**Impacts of Climate Change on Urban Infrastructure & the Built Environment**

**A Toolbox**

# Tool 3.2: Using RiskScape for Risk Analysis


**Author**

S. Reese

**Affiliation**

NIWA, Private Bag 14901, Wellington 6021

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# 1. Introduction

New Zealand is exposed to a wide range of natural hazards such as earthquakes, floods, tsunami, landslides, volcanic eruption and severe storms. The frequency of severe weather-related events is also increasing, not only because of global warming, but people also tend to be more vulnerable especially when attracted to settle in areas which are inherently at risk from natural hazards such as the coast or flood plains. These potential perils require tools and decision support systems that facilitate the analysis and comparison of impacts and risks from different hazards. The absence of a national standardised quantitative method prompted the New Zealand Science community to commission the development of RiskScape, a quantitative multi-hazard impact and risk analysis tool.

## 1.1 Purpose of the Riskscape Tool

RiskScape is a regional risk and impact assessment tool. Its primary purpose is to provide a framework in which the risk of impact to assets due to various hazards can be calculated. This information can be used for a wide range of applications, from planning to hazard management to asset management.

## 1.2 Importance of risk analysis

Natural disasters are a significant and rising cost to communities and will be exacerbated in most cases by climate change. Increasingly concerned about the impacts of disasters, the UN General Assembly declared 1990s the International Decade for Natural Disaster Reduction (IDNDR). The IDNDR was established to urge all countries to have comprehensive national risk assessments and risk analysis in place. Having good information on the costs of natural disasters serves various purposes. Risk analysis and assessments are normally part of an integrated risk management process and produce crucial information that is relevant to decision makers for identifying viable options for risk reduction. It also ensures that climate change is taken into account in long-term planning processes as it allows the climate change risk to be compared with other risks (MFE, 2008). According to MFE (2008, p72), “the purpose of risk assessment, in the context of climate change, is to identify risks and hazards that may be induced or exacerbated by climate change and to evaluate their effects and likelihood”. Hollenstein (2005) states that damage or risk assessments/analysis can help to assess the effectiveness of expenditure on mitigation measures, since they focus on damage rather than on hazards. According to the Bureau of Transport Economics (2003, p.1) “every dollar spent on mitigation is worth two dollars of response and recovery”. Benefit-cost analysis also requires quantification of impacts and risk, before and after implementation of a risk reduction strategy. The economic viability of communities also depends upon the continued operation of infrastructure and essential services. Hence, it is critical to know the possible impacts and associated risks from natural hazards in order to minimize them.

### 1.3 Risk analysis methods

Recommendations on how to conduct risk analysis can be found in the Australian and New Zealand Risk Management Guidelines (Standards Australia and New Zealand 2004). All components of risk including exposure and vulnerability can be analysed quantitatively, semi-quantitatively or qualitatively. Each method has its advantages and disadvantages. Qualitative analyses require little data and not a lot of skills, on the other hand they are often very subjective, and are not suited for a subsequent benefit-cost analysis. Quantitative analyses on the other hand need extensive input data, are very resource-intensive but have the advantage that the results are comparable, much more detailed, standardised and objective. The selection of the appropriate method basically depends on the available resources, what level of detail is required and the data availability. It is important to understand that the data input requirements and the constraints and limitations influence its outputs and hence its reliability and accuracy.

## 2. RiskScape

Emergency managers and planners are demanding increasingly more quantitative information on possible consequences and the risks associated with different hazards including tsunamis, to be in a position to compare the impacts across the different hazards before making investment decisions on risk reduction for their region (Blong 2003; Durham 2003; 2006; Reese & Smart, 2009). However, until recently no quantitative impact and risk analysis tool existed in New Zealand. Even though the CDEM Act 2002 requires from every council to identify and manage their risks, there is no nationally consistent approach. Most councils use different methods, mainly qualitative or semi-quantitative in the form of risk matrices that make comparisons extremely difficult because these analysis are largely judgmental rather than numerical. Therefore, a quantitative method to accurately estimate impacts and risk was needed. GNS & NIWA were commissioned in 2004 by the New Zealand Science community to develop such a quantitative tool. RiskScape was initiated, with the aim to allow a comparison of the impacts and risk posed by various hazards for different return periods to support decision-making by: a) determining which hazard represents the greatest risk to various sectors of a community; b) enabling investments in risk reduction to be prioritised according to the potential consequences (e.g., earthquake strengthening of buildings, upgrading stop-banks); c) avoiding inappropriate land-use development through planned risk avoidance measures and policies; and, d) through the preparation of effective emergency management plans.

## 2.1 History

The project was launched in 2004, with the aim to develop a Regional Riskscape tool which can be applied across a region for use by emergency, asset, and environmental managers and planners. Regional Riskscape is intended not only to benefit these agencies through supporting planning and investment decision-making prior to a natural disaster, but also to support emergency managers and government agencies with timely estimates of the consequences and disruption following a natural disaster.

Based on informal discussions with potential users a list of system requirements, useful features, and desired outputs was formulated before the launch of the programme. Those general requirements espoused by end-users are listed below. The vision was that the system would (Bell & King, 2009):

- cover multiple hazards and various damage categories,
- be available at reasonable cost,
- not be reliant on expensive GIS platforms or other software,
- be easy to learn and use,
- could be applied nationwide,
- be able to load new hazard and inventory data,
- be able to accept new hazard models without the need for extensive rewriting of code,
- be transparent, and
- be multi-functional / multi-purpose.

This task was daunting because of the variety of hazards, their impact, and the complexity and constant changes of the built-environments (people, buildings, infrastructure). Hence, it was obvious to first evaluate existing tool such as HAZUS, CityAware, etc. to see if they could be adapted and adjusted to New Zealand conditions. As none of the tools met the requirements, a proof-of-concept phase began in 2004 trying to develop a multi-hazard impact and risk analysis tool for New Zealand. During the initial phase, Riskscape targeted three selected regions, and focused just on the major natural hazards. After completion of phase I RiskScape was reviewed by an international expert panel. Based on the positive review, RiskScape was given extended funding to turn it into an operational tool. Even though the work is ongoing and there remain challenges to the development and implementation of a quantitative risk analysis tool, RiskScape is now available to the user as a prototype version (status June 2011).

## 2.2 System

Multi-risk modelling poses different challenges than classical risk analyses and has several features and implications to be considered – both in the modelling process and in using the results. In order to develop the capability to model and to compare loss estimates for different hazards and assets, a unifying framework for multi-risk assessment has been developed. This system calculates risks for any asset portfolio (e.g. buildings, critical infrastructure, a rural agricultural production area) exposed to multiple natural hazards – quickly and without reconfiguring the system (Schmidt et al. 2011).

RiskScape is based on open-source software (Java) and not embedded in a GIS environment. This makes it a unique multi-hazard tool even amongst its competitors and avoids expensive licence arrangements. The tool still has basic GIS-functionality and provides input/output processing so that results can be exported in a GIS compatible format and data important.  The RiskScape System is built on a modular modelling framework so that consequences for each region can be presented in a common platform across all natural hazards. New hazard, asset, or loss modules but also other tools such as cost-benefit models can be seamlessly integrated into the running system as new modules. A RiskScape module specification and module builder interface have been developed to facilitate this task. This provides the end-user with a high degree of flexibility and allows some end-user customisation (Bell & King, 2009). The RiskScape risk modelling framework consists of three fundamental components (modules), hazards, risk elements (assets), and vulnerability.

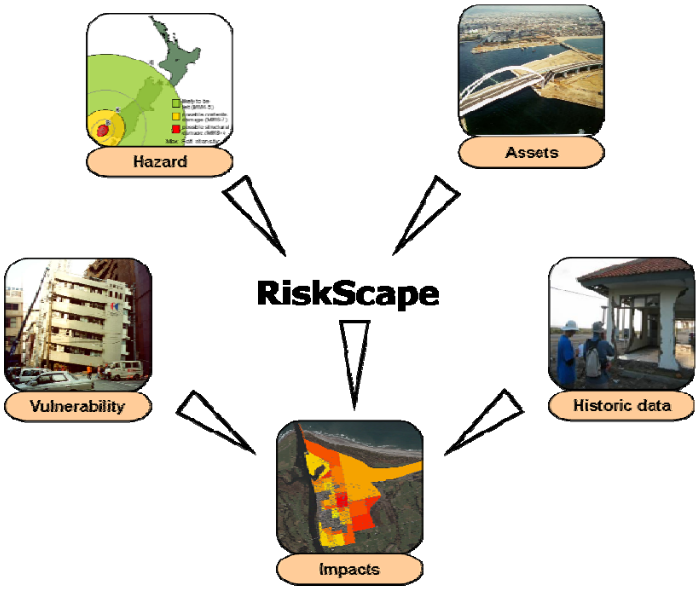


**Figure 2.1: Simplified concept of the Regional RiskScape tool.**

## 2.3 Modules

The plug-ins that form the calculation side of RiskScape are referred to as modules. There are three main modules in RiskScape. For more information about the architecture refer to the RiskScape manual available on the RiskScape website (www.riskcape.org.nz).

### 2.3.1 Hazards

The hazard module models the Hazard Exposure that describes the distribution and severity of the hazard. To be able to model the hazard exposure, the Hazard Module requires a number of parameters, typically the magnitude of the event impact and the frequency of the event (occurrence probability). Event magnitude can be expressed by a value of a physically measurable impact variable e.g. earthquake magnitude, or an inundation depth or wind speed at a particular point. Many variables – e.g. inundation or volcanic ashfall – have a spatial distribution; hence event magnitude needs to be expressed by a spatial pattern (a map) of magnitudes of the relevant physically measurable variable. Frequency is often expressed by a recurrence interval – bigger events happen less frequently. The recurrence interval has to be estimated from the historical record of the hazard type for the particular region of interest – for the case of flood inundation e.g. by flood frequency analysis. Hazard events – i.e. their magnitude and frequency – can be determined from historic events (e.g. inundation depth and extent and flood frequency from observed floods) or estimated by hazard models (e.g. run out distance from a landslide model) (Schmidt et al. 2011). RiskScape currently covers five hazards, Earthquakes, Volcanic ashfall, floods, wind storms, tsunamis and landslides are about to be implemented as well.

### 2.3.2 Assets

Impact and risk modelling also requires inventory datasets that characterise the items of value that can be potentially damaged or destroyed (e.g., built-environment, personal assets, infrastructure) or the people under threat (e.g., the distribution and demographic profile of the community or CBD). Thus, a comprehensive inventory of assets and people is the backbone of a loss-modelling tool. It provides critical input to several stages of the risk calculation. Dealing with different types of hazards and numerous assets and land uses (e.g., agriculture) requires a huge amount of information, particularly about the characteristics of the assets at risk e.g., construction characteristics of buildings, routes for utilities such as water supply, sewerage, road and power, demographic and business information. Thus, assets are specified by their spatial extent, location (necessary to determine exposure to hazards) and characterized by attributes describing their vulnerability relevant to the specific hazard, e.g. floor height of buildings necessary to calculate inundation depth from floods.

A nationally consistent database of the building stock or infrastructure is not currently available in New Zealand. Even though most of the required information does exist somewhere, there are currently no governmental efforts to establish such a database. Hence, RiskScape is currently developing its own national asset repository.

The database will be a key element of the multi-hazard loss modelling tool. The building inventory will be derived from a national property dataset maintained by Quotable Value Limited (QV), a New Zealand state owned enterprise for marketing property information. The inventory is available as point datasets of property centroids with a range of attributes attached to it, such as building age, number of storeys, building material, etc. Additional attributes that QV does not hold such as floor heights or roof pitch have to be added based on survey information and general rules derived from building surveys. RiskScape will allow users to update the database when additional or more detailed local information is available so that with time the QV data gets replaced with local and more detailed information. The compilation of infrastructure data is significantly more challenging as most of the data is held by private companies, in different formats with inconsistent information. Nevertheless, efforts are made to ensure the especially critical infrastructure data becomes part of the RiskScape asset database. Different levels of security are available to protect sensitive data. In parallel alternative ways are being pursued to derive some of these attributes from other sources where the data doesn't exist. New techniques such as satellite imagery or laser-scanning (LiDAR) are used to derive the necessary information (e.g. building footprint) about the elements at risk.

### 2.3.3 Vulnerability

Vulnerability refers to the potential for casualties, destruction, disruption or other form of damage or loss with respect to a particular element/asset. Vulnerability is in some ways a predictive parameter and describes the susceptibility of the element at risk. It identifies what may happen to it at risk under conditions of a particular hazard (Canon et al. 2005). Risk combines vulnerability with the probable frequency of impact to be expected from a known magnitude of the hazard. Vulnerability should not be confused with exposure; they are two separate, but complementary components of risk.

As magnitude-damage relationships reflect the vulnerability of an element at risk, depth-damage functions, also called stage-damage curves, damage or fragility curves, are the most common quantitative method to describe vulnerability and estimate potential damages respectively (Reese in press). According to Douglas (2007) and

Schultz et al. (2010) fragility functions are key components in a risk analysis/assessment framework, and the backbone of rigorous risk and damage estimation.

"Reese et al (2011, p.157) state that "fragility functions describe a (probabilistic) relationship between demand and damage. Therefore, in the case of structures subjected to a flood for example, the demand on structures needs to be quantified as a function of one or more predictor variables such as water depth and velocity".

Damage curves or functions on the other hand relate tsunami characteristics such as inundation depth, velocity or duration to the percentage damage (relative to replacement cost) for a variety of elements such as buildings, cars, household goods (Reese & Ramsay 2010).

Fragility or damage functions are typically based on either (Reese, in press):

- Empirical curves developed from historical events + damage survey data or
- Synthetic functions (hypothetical curves) based on expert opinion developed independently from specific events and damage survey data.

Both methods have their advantages and disadvantages (see Middelmann-Fernandes 2010). RiskScape for instance uses a combination of both as it has been found that synthetic damage curves calibrated against observed damage gave the most accurate results (McBean et al. 1986).

## 2.4 Outputs

As a multi-hazard impact and risk modelling tool, RiskScape provides a wide variety of results in different formats. Both, tangible and intangible effects are addressed as well as direct and indirect effects. Direct effects are the first order and most visible consequences due to the immediate impact, such as structural damage. Indirect effects emerge later as a consequence of the event, but not due to the direct impact, examples are the disruption of economic and social activities. Tangible effects can be quantified monetarily, while intangible effects cannot.

RiskScape can for instance estimate the number of affected people, expected number of injuries and fatalities, and number of people who would require temporary accommodation. The results also include how many buildings and infrastructure elements might sustain damage or what the functional downtime will be. The building and infrastructure damage can be expressed either as damage in dollars, percentage damage (damage ratio) or as relative level of damages. Table 2.1 gives an overview of the impacts that RiskScape currently covers.

The RiskScape inputs and outputs can be displayed as spatial layers in the user interface. Maps and statistics from the final output can be derived and saved in various formats, as tabular (CSV/Excel), written (PDF) and graphical reports (maps), Google Earth maps or shapefiles which can then be further manipulated or analysed in the users' GIS environment. The output of the analysis can be viewed on an individual building level but must be aggregated to an aggregation unit for the output. The default RiskScape install includes meshblocks, suburbs and a 1km grid in each area for which the default install also includes asset data, but custom aggregation units can easily be added using the respective toolbox.

**Table 2.1: Summary table of impact categories currently addresses in RiskScape (as of June 2011).**

| | Hazards | | | | |
|---|---|---|---|---|---|
| | Earthquakes | Volcanic ash | Floods | Tsunami | Wind |
| Direct impacts | | | | | |
| Buildings | ? | ? | ? | ? | ? |
| Content | ? | ? | ? | ? | ? |
| Vehicles | ? | | ? | ? | |
| Roads | | ? | ? | ? | |
| Railway | | | | | |
| Water supply netwk | ? | ? | ? | ? | ? |
| Sewage netwk | ? | ? | ? | ? | ? |
| Stormwater netwk | ? | ? | ? | ? | ? |
| Telecommunications | | | | | |
| Power netwk | | | ? | | |
| Agricultural | | ? | | | |
| Indirect impacts | | | | | |
| Displacement | ? | | ? | ? | ? |
| Clean-up time | | | ? | ? | ? |
| Clean-up costs | | | | | |
| Network disruption | | | | | |
| Business disruption | | | ? | ? | ? |
| Loss of revenue | | | ? | ? | ? |
| Costs of relocation | | | | | |
| Increased costs medical treatment + care | | | | | |
| Costs of emergency response & relief | | | | | |
| Injuries | ? | | ? | ? | ? |
| Fatalities | ? | | ? | ? | ? |
| Human susceptibility | | | ? | | |
| Social vulnerability | | | | | |
| Deprevation index | ? | ? | ? | ? | ? |

? implemented

## 2.5 Limitations

The Regional RiskScape decision-support tool has been through a 7-year development phase, including the 4 year proof-of-concept. Much has been achieved in firming up the concepts and undertaking development through the cooperative effort of two institutes working together. However, the lack of a national asset database and the absence of good damage/vulnerability data in New Zealand have had some influence on the progress of the development. Even though RiskScape is now available at no costs with a 2 months test licence, it is not quite ready to become operational. A lot of effort is currently being put into the asset repository and a national building database, which will allow users outside the three partner regions (Christchurch, Buller District and Hawkes Bay Region) to make use of RiskScape. In parallel, progress is being made on getting access to critical infrastructure information.

Riskscape needs more input and feedback from end-users to get a better idea of what functionality is required and if the output formats meet their requirements. The presented system is currently only capable of modelling and comparing multiple independent risk scenarios. The system does not allow modelling the interaction between multiple hazards and assets in a risk scenario. Often multiple hazards occur simultaneously, for example landslips related to storm or earthquake events. This will be addressed in the future as well as uncertainties. It is planned to include uncertainty quantifiers in the hazard, asset, and fragility modules. Then, the RiskScape System will be able to quantify both the contribution of input errors and model errors to the final risk calculation and can quantify risk uncertainty as upper lower bounds of expected losses around the currently estimated loss.

Despite its limitations, the generic framework is the strength of the developed system. As long as a user accepts the constraints of the definitions of the system as described in this paper, any (natural) hazard can be applied to any inventory to calculate risk, as long as the necessary inventory attributes are in place to allow application of the new hazard exposure via the new fragility curves (Schmidt et al. 2011).

## 2.6 Obtaining the Riskscape Tool

Contact the author of this report for information about obtaining and using this Tool.

# 3. References


Bell, R. and King, A. (2009). RiskScape Project: 2004 - 2008, NIWA Science Report 2009/75. 172p.

Blong, R. (2003). A new damage index. Natural Hazards, 30 (1): 1–23.

Bureau of Transport Economics (2001). Economic costs of natural disasters in Australia. Report 103, Bureau of Transport Economics, Commonwealth of Australia, Canberra.

Cannon, T.; Twigg, J.; Rowell, J. (2005): Social Vulnerability, Sustainable Livelihoods and Disasters [online]. Report to DFID Conflict and Humanitarian Assistance Department (CHAD) and Sustainable Livelihoods Support Office. London. Available at: http://www.proventionconsortium.org/themes/default/pdfs/CRA/DFIDSocialvulnerability_meth.pdf [Accessed 17 May 2011]

Douglas, J. (2007). Physical vulnerability modelling in natural hazard risk assessment. Nat. Hazards Earth Syst. Sci., 7: 283–288.

Durham, K. (2003). Treating the Risks in Cairns. Natural Hazards, 30 (2): 251–261.

Hollenstein, K. (2005). Reconsidering the risk assessment concept: Standardizing the impact description as a building block for vulnerability assessment. Natural Hazards and Earth System Sciences, 5, 301–307.

Ministry for the Environment (2008). Climate Change Effects and Impacts Assessment: A Guidance Manual for Local Government in New Zealand. 2nd Edition. Mullan B; Wratt D; Dean S; Hollis M; Allan S; Williams T, Kenny G and MfE. Ministry for the Environment, Wellington. xviii + 149 p.

McBean E., Fortin M., Gorrie J. (1986). A critical analysis of residential flood damage estimation curves. Can. J. Civ. Eng., 13: 86–94.

Middelmann-Fernandes, M.H. (2010). Flood damage estimation beyond stage-damage functions: an Australian example. Journal of Flood Risk Management, 3: 88-96.

Reese, S. & G. Smart (2008). High resolution inundation modelling as part of a multi-hazard loss modelling tool. In: Samuels, P., Huntington, S. Allsop, W. & J. Harrop (eds): Flood Risk Management. Research and Practice. Proceedings of the European Conference on Flood Risk Management Research into Practice (FloodRisk 2008), Oxford, Uk, 30.09-02.10.2008, pp. 1663-1668.

Reese, S. & D. Ramsay (2010). Riskscape: Flood fragility methodology. NIWA technical report, WLG-2010-45.

Reese, S. Bradley, B.A., Bind, J., Smart G.M., Power, WJ., Sturman, J.D. (2011). Empirical building fragilities from observed damage in the 2009 South Pacific tsunami. Earth Science Reviews, Special issue. doi:10.1016/j.earscirev.2011.01.009

Reese, S. (in press): Tsunami impacts. Chapter in the National Tsunami Review for the Ministry of Civil Defence and Emergency Management. GNS-Report.

Schmidt, J., Matcham, J., Reese, S., King, A., Bell, R., Smart, G., Cousins, J. Smith, W., and D. Heron (2011). Quantitative multi-risk analysis for natural hazards: a framework for multi-risk modelling. Nat Hazards. DOI: 10.1007/s11069-011-9721-z

Schultz, M.T., Gouldby, B.P., Simm, J.D., Wibowo, J.L. (2010). Beyond the Factor of Safety: Developing Fragility Curves to Characterize System Reliability. USACE Water Resources Infrastructure Program, Final report ERDC SR-10-1.

Standards Australia/Standards New Zealand (2004). Risk Management Guidelines. Companion AS/NZS 4360:2004. Sydney & Wellington.

RiskScape manual: Available online at www.riscscape.org.nz