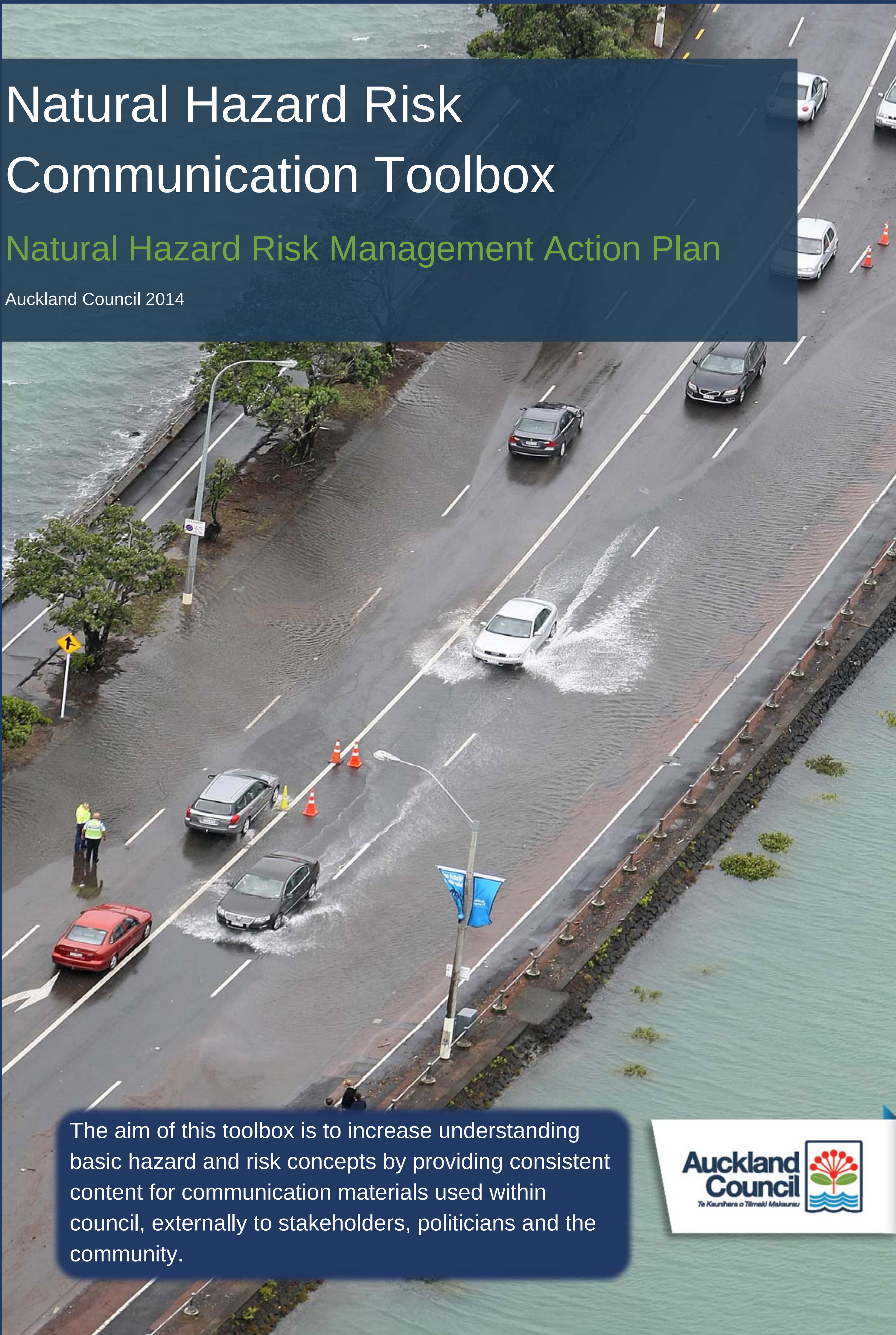
Natural Hazard Risk Communication Toolbox

Natural Hazard Risk Management Action Plan

Auckland Council 2014



The aim of this toolbox is to increase understanding basic hazard and risk concepts by providing consistent content for communication materials used within council, externally to stakeholders, politicians and the community.

Auckland Council
Te Kaunihera o Tāmaki Makaurau

Natural Hazard Risk Communications Toolbox

Auckland council in conjunction with GNS Science, have developed a Natural Hazard Risk Communications Toolbox. The purpose of this toolbox is to increase understanding of basic hazard and risk concepts by providing consistent content for communication materials used within council and externally to stakeholders, politicians and the community.

Staff from a wide range of Council teams work with a wide range of people in all aspects of natural hazard and/or risk management. The benefit of adopting common terminology and definitions provided by this toolbox can help to foster a better understanding of sometimes complex terminology when communicating natural hazard and risk concepts.

The toolbox has been produced to support the development of the Natural Hazard Risk Management Action Plan.

What is the Natural Hazard Risk Communications Toolbox?

The toolbox contains written and visual materials to describe 13 frequently used natural hazard risk management concepts. For each concept the following information is provided:

- Brief text explanations
- More detailed explanations
- Visual representation
- Auckland case study (where possible)

Why have we created this toolbox?

Staff identified several issues when communicating natural hazard and risk terminology including:

- Many of the terms used for natural hazard management are technical and abstract making the exchange of information difficult at times;
- Auckland Council staff have different levels of understanding and varying personal experiences which influence their understanding;
- Different terms are sometimes used interchangeably with the same meaning, or terms are used in the wrong context creating misunderstanding among different audiences; and,
- Auckland Council does not have standard definitions for natural hazard risk terminology.

The toolbox has been created with these issues in mind and aims to provide staff with the appropriate tools to communicate natural hazard concepts with other staff in council. The toolbox provides one set of definitions which can be used to create a shared understanding within council, creating a consistent and integrated approach to communicating natural hazard risk management

Contents

Hazard Vs Risk

Definitions

A natural hazard means any atmospheric-, earth-, or water-related occurrence (including earthquake, tsunami, erosion, volcanic and geothermal activity, landslip, subsidence, sedimentation, wind, drought, fire, or flooding), the action of which adversely affects or may adversely affect human life, property, the economy, or other aspects of the environment (combined, these are often referred to as elements at risk; Resource Management Act, 1991).

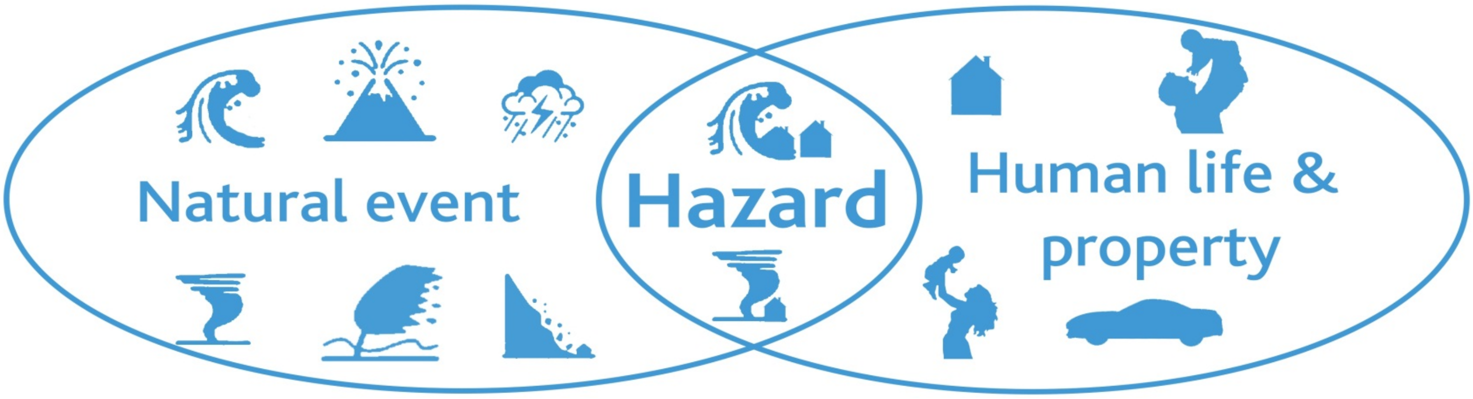


Figure 1. A hazard involves an interaction between human life and property and natural events that could cause damage.

Risk is the "*likelihood and consequences of a hazard*" (NZ CDEM Act, 2002). Therefore risk considers the consequences which may be caused by the hazard. 'Consequences' refers to an impact on the natural, economic, built or social environments as a result of the hazard. The consequences are influenced by the vulnerability of elements at risk, by the exposure of elements at risk to the hazard, and by the characteristics of the hazard. Risk also considers the likelihood of the hazard occurring, which depends on the type of hazard.

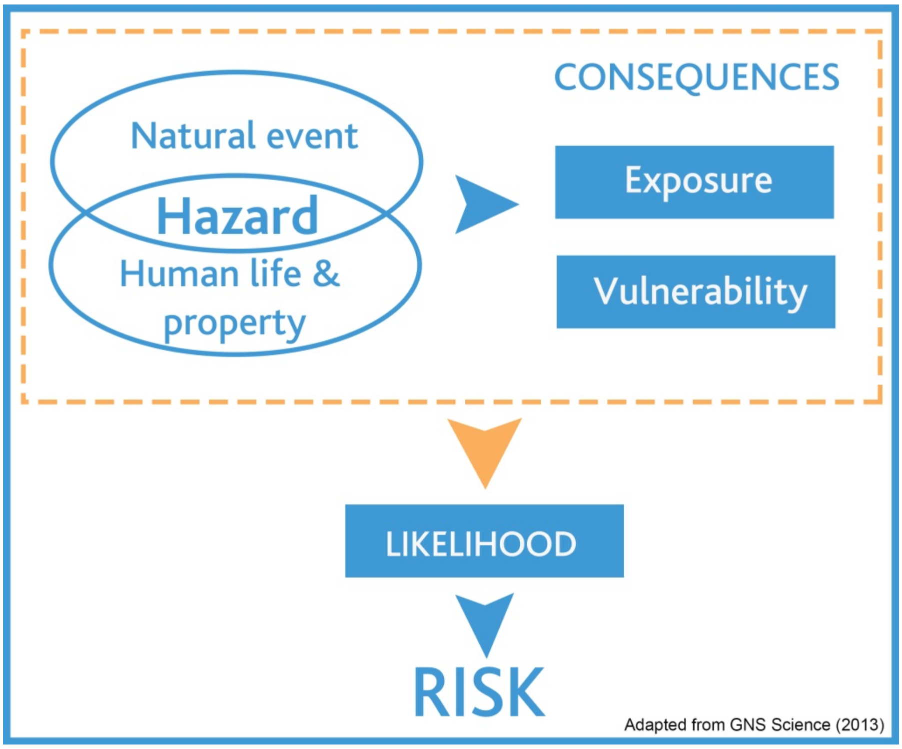


Figure 2. Schematic showing the components of risk.

Explanation

A hazard is an event that is actually occurring, which is having, or has the potential to impact on human life, property, buildings, lifelines, and the economy (combined, these are referred to as elements at risk). The level of hazard depends on the event characteristics. Natural hazards are often classified by:

- Magnitude – how large is the event in terms of energy produced (earthquakes, wildfire), volume (flood, volcanic ash), wind speed (storms), or material displaced (landslides, coastal erosion)?
- Duration – how long will the event last?
- Extent – what geographical area will potentially be affected?
- Speed of onset – will the onset be a few seconds to a few hours (e.g., earthquakes, local source tsunami, flash floods); a few hours to a few days (e.g., storm winds, storm surge, frosts, river floods) or will it have a slow onset (e.g., drought)?
- Risk refers to future events, because as well as considering the characteristics of the hazard and the potential consequences, risk also considers likelihood.

The figure below (figure 3) shows a flooded river in a town. Away from civilisation, the flooded river is just a natural event. In this section of the river, it is a hazard to the houses, people and infrastructure etc. that are being directly or indirectly affected by this event. If this flood was increasing in magnitude with flood waters rising, there is a potential that a larger area could be flooded. Those areas would be at risk of being impacted by the flood. To determine the level of risk posed to these areas, the follow things need to be considered:

- The natural event (e.g. the duration and intensity of rainfall causing the flood, the potential water level increase, the extent of the area potentially affected).
- Elements at risk in the area (e.g. the number and locations of people, the cultural and economic value of the property and buildings, the location and type of infrastructure).

- The potential consequences of the flood on those areas, influenced by the characteristics listed in the above two bullet points, as well as the exposure and vulnerability:
- exposure (e.g. the length of time a person will be in the area, how long an asset will be subject to the floodwater, and to what depth).
- vulnerability (e.g. the robustness of infrastructure and buildings, the health and resilience of people in the area).
- The likelihood of the event occurring (i.e. the chance of the river flooding to a specific level, or inundating a certain area).

Figure 3. The interaction of a flooded river with a town is a hazard. The risk of future floods can be estimated by considering the characteristics of the natural event and elements at risk, the potential consequences of the event, and the likelihood of the event occurring. Source: Ministry of Civil Defence and Emergency Management.

If people in the area receive a warning and are able to evacuate before the rising floodwaters inundate the houses, their exposure, and therefore their risk, is low. Buildings are unlikely to be able to be moved in time, causing their exposure to the flood to be high. The level of risk for these buildings depends on the flood characteristics and on the vulnerability of the buildings. Both the buildings and the people are affected by the same hazard, but there is a difference in the level of risk they face.

A risk eventuates when elements (e.g. human life and property) are vulnerable and exposed to a hazard. The level of risk can be described quantitatively (e.g. dollar losses, fatalities) or qualitatively (e.g. minor, moderate, severe), and incorporates the likelihood of a particular hazard event impacting elements at risk.

The greater Auckland area is potentially at risk from a wide range of hazards. Knowing the hazards which will affect Auckland only assists with part of the risk management process. The likelihood, vulnerability, and exposure of elements at risk to the hazards should be considered in order to ascertain the risk, and to determine how best to reduce possible consequences.

Risk is managed in a range of different ways. It is very rarely possible to eliminate all risk, and therefore some potential consequences usually remain despite effective risk management. These potential losses or impacts are termed the residual risk.

References

- Civil Defence Emergency Management Act (2002) The Ministry of Civil Defence and Emergency Management, 7, 33 Stat. 71 (1 December 2002)
- Resource Management Act (1991) Part 1, Section 2.

Resilience

Definition

Resilience can be defined as the ability to adapt to the demands, challenges and changes encountered during and after a disaster (Paton, 2006).

Explanation

Improving resilience contributes toward ensuring society as a whole can adapt to a disaster. Resilience helps to reduce the impact of an event on society, including during recovery.

Resilience applies to a wide range of contexts. Community members need to adapt individually and collectively in order to effectively respond to, and recover from, a disaster. Likewise, businesses and wider societal organisations need to adapt at short notice to a disaster, which is an important component of reducing the impact on the economy. Critical infrastructure needs to be designed and maintained to ensure a certain level of service is provided after a disaster, and to ensure that full services can be restored as quickly as possible.

In adapting, it will be necessary to draw upon relevant resources including those for individuals, communities, and organisations. Resources can be considered in a broad context and may include human resources (e.g. personal abilities and competencies, personnel), physical resources (e.g. items available for use during and after a disaster such as generators, spare equipment, food, and water), and financial resources (e.g. insurance, and money available to fund adaptive efforts).

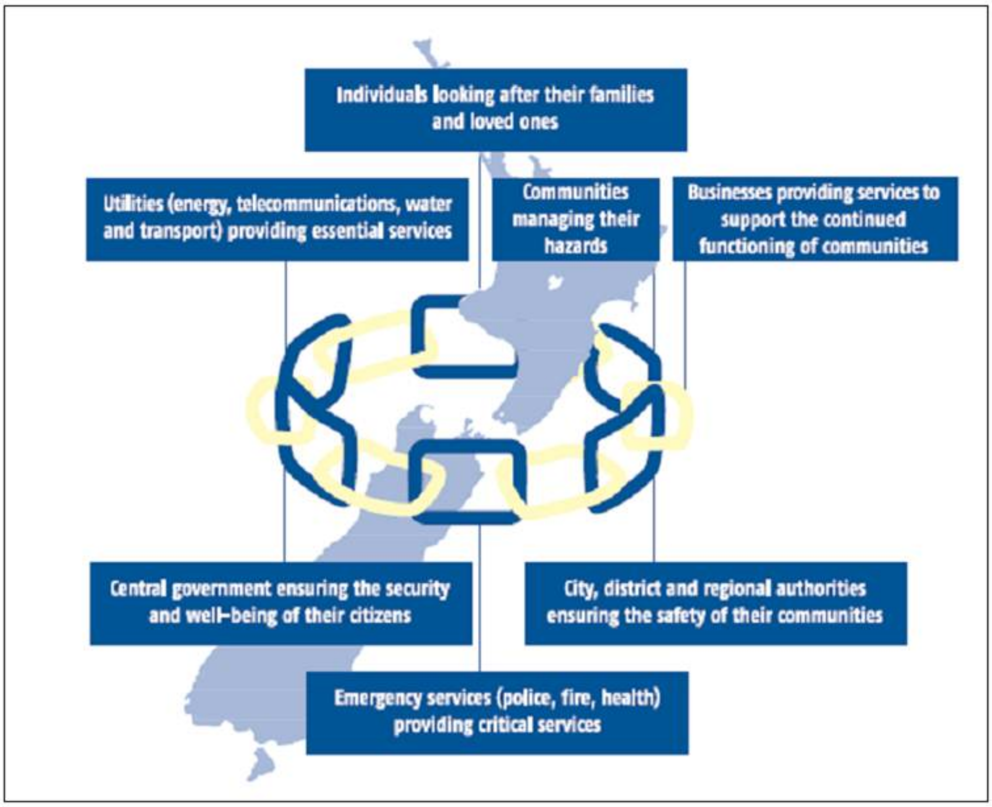


Figure 4. Key components of resilience (MCDEM, 2008, p 7).

The following list has been adapted from UN-ISDR (2012) as a description of a disaster-resilient community:

- Is one where consequences are minimised because the community lives in homes and neighbourhoods with organised services and purpose-built infrastructure that adheres to building codes, and without inappropriate development built on unsuitable land (such as flood plains or steep slopes) because no other land is available.
- Has an inclusive, competent and accountable local government that is concerned about sustainable urbanisation, and that commits the necessary resources to develop capacities to manage and organise itself before, during, and after a natural hazard event.
- Is one where the local authorities and the community understand their risks and develop shared, local information based on both real and potential disaster losses, hazards, and risks, including who is exposed and who is vulnerable.
- Is one where people are empowered to participate, decide, and plan their city together with local authorities, and to value local and indigenous knowledge, capacities and resources.
- Has taken steps to anticipate and mitigate the impact of disasters, incorporating monitoring and early warning technologies to protect infrastructure, community assets and individuals (including their homes and possessions), cultural heritage, environmental and economic capital; and is able to minimise physical and social losses arising from extreme weather events, earthquakes or other natural or human-induced hazards.
- Is able to respond to the situation, implement immediate recovery strategies, and quickly restore basic services to resume social, institutional, and economic activity after an event.
- Understands that most of the above is also central to building resilience to adverse environmental changes, including climate change, in addition to reducing greenhouse gas emissions.

By incorporating these strategies, vulnerabilities are identified and decreased, and potential consequences are minimised, increasing resilience. Research has investigated various aspects relating to resilience (see Daly et al., 2009; Paton, 2007; and Stephenson et al., 2010 for more details).

Case Studies

Example 1

An example of the components of resilience, specific to flooding (from Queensland, Australia), is shown in the figure below. In this example, the focus is on integrated floodplain management with an emphasis on land use planning. Many of the underlying components of resilience are included: through community awareness, individuals are looking after themselves and others; infrastructure providing essential services; communities managing their hazards with the flood information and suite of measures available; and emergency plans providing critical services (e.g., flood warning and evacuation planning). The figure is set within the wider context of state and local government providing for the well-being and safety of their communities.

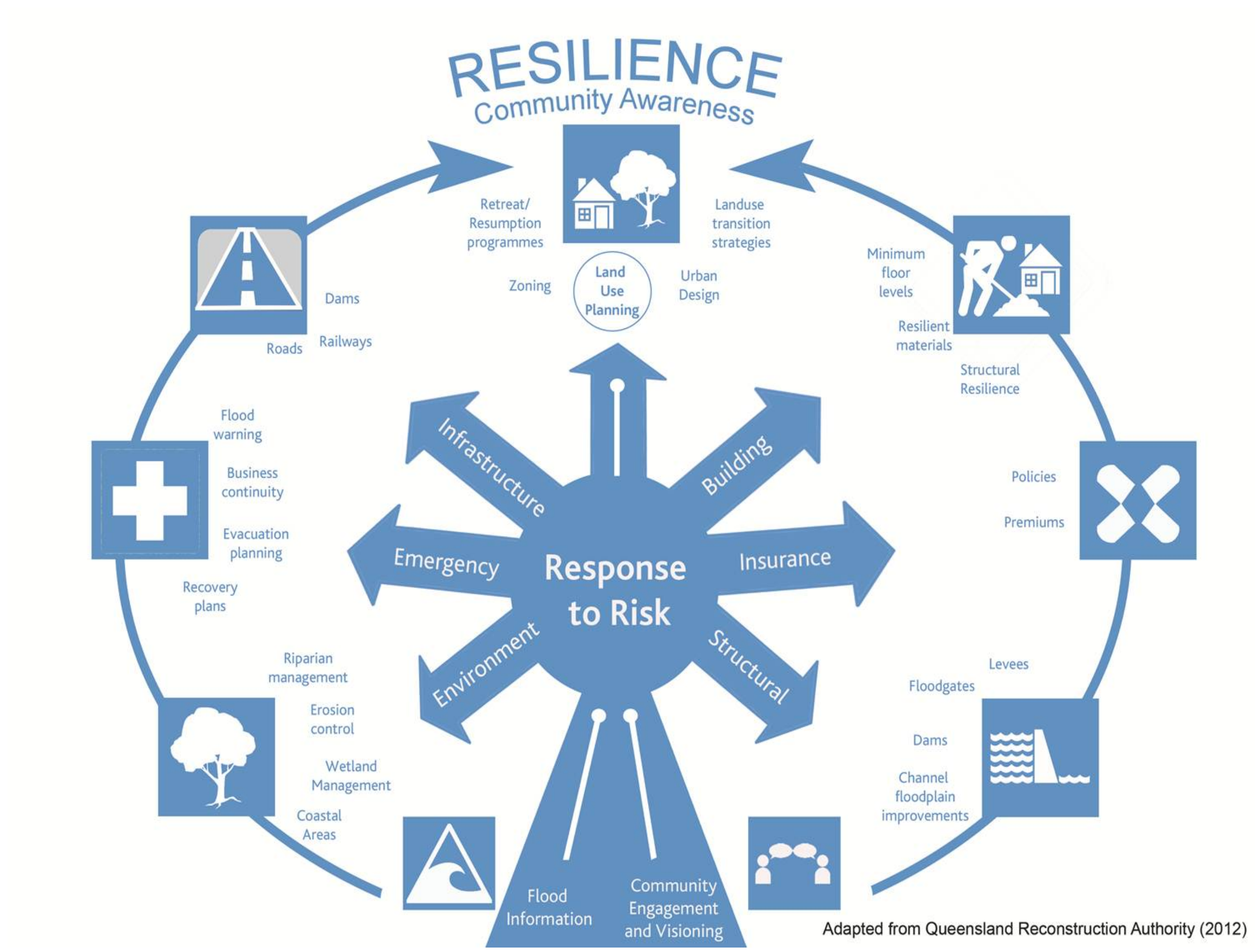


Figure 5. A comprehensive suite of measures that contribute to building resilience in the floodplain (Queensland Reconstruction Authority, 2012, p 5).

Example 2

The Auckland Engineering Lifelines Group (http://www.aelg.org.nz), which was formed in 1996, seeks to improve the resilience of Auckland's critical infrastructure to hazard events, so that the community is better able to recover. The AELG provides advice and assistance to lifeline utilities such as water, transport, power, fuel, and telecommunications organisations, to identify hazards, lifeline vulnerabilities, and mitigation options. The work focuses on the interdependencies of lifelines (i.e. reliance on each other) and on the combined networks as a system. Similar improvement in resilience of lifelines in Christchurch proved to be valuable, reducing damage and destruction following the Canterbury earthquakes.

References

- Daly, M., Becker, J., Parkes, B., Johnston, D., Paton, D. (2009). Defining and measuring community resilience to natural disasters: a case study from Auckland. Tephra 22: 50-20.
- MCDEM (2008). National Civil Defence Emergency Management Strategy 2007. Wellington: Department of Internal Affairs.
- Paton, D. (2006). Disaster resilience: Integrating individual, community, institutional and environmental perspectives. In D. Paton & D. Johnston (eds.), Disaster resilience: An integrated approach. Springfield, Ill., Charles C. Thomas.
- Paton, D. (2007). Measuring and monitoring resilience in Auckland, GNS Science Report 2007/18. 88 p.
- Queensland Reconstruction Authority (2012). Planning for stronger, more resilient floodplains: State of Queensland.
- Stephenson, A., Vargo, J., Seville, E. (2010). Measuring and comparing organisational resilience in Auckland. The Australian Journal of Emergency Management, Volume 25, No 2, pp 27 - 32
- UN-ISDR (2012). How to make cities more resilient: A handbook for Local Government leaders. A contribution to the global campaign 2010-2015, Making Cities Resilient – My City is Getting Ready! United Nations, Geneva, March 2012.

Levels of Risk

Definition

The level of risk can be described quantitatively (e.g. dollar losses, fatalities) or qualitatively (e.g. minor, moderate, severe; or low, medium, high), and incorporates the likelihood of a particular hazard event impacting elements at risk (e.g. human life and property). To assist with risk management, these levels of risk can be categorised as acceptable, tolerable, and intolerable.
These categories are defined by Standards New Zealand (2004) as:

1. **Acceptable risks**, where positive or negative risks are negligible, or so minimal that no mitigation measures are required;
2. **Tolerable risks**, where opportunities (benefits) are balanced against potential adverse consequences (costs). Tolerable risk is a willingness by society (although perhaps not by specific individuals) to live with risk in order to gain certain benefits, and requires the risk to be managed in some way (Health & Safety Executive, 2001); and\
3. **Intolerable risks**, where the risks are intolerable regardless of the benefits the activity may bring, and risk reduction measures are essential no matter the cost.

Explanation

Our lives will never be completely risk free as, realistically, zero risk is unobtainable. We need to create some sort of baseline explaining which levels of risk are acceptable and which are not. The 'as low as reasonably practicable' (ALARP, as shown in the figure below) approach is often used, where a level of risk is deemed tolerable where benefits outweigh the costs, and/or risk reduction measures are considered adequate.

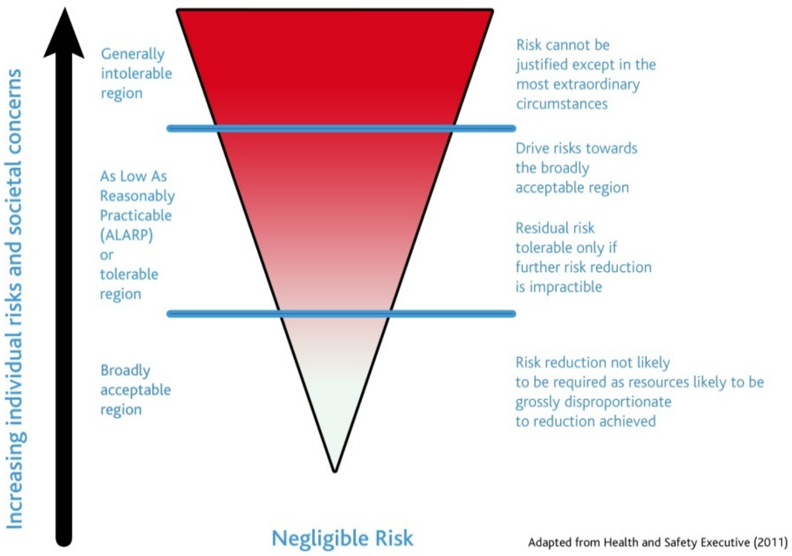


Figure 6. The 'As Low As Reasonably Practicable' (ALARP) approach (Health & Safety Executive, 2001).

For example, people who live in coastal locations may tolerate occasional flooding of their property for the perceived benefits of their proximity to the beach, views, and amenity value. However, if their property was to continually flood (e.g. due to sea level rise), the risk may become intolerable. A risk reduction response may then be required, such as managed retreat, to reduce the risk.

There are three primary methods for measuring levels of risk:

1) **Qualitative analysis**, which uses words to describe the magnitude of potential consequences, and the likelihood that the event will occur. An example of this is a risk matrix, which can be colour-coded to make it easier to understand the level of associated risk (as shown in the table below). A high level of risk (red) can be deemed intolerable; a medium level of risk (yellow) tolerable, and a low level of risk (green) acceptable.
2)

	Consequences		
Likelihood	**Minor**	**Moderate**	**Major**
Likely	Medium level of risk	High level of risk	High level of risk
Possible	Low level of risk	Medium level of risk	High level of risk
Unlikely	Low level of risk	Low level of risk	Medium level of risk

Example of a qualitative risk matrix to determine a level of risk (adapted from Standards New Zealand, 2004, p56)

2) Quantitative analysis, which uses numerical values for both consequences and likelihood, as shown in the figure below.

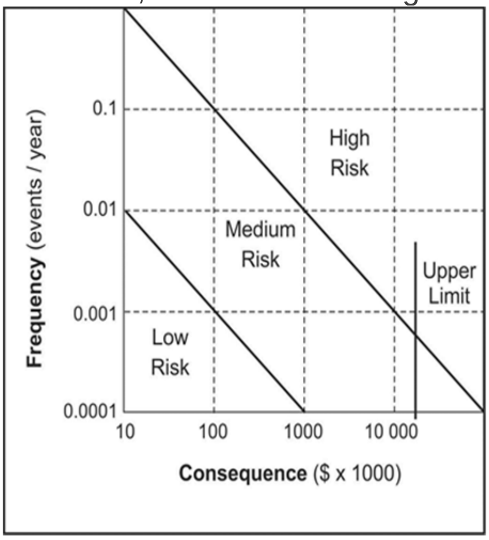


Table 1. Quantitative method for estimating risk (Standards Australia/New Zealand (2004, p50-52)

3) Semi-qualitative analysis, which uses a combination of words and numerical values, as shown in the Figure below.

Frequency (events / year)				
0.1	10	30	100	300
0.01	1	3	10	30
0.001	0.1	0.3	1	3
0.0001	0.01	0.03	0.1	0.3
	V.Low (100	**Low** 300	**Medium** 1000	**High** 3000)
	Consequence ($ x 1000)			

Table 2. Semi-quantitative method for estimating risk. 'Frequency' is equivalent to 'likelihood' used in the text (Standards Australia/New Zealand (2004, p50-52)

References

- Health and Safety Executive (2001). Reducing risks, protecting people: HSE's decision making process. Sudbury: HSE Books.
- Standards Australia/New Zealand (2004). Risk Management Guidelines. Companion to AS/NZS 4360:2004. Wellington: Standards Australia/Standards New Zealand.
- Standards New Zealand (2004). Risk Management Guidelines: companion to AS/NZS 4360:2004: Standards Australia/Standards New Zealand.

Consequences

Definitions

A consequence can be defined as an impact on the natural, economic, built or social environment as the result of a hazard event. Consequences are influenced by the exposure and vulnerability of elements at risk (e.g. human life and property) to the hazard, and by the hazard characteristics.

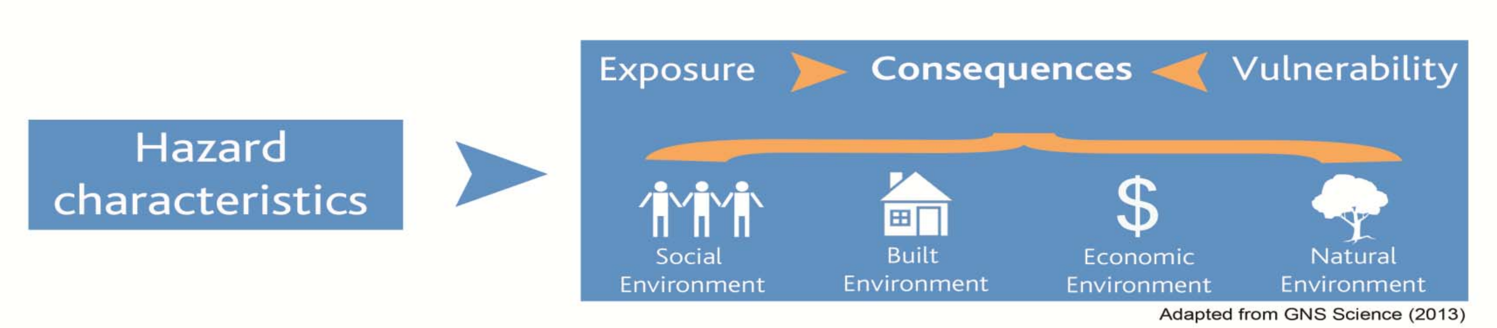


Figure 7. Consequences are determined by the exposure and vulnerability of elements at risk (e.g. human life and property) to the hazard, and by the characteristics of the hazard. For Civil Defence Emergency Management Purposes, consequences are considered in four main environmenta, centralised by the community.

Explanation

The consequences of a natural hazard event are usually determined by considering the following aspects:

Hazard characteristics:

- What hazards could affect elements at risk in a certain area?
- What are the characteristics of those hazards, e.g., the magnitude, duration, extent and speed of onset?
- How do we value the elements potentially at risk of being impacted by the natural event (e.g., dollars, function, people's health)

Exposure:

- What is the exposure of the elements at risk to the potential hazards?

Vulnerability:

- How vulnerable are the elements at risk in the area to each type of hazard?

For Civil Defence Emergency Management purposes, we typically consider consequences for four environments of interest: social, built, economic and natural.

These are shown in the table below.

The consequences of an event are influenced by the elements at risk (including human life and property), considered in four main environments

Environment	Elements at risk
Built	Commercial, residential and inductrial buildings; infrastructure; urban fabric; and, community facilities (schools, hospitals, churches etc.)
Social	Casualties (injuries or deaths of people), community assets and networks, relationships and support systems
Economy	Businesses, jobs, trade and services.
Natural	Ecosystems and their services, recreational amenities (e.g. parks), agriculture and horticulture.

Consequences can be described qualitatively (e.g. minor, moderate, severe) or quantitatively (e.g. numbers of deaths or injuries, dollar losses, cost of reconstruction, number of jobs lost; e.g. Schmidt-Thomé et al., 2007). It is possible for the consequences of events to be both positive and negative. For example, an event which destroys many buildings (primary impact is on the built environment) may provide the opportunity for urban renewal and growth in construction sector employment rates (positive for the economic and social environments). There may also be a mix of consequences for the social environment, with casualties, insurance pay-outs, strengthened neighbourhood support networks, and the loss of social services; and the natural environment, with debris disposal, or land-use changes (e.g. from developed to recreational). Determining both positive and negative potential consequences of a natural hazard impact allows the risk relating to future events to be assessed.

Describing consequences is an important part of being able to communicate risk. There are many tools available that can graphically illustrate the consequences of an event, which, in combination with an understanding of the likelihood of the event occurring, can help people to better understand and appreciate their potential risk. These tools include scenarios, experiential simulations or exercises, and computer models. Records, images and stories from actual natural hazard events can also be powerful in representing the types of consequences that can result from a range of hazards.

Case Studies

Example

A single event can create consequences across the four environments shown in Figure A 10. This is demonstrated by the tornado which struck the Whenuapai and Hobsonville area on 6 December 2012 (as shown on the figure and table below). The consequences were a result of the hazard (the tornado interacting with elements at risk) and its characteristics (including high wind speed, a relatively small area impacted, the duration of the tornado on the ground, and the fast onset limiting preparation and warning time), combined with the extent of the exposure of elements at risk to the hazard (i.e. the number of buildings and type of infrastructure hit by the tornado), and the vulnerability of the exposed elements at risk to the hazard (e.g. the susceptibility of buildings to be damaged by the high wind speed).

Figure 8. The 6 December 2012 tornado at Whenuapai resulted in major damage to dwellings, resulting in people being displaced from their homes (i.e. consequences to the built and social environments). Source: Auckland Council.

Qualitative and quantitative consequences caused by the 6 December 2012 Whenuapai tornado (sources are Auckland Council 2012; NIWA, 2012; Insurance Council of New Zealand website).

Social	Economic	Built	Natural
3 deaths 7 hospital admissions 79 people requiring welfare support 123 people requiring emergency accommodation Power disrupted to 1300 homes	$8.7m in insurance claims $12m clean up 33 flights cancelled	384 properties damaged 8 power poles needed replacing Roads closed due to surface flooding	Trees uprooted

References

- Auckland Council (2012). Auckland Group Emergency Operating Centre (GEOC) Update Number 13 - Tornado event and severe weather at Whenuapai, Hobsonville and other parts of Auckland.
- Insurance Council of New Zealand. The Cost of Disaster Events. http://icnz.org.nz/statistics-data/the-cost-of-disaster-events/ accessed 19 September 2013.

Likelihood

Definition

Likelihood is the chance of something occurring. When describing the likelihood of a natural hazard event, two main descriptors are used:

- *Average Recurrence Interval (ARI)* – the average period of time between hazard events of a given magnitude, and often referred to as a return period (e.g., a 1 in 100 year event).
- *Probability of Exceedance* – the probability that a natural hazard event of a certain size will occur, or will be exceeded, in a given time period. If the time period is one year, it is referred to as an *Annual Exceedance Probability (AEP)*.

Explanation

Estimating the likelihood of a natural hazard event to occur in the future is a key part of assessing risk. To calculate the likelihood, the first step is knowing how often (also known as the frequency) that type of event has occurred in the past.

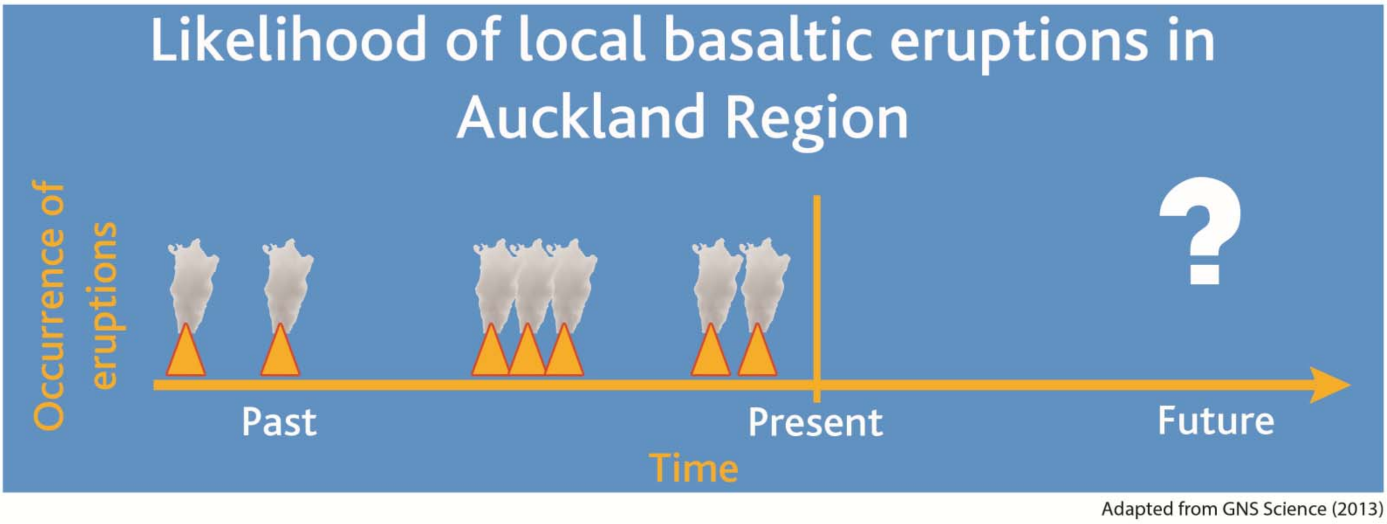


Figure 9. The likelihood of future local basaltic eruptions depends on how often similar events have occurred in the past.

As an example, a local basaltic volcanic eruption may have occurred 20 times in the past 20,000 years in the Auckland region (note that these numbers may not be accurate; they are just being used to help demonstrate the concept of likelihood). To estimate the likelihood of a future local basaltic eruption in the Auckland region, this information can be dealt with in terms of either the average period of time between eruptions (ARI, or return period), or the probability of an eruption in a certain time period (known as the AEP if that time period is one year).

Average Recurrence Interval (ARI)

The ARI of a natural hazard event is often expressed as a return period. It is calculated by dividing the length of time by the number of specific hazards events which occurred. For example, the ARI of a local basaltic eruption in Auckland region is calculated by:

$$ARI = \frac{\text{Duration of Time}}{\text{Number of Events}} = \frac{\text{20,000 years}}{\text{20 eruptions}} = 1000$$

Another example is a flood of a certain magnitude with an ARI (or return period) of 1 in 100 years. This may also be referred to as a 1 in 100 year event, or as 1:100. The lower the ARI is, the more likely the event is to occur.

It is commonly found that the use of ARI can be confusing as it implies that the event will occur only at the stated return period, i.e. regularly once every 100 years. However, a 1 in 100 year event may occur several times in 100 years, or not at all. Using a dice as an analogy, there is a 1 in 6 chance that you will roll a five. However, if you roll a dice six times you may not roll a five at all, or you may roll a five multiple times. But over a larger sample of dice rolls, it would be expected that each number would be rolled an equal amount of times, giving an overall chance of 1 in 6 of rolling a number five.

To assist with overcoming the issue of understanding associated with the use of ARIs, it has been suggested that AEP is the preferable term to use (MfE, 2008).

Probability of Exceedance

As this measure of likelihood is in the form of a probability, it is expressed as a percentage or decimal value between 0 and 1. The probability of an event occurring refers to a specific time period, of any duration. The annual probability is often used, referred to as the AEP.

As the time period is increased, the chance of an event of this magnitude occurring or being exceeded increases (as indicated in the table below). The higher the AEP, the more likely the event is to occur. When comparing probabilities of exceedance, be sure to check the time periods used (they need to be the same for a direct comparison).

Using a 1 in 100 year flood as an example, there is a 1% probability of there being one or more floods in a certain location in any given year (this is equivalent to an event with an ARI of 1:100 years, see tables below). There is also the possibility that more than one of these events could occur in the same year (Saunders & Glassey, 2007).

	Chance of a 1% AEP event occurring or being exceeded in a certain timeframe			
Number of events	Single Year	10 year period	50 year period	100 year period
1	1%	9.6%	39.5%	63.6%
2	0%	0.4%	7.6%	18.5%
3	0%	0.01%	1.2%	6.1%

Table 3. Note that the ARI and probability of exceedance values refer to the likelihood of the event, but are not accurate descriptors of risk due to the lack of consideration of the potential consequences of the hazard.

The relationship between ARI and AEP is defined by the following formula:

AEP = 1 - exp (-1/ARI)

For natural hazard events with an ARI of greater than ten years, the AEP and ARI largely directly correspond to one another. Natural hazard events with an ARI of less than ten years have less correlation, as shown in the table belo. An event with a return period of 1 year has a 63.2% chance of occurring (AEP) in any given year. The AEP isn't 100%, because it isn't guaranteed to happen every year.

Relationship between the ARI and AEP

ARI (years)	AEP (%)
1	63.2
2	39.3
5	18.1
10	9.5
20	4.9
50	2
100	1
1000	0.1

Case Studies

Example

As part of the Auckland Engineering Lifelines Project in 1997 (Auckland Regional Council, 1999), ARI (return periods) and probabilities of exceedance over time periods of 1 year (i.e. AEP), 50 years and 100 years were calculated for a number of scenarios in the Auckland region (Table below). These were developed to assist lifelines (water, power, transport, fuel, telecommunications etc.) organisations to understand the likelihood of different hazard events occurring as a contribution to risk management (Auckland Regional Council, 1999). Table 1indicates that storm surge caused by a storm with a centre near Auckland is expected to occur more frequently (i.e. it is more likely) than other hazards listed in the table. The least likely hazard in this table is a 2.5 m local source tsunami, as it has the longest return period (ARI) and lowest AEP. The local basaltic eruption has a return period of 1000 years, and an AEP of 0.1 (Table below).

Return periods (ARI) and probability of exceedance for 1, 50 and 100 years for selected hazards in the Auckland region. Modified from Auckland Regional Council (1999).

		Probability of Exceedance (%)		
Hazard	**Return Period (years)**	**1 year**	**50 years**	**100 years**
Ground shaking (peak horizobtal ground accelerations, PGAs)	2000 (<0.3g)	0.05	2.5	4.9
As above	500 (<0.2g)	0.2	9.5	18
Liquefaction susceptibility	2000	0.05	2.5	4.9
Volcanic eruption (Distant andesite)	50 - 300	0.33 - 2.0	15 - 63	15 - 86
Volcanic eruption (Distant rhyolitic)	1000 - 2000	0.05 - 0.1	2.5 - 4.9	4.9 - 9.5
Volcanic eruption (Local basaltic)	1000	0.1	4.9	9.5
Tropical cyclone	100	1.0	39	63
Rain induced slope instability	100	1.0	39	63
Tsunami (2.5m local wave)	7000	0.014	0.71	1.4
Tsunami (1m wave)	1000	0.05	2.5	4.9
Tsunami (1 - 4m wave, far field)	75	1.3	49	74
Storm surge (centre crosses Auckland)	100	1.0	39	63
Storm surge (centre near Auckland)	6 - 7	13 - 15	99	99

References

- Auckland Regional Council (1999). Final Report – Stage 1 Auckland Engineering Lifelines Project Technical Publication No. 112 November 1999 ISSN No. 1172 6415
- MfE (2008). Coastal hazards and climate change: a guidance manual for local government in New Zealand. Wellington, Ministry for the Environment.
- Saunders, W. S. A., Glassey, P. (2007). Guidelines for assessing planning policy and consent requirements for landslide-prone land. GNS Science Miscellaneous Series 7. Lower Hutt, GNS Science: 76.

Vulnerability

Definition

Vulnerability is described as the characteristics and circumstances of elements at risk (e.g. human life and property) that make them susceptible to the damaging effects of a hazard.

Figure 10. Image outlining the concept of vulnerability

Explanation

Different characteristics of the natural, social, built and economic environments result in differences in vulnerability to hazards. Elements at risk (e.g. people, buildings, infrastructure, and the economy) may experience the same exposure to the same hazard, but be vulnerable in different ways, leading to differences in consequences, and subsequently, risk. Due to differences in how loss can be experienced, it is possible to be both vulnerable and resilient.

People can be considered less vulnerable than buildings to volcanic lava because they are more mobile and can move away from the lava flow front, but more vulnerable to toxic volcanic gases than buildings because buildings do not breathe. Vulnerability in people can be created in a variety of ways. The following examples highlight some possible contributors to vulnerability: pre-existing health conditions, limited mobility, lack of access to resources or transport for evacuation, hearing loss which prevents receipt of warnings or through limited capacity to understand warnings due to language comprehension difficulties. With regards to tsunami evacuation the elderly and very young are often seen as highly vulnerable, as they will typically require assistance to reach safety.

How structures will perform during natural hazard events is often described through the use of fragility curves. Fragility curves can show how all buildings of the same type based on attributes such as construction materials and number of storeys will respond to different intensities of a hazard (e.g. how all masonry buildings will respond to increasing intensities of earthquake shaking). These curves can also compare different building types (e.g. timber vs. concrete) exposed to the same hazard intensity as shown in the figure below. Fragility curves can also be used to calculate the risk from various events when combined with the value of the assets and the likelihood of an event. Structural measures can often be applied to reduce the vulnerability of buildings.

Once the vulnerability of people, buildings, infrastructure and other elements at risk have been determined, it can be reduced if necessary through risk treatment, as part of a risk management approach to managing natural hazards. Reducing the vulnerability to natural hazards contributes to increased resilience, reduced consequences, and reduced recovery times for future events.

References

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- Reese, S., Reid, S. (2006). Dealing to wind hazards in New Zealand. Water and Atmosphere Vol.14 No.4 - December 2006. NIWA.
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Changes in Risk Over Time

Definition

Sometimes risk changes over time. This can be referred to as 'time varying risk', which is simply the consideration of increases and decreases in risk over time.

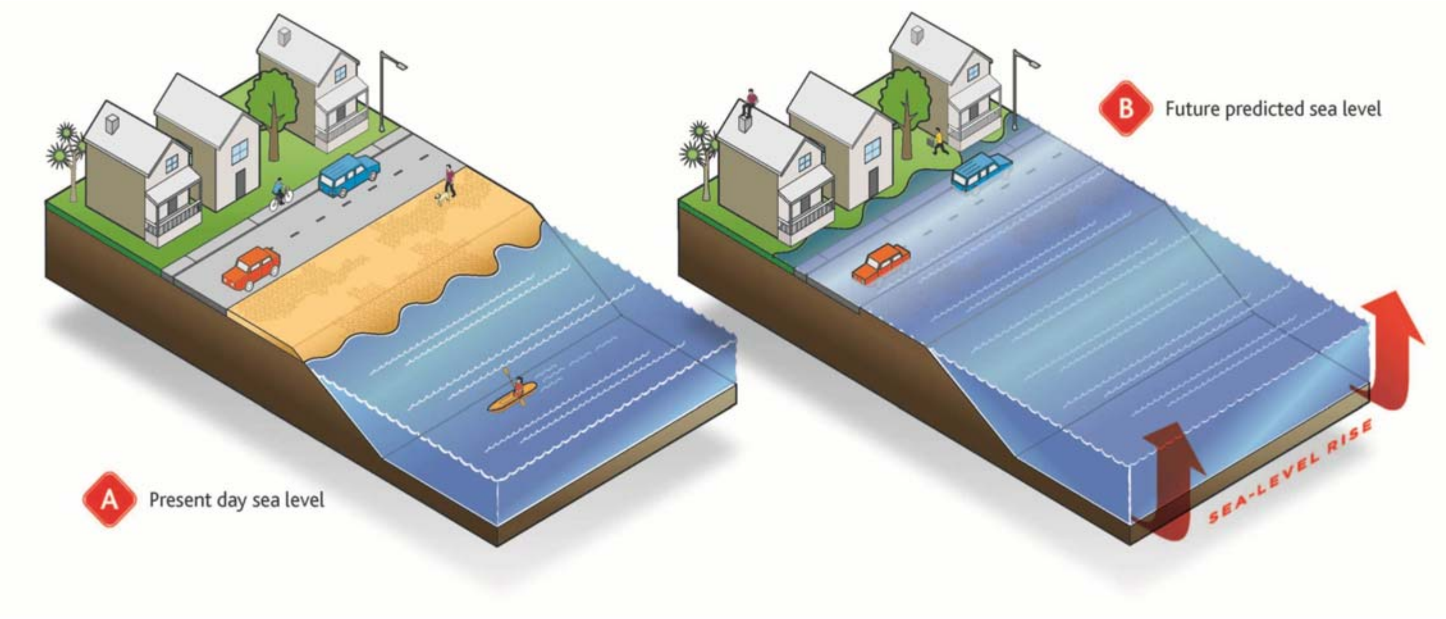


Figure 11. Example of changes in risk over time as a result of rising sea levels. Please click here for a full range of downloadable graphics.

Explanation

Risk is defined by New Zealand's CDEM Act (2002) as the likelihood and consequences of a hazard. Both likelihood and the potential consequences change over time, influencing the level of risk. For example, changes may be due to:

- A change in the likelihood of the natural hazard event occurring (e.g. ground shaking due to aftershocks is much more likely immediately following a large earthquake;
- A change in the level of consequences resulting from an event (due to an increase or decrease in either the level of exposure and/or the vulnerability of elements at risk; or
- A change to both the likelihood and potential consequences.

For example, there is a general trend for the economic risk to increase over time due to urban development in areas susceptible to natural hazards. There is also a general trend for health and safety risk to decrease over time from natural hazards, due to better building practices, warnings, and response actions following an event.

There are only a very limited number of examples where the risk from a natural hazard would not vary with time. An example of this is where there are a fixed number of assets which could be at risk from a natural hazard event. Many national parks in New Zealand contain baches that have historically been constructed on Department of Conservation land. The Department of Conservation no longer allows for further baches to be constructed on their property or for additions to be undertaken to existing buildings. As such, the consequences of the hazard are relatively fixed, and so, assuming there is no change in the likelihood of hazard events occurring, there is very little change in the level of risk over time.

Case Studies

Example 1

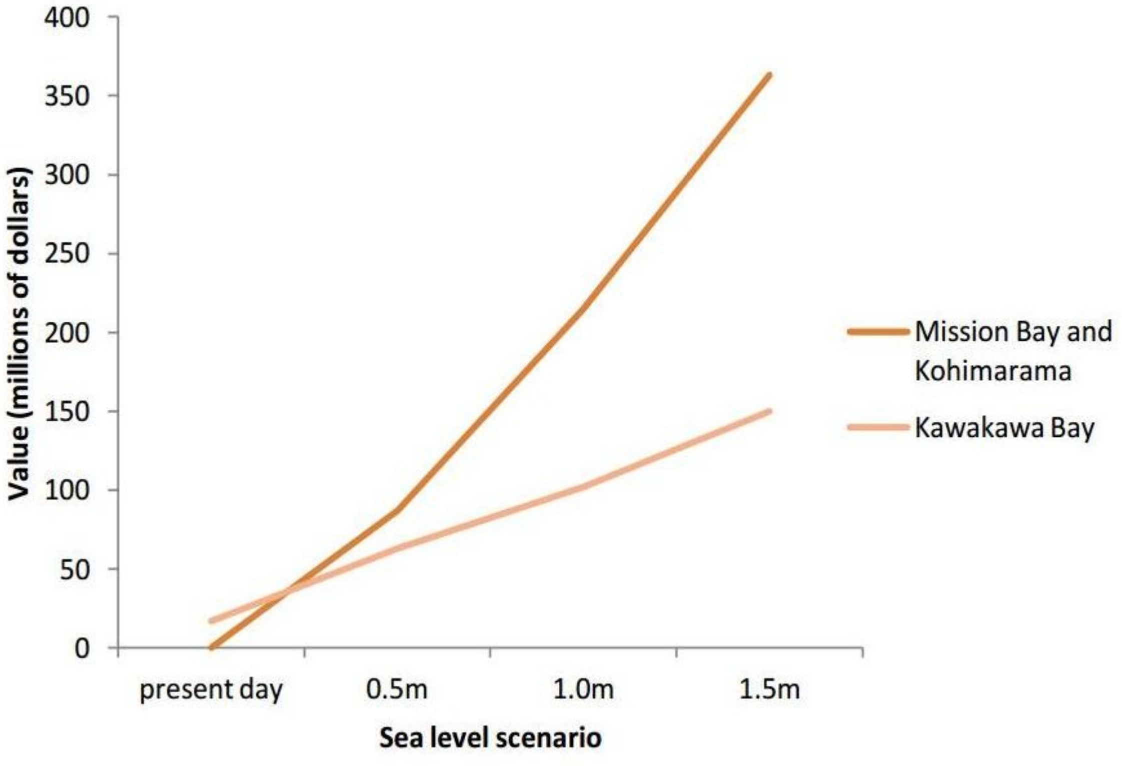
Due to climate change, the risk to coastal margins is changing over time, with a trend towards increasing risk. The reasons for this are as follows:

- Climate variation over time due to a combination of natural variability and the influence of climate change drivers, both of which influence the occurrence and magnitude of the hazard (e.g. storms);
- Changes in natural defences over time (e.g. a narrowing of beaches, or dune erosion), which influences the occurrence or magnitude of the hazard. This in turn can lead to increased consequences from storm events;
- Increased development over time along the coastal margins. This increases the consequences from storm events as more properties are being developed on the coastal margin which could be affected by storm events; and
- The value of the assets on the coastal margins is generally changing with time. Generally, the value of the assets is increasing, thereby increasing the economic consequences resulting from climate change influenced events (MfE, 2008).

Mission Bay is a coastal community and therefore is susceptible to changes to its risk profile over a long duration (decades) due to climate change. Table 1 summarises the likely number of people affected by a 1% AEP storm event for a variety of scenarios of sea level rise.

This table demonstrates the percentage of people in Mission Bay affected by a coastal inundation in a storm event with an AEP of 1% for a variety of sea level rise scenarios. Source: Hart (2011).

Mission Bay Population	**Sea Level Rise (SLR) Scenario**			
	Present Day	**0.5 m**	**1.0 m**	**1.5 m**
Total number	0	~518	~518	~1653
% of population affected	0%	4.2%	4.2%	13.6%



Graph demonstrating the total economic value of the properties potentially affected by coastal inundation during a storm event with an AEP of 1% for a variety of sea level rise scenarios for Mission Bay and Kawakawa Bay. Source: Hart (2011).

The table and figure below demonstrate that as the sea level changes over time, the number of people and the total value of the properties affected by coastal inundation from a storm event with a 1% AEP increases. As such, the risk from a storm event with a 1% AEP for Mission Bay is increasing with time.

Example 2

An example of a short-duration, time-varying risk is from damaging earthquake aftershock events from the four major Canterbury earthquakes in September 2010, February 2011, June 2011, and December 2011.
The table below summarises the expected probabilities of exceedance of further earthquakes anywhere in the entire Canterbury region aftershock zone. The figures are based on the behaviour of aftershock sequences worldwide and on the specific knowledge that scientists have of the Canterbury aftershock sequence since September 2010. The figures are generated from computer models that are updated as the aftershock sequence continues.

The table shows that as time passes these probabilities become smaller, but any further significant earthquakes that do occur cause these probabilities to change. The magnitude categories illustrate clearly how the probability decreases as magnitude increases. With every month that passes without a major aftershock, probabilities will continue falling. However, if another large aftershock occurs it can re-energise the system and spark a resurgence of earthquake activity for a month or so (increasing the likelihood of earthquakes); this was seen after both the February and June 2011 magnitude 6.3 earthquakes.

These figures are for the entire aftershock zone, not just for Christchurch City. The zone extends from Hororata in the west to large parts of Banks Peninsula, and from Kaiapoi in the north to Lincoln in the south.

Probabilities of exceedance for earthquakes in the Canterbury region in May 2013, for time periods of one month and one year. Changing likelihoods of certain magnitude earthquakes over time results in changes in risk over time.

One month (May 2013)			
Magnitude range	Expected range	Expected average	Probability (%)
5.0 - 5.4	0 - 1	0.10	10
5.5 - 5.9	0 - 1	0.028	3
6.0 - 6.4	0 - 1	0.008	1
6.5 - 6.9	0 - 1	0.0021	<1
7.0 - 7.9	0 - 1	0.0008	<1
One year (May 2013 - May 2014)			
5.0 - 5.4	0 - 3	1.0	63
5.5 - 5.9	0 - 2	0.29	25
6.0 - 6.4	0 - 1	0.082	8
6.5 - 6.9	0 - 1	0.022	2
7.0 - 7.9	0 - 1	0.008	1

Example 3

Another short time varying risk example is the eruptions at Mt Tongariro in the central North Island of New Zealand in 2012. This volcanic event meant that risk to people using the tracks around the mountain had to be assessed on a daily basis and decisions made about track closures. As the volcanic activity was variable and fluctuated on a daily basis, so too did the likelihood of a hazardous eruption, and therefore the risk.

References

- Civil Defence Emergency Management Act (2002). The Ministry of Civil Defence and Emergency Management, § 7, 33 Stat. 71 (1 December 2002).
- Hart (2011). Vulnerability and adaptation to sea-level rise in Auckland New Zealand. New Zealand Climate Change Research Institute NZCCRI report 08.
- MfE (2008). Coastal hazards and climate change: a guidance manual for local government in New Zealand. Wellington, Ministry for the Environment.

Residual Risk

Definition

Residual risk is the risk that remains after risk treatment (i.e. through risk avoidance, reduction/mitigation, transfer or retention/acceptance) has been applied to reduce the potential consequences.

Explanation

Various treatment options are available to avoid, reduce, transfer or accept risk from natural hazards. However, unless total avoidance of a hazard is possible and avoidance does not expose elements to new risks, there will remain a residual risk which must be considered. Figure 1 shows that while some risk is able to be reduced, due to the characteristics of the hazards, and the exposure and vulnerability of elements at risk, there will be some residual risk.
Residual risk arises because of our societal acceptance of certain risks and our employment of different risk treatment options (i.e. cost-benefit decisions). Many New Zealanders choose to live by the coast because of the amenity and recreational opportunities, while potentially exposing themselves to life safety risk from tsunami, and/or potential economic losses from land loss through erosion or rockfall. As the risk management process cannot eliminate all risk (partially due to the finite nature of funding to decrease risk), this willingness to live by the coast demonstrates an acceptance of the residual risk. The risk management process includes risk treatment, but also recognises that residual risk is likely.

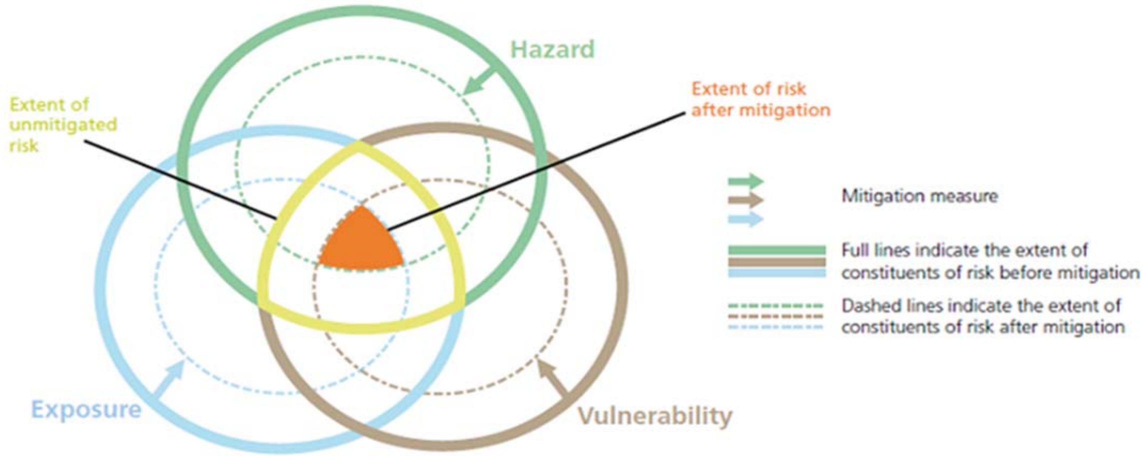


Figure 12. Schematic of risk before and after mitigation with the resulting residual risk (Gold Coast City Council, 2010).

For example, risk treatment for coastal inundation often involves the construction of seawalls. These seawalls are typically designed to accommodate a given magnitude of wave impact. Due to the cost of construction and the low likelihood of extreme events, the seawall design standard will typically apply to the majority of storm events (e.g. events expected with an Average Recurrence Interval (ARI) of 100 or 250 years). Although events which exceed the design capability are less likely to occur, they are still possible, resulting in residual risk to the community from extreme events despite seawall construction (Figure 2).

These structural measures to reduce risk from frequent smaller events can also have the effect of increasing risk from larger events if development intensifies behind seawalls (resulting in increases in the number of people and structures exposed to the hazard).

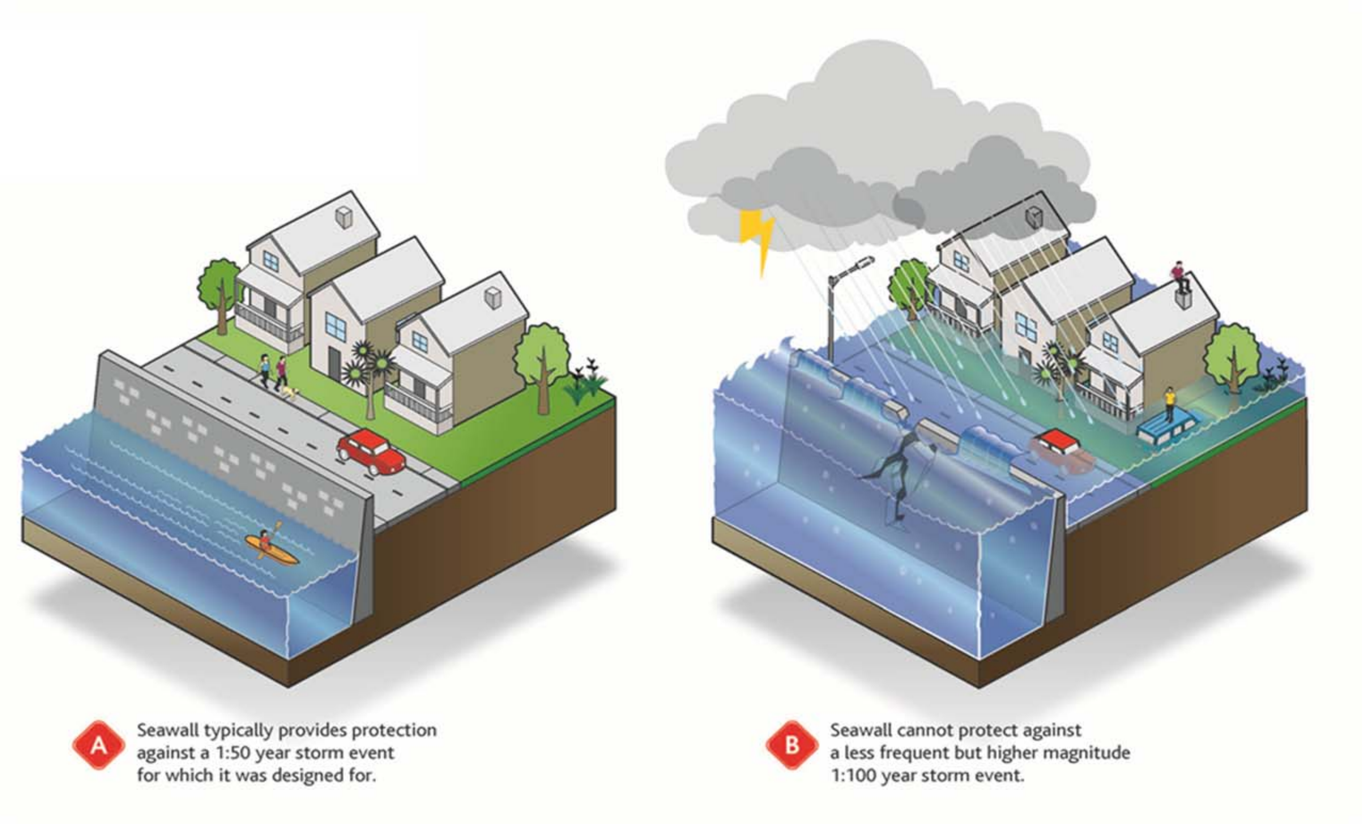


Figure 13: Residual risks from coastal flooding can arise due to design limits for coastal defence structure s. While most storms (smaller events with lower return periods (ARIs)) will be within design standards (left), extreme events (with higher return periods) can exceed structural performance (right). The trade-off between affordability and safety creates an environment in which communities are subject to residual risk.

Some risk treatments focus on one consequence or element at risk (e.g. human life and property) more than others. For example, building codes and standards for buildings exposed to earthquake shaking are designed for maximising life safety. This means that the risk of economic loss through non-structural or non-life threatening building damage exists as a residual risk to building owners. Other risk treatment options may be applied to partially manage this residual risk, such as risk transfer through insurance, or anchoring and securing contents and fittings.

Tsunami risk is typically managed in New Zealand through the use of evacuation plans for life safety. The residual risk to buildings and infrastructure from tsunami is currently considered acceptable to most communities and councils. However, some local bodies are currently investigating how tsunami risk to the built environment can be better included in land use planning policies and guidelines through restriction of new buildings in tsunami hazard zones

Case Studies

Urban flood risk is usually managed through concentrating and collecting rainfall via the storm water system and delivering the resulting runoff to large water bodies such as rivers or the ocean. This channelling of rainwater creates residual risk when channels or pipes are not large enough to cope with extreme rainfall events, or if the infrastructure fails for some reason. In some instances residual risk develops because infrastructure does not keep pace with development. As impermeable surfaces (e.g., concrete and sloped roofs) efficiently channel rainwater directly to downpipes and storm water systems, pipe capacity and strength is put under pressure. While provision has been made for capturing rainfall runoff, aging infrastructure and urban growth can result in residual risk increasing with time, and can cause events such as the flash flooding in the Glen Eden area in 2012. In the case of the flooding in Great North Road and Cartwright Road, a storm water pipe was blocked and the resulting pressure caused it to collapse, resulting in localised flooding (as below).

Figure 14. Flooding on Great North Road in 2012 (left image) following the collapse of a stormwater drain. The stormwater system was not adequate for more intense rainfall events, and the residual risk was realised when the system failed. (Right Image) Flooding in Cartwright Road, 2012. (note the height of floodwaters from the vehicle roof in the foreground). When natural drainage systems are replaced with piped infrastructure, the residual risk arises from events which supply more rainfall runoff than the pipes can carry. Source: Stuff news.

References

- Gold Coast City Council, (2010). Gold Coast City Council Sustainable Flood Management Strategy.
- Stuff news. http://www.stuff.co.nz/auckland/local-news/650788pp1/Auckland-Council-should-pay-for-flood-damage. Accessed on 15 May 2013

Risk Treatment

Definitions

Risk treatment is one step in the risk management process, aiming to reduce the level of risk. It involves selecting methods from:

- **Risk avoidance -** Measures undertaken to avoid risk from natural hazards. These measures could include avoiding development in hazardous areas, relocating people or assets away from hazardous areas, or developing buffer zones.
- **Risk reduction/mitigation** – Measures undertaken to reduce the risks from natural hazards, such as by strengthening buildings against ground shaking from earthquakes.
- **Risk Transfer** – Measures taken to transfer the risk from a natural hazard from one party to another, such as property insurance.
- **Risk Acceptance** – The acceptance of risk from a natural hazard; any realised losses will be borne by those parties exposed to the hazard. This is not specifically a treatment option as no action is taken, but as it is an option of addressing risk, it is included here.

Explanation

The four risk treatment options are future described below.
Risk avoidance is the process undertaken to avoid creating risk. This is typically achieved by avoiding development in, or relocating away from, areas that are susceptible to a natural hazard. For example, in the land use planning process, areas that are susceptible to flooding can be vested as reserves (such as esplanade reserves) with council as part of the subdivision process. This ensures that no development on this land occurs, therefore avoiding the flooding risk to communities.

Risk reduction/mitigation are measures that are undertaken to reduce the risk from a natural hazard event, such as engineering, education and public education solutions. However, after a range of solutions have been implemented there is often a remaining residual risk. Common risk reduction/mitigation measures that are used for landslide risks are outlined in the figure below.

Risk transfer is the process of transferring risk from a natural hazard to a third party. The most common approach to transfer risk is through insurance. Insurance allows the property owner to pay an annual premium for their site, which is based on a number of factors, including risk. Often, the higher the risk is, the greater the premium that the property owner pays. This process means that in the event of a natural hazard, the property owner receives a payout for the physical damage to their property.

Unlike risk avoidance and risk reduction, risk transfer does not include undertaking any physical measures to reduce the risk to a development. As such, if insurance companies consider that the risk they are being asked to take on, relative to the premiums they can reasonably charge is too great, they will not provide insurance to the property owner. This means that the risk to the property is being completely carried by the property owner.

Risk acceptance is where a party (or parties) accepts the risk and any associated consequences that may arise when a natural hazard event occurs. Unlike risk transfer, the individual at risk from the natural hazard must bear any personal losses, monetary or otherwise, that may occur and these costs are not covered by a third party. If the risk of loss is accepted, insurance doesn't cover this loss, and the costs are planned for (e.g. through an individual saving money to cover the loss), this is risk retention. Risk acceptance may be a voluntary process where an individual chooses not to insure their property, or chooses to construct a building in a hazardous environment. It can also be an involuntary process where insurance companies may refuse to provide insurance cover due to the risk to a property from a natural hazard.

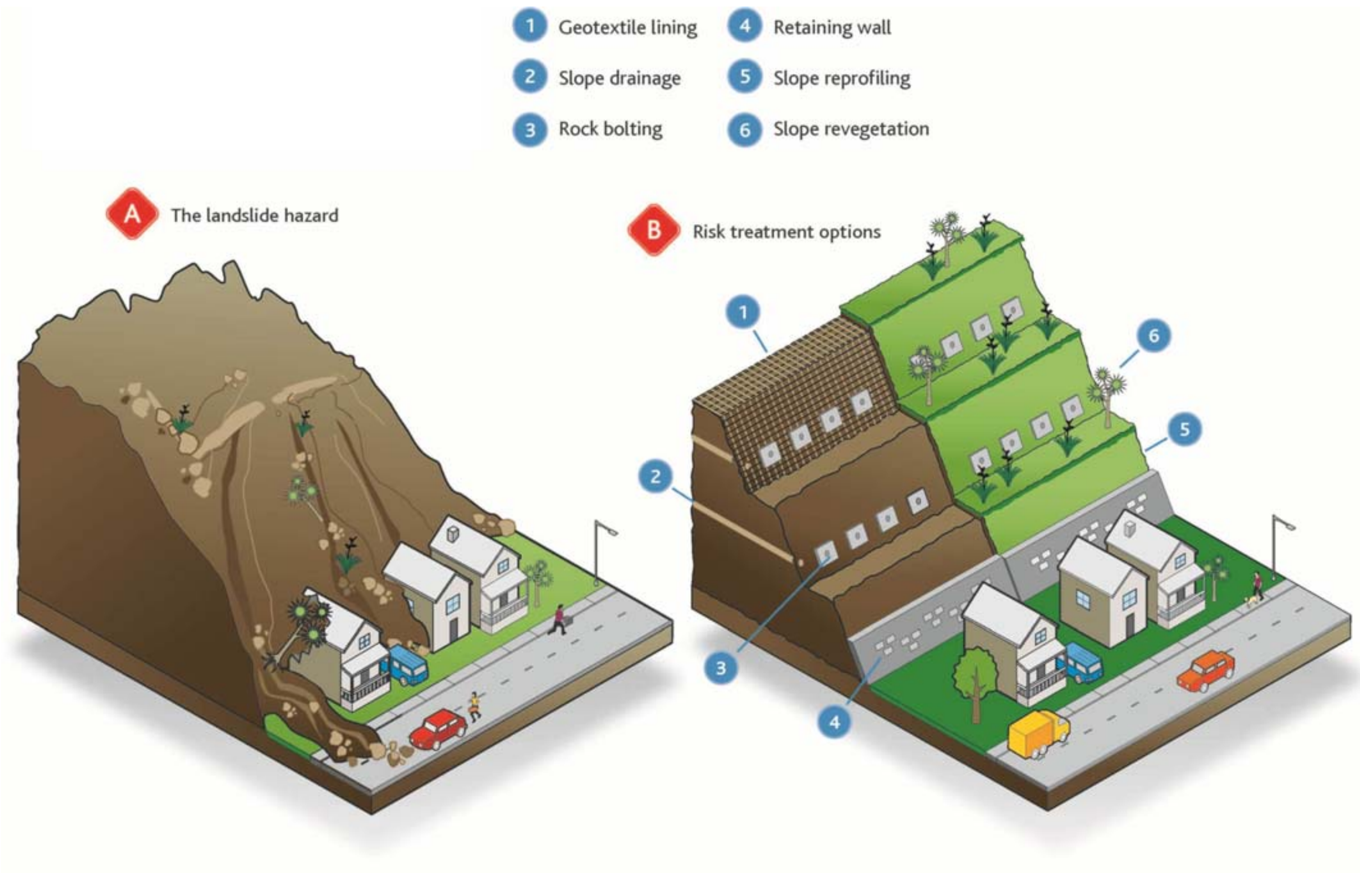


Figure 15. Potential risk reduction/mitigation options for landslide hazards. Please click here for a full range of downloadable graphics.

Case Studies

Example – Risk Transfer

The insurance costs from the Hobsonville tornado were $8.7 million (Insurance Council of New Zealand, 2013). However, the total costs associated with the clean-up from this event were $13.5 million (NIWA, 2012). So 64% of the costs associated with this event were paid for by a third party, demonstrating risk transfer.

Example – Risk reduction/mitigation

In the winter of 2008 Auckland received 150% of its normal rainfall, and this rainfall contributed to the reactivation of the Kawakawa Bay landslide. This landslide closed the access road to Kawakawa Bay for 1 month and resulted in the demolition of one dwelling. In response, works were undertaken to permanently stabilise this landslide,

which included earthworks being undertaken at the top of the landslide as well as the installation of drainage holes (as shown in the figure below).
These measures have ensured that the likelihood of a future landslide occurring on this site, and therefore the overall risk, has been reduced.

Figure 16. Remedial works to stabilise the landslide at Kawakawa Bay were well advanced in early February 2009. The measures used have included horizontal drains drilled into the lower slope, and extensive earthworks at the top of the landslide to unload the head of the slide, part of which required removal of a house built just below the headscarp. Source: Hancox, G.T., Nelis, S. (2009)

Example – Risk Avoidance

Following the Canterbury earthquake sequence, extensive studies have been undertaken on the risk to life from rockfall and cliff collapse on the Port Hills. The Government decided to red zone the properties where the risk to life is considered to be unacceptable (as shown in the figure below). This red zoning process allows the Government to purchase the land to prevent any resettlement from reoccurring in the immediate future. By preventing resettlement, it is avoiding future risk to properties and lives from rockfalls.

Figure 17. The extent of the red zones in Horotane Valley and on the banks of Mt Pleasant in the Heathcote Valley (Canterbury). Source: Stuff news (2013).

References

- Hancox, G.T., Nelis, S., (2009). Landslides caused by the June–August 2008 rainfall in Auckland and Wellington, New Zealand. GNS Science Report 2009/04. 30pp.
- Insurance Council of New Zealand (2013) http://icnz.org.nz/statistics-data/the-cost-of-disaster-events/. Accessed 13 May 2013.
- National Tsunami Hazard Mitigation Program (2001). Designing for tsunamis: seven principles for planning and designing for tsunami hazards, National Tsunami Hazard Mitigation Program: 60.
- NIWA (2012). Historical Weather Events catalogue, December 2012 Tornado. http://hwe.niwa.co.nz/event/December_2012_Auckland_Tornado accessed 19 September 2013.
- Stuff news (2013) http://file.stuff.co.nz/thepress/porthills/redzones/ accessed 13 June 2013.

Risk Management Process

Definition

Risk Management is a process that includes the following key steps: establish the context in which you are working; identify risks; analyse risks; evaluate risks; and treat risks. Throughout these steps, concurrent activities of monitoring and reviewing, and communication and consultation occur to ensure a robust risk management approach.

Explanation

Risk management for natural hazards can be applied using the same systems process as that which can be applied to other types of risk, e.g. financial risk. This process is outlined in International Standard 31000. The process is flexible and generalised enough in its framework to incorporate the complexity, uncertainty and range of treatments available for risks resulting from natural hazards. The risk management framework is shown in the figure below.

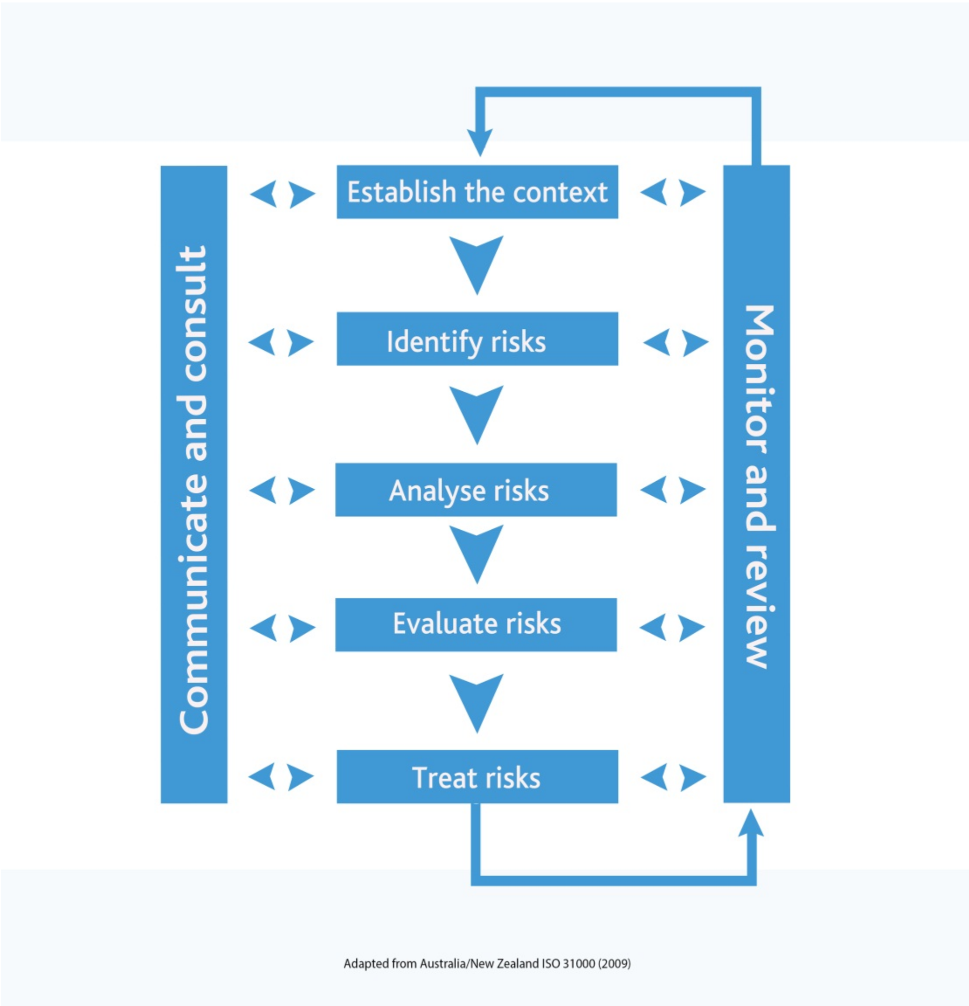


Figure 18. Simple diagram showing the steps of the risk management process. Adapted from Australia/New Zealand ISO 31000:2009.

The steps for risk management are:

- Establish the context: what is the scope for this piece of work, what area will it cover, what methodology will be employed, and who are the stakeholders. Who is responsible for managing risk, and who is at risk
- Identify Risks: What natural hazards could occur in our area of interest, what are the possible magnitudes, frequencies, extent and/or durations of these hazards
- Analyse Risks: What is the likelihood of hazard events of certain magnitudes occurring? What is exposed? What are the elements at risk, how vulnerable are they, how do we value them and what are the potential consequences of an event?
- Evaluate Risks: Are the likelihood and consequences acceptable, tolerable, or intolerable? Which forms of risk treatment are available? To what degree will various risk treatments reduce the risk? Are there other benefits or negative outcomes of particular risk treatment methods? How much will risk treatments cost?
- Treat risks: Will the treatment be to avoid the risk, reduce the likelihood or consequences, transfer the risk, or accept the risk? What is the residual risk following treatment?
- Communicate and consult: Who is at risk? Who will pay for risk treatment? Do these stakeholders agree with the analysis and outcomes
- Monitor and review: Do we need to revisit previous steps in light of results or new information throughout the process? Is the residual risk acceptable?

Case Studies

Example 1

The figure below provides more depth of explanation with regards to the risk analysis procedure for landslide hazards.

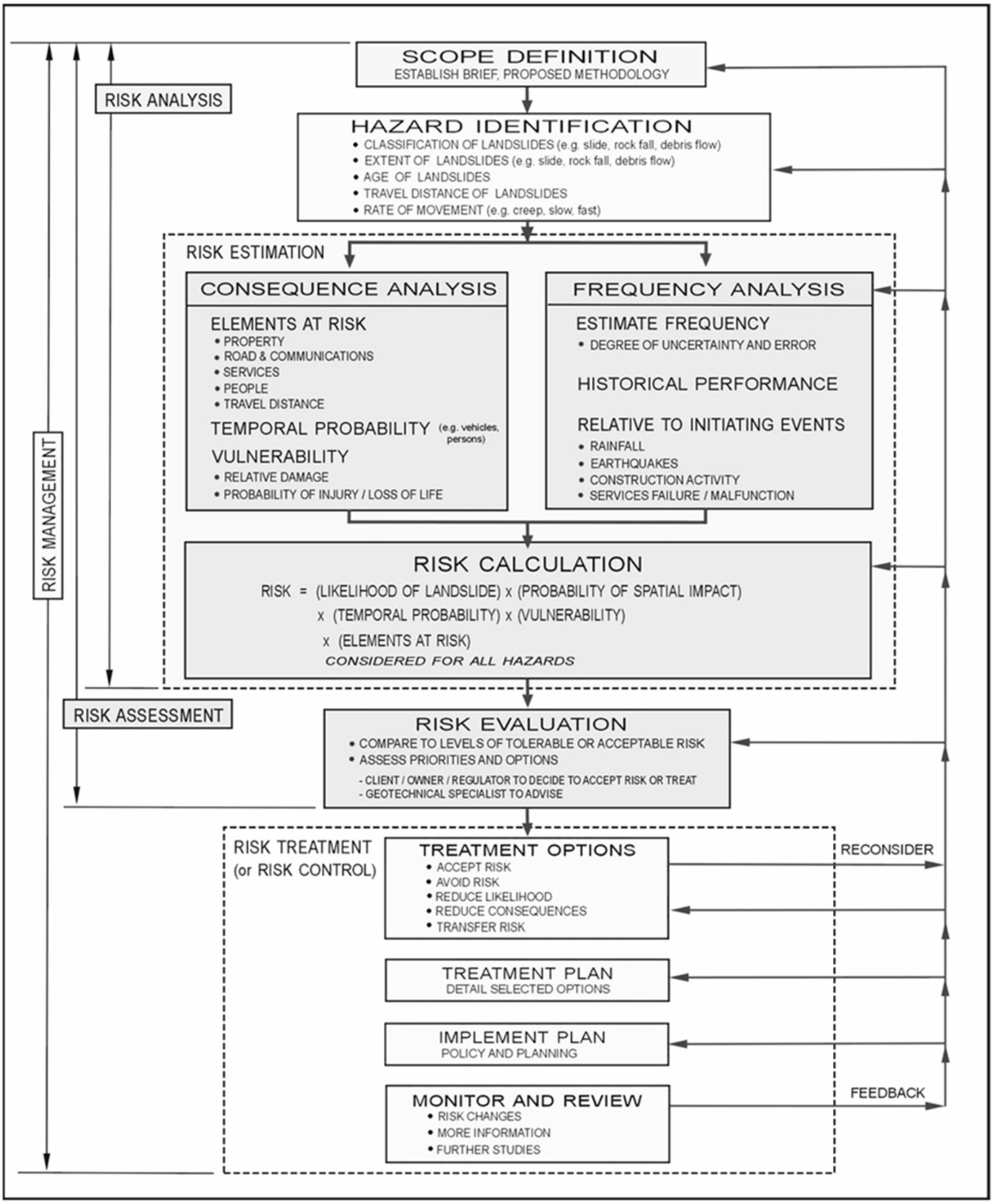
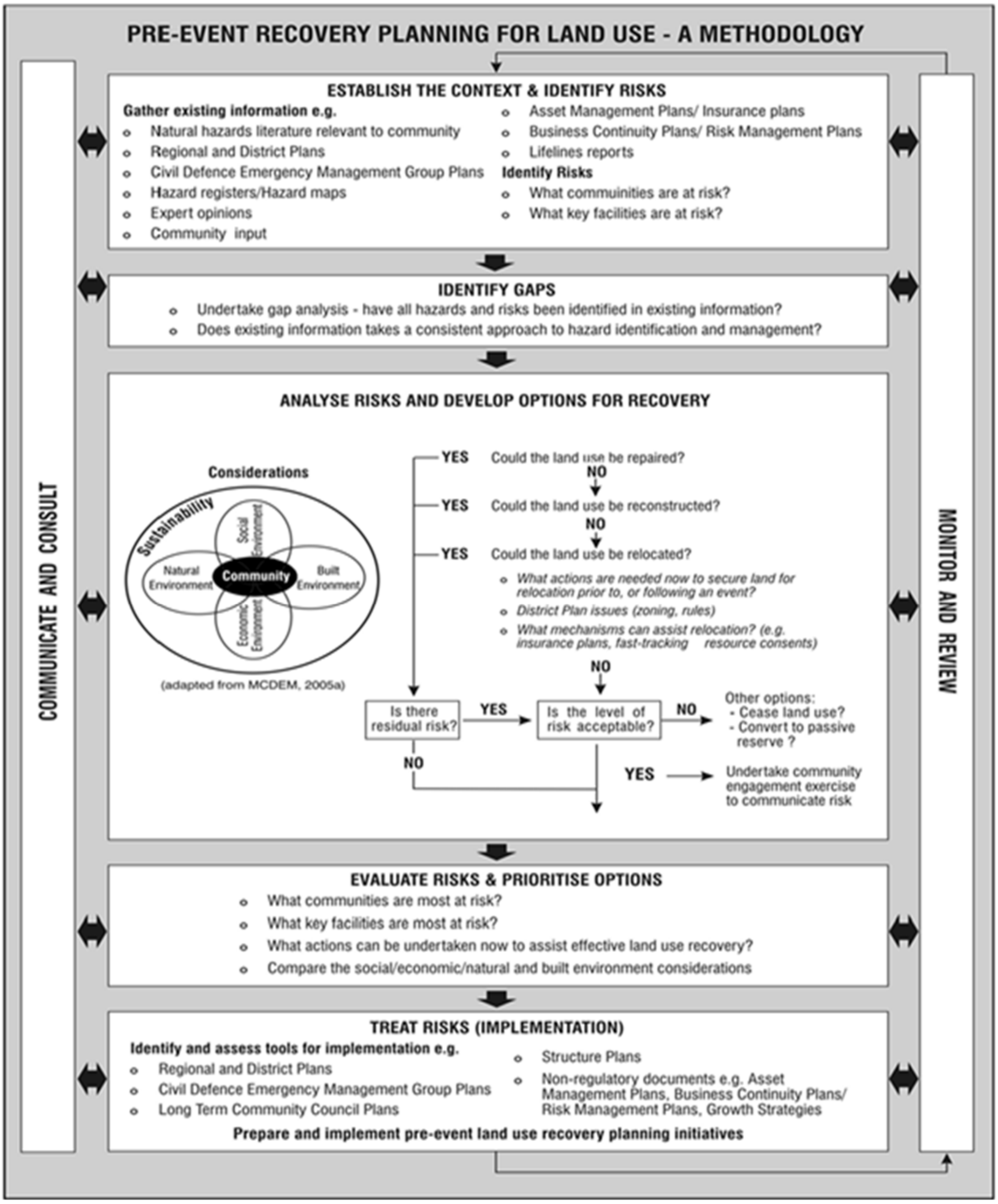


Figure 19. Risk management process applied to landslide hazard (Australian Geomechanics Society, 2000).

Example 2

Figure 20 describes a pre-event planning methodology using the risk management framework to explore decision-making for land use arising during recovery from natural hazard events.



References

- Australian Geomechanics Society (2000). Landslide risk management concepts and guidelines. Sub-committee on landslide risk management.
- Australian/New Zealand Standard. Risk Management. AS/NZ 4360:2004. Standards New Zealand.
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- Becker, J.S., Saunders, W.S.A., Hopkins, L., Wright, K.C., Kerr, J.E., (2008). Pre-event recovery planning for land-use in New Zealand: an updated methodology. Lower Hutt: GNS Science. GNS Science report 2008/11. 36 p.
- International Organisation for Standardisation.

Cumulative Vs Cascading Hazards

Definitions

Cumulative hazards are where two or more unrelated natural hazard events have the potential to affect human life and/or property. For example, an area may be susceptible to flooding, bush fires, and fault rupture.

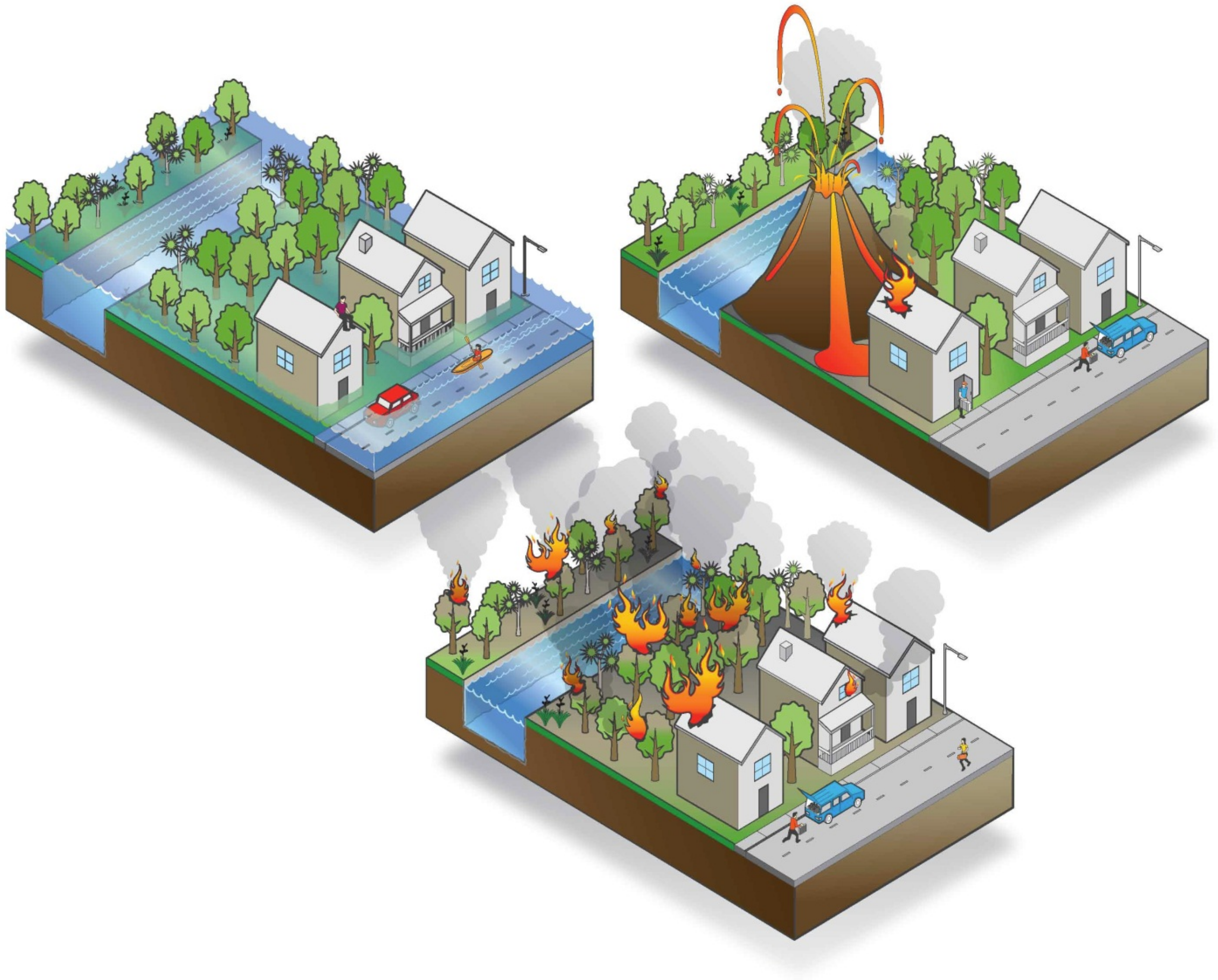

Figure 21. Cumulative natural hazards.

Cascading hazards are where two or more natural hazards, caused by the same ‘trigger’ event, affect human life and/or property. For example a storm may result in a specific area experiencing both a tornado and flooding. Both of these have been caused by the first event.

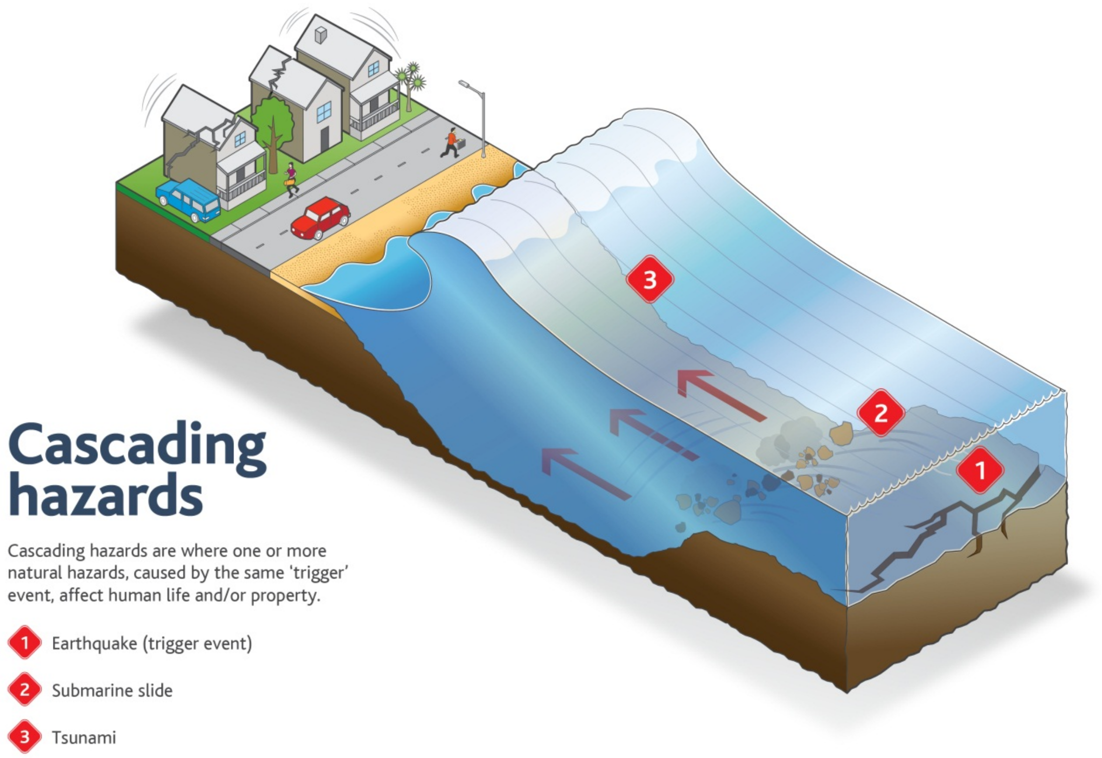

Figure 22. Cascading natural hazards.

Explanation – Cumulative Hazards

Cumulative hazards involve multiple unrelated natural hazards affecting a property or area. As the natural hazards are unrelated it is unlikely that any given area would be affected by all of the natural hazards at the same time. Areas subject to cumulative hazards have a higher exposure and likelihood to experience one of the natural hazard events, and therefore a higher risk, than an area that is exposed to one natural hazard. For example, an area of land is exposed to three natural hazards as detailed in the table below.

Three different natural hazards and their associated likelihoods (Average Recurrence Interval (ARI) and Annual Exceedance Probability (AEP)) in an example location.

Natural Hazard	ARI (Years)	AEP
Flooding	1:100	0.010
Tsunami (distant sourced)	1:200	0.005
Liquefaction (locally generated)	1:500	0.002

Using the above table, the likelihood of a hazard occurring at the example location is calculated as follows:

- Step 1: annual exceedance probability = 1 – (1 – 0.01) x (1 – 0.005) x (1 – 0.002) = 0.0169. This means that there is a 0.0169% chance of an event occurring in any given year
- Step 2: Average Recurrence Interval = the inverse of the probability. This equation is 1 / 0.0169 = 59.

This means that there is a likelihood of the area of land being affected by one of the above natural hazards on average once in every 59 years. This in turn demonstrates that areas of land subject to cumulative hazards have a higher susceptibility to a natural hazard event.

It is important to note that this equation only works when considering probabilities.

Explanation – Cascading Hazards

Cascading hazards are where two or more natural hazards result from a single trigger event. This means that when the trigger event occurs, the people and property in the cascading hazard zone are likely to be affected by all of, or a combination of, the resulting hazards (see the case study below for an example). Therefore, properties in cascading hazard zones are likely to experience greater damage when the 'trigger event' occurs than properties not located in areas susceptible to cascading hazards during that event.
With cascading hazards, the probability of an event occurring is governed by the probability of the trigger event (unlike cumulative hazards).

Case Studies

Cumulative Hazards

An area of Auckland that is subject to cumulative hazards is Great Barrier Island. This island is susceptible to multiple unrelated natural hazards such as coastal erosion (triggered by storms and sea level rise), bush fires (triggered by drought and climate change) and tsunami inundation (triggered by offshore earthquakes, both local and distant). The likelihood of these natural hazards occurring varies greatly with Annual Exceedance Probabilities of between 0.1% (storms) to 0.0015% (large Kermadec Trench Fault rupture) (Beban et al., 2011). The susceptibility and vulnerability of the community to these hazards varies across the island depending on population density, location of assets, aspect, vegetation cover, topography and geological composition.

Cascading Hazards - Case Study

In December 2012, an active thunderstorm front passed through Auckland. This active thunderstorm front was the trigger for the damaging Hobsonville tornado (Niwa, 2012). In addition to the tornado, there was widespread surface flooding throughout Auckland and Hobsonville, which also resulted in damage to property and disruption of services. This demonstrates that a number of separate hazards can be triggered by the same event (in this case, the active thunderstorm front) – an example of cascading hazards.

References

- Beban, J. G., Cousins, W. J., et al. (2011) Modelling of the tsunami risk to Papamoa, Wairakei and Te Tumu and implications for the SmartGrowth strategy. GNS Science Consultancy Report 2011/294.
- NIWA (2012)http://hwe.niwa.co.nz/event/December_2012_Auckland_Tornado Accessed 24 June 2013.

Estimating Risk Using Modelling

Definition

Risk modelling is the process of determining the level of risk to exposed elements (e.g. human life and property), by calculating the potential consequences of natural hazard events. Risk modelling considers the natural hazard characteristics, exposure and vulnerability of the elements at risk (including damage and injury states), as well as the value (e.g. direct/indirect losses) to provide outputs useful for risk management decision-making (as shown in the figure below).

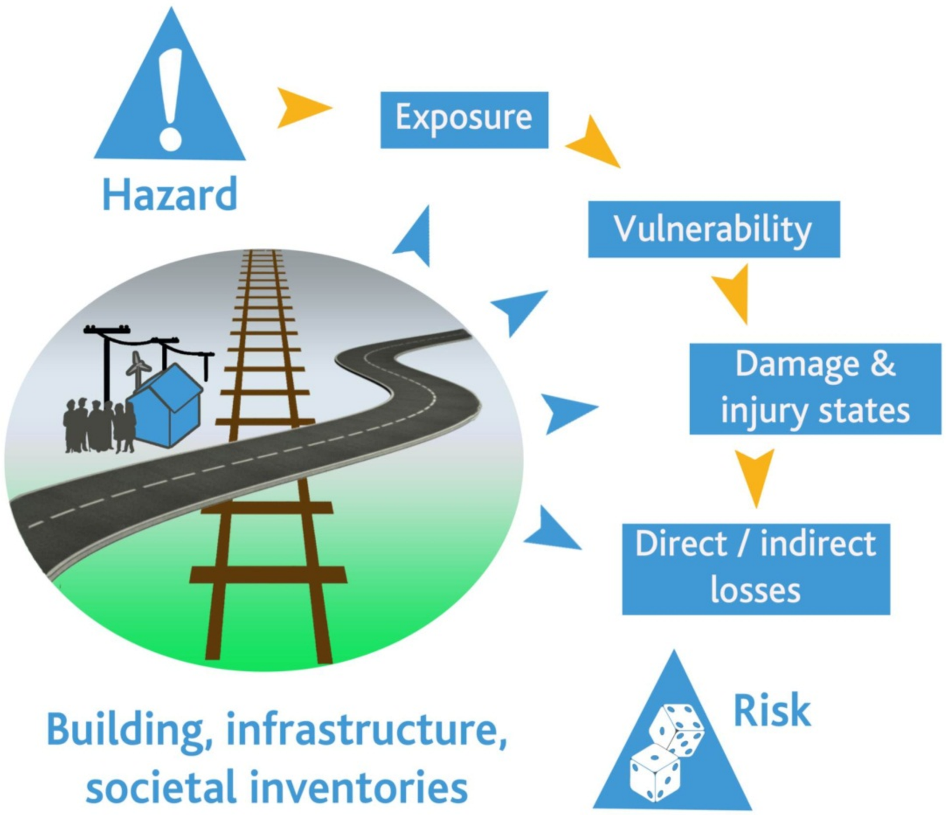

Figure 23. Simple diagram outlining the steps in the process of natural hazard risk modelling (source King et al., 2009). Please click here to download the graphic.

Explanation

The risk to elements can often be calculated through analysis of statistics and records of losses (e.g. for road safety through examining injury and fatality statistics over time). When there is insufficient statistical data to estimate risks associated with natural hazards, or for extreme events which could happen but have not happened in historical times, risk modelling can provide a quantitative estimation. Risk modelling of natural hazards is typically calculated spatially and is most simply displayed in map form.

Models require the following inputs:

- Quantified hazard information; not just what is happening but the location, extent and magnitude of hazard effects. For example: for floods, depth and velocity of flow; for earthquakes, shaking experienced or ground acceleration, landslides triggered, and liquefaction; for volcanoes, ash data (volume and depth at specific locations), pyroclastic flow and lava flow impacts, lahars, and gas, etc. Is the model based on a specific hazard scenario (e.g. 100 year Annual Exceedance Probability (AEP) flood), or a probabilistic hazard layer (such as the seismic hazard model for NZ)?
- What is the exposure of elements at risk? What valued elements are located in hazardous areas; people, buildings, businesses, emergency facilities, lifeline infrastructure, etc.
- Vulnerability information: what are the attributes of the elements at risk that make them vulnerable to the hazards being modelled? How will vulnerability be quantified? How can this information be converted into mathematical terms such as fragility functions?

Risk Calculation and Outputs

Risk equations and fragility functions are used to quantitatively determine the probability of damage from the combination of magnitude and vulnerability. Fragility functions are developed so that the possible outcome for any element (e.g., a building) will fall between 0 (no damage) and 1 (total loss). The table below shows a translation of damage ratio classes for buildings described in quantitative and qualitative terms. For a given magnitude of hazard, all buildings will fall into one of the five classes shown in the table, depending on the characteristics of the hazard experienced at their location (exposure) and the attributes of that building that make it more or less likely to withstand the effects of the hazard (vulnerability). An example of a risk calculation equation applied to determine life safety hazard from rockfall hazard in the Port Hills is shown below (from Massey et al., 2012):

$$R(LOL) = P(H) \times P(S{:}H) \times P(T{:}S) \times V(D{:}T)$$

- *R(LOL)* is the risk (annual probablity of loss of life (death) of a person) from rockfall;
- *P(H)* is the annual probability of a rockfall-initiating event;
- *P(S:H)* is the probability of a building or person, if present, being in the path of one or more boulders at a given location;
- *P(T:S)* is the probability that a person is present at that location; and
- *V(D:T)* is the vulnerability, or probability of a person being killed (or receiving injuries which prove fatal in the near aftermath of the event) by a rockfall.

A risk model will calculate damage based on a given magnitude of hazard, and the vulnerability of exposed elements. The results can be displayed as a risk estimation when consideration is made of the likelihood of the event and can be presented either quantitatively or qualitatively, as shown in this example.

Damage Ratio	Damage State	Damage State Description
0 - 0.02	Insignificant	No damage or minor non-structural damage
0.02 - 0.10	Light	Non-structural damage only
0.10 - 0.50	Moderate	Reparable structural damage
0.50 - 0.90	Severe	Irreparable structural damage
0.90 - 1.0	Collapse	Structural integrity fails

The results of risk modelling can be presented in a variety of ways. Mapping of results is one of the most common methods, as it presents results spatially. Other model outputs could include spreadsheets, tables or graphs. The results of natural hazard risk modelling are used to determine quantitative consequences and risks from natural hazard events.

Uncertainty in Risk Modelling

The results of any model are only as good as the information that is fed into it. Uncertainty also arises from assumptions made throughout the modelling process, and the modelling methodology employed. Any quantitative risk model should identify uncertainties and the limits of the model, and results. Possible causes of uncertainty in models are:

- Uncertainty in inputs: are the boundaries of our hazard model accurate? Could the hazard become more or less frequent with time or more or less intense over time? How do we account for variability among events?
- Uncertainty in inputs: do we know the 'where' and 'what' of all our elements at risk? Is there uncertainty in the numbers of elements, the types of elements or their vulnerability attributes (e.g. the construction material of buildings or the mobility of people)?
- Uncertainty in methodology: are modelling assumptions and fragility functions realistic?
- Uncertainty in results: are differences in results due to valid and explained variations because no two hazard events are exactly alike and the model captures this, or because our model is not functioning correctly (e.g. bugs or errors in software code).

When using risk modelling for undertaking risk analysis or evaluation and for risk treatment decision-making, consideration must be made of how uncertainty within the modelling affects results and how these effects will be satisfactorily managed. A sensitivity analysis can be applied to a model to determine which inputs of a model have the greatest influence over the final results, and whether uncertainties in the inputs are likely to cause significant changes to results or are within reasonable bounds. Where similar hazard events to the ones employed in our model have occurred elsewhere in New Zealand or internationally, these events can be also be used as a calibration of model inputs and results to determine whether results are within reasonable bounds.

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Types of Maps Showing Hazard Information

Definition

There are many different ways to map various hazards and risks, for example:

- hazard maps;
- susceptibility maps;
- inventory maps;
- evacuation maps; and
- risk maps

Each of these is explained in more detail below.

Hazard map

Hazard maps include a likelihood reference. A hazard map can be used to show the extent of a particular hazard, but does not show the risk associated with the hazard. For example, the map in the figure below shows a scenario of the 100 year average recurrence interval (ARI) for flood extent on the North Shore.

Susceptibility map

Susceptibility maps combine different factors which contribute to a hazard, to give an indication of where a hazard is more likely to occur. For example, the fiugure shows the susceptibility of slopes to instability for the Auckland Region. It has been determined from rock and soil geotechnical characteristics and slope angle. No time factor (e.g. likelihood or probability) is associated with a susceptibility map (unlike a hazard map).

Hazard Inventory Map

A hazard inventory map shows a collection of hazard events that have occurred at a location. The location of previous events is a good indicator of where future events may occur, and allows analyses and testing of susceptibility, hazard, and risk analyses. The figure shows an example of an inventory map - recorded earthquakes in the wider Auckland region from 1966 until May 2013, ranging in magnitude of 1 to 5.

Evacuation map

An evacuation map is used by emergency managers and communities to plan for evacuation in an event. For example, the Wellington evacuation map for tsunami is shown in the figure. It displays three different zones that may be required to be evacuated. A map like this is based on modelling of events.

Risk map

Risk maps show the consequences of an event with a likelihood scale. The figure shows Mission Bay with a 100 year ARI flood hazard mapped on the left (i.e. a hazard map); and the figure on the right shows a risk map of the asset repair costs (i.e. a consequence) by meshblock for the same event. Risk maps are useful for determining where the greatest loss from an event may occur.

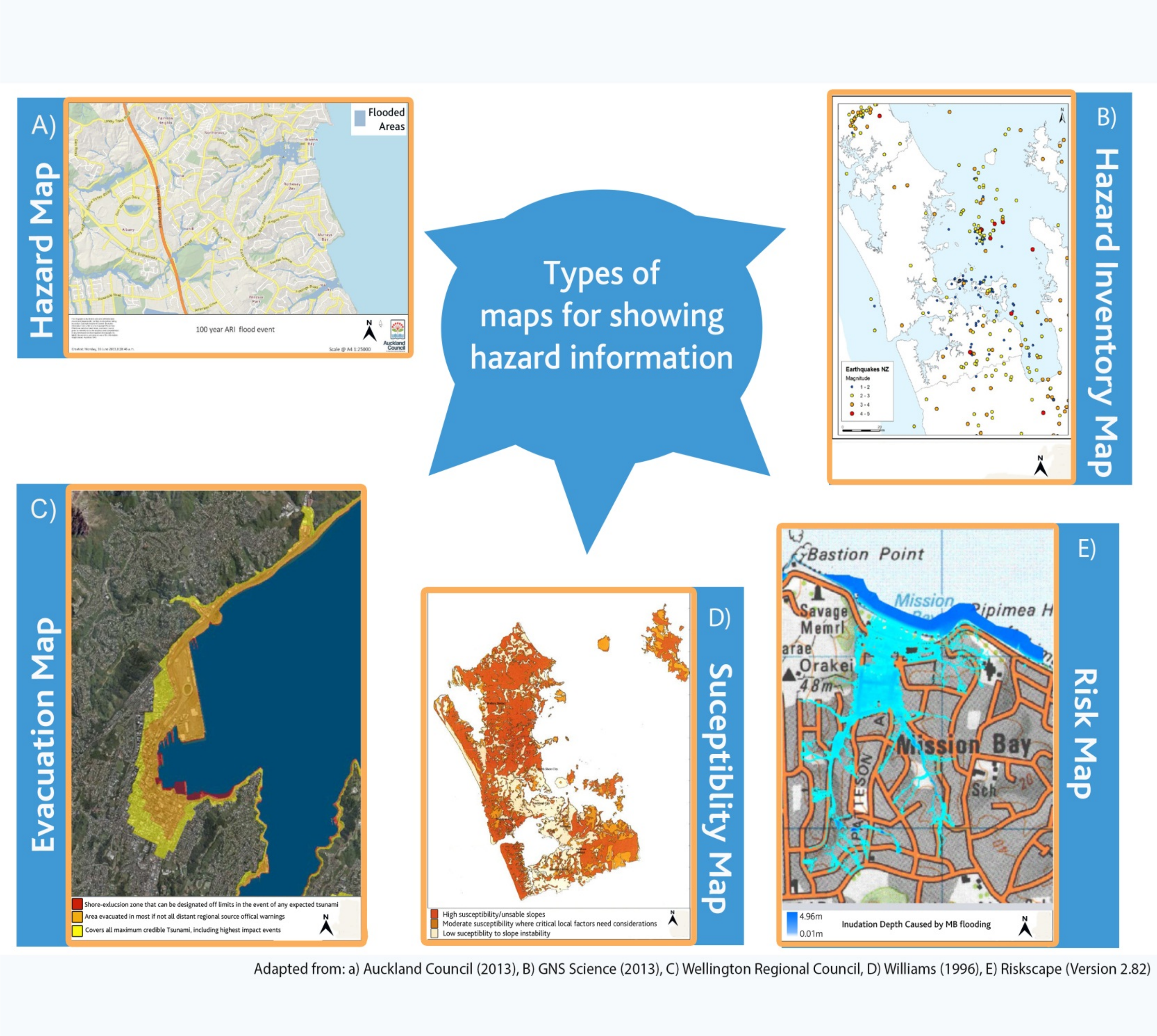

Figure 24. Overview of the range of hazard maps that can be produced.

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