BEFORE THE ENVIRONMENT COURT **ENV-2020-AKL-000064**
AT AUCKLAND

I MUA I TE KOOTI TAIAO O AOTEAROA
TĀMAKI MAKAURAU ROHE

IN THE MATTER of an appeal under the first schedule of the Resource Management Act 1991 (**RMA**)

BETWEEN **AWATARARIKI RESIDENTS INCORPORATED**

Appellant

AND **BAY OF PLENTY REGIONAL COUNCIL**

First Respondent

AND **WHAKATĀNE DISTRICT COUNCIL**

Second Respondent and
Requestor of Plan Change 17

STATEMENT OF EVIDENCE OF CHRIS MASSEY ON BEHALF OF WHAKATĀNE DISTRICT COUNCIL

LANDSLIDE RISK ANALYSIS AND EARLY WARNING SYSTEMS

10 August 2020

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1. EXECUTIVE SUMMARY

1.1. My evidence relates to:

(a) The landslide risk analysis methods and approaches used to quantify the risk to people living on the Awatarariki fan from debris flow hazards; and

(b) The efficacy of landslide early warning systems to reduce the risk to the people exposed on the debris fan.

1.2. Based on the information presented in my evidence before the Hearings Commissioners and the key documents I have used, or referred to, it is my opinion that a multi-staged debris flow early warning system – based on the potential design and effectiveness framework – adopting any of the scenarios discussed, is unlikely to allow ALL potential people present in the hazard zone at the time that a debris flow event is initiated, to evacuate to safe areas, irrespective of where they are on the fan. Therefore, people who don’t notice the alert, or do not/or cannot evacuate would continue to be exposed to the risk levels given in Tonkin & Taylor (2015), depending on their location on the fan.

1.3. Given the uncertainties associated with a debris flow early warning system as listed in my evidence, adopting such a system as the means to mitigate the risk to people living on the fan is, in my opinion, not aligned with taking a precautionary approach, as stated in Section 1.7 of the Bay of Plenty Regional Policy Statement (**BOPRPS**).

1.4. The BOPRPS and AGS (2007) methods to calculate the annual individual fatality risk are comparable, but they do differ based on their calculation routes. The results from the two methods can give similar values if similar inputs are used.

2. INTRODUCTION

2.1. My full name is Christopher Ian Massey.

2.2. My evidence is given on behalf of the Whakatāne District Council (the **District Council**) in relation to:

(a) Proposed Plan Change 1 (Awatarariki Fanhead, Matatā) to the Operative Whakatāne District Plan; and

(b) Proposed Plan Change 17 (Natural Hazards) to the Bay of Plenty Regional Natural Resources Plan (a private plan change request from the District Council)

(together referred to as the **Proposed Plan Changes**).

2.3. My evidence relates to:

(a) The landslide risk analysis methods and approaches used to quantify the risk to people living on the Awatarariki fan from debris flow hazards; and

(b) The efficacy of landslide early warning systems to reduce the risk to the people exposed on the debris fan.

2.4. My evidence will cover:

(a) An overview of landslide risk analysis methods, approaches and practice, risk tolerability thresholds, and the role of landslide early warning systems (**EWS**) as a method to mitigate risk; and

(b) The potential design and effectiveness framework of a public-facing EWS for debris flows onto the Awatarariki fan, as an option to reduce the risk to people living in properties on the fan.

2.5. I attended the public hearing of submissions to the Proposed Plan Changes held in March 2020 and presented expert evidence to the Hearing Commissioners.

3. QUALIFICATIONS AND EXPERIENCE

3.1. I hold the position of Principal Scientist at the Institute of Geological and Nuclear Sciences Limited (**GNS Science**). I have been a scientist at GNS Science since February 2006. My experience is in engineering geology and I have 23 years of consultancy and research experience in the investigation and analysis of complex geological and geotechnical data for landslide and slope stability including landslide monitoring, foundation design, underground/surface rock support and groundwater problems. I have applied these skills to geohazard and risk assessments, oil and gas pipelines, highway, railway, mining engineering and town planning projects in Malawi, Bhutan, Nepal, Ethiopia, Russia (Sakhalin Island), Tajikistan, Hong Kong, Australia, Europe, UK and New Zealand. I have **attached** a copy of my CV as **Appendix 1**.

3.2. I hold the following qualifications:

(a) PhD (Engineering Geology) from Durham University, UK. 2010;

(b) MSc (DIC), (Engineering Geology) from Imperial College, London, UK. 1999;

(c) BSc Hons (Geology) from Leeds University, UK. 1996; and

(d) Chartered Geologist from the Geological Society of London. 2005.

3.3. I am also a member of New Zealand Geotechnical Society, the New Zealand Society for Earthquake Engineering and a Fellow of the Geological Society of London, UK.

3.4. My current responsibilities include managing many of the engineering geological consultancy projects carried out by GNS Science, the most recent being landslide and rockfall risk assessments for the Department of Conservation and Franz Josef Glacier Guides for staff and visitors to the Fox and Franz Josef Glacier Valleys.

3.5. I also conceived and led an assessment of the landslide hazards and route resilience of the main road and rail corridors situated on the Kaikoura coast that were badly affected by the 2016 earthquake.

3.6. I have provided peer review services to Hastings District Council and Queenstown-Lakes District Council on several landslide risk assessments carried out for them by consultants.

3.7. I manage the landslide research for GNS Science, which involves setting the research strategy and goals and building relationships with other partners and collaborators in New Zealand and overseas.

3.8. I recently led a Ministry of Business, Innovation and Employment (**MBIE**) funded 4-year project investigating the impact of anthropogenic slopes in Wellington, which was completed in 2019.

3.9. I am currently leading a 5-year MBIE funded Endeavor Programme investigating earthquake induced landscape dynamics.

3.10. I’m also leading GeoNet projects to establish near-real time landslide forecast tools for New Zealand. These tools would provide stakeholders with rapid advisory information on landslide locations and their severity in response to strong earthquakes and significant rain events, such as the 2016 Kaikoura Earthquake and July 2020 Northland storm.

3.11. I have more than 20-years’ experience responding to landslide events, many of which have involved setting up landslide monitoring systems to provide hazard warning. I was involved with the 2007 Ruapehu Lahar and helped the Department of Conservation monitor the stability of the tephra dam at the crater lake, as part of the Eastern Ruapehu Lahar Warning System. I managed GNS Science landslide response to the 2010/11 Canterbury earthquakes and the 2016 Kaikoura earthquake.

3.12. I have been pioneering landslide modelling and quantitative landslide risk assessment methods and practices in New Zealand since the 2010/11 Canterbury Earthquakes, and have provided expert witness advice on such matters in the Environment Court on behalf of local and central government agencies.

4. MY ROLE

4.1. I was asked by the District Council to give expert advice on landside risk analysis and landslide EWS. As part of this work I authored GNS Science Consultancy report CR 2019/77, listed in the key documents below, which describes an effectiveness framework, for a public-facing EWS for debris flows onto the Awatarariki fan.

4.2. Throughout my statement of evidence, I refer to "my opinion", it should be noted that "my opinion" is based on the results of my review of the information provided by the District Council (items 4.4(a) to (h) below) and other information listed below.

4.3. I have also relied on observations I made during a field visit to the Awatarariki catchment and fan on 15/08/2019. The field visit comprised aerial reconnaissance of the fan and catchment via helicopter.

4.4. The key documents I have used, or referred to, in forming my opinions while preparing this brief of evidence are:

(a) Hegan. B., Johnson, D., Severne, C. 2001. Landslide risk from the Hipaua geothermal area near Waihi village at the southern end of Lake Taupo. Proceedings of New Zealand Geotechnical Society Symposium, Christchurch, August 2001. Pp439–448;

(b) 06/2005: Davies, T.R.H., 2005. Debris flow emergency at Matatā, New Zealand, 2005. Inevitable events, predictable disaster. Report Natural Hazards Research Centre, Department of Geological Sciences, University of Canterbury, New Zealand;

(c) 2005: McSaveney M.J., Beetham, R.D., Leonard, G.S., 2005. The 18 May 2005 debris flow disaster at Matatā: causes and mitigation suggestions. Institute of Geological and Nuclear Sciences Client Report 2005/71 prepared for Whakatāne District Council;

(d) AGS. 2007c. Guideline for landslide susceptibility, hazard and risk zoning for land use planning. In Australian Geomechanics. Australian Geomechanics Society;

(e) 2007: AGS. 2007d. Practice Note Guidelines for Landslide Risk Management. In Australian Geomechanics. Australian Geomechanics Society;

(f) 2009: AS/NZS ISO 31000:2009. Risk Management – Principles and guidelines is a joint Australia/New Zealand adoption of ISO 31000:2009;

(g) Massey, C. I., Beetham, R., Severne, C., Archibald, G., Hancox, G. T. H., Power, W. 2009. Field investigations at Waihi Landslide, Taupo 30 June & 1 July 2009, GNS Science Report 2009/34;

(h) 2011: Taig, T., Massey, C.I., Webb, T., 2012. Canterbury Earthquakes Port Hills Slope Stability: Principles and criteria for the assessment of risk from slope instability in the Port Hills, Christchurch. GNS Science Consultancy report 2011/319;

(i) 2012: Taig, T., Massey C.I. 2012. Understanding life-safety risk concepts for rockfall and cliff collapse in the Port Hills, Christchurch (Summary Series 1/3): https://ccc.govt.nz/assets/Documents/Environment/Land/gns-ph-Summary1-3web.pdf

(j) 11/2013: Tonkin & Taylor Ltd., 2013. Quantitative Landslide and Debris Flow Hazard Assessment Matatā Escarpment. November 2013: Report 29115;

(k) 10/2014: Bay of Plenty Regional Policy Statement. Appendix L – Methodology for risk assessment;

(l) 2015: Tonkin & Taylor Ltd., 2013. Supplementary Risk Assessment Debris Flow Hazard Matatā, Bay of Plenty: Report 29115.1000;

(m) 10/12/2015: Email from Nicola Litchfield (GNS Science) to Jeff Farrell (the District Council), RE: Matatā early warning system;

(n) 2016: United Nations report of the Open-ended Intergovernmental Expert Working Group on Indicators and Terminology Related to Disaster Risk Reduction (OIEWG), adopted by the General Assembly on 2 February 2017 (A/RES/71/276). A/71/644;

(o) 23/02/2016: Whakatāne District Council: Mitigation of debris flow risk – Awatarariki Fanhead, Matatā – Updated 23 February 2016;

(p) 2017. Potter S.H., Scott B.J., Fearnley C.J., Leonard G.S., Gregg C.E., 2017. Challenges and benefits of standardising Early Warning Systems: A case study of New Zealand's Volcanic Alert Level System. In: Fearnley CJ, Bird D, Jolly G, Haynes K, McGuire B, editors. Observing the Volcano World: Volcanic Crisis Communication. Springer. p. 350. (Advances in Volcanology;

(q) 12/2017: Davies, T.R.H., 2017. Awatarariki Fan, Matatā: Debris flow early warning systems feasibility study. 19 December 2017;

(r) 2018: United Nations Development Programme (**UNDP**): Five approaches to build functional early warning systems;

(s) 11/2019: Blackwood, P., Bassett, T., 2019. Matatā Flooding 18 May 2005: Meteorology Update. November 2019;

(t) 31/10/2019: Technical Assessment: Debris Flow Risk Management Awatarariki Fanhead, Matatā, Bay of Plenty. GHD;

(u) 01/2020: GNS Science Client report: Massey, C.I., Potter, S.H., Leonard G.S., 2019. Design and effectiveness-evaluation framework of a public facing Early Warning System for debris flows on the Awatarariki Fanhead, Matatā. (GNS Science report; 2019/77). doi:10.21420/8D3K-HD78;

(v) 01/2020: Statement of evidence of Tim Davies, on behalf of the District Council;

(w) 01/2020: Statement of evidence of Kevin Hind, on behalf of the District Council;

(x) 01/2020: Statement of evidence of Chris Phillips, on behalf of the District Council;

(y) 01/2020: Statement of evidence of Mauri McSaveney, on behalf of the District Council; and

(z) Massey, C.I., Lukovic, B., de Vilder. S., Archibald, G.C., Abbott, E.R. 2020. Landslide risk analysis for Clifton Beach, Cape Kidnappers, Hawke's Bay. Lower Hutt (NZ): GNS Science. 101 p. Consultancy Report 2020/28.

5. CODE OF CONDUCT

5.1. I confirm that I have read the Code of Conduct for Expert Witnesses contained in the Environment Court Consolidated Practice Note 2014. I also agree to comply with the Code when presenting evidence to the Court. I confirm that the issues addressed in this brief of evidence are within my area of expertise, except where I state that I rely upon the evidence of another expert witness. I also confirm that I have not omitted to consider material facts known to me that might alter or detract from the opinions.

6. SCOPE OF EVIDENCE

6.1. This statement of evidence covers the following:

(a) A summary of my evidence (**Executive Summary**);

(b) An overview of the landslide risk analyses, landslide early warning systems and issues and risk tolerability thresholds relevant to the Plan Changes;

(c) Appendix L of the BOPRPS and AGS 2007;

(d) Variability in debris flows;

(e) Response to the grounds of appeal (**Response to Appeal**); and

(f) Conclusions.

7. LANDSLIDE RISK ANALYSIS AND EARLY WARNINGS

7.1. Risk means many things to different people, so it is important always to define what is meant by the term. The general framework for managing risk is that:

(a) Hazards with potential to harm people are identified;

(b) The associated risk is then estimated in quantitative terms; and

(c) Criteria are established as to what level of control over risk is appropriate at what risk level.

7.2. It is the role of the technical expert to provide information relating to bullets 7.1(a) and (b). It is not the role of the technical experts to make decisions about how risky is too risky, e.g., setting risk tolerability thresholds, bullet 7.1(c). Such thresholds and levels of control should be set by the decision makers in consultation with those at risk and the technical experts who quantified it. This process is outlined on behalf of the District Council in Mr Farrell’s evidence.

7.3. Landslide risk is defined as a measure of the probability of a landslide hazard occurring and severity of a consequence to life, health, property, or the environment (Corominas et al., 2015). Landslide risk needs to be analysed first in order to:

(a) Assess it; and

(b) Determine if the risks are too risky, manage it.

7.4. Risk management addresses the following questions (adapted from Ho et al., 2000; Lee and Jones, 2014):

(a) What can cause harm (Landslide Characterisation, e.g., the type and nature of the landslide)?

(b) How often does this occur (Frequency Analysis)?

(c) What can go wrong and how bad could it be (Consequence Analysis)?

(d) What is the probability of damage occurring (Risk Estimation)?

(e) So, what (Risk Evaluation)?

(f) What can be done, at what cost, to manage and reduce unacceptable levels of damage (Risk Treatment)?

7.5. The overall risk management framework, adapted from AGS (2007c) and AS/NZS (ISO 31000:2009) is shown in Figure 1, which comprises:

(a) Risk analysis, bullets 7.4(a) to (d);

(b) Risk assessment, bullet 7.4(e); and

(c) Risk management, bullet 7.4(f).

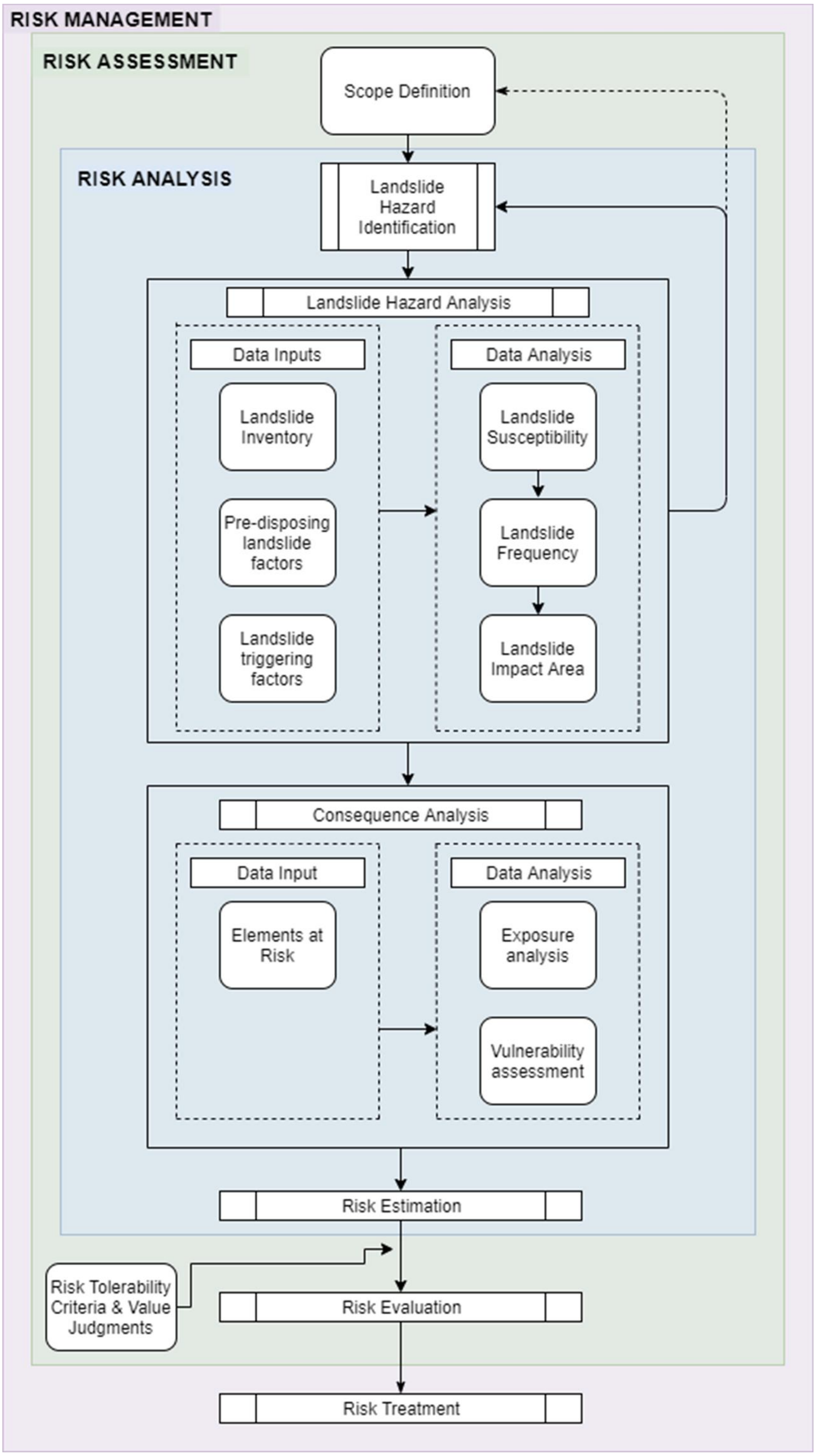


Figure 1. Landslide risk management framework (adapted from AGS, 2007c; AS/NZS ISO 31000:2009).

7.6. Quantitative risk analysis is systematic, objective and reproducible (Corominas et al., 2014). This enables the risk from multiple hazards, spanning the full range of severity (from small to large) that could feasibly occur at the site, at the same location or various locations, to be compared. This allows risk tolerance and acceptability levels to be more readily determined, and provides stakeholders, planners and policy makers (the decision makers) with an objective foundation on which to base their decisions.

7.7. The risk to people living on the Awatarariki Fan has been analysed by Tonkin and Taylor (2013, 2015) by quantifying the landslide risk to a single individual adopting the annual individual fatality risk as the metric of choice.

7.8. The main landslide hazards – defined as the probability of a given type of landslide occurring within a defined time period and area (Corominas et al., 2015) – identified and analysed by Tonkin & Taylor (2013, 2015) as affecting the site are debris flows, initiated by high intensity rain. I refer to the evidence of Professor Davies for the definition of a debris flow. Other types of landslide from different types of trigger, such as earthquakes, have not been analysed by Tonkin & Taylor (2013, 2015).

7.9. The risk from debris flow hazards to people living on Awatarariki Fan was calculated by Tonkin & Taylor (2013, 2015) following the AGS (2007c) guidelines, and adopting the following equation in AGS (2007d):

(a) $R_{(D)} = P_{(H)} \times P_{(T:S)} \times P_{(S:H)} \times V_{(D:T)}$ where:

(i) $R_{(D)}$ is the annual risk (probability) of loss of life (death) of a person from landslides, the annual individual fatality risk (**AIFR**);

(ii) $P_{(H)}$ is the annual probability of the initiating event (rain), and the likely size of the debris flow(s) initiated by the event, spanning the range of events and debris flows from small to large, which could feasibly occur at the site;

(iii) $P_{(T:S)}$ the probability that an element at risk is present at that location when the debris reaches/passes through it;

(iv) $P_{(S:H)}$ is the probability that the element at risk, if present, is in the path of the debris at a given location; and

(v) $V_{(D:T)}$ is the vulnerability of the element at risk to the debris, or in this case the probability that a person is killed if present and in the path of debris.

7.10. The AIFR estimates produced by Tonkin & Taylor (2013, 2015) were peer reviewed by Dr McSaveney and Professor Davies who identified an area on the fan that was considered unsuitable for residential use. This area reflected the area bound by the Tonkin & Taylor (2013, 2015) modelled AIFR contour line of 0.001 % (10^{-5}) which the peer reviewers' considered better reflected an AIFR level of 0.01 % (10^{-4}). The District Council accepted the advice of Dr McSaveney and Professor Davies. An AIFR of 0.01 % (10^{-4}) was adopted as "intolerable for existing development" by the District Council. I refer to the evidence of Mr Farrell for these details. This is also the level recommended by the Australian Geomechanics Society for contexts including slope collapse, and it roughly corresponds to the lifetime average risk faced by New Zealanders from road accidents. This is also the risk level adopted by the Canterbury Earthquake Recovery Authority and Christchurch City Council for their decision-making post 2010/11 Canterbury Earthquakes (e.g., Taig et al., 2011). In Section 8.0 of my evidence I discuss risk tolerability thresholds further.

7.11. The District Council reviewed various risk treatment (mitigation) options to try to reduce the AIFR to below 0.01 % (10^{-4}). These included the EWS, catchment management options and the relocation of people.

7.12. In 2015, Mr Farrell of the District Council contacted GNS Science to discuss the feasibility of installing a landslide EWS as a potential option that could reduce the risk to tolerable levels. A meeting between Mr Farrell, Dr McSaveney (GNS Science), Dr Litchfield (GNS Science) and me was held in Wellington on 7/12/2015. In this meeting Mr Farrell requested that GNS Science provide information to the District Council on how they would go about designing a debris flow EWS for the Awatarariki catchment and fan. These discussions were summarised in a memo emailed to Mr Farrell from Dr Litchfield on 10/12/2015.

7.13. Professor Davies was commissioned by the District Council in 2017 to assess the feasibility of an EWS to reduce the risk to people living on the Awatarariki fan. This work followed the steps outlined in the GNS Science 10/12/2015 memo. The work comprised:

(a) The reliability of the debris-flow detection or inference system (false alarms and false negatives);

(b) The impacts of a debris-flow on the assets exposed and consequences;

(c) The time between the warning being issued and the debris-flow impacting the asset;

(d) The time taken to remove assets from the hazard zone when the warning has been issued;

(e) The residual risk once the system is operational; and

(f) System cost – setup, operation and maintenance.

7.14. The report focused primarily on items 7.13(a) to (d). The main findings from this report were:

(a) It is feasible to develop a reliable debris-flow warning system that will reduce risk-to-life to road and rail users crossing the Awatarariki fan;

(b) Trip-wire detectors were the preferred sensor to detect whether a debris flow had been initiated. These would comprise several wires installed across the stream at a height above the channel bed greater than that of the water surface in a flood but lower than the depth of a debris flow. The wire(s) would be connected to an electrical circuit such that an alarm is triggered if a wire breaks; and

(c) Other debris-flow warning systems, e.g. those based on rainfall totals and intensities that generate debris-flows or those that infer debris-flow presence via ultrasound or seismic signals, are not feasible in Awatarariki Stream due to the lack of the necessary calibration data and the time (decades to centuries) that would be required to collect such data, as well as inevitably generating a high proportion of false alarms – when an alert is triggered but no debris flow occurs.

7.15. Although Davies (2015) states that it is feasible to develop a reliable EWS, he goes on to conclude that:

(a) The trip-wire system cannot provide adequate warning time to guarantee the ability of residents to exit dwellings and reach safety, because of the short distance between the detector sites (tripwires) and the dwellings on the fan and the need to apply a realistic factor of safety to calculations of warning and evacuation times; and

(b) Debris flow velocities were estimated to be in the order of 5 m/s in the catchment and 3 m/s on the fan. For the furthest dwelling on the fan the warning time (time from when the trip wire breaks to debris impacting a given location) was estimated to be about 3 to 6 minutes, and 3 to 5 minutes around the road and rail corridors. Evacuation distances for the furthest dwelling to relative safety were assessed as being about 600 m.

7.16. On 1/11/2019 GNS Science was commissioned by the District Council to scope out the potential design and effectiveness-evaluation framework of a public facing (it is designed to notify “warn” those people affected directly) EWS for debris flows on the Awatarariki Fanhead, Matatā, and identify any initially obvious “show stoppers”, and whether an EWS would be suitable/unsuitable for Council to consider as an option to manage the risk. The results from this work are contained in GNS Science Client Report 2019/77 (GNS Science, 2019).

7.17. This work built upon the previous advice by GNS Science to Jeff Farrell (10/12/2015) and the subsequent study carried out by Davies (2017) by assessing in more detail the various aspects of an EWS, via the following objectives:

(a) Objective 1: How to design and evaluate an EWS;

(b) Objective 2: Outline of necessary community consultation;

(c) Objective 3: Summary of any potential 'show stoppers' identified at this stage, and an assessment of the suitability/unsuitability of an EWS as an option the District Council could use to manage the risk; and

(d) Objective 4: Recommendations for next steps.

7.18. A summary of the approach used, and the main findings from GNS (2019) are set out below.

7.19. An EWS is "an integrated system of hazard monitoring, forecasting and prediction, disaster risk assessment, communication and preparedness activities, systems and processes that enables individuals, communities, governments, businesses and others to take timely action to reduce disaster risks in advance of hazardous events" (United Nations 2016).

7.20. According to the Sendai Framework, it is best practice to develop an EWS that can be used for multiple hazards (UNDP, 2018). A people-centred EWS (designed to meet the needs of the people relying on it) empowers individuals and communities threatened by hazards to act in a timely and appropriate manner, to reduce the chance of death, injury and illness, and impacts to property, assets, and the environment (UNDP, 2018). There are four key elements of a people-centred, end-to-end EWS: Disaster risk knowledge; Detection, monitoring, analysis and forecasting of the hazards and possible consequences; Warning dissemination and communication; and Preparedness and response capabilities (Figure 2).

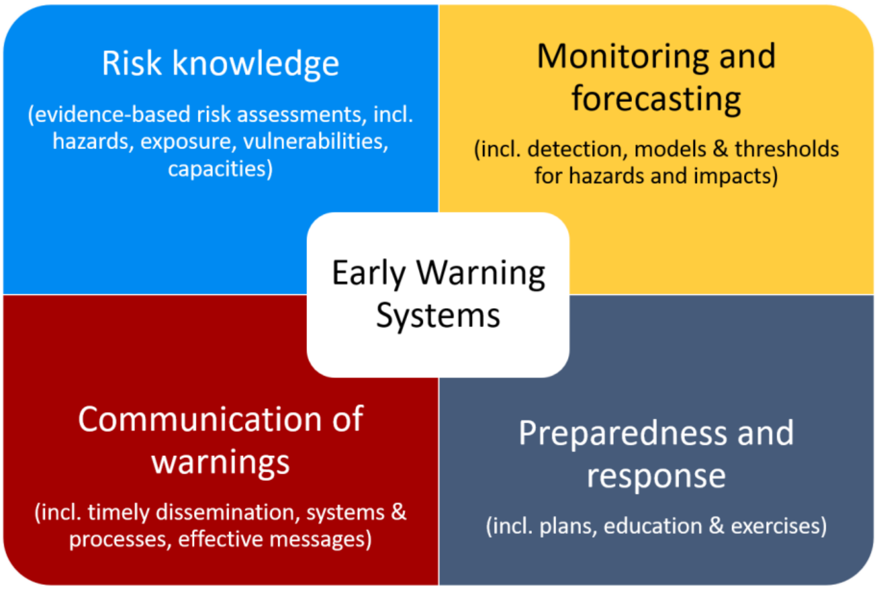


Figure 2. Critical elements of people-centred Early Warning Systems. Adapted from GNS (2019), based on the UNDP (2018).

7.21. The elements, or components of an EWS need to link seamlessly in order for the EWS to be effective and be flexible to adjust to local events and contexts. Factors which can assist the linkages between the elements are:

(a) Establishing effective communication networks between all parties;

(b) Empowering the community at risk by making scientific knowledge and risk assessments available and comprehendible;

(c) Developing effective decision-making processes, including acknowledging the local context and defining accountability and responsibility;

(d) Incorporating elements of behavioural response, such as understanding risk perceptions, levels of awareness, preparedness, and trust; and

(e) Considering technocratic and participatory approaches in EWSs (i.e. increasing public participation in processes).

7.22. It is also important to allow for the local context to drive warning system design and implementation, as set out in Figure 3.

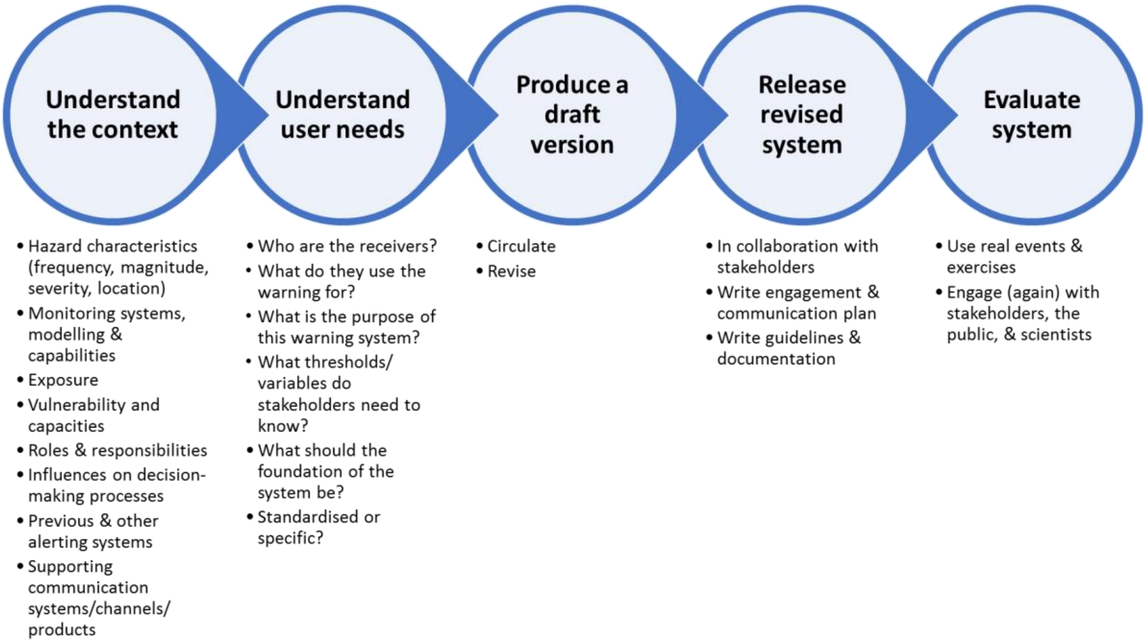


Figure 3. Overview of developing a warning system. Adapted from Potter et al. (2017).

7.23. GNS Science (2019) developed an effectiveness-evaluation framework of a public facing EWS for debris flows on the Awatarariki Fan (Figure 4), which considers the context and user needs as set out in Figure 3. It should be noted that it was not the intent of this work to carry out the detailed design of an EWS. GNS Science (2019) relied on information contained in McSaveney et al. (2005), Tonkin & Taylor (2013; 2015) and Davies (2017) to help set the site-specific context for the EWS. Information with regard to user needs was derived from discussions with Jeff Farrell and others present at the expert's workshop – organised by the District Council and held in Whakatāne on 15/08/2019, and during various other meetings – as community consultation and discussion was not feasible at the time.

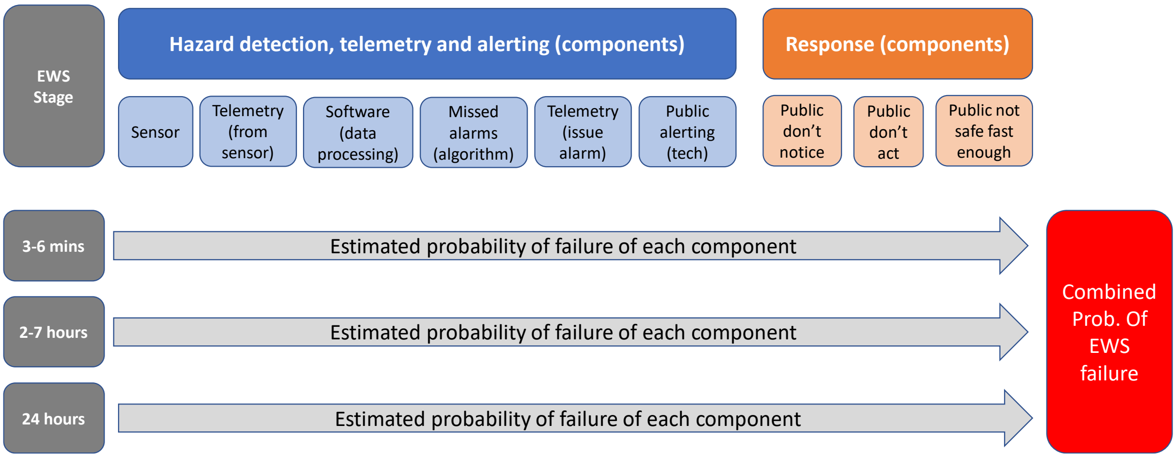


Figure 4. Effectiveness-evaluation framework of a public facing Early Warning System (EWS) for debris flows on the Awatarariki Fan (GNS Science, 2019).

7.24. Three different EWS stages typically used for debris flows were adopted and combined as part of the debris flow EWS design. These stages were based around the minimum time between a “positive” on the EWS algorithm (that triggers a warning that a debris flow could potentially occur) and the potential debris flow hitting dwellings on the fan.

7.25. In the literature review cited in GNS (2019) most EWS (about 80%), rely on a multi stage approach using different types of data to trigger the alerts. Most EWS adopt rainfall data from synoptic, radar and gauges for the first stages of the EWS (1-24 hours), linked to rainfall intensity/duration thresholds established using precedent and local knowledge of landsliding. Tilt meters and tripwires are then typically used for the later stages, to detect when a landslide initiates or landslide movement exceeds a given threshold.

7.26. The stages, and time lines for the alerts, evaluated as part of the debris flow EWS effectiveness-evaluation framework for the Awatarariki Fan are:

(a) 24 hours – based on Synoptic meteorological data from MetService;

(b) 2-7 hours – based rain radar (MetService) augmented with onsite rain gauge(s); and

(c) About 3-6 minutes – based on trip wire(s) located as per those shown in Davies (2017).

7.27. The effectiveness framework is based around nine components of an EWS system (shown in Figure 4), along with estimates of their probability of failing. These are:

(a) Sensors (and associated technology): 24 hours = synoptic (from MetService); 2-7 hours = rain radar (from MetService) and local rain gauge(s); and 3-6 minutes = trip wire(s);

(b) Telemetry: to transfer data from the instruments on site e.g., from the rain gauges and trip wires, and to get it to the place where it's needed. For MetService data, the data is provided via cloud-based data services, thus not requiring any on site sensors or telemetry;

(c) Software and computer processing: Data from the various sensors are processed and compared to pre-determined thresholds, typically carried out by an algorithm trained on past events, which then issues the alarm if the threshold(s) are exceeded;

(d) Missed alarms: This relates to an event that the algorithm misses and only relates to the rainfall data streams as the trip wires would be linked directly to the public alerting technology, thus not needing any data processing algorithm;

(e) Telemetry: to issue alerts e.g., satellite, cell, wifi and wifi and cell combined, to trigger the public alerting technology. For example, in the case of Stage 3, the trip wire would be linked by wifi to e.g., the siren and lights with less than a minute for siren/lights to operate after the trip wire triggers. This time might be slightly longer for text messages to be issued;

(f) Public alerting (technology): e.g. door knocking, voice sirens (with instructions about what to do), US Federal audible sirens, home-made sirens and flashing lights;

(g) Public don't notice: the public might not see the alert e.g., text message or flashing lights, or hear the sirens;

(h) Public don't act, including the effect of false alarms: the public decide not to act e.g., 24 hours prior, there will be a low certainty about the event (rain) occurring that could trigger the debris flow.

There would be many false alarms and thus a fostering of a low threat perception and decrease in trust of the warnings. The rate of false alarms will depend on the sensor type/data used. Even at the 3-minute stage, people tend to delay acting in order to confirm the threat, which leaves very little time to respond; and

(i) Public not safe fast enough: From international literature, at the 2- or 24-hour stages there is typically a low evacuation rate (if not mandatory and forced) due to many reasons. High rates of evacuation don't usually occur until the 3-minute stage, because of the certainty at that time about the hazard. However, if people leave it too late, e.g., at the 3-minute stage, then flooding may prevent them from evacuating.

7.28. This framework was applied to the 7.26(a)-(c) stages by adopting three scenarios across each, where: (1) is Good, (2) is Middle and (3) is Bad. Varying estimates of the probability of failure – for each of the 9 components set out at 7.27 – were adopted for each scenario (1)-(3). For the Bad scenario, the more pessimistic assumptions and values relating to the probability of failure for each component, were adopted. For the Good scenario, the more optimistic assumptions and values were adopted, whilst the Middle scenario adopted assumptions and values in between those adopted for the Good and Bad scenarios. The middle scenario should therefore be viewed as the most likely performance of the EWS.

7.29. Estimates of the probability of failure of each of the 9 components, for each of the 3 scenarios, were based on: i) the experience of the authors; ii) the relevant literature; and iii) other technical experts with hands on knowledge of such issues. These probabilities of failure were then combined to derive a combined probability of failure for each scenario (1)-(3) under each stage (a)-(c), which were combined, assuming the EWS comprises all three stages.

7.30. These probabilities of failure were then used to estimate the long-term average number of people who could be exposed to the hazard in each event, for scenarios (1)-(3), expressed as a percentage of all the people living on the fan. This was done to indicate the range of likely effectiveness of the EWS.

7.31. Based on the GNS Science (2019) report and information in the previous sections of my evidence in chief, my opinion of the main findings/show stoppers relating to an EWS to manage the risk to people on the fan from debris flow hazards are:

(a) For stages 7.26(a) and (b) (2 – 7, and 24 hours lead time): The ***“public don’t act”*** component dominates the probability of failure of the EWS under scenarios Bad and Middle.

(b) The Good Scenarios all rely on mandatory forced evacuation at least 24- to 2 - hours ahead of a potential debris flow, which may or may not be feasible from logistical or legal perspectives (such perspectives are outside the scope of my technical expertise). In the Good scenario it could be that 50-60% of the people in the hazard zone are still present when the hazard occurs. This is because there is still a residual risk that an alarm is not given, if for example an event is missed, or equipment fails.

(c) The Middle and Bad scenarios rely on people making the decision to act for themselves. If the alert is given with a long lead time (and high uncertainty), then most people won’t leave, and/or would leave it too late to leave, and then will not be able to leave due to e.g., flooding or even smaller debris flows that may not threaten life but impede evacuation. In these scenarios, it could be as high as 90% of the people in the hazard zone are still present when the hazard occurs.

(d) For stage 7.26(c) (3-6 minutes and adopting trip wire sensors) and assuming some people are evacuated during stages 7.26(a) and (b): The ***“sensor”***, the “***public don’t notice***” the alert and ***“public not safe fast enough***” are the components that dominate the probability of failure of the EWS. This is because the trip wire has up to a 25% failure rate and has a very “short fuse” – short fuse means minimal time between the event occurring and the debris impacting the fan, which hampers awareness, decision making and evacuation – so some or many people would not be able to move fast enough to evacuate from the hazard zone, especially if the area is flooded by water preceding the first surge of a debris flow.

(e) In the Good scenario – which assumes most people who are still present in the hazard zone even after being issued with alerts 24 hours and 2 hours prior, based on the rain radar and rain gauge and synoptic data – there is a relatively high probability that the trip wire could fail (up to 25% failure rate based on precedent) to initiate the siren alerting people to evacuate.

(f) In the Good scenario, it could be that 10-20% of the people in the hazard zone are still present when the hazard occurs because either the trip wire fails, the two phases of mandatory warning – in stages 7.26(a) and (b) – still don't get triggered in a subset of cases, and finally, even if the EWS works people may have to run through flood waters to evacuate to safe areas.

(g) In the Middle scenario, the more realistic scenario, it could be that up to 80% of the people in the hazard zone are still present when the hazard occurs, especially if most people cannot run or evacuate due to flooding.

(h) The length of the evacuation route – i.e., shorter distances allowing people to get to safety quicker – is not a significant factor for those in the hazard zone. This is because there is still a residual risk that the sensor fails or the public don’t notice the alert.

(i) Other factors that might prevent people from evacuating at the different stages are e.g.: missed alarms, which will vary for sensor types; and the number of false alarms, which would be higher at the 2 to 24-hour stages, thus fostering a low threat perception and lack of trust in the warning system.

(j) Flooding is a potential impediment for people evacuating. According to the evidence of Mauri McSaveney, flooding occurred several hours prior to the debris from the 2005 debris flow reaching the fan. Flooding may also be accompanied by relatively small volume debris flows, which may not threaten life but could impede evacuation.

7.32. Section 1.7 of the BOPRPS calls for a ‘precautionary approach’ where uncertainty exists. Given the uncertainties associated with a debris flow EWS as listed in my evidence, adopting an EWS as the means to mitigate the risk to people living on the fan is, in my opinion, not aligned with taking a precautionary approach.

8. RISK TOLERABILITY THRESHOLDS

8.1. The risk values presented by Tonkin & Taylor (2013; 2015) are relatively small in terms of the likelihood of a particular individual being killed per year. The Tonkin & Taylor (2013; 2015) reports and those of AGS (2007) make use of terminology which expresses risk as probabilities. I refer to the evidence of Professor Davies who describes the different ways life risk estimates are typically expressed.

8.2. Whether a particular level of life risk is tolerable/acceptable or intolerable/unacceptable is a matter of debate, as this it is not currently quantified in New Zealand legislation, and adopting one threshold value may not suit all applications. It is my opinion that risk tolerability thresholds and levels of control should be set by the decision makers in consultation with those at risk and the technical experts who quantified the risk, and not by the technical experts alone.

8.3. Tonkin & Taylor (2013) noted that the calculated annual individual fatality risk for people on the Awatarariki Fanhead was greater than the 0.01 %/annum level (I refer to the evidence of Mr Hind), which is the level adopted by AGS (2007) as being the boundary between acceptable and unacceptable.

8.4. In 2016, after the Tonkin & Taylor (2013; 2015) debris flow risk assessments had been completed, the natural hazard provisions of the PRPS were published. In the BOPRPS, an annual loss of life risk of greater than 0.01 %/annum is classified as being “high” – refer to BOPRPS Appendix L, Step 5(b ii).

8.5. When considering the acceptability or otherwise of a risk associated with a natural hazard, it is appropriate to compare it to other risks that are likely to be more familiar. I have included some examples in the following sections.

8.6. Example 1: Cliff collapses at Cape Kidnappers, Hawkes Bay and landslides at Fox and Franz Josef Glaciers, compared to the fatality risks faced by people working in various sectors of New Zealand (Figure 5).

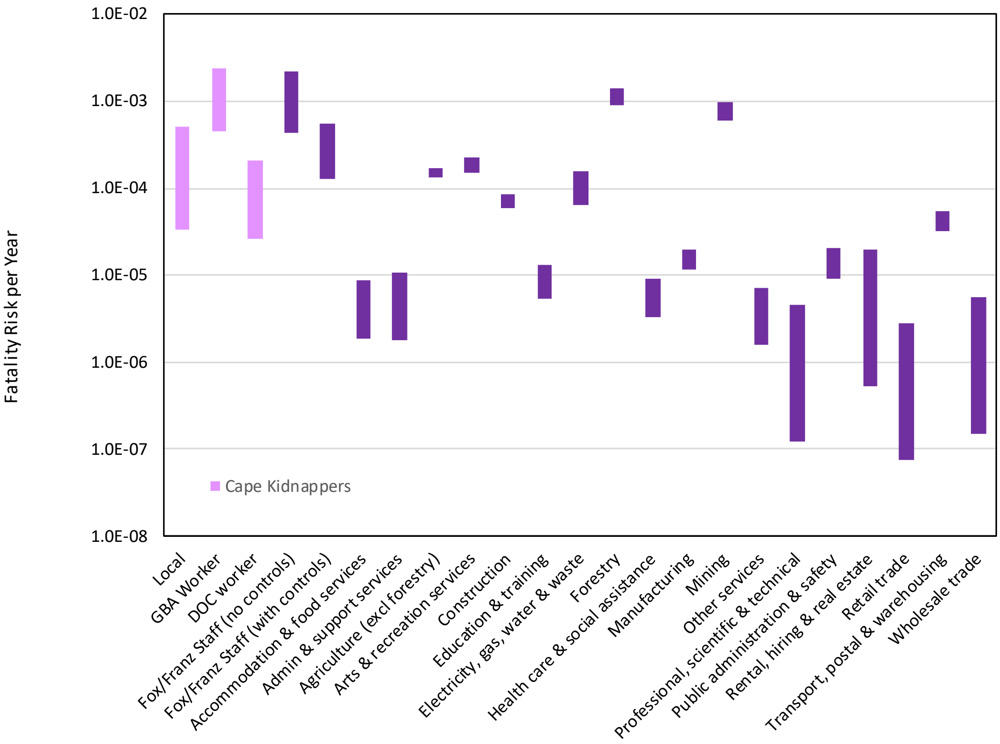
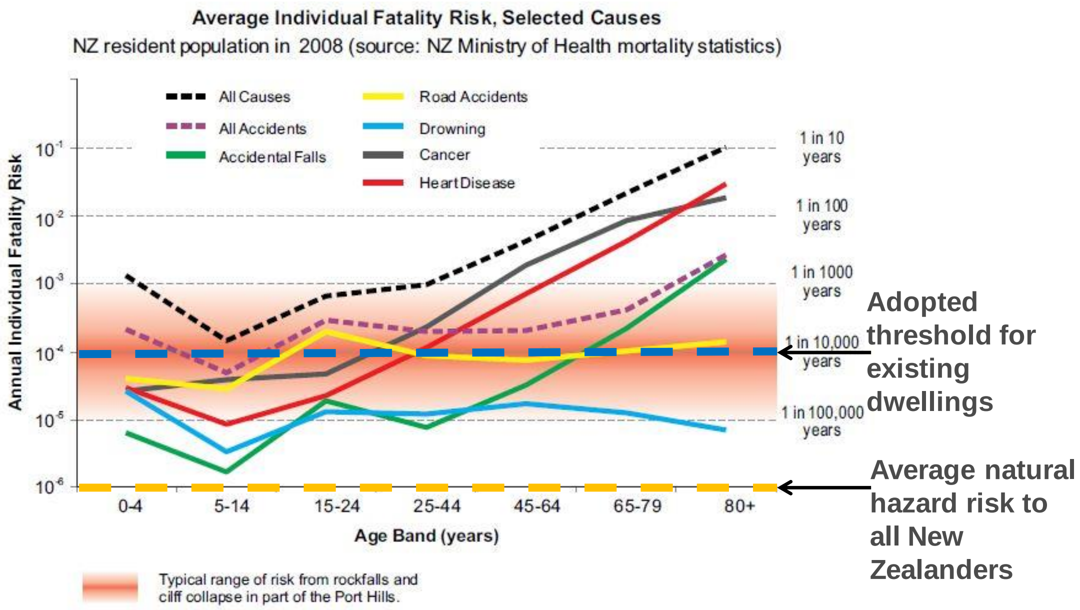


Figure 5. The total fatalities per employee per year for the Department of Conservation (**DOC**) and Gannet Beach Adventures (**GBA**) staff at Cape Kidnappers, and DOC staff at Fox and Franz Josef Glaciers compared with those from other New Zealand industries (2007–2017 Department of Labour data), shown as dark purple. Notes: Statistics on deaths in workplaces (these include all deaths, not just those of people at work, so they tend to overstate the risk to workers themselves) are collected and published by the Department of Labour (DOL, now part of the MBIE). These have been normalised per employee per year (based on numbers of people employed in each sector published by the Ministry of Economic Development, [MED]). Source: Massey et al. (2020).

8.7. DOC decided that the levels of risk at Cape Kidnapers, Fox and Franz Josef Glaciers were too high for their employees (>0.01%) and so have put in a place risk mitigation controls to reduce the risks to being as low as reasonably practical (**ALARP**).

8.8. Example 2: Rockfalls and cliff collapse risk in the Port Hills, Christchurch, and risk thresholds (0.01%) used by the Canterbury Earthquake Recovery Authority (**CERA**) for their Port Hills residential red zone offer (Figure 6).



Adopted threshold for existing dwellings

Average natural hazard risk to all New Zealanders

Figure 6. Risk comparison, showing the typical range of annual individual fatality risk (**AIFR**) from rockfalls and cliff collapses in the Port Hills of Christchurch following the 22 February 2011, earthquake, compared to the risks from other hazards people are typically exposed to. The adopted threshold for dwellings (0.01%), is the level of AIFR adopted by the CERA as part of their residential red zone offer. Dwellings exposing their occupants to AIFR's greater than the threshold were offered compensation to move. Source: Taig and Massey (2012).

8.9. Example 3: Debris flows at Te Rapa (Little Waihi) Lake Taupo, an example where locals made the decision to relocate without the risk being quantified and without government/council intervention.

(a) Several large landslides have occurred on the Waihi Fault scarp above the Hipaua thermal field at the southern end of Lake Taupo in the last c. 230 years which have transformed into very large debris flows in Waimatai Stream (Appendix A of Massey et al., 2009).

(b) A debris flow (possible landslide dam breach) occurred at night in May 1846 with the loss of 64 lives in Te Rapa (Little Waihi) village, including the chief Te Heu Heu. Another occurred on the morning of 20 March 1910 with the loss of only one life as people were alerted and escaped the debris flow (Figures 2 and 3 in Massey et al., 2009). There is also evidence of an earlier failure in about

1780, which apparently buried a pa at the mouth of nearby Omoho Stream with the loss of possibly 150 lives. The source area of the 1780 landslide is uncertain, but it could have been in the Waihi Fault Scarp just north of the 1910 failure scar, or possibly in Omoho Stream ~500-700 m upstream of SH 41 (Hegan et al., 2001).

(c) Following the 1846 debris flow the village was relocated but was still near to the old village site. This new village was again partially hit by debris from the 1910 debris flow. Following the 1910 debris flow the village was relocated again, further north outside the main area inundated by debris from the 1910 debris flow[1].

(d) Based on the frequency of historical failures from Hegan et al. (2001), I have estimated the annual frequency ($P_{(H)}$) of a large, rapid debris flow at Waihi in the future, as being somewhere between 0.009 (0.9% chance per year) to 0.016 (1.6% chance per year) with a mean of 0.013 (1.3%). I have simply assumed that the probability of the Te Rapa village (at its original location) being inundated by debris ($P_{(S:H)}$), is between 0.9 and 1.0, as most of the area of the original village was impacted by debris on the three historical occasions. For the probability of a person being present ($P_{(T:S)}$), I have assumed values of between 0.4 (typical of a person who works during the day and is away on some weekends) to 0.7 (somebody at home most of the time e.g., young children and older people). I have assumed vulnerability values (V) that also consider a level of protection (or not) a dwelling may give to its occupants. I have assumed V-values of 0.7 (assuming the dwelling offers some protection to the occupant from the debris) to 0.2 (the dwelling offers little protection to its occupant).

(e) I have estimated the AIFR using the AGS (2007) equation in Section 7.9 (a) of my evidence, assuming: 1) all the pessimistic input variables; and 2) the less pessimistic variables as set out above. Please note that this is a rudimentary risk analysis as I am only estimating the risk for a large debris flow similar to those in

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[1] https://nzhistory.govt.nz/new-zealands-most-devastating-landslide-at-te-rapa-lake-taupo

1780, 1846 and 1910, and not smaller ones, which could still reach the area of the old village. I have also not assessed the annual frequency of occurrence based on an assessment of the physical reasons that could initiate a failure. Neither have I rigorously assessed the appropriateness of the other variables I have assumed. These variables, are however, similar to those used by Tonkin & Taylor (2013).

(f) Taking these limitations into account, this rudimentary risk analysis gives a range of AIFR of between 0.5% to 0.05% (5×10^{-3} to 5×10^{-4}), for dwellings in the main part of the debris fan (assuming the 1910 extent of debris, as per Massey et al., 2009).

(g) I believe they are useful values to compare against those estimated by Tonkin & Taylor (2013; 2015), as the people who lived in the village at the time decided to move to a safer location, based on their perception of the risk, i.e., they believed the risk to life and/or their wellbeing, from debris flow hazards in the original village location was too risky. These levels of risk are similar to those risk levels estimated by Tonkin & Taylor (2013; 2015) for the Awatarariki Fanhead.

8.10. These examples show that the level of risk adopted by the District Council as being the threshold for tolerability (0.01%) is consistent with the level adopted by others.

9. APPENDIX L BOPRPS AND AGS 2007

9.1. This section of my evidence addresses how the application of appendix L of the BOPRPS to assess risk on the fanhead produces essentially the same result as the application of AGS (2007).

9.2. The AIFR is the annual risk (probability) of loss of life (death) of a person from landslides, refer to Section 7.9 (a) of my evidence for the formula as given by AGS (2007). The AIFR is the product of the probability of the rainfall (or earthquake) event that initiates landslides of a given volume, multiplied by the probability the person is present at the location when the landslide debris reaches/passes, multiplied by the probability that the person is in the path of the debris, multiplied by the probability that the person is killed. This AIFR formula is similar to that used by BOPRPS in the BOPRPS Appendix L, both are used to derive the AIFR.

9.3. The BOPRPS and AGS (2007) methods are comparable, but they do differ based on their calculation routes. The formula used in BOPRPS, Appendix L is: AIFR = (D x P)/N, which I now refer to as Equation 1. Where: D = number of anticipated (modelled) deaths from the event if it occurs; N = population (maximum number of people present within the hazard assessment area at any point in time over a 24 hour period), which is the number of people exposed to the hazard; P = the computed annual exceedance probability, which is essentially the annual frequency of the event that could kill the given number of people.

9.4. The AIFR calculated using Equation 1, is the annual probability of a person being killed by the given event if it were to occur. The AIFR formula given in my evidence (and in the evidence of Mr Hind), which comes from the AGS (2007c) and JTC-1 (Fell et al., 2008) guidelines is given by the formula: AIFR = $P_{(H)}$ x $P_{(S:H)}$ x $P_{(T:S)}$ x V, which is the same formula given in Section 7.9 (a), which I refer to here as Equation 2.

9.5. Where: $P_{(H)}$ annual frequency of the event occurring; $P_{(S:H)}$ is probability of spatial impact – i.e. the probability of a given location being impacted by landslide debris; $P_{(T:S)}$ is the probability of a person (the person most at risk) being present and hit by debris at the given location and is nothing to do with the number of people exposed; V is the vulnerability of the person if present and hit by debris.

9.6. If we were to remove the $P_{(H)}$ part in Equation 2, the result would be the probability of killing an individual if the given event occurred. If we were to multiply this by the number of people exposed to the same level (magnitude of hazard) (N in Equation 1) then the result would be the number of anticipated deaths from the event if it occurs (D in Equation 1). If we were to multiply this result by ($P_{(H)}$ in Equation 2; or P in Equation 1), the result would be the same as that from Equation 1. Whether or not the two formulas give a similar result would depend on how D in Equation 1 was calculated. If they were calculated using the same inputs, then the results would be the same. I have demonstrated this in a simple spread sheet that I put together which is attached as **Appendix 2** to my evidence.

9.7. It should be noted that:

(a) D (Equation 1) will also vary spatially at the local scale, for example debris from larger landslides will travel further than smaller ones and as a result, the exposure and vulnerability of a person exposed may also change. Such local-scale spatial variations are not captured in Equation 1 but are by Equation 2.

(b) To estimate the true annual individual fatality risk (Equation 2), requires an estimate of the time the person most at risk is within the hazard area.

(c) AGS (2007) points out that the AIFR should also be calculated for the range of events (spanning the range of magnitude from small to large and severity), which could feasibly occur in the area of interest, and then summed. Where the true AIFR (all events) is the sum of the AIFR calculated for each representative event. This is not the case for the BOPRPS, which adopts a single event as the basis of the risk calculation.

9.8. In summary, the results from the two equations can give similar values if similar inputs are used. Equation 2, however, does not consider the number of people who may be present and exposed to the hazard, it calculates the annual individual fatality risk for the person most exposed, which is the person who spends the most time in the hazard area. Equation 1, calculates the annual frequency of a single person being killed as a function of the total population exposed to the hazard, based on estimating the total number of people who may be killed by the given hazard, assuming an individual event. Equation 1 therefore, is not really a true calculation of the AIFR as set out in Equation 2 and the AGS (2007c) guidelines. Thus, the results could differ.

10. VARIABILITY OF DEBRIS FLOWS

10.1. I acknowledge the evidence of Mr Hind, the findings of the reports Tonkin & Taylor (2013; 2015), and the evidence of Dr McSaveney and Professor Davies. In my opinion, people present at the time of the debris flow were very lucky not to have been killed or seriously injured. This may have been for several reasons, i.e.: the debris height and velocities meant that the debris could not penetrate all homes that were hit; of those homes hit and penetrated by debris, people may not have been present, or if they were they managed to get out of the way; and/or people were awake and aware of the situation and thus could take evasive actions? I point to a recent example at Howden Hut[2], on the Routeburn track in Fiordland, which was hit by a debris flow on the 4th February 2020. Two of the occupants of the hut were injured by the impact of the debris on the hut. However, most of the debris was prevented from hitting and entering the hut, as logs and other vegetation in the debris formed a natural dam protecting the hut. I carried out the GeoNet landslide response to this incident and interviewed the hut warden and the two people who were injured.

10.2. From what they told me and what I saw on the ground, the hut only received a "glancing blow", but debris heights were in the order of 1 to 1.5 m (against the hut) and there were several large trees that were entrained in the debris, which created a natural dam protecting the corner of the hut from being hit by more debris in the flow. On the other flank of the debris flow trail there was a similar structure (a store constructed in a similar way to the hut), it also had 1 to 1.5 m of debris against it (similar to that of the hut), but here there was no natural dam effect, and the debris entered the structure, damaging it and filling it up. The toilet block, which took the full impact from the debris was in the middle of the debris flow trail, it was destroyed and bits of it carried many tens of meters down slope. The toilet block also appeared to be of a "lighter" construction to that of the hut and store. I believe these observations highlight the importance of the type of building, where it is positioned relative to the debris flow path and where it is hit by debris, on whether debris is able to penetrate a structure. In my opinion, the people in Howden hut were lucky to escape with only minor injuries.

10.3. In other cases, people have not been lucky. For example, several debris flows occurred in Southern California in January 2018, northwest of Los Angeles in Santa Barbara County. These debris flows resulted in 23 deaths and injured approximately 167 people[3]. These examples show that there is a certain amount of variability with regards to the impacts from debris flows on dwellings and the people in them.

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[2] https://www.nzherald.co.nz/nz/news/article.cfm?c_id=1&objectid=12305926

[3] https://pubs.geoscienceworld.org/gsa/geosphere/article/15/4/1140/571496/Inundation-flow-dynamics-and-damage-in-the-9

10.4. The point I want to make is that each debris flow is different, and there is a certain amount of variability (randomness) from one to the next, and also between debris-flow pulses during an event, which makes risk analysis of them inexact at best, hence the appropriate range in the risk estimates given by Mr Hind in his evidence.

11. RESPONSE TO APPEAL

11.1. I have reviewed the Awatarariki Residents Society appeal and comment as follows on the issues that relate to my expertise.

11.2. As a starting point, I refer to the evidence of Mr Hind, which relates to the non- effectiveness of engineering works to reduce the risk. Even if such works were feasible, based on the work by GNS (2019) and Davies (2017), it is my opinion that a debris flow EWS is unlikely to allow all people present in the hazard zone at the time that a debris flow event is initiated, to evacuate to safe areas, irrespective of where they are on it.

11.3. Paragraph 17:

(a) I am unsure as to which inputs are incorrect and why, as they are not listed. I would like to know what alternative values should be used and on what basis/evidence should they be used? If inappropriate values are used in the risk analysis, it could lead to carelessness, which is the opposite of precautionary. I refer to the evidence of Mr Hind, who states in Section 1.11, “The adoption of unconservative values as input into the calculations was unable to bring the estimated Loss of Life Risk for the affected properties to less than 0.01% per annum, let alone 0.001%.” This indicates that even if less conservative values were adopted in the risk assessment, they would have little impact on reducing the risk to tolerable levels.

(b) With regards to the scale of the risk assessment, and whether “inner property features” should be taken into account, I refer to the Evidence of Mr Batchelar.

(c) With regards to the effectiveness of an EWS, I refer to my Evidence, where I conclude that: an EWS is unlikely to allow a potential people present in the hazard zone at the time that a debris flow event is initiated, to evacuate to safe areas, irrespective of where they are on the fan.

11.4. Paragraph 20:

(a) I am unsure as to what the question or issue is that is referred to in this paragraph. Based on my understanding, I refer to the evidence of Mr Hind, Professor Davies and Dr Phillips with regards to the appropriateness, or not in this case, of hazard mitigation works to reduce the risk, which also include options other than engineering structures. I agree with Mr Hind, Professor Davies and Dr Phillips that mitigation works have been explored and found not to be viable.

11.5. Paragraph 24 (c):

(a) With regards to the effectiveness of an EWS, I refer to my Conclusions below.

12. CONCLUSIONS

12.1. Based on the information presented in my evidence in chief and the key documents I have used, or referred to, it is my opinion that a multi-staged EWS – based on the potential design and effectiveness framework – adopting any of the scenarios contained in GNS (2019), is unlikely to allow all potential people present in the hazard zone at the time that a debris flow event is initiated (i.e., the trip wires cut), to evacuate to safe areas, irrespective of where they are on the fan. Therefore, people who don’t notice the alert, do not/or cannot evacuate would continue to be exposed to the risk levels given in Tonkin & Taylor (2015), depending on their location on the fan.

12.2. Given the uncertainties associated with a debris flow EWS as listed in my evidence, adopting an EWS as the means to mitigate the risk to people living on the fan is, in my opinion, not aligned with taking a precautionary approach.

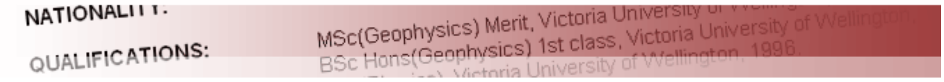
12.3. The BOPRPS and AGS (2007) methods to calculate the annual individual fatality risk are comparable, but they do differ based on their calculation routes. The results from the two methods can give similar values if similar inputs are used.

12.4. However, AGS (2007) does not consider the number of people who may be present and exposed to the hazard, it calculates the annual individual fatality risk for the person most exposed. The BOPRPS calculates the annual frequency of a single person being killed as a function of the total population exposed to the hazard, based on estimating the total number of people who may be killed by the given hazard.

Dr Chris Massey

10 August 2020

APPENDIX 1 – CV



View Profile > Chris Massey

STAFF PROFILE
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Staff Profile menu
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Created 10 Jul 2006 by Adriana Heinzen
Modified 30 Aug 2019 by Chris Massey

General Information

Name	**Chris Massey**
Position	**Engineering Geologist**
Division	**Science**
Dept	**Surface Geosciences**
Date Of Birth	**Not Specified**
Personal Website(s)	http://www.gns.cri.nz/who/staff/2205.html
Short CV (optional)	Dr Chris Massey is an engineering geologist with more than 23 years of consultancy and research experience in the investigation and analysis of complex geological and geotechnical data for landslide and slope stability including landslide monitoring, foundation design, underground/surface rock support and groundwater problems. He has applied these skills to geohazard and risk assessments, oil and gas pipelines, highway, railway, mining engineering and town planning projects in Africa, the Himalayas, Europe, South East and Central Asia and Australasia. Chris has a degree in geology from Leeds University, UK; a masters in Engineering Geology from Imperial College, London, UK; and a PhD in engineering geology from Durham Uni.

A summary of a person's experience for commercial purposes. To be used in the proposal documents for EOI, RFP, tenders.

Education and Qualifications

Education and Academic Qualifications

Date	Organisation	Qualification
2010	Durham University	PhD(Engineering Geology)
1999	Imperial College, London (UK)	MSc(DIC Engineering Geology)
1996	Leeds University, UK	BSc(Hons, Geology)

Year undergrad degree conferred 1996

Other Training

Date	Description
July 2019	Mountain Skills
April 2019	Itasca 3DEC Training
March 2019	4WD Course
May 2014	Itasca UDEC course (3days) in Melbourne
March 2013	First Aid Certificate

Languages

Language	Proficiency
English	Native speaker

Honours and Distinctions

Honours, Distinctions excluding conference invitations
Invitations to 'by invitation only' conferences should also be entered here

Date	Description
2019	Oregon State University: Associate faculty position
2017	Ministry of Business, Innovation and Employment: Won an Endeavor Programme Grant $9M
2017	NSF: Invited Steering Committee Member for the RAPID center
2015	International Society for Rock Mechanics: Invited Keynote Speaker
2015	Ministry of Business, Innovation and Employment: Invited Expert Panel Member
2015	International Association of Engineering Geology: Member JTC-1 Slopes and landslides
2014	National Science Foundation: Invited Expert Panel Member
2014	International Society for Soil Mechanics and Geotechnical Engineering: Invited Expert Panel Member
2014	New Zealand Society for Earthquake Engineering: Commendation
2014	International Society for Soil Mechanics and Geotechnical Engineering: Joint Technical Committe
2010	International Consortium on Landslides: Best Paper Award for 2010
2006	Geological Society of Great Britain: Chartered Geologist

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Conferences Attended
Includes keynote and session chairman invitations

Role	Date	Conference
Keynote speaker	2018	5th International Symposium on Mega Earthquake Induced Geo-disasters and Long Term Effects (MEGE 2018) (Chengdu, China)
Keynote speaker	2018	South Island CDEM Conference Brian FM (Blenheim, New Zealand)
Keynote speaker	2018	New Zealand Society of Earthquake Engineering Annual Meeting (Auckland, New Zealand)

Presenter	2018	XIII IAEG CONGRESS Engineering Geology for a Sustainable World (San Fransisco, United States)
Presenter	2017	PATA DAYS 2017: 8th International Workshop on Paleoseismology, Active Tectonics and Archeoseismology (Blenheim, New Zealand)
Presenter	2016	AGU Fall Meeting (San Francisco, United States)
Keynote speaker	2016	International Symposium on Landslides (Naples, Italy)
Presenter	2015	International Conference on Earthquake Geotechnical Engineering, (Christchurch, New Zealand)
Presenter	2015	AGU 2015 (San Fransisco, United States)
Keynote speaker	2015	International Society for Rock Mechanics, 2015 Congress (Montreal, Canada)
Presenter	2014	AGU Fall meeting (San Francisco, United States)
Presenter	2014	International Association of Engineering Geologists, XII Congress (Torino, Italy)
Keynote speaker	2013	Hanging by a thread. 19th Symposium of the New Zealand Geotechnical Society. 20-23 November 2013 (Queenstown, New Zealand)
Convener	2013	World Landslide Forum 3 (Beijing, China)
Presenter	2013	The international Symposium in commemoration of the 5th Anniversary of the 2008 Wenchuan Earthquake (Chengdu, China)
Presenter	2010	GeoNZ 2010: Geoscience Society of New Zealand. Auckland, 21-24 November 2010 (Auckland, New Zealand)
Convener	2010	11th Congress of IAEG (Auckland, New Zealand)
Presenter	2008	The First World Landslide Forum (Tokyo, Japan)
Presenter	2007	10th Australia New Zealand Conference on Geomechanics (Brisbane, Australia)
Presenter	2006	International Association of Engineering Geologists 10th International Congress (Nottingham, United Kingdom)

Professional Memberships

Professional Memberships
Membership of professional societies, institutions, committees

From	To	
2014	Present	International Society for Soil Mechanics and Geotechnical Engineering: Joint Technical Committee (JTC-1) Natural slopes and landslides: Technical panel member
2014	Present	Ministry of Business, Innovation and Employment: US-NZ Joint Commission Meeting on Science.: leader of Activity 5 Landslide threat assessment
2013	Present	NZ Geotechnical Society : Member
2006	Present	Chartered Geologist: Geological Society of London, UK: Member
2000	Present	Fellow of the Geological Society (FGS): Geological Society of London: Fellow

Present Employment

Employer	**Institute of Geological and Nuclear Sciences**
Position	**Engineering Geologist**
Start date of current position	**20 February 2006**
Work address	**1 Fairway Drive** **Avalon** **Lower Hutt 5010**
Current duties	**Dr Massey is responsible for managing many of the engineering geological consultancy projects carried out by GNS Science, the most recent being landslide and rockfall risk assessments for the Department of Conservation and Franz Josef Glacier Guides for staff and visitors to the Fox and Franz Josef Glacier Valleys. Chris also conceived and led an assessment of the landslide hazards and route resilience of the main road and rail corridors situated on the Kaikoura coast that were badly affected by the 2016 earthquake. Chris also manages the landslide research for GNS Science. This involves setting the research strategy and goals and building relationships with other partners and collaborators in New Zealand and overseas. Chris successfully led a Ministry of Business, Innovation and Employment (MBIE)-funded 4-year project investigating the impact of anthropogenic slopes in Wellington, which was completed in 2019. He is currently leading a 5-year MBIE funded Endeavor Programme investigating earthquake induced landscape dynamics. Chris is now leading GeoNet projects to opperationalise the results from these and other research projects carried out by the engineering geology team, in the form of near-real time landslide forecast tools for New Zealand. Chris has been pioneering landsliding modelling and quantitative landslide risk assessment methods and practices in New Zealand since the 2010/11 Canterbury Earthquakes, and he has provided expert witness advice on such matters in Environment Court on the behalf of local and central government agencies.**

Consultancy work during current employment

From	To	
Jul 2019	Present	**Natural hazard risk assessment framework**. Client: DOC. Position: Principle Investigator. DOC has asked us to create a standardised methodology for quantifying risk from the geological hazards of landslide, volcano and tsunami. The method will be based on international best practice and standards, while providing a standardised template for all risk assessments for DOC sites. This methodology will then be distributed to and used by all geotechnical practitioners undertaking risk assessments for DOC.
Jan 2019	Present	**Expert witness: Awatarariki Plan Changes (Matata)**. Client: Whakatane District Council. Position: Expert witness. In 2005, the township of Matata on the western side of the Rangitaiki plains was impacted by several debris flows. Time and effort has gone into understanding the debris flow hazard to the town and how to best manage the associated risks. A plan to manage the risks has been developed. One of the features of the current plan is a plan change hearing to rezone some of the affected properties from land zoned as residential to land zoned as reserve as a means to reduce the risk.My role is to provide the Council with expert advice on landslide risk assessment method and practice and the efficacy of landslide early warning systems as one potential tool to manage the risk to people living on the fan from debris flow hazards.
Jul 2019	Present	**GeoNet: Earthquake- and Rainfall-induced landslide forecast tools**. Client: EQC. Position: Principle Investigator and leader. The aims of the overall project are to allow the GeoNet landslide duty officers (the end users) to: 1) Rapidly identify whether an earthquake or a rain event can generate landslides and the severity of landsliding; and 2) Rapidly generate advisory information such as a spatial representation (map and table) of where landslides could occur in a significant earthquake or rainfall event, which can be used to help target response activities.
Jul 2015	Present	**It's Our Fault**. Client: EQC, Wellington City and Greater Wellington Regional Council. Position: Principle Investigator. In 2006, the It's Our Fault research programme was established to provide a comprehensive study of Wellington's earthquake risk. For ten years, the programme examined the likelihood of major earthquakes, the effects of ground shaking, and looked at how earthquakes will affect people and the built environment. As part of this programme, I lead the

		research on learning about the stability of Wellington slopes under earthquake shaking and heavy rainfall. This involves working with the stakeholders to provide the science to underpin policy development to reduce the impact of landslides in the region.
Aug 2019	Aug 2019	**Expert witness: Landslide and rockfall hazards affecting the proposed gondola expansion in Queenstown**. Client: Otago Regional Council. Position: Expert witness. I was asked by the Otago Regional Council (ORC) to give expert evidence on whether the proposed mitigation measures to address slope stability hazards (rockfall and debris flow) affecting the proposed car park and terminus buildings for the Gondola facilities in Queenstown, can be managed appropriately, and that the life risk from such hazards, has been reduced to tolerable levels.
Jun 2017	Aug 2019	**Predicting seismic-induced rockfall hazard for targeted site mitigation**. Client: Oregon Dep. Transport and US Federal Highway Administration. Position: Principle Investigator. Oregon's highways traverse particularly unstable terrain throughout much of the state, resulting in maintenance, system unreliability due to frequent closures and restrictions, and safety hazards due to landslides and rockfalls. Seismic activity amplifies these negative economic and community impacts of rockfalls. This research develops methods to predict seismic rockfall hazard areas by integrating two recent complementary research products (1) a lidar database of terrestrial surveys of rock slopes that span multiple earthquake events in Canterbury, New Zealand, and (2) a streamlined lidar-based rockfall hazard assessment method called RAI (Rockfall Activity Index). It is intended that the use of the knowledge and tools developed by this project will help transportation planners prioritize and consider which sites may be most critical in the aftermath of an earthquake event as well as estimate increased maintenance needs for debris removal.
Jul 2010	Jun 2019	**Strategic Science Investment Fund: Geological hazards theme**. Client: MBIE. Position: Principle Investigator and leader. Landslide hazards programme leader. Responsible for managing the landslide research carried out by the engineering geological team, and others, under the Landslide Hazard Programme.
Apr 2018	Mar 2019	**Landslide hazard and risk assessment for the Fox and Franz Josef Glacier valleys**. Client: DOC. Position: Project Leader. The objectives of this study were: 1) to inform DOC of the spatial and temporal variation of risk and of the factors most contributing to landslide risk in the two glacier valleys; and 2) use the information from the quantitative landslide risk assessments to provide advice to help DOC to manage visitor and staff safety so that the risk is as low as reasonably practicable. The risk assessment quantifies the risk, in this case the loss of life, to visitors and DOC staff from landslide hazards in the Fox and Franz Josef Glacier valley study areas.
Oct 2016	Dec 2018	**SLIDE (Wellington): Vulnerability of dwellings to landslides (Project No. 16/SP740)**. Client: EQC, Wellington City and Greater Wellington Regional Council. Position: Principle Investigator and leader. The aim of this research project was to quantify the vulnerability of people and dwellings to the types of landslide hazards affecting Wellington and other parts of New Zealand. This research comprised two main objectives: 1. Investigate what landslide intensity metric(s) best correlate with the different consequences such as economic loss and/or physical damage state; and 2. Develop appropriate correlations/relationships between the preferred hazard intensity metric(s) and consequence type. These relationships can now be used for landslide loss and risk assessments all over New Zealand.
Jun 2017	Jan 2018	**Pilot study for assessing landslide hazards along the road and rail corridors**. Client: The North Canterbury Infrastructure Recovery Alliance (NCTIR). Position: Project Leader. This work quantified the the hazard posed by landslides in two pilot study areas along a section of State Highway 1 (SH1) and the South Island Main Trunk (SIMT) Railway along the Kaikoura coastline, which were badly affected from landslides triggered by the MW 7.8 14 November 2016 Kaikoura earthquake. The objectives of this study were to inform NCTIR of the estimated forecast frequency and volume of landslides that could be generated in the two pilot study areas from earthquake and non-earthquake (e.g., rain) triggering events. The results from this work fed into the NCTIR "Resilience Study"
Jul 2016	Aug 2017	**Franz Josef Guiding Area Landslide Risk Assessment**. Client: Franz Josef Glacier Guides. Position: Project Leader. The objectives of this study were to inform Franz Josef Glacier Guides of the spatial variation of risk and of the factors most contributing to risk to help them with managing their guiding trips on the glacier to be as safe as possible i.e., as low as reasonably practical (ALARP). The risk assessment quantifies the risk, in this case the loss of life, to Franz Josef Glacier Guides staff and clients from landslide hazards in their two study areas
Feb 2006	Jun 2016	**GeoNet – Real-time Landslide Monitoring Project**. Client: Earthquake Commission. Position: Principle Investigator and leader. Responsible for setting up of a landslide monitoring programme designed to safeguard key facilities, as well as to provide data to underpin near real-time landslide warning systems for at-risk facilities (e.g., the North Island Main Trunk Railway) and residential properties and communities (e.g., in the Port Hills of Christchurch). Dr Massey is involved with all aspects of this project, from the initial conceptual planning, procurement and installation of equipment through to setting the event based responses.
Jan 2016	May 2016	**Estimates of Probable Maximum Loss for the EQC Portfolio**. Client: Aon Benfield and EQC. Position: Associate investigator. This project modeled the Probable Maximum Loss (PML) estimates to the EQC portfolio for four major scenarios in order to constrain an upper limit on PML to the EQC. These scenarios included the 'Mt Ruaumoko' volcanic eruption in Auckland, an earthquake sequence consisting of 5 ~M7 earthquakes occurring over 13 years, a M7.5 Wellington Fault earthquake and a M9.0 earthquake and tsunami on the Hikurangi megathrust.
Oct 2014	Feb 2016	**Expert witness: Christchurch Replacement District Plan**. Client: Christchurch City Council and the Crown. Position: Expert witness. I was engaged by the Council and the Crown to give evidence in relation to rockfall, cliff collapse and mass movement (landslide) risk assessments in the Port Hills carried out by GNS Science for Council and the Crown. This evidence relates to the provisions regarding natural hazards (Slope Hazard) in Proposal 5 (Natural Hazards) of the proposed Replacement District Plan.
Feb 2011	Feb 2016	**Assessing the rockfall and landslide risk to residential homes in the Port Hills of Christchurch, New Zealand, following the 2010/2011 Canterbury earthquake sequence**. Client: Christchurch City Council and CERA. Position: Project Leader. Responsible for developing the risk assessment methodology, data collection, assessment and analysis, managing the international peer review process and disseminating the results. This work was used to underpin the Crown's Residential Red Zone offer and Christchurch City Councils Replacement District Plan.
Jun 2015	Dec 2015	**Examination of the potential effects of abutment topographic amplification at the Patea Dam**. Client: Trustpower Ltd. Position: Principle Investigator and leader. An examination of the potential effects of topographic amplification on the recommended free field Peak Ground Acceleration estimates, particularly on the left abutment where the spillway and other facilities are located.
Jul 2012	Jun 2015	**Quantifying seismically unstable slopes in Christchurch and Wellington, New Zealand**. Client: New Zealand Natural Hazards Research Platform. Position: Principle Investigator. Responsible for managing the team, and carrying out research into the amplification relationships between the near surface geology, topography and seismic inputs.
Oct 2014	Jun 2015	**Rockfall Protection Design Guide**. Client: Ministry of Business Innovation and

		Employment. Position: Review panelist. To provides technical guidance for the design of passive rockfall protection structures (RPS) that act to reduce the effects of falling rock on people and /or infrastructure. The guidance is intended to inform designers on the methodology for undertaking design of RPS within the context of the NZ Building Code.
Dec 2011	Aug 2012	**Landslide stability assessment for a Uranium mine in Malawi, Africa**. Client: Paladin Energy Ltd. Position: Principle Investigator. Responsible for assessing the stability of a large reactivated landslide affecting a mine processing plant under various scenarios including earthquake and rainfall conditions, and design of mitigation works comprising earth and drainage works.
Jul 2011	Aug 2011	**Emergency response and reinstatement of the Maui gas pipeline following a landslide-induced rupture in 2011**. Client: Vector (Gas) Ltd.. Position: Principle Investigator and leader. Responsible for managing the GNS Science response, and providing the client with expert advice concerning geotechnical issues relating to the rupture of the Oaonui-Huntly pipeline (the Maui pipeline).
Feb 2006	Feb 2011	**Assessment of landslide and other erosion hazards along the Maui Gas Pipeline, New Zealand. Client: Vector Ltd**. Client: Vector (Gas) Ltd. Position: Principle Investigator and leader. Responsible for assessing the landslide and other erosion hazards along the pipeline, including detailed investigation, assessment and analysis of specific landslides affecting the pipeline.
Feb 2006	Feb 2011	**Slow moving landslides**. Client: Foundation for Research Science and Technology & EQC. Position: Principle Investigator and leader. The primary aim of this research was to study the relationship between landslide motion and its causes, with reference to large (>1M m3), deep-seated (slip plane typically > 10 m below ground level), reactivated translational slides, that typically move at rates varying from extremely slow to very slow.
Feb 2009	Feb 2010	**Geotechnical assessment of the Utiku landslide, New Zealand**. Client: Kiwi Rail. Position: Principle Investigator and leader. Responsible for the investigation and assessment of the Utiku landslide (a large slow moving reactivated landslides), affecting the North Island Main Trunk (NIMT) railway line.
Feb 2006	Jul 2006	**Pre-feasibility information relating to Mokihinui River hydro development**. Client: Meridian Energy. Position: Engineering Geologist. Investigate the geological and geotechnical conditions present at the proposed dam sites. Including field mapping, logging of drillhole cores and assessment of landslide hazards.
Feb 2006	Jun 2006	**Maraetai I Power Station: Review of Geological and Foundation data**. Client: Mighty River Power. Position: Engineering Geologist. Review and document information on the geological materials forming the power station foundations. Compile and summarise the geological records for the foundations of the power station structure. Prepare a geological and geotechnical model for the main power station structures.

Present Research / Professional Speciality

Present research/professional speciality

Present research/professional speciality: Geology

Fields of Special Competence

Category	**Skill**
Geology	Landslide Hazard Assessment
Geology	Engineering Geology
Geology	Engineering Geomorphology
Geology	Landslide Processes
Geology	Earthquake-induced landslide estimates
Geology	Rock mechanics
Geophysics	Geohazard assessments
Geophysics	Landslide Modelling
Geophysics	Rock fall analysis and design
Geophysics	Rock and soil slope analysis
Geophysics	Landslide monitoring
Business Development	Hazards Warning Systems
Business Development	Numerical Modelling
Business Development	Risk Assessment
Business Development	Hazard Assessment
Geomorphology	Geological and geomorphological mapping

Present Specialisation
You can choose one Skill from your Fields of Special Competence

Present Specialisation: Engineering Geology

International Linkages

Citizenship

United Kingdom

International Work

Australia, Bhutan, China, Ethiopia, Gibraltar, Hong Kong, Malawi, Nepal, New Zealand, Russian Federation, Tajikistan, United Kingdom, United States

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Work History (Professional Positions Held)

Employment Record

2005 - 2006 **Senior Engineering Geologist/Geotechnical Engineer**

Employer: Connell Wagner Ltd, Auckland
New Zealand

Description of duties:

Responsible for planning and leading geotechnical investigations and carrying out detailed design for various projects in the Auckland region of New

Zealand. Mr Massey was Involved with a number of projects ranging from: geohazard assessments (landslides and rockfalls) for a new road through unstable terrain; ground investigation and foundation design for numerous commercial properties; and the detailed investigation, analysis and design of retaining structures for the Busway project in Auckland.

Consultancy work during employment

From	To	
Aug 2005	Jan 2006	**Pacific Palms – Stage 3 Design**. Client: Pacific Hibiscus Ltd.. Position: null. From review of aerial photographs and ground truthing Mr Massey identified several large, active and potentially deep-seated landslides. Through geomorphological mapping he delineated these features on the ground. He then planned and reviewed the results from the ground investigation to determine the depth of the landslides and nature of the local groundwater regime as well as producing an engineering geological model of the site.
Sep 2005	Jan 2006	**Northern Busway, Stage 1C, Auckland, New Zealand**. Client: Transit New Zealand. Position: Geotechnical Engineer. The project involved the widening of an existing arterial highway heading north out of Auckland, New Zealand and comprised the addition of two lanes to the existing four-lane highway. Mr Massey was responsible for carrying out the detailed design of several of the retaining walls, utilising both gabion and reinforced soil wall types. The walls were designed using Maccaferri software and checked using SlopeW (geotechnical slope stability software).
Aug 2005	Oct 2005	**Te Toka Road Upgrading Project**. Client: Providence Developments Ltd. Position: Engineering Geologist. Upgrade of existing gravel road to a sealed road through an area of steep terrain located in North Island, New Zealand. From a review of aerial photographs and ground truthing I identified several sections of the existing gravel road that had been severely affected by landslides and rock fall. I delineated the main landslides and carried out back analysis of the critical landslides as well as deriving the engineering geological models for the site.

2002 - 2005 **Engineering Geologist/Geotechnical Engineer**

Employer: Scott Wilson
United Kingdom

Description of duties:

Whilst with Scott Wilson Mr Massey worked for their International Division, and was primarily involved with development projects centred in many different countries around the world. He worked on landslide hazard assessments in Bhutan and Nepal, road rehabilitation in Ethiopia and highway upgrading in Tajikistan, to name but a few. During his time at Scott Wilson, Mr Massey was involved with all aspects of geotechnical engineering/engineering geology. Responsible for supervising geotechnical investigations for highways, pipelines and residential/commercial properties, and was responsible for the design and construction supervision of landslide and rock fall mitigation measures, rock/soil slopes, earthworks, bridge foundations, retaining walls and underground rock support. Whilst working on these projects, Mr Massey has developed detailed knowledge and experience of using specialist geotechnical software including slope stability, rockfall and geographical information systems (GIS).

Consultancy work during employment

From	To	
Aug 2004	Aug 2005	**Geotechnical Assessment of the Geohazards Affecting the construction of an Oil and Gas Pipeline, Sakhalin Island, Russia**. Client: Sakhalin Energy (SEIC). Position: Eng Geologist/Geotechnical Engineer. The project involved the identification of critical sections of the pipeline that where potentially at risk from landslides. Mr Massey was responsible for carrying out the aerial photograph interpretation of the different ground conditions along the pipeline route in order to identify the locations of existing landslides that could pose problems for the long-term sustainability of the pipeline.
Jul 2004	Aug 2005	**Design of Rock Fall Mitigation Measures, Both Worlds, Gibraltar**. Client: ABCO International. Position: Geotechnical Engineer. Scott Wilson were asked to undertake a study of the rockfalls that could potentially impact a proposed residential development situated at Sandy Bay on the eastern coast of Gibraltar at the toe of the Famous Rock of Gibraltar in the Mediterranean.
Jan 2004	Feb 2005	**Detailed Hydrogeological Investigation and Geohazard Assessment for the Catchment Above Po Shan Mansions, Mid Levels, Hong Kong**. Client: Geotechnical Engineering Office, Hong Kong SAR. Position: Engineering Geologist. Scott Wilson were asked to carry out a hydrogeological study and geohazard assessment for the catchment immediately upslope of Po Shan Mansions. Mr Massey carried out the API, field mapping and supervised the ground investigation, which enabled him to develop the engineering geological models for the site and determine the likely surface/groundwater flow paths that lead to the development of the cracks.
Nov 2004	Jan 2005	**Geotechnical Assistance for the Rural Access Project, Bhutan**. Client: SNV, World Bank and Department of Roads, Bhutan. Position: Eng Geologist/Geotechnical Engineer. The project reviewed the stability of several roads that had either been constructed or were about to be constructed under the Rural Access Project (RAP) using environmentally friendly road construction (EFRC) techniques.
May 2003	Sep 2004	**Combe Down Stone Mines Project (UK) – Emergency Works Design and Supervision**. Client: English Partnerships, UK Government. Position: null. Scott Wilson Mining was awarded the design and supervision of the emergency works for the Combe Down Stone Mines in March 2003. The objectives of the emergency works were to stabilise the disused mine workings located beneath the village of Combe Down, UK. Through underground mapping, rock mass classification and GIS (ArcMap□) analysis Mr Massey was able to develop a methodology to identify areas of potentially high hazard within the mines.
Nov 2003	Jul 2004	**Hirna to Kalubi, Road Upgrading Project, Ethiopia**. Client: Ethiopian Roads Authority and World Bank. Position: Eng Geologist/Geotechnical Engineer. Following a rainstorm in April 2003 several sections of the newly constructed road between Hirna and Kalubi were completely destroyed by landslides, most of which were triggered by heavy rainfall during the wet season between June to August 2003. Following these events Scott Wilson were asked to carry out the investigation and design of the mitigation measures within the landslide areas.
Oct 2003	Nov 2003	**Shagon – Zigar, Road Upgrading Project, Tajikistan**. Client: Islamic Development Bank. Position: Eng Geologist/Geotechnical Engineer. The Shagon-Zigar road is located in the foothills of the Pamir Mountains in the southern part of Tajikistan along the border with Afghanistan. The road corridor is 34 km long and runs along the northern bank of the Pyenj River, which forms the Tajik/Afghan border. Through detailed engineering geological mapping of the rock slopes along the road alignment, Mr Massey was able to identify the dominant structural geological features and geomorphological processes that could impact the road.
Jan 2003	May 2003	**Design of Bridge Foundations, M77 Glasgow Southern Orbital, UK**. Client: Highways Agency (UK). Position: Geotechnical Engineer. Mr Massey was responsible for carrying out the geotechnical assessment of the ground conditions at four bridge sites. This included interpretation of ground investigation data and laboratory test results for the four bridges, drawing of engineering geological cross sections through each of the four sites, development of the engineering geological models for the site and detailed foundation design for the bridge piers and abutments.
Jul 2002	Jan 2003	**Landslide Risk Assessment Project, Bhutan and Nepal**. Client: Department for International Development (DFID), UK. Position: null. This research project focused on the development and testing of rapid techniques to assess landslide risk in remote mountainous areas for purposes of rural access planning. The

project involved researching the main factors that contribute towards the development of landslides in Nepal and Bhutan. Mr Massey was responsible for carrying out detailed landslide hazard assessments for several of the study areas in Bhutan.

1999 - 2002 **Engineering Geologist**

Employer: Fugro Ltd.
Hong Kong

Description of duties:

Responsible for carrying out aerial photograph interpretations, engineering geological mapping (including geomorphological mapping), landslide hazard mapping, planning/supervising ground investigations and laboratory testing, carrying out analysis of complex geotechnical data using specialist software, designing slopes, retaining walls and drainage measures as well as supervising construction activities. It was during his time with Fugro that Mr Massey spent two years working on the high profile landslide Investigation Consultancy for the Geotechnical Engineering Office (GEO) in Hong Kong. Mr Massey was a team leader responsible for carrying out emergency 24 hour response to landslide events. This involved the organisation, management and investigation of landslides immediately after the event as well as carrying out the design of any emergency mitigation measures.

Consultancy work during employment

From	**To**	
Dec 2001	Jul 2002	**Tsing Shan Natural Terrain Hazard Study, Hong Kong**. Client: Geotechnical Engineering Office, Hong Kong. Position: Engineering Geologist. Following a rainstorm in 2000, approximately 120 landslides where initiated on the steep slopes above the town of Tuen Mun in Hong Kong. As part of this project, Mr Massey was responsible for reviewing all the existing geological and geotechnical data in order to derive the locations of the landslides as well as to map (using aerial photographs) the different geological/geomorphological processes and materials present within the study area.
Jan 2000	Jul 2002	**Landslide Investigation Consultancies, 1999, 2000 and 2001 Agreements, (Hong Kong)**. Client: Geotechnical Engineering Office (GEO), Hong Kong SAR. Position: Team Leader. For two years Mr Massey was part of a landslide rapid response team on call 24 hours a day. As part of this work he was responsible for the organisation, management and reporting of detailed investigations of landslides in this high profile consultancy for the Hong Kong government. Mr Massey's involvement included all aspects of landslide investigation.
May 2000	Nov 2001	**10-Year Extended, Landslide preventative Measures Program**. Client: Geotechnical Engineering Office, Hong Kong. Position: Geotechnical Engineer. The project included the design and construction supervision of over 20 slopes within the landslide preventative measures program. Mr Massey was given the task of designing and supervising the construction of several of the slopes within the contract. For this project Mr Massey carried out the desk study, field mapping, stability analysis, slope design and construction supervision.

1998 - 1999 **Geoscientist**

Employer: Leeds University
United Kingdom

Description of duties:

Rock Deformation Research at Leeds University (UK) Innovation Business Group. Involved in several projects for clients including Shell, BP and Mobil. Primarily responsible for planning and carrying out the fieldwork programmes as well as analysing the field data for several of the projects.

1997 - 1998 **Assistant Geologist**

Employer: Coal Operations Australia Limited (BHP Billiton)
Australia

Description of duties:

Primarily involved in the exploration of a coal deposit located 100 km north of Sydney, Australia. Assisted the senior geologist in all aspects of coordinating the exploration program. He was also involved with the underground mining operations where he was responsible for assisting the senior engineering geologist in both the underground and exploration aspects of coal mining.

Publications

Major Publications Peer reviewed papers currently considered major to your career

Carey, J.M.; Massey, C.I.; Lydnsell, B.M.; Petley, D.N. 2019 Displacement mechanisms of slow-moving landslides in response to changes in pore water pressure and dynamic stress. *Earth Surface Dynamics, 7(3):* 707-722; doi: 10.5194/esurf-2018-73 [Link to electronic copy]

Allstadt, K.E.; Jibson, R.W.; Thompson, E.M.; Massey, C.I.; Wald, D.J.; Godt, J.W.; Rengers, F.K. 2018 Improving near-real-time coseismic landslide models : lessons learned from the 2016 Kaikoura, New Zealand, earthquake. *Bulletin of the Seismological Society of America, 108(3B):* 1649-1664; doi: https://doi.org/10.1785/0120170297 [Link to electronic copy]

Grant, A.; Wartman, J.; Massey, C.I.; Olsen, M.J.; O'Banion, M.; Motley, M. 2018 The impact of rockfalls on dwellings during the 2011 Christchurch, New Zealand, earthquakes. *Landslides, 15(1):* 31-42; doi: 10.1007/s10346-017-0855-2 [Link to electronic copy]

Massey, C.I.; Townsend, D.B.; Rathje, E.; Allstadt, K.E.; Lukovic, B.; Kaneko, Y.; Bradley, B.; Wartman, J.; Jibson, R.W.; Petley, D.M.; Horspool, N.A.; Hamling, I.J.; Carey, J.M.; Cox, S.C.; Davidson, J.; Dellow, G.D.; Godt, G.W.; Holden, C.; Jones, K.E.; Kaiser, A.E.; Little, M.; Lyndsell, B.M.; McColl, S.; Morgenstern, R.M.; Rengers, F.K.; Rhoades, D.A.; Rosser, B.J.; Strong, D.T.; Singeisen, C.; Villeneuve, M. 2018 Landslides triggered by the 14 November 2016 Mw 7.8 Kaikoura earthquake, New Zealand. *Bulletin of the Seismological Society of America, 108(3B):* 1630-1648; doi: 10.1785/0120170305 [Link to electronic copy]

Massey, C.I.; Della-Pasqua, F.N.; Holden, C.; Kaiser, A.E.; Richards, L.; Wartman, J.; McSaveney, M.J.; Archibald, G.C.; Yetton, M.; Janku, L. 2017 Rock slope response to strong earthquake shaking. *Landslides, 14(1):* 249-268; doi: 10.1007/s10346-016-0684-8 [Link to electronic copy]

Massey, C.I.; Abbott, E.R.; McSaveney, M.J.; Petley, D.N.; Richards, L. 2016 Earthquake-induced displacement is insignificant in the reactivated Utiku landslide, New Zealand. p. 31–52; doi: 10.1201/b21520-5 IN: Aversa, S.; Cascini, L.; Picarelli, L.; Scavia, C. (eds) *Landslides and engineered slopes : experience, theory and practice : proceedings of the 12th International Symposium on Landslides.* Boca Raton, Fla.: CRC Press [Link to electronic copy]

Massey, C.I.; Petley, D.N.; McSaveney, M.J.; Archibald, G.C. 2016 Basal sliding and plastic deformation of a slow, reactivated landslide in New Zealand. *Engineering Geology, 208:* 11-38; doi: 10.1016/j.enggeo.2016.04.016 [Link to electronic copy]

Taig, T.; Massey, C.I.; Taig, M.; Becker, J.S.; Heron, D.W. 2015 Validating the rockfall risk models developed for the Port Hills of Christchurch, New Zealand. p. 1353-1361 IN: Cubrinovski, M.; Bradley, B.A.; Price, C.; Chin, C.Y. (et al) (Organising Committee) *6th International Conference on Earthquake Geotechnical Engineering, 1-4 November 2015, Christchurch, New Zealand.* N.Z.: New Zealand Geotechnical Society (NZGS)

Massey, C.I.; McSaveney, M.J.; Taig, T.; Richards, L.; Litchfield, N.J.; Rhoades, D.A.; McVerry, G.H.; Lukovic, B.; Heron, D.W.; Ries, W.; Van Dissen, R.J. 2014 Determining rockfall risk in Christchurch using rockfalls triggered by the 2010-2011 Canterbury earthquake sequence, New Zealand. *Earthquake Spectra, 30(1):* 155-181; doi: 10.1193/021413EQS026M [Link to electronic copy]

Massey, C.I.; Petley, D.N.; McSaveney, M.J. 2013 Patterns of movement in reactivated landslides. *Engineering Geology, 159:* 1-19; doi: 10.1016/j.enggeo.2013.03.011 [Link to electronic copy]

Massey, C.I.; Manville, V.R.; Hancox, G.T.; Keys, H.J.; Lawrence, C.; McSaveney, M.J. 2010 Out-burst flood (lahar) triggered by retrogressive landsliding, 18 March 2007 at Mt Ruapehu, New Zealand : a successful early warning. *Landslides, 7(3):* 303-315; doi: 10.1007/s10346-009-0180-5 [Link to electronic copy]

Dunning, S.A.; Massey, C.I.; Rosser, N.J. 2008 Structural and geomorphological features of landslides in the Bhutan Himalaya derived from terrestrial laser scanning. *Geomorphology, 103(1):* 17-29; doi: 10.1016/j.geomorph.2008.04.013 [Link to electronic copy]

Peer Reviewed Journal Articles Peer reviewed journal articles

Carey, J.M.; Massey, C.I.; Lydnsell, B.M.; Petley, D.N. 2019 Displacement mechanisms of slow-moving landslides in response to changes in pore water pressure and dynamic stress. *Earth Surface Dynamics, 7(3):* 707-722; doi: 10.5194/esurf-2018-73 [Link to electronic copy]

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Achievements

Patents

Year	Type	Description

No patent achievements listed

Major Achievements

Products launched etc. not included elsewhere

Year	Type	Description
2017	Project Leader	Endeavour Programme: Earthquake-Induced Landscape Dynamics. Client: Ministry of Business Innovation and Employment. Position: Principle Investigator and leader. $9M over five years.
2015	Project leader	SLIDE (Wellington) Including the MBIE funded "Targeted" three-year research project ($1.5M): Anthropogenic Slope Hazards. EQC funded vulnerability study ($80K), It's Our Fault funding ($70K) and NZTA funding ($250K)
2015	Principal Investigator on National Science Foundation Grant	EAGER: A Platform for Regional-Scale Landslide Risk Assessment. In the US a number of geologic hazard policy initiatives have been enacted, or are being proposed in response to the deadly 2014 Oso, Washington Landslide. In this project, we aim to develop a computational platform to enable low-cost, high-resolution regional-scale landslide risk mapping. This research is being led by J. Wartman (University of Washington), and C. Massey is co-PI, with in kind funding provided by EQC.
2014	Principal Investigator on National Science Foundation Grant	RAPID: Rockfall Impacts on Structures: High Resolution Data Acquisition, Visualization, and Analyses. This research seeks to acquire, process, and archive data pertaining to the impact of rockfalls triggered by the 2010/11 Canterbury earthquakes on residential and commercial structures. The project includes development of preliminary guidelines on building system resilience to rockfalls. It is in collaboration with the University of Washington and the University of Oregon, USA.
2011	Project Leader	Response, Recovery and rebuilding after the 2010/11 Christchurch Earthquakes. The GNS Science team produced more than 40 reports containing expert analysis on the risk of landslides to people, homes and infrastructure in the Port Hills of Christchurch. The results from these reports have been used by Christchurch City Council and the Canterbury Earthquake Recovery Authority to develop their land use policies and it underpins the relevant parts of the Christchurch Replacement District Plan.
2010	Project leader	I led the SSIF Landslide Hazards Programme at GNS Science for nine years. This involved managing and developing the strategic research agenda with the GNS Science and external teams. This involved convening meetings between the different team members (both GNS Science and external members), mentoring staff, developing core skills and identifying future research trends in order to strategically place our team as the primary provider of landslide research and consulting knowledge in New Zealand.
2006	Chatership	In 2006 I became a Chartered Geologist of the Geological Society of London. The Chartered 'designation' indicates a professional practitioner who has been peer assessed as having key professional competencies and experience in their field of practice. Typically you need more than six years of professional experience to qualify for chartership.

Previous Research Work

Previous Research Work

Title	Principal Outcome	Principal End-user	Contact
Endeavour Programme: Earthquake-Induced Landscape Dynamics ($9M)	Over what time scales do landscapes heal after major earthquakes? This research programme 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 hillslopes and rivers will respond to future earthquake and rainfall events. From these results we will develop an integrated set of predictive tools guided by an evidence-based decision-making framework.	MBIE, Regional and District Councils, EQC, Infrastructure providers and the NZ public	Sarah.McDermott@mbie.govt.nz
Kaikoura Earthquake Short-Term Project: Landslide inventory and landslide dam assessments ($250K)	The M7.8 2016 Kaikoura Earthquake generated more than 28,000 mapped landslides and 200 landslide dams. The goal of this short-term project was to collect perishable data on landslides and landslide dams generated by the earthquake. The landslide inventories developed for this earthquake will compliment those collated from past New Zealand and international earthquakes, and have added to, and complimented the international "body of knowledge" relating to earthquake-induced landslides.	NHRP, District and Regional Councils, Landslide community of researchers	c.pinal@gns.cri.nz
Natural dams and their failure modes (Marsden fund $300K)	Research on the stability of natural dams, their failure modes and longevity on the landscape, with reference to: i) the Ruapehu Crater-lake dam, which failed in 2007; and ii) the Young River dam, which was formed by a landslide 2007 and is still present on the landscape. This research has given DOC a better understanding of dam failure modes based on emplacement mechanisms, allowing them to manage these hazards more effectively.	Department of Conservation	Dr Harry Keys hkeys@doc.govt.nz
Quantifying the seismic response of slopes in Christchurch and Wellington ($300K)	Research on the effects that slope geometry, geology and earthquake source have on amplifying ground shaking leading to slope failure. The research has shown that tall and steep slopes, contrasting materials and sharp breaks in slope cause measurable increases in ground accelerations. Our findings in the Port Hills were used by regulatory authorities as one of the inputs to developing land zoning policy. The lessons from Christchurch are influencing decision making across the country.	NHRP, CERA, Christchurch City Council and MBIE	porthillsgeotech@ccc.govt.nz
SLIDE (Wellington) Emerging Anthropogenic Slope Hazards ($2M)	To improve the resilience of New Zealand's infrastructure through better knowledge of the behaviour of 'anthropogenic' slopes and develop improved strategies for identifying and dealing with potentially unstable slopes. Stakeholders and end users are using the findings from this project to identify potential "problem areas" and to quantify the resilience of their infrastructure to landslides and to help reduce the incidence of slope failures in urban areas.	MBIE, NZTA, Wellington City Council, Greater Wellington Regional Council and EQC	Sarah.McDermott@mbie.govt.nz
Strategic Science Investment Fund: Landslide Hazards Programme ($525K/year)	I led the SSIF Landslide Hazards Programme at GNS Science for nine years. Outcome was to make New Zealand more resilient to landslide hazards via investigating the initiation and runout mechanisms of landslides and methods to quantify the hazard and risk they pose to people and infrastructure.	MBIE, Regional and District Councils, EQC, Infrastructure providers and the NZ public	c.pinal@gns.cri.nz
The dynamics of reactivated landslides ($700K)	The main outcome from this research is our improved understanding of how these landslides respond to rainfall and earthquakes. This new knowledge has enabled us to provide the Earthquake Commission, KiwiRail and Vector Ltd., with information on the spatial extent and temporal probability of reactivation of these types of landslide, which has been used by them to inform their claims policies (EQC) and engineering works (KiwiRail and Vector Ltd.).	EQC, KwiRail and Vector Ltd.	c.pinal@gns.cri.nz

Commercial, Social or Environmental Impact

Description:

Describe the commercial, social or environmental impact of your previous research work.
Provide no more than 5 examples relevant to your proposal.

1) In 2016, Chris and his team produced the final set of reports in a series of expert analysis on the risk of landslides, cliff collapse, and rockfall for the Christchurch City Council. These reports covered 126 properties where the risk from landslides was considered intolerable. The results from these reports have been used by Council to develop their land use policies relating to at-risk-homes. This work built on earlier rockfall and cliff collapse risk assessments carried out by Chris and his team, which were used by the Canterbury Earthquake Recovery Authority to zone about 1,200 dwellings in the Port Hills after the 2010/11 Canterbury Earthquakes. This work resulted in central government offering to purchase about 470 eligible dwellings (a cost to government of c. NZ$300M), where the risks were assessed as being intolerable. 2) This year Chris and his team have been working on finalising a set of reports in a series on the potential impacts of landslides in Wellington. The reports assess the impact of both earthquake- and rain-induced landslides on infrastructure in the capital city. The results from these reports will be used by Wellington City Council and others to develop their land use policies relating to landslide hazards. 3) Also this year, Chris and his team carried out landslide hazard and risk assessments for the Department of Conservation (DOC) and Franz Josef Glacier Guides (FJGG) (Ngāi Tahu Tourism), focused on the Fox and Franz Josef Glacier valleys. These assessments quantify the risk to DOC and FJGG staff and visitors to the valleys from rockfalls and landslides. The results are being used by DOC and FJGG to help them plan the locations of walking routes, roads and guiding areas within these valleys and to manage the risks to their staff and visitors.

Relationships with End-Users

Description:

Demonstration of relationships with end-users.
Provide no more than 5 examples relevant to your proposal.

1) Following the 2016 Kaikoura earthquake, Chris managed GNS Sciences technical response to issues raised by the Department of the Prime Minister and Cabinet (DPMC) and other members of the multi-agency Kaikoura earthquake National Recovery Office (NRO) – including stakeholders from national level to regional and district councils – with regards to the landslide impacts and advice. 2) Chris also provided geotechnical support to NZTA and KiwiRail, working on rebuilding the road and rail post the Kaikoura Earthquake. This culminated in the consulting report: The North Canterbury Infrastructure Alliance (NCTIR): Pilot study for assessing landslide hazard along the road and rail corridor ($120K) 3) Chris established the National Stakeholder Advisory Group (NAG) for the Earthquake-induced landscape dynamics (EILD) programme, funded by MBIE’s Endeavour Programme. The NAG is chaired by Roger Fairclough (Chair of the NZ Lifelines Council), and comprises senior management and policy makers from EQC, WCC, Auckland Council, NZTA, KiwiRail, Insurance Council, MPI and MBIE. The NAG meets once a year to discuss the EILD programme and other nationally important landslide research, including: i) how the results and data from the research can be put into use; and ii) to enable them to feed into our future research agenda.

Specialist Profiles

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APPENDIX 2

APPENDIX 2 – BOPRPS (2014) and AGS (2007) EXAMPLE RISK CALCULATION

Equation 1 (E1): BOPRPS (2014) where AIFR = (D x P)/N

Equation 2 (E2): AGS (2007) where AIFR = P(H) x P(S:H) x P(T:S) x V

						AGS (2007)	BOPRPS (2014)
P(H) (E2) or P(E1) (annual frequency of debris flow)	**P(S:H)**	**P(T:S)**	**V**	**D (estimated deaths)**	**N people present in hazard zone**	**AIFR (E2)**	**AIFR(E1)**
0.01	0.1	0.7	0.5	0.9	25	3.50E-04	0.00035
0.001	0.5	0.7	0.5	4.4	25	1.75E-04	0.000175
0.0001	1.0	0.7	0.5	8.8	25	3.50E-05	0.000035
			SUM	14.0		5.60E-04	5.60E-04

Note the numbers are made up for comparison purposes only