Summary

Summary

Client report summary:

Key:	CONT-52007-ENDRP-GNS C05X1709-CR-6
Project:	Earthquake-induced Landscape Dynamics
Contract ID:	C05X1709
Investment process:	ENDRP 2017 Endeavour Fund - Research Programmes
Organisation:	GNS Institute of Geological & Nuclear Sciences Limited - Trading as GNS Science
IMS assigned to:	Donato Romanazzi
Reporting period:	01/07/2022 to 30/06/2023
Contract total value:	$9,420,932.25
Team:	

Progress Reporting

Annual Update

2022-23 Annual Update

2022-23 Annual Update

The focus of this year across Research Aims (RAs) 1 to 6 has been on writing and disseminating the results from the research and publishing the online tools (via RA1.7) developed during the programme. We have achieved 6 critical steps this year. Some highlights from each Research Aim and their benefits are described in the table below and on our website: SLIDENZ.net. In addition,

- Five of our seven PhD students have now submitted their PhD's and four have been awarded their doctorates. The other two will submit in August 2023.
- RA 1.7 has continued to be a big focus this final year. We have continued to develop and finalise the 'tools' we'd already been creating, with our research and advisory teams. Most of these are now ready for use and are published on our Programme's website https://slidenz.net.
- The tools and website were discussed at both the Regional (7 September 2022) and National (8 November 2022) Advisory Group meetings. The tools and website information had been disseminated as 'beta' versions, to our advisory groups and other end users prior to the workshops along with an online feedback form for comments. The comments were also discussed at the meetings. One of the goals of these advisory group meetings was to ensure the outputs – in this case 'tools' – are useful, useable, and used, and scientifically robust.
- A significant 'tool' highlight has been the development of the Landslide Planning Guidelines. This guidance sets out how landslide risk can be reduced through consistent land-use planning practices and approaches. The Landslide Planning Guidelines document updates the 2007 guideline (Saunders and Glassey 2007). It is provided primarily for planning, policy and building compliance staff, but will also be of use to consultants, developers and professionals who provide landslide susceptibility, hazard, and risk analyses. This year, this work involved three meetings with the Landslide Planning Guidance Steering Group Committee, which comprises a group of senior GNS Science research leaders and external council-based planners, technical experts from EQC and independent planners.
- From 27 February to 1 March 2023, a three-day workshop was held at GNS Science in Avalon, followed by a 5-day fieldtrip to Kaikoura. This workshop and fieldtrip brought together the internationally based Science Advisory Group (SAG) members, the students, and senior Earthquake-induced Landscape Dynamics (EILD) researchers. This focused workshop and fieldtrip provided an opportunity for the research team and students to discuss their main research findings with the SAG and others, and to elicit their feedback on the near final versions of the risk management framework and tools.
- Results from the research are also being used by Te Rūnanga o Kaikōura in Kaikoura. On 7 September 2022, three research aim leaders met with Ngati Kuri in Kaikoura to discuss the results of the programme and how they might be used by Ngati Kuri. It was also an opportunity to link their 'front of mind' issues with the relevant research from the programme. This identified a few key topics where research from EILD could help answer their questions – particularly regarding sediment supply times, from the quake damaged slopes to the coastal plains. This information allows them to sustainably manage their local resources.
- In addition to completing the critical steps, this year the team have also published 10 journal papers and 4 book chapters (see website) and a further five papers are currently in review. In addition, a total of 14 conference abstracts and two book chapters were published. These outputs will be included on the website. These outputs are all more than what was originally planned under this programme.

2022-23 Annual Update: Outcome Benefits to New Zealand

Table1: Summary of major programme highlights and the benefit implementation from our 2022-2023 programme outputs

Research Aim (RA)	Highlights	Benefit
1.1	Landslide susceptibility models developed on the Kaikoura Earthquake (EQ) landslide inventory (from CS1.1.5) were re-trained using other NZ earthquake-induced landslide (EIL) inventories (from the 1929 Murchison and 1968 Inangahua earthquakes), creating Version 2.1 of the EIL forecast tool (CS1.1.6). The EIL forecast tool was updated to use 'dynamic' ShakeMap NZ products (in this case a map of the Peak Ground Accelerations (PGAs) caused by the earthquake) now available in near-real time post a major earthquake in NZ. The EIL forecast model was also used to create 'static' EIL probability maps for all NZ, based on the PGAs associated with different return periods of shaking (100-, 250-, 500- and 1000- year), taken from the National Seismic Hazard Model (NSHM).	Version 2.1 of the EIL forecast tool was implemented within the National Geohazards Monitoring Centre. This tool is operated by the Geohazard Analysts and can be used 24/7. It provides a forecast of the distribution and severity of landslides across all NZ, immediately after a major EQ. End users can respond more quickly and efficiently to EIL, and assess the location, scale and impacts from EIL as soon as possible after a major EQ. Such products generated by the tool have used to model landslides triggered by several recent earthquakes that affected the North Island of New Zealand and Raoul Island in 2021-2023. The static EIL probability maps based on the NSHM outputs are available for all NZ and can be accessed via our programmes website https://slidenz.net. End users can now make informed decisions about where EIL might occur in NZ and thus avoid/remediate their impacts more efficiently.
1.2	Regional-scale landslide susceptibility models were derived to quantify landslide severity at different magnitudes of rain amount and duration (CS1.2.6). These rainfall-induced landslide (RIL) models were trained on landslide inventories triggered by two pre-Kaikoura EQ rain events and four post-EQ rain events, so the differences caused by the EQ with respect to landslide susceptibility can be investigated and quantified.	Following a major earthquake, slopes become more susceptible to RIL, as the EQ damages the ground. Quantifying this post-EQ increase in RIL susceptibility, and the time it takes to decay post-EQ, is important for post-EQ recovery and rebuilding. End users are more aware of the changing susceptibility of slopes over time, following a major EQ. This knowledge can be used to 'build back better' meaning that potentially dangerous slopes – slopes more susceptible to post-EQ RIL – can be identified and if needed, avoided.
1.3	The first national NZ landslide dam inventory has been completed, and the accompanying paper accepted for publication. Both datasets will be publicly available. This data set has been fundamental in allowing the factors that control landslide dam occurrence and stability (longevity) to be evaluated.	Landslide dam potential in future earthquakes can now be more accurately predicted. Another key benefit is that a method to assess the longevity and downstream impacts of landslide dams, post-formation has now been established, based on the performance of past landslide dams. This method/approach was adopted to assess a landslide dam triggered by Cyclone Gabrielle (February 2023).

Research Aim (RA)	Highlights	Benefit
1.4	Empirical-statistical landslide runout relationships (database and paper) and physics-based landslide runout models (paper) have been established.	These landslide runout models have been used by end users (Kaikoura District Council, West Coast Regional Council) to identify areas where the debris from future landslides might impact. They are also being used to investigate the impact from landslides triggered by Cyclone Gabrielle (Feb 2023).
1.5	Forward modelling to predict timeframes and magnitude of morphodynamic response to earthquake-induced landslide derived sediment (CS1.5.4)	Auckland University and Victoria University have used results and findings from their work studying the rivers affected by the Kaikoura earthquake, to provide insights to support rehabilitation of Anthropocene riverscapes in the East Coast Region of Aotearoa New Zealand.
1.6	Three reports were completed, the first is a site investigation report which presents a compilation of the site investigations carried out on select slope failures following the Kaikoura earthquake. The second summarises the geotechnical back analyses of earthwork failures along the road network triggered by the Kaikoura earthquake, and the third uses these learnings, with knowledge gained from consultation with international specialists, to develop recommendations for earthquake resilient design of earthworks for infrastructure and the built environment.	This work by WSP consultants will be used by asset owners, councils and design practitioners, to enable them to design earthquake-resilient earthworks adopting 'lessons learnt' from the Kaikoura earthquake.
1.7	The development of the landslide risk management framework and tools have been the focus of this last year's work. The interactive tools: Rockfall Activity Rate System (RoARS); landslide runout (F-angle); and Landslide dam dimensionless Blockage Index (DBI), are now finished and are on our website. The landslide Early Warning System design framework report and the Landslide Planning Guidelines, have both been written and shared with end users and their feedback incorporated into them. The reports are now going through final checking before being made public.	We have now developed a landslide risk management framework and tools that can be used by our end users to collectively and effectively manage the risks to people and infrastructure from landslide and sediment hazards caused by the Kaikoura earthquake, and other future earthquakes, both here in NZ and overseas. GNS Science has also agreed to incorporate the EILD website into their official website and the tools will be hosted and maintained via GeoNet, thus making them accessible to many people. We hope the benefits from this research will continue to be realised in the future.

2022-23 Annual Update: Implementation Pathway

- To ensure the research is directed and implemented by our stakeholders, we held the 8th (our last)

Regional Advisory Group (RAG) meeting in Kaikoura on the 7 September 2022. These meetings are a time when our RAG all gets together, however, we are in touch with individual members throughout the year as/when needed. The knowledge gained from the RAG meeting and other meetings was disseminated to our National Advisory Group (NAG) at a meeting in Wellington on 8 November 2022. This meeting was a highlight of the year. It comprised about 30 attendees. The attendees were impressed with the amount of work done by the team, and it provided us with an opportunity to show our end users how their feedback had been used to update the tools (under RA1.7). The RAG and NAG meetings were attended by representatives from GNS, ECAN, KDC, BRANZ, DOC, DIA, ICNZ, LGNZ, LINZ, MBIE, NEMA, MFE, MPI, NZGS, NZPI, RSC, Treasury/National lifelines group, Waka Kotahi, Transpower, KiwiRail, DPMC and WeLG, QLDC, EQC and Auckland Council.

- Further to these groups, we had established the Landslide Planning Guidelines Steering Committee (in 2021) to guide the development of this important report (CS 1.7.3). Three meetings were held this year with representatives from EQC, QLDC, NZGS, ECan, Environmental Planning, Nelson City Council, MfE. The report, incorporating their feedback was also sent to the wider audience of planners and other end users to ellicit their feedback. This report is now being finalised with the feedback received, and we hope to make this available via our website very soon. This report is important for us as it provides a pathway for our research to be implemented by land use planners, which should allow them and the councils to make more informed decisions about where to build better, with a view to reducing the number of people, buildings and infrastructure impacted by landslides caused by future earthquakes and rain.
- EILD members presented science findings to Te Rūnanga o Kaikōura (Ngāti Kurī, Ngai Tahu) at the Takahanga Marae in Kaikoura on the 7 September 2022. Phil Glassey, Andrea Wolter and Chris Massey presented results relating to the timeline of sediment cascading from the earthquake damaged slopes to the coastal plain, which was of particular interest to Te Rūnanga o Kaikōura as they had been dealing with assessing future gravel abstraction rates from the rivers in the region.
- Another achievement this year has been using the results from RA1.1 (CS1.1.6, earthquake-induced landslide forecast model). The EIL outputs (landslide probability forecasts) using V2.1 of the tool, were generated for several EQ scenarios, as requested by NEMA, to help inform their emergency response capabilities. The EIL tool was also used by the NGMC to generate landslide forecasts for the M5.6 26 April 2023 Porangahau earthquake.

2022-23 Annual Update: Research, Science and Technology (RS&T) Benefits to New Zealand

- A major science highlight of the year was the final technical Programme workshop (27 February to 1 March 2023), which was held at GNS Science in Avalon, and was followed by a 5-day fieldtrip to Kaikoura. This workshop brought together the internationally based Science Advisory Group (SAG) members, the students, and senior Earthquake-induced Landscape Dynamics (EILD) researchers. The workshop was attended by about 30 scientists from GNS Science, Victoria University, the University of Canterbury, the University of Auckland, Washington State University (USA), Oregon State University and the Oregon University, USA. The field trip was organised as part of the National Science Foundation (USA) research project, which is affiliated to the EILD programme, see: (https://www.nsf.gov/awardsearch/showAward?AWD_ID=2050047&HistoricalAwards=false). It provided an opportunity of EILD researchers to work with USA-based researchers on post-EQ landscape response processes.
- **EILD researchers presented some of the key findings from their EILD research at:**
    1. QuakeCoRE, Napier NZ, August 2022: four abstracts and presentations;
    2. American Geophysical Union (AGU) in San Francisco, December 2022: one abstract and talk;
    3. European Geophysical Union (EGU) in Vienna, Austria, April 2023: two abstracts and talks; and
    4. Geoscience New Zealand (GSNZ), Palmerston North, December 2022: two abstracts and talks.
- **A new book published titled "Coseismic landslides: phenomena, long-term effects and mitigation"** and published by Springer as part of their natural hazards publications, contains two chapters (papers) contributed by EILD researchers. The first chapter describes the EIL forecast tool developed under RA1.1 (CS1.1.6), and the second chapter describes coseismic landslide susceptibility and triggering analyses methods and techniques using examples from the EILD research. The book is also edited by the EILD programme lead. The book contains 18 chapters and is the result of an elaborate project initiated by the Joint Technical Committee (JTC-1) of 1) the International Society for Soil Mechanics and Geotechnical Engineering, 2) the International Association for Engineering Geology and the Environment, 3) the International Society for Rock Mechanics, and 4) the International Geotextile Society, with the focus on natural slopes and

landslides. The framework of the book sets out the steps, based on recent disaster experiences in the twenty-first century, leading to the assessment of earthquake-induced landslide hazards. It contains: 1) important cases of landslides triggered by earthquakes around the world; 2) investigation into the characteristics of ground motion site response; 3) methods to determine landslide susceptibility and triggering thresholds and their comparative study; and 4) commentary on the production of earthquake-induced landslide hazard maps. All the contents are the result of the latest research on related areas. The book is a valuable resource for researchers, designers, consultants, academicians, government officials, and all others who are involved in the mitigation of coseismic landslides. The book contributes toward the development of a new chapter in disaster prevention and mitigation of landslides induced by earthquakes. It serves as a valuable resource not only for researchers but also for geotechnical designers and government officials.

- **Development of 3 interactive web-based tools:**
    - RoARS: The Rockfall Activity Rate System (RoARS) provides indication/forecasts of the magnitude of rock/debris that could fall from a slope – of a given height, angle, and area – at different levels of earthquake shaking.
    - F-Angle: The Fahrböschung (F-) angle is the angle between the crown of a landslide source and the toe of the landslide deposit. Back-analyses of the runout of over 1100 landslides of several different types have determined empirical relationships between the height of the slope and the volume of the landslide mass, from which the F-angle can be estimated (Brideau et al 2021). This F-Angle tool calculates a Fahrböschung angle, that can be used, with further analysis, to estimate the runout distance for a certain type of landslide from a slope. The output(s) of the tool can be used to generate a first approximation of runout distance. The tool should be used by landslide practitioners and researchers that have a good technical understanding of landslides.
    - DBI: The Dimensionless Blockage Index (DBI) tool indicates how stable a landslide dam might be, given the dam height and volume, and catchment area upstream of the dam. The DBI is a tool for carrying out preliminary forecasting on the stability of landslide dams.
- **Launch of the EILD webmap:** The EILD webmap includes landslide locations, photos, fault traces and active faults, Earthquake induced landslide probability map for four return rates (100, 250, 500 and 1000 years) and a geological base layer. This can be accessed at https://slidenz.net/data-tools/.
- **Geomechanics News:** We promoted our online tools through the publication of a Geomechanics news article, "Tools for managing landslide hazards resulting from the next large earthquake". The suite of tools developed as part of this programme are described in the NZ Geomechanics Society newsletter, which is mostly read by practicing engineering geologists and geotechnical engineers (https://slidenz.net/data-tools/). In this article we summarise the risk management framework and some of the major programme tools including the EILD webmaps, guidelines, calculators, probability maps and data that can be utilised for managing landslide hazard when NZ has its next large earthquake.
- **Earthworks performance reports:** WSP produced three reports as a culmination of work related to Earthworks performance:
    - Site investigation report which presents a compilation of the site investigations carried out on selected slope failures triggered by the Kaikoura earthquake.
    - Assessment report which evaluated selected landslides from the Kaikoura event to characterise slope failure mechanisms and their relationship to observed impact.
    - Recommendations for earthquake resilient design of earthworks report – which using the results from the other two reports combined with local and international best-practice knowledge – identified critical factors that contributed to slope failure impacts. It also provides recommendations for best practice measures for the resilient design of earthworks.

2022-23 Annual Update: Other information

1. **RA1.1 and 1.2: Cao et al. (2022) Slow-moving landslides triggered by the 2016 Mw 7.8 Kaikoura earthquake, New Zealand** : a new InSAR phase-gradient based time-series approach. This research developed a new approach using InSAR deformation-time histories to identify the locations of coseismic- and post-seismic landslides, and their movement patterns, and how they vary over time (CS1.1.2 and 1.2.5). It's the first time such an approach has been used and it highlights the importance of different styles of landslide movement and what mechanisms/processes that cause them.

2. **RA1.3: Wolter et al. (2023) The Hapuku Rock Avalanche** : breaching and evolution of the landslide dam and outflow channel using high spatiotemporal resolution datasets. This work highlights the importance of using high resolution datasets to capture landslide dam failures, post formation. It provides an important case history to add to the others compiled under this research aim, and together such information has provided important 'lessons learnt' which have been incorporated into the way such hazards are managed e.g., Tokomaru bay landslide dam (Gisborne region) that was triggered by Cyclone Gabrielle in February 2023. The hazard analyses of this landslide dam followed the approach and used the results developed under RA1.3 (CS1.3.6 and 1.3.8). In addition, the first national NZ landslide dam inventory has been completed (CS1.3.7), and the accompanying journal paper accepted for publication (Morgenstern et al., 2023).
3. **RA1.4: de Vilder et al (2023) What drives landslide risk?** Disaggregating risk analyses, an example from the Franz Josef Glacier and Fox Glacier valleys, New Zealand. This work uses landslide runout model relationships developed as part of this RA (CS1.4.1 and 1.4.2). Such relationships are also being used in landslide hazard and risk analyses elsewhere in NZ, to aid in the quantification of landslide impacts caused by Cyclone Gabrielle in February 2023.

End of Programme

End of programme: Outcome Benefits to New Zealand

The main benefit to New Zealand from this research is the improved resilience of New Zealand's homes and infrastructure via the knowledge gained, risk management framework and tools – designed to make this knowledge accessible and used – developed by this programme. We have made available cutting-edge internationally leveraged science to our end users – people, councils, infrastructure providers and central government agencies – which has given them the ability to avoid costs and trauma from prolonged landscape instability caused by earthquakes.

This new knowledge was combined with legacy and aligned 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 has already benefited those affected by the Kaikoura earthquake, it has also already been of benefit to those living in other seismically-prone hilly areas of New Zealand and overseas and will provide more benefits as time goes by and the results from this programme are used.

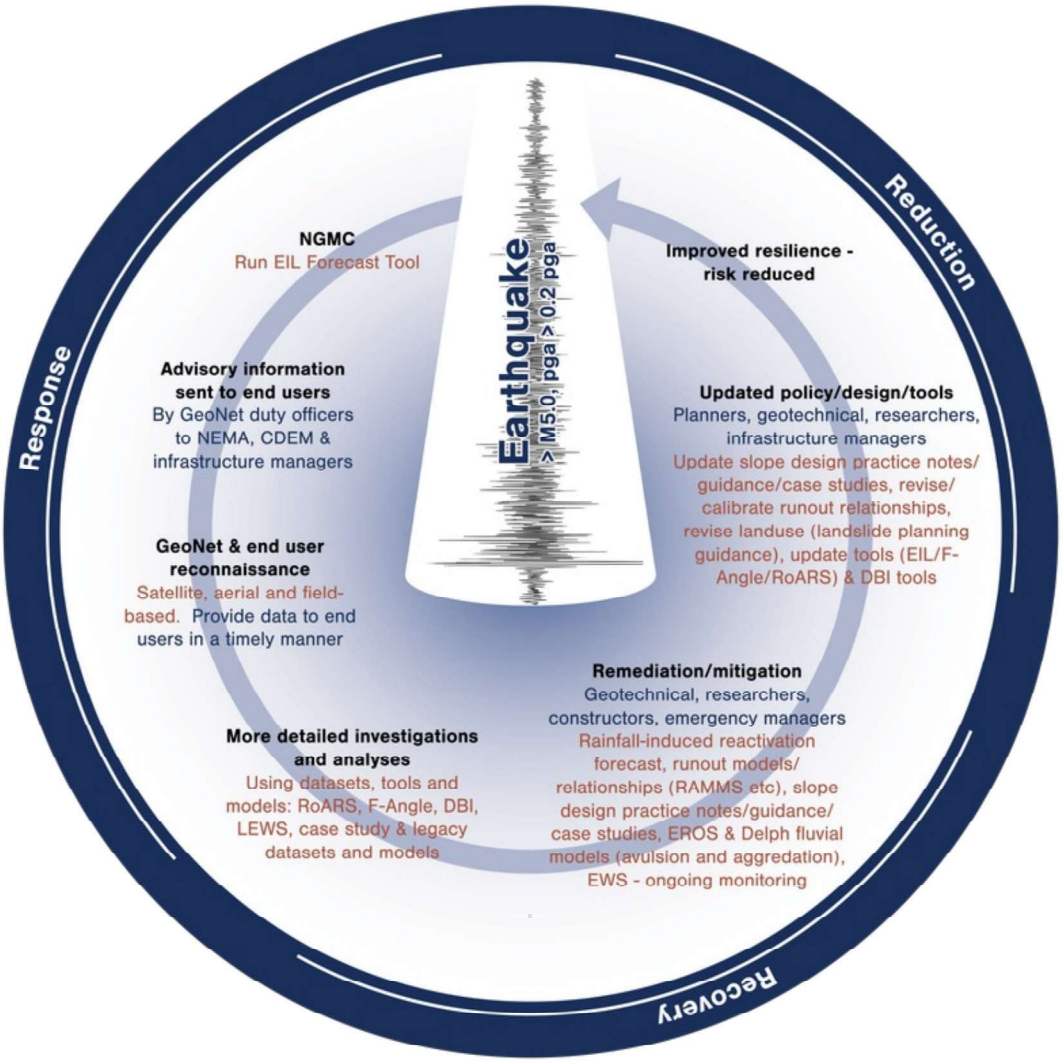


Figure 1: Graphic shows the tools, data and methods made available from research outputs as a result of this programme and how they will be used to

- **Respond to an Earthquake**
- **Recover from landslides induced by an earthquake** and other sedimentation hazard
- **Prepare for the next earthquake and the potential resulting lanscape changes**

End of programme: Implementation Pathway

To ensure our research provides what end users need and want, we established regional (RAG) and national (LNAG) advisory groups to guide the tool development. We held eight RAG and seven LNAG meetings over the course of the programme. These were also guided by our Science Advisory Group (SAG), who attended all five of our annual programme workshops. We also had three workshops/meetings with Te Rūnanga o Kaikōura over the length of the project. All these meetings and workshops provided opportunities to focus the research being done, and to work with our end users to help direct the research.

Our tools and datasets have been used by end users to inform and in some cases change their approaches. An early example is the work we did for the North Canterbury Transport Infrastructure Recovery (NCTIR), where our landslide mapping and hazard modelling helped them locally realign sections of state highway SH1 post-Kaikoura earthquake. Another example is the use of our landslide hazard and risk models by Kaikoura District Council and Environment Canterbury, to create the landslide hazard zones within their District Plan.

Landslide runout models that we developed are being used by the Department of Conservation to carry out landslide risk analyses for their tracks and huts and other assets. These models are also being used by West Coast Regional Council in their landslide hazard and risk analyses work. The same models are currently being used by the RiskScape project to forecast landslide hazards for Auckland, Tairawhiti and Hawke's Bay, following Cyclone Gabrielle (February 2023).

End of programme: Research, Science and Technology (RS&T) Benefits to New Zealand

The following are an example of the key science outputs from this programme and how they have already been implemented to realize benefit:

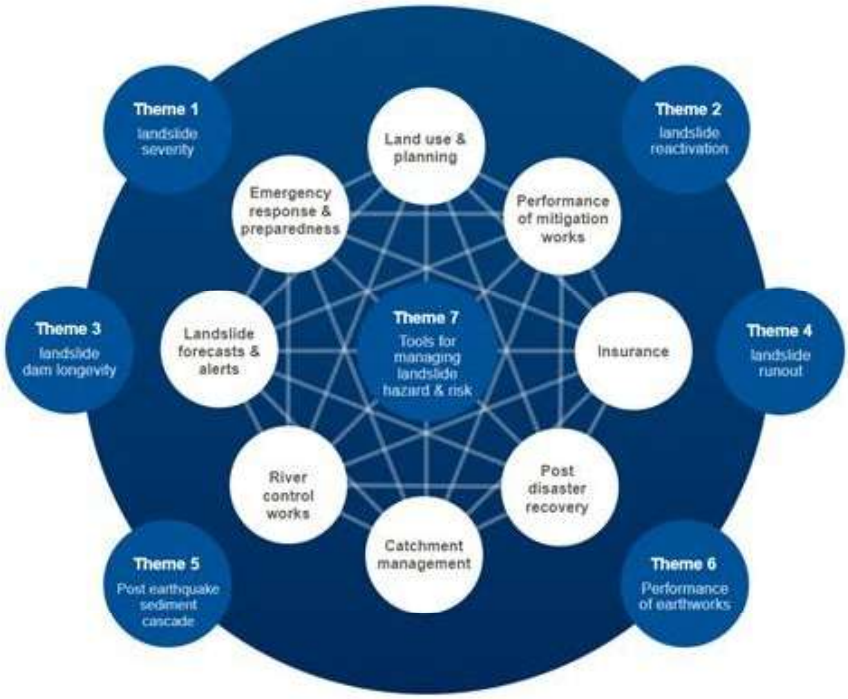
- **EIL forecast tool:** This earthquake-induced landslide (EIL) tool provides rapid advisory information about the 'intensity' and likely location of landslides following a major earthquake in New Zealand. The tool produces a model of landslide probability after a significant earthquake in near-real time – approximately 7 minutes after being triggered. The tool is operational within the National Geohazard Monitoring Centre of GeoNet. The tool is also being used by other researchers to forecast landslide occurrence for specific earthquake scenarios such as the Alpine Fault, Wellington Fault and multi fault rupture events.
- **Landslide and landscape erosion (and river change) datasets:** So far we have generated V3.0 of the Kaikoura earthquake landslide distribution, containing more than 31,000 landslides. We have created six rainfall-induced landslide inventories (pre- and post-earthquake) containing more than 40,000 landslides combined.
- **NZ landslide dam** inventory (Morgenstern et al. 2023): We have created New Zealand's first landslide dam inventory. Version 1.0 of the New Zealand Landslide Dam Database (NZLDD) includes compilation and re-mapping of 1036 dams, including those generated by the 2016 Kaikōura Earthquake. A representative subset of 265 dams was selected to analyse dam stability and breaching in detail. The database architecture, description of datasets included, attribute definitions, and some summary statistics are presented in a new paper published in the journal Landslides. The NZLDD represents a significant increase in catalogued landslide dams – almost doubling the existing number of known and studied dams worldwide.
- **Online tools:** We produced three interactive web-based tools: RoARS, F-Angle and DBI. The RoARS tool is being used in Oregon, USA by the Oregon Department of Transport, to identify earthquake prone slopes and forecast the likely volumes of material that could fall from them at different levels of shaking. RoARS is being updated via an aligned NSF (USA) research project with datasets from Alaska and other parts of the USA.
- **Online maps, photos and datasets:** The inventories, datasets and results of the research are being made available via five interactive tools and maps. These can be accessed online via our website: (https://slidenz.net/data-tools/webmap/)
- **Landslide Planning Guidelines:** This guidance sets out how landslide risk can be reduced through consistent land-use planning practices and approaches. It is provided primarily for planning, policy and building compliance staff, but may also be of use to consultants, developers and professionals who provide landslide susceptibility, hazard and risk analyses. This guidance provides examples of how landslide hazard and risk analysis can support and be incorporated into planning documents and assist in formulating policy; decision-making; and preparing and assessing land-use, subdivision and building consent applications. End user engagement and guidance was integral in the production of the document.
- **Landslide Early Warning System:** This guidance document outlines key considerations in the design and development of a Landslide Early Warning System (LEWS) in Aotearoa New Zealand. The document incorporates four components of an effective Early Warning System (EWS) and draws on global and national guidance for developing EWSs, such as international standards, New Zealand EWS guidance, LEWS-specific journal publications, and results from previous stakeholder engagement for this research programme. The intended audience for this report is the emergency management sector, local government, critical infrastructure agencies, occupiers of buildings, consultancies, science agencies and land stewards involved in landslide hazard and risk management.
- **Contributions to landslide research:** We worked with collaborators in 7 countries and 10 students have worked directly on programme data and research leading to six submitted theses and several with ongoing work beyond the programme. During the programme we have shared our knowledge and expertise through sabbatical visits (four), dozens of national and international conferences,

targeted end user workshops, press articles and media (see https://slidenz.net/news/). Our researchers have published over 113 publications in peer reviewed journals (34+), abstracts (44), books and book chapters (seven), new articles and reports (27+).

Publicly Available Information

Publicly available information for use in relevant media releases and Ministerial reporting

Large earthquakes, like the November 2016 Mw 7.8 Kaikōura earthquake, can generate thousands of landslides, landslide dams and damage hillslopes that are susceptible to failure during rainstorms and aftershocks. This debris, when mobilised, creates new hazards, including further landslides, landslide 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 may persist for decades and therefore represent a prolonged risk that must be managed by the impacted communities and stakeholders. Here, we summarise the results from a five-year research programme (2018-2023) Eathquake Induced Landscape Dynamics (EILD). The EILD programme focused on developing a framework and set of tools that will better inform landslide risk avoidance and residual risk-management methods and practices for people and stakeholders affected by the Kaikōura earthquake and by future earthquakes in New Zealand and overseas. The research programme has seven themes: https://slidenz.net



The main hypothesis driving this research was: over what time scales do landscapes heal after major earthquakes? Our results demonstrate that it is the complex interaction and linkage – at varying scales – between the earthquake shaking; geological materials and structure; landslide type, mechanisms, and volume; and pre- and post-earthquake rainfall-induced landslide occurrence, that control the time a landscape may take to heal following a major earthquake. This five-year research programme explored these linkages, and created novel methodological advances that were used to investigate and decipher them.

One specific aspect of this Endeavour Programme research is the development of landslide and landslide dam, forecasting capability. GNS Science is developing a series of tools that will forecast the likely location, size and runout of earthquake- and rainfall-induced landslides to provide rapid information for responding agencies and infrastructure operators. The tools are designed to produce information on the likely location, extent and impacts of landslides within minutes of a large earthquake, or in the days and hours before a major storm is likely to hit New Zealand. Data and models developed from this programme underpin the GNS Science landslide forecast tools.

The programme is now finished. In this last year our focus was on finalising the tools and landslide risk management framework and publishing our results. The tools can be accessed via our website: SLIDENZ.net.

Highlights from this year are:

- We published (had accepted for publication) 14 scientific journal papers and book chapters including two chapters to a book titled “Coseismic landslides: phenomena, long-term effects and mitigation”. The book contains 18 chapters and is the result of an elaborate project initiated by the Joint Technical Committee (JTC-1) of 1) the International Society for Soil Mechanics and Geotechnical Engineering, 2) the International Association for Engineering Geology and the Environment, 3) the International Society for Rock Mechanics, and 4) the International Geotextile Society, with the focus on natural slopes and landslides.
- Version 3.0 of the Kaikoura Earthquake (EQ) landslide inventory is now complete and currently in review, due for public release this year.
- Version 1.0 of the NZ landslide dam inventory and accompanying journal paper is about to be publicly released.
- Other information, data, blog posts, movies and links to research papers relating to the programme are all accessible via our public web page: www.SLIDENZ.net

Our research has already been used by end users. Another highlight this year has been the implementation of our EQ-induced landslide forecast models developed under this programme. Data and models developed under the EILD programme were used to help The National Emergency Management Agency (NEMA) to forecast landslide impacts from a series of earthquake scenarios.

Our team has also presented nationally and internationally including at the European Geophysical Union in Vienna, Austria, the American Geophysical Union meeting in USA. Keynote talks were given at the international workshop on “Earthquake and climate change-induced geological hazards in high mountain areas" 11-12 May online. This workshop was organised by the State Key Laboratory of Geohazard Prevention and Geoenvironment Protection (SKLGP), Chengdu University of Technology, China. Our team will continue to present programme findings including two invited talks at the IAEG congress in China in September.

Project Deliverable Status

Click on the deliverable to enter a status

Sequence	Short title	Type	Due Date	Status	Reason	Action
1	Over what time scales do landscapes heal after major earthquakes? Earthquake- and post-earthquake landslide risk in New Zealand is effectively managed using an integrated set of predictive tools within a decision making framework	Impact statement	30/09/2022	Achieved		
1.1	Forecasting landslide severity at different levels of earthquake ground shaking and focal mechanisms	Research aim	30/09/2021	Achieved		
1.1.1	Regional scale landslide distribution (frequency, area and volume) assessed using the Kaikoura landslide inventory	Critical step	30/09/2018	Achieved		
1.1.2	Kaikoura landslide distributions determined at site scale	Critical step	30/09/2021	Achieved		
1.1.3	Paleo-seismic evolution of the three areas determined	Critical step	30/09/2019	Achieved		
1.1.4	Fault rocks and other rock properties at the three sites parameterised	Critical step	30/09/2020	Achieved		
1.1.5	Models generated to describe the Kaikoura distribution	Critical step	30/09/2021	Achieved		
1.1.6	Models calibrated with New Zealand and overseas datasets	Critical step	30/09/2021	Achieved		
1.2	Landslide reactivation thresholds	Research aim	30/09/2021	Achieved		
1.2.1	Slopes classified by type and material properties	Critical step	30/09/2018	Achieved		
1.2.2	Characteristic slope types and materials sampled	Critical step	30/09/2018	Achieved		
1.2.3	Conventional lab testing carried out to characterise the main materials	Critical step	30/09/2019	Achieved		