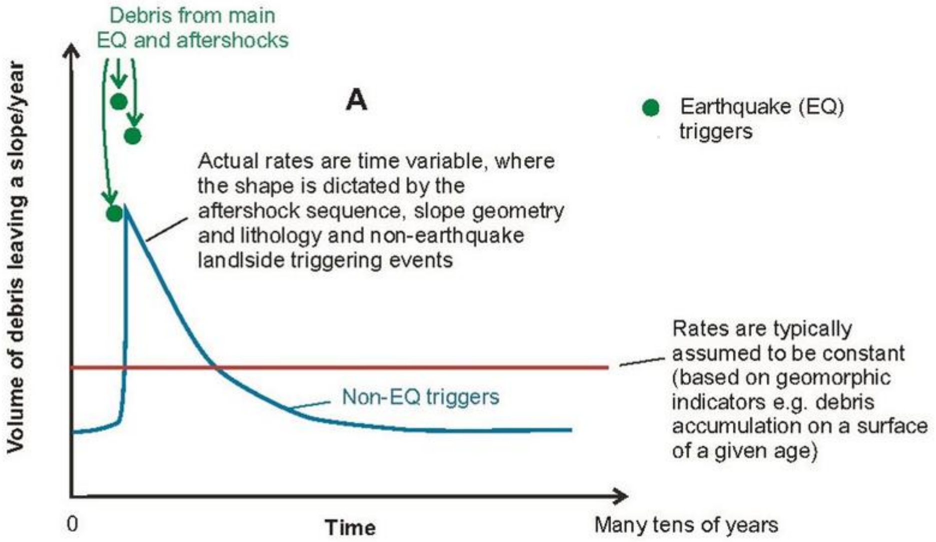

Figure 4. Schematic diagram showing the time-variable nature of landslide rates following a major earthquake

Science Excellence

Our research programme will collect perishable data and inform new modelling approaches to better predict how the hillslopes and rivers affected by the Kaikoura Earthquake will be impacted post-earthquake, and for how long. We will use state-of-the-art field mapping, monitoring techniques and equipment, laboratory testing of material properties, and numerical simulations, to quantify the geological processes being studied. The results from the Kaikoura-centric research will be combined with legacy research to quantify the time-frame over which landscapes heal following major earthquakes.

RA1.1: Landslide-fault interaction and landslide severity: We will forecast landslide severity at different levels of earthquake ground shaking and focal mechanisms for different post-major earthquake slope damage states. To do this, we will investigate the interaction between surface fault rupture and the initiation of landslides, including the large landslides and their failure mechanisms, using geophysical field data collection and monitoring techniques, laboratory testing and numerical modelling. The largest landslides triggered by an earthquake are located either on or adjacent to faults that ruptured on the ground surface (Figure 5), are distributed across a broad area of intense ground shaking and not clustered around the earthquake epicentre, and their location appears to have a strong structural geological control[16]. The mapped landslide distribution from the M_W 7.8 Kaikoura Earthquake, therefore suggests a complex interaction among earthquake ground shaking, geology (materials and structure), and topographic slope angle, which drives the occurrence of the largest landslides generated by this event.

We will build expertise and produce new knowledge on a long-term problem associated with earthquake-induced landslides; that is, predicting the occurrence and severity of different types of landslide at different levels of shaking in varying terrains. As Figure 6[15] shows, the same landslide probability density can produce landslides that differ in size by up to one order of magnitude, even for similar sized earthquakes. The uncertainty or spread in the data, as shown in the grey shaded area in Figure 6, will be investigated as part of this research to better understand the physics that determines the size of a landslide. We will also use the results from landslides reactivation research (RA1.2), to develop new physics-based models. These will be combined with the statistical models, to better predict post-earthquake landslide severity from aftershocks and rain events, addressing landslide production rates after earthquakes[17] Incorporating such time-variable rates into landslide risk assessment and engineering practice really is novel[12].

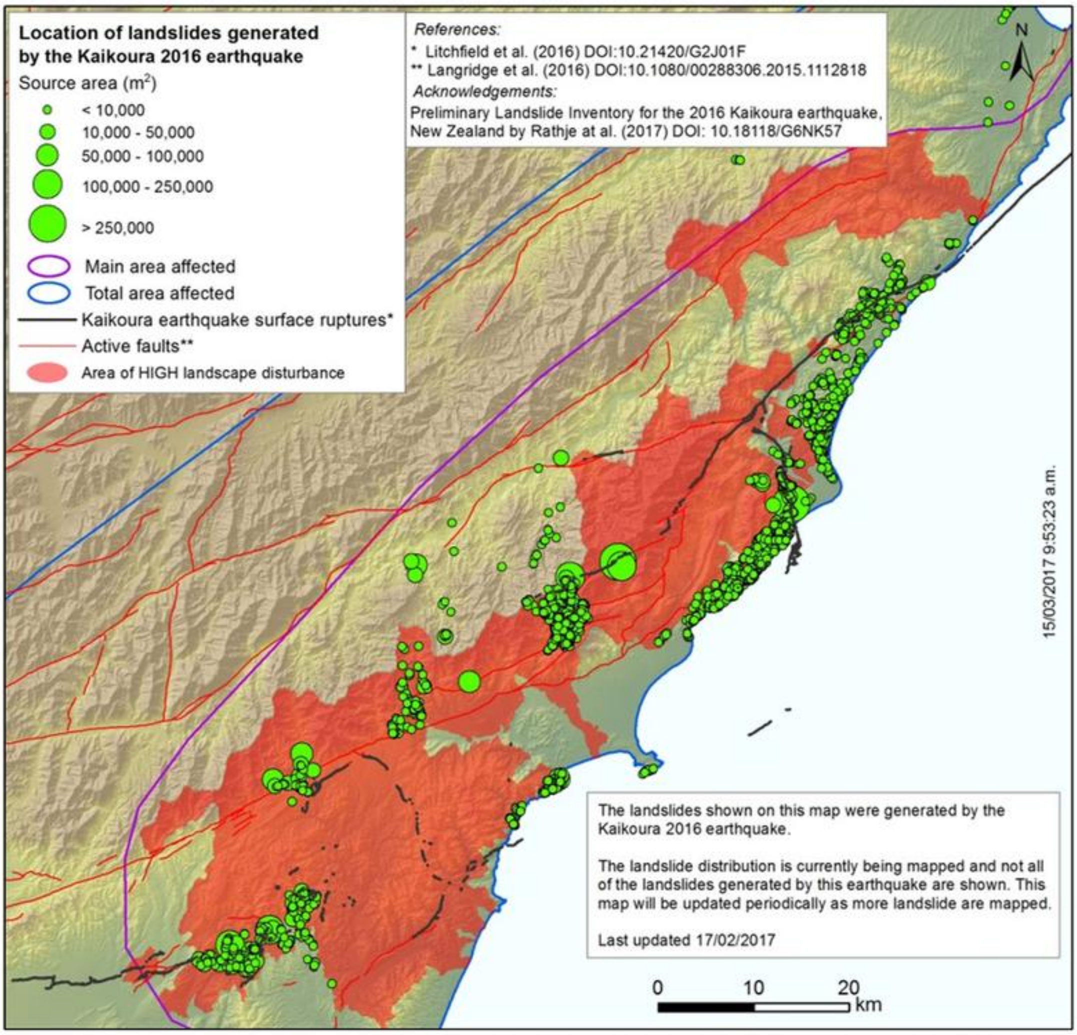

Figure 5. Landslides and surface fault ruptures generated by the Nov. 14, 2016, Kaikoura Earthquake.

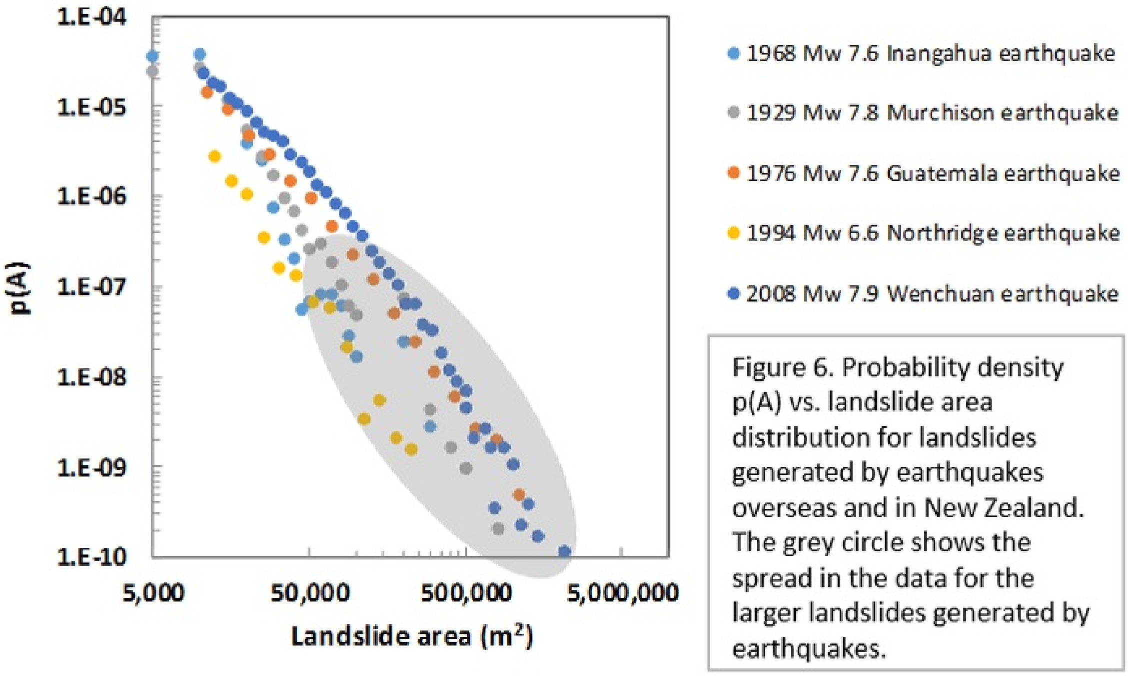

Figure 6. Probability density p(A) vs. landslide area distribution for landslides generated by earthquakes overseas and in New Zealand. The grey circle shows the spread in the data for the larger landslides generated by earthquakes.

RA1.2: Landslide reactivation during aftershocks and rainstorms: Novel laboratory testing[18] will be used to investigate the effects of the Kaikoura earthquake on post-earthquake landslide rates. This will be done to define potential rock and soil failure mechanisms and their thresholds during different post-earthquake rainfall and aftershock scenarios. We will undertake bespoke Dynamic Back-pressured Shear-box (DBPSB, Figure 7) tests on intact field samples. Our research is needed to determine how this will be influenced by the markedly different New Zealand weather.

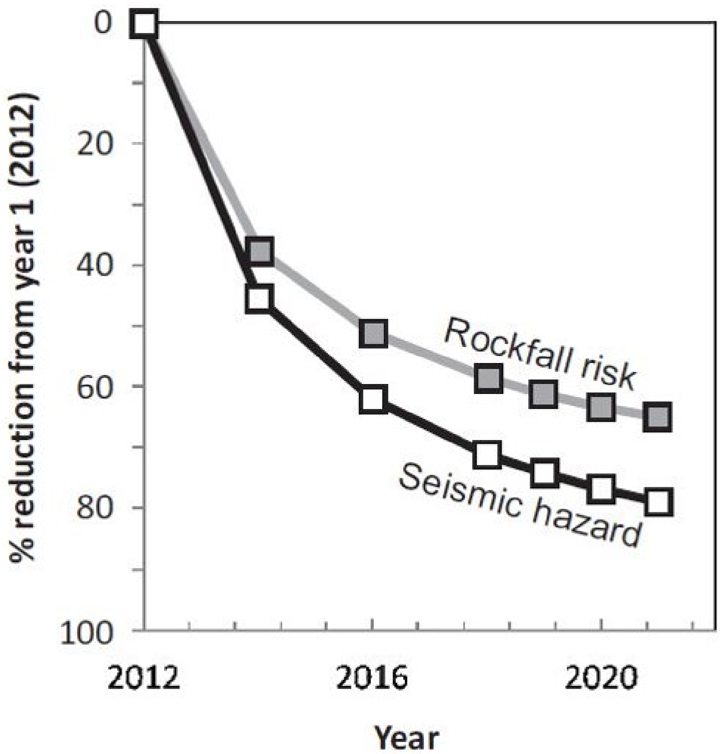

Figure 7: Time varying nature of the risk from rockfalls in the Port Hills of Christchurch after the 22 February 2011, MW 6.2 earthquake.

RA1.3: Landslide dam longevity: The formation of relatively short-lived landslide dams in river valleys becomes a significant cascading hazard, where the risk of potential break-out floods[19] often results in urgent engineering remediation and potential evacuation. The formation of multiple landslide dams after the 2005 M_W7.6 Kashmir Earthquake created long term difficulties[20-22]. We will geotechnically characterise the landslide dam materials and carry out 3D numerical simulations of potential dam-failure scenarios and debris runout to quantify their likely longevity and impact. Such physics-based approaches will test and transform the currently used empirical relationships to better predict dam longevity.

RA1.4: Landslide runout: A wide range of methods and underlying hypotheses exist for estimating landslide runout[23]. Existing statistical-empirical relationships will be improved by adding those landslides triggered by the Kaikoura Earthquake. This will be done to help quantify how far the debris from different types of landslide may travel down a slope in future events. Back analysis, using physics-based 3D numerical simulations of a suite of landslides, will also be used to investigate the controls on landslide runout and to calibrate the empirical relationships. Results can then be applied to landslides in different areas. If such approaches had been available at the time, the impact of the Oso Landslides (Washington State, USA) might have been anticipated[24].

RA1.5: Sediment cascades: The sedimentary hazards cascade initially triggered by an earthquake may persist for years to decades[25-32].

Monitoring and simulation of river catchments severely impacted by landsliding will be undertaken to quantify the supply and transport of sediment through river systems over time and the related hazards[33-35]. Quantifying the post-seismic sediment cascade and its impact on river dynamics, and developing numerical models capable of estimating cumulative impacts downstream are essential steps towards developing effective mitigation strategies.

RA1.6: Performance of earthworks: We will develop recommendations for assessment and geotechnical design of earthworks for enhanced resilience. Through investigation and analysis of the behaviour of earthworks cuts, fills and retaining systems in the area affected by the Kaikoura Earthquake, critical factors that need to be considered in the design and asset management will be identified, and recommendations developed for resilient design and asset management. Findings can be applied in current infrastructure project(s) as best practice case study recommendations.

RA1.7: Tools for managing landside hazards and risks: All new findings will be combined with relevant legacy data to generate the information and tools for managing landslide hazards and risk needed by our stakeholders. Figure 8 is an example of a ready- to use tool we will develop for engineers in the field.

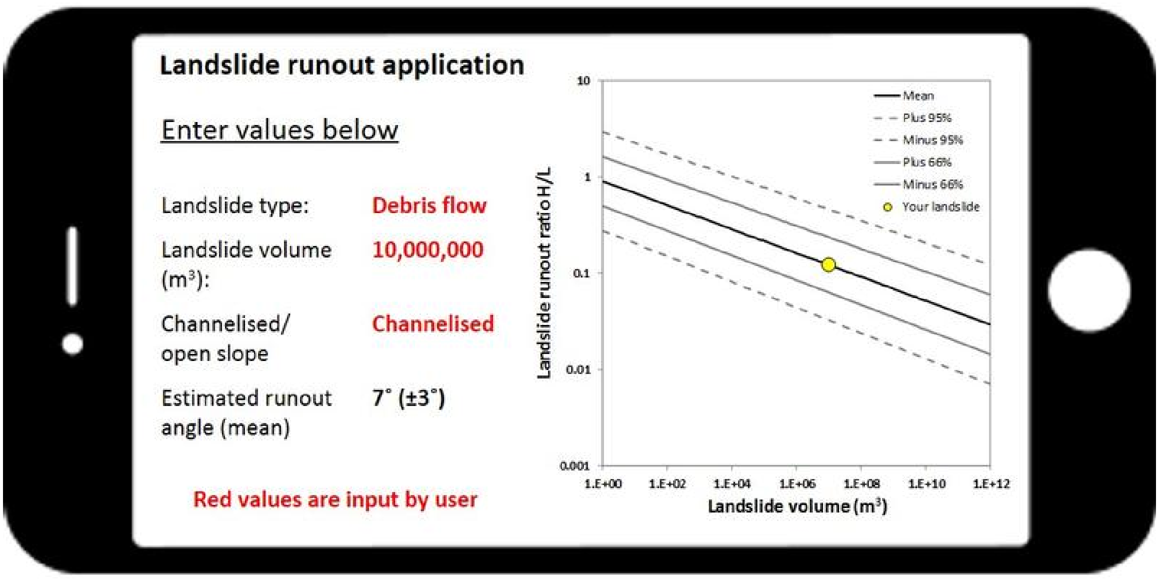

Figure 8: Web-based interactive application to estimate landslide runout.

Team

Team (560 words)

The research team assembled is fit for purpose, with expertise from all leading landslide research institutions in New Zealand, joined by international experts from Japan, France, Canada and UK, and industry practitioners from Opus. Science Leader, Dr Chris Massey (GNS Science), has 21 years of research and consulting experience in engineering geology and natural hazards, and was the technical leader for the Christchurch landslide risk assessments. Members of the team have collaborated well together on previous projects.

RA1.1 will be led by Dr Chris Massey, and supported by: Professor Julie Roland (University of Auckland; fault rupture mechanics); Dr Clark Fenton (University of Canterbury; fault rupture mechanics and seismology); Dr Anna Kaiser (GNS Science; geophysical surveys and slope seismology); Professor Doug Stead (Simon Fraser University; rock mechanics and numerical landslide modelling); Dr Nick Rosser (Durham University: geomorphology and landscape modelling); and Brenda Rosser (GNS Science; rainfall induced landslide relationships).

RA1.2 will be led by Dr Jon Carey (GNS Science; soil mechanics), and supported by: Dr Fernando Della Pasqua (slope stability and rock mechanics); and Drs Brenda Rosser and Sally Dellow (GNS Science: landslide frequency and rain amount and duration distributions and thresholds).

RA1.3 will be led by Dr Fernando Della Pasqua (GNS Science; landslides dam stability and runout modelling), and supported by Dr Chris Massey (GNS Science; landslide dam hazard and risk assessment); and Dr Gonghui Wang (DPRI, Kyoto University, Japan; landslide dam hazard and risk assessment specialist).

RA1.4 will be led by Dr Sally Dellow (GNS Science; landslide runout modelling), and supported by Dr Fernando Della Pasqua (GNS Science: landslide runout numerical modelling); Dr Martin Brook (University of Auckland; landslide runout numerical modelling); and Dr Simon Cox (GNS Science; landslide runout empirical modelling).

RA1.5 will be led by Dr Jon Tunnecliffe (University of Auckland), and supported by: Dr Jamie Howarth (Victoria University of Wellington; catchment geomorphology and landscape modelling); Professor Dimitri Lague (University of Rennes; landscape numerical modelling and hazard assessment); and Dr Phaedra Upton (GNS Science; landscape modelling).

RA1.6 will be led by Pathmanatham Brabhaharan (Opus International Consultants; geotechnical engineering and design), and supported by Dr Chris Massey.

RA1.7 will be led by Dr Wendy Saunders (GNS Science; land-use planning), and will be supported by a software engineer (consultant; development of web-based applications and tools); and Dr Sally Potter (GNS Science; landslide alerts and warnings).

The team will be supported by several laboratory technicians, field surveyors, GIS modellers, four PhD students (two each in RA1.1 and RA1.5) and a Post Doctoral fellow (RA1.5).