Natural hazards risk modelling: an approach providing risk management solutions for local government

N. Pondard M. Daly

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N. Pondard, GNS Science, PO Box 30368, Lower Hutt
M. Daly, GNS Science, PO Box 30368, Lower Hutt

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ABSTRACT

Infrequent, highly severe events such as earthquakes, floods and other natural hazards can cause significant casualties, property damage and business interruption to communities, ultimately impacting people, the economy, the environment, and the long-term development of a region. Quantitative risk modelling helps to get a more comprehensive insight into such hazards and their socio-economic consequences. It contributes to better risk management through: a) a clearer understanding of geographical concentrations of natural hazard risks, b) quantification of potential physical damage, business interruption and casualties, and c) identification of key risk drivers. This approach provides risk intelligence to assist local government to make more informed decisions.

KEYWORDS

Natural hazards, risk, modelling, local government.

1.0 INTRODUCTION

Assessing natural hazards risk quantitatively can provide local government with crucial information to guide risk management decisions in their respective regions and districts.

Barriers to a quantitative approach have limited the use of natural hazards risk models by local government. These barriers include perceived cost, liability issues, a lack of understanding of the relationships between the intensity of hazards and the degree of damage to some asset types, a lack of a consistent and widely accepted risk modelling approach, and a lack of asset inventories.

Over the past decade, there has been an effort within the scientific community to understand and overcome these barriers (e.g. Reese et al, 2007; Glavovic et al, 2010; Saunders, 2010; Smith, 2010; Saunders et al., 2011). Multi-disciplinary work, combining natural hazard related sciences, engineering, mathematics and social sciences, has improved our understanding of natural hazards consequences. Therefore the time is right for local government risk managers to undertake a more quantitative assessment of risk.

A barrier that persists is a lack of recognition of the value quantitative risk modelling brings to the decision making process.

This paper attempts to illustrate the value of quantitative risk modelling by providing some examples of how risk modelling can help achieve better natural hazards risk management through a) a clearer understanding of geographical concentrations of natural hazard risks, for various frequencies and severities of natural perils, b) quantification of potential physical damage, business interruption and casualties, and c) identification of key risk drivers.

2.0 IMPACTS OF NATURAL HAZARDS

Infrequent, highly severe events such as earthquakes, floods and other natural hazards can cause significant casualties, property damage and business interruption to communities, ultimately impacting the people, the economy, the environment, and the long-term development of a region. Worldwide, natural and man-made hazards caused USD 218 billion economic losses in 2010, more than triple the 2009 figure of USD 68 billion. Approximately 304,000 people died in these events, the highest number since 1976 (Swiss Re, 2011). In New Zealand, the 4th September 2010 Canterbury earthquake and its damaging 22nd February 2011 aftershock caused the death of 182 people and are projected to generate more than NZD 20 billion economic losses, months of business interruption, and the long-term displacement of thousands of Christchurch’s inhabitants (e.g. Kaiser et al., submitted). The impact of these events on New Zealand community is likely to be the worst since World War II.

New Zealand is highly exposed to natural hazards such as earthquakes (Figure 1), floods (Figure 2), landslides and tsunamis (Figure 1). While these events are not necessarily more frequent than in the past, the urban development in more precarious areas over the last decades has made the population and the economy more vulnerable to natural perils, resulting in higher losses. As urban areas grow further, socio-economic losses are likely to get worse, unless risk reduction measures are implemented. Therefore, it is crucial for governments to get access to the most appropriate scientific information to manage their risk. Taking a more quantitative approach is one way to better understand risk and make more informed decisions.

While there are numerous definitions of risk (see for example ISO, 2009; Manyena, 2006) the one used in the context of this discussion is: *risk = hazard * exposure * vulnerability*. These terms are explained in more detail in the following discussion.

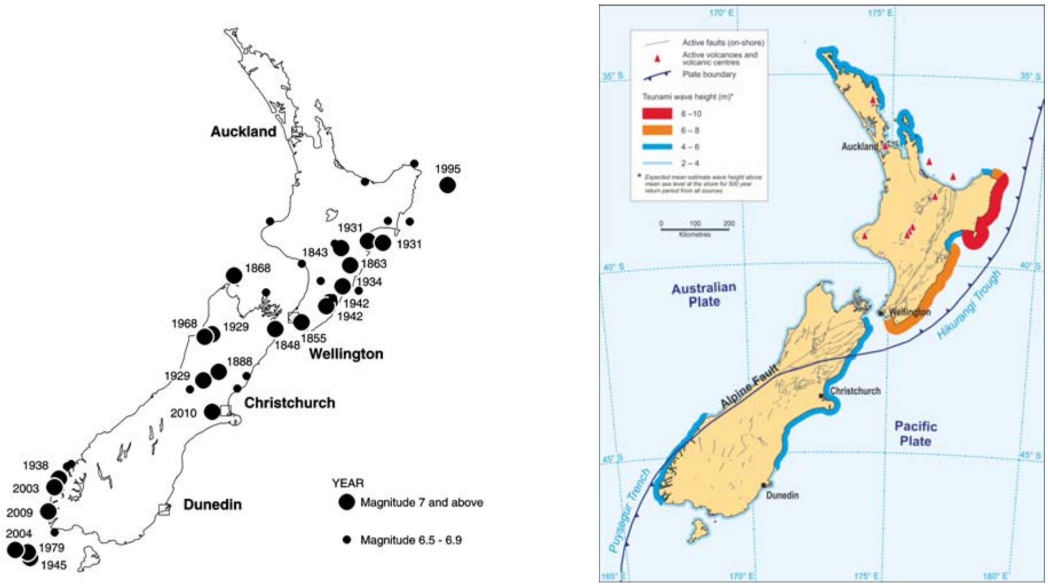

Figure 1 Left panel: Major historical earthquakes in New Zealand (magnitude greater than 6.5 on the Richter scale), from 1840 to 2010 (source: *GNS Science*), as an example of New Zealand high exposure to natural hazards. Right panel: Exposure to tsunamis, adapted from Glavovic et al. (2010).

3.0 QUANTITATIVE RISK MODELLING AND RISK MANAGEMENT SOLUTIONS

Quantitative risk modelling offers valuable information (e.g. Figures 3 and 4; Table 1) to assist local government and their communities to determine their risk and make more informed risk management decisions. Such an approach has been used extensively in the (re)insurance industry over the last 20 years (e.g. Grossi and Kunreuther, 2005), particularly since the landfall of Hurricane Andrew (Florida, 1992) with its severe consequences (USD 15.5 billion insured losses leading to the bankruptcy of nine insurance companies). Prior to this event, the common practice in the insurance industry was to assess natural hazards risk qualitatively, for example superimposing a hazard map (colour coded map representing the severity of an event at any given site) with the location of assets, for a single return-period (e.g. 1 in 250 years) (Figure 2). But what if the disaster occurring was a less frequent, more severe event (e.g. a 1 in 1,000 year event), or even a 1 in ~5,000 year event such as the recent Canterbury earthquakes in New Zealand? What would the consequences be of such events? Would the community be ready to accept the associated risk once it knew what it was? How do we assess these consequences in advance of these events occurring?

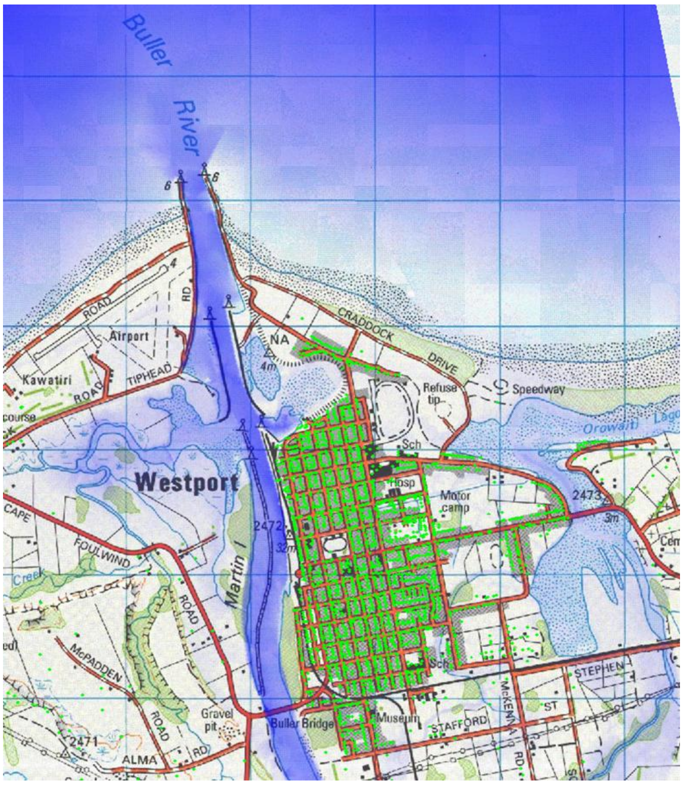

Figure 2 Up until the last 15 to 20 years, natural hazards risk assessments were generally limited to qualitative assessments in the (re)insurance industry, for example superimposing a hazard map (colour coded map representing the depth of a flood at any given site, here in various degrees of blue) with the location of assets (here in green), for a single return-period (e.g. here for a 1 in 250 year flood). This approach remains the most common method used by local government in New Zealand to guide risk management decisions for their respective areas. While useful in identifying the geographic spread of hazards and where potential damage to assets could occur, it gives no indication of the intensity of an event under varying scenarios (e.g. 1 in 500, 1 in 1000 year event). Also it doesn't give any indication of the performance of different assets, actual losses, or other aspects such as casualties, injuries, business interruption losses, etc. Depending on the condition of a particular asset, greater damage (expressed as a loss) could occur in a lower hazard area.

Risk modelling has improved the way the (re)insurance industry determines its risk. By assessing the consequences of natural hazards quantitatively, for a variety of return-periods (e.g. Figure 4), or for specific scenarios, such models have provided a framework that enabled insurance companies to make risk management decisions that align with their risk tolerance.

Such an approach is also valuable for local government, providing risk intelligence appropriate to their specific needs. In order to provide for the social, economic, environmental and cultural well-being of the community, as well as health and safety (particularly under the Resource Management Act, 1991; Civil Defence Emergency Management Act, 2002; Local Government Act, 2002; and Building Act, 2004), local government must address risks from natural hazards in their respective areas.

Current local government practice in assessing risk for land-use planning, growth management, infrastructure management and emergency management purposes, with a few exceptions, relies on hazard maps and infrastructure overlays such as used by the insurance industry 20 years ago (Figure 2). We discuss below how a more quantitative approach addresses government needs in terms of natural hazards risk management.

With New Zealand being highly exposed to natural hazards and local government having responsibility for addressing hazards and risks, a number of questions are important to be addressed:

- Where are our geographical concentrations of natural hazard risks (Figure 3)?
- What are the potential casualties, property damage and business interruption loss expectancies we may face on a regional and/or a single site basis (Figure 4)?
- How do these geographical concentrations of risk and loss expectancies compare with our current policies (e.g. land-use planning, emergency planning) and/or risk transfer programmes (e.g. Local Authority Protection Programme Disaster Fund or LAPP fund, insurance cover) (Figure 4)?
- How do changes in land-use policy, building requirements, and emergency planning affect our concentrations of risk and loss expectancies? Can we model these changes to help us determine what impact they will have on the risk profile?
- Can more than one site be affected by the same natural event and what are the interdependencies of our assets?
- Where are our main areas of exposure and how can knowledge of these be used to help us prioritise risk reduction measures (Table 1)?
- What risk reduction options can we consider (risk transfer, mitigation, retention, avoidance) and how do we choose? What are the benefit cost ratios of each?

We present below three basic examples (Figures 3, 4, and Table 1) illustrating how quantitative risk models address some of these questions.

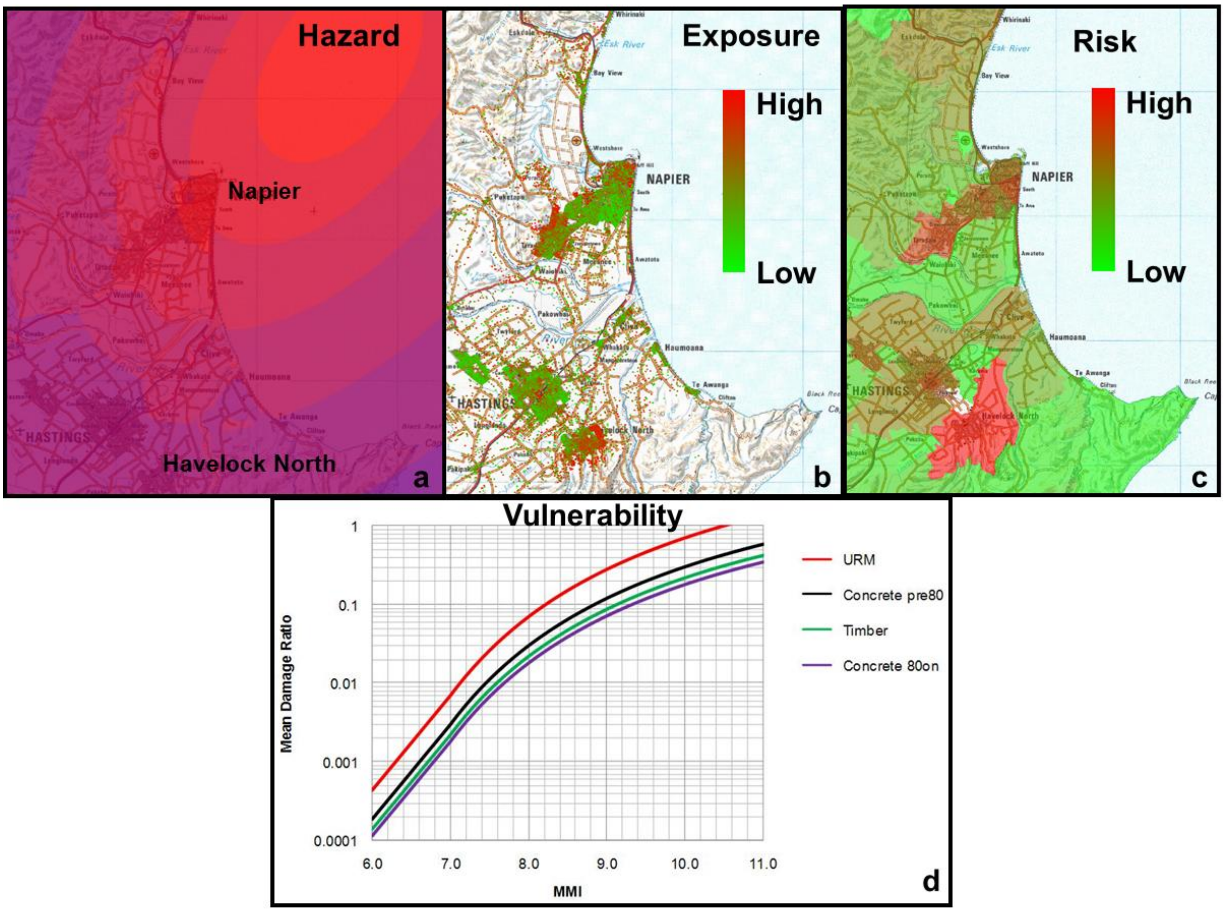

Figure 3 Geographic concentrations of natural hazards risk. Example from physical damage to the built environment associated with an “as if” 1931 Napier earthquake (M 7.8) in Hawke’s Bay (RiskScape project). a) Hazard component corresponding to the intensity of an event at any given site. The example provided here corresponds to the ground-shaking intensity during an earthquake. Red colour: higher intensity. Purple colour: lower intensity. b) Exposure component corresponding to the assets inventory (e.g. people, built environment, infrastructure). In this example buildings are coloured per reinstatement value. c) Risk (cost of repair in this example) resulting as a combination of hazard, exposure, and vulnerability. d) Vulnerability component of natural hazards risk, corresponding to the fragility of assets and how they would perform given the severity of an event (fragility curve). URM: unreinforced masonry buildings. MMI: Modified Mercalli Intensity (i.e. intensity of ground shaking during an earthquake). Being able to express vulnerability numerically such as through a fragility curve is an essential part of quantitative risk modelling.

Figure 3 gives an example of how government can have a clearer understanding of their geographical concentrations of natural hazards risk, in order to optimise their policies and risk reduction measures. This example represents the probable geographic distribution of physical damage to the current built environment (Figure 3c), would an “as if” 1931 Napier earthquake (M 7.8) occur again in Hawke’s Bay (RiskScape project; Schmidt et al, 2011). Similar concentrations can be visualised for other risks (e.g. casualties). Such visual representation is particularly useful to optimise land-use planning and emergency management. It can also serve to prioritise risk transfer, mitigation or avoidance decisions.

The risk represented in this map is quantified. Therefore its assessment is slightly more subtle than a simple superposition of hazard intensity and location of assets. Natural hazard risk is generally modelled as a combination of hazard, exposure and vulnerability, as detailed hereafter. The hazard component corresponds to the intensity of an event at any given site (Figure 3a). Intensity can for example correspond to ground-shaking intensity for earthquakes (MMI), wind speed for windstorms, water depth for floods, etc. In this example the "as if" 1931 Napier earthquake generates higher intensities of ground-shaking in Napier (red colour) and lower intensities in Havelock North east of Hastings (purple colour). Such intensity can be simulated for "as if" historical scenarios as presented here, or for various return-periods (e.g. 1 in 50 years earthquake, 1 in 500 years, 1 in 2500 years).

The exposure component (Figure 3b) corresponds to the detailed assets inventory (e.g. people, built environment, infrastructure). Inventory can correspond for example to construction type, year built, reinstatement value, people density, people location at any time of the day, etc. In this example buildings are coloured per reinstatement value. High exposures are concentrated in Napier, but also in Havelock North.

As a consequence, even if the hazard is the most severe in Napier, the resulting risk (cost of repair in this example) is actually high both in Napier and Havelock North (Figure 3c).

The vulnerability component is generally a less understood element by risk managers and decision makers (Figure 3d). However it is an essential part of natural hazards risk quantification and is often missing from current risk assessments undertaken by local government for land-use planning, growth management, infrastructure management and emergency management purposes. It corresponds to the fragility of assets and how they would perform given the severity of an event. For example, in this figure the damage to unreinforced masonry buildings (URM) would be more than 4 to 5 times greater than the damage to concrete buildings built after 1980, for the same intensity of shaking (MMI). Such fragility has therefore a direct impact on the resulting quantitative risk (e.g. on the repair cost or casualties within the building).

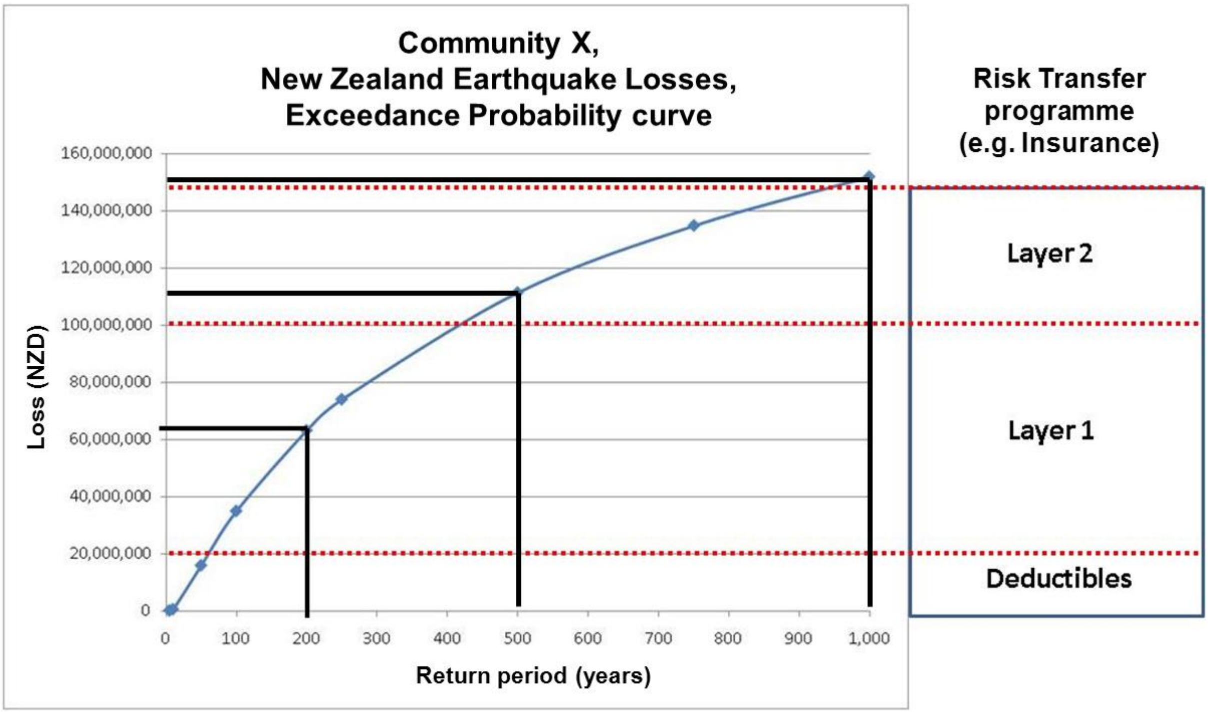

Figure 4 Probable loss expectancies (e.g. casualties, economic loss) for various return period earthquakes, illustrating how this information could be used to support risk management decisions, for example, a decision about the level of insurance cover to take out for certain assets (risk transfer). See the text for further explanation.

The example in Figure 4 represents loss expectancies (e.g. casualties, economic loss) for various return periods, and how they can be compared with the current risk treatment option in place (insurance cover, LAPP fund for local government assets, etc.). Such information can be used to define the risk tolerance of a community and to optimise its risk transfer programme accordingly, for example. In this example, the Exceedance Probability (EP) curve shows how often Community X will sustain a loss of a given size or greater, after a specific earthquake. Community X is likely to sustain an economic loss equal to or greater than ~NZD 63m once in any 200 years, following a single event. The loss goes up to ~NZD 110m for a less frequent 1 in 500 years event, and ~NZD 150m for a 1 in 1,000 years earthquake. In this example, the first layer of Community X insurance structure is activated once in any ~60 years, and the second layer is activated once in any ~420 years. Therefore the EP curve helps to adapt the programme (e.g. layer limits and deductibles) to better reflect the community's risk tolerance.

In addition to assisting with community risk management decisions, such information can also facilitate commercial transactions as it gives insight on the actual risk taken by the insurers. Therefore the community using these models is in a stronger position to negotiate and potentially achieve lower premiums.

Table 1 Identifying key risk drivers for specific return periods. In this example, quantifying the risk for specific assets or locations allows the asset owner to see what percentage of the overall loss is contributed by a particular asset. Risk mitigation efforts can then focus on those selected assets that are contributing the greatest to the overall loss. More explanation is given in the text. PML 1-500: Probable maximum loss to the asset portfolio, sustained once in any 500 years (therefore called a 1 in 500 year loss).

Rank	Site	Portfolio PML 1-500 ($m)	Decrease
portfolio		115.5	
1	Location A	97	-16.0%
2	Location B	73.8	-36.1%
3	Location C	51.2	-55.7%
4	Location D	33.2	-71.3%
5	Location E	25.1	-78.2%

Finally, Table 1 shows an example of how a quantitative risk model helps identify key risk drivers within an area, e.g. related to casualties, property damage, business interruption, for specific return periods, assisting in prioritising risk reduction measures (e.g. mitigation, avoidance). In this example, Community X's asset portfolio exists across 500 locations in a given area. Once in any 500 years, Community X is likely to sustain a loss equal to or greater than ~NZD 115.5m (column Portfolio PML 1-500), after a specific earthquake. If location A is removed from the portfolio, losses to the portfolio drop by 16%, to ~NZD 97m. If locations A and B are removed from the portfolio, losses to the portfolio drop by 36.1%, to ~NZD 73.8m. The example shows that only 5 locations out of 500 sites contribute to 78.2% of community X losses. Such information helps the community to consider undertaking mitigation measures or removing these locations from the portfolio to simply avoid the risk, therefore reducing the community property damage and business interruption losses. Such an exercise can also be performed for other risks such as casualties.

4.0 CONCLUSION: KEY BENEFITS OF NATURAL HAZARDS RISK MODELLING

The examples described above represent only a few opportunities offered by quantitative risk modelling. This approach is not the absolute answer and the community needs to be involved to determine levels of acceptable, tolerable and intolerable risk. However, risk modelling helps to get a more comprehensive insight into natural hazards and their socio-economic consequences. This approach provides quantified risk intelligence to assist governments to define their risk tolerance and make more informed decisions. It helps to achieve better natural hazards risk management through: a) a clearer understanding of geographical concentrations of natural hazard risks, for various frequencies and severities of natural perils, b) quantification of potential physical damage, business interruption and casualties, and c) identification of key risk drivers. Risk modelling supports risk managers and decision makers to consider ways of reducing their risk exposure. Finally, it can assist local government to better communicate risk to their local communities who are involved in the decision making process.

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www.gns.cri.nz

Principal Location

1 Fairway Drive
Avalon
PO Box 30368
Lower Hutt
New Zealand
T +64-4-570 1444
F +64-4-570 4600

Other Locations

Dunedin Research Centre
764 Cumberland Street
Private Bag 1930
Dunedin
New Zealand
T +64-3-477 4050
F +64-3-477 5232

Wairakei Research Centre
114 Karetoto Road
Wairakei
Private Bag 2000, Taupo
New Zealand
T +64-7-374 8211
F +64-7-374 8199

National Isotope Centre
30 Gracefield Road
PO Box 31312
Lower Hutt
New Zealand
T +64-4-570 1444
F +64-4-570 4657