Disaster risk management decision-making: review

Full cost accounting of disaster risk management decisions

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List of Abbreviations

AHP	Analytical Hierarchical Process
BCR	Benefit Cost Ratio
BTM	Benefits Transfer Method
CBA	Cost Benefit Analysis
CDEMA	Civil Defence Emergency Management Act 2002
CEA	Cost Effective Analysis
CGE	Computable General Equilibrium
DDR	Declining Discount Rates
DRM	Disaster Risk Management
EMA	Environmental Management Accounting
EP	Exceedance Probability
FCA	Full Cost Accounting
FEMA	Unites States Federal Emergency Management Agency
GIS	Geographic Information Systems
GPI	Genuine Progress Indicator
GTZ	German Technical Cooperation Agency
HLS	Treasury Higher Living Standards Framework
LGA	Local Government Act
LGOIMA	Local Government Official Information and Meetings Act 1987
LIM	Land Information Memorandum
LTCCP	Long-Term Council Community Plan
MCA	Multi Criteria Analysis
MERIT	Measuring the Economics of Resilient Infrastructure
MMC	Multihazard Mitigation Council
OAT	One-At-a-Time (sensitivity analysis)
NPV	Net Present Value
RMA	Resource Management Act
TEV	Total Economic Value
WTA	Willingness to Accept
WTP	Willingness to Pay

1. Introduction

Natural disasters bear a heavy cost for New Zealand both in terms of financial losses and societal and environmental disruption. A number of studies have illustrated that the benefits from disaster risk reduction and mitigation can potentially far exceed the financial costs involved (see, for example, Rose *et al.* (2007), Fenwick (2012), Mechler et al. (2014) and Shreve and Kelman (2014)). If we accept that the role of government is to facilitate communities to best provide for their well-being, or in other words ensure high living standards, there is clearly an important role for government in disaster risk management (DRM). Furthermore, effective DRM requires methodologies and frameworks that provide a good 'evidence base' for decision making.

Cost benefit analysis and multi-criteria analysis are among the most popular tools or frameworks used by governments to assist decision-making across a broad range of policy contexts. The evaluation of risk management options is, however, characterised by some important challenges that can call into question established decision making processes, routines and assumptions. Perhaps of most important, risk management options tend to be characterised by a dichotomy between costs and benefits. While the costs of implementing risk management tend to relatively certain, immediate and easily quantifiable in financial terms, benefits tend to be subject to high levels of uncertainty, experienced over long time horizons, and difficult to quantify.

Within the New Zealand policy context there is also a clear recognition that well-being and living standards are influenced by wide range of factors, i.e. not just economic performance, and these need to be considered in decision making. The so-called 'multi-capital' approach is clearly evident in the Treasury's Higher Living Standards (HLS) (New Zealand Treasury, 2011). The Resource Management Act also effectively requires multi-capital decision making. According to Counsell (2010), however, the tools currently available cannot do this robustly, transparently or in an agile fashion.

This literature review is part of a government funded research project 'Full Cost Accounting of Disaster Risk Management: Risk, meanings and metrics with uncertainty'. This project seeks to develop a prototype decision making framework fit for DRM. Within the project the prototype framework will also be applied to a specific DRM case study. This literature review is the first part of the project and simply aims to provide a concise summary of background information, both for researchers and stakeholders. Included in the literature review are the following topics:

- A brief discussion of the concepts of risk and risk management, including how these concepts are defined in this project (Section 2),
- An overview of the risk management policy context, including the empowering legislation under which decisions around risk management are exercised (Section 3),
- A summary of formal decision making approaches or frameworks (Section 4),
- An overview of special considerations that arise in the context of evaluating decisions, particularly in a risk management context (Section 5),
- A summary of existing DRM decision-making frameworks, both in NZ and abroad (Section 6), and

- An overview of information that can be used by decision makers to assist in the identification and evaluation of potential outcomes of risk management options (Section 7).

2. Disaster risk management

DRM is a broad concept with multiple definitions and applications. In this section we briefly state our definition of DRM and outline the focus of our study.

2.1. What is risk management?

The ISO 31000 Risk Management guidelines (Joint Standards Australia Standards New Zealand Committee, 2009) uses the following definition for risk:

> ***risk***
> *effect of uncertainty on objectives*

The risk of a given event is a combination of event likelihood (chance of occurrence e.g. return period of flood) and consequences. The guidelines highlight that effects can be positive and negative and objectives will depend on the goals of those doing the assessment.

ISO 31000 defines risk management as:

> ***risk management***
> *coordinated activities to direct and control an organisation with regard to risk.*

2.2. What is disaster risk management?

A disaster could be any number of different events: natural, technological; sudden, slow creep; cascading; simple, complex. For the purposes of this research, we will focus on natural, single hazard, non-cascading events – ranging from high to low frequency events. The scope has been narrowed to facilitate the development of a targeted framework that can be readily applied within the New Zealand context. The framework could be adapted for application on complex, man-made and cascading disasters, however, the uncertainties involved and range of potential events will require significantly more analysis.

The New Zealand Ministry of Civil Defence and Emergency Management approach to DRM are expressed in terms of the 4 R's (MCDEM, n.d.): reduction, readiness, response and recovery. These are defined below:

> ***Reduction:*** *Identifying and analysing long-term risks to human life and property from hazards; taking steps to eliminate these risks if practicable, and, if not, reducing the magnitude of their impact and the likelihood of their occurring.*
> ***Readiness:*** *Developing operational systems and capabilities before a civil defence emergency happens; including self-help and response programmes for the general public, and specific programmes for emergency services, lifeline utilities and other agencies.*

Response: *Actions taken immediately before, during or directly after a civil defence emergency to save lives and protect property, and to help communities recover.*
Recovery: *The coordinated efforts and processes to bring about the immediate, medium-term and long-term holistic regeneration of a community following a civil defence emergency.*

(MCDEM, n.d.[1])

Interventions to reduce disaster risk, or specifically to reduce the consequences of a given event, can be applied at any of the above stages.

For the purposes of this research project, we will focus on the first two R's: reduction and readiness. These are the measures that are taken before a disaster event to reduce the consequences and are likely to be where decisions around policy and investment in interventions are most likely.

2.3. Resilience

The term 'resilience' has been increasingly used in the field of DRM. In a recent analysis of resilience literature, Stevenson et. al. (Stevenson, Vargo, Ivory, Bowie, & Wilkinson, 2015) propose a meta-definition for resilience:

> *"The ability to absorb the effects of a disruptive event, minimize adverse impacts, respond effectively post-event, maintain or recover functionality, and adapt in a way that allows for learning and thriving, while mitigating the adverse impacts of future events."*

Risk management focuses on the known unknowns: events that we know will happen but there is uncertainty around the exact frequency and nature of the potential events. Resilience encompasses both preparing for the known unknowns as well as the unknown unknowns (Blake, 2013, p6). The concept builds on risk management and includes capacity building (within systems, processes, organisations, etc.) for managing the unexpected and adapting to a changed environment.

While this project focuses primarily on developing a tool for risk management decision-making, the principles of resilience, where practicable, will be included. More specifically, we will be considering how resilience principles, such as adaptive capacity building, can be integrated and valued in the disaster risk management decision making process.

[1]MCDEM. (n.d.). The 4R's. Retrieved from http://www.civildefence.govt.nz/cdem-sector/cdem-framework/the-4rs/

3. Risk management context in New Zealand

New Zealand has an integrated approach to managing natural hazards. There are five key pieces of legislation that have a primary influence on natural hazard management: the Resource Management Act 1991 (RMA), which controls land use planning for natural hazards; Building Act 2004, which controls building standards and requirements; Civil Defence Emergency Management Act 2002 (CDEMA), based around the '4R' philosophy of readiness, response, recovery and reduction; and Local Government Act 2002 (LGA), which provides the governance framework for funding and spending for local government; and to a lesser extent the Local Government Official Information and Meetings Act 1987 (LGOIMA), which provides for hazard disclosure for property through a Land Information Memorandum (LIM). The four key statutes are intended to be integrated in their purposes, which promote sustainable management or in the case of the Building Act, sustainable development. Other statutes also contribute to natural hazard management, to a lesser degree. These include the Environment Act 1986; Conservation Act 1987; Soil Conservation and Rivers Control Act 1941; Land Drainage Act 1908; and the Forest and Rural Fires Act 1977 (see Tonkin & Taylor, 2006 for further information).

3.1. Integrated roles and responsibilities

The practice of hazard management can be improved by understanding how the various roles and responsibilities of central government agencies, regional councils, territorial authorities, and non-statutory planning tools can work together to provide a holistic approach. Figure 1shows these relationships, and areas for improvement.

Figure 1presents the five main statutes that govern natural hazards planning at different levels of government, namely central (orange), regional (green) and district/city (blue) levels. The hierarchy of plans established under each statute provides various regulatory and non-regulatory tools for natural hazards planning. The solid arrows show established relationships in the hierarchy of provisions. The dashed arrows highlight relationships between existing provisions where there is an opportunity for strengthening linkages. The relationships may be one- or two-way. These legislative provisions and the array of tools they provide constitute a robust 'toolkit' for natural hazards planning. However, many of these tools are not well known amongst either planners or emergency management officers, nor used to their full potential to reduce hazard risk and build community resilience (Glavovic*et al.,*2010; Saunders*et al.,* 2007).

Table 1shows the purposes of RMA, Building Act and CDEMA, which are consistent in that they have a focus on sustainable management or development, and refer to the social, economic, environmental and cultural well-beings, as well as health and safety. However, while sustainable management is defined under the RMA, it is not defined in the CDEMA; sustainable development is also not defined in the Building Act or LGA. Also, balancing of the four well-beings is not required; rather, economic considerations can often take priority over social, environmental and cultural well-beings. This priority reflects the political prerogative to encourage market solutions to the management of natural and physical resources (Ericksen *et al.*,2003).

Other high-level examples of other non-statutory tools may include the 100 Resilient Cities initiative, Treasury's Higher Living Standards, the Sendai Framework for Action, and other local initiatives (e.g. Auckland Council risk management platform).

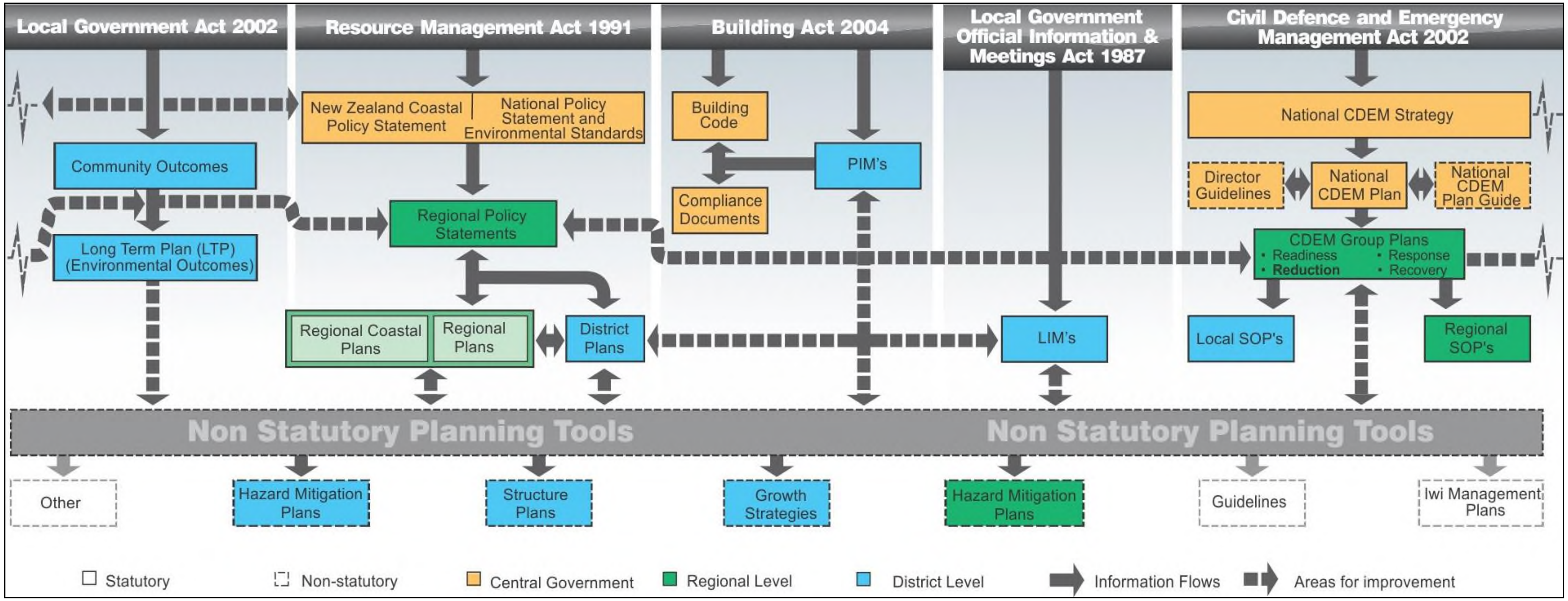

Figure 1 Legislative roles and responsibilities for hazard management in New Zealand. Source: Saunders & Beban (2012). Orange shows the national level policies and plans; green are regional level policies and plans; and blue are district level policies and plans. The dotted arrows show areas were information transfer can be improved. CDEM = Civil Defence Emergency Management; PIM's = Project Information Memorandum; LIM's = Land Information Memorandum; SOP = Standard Operating Procedures.

Table 1 Purposes of key legislation for the management of natural hazards (emphasis added).

Statute	Purpose
RMA 1991 (Part 2, Section 5)	To promote the sustainable management of natural and physical resources. Sustainable management means managing the use, development, and protection of natural and physical resources in a way, or at a rate, which enables people and communities to provide for their social, economic, and cultural wellbeing and for their health and safety.
Building Act 2004 (Part 1, Section 3)	To provide for the regulation of building work, the establishment of a licensing regime for building practitioners, and the setting of performance standards for buildings, to ensure that: (a) people who use buildings can do so safely and without endangering their health; and (b) buildings have attributes that contribute appropriately to the health, physical independence, and well-being of the people who use them; and (c) people who use a building can escape from the building if it is on fire; and (d) buildings are designed, constructed, and able to be used in ways that promote sustainable development.
CDEMA 2002 (Part 1, Section 3)	To improve and promote the sustainable management of hazards in a way that contributes to the social, economic, cultural, and environmental well-being and safety of the public and also to the protection of property
LGA 2002 (Section 3)	To provide for democratic and effective local government that recognises the diversity of New Zealand communities; and, to that end, this Act— (a) states the purpose of local government; and (b) provides a framework and powers for local authorities to decide which activities they undertake and the manner in which they will undertake them; and (c) promotes the accountability of local authorities to their communities; and (d) provides for local authorities to play a broad role in meeting the current and future needs of their communities for good-quality local infrastructure, local public services, and performance of regulatory functions.

Section 11A of the LGA requires that in performing its role, a local authority must have particular regard to the contribution that certain core services make to its communities, which includes the avoidance or mitigation of natural hazards.

At the national level MCDEM promotes risk reduction and, as stated throughout CDEM documents (National Plan, Guide to the Plan, Review of Group Plans 2009 etc) risk reduction is carried out through other legislation. Figure 2 shows this assumption, where local risk reduction is shown as being managed under local RMA plans, business continuity planning, Long-Term Council Community Plans (LTCCPs) etc. However, while the RMA provides the key opportunity to reduce and manage risks, currently it only manages the natural hazard (i.e. the likelihood of a natural hazard event), rather than the risk (i.e. likelihood and consequence). This has caused some land uses to proceed that increase - rather than reduce – risks from natural hazards (Saunders *et al.*, 2007). As shown in Figure 2 there is a good linkage between the CDEMA and the RMA, however at the local level, the assumption of the RMA being the key tool to manage local risk reduction is reinforced. This inconsistency has been recognized (Ministry for the Environment,

2015) and is currently being address in the latest proposed reform package of the RMA, where the significant risk from natural hazards will need to be managed.

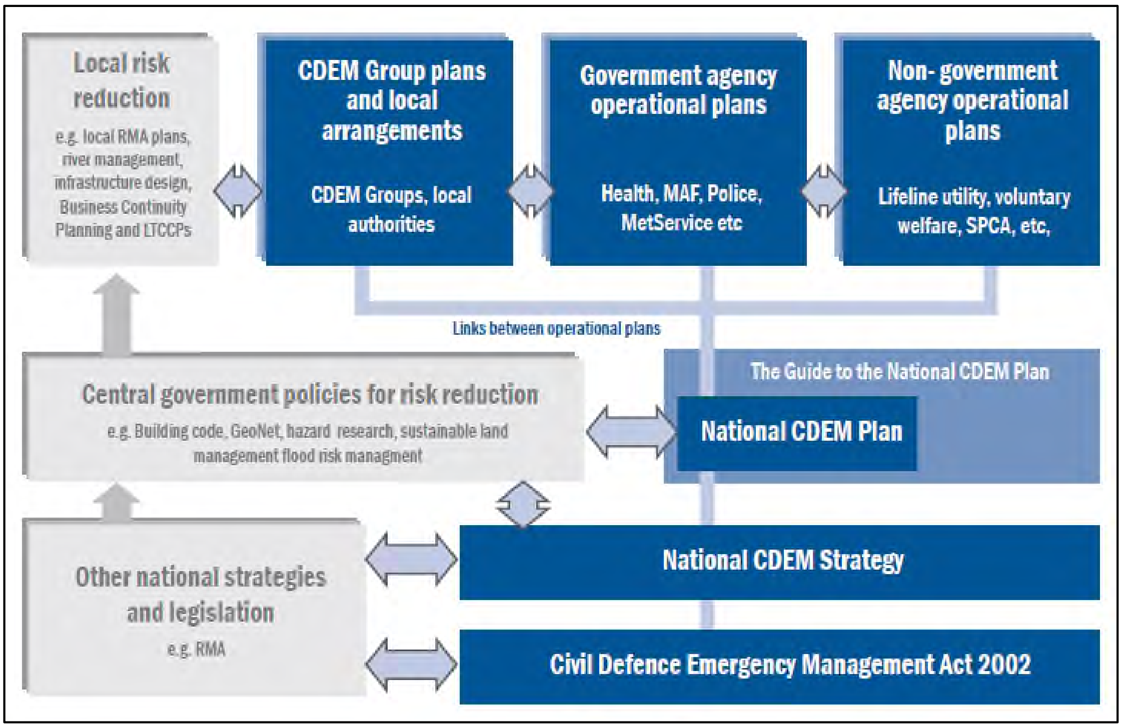

Figure 2 **Linkages between national, regional and local operational plans and arrangements and risk reduction policies and programmes (MCDEM, 2008).**

The proposed RMA reforms announced in December 2015 will seek to strengthen the natural hazard provisions in the RMA, as well as the risk linkage to the CDEM Act. These amendments include an addition to Section 6 (Matters of national importance), "the management of significant risks from natural hazards"[2]. This amendment will change the focus from the likelihood of natural hazards, to their likelihood and consequences, which in turn will strengthen the focus on reducing risks.

3.2. Sustainability, resilience, and higher living standards

As highlighted in the previous section, sustainability needs to underpin any approach to managing natural hazards. Under the CDEMA, resilience is also a key component (MCDEM, 2008). As the term 'resilience' can mean many things (Saunders & Becker, 2015), MCDEM are conceptualizing resilience as being seven key components (see Figure 3). Figure 3shows that resilience results from a broad range of activities, and acts on a range of scales, in both time and community levels. While still under development, Figure 3provides a clear direction for what resilience encompasses.

[2] http://www.legislation.govt.nz/bill/government/2015/0101/latest/DLM6669158.html?search=ta_bill_R_bc%40bcur_an%40bn%40rn_25_a&p=1, retrieved 17 December 2015.

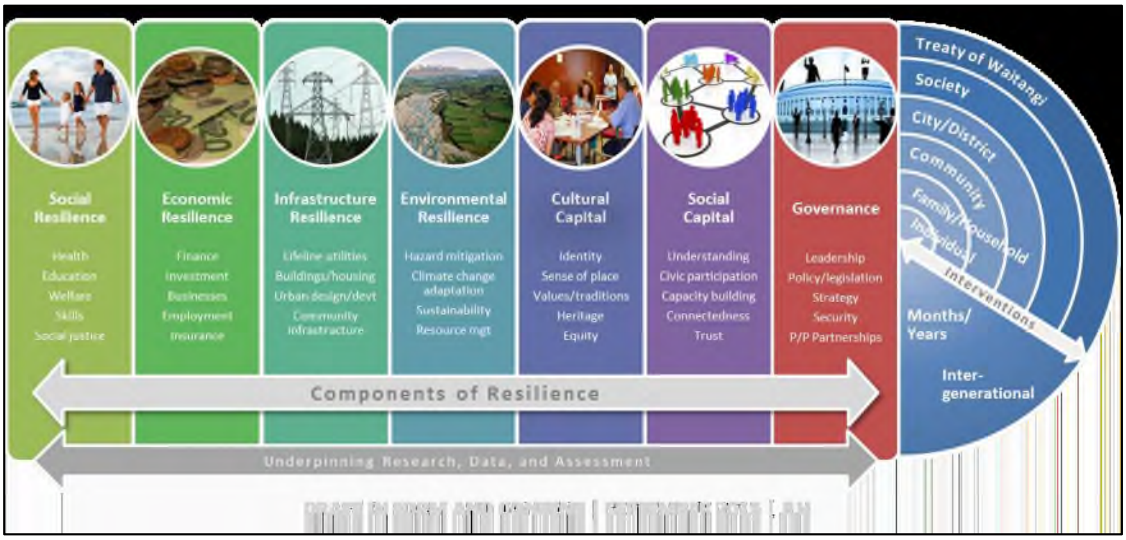

Figure 3 Conceptual diagram of resilience (still under development) (MCDEM, 2015).

However, sustainability and resilience are not one and the same; rather they are interdependently linked (Saunders & Becker, 2015). A sustainable community can only be sustainable if it holds some degree of resilience - which is reflected in the definition by the UN Commission on Sustainable Development (Godschalk, 2002), which suggests that "Sustainable development… cannot be successful without enabling societies to be resilient to natural hazards". In 2012, 17 sustainable development goals were developed through Rio+20 (the UN Sustainable Development Conference, 2012). One goal – Sustainable Goal 11 – has a focus on resilience and sustainability. The goal is to "Make cities and human settlements inclusive, safe, resilient and sustainable". This is supported by the aim to "increase … the number of cities and human settlements adopting and implementing integrated policies and plans towards inclusion, resource efficiency, mitigation and adaptation to climate change, resilience to disasters, and develop and implement, in line with the Sendai Framework for Disaster Risk Reduction 2015-2030, holistic disaster risk management at all levels" (UN Division for Sustainable Development, 2015).

At a central government level, the New Zealand Treasury has produced a HLS, summarised in Figure 4.

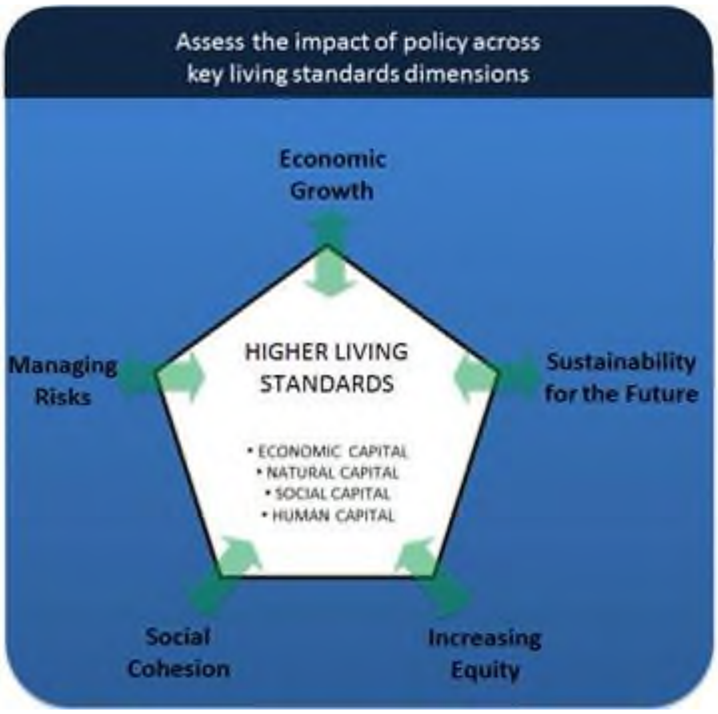

Figure 4 Treasury Higher Living Standards Framework (The Treasury, 2016)

The HLS describes a broad range of factors – including income and wealth – that theory and evidence suggest are important to living standards. It sets out points to consider when developing policy advice: the level and distribution of factors that underpin living standards, and the interactions, trade-offs and synergies among them (Gleisner *et al.,* 2011). Treasury acknowledges that there is an increasing complexity of issues as there is a move from managing risk, to supporting resilience, and ultimately enabling sustainability (Blake, 2013).

Figure 5 shows how Treasury reconciles these concepts, which also includes risk management. The Treasury diagram implies that resilience should be focused on short and long term adaptability, while sustainability takes a longer term "future generations" stance.

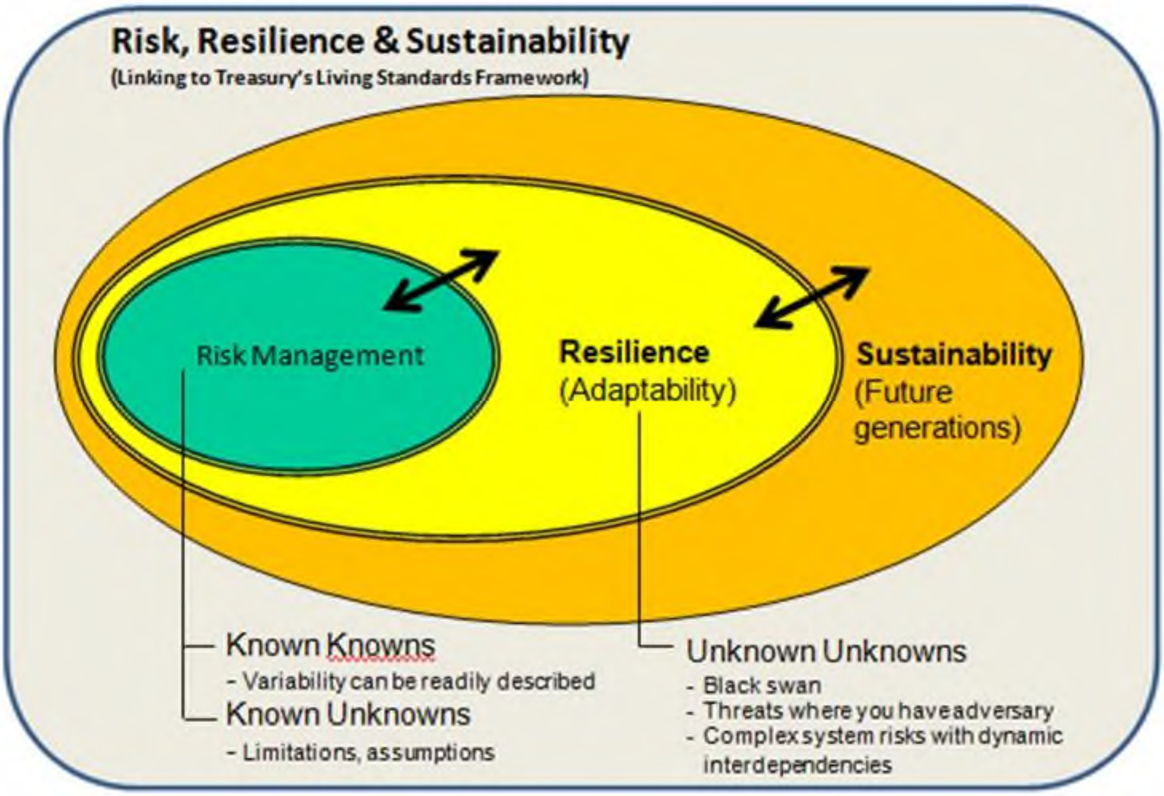

Figure 5 Relationship between sustainability, resilience and risk management (Blake, 2013, p6).

In reconciling the HLS with the MCDEM concept of resilience (Figure 3), social resilience is linked to human capital; economic and infrastructure resilience with financial and physical capital; environmental resilience with natural capital; and cultural and social capitals with HLS social capital. Governance within the MCDEM resilience concept is linked to all components of resilience and HLS.

3.3. Decision Making Processes Required under the RMA

The following discussion is a summary from the publication "*A guide to section 32 of the Resource Management Act: Incorporating changes as a result of the Resource Management Amendment Act 2014*"(Ministry for the Enivornment, 2014).

The RMA provides a process through which local authorities and their communities develop policies and plans for sustainably managing natural and physical resources. Policy and plan making under the RMA often involves difficult and complex decisions, trade-offs between values, and multiple, sometimes competing, interests. The development of RMA policies and plans follows a systematic, rational approach to identifying issues, establishing objectives, selecting and implementing policies and methods, and evaluating the outcomes (see Figure 6).

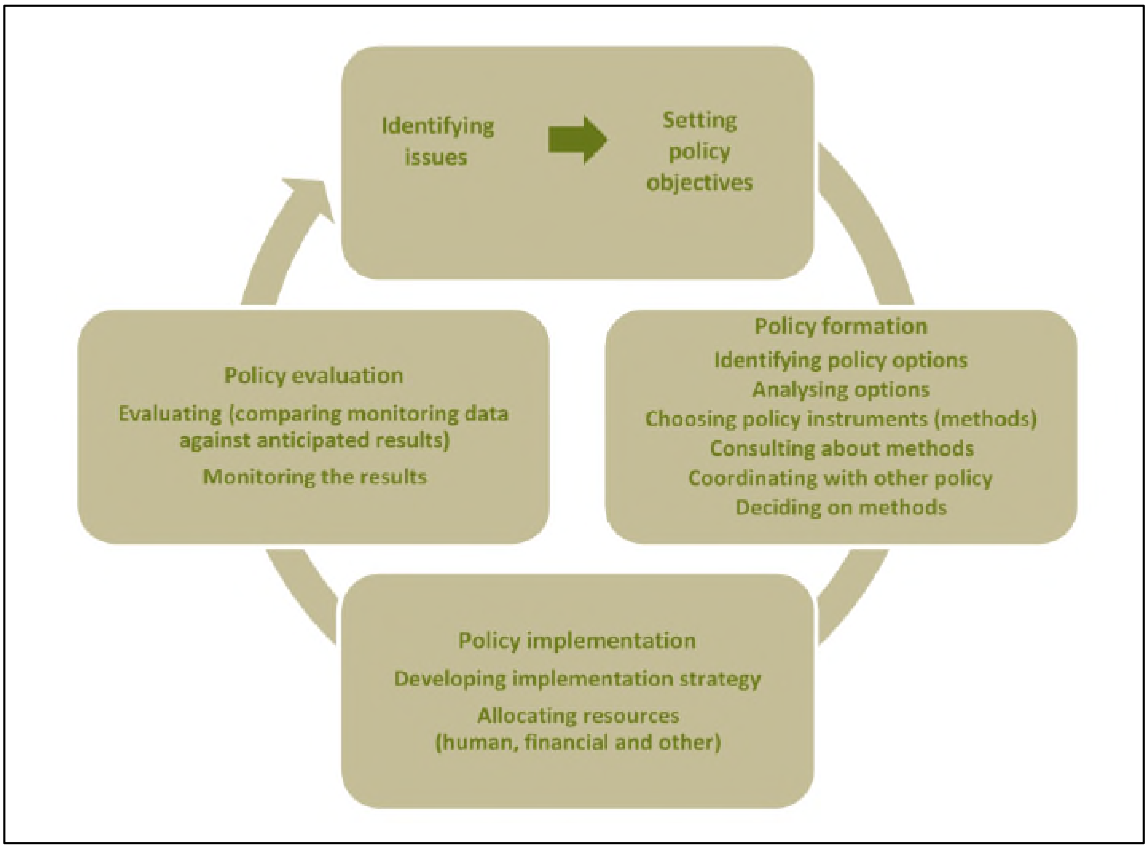

Figure 6 The RMA planning cycle (Ministry for the Enivornment, 2014, p9).

During the policy formation step, a Section 32 (s32) report is required. An s32 report helps planners to demonstrate that:

- objectives, policies and methods of proposed RMA planning documents have been well tested against the purpose of the RMA, and
- anticipated benefits of introducing new regulation outweigh the anticipated costs and risks.

Plans that are developed using sound evidence and rigorous policy analysis lead to more robust, enduring provisions, and can mean issues are resolved early on in plan-making, reducing opposition during hearings or at appeal.
S32 evaluations aim to transparently communicate the thinking behind RMA proposals to the community and decision-makers. They tell the 'story' of what is proposed and the reasoning behind it. Decision-makers then have clearly communicated, sound policy analysis on which to base their decisions about resource management issues.

The s32 evaluation also provides a record for future reference of the process, including the methods, technical studies, and consultation that underpin the plan change / policy process, including the assumptions and risks.

S32(1)(b) specifically requires the efficiency and effectiveness of proposed provisions to be assessed. As part of assessing efficiency and effectiveness, s32(2)(a) requires the responsible agency to:

> "Identify and assess the benefits and costs of the environmental, economic, social and cultural effects that are anticipated from the implementation of the provisions, including the opportunity of economic growth and employment that are anticipated to be provided or reduced."

A cost, or negative effect, can be described as what society has to sacrifice to obtain a desired benefit. A benefit, or positive effect, can be described as the outcome of an action (eg, a plan change) that enhances well-being within the context of the RMA.

The benefits and costs of environmental, economic, social, and cultural effects anticipated must be identified and assessed. This is to ensure all of these types of effects are considered in the s32 evaluation, rather than to create an artificial distinction between these categories. This ensures the regulatory impact of a proposal on society is comprehensively evaluated.

S32(2)(a)(i) and (ii) requires that the opportunities for economic growth and employment that are anticipated to be provided or reduced are assessed. Economic growth is the net increase in the size of the economy. The economy should be considered from a broad perspective to include people, business/government, and the biophysical resources affected by production and consumption. For these reasons, growth is not simply the increases in business activity, household income or population gain, but should be seen from a broad district, regional or even national perspective.

Employment opportunities are the potential for economic growth or any other aspect of a proposal to generate job or work opportunities. Both positive and negative effects on economic growth and employment should be considered. Specifically referring to economic growth and employment opportunities is not to add greater weight to these matters, but to ensure they are addressed as part of the evaluation. This recognises that Part 2 of the RMA includes economic well-being, and the use and development of natural and physical resources invariably involves economic activity.

As part of the s32 process, s32(2)(b) requires costs and benefits to be quantified if practicable. To quantify means to place a numerical value on, not necessarily to monetise. Quantification of costs and benefits can help decision-makers make informed decisions. The inclusion of 'if practicable' recognises that for either ethical reasons or methodological limitations it may be difficult to quantify particular impacts.

'If practicable' can be taken to mean that quantitative data should be collected if:
- It is possible to collect quantitative data,
- The costs of collecting the data are appropriate to the scale and significance of the impacts or the overall problem to be addressed, or the costs of choosing an inferior policy option, and
- The data can be analysed or compared in a meaningful way.

S32 does not require a fully monetised cost-benefit analysis, but encourages increased analytical rigour in evaluations. It recognises that a range of methods can provide a robust analysis where there is a mixture of qualitative, quantitative and monetised data.

3.4. Challenges for long term planning

There are a number of additional challenges that affect long term land-use planning, which have been identified in Glavovic et al 2010(a)(b), Saunders, Beban *et al* 2014, and Saunders, Grace *et al* 2014. These include (but are not limited to):

- Political election cycles, both national and territorial,
- Governance arrangements,
- Understanding the nature of hazards and risks,
- Prioritising mitigation above risk avoidance,
- Support for managed retreat,
- Mainstreaming climate change adaptation,
- Information management, including cost, storage, quality and reliability,
- Existing use rights and associated property rights,
- Historical planning decisions, and
- Staff turnover within councils, leading to a loss of institutional and local knowledge.

3.5. Summary

In New Zealand, risk management is governed by a package of regulatory tools – it requires a deliberate mix of regulatory control through land-use planning, building requirements, emergency management, access to information, and local governance arrangements. No one policy response is adequate for successful risk management; it requires the combination and integration of each element to reduce risks.

A common theme for each regulatory mechanism is the underlying purpose of sustainability. Managing risks, sustainability, and allowing for economic growth, is key to the HLS, which forms part of the risk management context for New Zealand. This framework, which includes resilience and risk management as a subset of sustainability, provides a strong relationship to risk management to ensure that a resilient community is also a sustainable one.

Associated with sustainability is the well-being of communities. The RMA requires an analysis of benefits and costs for all new policies and plans. This includes identifying and assessing the benefits and costs of environmental, social, economic, and cultural effects. The proposed framework will play an important role in enabling government authorities to fulfil this obligation.

4. Formal approaches to decision-making

This section provides a brief overview of formal frameworks or decision making approaches that have been applied for decisions at a government level, including in the context of risk management.

4.1 Cost Benefit Analysis

Although Cost Benefit Analysis (CBA) emerged as a policy tool in the 1940s, the extensive use of CBA as a practical tool for guiding decisions with environmental impacts is a relatively recent development (Atkinson & Mourato, 2008). Essentially the purpose of CBA is to determine whether a change in the world (i.e. as introduced by a policy or project investment) is beneficial or not to society, by systematically assessing the costs and benefits, according to certain accounting conventions. In summary CBA:

- Is a formal discipline used to help appraise projects or policies,
- Is predominantly used by governments to evaluate the desirability of a given intervention,
- Monetises benefits and costs and adjusts for the time value of money through discounting, and
- Estimates both flow (e.g. annual higher property value resulting from disaster risk protection) and stock effects (e.g. one-off capital expenditure of seismic retrofits).

4.1.1. General theory and background

CBA originates within welfare economics[3] and embodies an underlying concept of efficiency, meaning that the objective of economic analysis and government intervention is to assist society to maximise well-being, subject to resource constraints and competing needs and wants.

The concept of well-being, which is often used interchangeably with welfare, utility or satisfaction, is itself subject to much debate.[4] According to welfare economics, individual preferences, typically as revealed by observed market behaviour, are the appropriate source of information for ranking options according to the well-being they generate. Traditionally, welfare economics has also been characterised by a strong avoidance of comparing utility/well-being between individuals, and thereby potentially making trade-offs between the welfare of individuals. Instead, such decisions have been considered entirely the domain of the political process.

Strictly speaking, the economic efficiency, also termed 'Pareto optimality' is satisfied when resources are allocated such that no further reallocation is possible that would provide welfare gains to some individuals without simultaneously imposing losses on others. A change that makes at least one individual better off, without making any other individual worse off is called a Pareto improvement. In real life, however, very few policy changes or investments will meet the strict Pareto standard, as virtually all contexts involve both gainers and losers. Practical

[3]Notable contributions to welfare economics come from Dupuit (1844, 1853), Pareto (1909), Pigou (1912), Robbins (1938), Hicks (1939, 1943) and Kaldor (1939), among others

[4]One commentator has stated, "There are at least as many views on how the welfare of individuals should be compared as there are authors who write on the subject (Binmore, 2009, p.450).

applications of CBA have therefore generally sought instead only to satisfy the *potential* for a Pareto improvement,[5] in that the individuals benefiting from the subject intervention could in theory compensate those who are adversely affected, and still be better-off.

There are a number of conceptual limitations associated with CBA. The difficulty of accounting for equity is considered in more detail below (Section 4.1.3). Like many other analytical techniques, properly accounting for and representing uncertainty is also a particular challenge for CBA. Another common criticism is the tendency to only include in an evaluation those costs and benefits that are easily monetised or quantified.

A variety of theoretical challenges have also been levelled at CBA (Samuelson, 1942; Scitovsky, 1941; Little, 1950; Arrow, 1951; van de Graaf, 1957; Boadway, 1974; Chipman and Moore, 1978; Henderson and Quandt, 1980). Many of these involve quite complex and technical arguments. However, some of the key points to note are:

- CBA often uses marginal prices and analyses changes that impact on different parts of the economic system in isolation. In the real world, economic systems are interconnected and changes within one part of the system may cause changes in another part of the system, including changes in the very prices used to evaluate the relative magnitude of costs and benefits.

- The application of the compensation test is not free from value judgements and involves comparing and balancing losses in utility for some individuals against gains in utility for other individuals. For example, if a proposed policy results in a gain of $100 to individual A and a loss of $50 to individual B, we cannot assume that social welfare has increased; for if A is rich and B is poor, it may be that the loss of satisfaction to B of $50 is far greater than the gain of $100 for A.

- Welfare economics (and CBA) postulates that consumption choices are rational, i.e. individuals make choices maximising well-being. In the real world, however, individuals are often subject to imperfect information and cognitive limits prevent individuals from identifying so-called rational options. On a related point, individuals may be altruistic and consider others' well-being when making decisions and/or judge their own well-being relative to others. This calls into question mathematical models that have been used to identify the optimum conditions for society as derived from the collective behaviour of many self-regarding individuals.

These challenges have in part enticed researchers to find new ways for measuring well-being. Happiness economics studies the relationship between individual satisfaction and economic issues, such as employment and wealth.[6] Often

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[5]Known as the Kaldo-Hicks compensation test (Hicks, 1939; Kaldor, 1939).

[6]Surveys of the research are provided by Layard (2005) and Frey and Stutzer (2002), among others.

econometric analysis is used to reveal the factors that change human well-being and quality of life and the work does not necessarily involve monetisation of impacts such as CBA would. Other attempts made at quantifying social welfare/well-being include other aspects such as economic freedom [7] into decision-making. Whether these new lines of research evolve into the development of practical decision-making frameworks is largely still to be seen.

We can note that despite the critiques and search for alternatives, CBA has flourished as an applied economic evaluation tool the world over. Numerous texts and best practice guides have developed. Those developed in New Zealand and/or specifically for the risk management context are noted later in this review. There are, however, numerous others covering the field (see, for example, Boardman *et al,* (2001), Just *et al.,* (2004), Pearce *et al.* (2006) and Florio (2014), to name just a few). It has been reasoned that this is because CBA has been "the best game in town" and that many of the criticisms may be relatively unimportant in real world policy (Pearce *et al.,* 2006, p.33).

Importantly, many alternative social welfare functions have been put forward through which to assess the overall welfare/well-being change arising from a policy or investment for society. When aggregating utilities across different individuals, methodologies now explicitly acknowledge the possibility of assignment of varying weights to benefits and costs experienced by different individuals, reflecting value judgements on equity needs for society (e.g. Samuelson, 1947; Boadway and Bruce, 1984). [8] It is acknowledged that an objective social welfare function cannot be built, and that social welfare can be analysed in different ways, with the different concepts tailored to answer different questions (Florio, 2014). Today CBA is more openly pragmatic, with greater acknowledgement of the role of value judgements within economic analysis, including in the selection of social welfare function and welfare weights, discount rates, and in the selection of individuals considered relevant to the assessment (cf. Florio, 2014).

4.1.2. Measures of welfare

CBA measures changes in welfare arising out of a policy or other intervention by identifying all effects, beneficial and adverse (i.e. benefits and costs), and where possible placing monetary values on these effects. Typically, future benefit and costs streams are discounted using an appropriate discount rate (discussed below). The result of CBA is generally expressed in dollar terms as a Net Present Values (NPV), which represents the total excess of benefits over costs, assessed in constant dollars. A positive NPV shows there is a gain in well-being to society, whereas a negative NPV means that there is a net loss.[9]

[7]An example of this is the capability approach developed by Amartya Sen in the 1980s as an approach to welfare economics. The purpose was to bring in the concept of people's ability to achieve outcomes that they value, an idea not included in the traditional approach to welfare economics.

[8]Although we can note that in many analyses, non-weighted welfare functions are still applied. This is perhaps a reflection of limited information upon to develop appropriately weighted functions or perhaps an aversion by analysts undertaking the CBA task to undertake the weighting (Pearce, 1998).

[9]Benefit cost ratios (BCR) are another way of comparing outcomes by showing the relationship between cost and benefits. A course of action is worthwhile undertaking if the BCR is greater than one and projects can be ranked

Valuations of costs and benefits are based on concepts of willingness to pay (WTP) for a benefit and willingness to accept (WTA) compensation for a cost. WTP and WTA are firmly grounded in the theory of welfare economics and are linked to the consumer surplus principle redefined by Hicks (1943).[10] Ideally, CBA uses shadow prices to evaluate welfare changes. A shadow price is defined as the change of social welfare around the optimum of a unit increase of supply of one good (Florio, 2014). Very often, however, for reasons of information and budget constraints and convenience, market prices rather than shadow prices are used. The extent to which market prices vary from shadow prices depends on the degree of distortion in the economy. Reasons for price distortion include application of duties and quotas, existence of monopolies, and the presence of externalities. The importance of using shadow prices rather than market prices has been emphasised particularly for developing countries, on the basis that market prices are highly distorted (Ganderton 2005).

Analysts often refer to the total economic value (TEV) concept, initially used in an environmental economics context (Daily, 1997; Pearce *et al.,* 1989; Turner, 1999), as a means of conceptualising and categorising the different types of benefits and costs that may arise out of an investment or policy. The TEV thus serves as a type of checklist to help ensure all relevant indirect effects and externalities are taken into consideration. The TEV separates economic values into two broad categories, use values and non-use values. The first covers use values that are both in the present and in the future, and may be further divided into actual use (direct and indirect)[11] and option values. Non-use values (originally theorised by Krutilla (1967)) apply when individuals who do not use or intend to use a good nevertheless feel a deprivation if the resource were to vanish or be withdrawn.[12]

A number of economic valuation techniques have been developed over the last few decades to quantify WTP or WTA measures in relation to items not typically traded within markets. A concise summary of these is provided in Table 2. Although it is noted that classification of non-market valuation methods varies between authors (cf de Groot *et al.,* 2002; Vecvagars, 2006; Meyer *et al*., 2013), three broad categories of non-market valuation techniques are identified in the table: stated preference methods, revealed preference methods, and cost-based valuation techniques. Various limitations have been recorded for the different

accordingly. In case of budget constraints, a BCR ranking procedure can prioritise projects according to the highest ratio until the budget is exhausted. The BCR is not always the best decision rule to use. For example, it is sensitive to how benefit costs are classified (Pearce et al. 2006). For example, a new stopbank along a river may generate benefits for some households, but will come as a cost for others.

[10]A commonly cited textbook covering these and other key CBA concepts is Boardman et al (2001).

[11]Direct-use values are those based on conscious use of a resource in consumption or production activities, for example in the case of a water resource, use of water for drinking, irrigation and industrial processing. Increasingly the recreational and aesthetic values received directly from water bodies are also recognised as important direct values, while the role of water in ecological systems that provide important ecosystem services is an example of indirect use values. The other use value identified, option value, recognises that individuals who do not presently use a resource may still value the option of using that resource in the future.

[12]Existence values are a type of non-use value arising when individuals express value in the retention of a resource which will never be used personally or by future generations. Bequest values refer to the satisfaction derived from knowing that a resource has been preserved for use by future generations. Altruistic values are derived from the value individuals place on a resource that they themselves may never use, but for which they are concerned about the availability to others in the current generation.

valuation techniques. Only stated preference methods are capable of capturing non-use values. However, the studies can be very difficult to implement and must be carefully designed and implemented to avoid biases. Also, the 'free-rider' problem can create incentives for respondents to misrepresent real preferences (Kerr, 1986). Travel cost and hedonic pricing methods are known to be sensitive to model specification, including choice of functional forms (Navrud and Magnussen, 2013). Cost-based valuation methods are not considered to have a sound basis in welfare theory (Brander *et al.* 2006) but nevertheless may be of use when there is limited time and resources available and only approximate estimates are necessary.

Given that many of these economic valuation techniques are highly resource intensive in application (for example, often requiring extensive surveying), a complementary approach, the Benefits Transfer Method (BTM) has arisen. It essentially involves extrapolating values derived from primary economic valuation studies for application in alternative policy contexts. Although the BTM enables a broader range of potential benefits and costs to be considered within budget and time constraints, doubt is often expressed on the appropriateness of applying values derived under one situation to a different context. A lack of suitable guidelines upon which to evaluate the appropriateness of value transfers has been noted (Navrud and Magnussen, 2013).

It was originally thought that the difference between WTP and WTA measures of a change in well-being would be small and of no practical policy relevance. Over the last few decades, however, empirical studies have shown that these alternative approaches do lead to different outcomes, sometimes significantly different. The reason is that people tend to demand higher monetary compensation to give up goods they have, than the price they say they would be willing to pay to buy the same good they do not have (Florio, 2014). Thus, the selection of either WTA or WTP as the appropriate measure of welfare depends on existing institutional structures and whether individuals have the existing right to receive a benefit (or avoid a cost).

Table 2 Non-Market Valuation Techniques

Technique Category	General Description	Specific Valuation Techniques	Examples of application
Stated Preference Methods	Utilise surveys or experiments to elicit what would hypothetically be paid for values not traded in markets	*Contingent valuation* Use of surveys to elicit the monetary value people are willing to pay to avoid a decrement of some type of non-market good or service, or the value they are willing to accept for its deterioration. *Choice modelling* Similar to contingent valuation except that willingness to pay is elicited from experiments in which respondents are asked to rank preferences for different attributes of non-market goods or services.	Willis and Agary (1997), using a survey of real estate agents, conclude that there is a willingness to pay for buildings implementing earthquake risk reduction measures, and provision of better information may further increase the sensitivity of the housing market in regards to earthquake risk. Asgary et al. (2007) apply CV to evaluate the benefits of hypothetical earthquake early warning systems, suggesting that their results could be used by policy makers and firms to determine optimal investment in such systems.
Revealed Preference Methods	Estimation of the value of a non-market good or service based on observed behaviour toward some closely connected marketed good or service	*Travel Cost Method* The costs of travel to a site are used to infer the value of some attribute of that site. Typically used to value recreational values, including experience of cultural heritage sites. *Hedonic Pricing* Concerned with inferring the value of individual attributes of a market commodity.	The travel cost method has been identified as a possible means of valuing loss in beach recreation value at tourist destinations in Thailand following the Asian tsunami. Hedonic pricing has been used to ascertain the value people implicitly pay for housing with reduce seismic risk, or the loss in value of housing following changing perceptions of risk, based on information from real estate markets (Bernknopf*et al.,*1990; Murdoch *et al.,*1993; Lin *et al.,* 2006; Naoi*et al., 2009).*
Cost-based valuation methods	The various cost based methods do not strictly attempt to extract people's willingness to pay or willingness to accept compensation, but rather assume that some set of observed market costs can be used as a proxy for the value of an asset	*Cost of illness approach* Utilises expenditures on health care and/or lost wages from illness as a proxy measure of the value of physical injuries and/or psychological trauma. *Replacement cost or restoration cost methods* Typically used to value natural capital by considering the costs of building infrastructure that would perform similar functions.	Cost of illness approach has been used to value physical injuries and trauma from seismic events (Salcioglu *et al*., 2007; Fukuda *et al*., 1999).

4.1.3. Equity

In a world of scarce resources, efficiency is an important aspect to consider, although it is not the only one. How costs and benefits are distributed across individuals is of concern to decision-makers and how the distribution of cost benefits is managed will determine equity outcomes. As already introduced by the discussion in Section 4.1.1, appropriate consideration of the distributional incidence of costs and benefits, i.e. the winners and losers as a result of a policy is a long standing issue within CBA.

Many applications of CBA are still based around the compensation test. However, given that in most situations where CBA is applied there is no guarantee of compensation to losers, there is a clear need to also consider implications on equity. This is particularly important given that those responsible for the costs of implementing the intervention are not necessarily the recipient of the benefits - instead they are shared among the wider community. The introduction of rain tanks to a residential property, for example, may benefit the whole community in terms of reduction in stormwater run-off, but it comes at a considerable cost to the property owner. Often distributional effects in CBA are not taken into account.

One way of accounting for distributional effects in decision making is to separately record the costs and benefits against the different parties to which these accrue, and further record any financial transfers between the parties (Krutilla 2005). The Waikato Regional Council, for example, conducted a CBA on two Coromandel beaches to identify the preferred coastal erosion policy. The overall net analysis showed that a seawall would benefit society – an indication that this was the preferred policy (WRC, 2006). Further analysis into the distributional effects of the policy teased out the winners from the losers. There was a net gain for property owners from protecting their assets; however, the general public experienced a direct net loss as a result of a decline in 'naturalness'[13] of the beach.

As noted above, it is also possible to apply different types of social welfare functions - these will differ in the way they are constructed and to what degree they reflect distributional effects. The environmental and ecological economics literature highlights the importance of equity considerations not only within generations but also between generations. When a community is concerned with the potential flooding of a river, for example, whether it is efficient or optimal to invest in flood protection may ultimately depend on whether the community considers it important to consider future generations. Thus so-called optimal choices in welfare theory actually depend on prior resolution of entitlement or property rights (Pearce., 1989). Although it may not be openly acknowledged or discussed, different value sets regarding distribution and equity enter CBA in terms of the types of benefits and costs that are considered, the social welfare function applied, identification of the bounds for society (i.e. those people who have 'standing'), and in selection of an appropriate discount rate. The later topic is discussed in more detail below.

[13]Defined here as the overall natural qualities of the beach environment.

4.1.4. Consideration of time through discounting

CBA analysis involves comparing a range of costs and benefits over time; discounting ensures that these effects occurring in different time periods are expressed in their present value (EPA, 2010). Impacts occurring at different future times are compared by converting each future value into a common currency of equivalent present value (Gollier & Weitzman, 2009). The rationale behind discounting can be partly explained by people's rate of impatience (they want to consume today rather than tomorrow) and the opportunity cost of capital (the same money could be invested elsewhere to give a future return) (Atkinson & Mourato, 2008).

The approach taken to discounting remains a highly controversial matter within the environmental economics literature. Historically, CBA was developed for short to medium term projects, i.e. less than 25 years (Turner, 2006). The rise of environmental challenges and ensuing management pressures means that much longer time horizons need to be taken into account, e.g. beyond 100-years (Brouwer *et al,.*2010). However, the use of constant positive discount rates[14] does not take into account effects beyond a certain timeframe, e.g. 25-30 years. On the other hand, a lower discount rate (or even a zero discount rate) means that the current generation needs to save and invest more, implying some form of sacrifice (Pearce *et al,.*2003).

This traditional aspect of CBA leads to what the literature refers to as the 'tyranny of discounting', where future impacts are more heavily discounted than present effects (Atkinson & Mourato 2008; Hepburn 2007; Pearce *et al.,* 2003). There is an inherent risk of burdening future generations, particularly in terms of climate change and sea level rise and its consequences on the built environment. The impacts of flooding will entail rising damage costs over time as more assets are exposed - this is exacerbated by unchecked coastal development.

This disparity in current versus future generation needs has not gone unnoticed. There has been much discussion in the literature about the need to include inter-generational discounting (Cropper 2012; Gintis 2000; Gollier 2010; Gollier and Weitzman, 2009). Investment decisions with higher initial costs *and* larger future benefits only start to become favourable when discount rates are nearing zero (EPA, 2010). Risk management often requires substantial upfront investments, e.g. moving houses away from shorelines can be very costly.

A new approach has evolved in recent years, i.e. the use of declining discount rates (DDR), in the form of hyperbolic discounting[15], where individuals value the medium and distant futures on an equivalent basis and the discount rate falls the longer the time horizon (Cropper 2012; EPA 2010; Karp 2005; Pearce *et al.,*2003; Turner 2006). DDR is partially justified by the fact that people's discount equations are hyperbolic; their discount rates are likely to decline as time passes (Pearce *et al.,*2003). Weitzman (1998) suggests using 3-4% for the first 25 years of the project life, 2% for 25-75 years, 1% for periods of 75-300 years and zero %

[14]The higher the rate, the less future cost and benefits are taken into account. Typical constant discount rates range between 8 and 12%.

[15] This is in contrastto the constant discounting which behaves exponentially.

for 300 years plus. The World Bank now recommends for projects with costs or benefits extending beyond 30 years, use of a DDR beginning at 5% and falling to 1% over the very long-term. Other examples will involve a more complex declining discounting schedule.

Some countries are aware of these issues and have been dealing with it in different ways. In the United Kingdom, HM Treasury have officially accepted DDR (Groom*et al.,* 2005), using a rate of 3.5 percent in year 10, a rate of 2.5 percent in year 70, with the rate falling to 1 percent in year 300 (Cropper, 2012). France and Canada are also using DDR schedules.

Research undertaken on social discount rates in Australia, Canada, Germany and the United Kingdom, show that there are substantial differences in the appropriate schedule of discount rates to be used (Hepburn*et al.,* 2009). For example, Canada uses faster declining discount rates than the other countries, reflecting higher uncertainty in past Canadian interest rates. This implies that each country needs to develop its own tailor-made DDR schedule for DRM.

In some instances, such as if climate change and sea level rise causes catastrophic changes and more urgent action is required, it has been suggested to use negative discount rates (Weitzman, 2009). Negative, small or falling discount rates are rarely used in decision-making (Ganderton 2005), and probably even less so in DRM. The choice of discount rates becomes pivotal for projects involving long time horizons as the CBA results are highly responsive to even tiny changes in the discount rate. It is essential to carefully explain the rationale behind the discounting schedule chosen, regardless of whether this concerns the use of constant, declining or negative discount rates.

4.1.5. Important considerations

CBA is a pragmatic tool that applies a rigorous accounting framework to help assess the efficiency of alternative options available to decision makers. Like some other methods, CBA is conceptually wide enough to allow for consideration of environmental and other non-market impacts. It can thus provide a useful tool for the evaluation of DRM investments and policies.

There are, nevertheless, several limitations to CBA. It is noted that although there has been a proliferation of CBA manuals, for reasons of cost and lack of information, it is often simply impractical to follow best practice guidelines. One of the most well-known difficulties is that of estimating and including non-market values. Although several valuation techniques have evolved over the last few decades, these are complex, their application in decision-making still uncommon and they are not always affordable to governmental agencies, particularly those managing regional or local resources. Relevant data is often not available or too expensive to collect. In some cases, people are not able to or willing to make reliable trade-offs against money. There are also ethical questions around how to value human life (Mechler, 2005), cultural and biodiversity values.

Estimates of some benefits and costs can be subject to a certain degree of uncertainty because of disparities in data collection and underlying assumptions. Uncertainty about future impacts creates difficulties for policy formulation. This uncertainty can be expressed in different ways by either indicating a range of costs and benefits (rather than single values) or by testing the absolute values in a sensitivity analysis or other appropriate methods (see also Section 5.6). Examples of variables to be tested are dominant benefit and cost elements and the value of the discount rates. Often the strength of a CBA lies in the extent and effort put into these types of subsequent analyses. Also, the above discussion illustrates that value judgements enter a CBA process via a number of avenues despite a tradition for CBA to be viewed as an objective decision-making tool. Ensuring that assumptions and value propositions are transparent will improve the quality of CBA so that it can be best used as a platform for systematic consideration of the benefits and costs arising out of alternative policies and projects.

4.2. Cost Effectiveness Analysis

4.2.1. General theory

Cost effectiveness analysis (CEA) aims to compare the outcomes of different options or scenarios with their costs in order to optimise per unit costs (Brouwer *et al*., 2010). Alternatives are compared on the basis of their costs and a single quantified measure of effectiveness. The prerequisite is that the alternative options aim to achieve the same objective, for example which policy options would be the most cost-effective at reducing building damage in an event of an earthquake.

CEA is a fairly popular decision-making tool, particularly in the area of health policy where the efficacy of the outcome sought (e.g. less deaths) is already accepted. It has also been applied in Europe to the decommissioning of nuclear plants and contaminated land remediation (Hanley, 2001). CEA does not gauge whether prospective benefits of the preferred policy are greater or less than the costs, which means that society could be spending more resources than necessary. CEA is useful, however, in how to spend the least amount of money in achieving some pre-determined target. For example, if a new legislation in New Zealand was to windproof roofs of the existing housing stock, CEA would identify the least costly way of achieving this target.

In some instances, an alternative can be more expensive and, at the same time, more effective. Then the 'incremental cost effectiveness ratio', i.e. the extra cost divided by the extra effectiveness, can guide decision-makers in whether it is good value for money to pursue the alternative (Brouwer *et al.,* 2010).

It is good practice to use CEA when the benefits of alternative DRM options are relatively similar so that only costs need to be calculated. For example, several different options can reduce stormwater run-off in urban areas all resulting in a similar benefit. CEA would prioritise the most cost-effective option to achieve the outcome. The advantage lies in that CEA does not require the quantification of

benefits and in instances where this is difficult such as reducing disaster fatalities to a certain level, only costs can be compared.

4.2.2. Important considerations

Assessing the costs and benefits of DRM interventions can represent challenges. For example, weighing up the costs of a proposed change to land-use regulations against a general campaign on raising disaster risk awareness is not that straightforward. There is potentially a wide range of interventions to choose from and some will be harder to cost than others, whereas benefits may prove to be even more difficult to estimate. For most DRM projects, the lack of data, especially regarding benefits, means it is not easy to estimate the efficiency of policy options using CBA (Mechler, 2005; Toyama & Sagara, 2013). In a recent review of environmental regulations, the U.S. EPA found that all regulatory impact analyses estimated (some) costs, but less than half included some form of benefits (Hahn & Dudley as cited in Atkinson & Mourato, 2008). Only about a quarter provided a full range of benefit estimates. This shows that in practice benefits of policies are often omitted from analyses.

An advantage of CEA is that there is no need to monetise benefits which means that in some situations it is a more appropriate assessment framework than CBA, so long as a common benefit denominator can be found such as how effective each intervention is at achieving a predetermined goal. A difficulty arises in applying CEA, however, when there are multiple goals or benefits sought to be achieved and options involve trade-offs between the relative extents to which these benefits are achieved.

CEA also does not deal well with uncertainty in costs or benefits and therefore it needs to be applied in situations where uncertainty is low in regards to both the future risk and the success of the possible interventions. A CEA is most appropriate when:

- An investment area has already been targeted and thus the efficacy of the intervention is not in question, e.g. improving the drainage in a specific suburb, and the least cost or most effective policy option needs to be identified;
- The benefits of different investments are similar; and
- Benefits are likely to outweigh costs in the long term, but difficult to quantify (or can only be quantified partially) because they are indirect or intangible, i.e. environmental, cultural or social.

4.3. Multi Criteria Analysis

4.3.1. General theory

Decision-making regarding the reduction of disaster risk requires the evaluation of trade-offs between cultural, socio-political, environmental and economic impacts (Huang*et al.,* 2011). Multi Criteria Analysis (MCA) emerged as a formal methodology to incorporate these different types of impacts by allowing a structured comparison and ranking of alternative options or scenarios. Built on decision theory, this approach was first introduced by Keeney and Raiffa (1976).

The MCA process involves qualitative ranking of indicators or criteria by a number of stakeholders according to their preferences and belief systems.[16] Hence it relies on judgment to assign the ranking of options against the selected criteria. The outcome of an MCA tends to reflect the knowledge and value sets of the group who carry out the analysis.

MCA can assist policy development by taking into consideration the issues and concerns that are held by policy makers and capturing these within a set of indicators or criteria. It offers a number of ways of aggregating data on these individual criteria to provide an indication of the overall performance of scenarios (Dodgson *et al*., 2009). The success of a MCA exercise depends particularly on the quality of thought and preparation that goes into the early steps of the analysis, i.e. outlining the options and identifying appropriate criteria. Each criterion needs to be carefully evaluated, defined and tested to avoid double-counting and to ensure that it is understood and interpreted the same way by individuals with different backgrounds. The identification of appropriate costs and benefits for consideration is also important in a similar manner to CBA.

MCA is clearly a more flexible method than the economic approaches described above and can potentially be more comprehensive in its coverage. Information from various scientific fields and backgrounds can be included without the need for a common numeracy. Impacts do not necessarily need to be quantified, and can include wide-ranging aspects, not just financial costs and benefits. Additional criteria can be easily added as different stakeholders review the process. The incorporation of qualitative information can be valuable within a complex decision-making context such as DRM.

MCA is gaining in popularity, with significant increase in the number of MCA papers published in the environmental field over the last two decades (Huang *et al.*, 2011; Zavadskas & Turskis 2011). Less applications of MCA are found in the area of DRM, therefore there are opportunities to explore the use of this decision-support tool.

4.3.2. Structured process

Research has shown that group decision-making can potentially produce better outcomes than that which can be produced by individuals working separately (Regan-Cirincione 1994). There are several different ways to structure a MCA process; a common approach is the use of facilitated workshops to allow different disciplines to come together, discuss trade-offs and come to a more common understanding. It is typical for workshop participants to have different areas of expert knowledge and therefore represent a diverse mix of interest groups, disciplines and areas of interest. By working together, participants often discover interconnections between areas of apparently separate expertise (cf. Dodgson *et al.,*2009). The role of a facilitator is to focus on the process and to maintain a task

[16]Whenever a decision-maker is required or has the authority to make decisions taking into account a number of different considerations this could be termed 'multi criteria analysis'. In this review the term is confined to the formal decision making processes described in the literature as MCA and typically involve assessment criteria developed in conjunction with a number of decision makers or stakeholders.

orientation to the work. The facilitator ensures that all participants are heard, understands the dynamics of the group, is sensitive to the effects of group processes and intervenes to progress the work of the group.

Since a MCA is often qualitative in nature and potentially open to critique for subjectivity, it is beneficial to follow a specific structure to increase its robustness and credibility. A typical MCA structure based on overseas examples comprises several elements (Dodgson *et al*., 2009):

1. Brainstorming and definition of scenarios/options that broadly bracket possible future DRM;
2. Development of a range of environmental, socio-political, cultural and economic criteria to reflect the impacts likely to be generated by each of the options;
3. Ranking of criteria by a multi-disciplinary group through a facilitated workshop;
4. Assigning weights for each of the criteria to reflect the relative importance of the criteria to the decision (optional);
5. Combination of the results for each of the criteria (potentially weighting criteria);
6. Sensitivity analysis testing scores and weights assigned; and
7. Discussion of the results and conclusions.

It is helpful to fully brief participants prior to the workshop by providing maps, instructions, assumptions associated with methodology, and an opportunity to pre-rank scenarios. Any assumptions need to be explicitly stated (Dodgson *et al*., 2009).

4.3.3. Scoring, weighting and normalisation

MCA approaches differ in how data is combined, with some MCA techniques providing an explicit relative weighting system for application to the different criteria. Qualitative and semi-quantitative approaches differ in how weights under certain criteria are assigned. Consideration can be given to applying a separate weighting system/score to specific criteria to address any important imbalance.

The outcomes of an MCA can be represented in a performance matrix. Decision-makers assign a (numerical) score on the strength of a preference scale for each option and criterion. Then they assign the relative valuations of a shift between the top and bottom of the chosen scale. The individual performance assessments can either be descriptive, numerical, alphabetical, expressed as 'bullet point' scores, colour coded or a combination of these. An example of MCA performance matrix in the context of river flooding is given in Table 3. No ranking or weighting system has been applied and criteria have been assessed according to a combination of descriptive text, percentages and financial costs.

Table 3 MCA example assessing DRM adaptation and mitigation options using descriptive and numerical criteria

Potential DRM options for river flooding			Decision Criteria					
			How long would the option take to implement	How long would risk reduction benefits	Cost	% of assets affected benefiting from option	How difficult is the option to implement (politically etc.)	Other benefits / impacts
Making space for water	Ecosystem Adaptation	1 Riparian Planting 5km	10-15 years	50+ years	$10,000	5-10%	Straightforward	Some benefits
		2 Afforestation 10ha	5-10 years	50+ years	$30,000	30-49%		
		3 Mangroves 5ha	10-15 years	50+ years	$8,000	20-29%		
	Relocation	1 Landuse rezoning	5-10 years	50+ years	?	100%	Significant issues	Some impacts
		2 Relocate 2 schools	1-5 years	50+ years	$65,000	100%	Some issues	Some impacts
		3 Rebuild meeting house	1-5 years	50+ years	$25,000	100%	Some issues	Some impacts
Living with water	Retrofit	1 Raise 4 buildings	1-5 years	50+ years	$80,000	70-89%	Relatively easy	Neutral
		2						
	Engineering response	1 Widen river channel	1-5 years	25-50 years	?	45%	Some issues	Some impacts
		2 Build levee	1-5 years	10-15 years	$300,000	50-69%	Significant issues	Some impacts
		3						
	Managing residual risk	1 Awareness campaign	< 1 year	1-5 years	$25,000	?	Relatively easy	Neutral
		2 Premium adjustments	1-5 years	10-15 years	$40,000	?	Some issues	Neutral

Adapted from NIWA & Enveco (2015). Strengthening disaster and climate risk resilience in Urban Planning in the Pacific. Report prepared for the ADB.

Various analytical techniques have been used to combine these components to give an overall assessment of each option (Dodgson *et al.,* 2009). Several methods are appropriate to assess the scores (that are the basis of the performance matrix) and assign weights. There are at least two dozen different approaches available at present.[17] The more widely used analytical hierarchical process (AHP) developed by Saaty (1980) encompasses the theoretical background for multi-criteria evaluation. The basis for this process is a method for converting subjective assessments of relative importance to a set of overall scores or weights. For example, decision makers decide how important one criterion is relative to another criterion. These 'pairwise comparisons' help identify both weights for criteria and performance scores for options on the different criteria.

Improving on the AHP, alternatives such as REMBRANDT and MACBETH procedures have been developed (Dodgson *et al.,* 2009; Zavadskas & Turskis 2011). REMBRANDT uses a direct rating system that is on a logarithmic scale; whereas the MACBETH procedure asks decision makers to assess the attractiveness difference between each pair of options. The selection of the preferred MCA model depends on the objective, the stakeholders involved in the decision making process, available information and resources.

Once indicators or criteria have been ranked (often during a structured workshop as outlined in Section 4.3.2), a process is required to combine the qualitative rankings in a meaningful way to achieve an overall evaluation of scenarios/options. To achieve this, rankings can be assigned numerical values. In order to retain equal weighting during overall evaluation, a normalisation process is required, because the different categories, e.g. environmental, social, economic

[17] For an extensive list, refer to table 3, p.412 in Zavadskas&Turskis (2011).

and cultural, are often represented by unequal numbers of indicators. Some categories are likely to have more indicators than others. Normalisation equally distributes the weight of each category in the final decision.

Similar to the CBA process, a sensitivity analysis can help define the robustness of conclusions derived from a MCA. It would consist of varying one or more of the parameters/assumptions of the MCA to see how these variations affect the outcomes. Workshop participants are likely to have limited information about some of the key inputs. Sensitivity analysis is a way to deal with these uncertainties. Put another way, a sensitivity analysis tests the extent to which uncertainty, low levels of confidence and disagreements during the assessment affect the rankings of the individual indicators and therefore the overall option order.

4.3.4. Spatial multi criteria decision analysis

Given that DRM requires the analysis of large amounts of environmental, social and economic information and that this is often land-based, developing a spatial MCA framework has the potential to benefit DRM decision-making processes. This is likely to be especially the case in urban areas where there is a high value of assets and the interactions between DRM measures and their effects can be shown geographically.

Recently, MCA has had a spatial component added by integrating it with Geographic Information Systems (GIS), which is designed to capture, store, analyse, manage, and present any types of spatial or geographical data. Based on spatial MCA theory, a framework can be developed to review different DRM interventions. Like with a normal MCA, this framework needs to include option definition, development of criteria and appropriate spatial quantification, criteria weighting, decision rules, sensitivity analyses, and option appraisal (Yang*et al.,*2011). The framework will depend on the availability of data and adequate software.

4.3.5. Important considerations

In circumstances where time and monetary resources are limited or where quantification is impractical, MCA can be cost-effective, flexible and inclusive. It can provide a decision support framework to consider, assess and weigh complex multi-pronged issues in a DRM context. In New Zealand, DRM requires the involvement of multiple stakeholders and treaty partners within a legislative and socio-political framework influenced by the planning system in place. To deal with these different aspects and to encourage a participatory process, a multi-criteria decision support system may in some circumstance prove to be more useful than a more technical expert-led economic analysis.

The limitations of a MCA include reliance on the opinions of experts, and hence the subjective nature of the analysis. In addition, MCA cannot show that an action adds more to welfare than it reduces. Unlike CBA, MCA is not subject to the Pareto

Improvement rule requiring that benefits exceed costs, i.e. economic efficiency often is not the only objective of policy (Brouwer *et al.,* 2010).

4.4. Full Cost Accounting

4.4.1. Background

The term 'full cost accounting'[18] (FCA) has been increasing in popularity within New Zealand. As already explained above, this literature review is part of a government funded research project titled 'Full Cost Accounting of Disaster Risk Management: Risk, meanings and metrics with uncertainty'. The concept of 'full-cost accounting' is itself relatively undefined and open to broad interpretation. The purpose of this section is to provide a brief overview of work that has so far been undertaken under the name of 'full-cost accounting'.

It is worth noting, as the name suggests, full-cost accounting is a form of *accounting.* Accounting systems collect and aggregate information (i.e. collate measurements and create indicators) for decision makers. Accounting systems both arise from values, as we measure what we care about, and create values, as we care about what we measure (Meadows, 1998). As the name also suggests, full cost accounting is also particularly concerned with bringing the full and wide ranging costs (including environmental, social and economic) of a particular action into consideration. In this way the concepts of indirect effects and externalities often discussed in economics are equally relevant to FCA.

We can identify two broad streams of work where the concept of FCA has been influential. First, FCA has been applied in the context of accounting systems at the whole-of-society level. Here FCA typically involves the creation of accounts that supplement or provide an alternative to traditional measures used to track welfare/well-being or 'society's progress', including in particular the Gross Domestic Product or Gross Regional Product indicators.[19]The work of GPI Atlantic, who have been involved in researching and applying the concept of a Genuine Progress Indicator (GPI) in the province of Nova Scotia in Canada,[20] is particularly notable in this area. In New Zealand, Greater Wellington Regional Council has also committed to the development of full cost accounts for the development of its regional GPI. The GPI is a holistic measurement tool that governments and communities can use to measure whether a country or region's growth, increased production of goods, and expanding services have resulted in the improvement of the well-being of the people in the region or country.[21]Creation of the Wellington

[18]Other interchangeable terms can be found in the literature: full environmental cost accounting, total cost accounting and total cost assessment.

[19]Traditionally accounting systems track economic and financial transactions. The international Standard System of National Accounts and procedural rules for calculating national income and production accounts were agreed upon in 1968. These were codified in the 'Blue Book' produced by the UN Statistical Office. Reflecting prominent issues of the time, the rules concentrate on measuring economic production.

[20]http://www.gpiatlantic.org/ downloaded 23th October 2015.

[21]http://www.gpiwellingtonregion.govt.nz/ (Accessed 29 Nov.2015).

Region GPI has required, among other work, development of full cost accounts for physical inactivity within the region.[22]

Second, the FCA concept also falls under the umbrella of Environmental Management Accounting (EMA), and thus sits alongside life-cycle assessment, material flow accounting, balanced scorecard for sustainability and other related tools (cf. Jasinski *et al.,* 2015). Broadly, the objective of EMA is to provide organisations with information on the direct, indirect and potentially also external cost[23] of activities. Use of energy, materials, water and the ensuing environmental impacts caused by business activities are common considerations. Although up until the 1990s, FCA in this context had focused principally on environmental and economic parameters, over the last two decades there has also been growing consideration of social impacts (Jasinki *et al.,*2015). FCA can be further extended to consider the cultural implications of organisation's activities. FCA is thus clearly aligned to the Triple Bottom Line and Quadruple Bottom Line ideas that have been popularised to broadly reflect a concern that organisations should be evaluated not only according to financial performance but also other important outcomes.

A feature of FCA is that it is not necessary that all costs are quantified, i.e. qualitative indicators have also been used. Even when impacts are quantified, there may be a variety of numeracies applied. To date FCA has been largely concerned with identifying and describing *costs* of activities, i.e. benefits including co-benefits are not the focus.

4.4.2. Important considerations

A key point of difference between FCA and the other approaches discussed above is that while FCA may provide information that can inform current and future behaviour, it is primarily a backward-looking approach. In other words, FCA is about monitoring progress or performance. In contrast, CBA, CEA and MCA are forward-looking tools, used primarily to evaluate the consequences of, and select among, policies, investments or other interventions that will impact society in the future.

As FCA is concerned with making visible the wide-ranging consequences of activities, it necessarily involves consideration of cause-effect relationships (M.E 2012). Breuer (2008) notes that "instead of being an instrument that measures economic growth, [FCA] is an instrument that demonstrates the interconnected complexity of the overall system." This moves FCA beyond mere collection and presentation of information, to also an exercise in identifying and explaining complexities and inter-connectedness of indicators and phenomena. It should, however, also be noted that the same claim could be in relation to the other tools described above, when there is a real attempt to identify and evaluate the full range of consequences of a decision. A concern with identifying cause-effect relationships is both a strength and weakness. In the real world FCA techniques

[22] http://www.aucklandcouncil.govt.nz/EN/planspoliciesprojects/reports/technicalpublications/Documents/costsofphysicalinactivityreport.pdf (Accessed 20 Nov. 2015).

[23]The damages caused by an (economic) activity borne elsewhere in the system by a third party.

are constrained by limitations in knowledge and understanding of complex consequences.

4.5. Discussion

4.5.1. Summary of decision-support tools

The evaluation methods and tools outlined in this section are not necessarily mutually exclusive nor compete with each other. It may, for example, be beneficial and enlightening to complement economic CBA with MCA or other qualitative tools (Brouwer et al., 2010).

Table 4 provides a summary of key points from the above discussion, and provides indicative suggestions for the most appropriate use of each method/tool.

Table 4 Application of Decision-Support Tools within Disaster Risk Management

Tool	Description	Strengths	Challenges	Suggested Application
CBA cost-benefit analysis	Framework for comparing projects/policies based on efficiency Usually expresses costs and benefits in the common metric of today's money	Follows an established and open methodology Encourages disciplined consideration of choices	Valuation techniques are imperfect and loaded with assumptions Tempting to only include benefits/costs for which information is readily available Difficult to balance non-quantifiable costs/benefits with quantifiable Conclusions may be highly sensitive to assumptions, incl. discount rate Limited consideration of equity (intra and intergenerational)	Options are well defined and limited in number Costs/benefits that are not able to be quantified are unlikely to be significant or are at least included in decision making through other analyses
CEA cost effectiveness analysis	Compares costs of projects/policies against a defined goal or benefit (e.g. disaster risk reduction)	Follows an established and open methodology Does not necessarily require the monetisation of benefits	Objective or target must be well defined Limited ability to consider multiple and/or competing benefits See also challenges for CBA	There is a clearly defined goal or objective (benefit) sought to be achieved Prioritisation of least-costly options is paramount
MCA multi-criteria analysis	Establishes preferences between options by reference to an explicit set of agreed objectives and measurable criteria to assess the extent to which the objectives have been achieved	Enables decision-makers to overcome difficulties in handling large amounts of complex information in a consistent way Flexible to allow for alternative objectives and values Can incorporate diverse range of information	Subjectivity of assessment Time-consuming to undertake stakeholder engagement processes and buy-in is required Weighting dimension can be complex and hard to derive	Effects of a project/policy are likely to be complex and information on effects is diverse
FCA full cost accounting	Collects and aggregates information to monitor performance of an organisation/community, taking into consideration the full range of costs that may occur as a result of activities	Encourages consideration of a wide range of cause-effect relationships Can incorporate a diverse range of information	Lacks a clear and established methodology	Providing information and reporting on organisational, community or society performance

4.5.2. General challenges for risk management decision making frameworks

The challenges of applying decision making frameworks in the context of DRM should not be underestimated. Disaster risks are, by their very nature, difficult to evaluate and difficult to compare alongside other benefits and costs of decisions. Probabilities of disasters are often low; however consequences can be substantial and long-lasting. Stochastic methods provide one opportunity for evaluating disaster impacts but these require very detailed and robust risk assessments (Mechler, 2005). The establishment of such information can be very complex and resource intensive and in many cases data, particularly on indirect effects, is not available. Linking the results in a meaningful analysis can be fraught with difficulties.

Another challenge is the long-time horizons required for effectively dealing with disaster risks. For example, more frequent storm events as a result of global warming will affect low-lying coastal areas for centuries to come. Investments in DRM such as building seawalls or retreating houses away from the shorelines need to be carefully evaluated. In practice disaster risk decisions are often ad hoc, lack rigorous (economic) analyses and are subject to complex jurisdictional, consultative and legislative processes. Decision makers can be influenced by short-term politicians and outspoken community members leading them to make decisions that do not account for future generations. There is a natural tension between investing into long term environmental preservation and short term personal wants when managing disaster risks.

Any method is also limited by how well it is executed. Shreve & Kelman (2014) reviewed several CBA studies on disaster risk reduction and identified some shortfalls such as the lack of sensitivity analyses, meta-analyses critiquing the literature, climate change factor, evaluation of the duration of benefits, accounting for vulnerability and the potential dis-benefits of measures. For any assessment framework to adequately inform decision making, it needs to be able to incorporate the many facets of DRM and provide a transparent and comprehensive discussion platform.

5. Other considerations

This section provides a brief overview of some additional considerations that are important to DRM regardless of the particular decision making framework applied.

5.1. Stocks versus flows

In disaster risk analysis, economists tend to distinguish between the assessment of stocks and flows (Giorgetti 2013; Mechler, 2005; Rose 2004). The 'Stock' effect is the quantity of physical damage at a single point in time, and represents the loss of the capital stock. The 'Flow' effect is the impact of the event on production of goods and services over time. Part of this is translated into replacing lost capital stock, part will be interruptions in production, and part will occur even without damage to the capital stock of an affected business (Giorgetti, 2013). For example, a business may need to close down because of power outages or lost access to customers as a result of a tsunami or other hazard.

The distinction between stocks and flows is well-recognised within economics. A stock is a quantity of a system variable that exists at a single point in time, while a flow is a movement of materials or information to or from a stock over time. Examples of stock and flow measures from disasters are provided in Table. Traditionally disaster analysis has focused on stock measures, however there has been increasing emphasis placed on the measurement of flow impacts, in part because these are consistent with other indices such as GDP.

Table 5 Examples of stock and flow effects of disasters

Type of effect	Most relevant effects
Stock effect	• Damage to private, commercial, industrial and public assets, infrastructure including roads and public utilities, farmland • Human injuries and loss of life • Degradation of ecosystems and loss of wildlife (natural capital)
Flow effect	• Diminished production of goods and services due to business interruption • Increased costs of transportation as a consequence of destroyed roads • Loss or reduction of wages due to business interruption • Reduced tourist visits and expenditure as a result of loss of local amenity

Stock and flow impacts are clearly related. Usually, a flow impact or measure can be attributed as resulting from some type of impact (permanent or temporary) on capital. For example, while we might measure the loss of income and expenditure from tourists after a disaster, we can also note that these impacts arise because important natural (e.g. high amenity beaches) and physical capital (transport infrastructure) have been lost or degraded.

When comparing effects of disasters, it is important to keep in mind the distinction between stock and flow measures. Typically stock measures will be greater as they effectively account for the integration of flow impacts across time. Thus

when comparing impacts it is necessary to ensure that these are measured consistently, either as stocks or flows.

5.2. Establishing the counter factual and uncertain futures

Any valuation exercise is relative. Therefore benefits and costs arising as a result of implementing a DRM intervention are ideally compared to the situation without the intervention. A CBA therefore needs to evaluate a number of options against the status quo, which usually represents the 'do nothing' or 'business as usual' scenario, also called the 'counterfactual'. Establishing the counterfactual, which identifies what the outcomes would have been without the input of a specific course of action, is important as not to overemphasise benefits.

As the counterfactual is unobservable, it needs to be derived by evaluating what would have happened without the intervention, i.e. if nothing was done. Cost and benefits need to be estimated based on what they would be in absence of the proposed intervention project. Developing a counterfactual can itself prove challenging. DRM is set within complex political and management systems where it is challenging to separate out the effect of an individual intervention. Further testing of cost benefits using sensitivity analysis and including a wider initial choice of options will strengthen the analysis.

The task of establishing a set of alternative futures to analyse, i.e. both futures that include interventions and counterfactual 'futures', is made particularly challenging in the disaster risk management context given the long-time horizons involved. Particularly when considering low probability, high consequence events, it is necessary to estimate costs and benefits that are a long way into the future. In addition, our communities are dynamic: people move, industries change, cities grow and shrink. It is challenging therefore, if not impossible, to accurately predict future impacts.

5.3. Co-Benefits

In many cases, DRM interventions not only have benefits when a disaster strikes, they also may have benefits in the immediate term. These are called co-benefits. For example, in a cost benefit analysis of a Polder[24] for flood mitigation, as well as the benefits of reduced disaster impact, Mechler included everyday co-benefits, such as irrigation. For completeness Mechler also included negative effects of the Polder construction such as reduced agricultural activity(Mechler, 2005).

DRM solutions will be more valued if the every-day benefits, or co-benefits, can be identified and valued as part of the evaluation of their effectiveness.

5.4. Residual risk and moral hazards

Residual risk is that which remains even after risk management interventions have been put in place. The concept is specifically mentioned in this literature

[24]A polder is a low lying tract of land, surrounded by dykes, generally used for flood mitigation purposes.

review to remind us that interventions that seek to reduce the level of residual risk for a specific hazard may not end up realizing the target residual risk due to 1) changes in behaviour that increase vulnerability (moral hazard) or 2) by increasing the consequences of other hazard events.

A moral hazard is a situation where someone adopts risky behaviour because someone else is taking the burden of the risk. The use of insurance is often linked to moral hazards: if someone has insurance, they have less incentive to reduce the loss from occurring (Courbage and Stahel, 2012).

A risk mitigation intervention for a given hazard event may also affect the consequences of a different event. For example, in the context of flood risk, engineering interventions often seek to achieve reductions in flood probability, say changing the likelihood of stop bank incursion from a one- in-fifty to one-in-100-year likelihood. It is, however, feasible that the annualised risk does not actually decline if, say, the consequences of a greater than a 100-year event are actually increased due to the stop bank (for example through increased flash flooding potential, or increased exposure to more densely populated areas).

Attempts to evaluate or value risk management interventions must be careful to account for changes in hazard likelihoods and consequences as well as behaviours that may alter vulnerabilities and hence risk.

5.5. Cascading risks

Another specific type of risk that should be considered, common in a post-disaster environment, is cascading risks. That is, outcomes that result from one hazard event occurring. For example: following an earthquake fires will often occur due to damage to electrical and/or gas systems. To fully evaluate the effectiveness of a disaster risk intervention, the knock-on effects of that measure, positive or negative, needs to be included in the evaluation.

5.6. System modelling

System modelling takes on a variety of forms and is used for a wide range of purposes. Although system modelling is not in itself a specific decision making technique, it is important to recognise that system models of many different types have been used in a variety of contexts to provide information to support decision making processes, including information that serves as a direct input to formal processes such as CBA or MCA. More generally, particularly when dealing with problems involving complex systems as is characteristic of DRM, modelling is also used as a means of scoping the nature and extent of problems, testing theories and helping to build consensus.

We can define the various modelling approaches as being based either on optimisation, simulation or statistical techniques. Optimisation approaches are useful where the situation or problem can be formulated such that there is a specific objective or function sought to be optimised, typically under constraints (for example maximise flood risk reduction subject to a budget constraint on

capital expenditure, or minimise capital expenditure subject to the achievement of an agreed flood risk level). Simulation models vary significantly in their formulation and specification and can be either static or dynamic in nature (the latter is concerned with how systems change over time while the former is not). In the New Zealand context two examples of simulation models that may be useful for DRM are RiskScape and MERIT (refer to Section 6.1.5 below). Statistical models focus on providing an empirical basis to relationships, for building and testing theory and forecasting. Among the many possible examples is the use of real data from earthquake events to analyse how changes in building structures impact on likely damage under different shaking intensities. It is also worth noting that statistical modelling is often undertaken in combination with other forms of modelling, particularly for the purposes of parameter estimation.

5.7. Risk and uncertainty in decision-making

5.7.1. Types of uncertainty

Uncertainty can paralyse sound and effective decision-making and, therefore, needs to be managed carefully (Kalra et al., 2014). In DRM decision-making, we need to manage uncertainty from two main sources:

1. From our estimation of costs and benefits from a given hazard event both in terms of actual damages and the value of the damages and indirect impacts (for example, predicting the number of lives lost following an earthquake and valuing this). Generally this is epistemic[25] uncertainty, and stems from the limitations we have in models to predict outcomes. However, some variables may be able to be modelled by probability distributions, and are therefore considered aleatoric uncertainty[26].
2. From the hazard event itself. That is, will the predicted benefits be realised (for example, the probability of an earthquake occurring). Generally this is aleatoric uncertainty.

A particular source of uncertainty type 1), is identified in the literature as optimism bias. This is the tendency for assessors to be overly optimistic in situations where there is limited existing data that can be used in the assessment (Environment Agency, 2010a). There also may be uncertainty due to limited or poor quality data and assumptions.

In addition to these known risks, there are also likely to be unknown ontological[27] risks. As noted in Section 3.2, the emerging concept of resilience concentrates on improving adaptability to respond to both known and unknown crises. Examples

[25]**Epistemic Uncertainty**: variability due to model limitations, assumptions, lack of data. In theory this can be reduced by further model refinement and investigations but often this is present. For example: assuming that we can predict earthquake damage based on construction type of a building, or estimating the cost of flood damage based on flood height.
[26]**Aleatoric Uncertainty**: variability that can be readily described by probability distributions, and cannot be reduced by further testing. For example: the probability of an earthquake or flood event.
[27]**Ontological Uncertainty**: variability due to things that are wholly unknown or unexpected to us. For example: no one (arguably) predicted the extent of the 2008 Global Financial Crisis.

of this could include value and behaviour related uncertainty; and regulatory uncertainty (Ministry for the Environment, 2014). While it is important to be aware of ontological risks, management of these is outside the direct scope of this project.

5.7.2. How can we account for uncertainty in hazard likelihood?

As discussed above, the likelihood or probability of a natural disaster occurring is an aleatoric risk that must be considered during the assessment of risk management decisions. Mechler identifies that this a particularly challenging aspect to incorporate into a CBA assessment because of the information demands for low probability – high consequence events as well as the challenge of merging considerations for long-term DRM with far shorter administrative planning horizons (Mechler, 2005).

There are a number of ways to incorporate hazard risk in a cost benefit type assessment:

Annualised loss

A common approach to managing aleatoric uncertainty in project outcome in a CBA – that is, whether the benefits will be realised or not – is to multiply the calculated benefit by the probability of the benefit occurring. This results in an annualised cost of the event. This can also be referred to as the 'expected value' (HM Treasury, 2011).

For example, if the estimated cost of a flood mitigation measure is $200,000 and the benefits (i.e. losses avoided) are $1,000,000, the benefit cost ratio (BCR) without considering the likelihood of the flood is 0.2 (without discounting). However, if you consider the probability of the flood occurring, say the mitigation measure is designed for a 1 in 100-year flood (1% chance of occurring) then the BCR is calculated as shown in equation below. The CBR then becomes 20. The mitigation appears far less cost effective.

$$BCR = \frac{Benefit\ x\ probability\ of\ occurence}{Cost}$$

This can be done for a single event or for a range of hazard events. Several authors and frameworks recommend using a range of events to recognise the large loss contribution of the higher frequency, low consequence events (Environment Agency, 2010a) and the potential need to use different risk management strategies for different frequency events (Mechler et al., 2014). If a range of events are being considered, for example losses from floods up to and including a 100-year flood, then the annualised cost can also be calculated using an exceedance probability (EP) curve, such as shown in Figure 7. An EP curve plots the expected losses for a range of return period (annual probability) events. The expected value of losses is then calculated as the area under the EP curve (Smith & Vignaux, 2006). This value is then used to calculate the annualised loss.

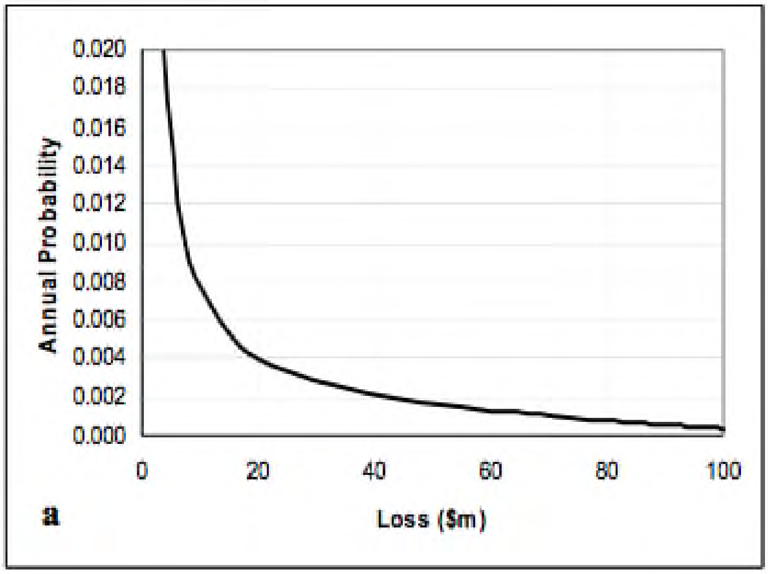

Figure 7 An example exceedance probability curve (Smith & Vignaux, 2006)

Expected Utility Theory

Smith & Vignaux suggest the integration of utility theory into the estimation of annualised losses for disaster risk mitigation decision-making (Smith & Vignaux, 2006). Expected utility theory takes into account the risk perceptions of decision-makers. That is, a decision-maker may prefer a guaranteed loss now, when compared to a potential but greater loss later. The assessment would need to be adjusted depending on the risk tolerance of the decision-maker: a more risk averse decision-maker would accept a higher guaranteed loss than a risk-taking decision-maker.

The utility function is applied to the annualised cost calculation to get the expected utility of losses. The inverse utility function is then applied to the expected utility of losses to return the annual losses in terms of actual losses (Smith & Vignaux, 2006).

Utility theory has also been applied to multi-attribute / multi-criteria assessments in an approach known as Multi-Attribute Theory (MAUT). The use of MAUT by scholars is growing (Wallenius et al., 2008) and has been applied to a number of hazard related decisions, including nuclear accidents (French, 1996), gas pipeline risk (A. J. Brito & de Almeida, 2009), evacuation planning (Kailiponi, 2010), and bridge seismic retrofit (Dong, Frangopol, & Sabatino, 2015).

Calculated risk levels

In multi-criteria analyses, hazard probabilities are often used in conjunction with hazard consequences to determine an overall risk to allow for ranking of intervention options. For multi-criteria analysis, the probability can be described quantitatively (i.e. as an annual probability) or semi-quantitatively (using nominal values e. 1-5). Similarly, the consequences can be expressed quantitatively or semi-quantitatively. The overall risk is then defined as the *probability multiplied by the consequences*.

Intervention options can be compared by estimating the consequences with and without the intervention. The most effective intervention will be the option that has the biggest reduction on risk. These results would then need to be compared with implementation costs.

In some cases multi-criteria analysis will be used prior to consideration of mitigation options, in an effort to determine what risks are acceptable and which are unacceptable. The likelihood and consequences are combined as above and then the risk levels are assessed to determine whether they are acceptable or unacceptable.

Not included

For cost-effectiveness analysis, hazard probabilities do not need to be included at all. Generally, cost-effectiveness assessments are comparing different options for addressing the same hazard event: prior to the assessment of mitigation options, decision-makers have defined the target hazard likelihood.

5.7.3. How can we account for input uncertainty?

As well as hazard likelihood, there will be a range of uncertainties, both epistemic and aleotoric, in some or all of the other inputs (variables and parameters) to any model. In order to evaluate confidence in the model results, it is important to assess the impact of these input uncertainties on the uncertainty in the output(s) of the model (known as uncertainty quantification). There are a number of different methods to achieve this.

Monte Carlo analysis

Monte Carlo analysis is a method of calculating outcome uncertainty based on a known input variable uncertainty. To perform a Monte Carlo analysis, inputs to the model are represented by probability distributions, the model output for a single run is then generated by random sampling from within the input probability distributions. This process is repeated a large number of times and the outputs of each run are used to generate an outcome probability distribution.

The NZ Treasury Social Cost Benefit Guide recommends using Monte Carlo simulation for epistemic uncertainty (The Treasury, 2015).

Sensitivity analysis

Due to the uncertainty in inputs to any model, there will be some uncertainty in the model outcome. Sensitivity analysis provides an evaluation of the impact of the uncertainty in each input on this outcome uncertainty, and identifies which input(s) the model outcome uncertainty is most dependent on. That is, a change in which input(s) will create the biggest change in the outcome. Sensitivity analysis can be thought of as addressing the question "if an input to my model (either a variable or a parameter) changes, what effect will this have on the output(s) of the model?".

Almost all techniques for sensitivity analysis involve running the model a number of times with carefully chosen changes in inputs. For a complex model with a large number of inputs and variables, the computational cost of running the model can

be the biggest limiting factor in being able to perform rigorous sensitivity analyses. The most commonly used technique is the one-at-a-time (OAT) approach, where the lower and upper bounds for each input are substituted in one at a time, while all other variables are held at the baseline (mean) value. The influence of each input is then determined by looking at how much the output(s) changed when that input was changed. This approach is favoured as it is simple to perform and requires a (relatively) low number of repeated runs of the model. However, the OAT approach assumes that the model is linear, the inputs are uncorrelated, and there are no interaction effects, which is unjustified in many models of interest (Saltelli and Annoni, 2010). There are several alternatives to OAT sensitivity analysis (Saltelli *et al.*, 2004, Ioss and Lemaitre, 2014), and although many involve a higher computational cost, some newly developed alternatives improve on OAT for no additional computational cost (Saltelli and Annoni, 2010).

Sensitivity analysis is a very useful process within any modelling approach. At a systems level, it allows a way to test the robustness of the model results to uncertainty in the system, and provides insight into the relationships between model inputs and outputs. At a model implementation level, it provides guidance as to which inputs should be the focus of more refinement in order to reduce uncertainty (for example where the outcome is sensitive to a highly uncertain input value), speeds up model calibration (for example by identifying the sensitive parameters to focus on), and allows for simplification of the model (for example by removing certain inputs that are found to not affect the output at all).

Sensitivity analysis is recommended in a number of decision-making frameworks (HM Treasury, 2011; Mechler, 2005; The Treasury, 2015). The UK flood and coastal disaster risk appraisal guidelines promotes sensitivity analyses and a similar sub-method called 'switching points'. This technique involves changing assumptions made for variables to determine the point at which the preferred option will change. This can be done using both monetised and non-monetised benefits (Environment Agency, 2010a).

Despite the widely recognised importance of sensitivity analyses, in a review of CBA application to DRM, Shreve and Kelman found that many of the studies reviewed did not carry out sensitivity analyses (Shreve & Kelman, 2014).

Optimism bias

As noted in Section5.7.1, optimism bias is a specific type of uncertainty that needs to be managed in cost benefit analyses. Optimism bias is the tendency for proponents of an initiative to be overly optimistic in their assessment of it – often leading to unrealistically positive CBA outcomes. The UK Treasury suggests that, to counter this issue, projected costs should be increased by a given percentage before the benefit cost ratio is determined. The adjustment values will depend on the certainty and evidence available to support the estimates used in the assessment (HM Treasury, 2011). A typical optimism bias adjustment is 60% for early project assessments and 30% for later assessments (Environment Agency, 2010a). This is generally an alternative, rather than additional, to Monte Carlo analysis or use of contingency sums.

Contingency

Another way of dealing with uncertainty is through the inclusion of contingency in the analysis. This is often suggested when cost benefit analyses include construction costs. For example, contingencies of 20-30% at detailed appraisal stage are recommended in the UK flood guide to compensate where adjustments for optimism bias have not been made or another risk treatment such as Monte Carlo analysis (Environment Agency, 2010a).

5.7.4. Discussion

Average annualised losses are a common method of accounting for hazard likelihood in cost benefit analyses. Theoretically this approach is strong but it does not account for the random nature of disaster events, nor their potential catastrophic nature. A key objective for some disaster managers is not only minimise annualised losses but to minimise the chance of catastrophic losses. Expected utility theory goes some way to addressing this by incorporating decision-makers' preferences for guaranteed losses now over potential but uncertain losses later.

Similarly, multi-criteria decision-making is usually based on a risk calculation: hazard likelihood multiplied by consequences. Therefore, users essentially rank the risks based on expected annual loss. The framework being developed in this project will need to carefully consider the goal of the assessment and how catastrophic events should be accounted for.

As well as hazard likelihood, there is considerable uncertainty over estimating costs and benefits. Disaster events being investigated may not occur until far in the future (where population, land-use and economy changes may significantly alter the predicted losses) and there may limited data on which to base loss estimation – particularly likely for non-market impacts. Monte Carlo, sensitivity analysis, manual adjustments for optimism bias and contingency allowances are all methods that can be used to minimise the impact of these uncertainties on analyses.

While the technical approaches to managing risk are important, consideration into how uncertainty is integrated into the decision-making process will be equally important in the framework development for this project. Kalra et al. (2014), for example, warns that decision-making can stall if agreement across all assumptions is required: as it is unlikely that all assumptions will be agreed to. Instead, Kalra recommends a more engaging process that allows stakeholders to explore options against a range of assumptions. Transparently integrating uncertainty into the proposed framework will be essential.

6. Existing disaster risk management decision-making and assessment frameworks

6.1. New Zealand

6.1.1. Introduction

In New Zealand there are no tools or resources that guide decision-makers specifically in the comparative evaluation of options for DRM. However, there are a number of guidelines that could be applied to DRM decisions. These are discussed below, with a focus on how they can be applied to the evaluation and comparison of different risk management decisions.

6.1.2. The Treasury Guide to Social Cost Benefit Analysis

In July 2015, The Treasury released practical guidelines on social cost benefit analysis (The Treasury, 2015). The guide focuses on providing a set of key steps in assessing the benefits and costs of a given project, including: establishing the counterfactual; identifying the full range of effects (for all people likely affected) and valuing the impacts; and discounting to a common time period. The guide is procedural more than prescriptive. It does not, understandably due to the breadth of decisions the guide could be applied to, provide guidance on exactly what factors should be considered. It provides some general guidance on appropriate methods for calculating costs and benefits and has recently developed a suite of impacts, including typical values, for users to apply in their CBA analyses. A number of worked examples are given for users to follow throughout the guide.

The guidelines encourage policy analysts to make multi-capital[28] assessments by urging the user to consider all benefits and costs. In particular, the document refers users to the HLS to ensure a multi-capital assessment is made – either within the CBA or alongside it (for more on the HLS, see Section 3.2).

For valuing the user identified costs and benefits the Treasury CBA guide makes several key recommendations:

- Benefits should be in terms of willingness to pay
- Costs should be opportunity costs
- Values should be in ranges (to reflect uncertainty in outcomes and valuations)
- The time period should be 'whole of life', with future costs discounted to reflect present value
- Benefits and costs should be in real terms (i.e. ignore inflation)
- Multiplier effects should be ignored (such as added employment – unless there is significant unemployment)

The guide acknowledges the difficulty in assigning monetary values to some costs and benefits and advises users to acknowledge them when reporting cost benefit

[28] The term multi-capital refers to multiple stocks of resources, including human, social, cultural, political, environmental, natural, built, economic etc. Multi-capital assessments, therefore, consider not only economic impacts but effects (positive and negative) on these wide ranging resources.

analysis results. No structured way is provided to compare or balance these non-monetary factors, other than the option to carry out a multi-criteria analysis and/or describe the issues in the report. The guide also specifically identifies that CBA is not effective at addressing equity/distributional issues and how costs and benefits fall across different groups of society. Again the guide recommends using narrative to describe these effects.

The guide discusses risks and uncertainty in terms of prediction of costs and benefits and recommends that ranges of costs and benefits are used to reflect the uncertainty involved. If there is uncertainty in the project outcome, for example whether a benefit will occur or not (as for mitigating a natural hazard risk), the guide states that the benefits should be multiplied by the probability of the benefit occurring (that is, an annualised loss should be included in the calculation).

The guide addresses a number of limitations to CBA. First, it identifies that the approach is partial equilibrium and only looks at direct benefits and costs. Second, it assumes future markets are perfectly competitive. Third, it measures willingness to pay rather than impact on welfare. And fourth, estimates of costs and benefits can be extremely uncertain.

The New Zealand Treasury CBA guidelines are similar to a number of international cost benefit guidelines such as UK Green Book (HM Treasury, 2011).

6.1.3. Ministry for the Environment Section 32 guidelines

As discussed in Section 3, Section 32 of the RMA requires that authorities:

> *(a) Identify and assess the benefits and costs of the environmental, economic, social, and cultural effects that are anticipated from the implementation of the provisions, including the opportunities for-*
>
> > *(i) Economic growth that are anticipated to be provided or reduced; and*
> >
> > *(ii) Employment that are anticipated to be provided or reduced; and*
>
> *(b) If practicable, quantify the benefits and costs referred to in paragraph (a); and*
>
> *(c) Assess the risk of acting or not acting if there is uncertain or insufficient information about the subject matter of the provisions.*

As a result, in 2014, Ministry for the Environment established guidelines for assessing proposals under the RMA (Ministry for the Environment, 2014). While the guidelines do not specifically address proposals relating to DRM, these guidelines could be applied to disaster risk mitigation measures such as flood bank construction, land-use planning and coastal protection.

The guide is "designed to assist practitioners and decision-makers to undertake good practice s32 evaluations, and in doing so to improve planning practice across New Zealand." The guide sets out a suitable process to follow for a robust assessment of the costs and benefits of proposals under the RMA.

Amongst other things, the guide identifies key groups affected and example costs and benefits on those groups. The guide leaves it to individual assessors to identify and quantify the effects. The example costs/benefits are included in the matrix of cost/benefits in Appendix B.

The guide lists a range of possible assessment techniques ranging from matrices to multi-criteria decision-making and cost benefit analyses. Multi-criteria analyses are described here as being better able to reflect the complexities of decisions than something like a cost-benefit analysis which can only reliably incorporate items that can be monetised.

Management of risks in the assessment process is also included. Epistemic risks such as data uncertainty and outcome uncertainty due to human factors are highlighted as important considerations. And the guide recommends, in some cases, that a risk assessment of options be undertaken. There is no specific guidance on how to apply the guidelines to DRM decisions.

The guide identifies the importance of systems thinking in understanding, and including the cause and effect relationships in analysis but does not provide details of how to manage that within an assessment.

6.1.4. Land-use planning risk management toolkit

In 2013, Saunders *et al.*(2013) developed an on-line tool kit for assessing and addressing risks in land-use planning (Saunders *et al.,* 2013). The tool is aimed at territorial authorities for establishing risk levels within their land-use plans. The tool is based around a likelihood, consequence matrix to assess and evaluate the risks. First, a semi-quantitative multi-criteria consequences table is provided (see Table 6). Five 'severity of impact' levels are set (scored 1-5). And for each level, consequences are categorised into Social / Cultural, Buildings, Critical Buildings, Lifelines, Economic and Health & Safety impacts. Users are advised to set the 'severity of impact level' based on the highest consequence category. Second, likelihood ratings are also suggested (scored 1-5) based on the return period of the hazard. The tool guides the user through the calculation of risk (likelihood x consequence) to arrive at an overall risk rating. Last the user is advised to set levels of acceptable, tolerable and intolerable risk, so that the outcomes can be interpreted. The tool also discusses mitigation, monitoring and communication of risks.

The decision-making element in the toolkit is in the setting of the unacceptable and acceptable risk levels. This framework is not a cost benefit framework. The costs are not considered. The framework is a tool to allow decision-makers to identify the risks that need to be mitigated (those risks deemed unacceptable/ intolerable). If mitigation measures are put in place to avoid any of the risks in the assessment, the benefits are the consequences *avoided*. However, the process could conceivably be manipulated to allow a form of cost benefit comparison.

Table 6 Consequences table, GNS Risk-based Planning Toolbox (Saunders, W. S. A., Beban, J. G., & Kilvington, 2013)

Severity of Impact	Built				Economic	Health &Safety
	Social/Cultural	Buildings	Critical Buildings	Lifelines		
Catastrophic (V)	≥25% of buildings of social/cultural significance within hazard zone have functionality compromised	≥50% of affected buildings within hazard zone have functionality compromised	≥25% of critical facilities within hazard zone have functionality compromised	Out of service for > 1 month (affecting ≥20% of the town/city population) OR out of service for > 6 months (affecting < 20% of the town/city population)	> 10% of regional GDP	> 101 dead and/or > 1001 inj.
Major (IV)	11-24% of buildings of social/cultural significance within hazard zone have functionality compromised	21-49% of buildings within hazard zone have functionality compromised	11-24% of buildings within hazard zone have functionality compromised	Out of service for 1 week – 1 month (affecting ≥20% of the town/city population) OR out of service for 6 weeks to 6 months (affecting < 20% of the town/city population)	1-9.99% of regional GDP	11 – 100 dead and/or 101 – 1000 injured
Moderate (III)	6-10% of buildings of social/cultural significance within hazard zone have functionality compromised	11-20% of buildings within hazard zone have functionality compromised	6-10% of buildings within hazard zone have functionality compromised	Out of service for 1 day to 1 week (affecting ≥20% of the town/city population) OR out of service for 1 week to 6 weeks (affecting < 20% of the town/city population)	0.1-0.99% of regional GDP	2 – 10 dead and/or 11 – 100 injured
Minor (II)	1-5% of buildings of social/cultural significance within hazard zone have functionality compromised	2-10% of buildings within hazard zone have functionality compromised	1-5% of buildings within hazard zone have functionality compromised	Out of service for 2 hours to 1 day (affecting ≥20% of the town/city population) OR out of service for 1 day to 1 week (affecting < 20% of the town/city population)	0.01-0.09 % of regional GDP	<= 1 dead and/or 1 – 10 injured
Insignificant (I)	No buildings of social/cultural significance within hazard zone have functionality compromised	< 1% of affected buildings within hazard zone have functionality compromised	No damage within hazard zone, fully functional	Out of service for up to 2 hours (affecting ≥20% of the town/city population) OR out of service for up to 1 day (affecting < 20% of the town/city population)	<0.01% of regional GDP	No dead No injured

6.1.5. Loss estimation tools

In New Zealand there are several tools that can be used to estimate the losses of disaster events. While they are not decision-making frameworks as such, they can be used to aid decision-making by generating estimated physical and economic losses from a given disaster event. Both RiskScape and Measuring the Economics of Resilient Infrastructure (MERIT), described below, also support changing parameters within the scenario so that different risk management strategies can be tested and resulting losses compared.

RiskScape (riskscape.niwa.co.nz)

RiskScape is a GIS based tool that enables users to estimate impacts and losses to given hazard events. The tool takes inputs from three different modules: hazard module, asset module and a vulnerability module. Currently the hazard modules are based on single hazard scenarios (i.e. a single return event), however, there are plans to develop these into probabilistic models which allow a range of events to be concurrently analysed. The asset module describes the human and physical infrastructure exposed and includes attributes such as cost of reinstatement, occupancy rates (day and night), building earning potential, vehicle numbers and value etc. The vulnerability module includes damage functions that relate hazard intensity to expected human and physical impacts. The expected losses are calculated by the overlay of these three modules.

Currently, the estimation of losses within RiskScape is limited to direct losses and downtime as defined in the asset module. It is a useful tool for estimating direct losses. RiskScape is under continual improvement, including development of the loss estimation particularly of more indirect costs.

MERIT

MERIT is a spatial decision support system for infrastructure disruption in New Zealand currently under development. The first version of the tool is due to be completed in September 2016. The system is designed to support government and infrastructure provider decision-making by enhancing their understanding of the economic impacts of infrastructure outages.

The core of MERIT is an economic module based on the principles of Computable General Equilibrium (CGE) models. In basic terms, the economic module creates a complex web of economic system components. It links multiple types of industries, commodities and factors, and models the relationships between these using a systems dynamics framework. Within MERIT, the economic module is applied spatially, at mesh block level. An infrastructure impact scenario (e.g. water supply disruption or volcanic event) is applied to the spatial model and this, in turn, shocks the economic model. In addition, there is a business behaviours module that moderates the impact of the infrastructure disruption by taking into account business adaptation. The MERIT output is the regional macro-economic impact of the given scenario. See Figure 8 for an overview of MERIT.

Like RiskScape, MERIT is a single scenario tool. MERIT complements RiskScape, in that it dynamically models indirect economic impacts of disruptions (and RiskScape is currently strong at calculating direct damages).

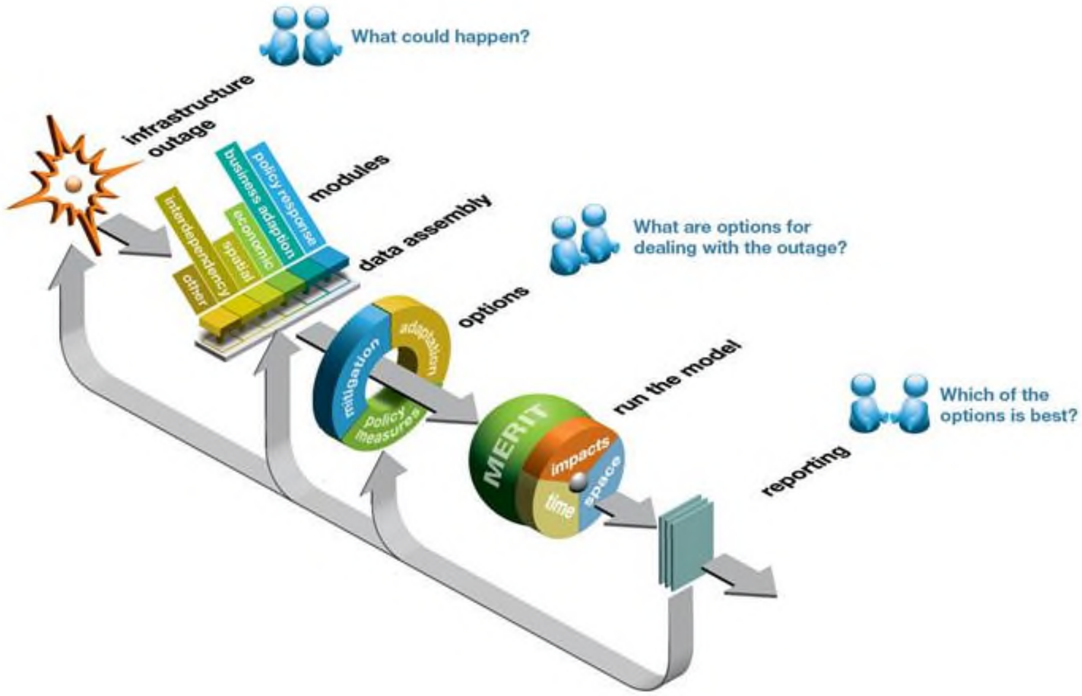

Figure 8 The relationships between the various components of MERIT (NHRP, 2014)

6.2. International

There are several existing DRM assessment and decision-making frameworks internationally. However, they do not appear to be widely adopted. An earlier study in 2007 found that only Britain, Japan and United States used cost benefit analyses for natural hazard DRM(Moench*et al.,* 2007). Our study also found that some recent guidance has been published in Australia and for developing countries.

Five frameworks were reviewed for this report:

- United States FEMA Benefit Cost Toolkit 5.2.1. (FEMA, 2015a); in conjunction with the national policy on CBA (Office of Management and Budget, 1992) and the national hazard loss modelling software Hazus (FEMA, 2015b),
- United Kingdom Environment Agency: Flood and coastal erosion risk management appraisal guidelines(Environment Agency, 2010a),
- Australian Business Roundtable for Disaster Resilience and Safer Communities (Deloitte Access Economics):Building our nation’s resilience to natural disasters(Deloitte Access Economics, 2013),

- GTZ (Mechler): Cost-benefit Analysis of Natural Disaster Risk Management in Developing Countries (Mechler, 2005), and
- World Bank: Climate-Smart Development. Adding up the benefits of actions that build prosperity, end poverty and combat climate change (World Bank, 2014).

Two of the studies focused on a specific hazard: climate change for the World Bank guidance and flood hazards in the UK guidance. The other frameworks presented a method transferable to multiple hazards.

Across the frameworks a number of key steps within the assessment were recommended. Generally these steps distill to:

1. Define the problem and assessment objectives
2. Establish the baseline ('do-nothing' option)
3. Risk analysis (including hazard intensity, recurrence, vulnerability)
4. Identify intervention options (could include hard (e.g. engineering) and soft (e.g. policy) approaches) and their probability of success
5. Identify and value the full range of costs and benefits
6. Carry out assessment (usually using NPV, Cost Benefit Ratio or an Internal Rate of Return)
7. Compare and select preferred option

A diverse range of potential costs and benefits are described in the frameworks. Generally these can be categorised into the following groups:

- Social, environmental, economic,
- Direct and indirect, and
- Tangible and intangible (market and non-market).

Determination of the value of these costs and benefits was either using a bottom-up approach – where impacts are derived from unit estimates from a given hazard impact; or top-down approaches using historical data and/or models that use fragility functions to estimate damages based on hazard exposure.

The majority of the frameworks use traditional CBA as the base method. The exception being the World Bank study, which uses cost effectiveness analysis and integrates macro-economic modelling. For integration of non-market costs and benefits, a range of approaches were adopted. The studies generally recommended costs and benefits be monetised, where possible. Methods for monetizing were generally the willingness to pay technique or the indirect method based on market losses. However, they also acknowledged that where established market valuation techniques were not possible for a given cost/benefit, it was not appropriate to include them directly in the CBA and these should be discussed qualitatively. Common non-market items that were monetised in the frameworks include statistical life, crop value, social cost of carbon, carbon dioxide mitigation cost, and energy savings.

The UK flood and coastal risk management appraisal guidelines outlines a variation on MCA for managing non-market values: the 'swing' method. In this method, within each type of impact, intervention options are weighted relative to

the difference between the worst and best outcome. The categories are then assigned 'implied' monetary values by comparing the monetised and non-monetised impacts and their relative weights. The rationale behind this method is to reduce the level of subjectivity in the MCA (Environment Agency, 2010b).

For the frameworks using cost benefit analyses, average annualised losses - based on hazard probability - are calculated to complete the assessment. Several of the frameworks specify that a range of hazards should be included in the assessment. This enables the benefits of not just the event being mitigated but also all the smaller, higher frequency events.

All the frameworks applied discount rates to their assessments. Discount rates range from 3%-12%. The UK flood and coastal guidance, based on UK Treasury policy, includes a declining discount rate for any assessments for periods over 30 years. Most frameworks recommend consideration of distributional costs but no implementation guidance is given on this.

The frameworks include cautionary advice to varying degrees. Advice includes:

- Ensure the analysis detail is proportionate to the size and complexity of the decision,
- Ensure benefits would not occur without the planned intervention,
- Analyse interactions between benefits and costs,
- Report international costs and benefits separately,
- Avoid transfer benefits (where a loss in one location becomes an equal benefit somewhere else),
- Account for risk and uncertainty (including doing sensitivity analyses),
- Work with stakeholders,
- Include whole of life costs,
- Control for optimism bias[29],
- Include for climate change (and other future changes),
- Consider knock-on or indirect effects,
- Assess changes in hazard risks due to intervention (e.g. erosion or events greater than those mitigated for),
- Cap losses at the risk-free market value of the asset and/or service, and
- Inclusion of co-benefits (benefits that occur even regardless of the hazard for example amenity value of a reservoir designed for flood mitigation).

The framework approaches are summarised in Table 7and more detailed descriptions are in Appendix A.

[29]Optimism bias is the tendency for proponents of an initiative to be overly optimistic in their assessment of it – often leading to unrealistically positive CBA outcomes.

Table 7 Summary of example disaster risk management decision frameworks

Framework	Hazard type	Primary evaluation method used	Management of intangible or non-market costs / benefits	Management of indirect costs	Management of hazard risk	Discount rate
Australian Business Roundtable for Disaster Resilience and Safer Communities: Building our nation's resilience to natural disasters (Deloitte Access Economics, 2013)	All	Cost benefit analysis	Qualitatively included		Average annualised losses	7% used in example
United States FEMA: Benefit Cost Toolkit 5.2.1. (FEMA, 2015a)	Earthquake, flood, hurricane, tornado, wildfire	Cost-benefit analysis	Not included directly. Opportunity to discuss but not integrated into the assessment	Not included – focus on direct costs	Average annualised losses	7%
United Kingdom Environment Agency: Flood and coastal erosion risk management appraisal guidelines (Environment Agency, 2010a)	Flood and coastal erosion	Cost-benefit analysis combined with swing multi-criteria analysis.	The guide recommends monetizing values where possible. Otherwise the guide advocates a variation on multi-criteria analysis (MCA) called the 'swing' method where, within each type of impact, options are weighted relative to the difference between the worst and best outcome. The categories are then assigned 'implied' monetary values by comparing the monetised and non-monetised impacts and their relative weights		Average annualised losses	3.5% as specified in UK Treasury Green Book with a declining rate for assessments over 30 years(HM Treasury, 2011)

Framework	Hazard type	Primary evaluation method used	Management of intangible or non-market costs / benefits	Management of indirect costs	Management of hazard risk	Discount rate
GTZ: Cost-benefit Analysis of Natural Disaster Risk Management in Developing Countries (Mechler, 2005)	All	Cost-benefit analysis	Recommends two methods: direct preference (price someone is willing to pay to prevent a consequence) and the indirect method (estimate of market losses).		Average annualised losses	12% (as used by Asian Development Bank)
World Bank: Climate-Smart Development. Adding up the benefits of actions that build prosperity, end poverty and combat climate change (World Bank, 2014)	Climate Change	Cost effectiveness analysis. Bottom-up modelling of future losses / benefits combined into a macroeconomic assessment tool.	Some established monetary valuations for benefits incorporated into financial modelling (value of statistical life, crop value, social cost of carbon, carbon dioxide mitigation cost, and energy savings). Others intangible benefits considered qualitatively.	Included through macro-economic modelling	N/A. Assessment techniques compares benefits of climate change mitigation (assuming that climate change effects are a certainty)	3% (benefits over 20 years)

7. Compilation of risk management outcomes (costs and benefits)

7.1. Matrix of likely costs/benefits of risk management decisions from literature

To help in the development of our DRM decision-making framework, and in particular the identification of specific types of outcomes (costs and benefits), we believe it is important to draw from existing measures and indicators. As demonstrated throughout this report, there are many disciplines and frameworks that take multi-capital perspectives. The approaches comprise a wide array of indicators and measures to facilitate both decision-making and 'state' assessments in areas such as well-being, resilience and sustainability. Many of the measures in these studies are likely to align with the costs and benefits associated with DRM decisions.

Aligning our framework with other frameworks, will help to ensure that we provide complete and comprehensive guidance on likely costs and benefits of DRM. Alignment with existing frameworks will also be beneficial in terms of data availability and in providing opportunities for decision-makers to more clearly identify full costs and benefits (including co-benefits) of DRM decisions.

In Appendix B, we provide a summary of the relevant indicators and measures already identified both in New Zealand and internationally. We identify:

a. Indicator description
b. Indicator measurement unit
c. Benefit / cost
d. Indicator type (stock or flow)
e. Relevant capital (Social, human, political, cultural, built, natural, economic)
f. Measurement method (where stated)
g. Hazard cost/benefit measured (in original study)
h. Measure data source
i. Reference

This summary is by no means complete. It will be a working document as we progress through this project. There are also other databases of impacts / costs/benefits/indicators that can be drawn on to ensure a comprehensive review and assessment of likely costs and benefits (see following section). Ultimately we aim to use this information to provide a list of typical costs and benefits with the proposed framework and guidance on how to value or assess them.

7.2. Other Relevant (Multi-Capital) Indicators/ Frameworks

7.2.1. General

As well as the potential costs and benefits identified in the studies examined in this literature review, there are other frameworks and databases that could provide possible impact (cost / benefit) measures. The following sections briefly describe some existing frameworks and research that will also be referenced in the framework development.

7.2.2. Treasury impacts database

Recently, as a companion to their social cost benefit analysis guide, the NZ Treasury has produced an impact database. The database includes monetised values for over one hundred different impacts. Impacts include aged care, employment, children and youth, education, health, and justice. The guide gives typical unit values for each impact (e.g. per year, per incident, per person). The database can be found at:
www.treasury.govt.nz/publications/guidance/planning/cost-benefitanalysis/cbax

7.2.3. National science challenge resilience indicators

In July 2015, researchers from the New Zealand National Science Challenge – Resilience to Nature's Challenge developed a comprehensive review of resilience frameworks and measurement tools (Stevenson*et al.,* 2015) . In parallel, they developed a list of potential multi-capital resilience indicators (Bowie *et al.*, 2015). The indicators generally correspond to attributes, rather than costs and benefits. However, the indicators cover multiple capitals (Natural, Social, Human, Cultural and Political, Economic and Financial, Organisational, Built and Infrastructure) and consider a breadth of aspects that risk management initiatives could impact (and therefore generate costs and benefits). This research will be a good resource for ensuring completeness of cost and benefit assessment in this project. In addition, the database points to potential data sources in New Zealand for many of the indicators. This review and indicator database was drawn from a number of different frameworks.

7.2.4. Sustainability and well-being frameworks

As discussed in Section 3.2, risk and resilience can be conceptualised as a sub-set of sustainability. In this framing, it is useful to consider existing sustainability frameworks and possible alignment with these. In particular, these will be helpful in identification of co-benefits, alongside longer-term disaster specific benefits.

There are numerous frameworks to consider, of varying levels of maturity. Examples include:

- Greater Wellington Regional Genuine Progress index (FCA),
- Statistics New Zealand Progress indicators (FCA),
- <IR> Integrated Reporting (Reporting Framework),
- GRI Global Reporting Initiative (Reporting Framework),
- Social Progress Imperative, and
- OECD Well-being indicators.

8. Discussion

Effective DRM is a clear legislative imperative in New Zealand. The RMA, LGA, Building Act and Civil Defence and Emergency Management Act all require the active management of risks. However, there is currently no specific guidance on how to effectively assess the best approaches to DRM, particularly for low frequency or long-term creep hazards such as climate change. And it is even more challenging assessing those benefits relative to competing budgetary pressures such as health, education and welfare and political preferences. Without a robust process to assess the effectiveness of DRM initiatives, at times it is difficult to justify investment and policy directives that invest in long term need rather than short term personal wants. There is a clear need in New Zealand for a robust and accessible framework to demonstrate the full benefits of DRM initiatives.

The regulatory environment in New Zealand also establishes the need for comprehensive broad assessments of policy and investment decisions. The HLS and the LGA, in particular, emphasises a multi-capital or well-being approach to decision-making. It is evident that disasters have more than an economic impact: they impact our environment, our communities and our people. It is vital that we create a disaster risk decision-making framework that explores DRM costs and benefits from these multiple perspectives.

Current international DRM decision-making frameworks demonstrate that Cost Benefit Analysis is the dominant paradigm for decision-making currently. However, the literature shows that cost benefit analyses have significant limitations when applied to highly complex policy decisions such as how to invest in reducing disaster risks. Shreve & Kelman (2014) reviewed several CBA studies on disaster risk reduction and identified some shortfalls such as: lack of sensitivity analyses; evaluation of the duration of benefits; assessment of spatially diverse vulnerability; inconsistent inclusion of consequences – particularly indirect effects; challenges in estimating costs / benefits for poorly understood hazards e.g. climate change; spatial and temporal effects are often not considered; tension between private and public risks; challenges in valuing human lives and the potential disbenefits of measures. Other authors have identified additional limitations including: difficulty of including behavioural changes; accounting for synergistic benefits (benefits that extend outside the project being analysed) (World Bank, 2014), variable use of discounting (Rose *etal.,* 2007).

Like CBA, MCA also has limitations and is dependent on the availability of data and quality of execution. In a study of 128 MCA studies, de Brito found that MCA studies currently have several common weaknesses, including lack of sensitivity analysis and stakeholder involvement in assessment criteria (M. M. de Brito & Evers, 2015). In addition, MCA shares many of the limitations that CBA has: generally poor consideration of spatial and temporal impacts, challenges in estimating costs and benefits, inclusion of long term behaviour and environment changes.

A particular limitation for all methods is the selection, valuation and comparison of the full range of costs and benefits: social, economic, environmental; direct and

indirect; market and non-market. Ultimately the effective identification and inclusion of costs and benefits will be up to the decision-maker, as is the appropriate valuation of the items, particularly those that are not standard market items. Mechler observes that the valuing of non-market benefits and costs is controversial, pointing to the example of the valuation of human life (Mechler, 2005). Careful valuation, or a decision not to give a monetary value to non-market items, is required for a transparent and comparative assessment process.

For fair and transparent comparison of different assessments, some clear minimum standards would be useful. This would need to include what impacts to include in the assessment and when to value non-market items and when not to. In particular, more guidance on how to include non-market items and compare them with market items would be valuable. We identified only one framework, the UK flood and coastal erosion risk management appraisal guidelines (Environment Agency, 2010a), that gave comprehensive advice on merging market and non-market items with a cost benefit analysis to enable a decision.

Assessing future costs and benefits will inevitably include varying degrees of uncertainty. Uncertainty, therefore, is an important aspect of the decision-making process and needs to be transparently integrated into the decision-making process.

Tool selection is likely to be dependent on the objective of the assessment (Mechler, 2014). For example, if the mitigation outcome has been defined, such as a building must withstand a 50 year return period earthquake, then a CEAis probably sufficient to determine which mitigation option reaches the objective for least cost. However, if the decision makers are unsure whether to mitigate a 50-year or 100-year return event, then a CBA is more appropriate. This allows the most efficient investment to be identified. Or alternatively, if it is necessary to compare the benefits of a risk mitigation option to some other government expense, say healthcare investment, then a CBA is also the most appropriate. These questions could also be answered using a MCA. Full Cost Accounting could also be adapted to be a more forward looking framework and applied to these problems.

Similarly, the choice of tool is likely to depend on the level of engagement in the decision-making that is desirable and the amount and accuracy of data available. In New Zealand, DRM decision-making often requires the involvement of multiple stakeholders within a consultative legislative and socio-political framework. In developing a DRM decision-making framework, potential use of the framework for stakeholder engagement purposes should also be considered. A plurality of approaches may be necessary to aid decision-makers during different phases or their process. For example multi-criteria approaches may be more useful in early stage community consultation and a more technical expert-led CBA may be more effective in detailed planning stage where more information is available.

Effective DRM requires a paradigm shift. Decision-makers need to move away from single project analyses to broader and more sustainable policies such as making space for water, land-use rezoning and strategic retrofitting. These need

to be appraised across a more extensive spatial and temporal scale than has been the case in the traditional system (Turner, 2006). There has been a role for economic analysis within a specific local context; however DRM would benefit from more strategic analyses providing a sound informative basis to make more long term sustainable decisions.

The framework being developed here needs to account for, and be designed in harmony with, the legislative and political environment in New Zealand. The limitations identified in this study of the current approaches will be considered carefully. And, in consultation with a key stakeholder group, a flexible, accessible and transparent framework for DRM decision-making will be developed.

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Appendix A: Description of international frameworks

Australia

The *Australian Business Roundtable for Disaster Resilience and Safer Communities* was formed in response to a growing number of disaster events in Australia. The aim of the group is to work "constructively with governments by contributing expertise, research and resources to address the challenge". In a 2013 report, the potential benefits of increased disaster risk reduction/ mitigation, through several case studies, are presented. A cost benefit analysis is used for this. The report also included a CBA Handbook aimed at local government carrying out CBAs for disaster risk reduction (Deloitte Access Economics, 2013).

The CBA handbook describes a CBA for disaster risk in terms of four key steps:

1. Estimate baseline natural disaster costs
2. Identify and cost a series of resilience measures
3. Re-estimate natural disaster costs
4. Compare costs of resilience to reduction in natural disaster costs.

The natural disaster costs considered in the CBA are included in the following table. Costs are split into tangible and intangible; direct and indirect costs. The handbook describes both top-down (historical data and modeling) approach and bottom-up (cost building through unit estimates) approach. The handbook indicates that bottom-up approaches are better for more detailed analyses and warns that top-down approaches can miss important features such as changes in risk exposure and hazard frequency.

	Direct	Indirect
Tangible	Damage to buildings Damage to infrastructure Damage to crops and livestock.	Emergency response costs Household costs Commercial costs Loss of production.
Intangible	Death Injury Personal items and memorabilia.	Psychological Inconvenience and stress.

In the report analysis, costs were generally estimated using a top-down approach based on historical data of costs and damages. The value for intangible losses such as deaths and injuries were based on nationally established values. Notably, loss of production was not included in the analysis as this was considered to be a transferable cost; that is, if production is lost in one location, it is assumed that the production demands will be increased in unaffected areas. The exception to this is where there is a niche production in a given area that cannot be substituted. Approaches for estimating the benefits of mitigation measures, were also bottom-up and top-down.

The handbook also includes typical unit costs to allow for bottom-up analyses. For example, unit costs for stock, area costs for crops etc are provided.

The report recommends that natural disaster losses are calculated relative to the return period, then annual average losses should be calculated (based on estimated losses multiplied by the return event) for the CBA analysis.

After adjusting the baseline costs to account for the proposed resilience measures, the final step is to calculate the benefit cost ratio using the present value of benefits divided by the net present value of costs. The handbook does not give specific guidance on the selection or use of a discount rate, but presents an example with a 7% discount rate.

United States

The Federal Emergency Management Agency (FEMA) requires all parties applying for FEMA's Hazard Mitigation Assistance Grant Programs carry out a detailed BCA. The application process is now through an online tool that includes built-in hazard modules and standard cost and benefit values/rates(FEMA, 2015a). Benefits and costs included in the tool are focused on direct impacts such as:

- Cost of mitigation project construction,
- Building and contents damages (Building replacement value),
- Lost infrastructure services (by type, $/person/day),
- Loss of life and injuries ($/person),
- Displacement costs of people,
- Loss of rent, and
- Loss of business income.

In a review of FEMA Hazard Mitigation Assistance Grant Program efficiency, the Multihazard Mitigation Council (MMC) altered the FEMA assessment process to include wider impacts such as business interruption, environmental damage and societal impacts(Multihazard Mitigation Council, 2005)

The FEMA CBA approach is governed by Office of Management and Budget Circular A-94, *Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs* (Office of Management and Budget, 1992).This document states that net-present value (NPV) is the standard criterion for project economic justification, however, it notes that non-monetary impacts are useful particularly where NPV is not computable.

The OMB Circular notes some other key considers in determining benefits for a CBA:

- Care to ensure benefits would not occur without the planned intervention,
- Analyse interactions between benefits and costs,
- Report international costs and benefits separately, and
- Avoid transfer benefits (where a loss in one location becomes an equal benefit somewhere else).

Willingness to pay, preferably based on market values, is the preferred mechanism for valuing non-market items.

The OMB Circular recommends a schedule of discount rates (Office of Management and Budget, 1992). The FEMA assessment uses an average annualised loss approach with a discount rate of 7%. The MMC study used 2% for the discount rate in their study as this was deemed more aligned with the long-term cost of borrowing for the federal government (Multihazard Mitigation Council, 2005).

Last, the OMB Circular notes the importance of managing uncertainty, including through use of sensitivity analyses and where the effects are notable, distributional impacts should be noted (Office of Management and Budget, 1992).

Hazus-MH is the national loss estimation software in the US(FEMA, 2015b). While it is not a decision-making framework, the tool can provide comprehensive estimates of disaster losses suitable for use in a disaster risk management decision process. The impacts that the tool includes are(depending on the hazard type being analysed):

1) Physical damage to residential and commercial buildings, schools, critical facilities and infrastructure,
2) Economic loss, including lost jobs, business interruptions, repair and reconstruction costs, and
3) Social impacts, including estimates of shelter requirements, displaced households and population exposed to scenario floods, earthquakes and hurricanes.

Losses within Hazus-MH are calculated using damage and loss-functions and are aggregated on an annualised loss basis. The GIS capability of the tool allows spatial distribution of the losses. The tool also allows for multi-hazard assessments to be made easily (for example where a project benefits more than just one hazard).

United Kingdom

The United Kingdom Environment Agency has developed comprehensive appraisal guidance for evaluating flood defence investment. The guidelines (Environment Agency, 2010c) are developed in line with the UK Treasury Green Book for general government project appraisal (HM Treasury, 2011) and Department for Environment, Food and Rural Affairs (Defra's) policy statement on Appraisal of flood and coastal erosion risk management (Defra, 2009). Use of the guidelines is a requirement for all publicly funded Flood and Coastal Erosion Risk Management strategies and projects developed by operating authorities (Environment Agency, 2010c).

The guidelines adopt a risk-based approach where both the likelihood and consequences of flooding are considered. The guidelines also emphasise the need for a proportionate approach that ensures that information detail used in the

appraisal is proportionate to the decision- both in terms of the size and complexity of the problem or in the differentiation between options considered. Other key appraisal recommendations included working with stakeholders and carrying out environmental assessments.

The key assessment steps are:

1. Define the problem – including setting problem boundaries, how the problem will change over time and highlighting the importance of the engagement of stakeholders in defining the problem.
2. Set the project objectives - this may include consulting relative plans and policies as well as stakeholder consultation.
3. Establish the baseline case – that is, define the 'do-nothing' or 'do-minimum' option.
4. Identify, develop and short-list options – this could include hard and soft engineering solutions or policy changes, it should also include assessment of the probability of success of the respective options.
5. Describe, quantify and value costs and benefits. For costs this includes, 1) calculating whole of life costs; 2) accounting for risk and uncertainty; and 3) controlling for optimism bias[30]. For benefits, this includes 1) quantifying and monetising all benefits; 2) accounting for various climate change scenarios; 3) considering knock-on or indirect effects; 4) assessing changes in hazard risks due to intervention (e.g. erosion or events greater than those mitigated for); 5) adjusting for transfer payments (where a loss at one location is transferred somewhere else – e.g. visitors moving location rather than decreasing); and 6) capping losses at the risk-free market value of the asset and/or service.
6. Compare and select the preferred option taking into account monetised and non-monetised impacts as well as uncertainties in the assessment.

For costs, the guide concentrates on 'engineering' or implementation costs. The guide does mention the need to consider potential environmental and climate change costs, however, it gives little guidance on how to do this. An appraisal summary table and guidance is provided alongside the guide (Environment Agency, 2010b) to assist in the valuation and comparison of different benefits. The guide recommends dividing benefits and cost to show distributional impacts as well as noting uncertainty in any of the values used. In this assessment approach, damages avoided are taken into account by comparing the 'do-nothing' option (and the associated impacts) with the 'do-something' options.

The guidelines include an array of economic, environmental and social benefits. These are described in the costs and benefits matrix (Appendix B). An associated guide details methods to value some, but not all, non-market items (Environment Agency, 2010b) and encourages non-market items to be valued to the extent possible (as detailed in the UK Treasury Green Book (HM Treasury, 2011)).

[30]Optimism bias is the tendency for proponents of an initiative to be overly optimistic in their assessment of it – often leading to unrealistically positive CBA outcomes.

However, recognizing that not all items can be valued in monetary terms, the guidelines also provide a very clear and prescriptive approach to merging monetised and non-monetised costs and benefits (Environment Agency, 2010a). The guide advocates a variation on multi-criteria analysis (MCA) called the 'swing' method where, within each type of impact, options are weighted relative to the difference between the worst and best outcome. The categories are then assigned 'implied' monetary values by comparing the monetised and non-monetised impacts and their relative weights. The rationale behind this method is to reduce the level of subjectivity in the MCA (Environment Agency, 2010a).

Flood mitigation options are compared by calculating the average annualised benefits. These are calculated by first taking the probabilities for a range of events, multiplying by the total losses of the corresponding events and dividing by the life of the proposed scheme. These annualised losses are then compared to the 'do nothing' option', the difference is the average annualised benefits. These are then discounted to give the net present value of the benefits. When choosing probabilities to include in the assessment, the guide recommends having a good range of events but to include more short-return period events, as benefits are generally weighted towards these events.

Users are also encouraged to consider benefits not only in terms of risk loss reduction but also benefits for other wider purposes or for multiple purposes.

Developing countries

This Cost-benefit Analysis of Natural Disaster Risk Management in Developing Countries manual (Mechler, 2005) presents cost-benefit analysis for disaster risk management in four clear steps:

1. Risk analysis (without mitigation) – including hazard intensity, recurrence, vulnerability.
2. Identification of risk management measures and costs.
3. Analysis of risk reduction (benefits).
4. Calculation of economic efficiency.

As a starting point, Mechler highlights the importance of defining the scope and purpose of assessment before starting – in particular aligning stakeholder expectations, expertise and resources available.

Mechler categorises quantifiable disaster impacts in three ways:

1) economic, social or environmental
2) direct or indirect
3) monetary or non-monetary

Mechler advises that macro-economic effects should not be included in project level assessments as there is potential for double counting of indirect effects.

As noted by others, direct costs are more easily quantified than indirect losses, largely due to the standard, existing databases of disaster losses focusing on direct

losses. Mechler recommends that indirect losses should be estimated on losses over 5 years following the disaster and can be based on previous disaster information (gathered through surveys or statistical databases). Indirect losses being defined as the difference between the projected economic position without a disruption and the actual economic performance.

For valuing non-market items, Mechler suggest two main approaches – direct preference and the indirect method. Direct preference relies on surveys determining to price someone is willing to pay to prevent premature death. AS Mechler points out, this is likely to be dependent on the level of income of those surveyed. The indirect method estimates the market losses due to the impact. For example, the lost income due to a death or cost of treatment of injury.

Mechler recommends an annualised losses approach to estimating damages in a CBA – where expected damages for a given event is multiplied by the probability of the event occurring.

The final step in the process is the evaluation. After project benefits and costs have been discounted, Mechler recommends either and NPV, CBR or an IRR assessment to determine project viability.

In 2014, the World Bank and ClimateWorks Foundation developed a framework to better assess and value 'Climate-Smart' development (World Bank, 2014) or, in otherwords, reducing the risk of future climate change. The framework is a four step process:

1. Identify the full range of benefits.
2. Identify appropriate benefits assessments tools.
3. Identify an appropriate macroeconomic tool.
4. Estimate and present significant benefits.

The framework considers project direct costs and benefits. Benefits are assessed using a range of 'bottom-up' models. Both the costs and benefits are then input into a macroeconomic assessment (in this case the Global Energy Industry Model by Oxford Economics) to reflect the dynamic interactions within an economy. The benefits are reported in both monetary and non-monetary terms. The report states that it is not necessarily appropriate to combine these different benefit types. However, the report does use some established monetary valuations for benefits such as: value of statistical life, crop value, social cost of carbon, carbon dioxide mitigation cost, and energy savings.

The World Bank study identified a number of areas for framework improvement, these include accounting for the challenge of behavioural changes, ensuring transferability of framework to individual project level, better evaluation of climate change benefits, and accounting for synergistic benefits (benefits that extend outside the project being analysed) (World Bank, 2014).

Appendix B: Matrix of costs and benefits identified in the literature

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				Dimension/Capital								
Benefit/cost description	**unit Measurement**	**Benefit / cost**	**Type of variable (stock or flow)**	**Social**	**Human**	**Cultural**	**Built**	**Natural**	**Economic**	**Method of measurement**	**Hazard cost/benefit assessed**	**Reference**
Reduced direct property damage (buildings, contents, bridges, pipelines)	$	Benefit	Stock				x			HAZUS MH	All	Rose, A., Porter, K., Dash, N., Bouabid, J., Huyck, C., Whitehead, J., … West, C. T. (2007). Benefit-Cost Analysis of FEMA Hazard Mitigation Grants. *Natural Hazards Review*. http://doi.org/10.1061/(ASCE)1527-6988(2007)8:4(97)
Reduced direct business interruption loss (e.g., factory shut- down from direct damage or lifeline interruption);	$	Benefit	Either						x	HAZUS MH	All	
Reduced indirect business interruption loss e.g., ordinary economic "ripple" effects	$	Benefit	Either						x	HAZUS MH	All	
Reduced nonmarket environmental damage e.g., wetlands, parks, wildlife;	$	Benefit	Stock					x		Willingness to pay / benefit transfer	All	
Reduced other nonmarket damage e.g., historic sites	$	Benefit	Stock	x		x				Willingness to pay / benefit transfer	All	
Reduced societal losses deaths, injuries, and homelessness;	$	Benefit	Either	x	x					HAZUS MH	All	
Reduced emergency response e.g., ambulance service, fire	$	Benefit	Either						x	HAZUS MH	All	
Psychological trauma,	-	Benefit	Either		x					omitted due to inability to quantify	All	
Indirect property damage e.g., prevention of ancillary fires	-	Benefit	Stock				x			omitted due to inability to quantify	All	
Avoided negative societal impacts relating to psychological trauma e.g., crime, divorce, air quality benefits	-	Benefit	Either	x						omitted due to inability to quantify	All	
Improvements in visibility and health due to reduced burning debris,	-	Benefit	Either	x	x					omitted due to inability to quantify	All	
Benefits from reduced disposal of debris,	-	Benefit	Either					x		omitted due to inability to quantify	All	
Land quality	-	Benefit	Stock					x		omitted due to inability to quantify	All	
Aesthetic benefits including visibility and odors of reduced debris	-	Benefit	stock	x	x			x		omitted due to inability to quantify	All	

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Social/cultural buildings (functionality compromised)	% buildings	Benefit	Stock			x	x			-	All	Saunders, W. S. A., Beban, J. G., & Kilvington, M. (2013). Risk-based land use planning for natural hazard risk reduction. *GNS Science Miscellaneous Series 67*. Retrieved from http://www.gns.cri.nz/Home/RBP/Risk-based-planning/A-toolbox/Risk-based-planning-approach-and-steps/Step-2-Determine-severity-of-consequences/Consequence-table
Buildings (functionality compromised)	% buildings	Benefit	Stock				x			-	All	
Critical buildings (functionality compromised)	% buildings	Benefit	Stock	x	x		x			-	All	
Lifelines (time and percent population affected)	% buildings	Benefit	Stock	x	x		x			-	All	
%GDP	% GDP	Benefit	Flow						x	-	All	
Health & safety - deaths	number people	Benefit	Stock		x					-	All	
Health & Safety - injuries	number people	Benefit	Stock		x					-	All	
Existing community -places, resources, sites valued by community	-	Cost		x						-	All	Ministry for the Environment. (2014). A Guide to Section 32 of the Resource Management Act 1991. incorporating changes as a result of the Resource Management Amendment Act 2013.
Existing community - social cohesion	-	Cost		x						-	All	
Existing community - opportunities for leisure and recreation	-	Cost		x						-	All	
Existing community - health and safety	-	Cost		x	x					-	All	
Existing community- access to employment opportunities	-	Cost		x	x					-	All	
Existing community - recreational and leisure opportunities	-	Benefit		x						-	All	
Existing community - ability for social interaction	-	Benefit		x						-	All	
Existing community - social cohesion, character and services in the community	-	Benefit		x						-	All	
Existing community - employment opportunities	-	Benefit		x	x					-	All	
Future generations - ability to experience highly valued resource or area	-	Cost		x	x					-	All	
Future generations- opportunities for leisure / recreation	-	Cost		x						-	All	
Future generations - health and safety and social cohesion	-	Cost		x						-	All	
Future generations - access to highly valued resources or areas	-	Benefit		x						-	All	
Future generations - recreation / leisure opportunities	-	Benefit		x						-	All	
Future generations - health and safety	-	Benefit		x						-	All	
Iwi/Maori - sites of significance to Maori	-	Cost		x	x	x				-	All	
Iwi/Maori - Iwi/Maori institutions and businesses	-	Cost		x		x			x	-	All	
Iwi / Maori - the ability to meet the principles of the Treaty of Waitangi	-	Cost		x		x				-	All	
Iwi/Maori - Natural resources of value to Iwi/Maori	-	Cost				x		x		-	All	
Iwi/Maori - places and areas of historical, spiritual or cultural significance	-	Cost				x				-	All	
Iwi/Maori - sites of significance to iwi/Maori or areas or resources valued by Iwi/Maori	-	Benefit				x				-	All	
Iwi/Maori - Iwi/Maori communities	-	Benefit				x				-	All	
Iwi/Maori - Iwi/Maori institutions and businesses	-	Benefit				x			x	-	All	
Iwi/Maori - quality of natural resources, including waterways	-	Benefit				x		x		-	All	
Landowners - direct adverse e.g. noise, traffic, dust, overshadowing, odour	-	Cost		x				x		-	All	
Landowners - reduced use or development rights	-	Cost							x	-	All	
Landowners - increased consent costs and time	-	Cost							x	-	All	
Landowners - Reduced property values	$	Cost	Stock						x	-	All	
Landowners - increase property values	$	Benefit	Stock						x	-	All	
Landowners - Direct positive effects i.e. reduction in noise, traffic, dust, overshadowing, improved accessibility	-	Benefit		x				x		-	All	
Landowners - Direct positive effects as a result in an increase in amenities	-	Benefit		x				x		-	All	
Landowners - reduced consent costs and time	-	Benefit							x	-	All	
Businesses - consenting cost	$	Cost	Either						x	-	All	
Businesses - cost familiarising with the regulations	$	Cost	Either						x	-	All	
Businesses - increased cost materials and production	$	Cost	Either						x	-	All	
Budinesses - lost sales due to restricted access to markets	$	Cost	Either						x	-	All	
Businesses - increased licence fees and other charges	$	Cost	Either						x	-	All	
Businesses - meeting reporting, monitoring or record-keeping requirements	$	Cost	Either						x	-	All	
Businesses - increase in revenue and sales	$	Benefit	Either						x	-	All	
Businesses - reduction in consent costs and licencefees	$	Benefit	Either						x	-	All	

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Benefit/cost description	**Measurement unit**	**Benefit / cost**	**Type of variable (stock or flow)**	**Social**	**Human**	**Cultural**	**Built**	**Natural**	**Economic**	**Method of measurement**	**Hazard cost/benefit assessed**	**Reference**
Businesses - reduced costs of materials required to comply	$	Benefit	Either						x	-	All	
Businesses - lower production costs	$	Benefit	Either						x	-	All	
Businesses - reduced compliance costs	$	Benefit	Either						x	-	All	
Consent authority - cost of providing information (about new provisions)	$	Cost	Either						x	-	All	
Consent authority - cost of recruiting and training staff	$	Cost	Either						x	-	All	
Consent authority - cost of processing consent applications	$	Cost	Either						x	-	All	
Consenting authority - reduced resource, administrative, compliance and enforcement burden	$	Benefit	Either						x	-	All	
Value of Life	$	Benefit	Stock		x					Standard value $3.85million (MOT 1991 study)	None	The Treasury. (2015). Guide to Social Cost Benefit Analysis. New Zealand Government. Retrieved from http://www.treasury.govt.nz/publications/guidance/planning/costbenefitanalysis/guide/
Health costs of air pollution	$	Benefit	Flow		x					$40 per person per year per microgram/m3.	None	
Financial wealth	-	Either	Stock						x	-	None	The Treasury. (2015). An Introduction to Using the Living Standards Framework. Retrieved from http://www.treasury.govt.nz/abouttreasury/higherlivingstandards/his-usingtheframework-v2.pdf
Housing	-	Either	stock				x			-	None	
Infrastructure	-	Either	stock				x			-	None	
Skills	-	Either	Stock		x					-	None	
Health	-	Either	Stock		x					-	None	
Institutions	-	Either	Stock	x						-	None	
Trust	-	Either	Stock	x						-	None	
Climate	-	Either	Stock					x		-	None	
Biodiversity	-	Either	Stock					x		-	None	
Water	-	Either	Stock					x		-	None	
Income	-	Either	Flow						x	-	None	
Consumption	-	Either	Flow						x	-	None	
In-kind service	-	Either	Flow						x	-	None	
Employment	-	Either	Flow		x					-	None	
Leisure	-	Either	Flow		x					-	None	
Innovation	-	Either	Flow		x					-	None	
Freedom	-	Either	Flow	x						-	None	
Security	-	Either	Flow	x						-	None	
Environmental services	-	Either	Flow					x		-	None	
Environmental Amenities	-	Either	Flow					x		-	None	
Roading benefits (includes benefits for infrastructure upgrades, public transport, demand management) and provides a range of benefits	-	Benefit			x		x	x	x	Details provided in reference	None	NZ Transport Agency. (2013). *Economic evaluation manual* (Vol. 2).
Roading costs	-	Cost					x			Details provided in reference	None	
Time	$	Either	Either		x					Details provided in reference	None	HM Treasury. (2011). *The Green Book: Appraisal and Evaluation in Central Government*.
Health	$	Benefit	Either		x					Details provided in reference	None	
Prevented fatality or prevented injury	$	Benefit	Stock		x					Details provided in reference	None	
Design quality	$	Benefit				x	x			Details provided in reference	None	
Environmental impact (greenhouse gas, climate change, landscape, water, biodiversity, noise, recreational and amenity values for forest, disamenity)	$	Benefit	Flow			x		x		Details provided in reference	None	
Acquisition and use of property	$	Cost	Stock	x			x			Details provided in reference	None	
Leases and rents	$	Cost	Flow						x	Details provided in reference	None	
Property	$	Either	Stock						x	Multi-coloured handbook	Flood	Environment Agency. (2010). Flood and coastal erosion risk management appraisal guidance: Supporting Document for the Appraisal Summary Table, (March). Retrieved from http://webarchive.nationalarchives.gov.uk/20131108051347/http://a0768b4a8a31e106d8b0-50dc802554eb38a24458b98ff72d550b.r19.cf3.rackcdn.com/geho0310bsdd-e-e.pdf
Emergency	$	Benefit	Flow						x	Multi-coloured handbook	Flood	
Infrastructure	part $	Either	Either				x		x	Multi-coloured handbook	Flood	
Transport	part $	Either	Either				x		x	Multi-coloured handbook	Flood	
Agriculture	$	Either	Stock					x	x	Multi-coloured handbook	Flood	
Land use	none	Either	Either					x	x	Multi-coloured handbook	Flood	
Indirect effects on Businesses	part $	Benefit	Flow					x	x	Multi-coloured handbook	Flood	
Ecosystem services	part $	Either	Flow					x		Multi-coloured handbook	Flood	
Status under' water framework directive'	part $	Either						x		WFD manual	Flood	
Historic environment	none	Either				x		x		None	Flood	

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Landscape	none	Either						x		None	Flood	
Way of life	part $	Either	Either							Multi-coloured handbook	Flood	
Culture	none	Either								None	Flood	
Community	none	Either								None	Flood	
Political systems	none	Either								None	Flood	
Health and well-being	part $	Either	Either							Defra Supplementary Guidance on stress from flooding and Defra Supplementary Guidance on risk to life	Flood	
Personal and property rights	part $	Either	Either							Defra Supplementary Guidance on distributional impacts	Flood	
Fears and aspirations	none	Either								None	Flood	
Capital: materials, compensation, land, legal fees, design, mitigation	$	cost	stock						x	None	Flood	
Phasing, additional construction in future years;	$	cost	stock						x	None	Flood	
Operational costs	$	cost	flow						x	None	Flood	
Running costs (fuel, staff)	$	cost	flow						x	None	Flood	
Maintenance	$	cost	flow						x	None	Flood	
Decommissioning	$	cost	stock						x	None	Flood	
Monitoring	$	cost	flow						x	None	Flood	
Refurbishment	$	cost	stock						x	None	Flood	
Loan repayments	$	cost	flow						x	None	Flood	
Social - households - number of causalties	number people (	Benefit	stock	x	x					Possibly monetise through direct - survey methods on willingness to pay for avoided impacts) or indirect methods through lost market benefits (e.g. lost income through death)	All	Mechler, R. (2005). *Cost-benefit Analysis of Natural Disaster Risk Management in Developing Countries*. Retrieved from http://pdf-release.net/external/3508/pdf-release-dot-net-0003131-environment-cost-benefit-analysis-of-natural-disaster-risk-management-in-developing-countries-manual.pdf
Social - households - number injured	number people (	Benefit	stock	x	x					Possibly monetise through direct - survey methods on willingness to pay for avoided impacts) or indirect methods through lost market benefits (e.g. lost income through death)	All	
Social - households - number affected	number people (	Benefit	stock	x	x					Possibly monetise through direct - survey methods on willingness to pay for avoided impacts) or indirect methods through lost market benefits (e.g. lost income through death)	All	
Social - households - increase of diseases (indirect)	number people (	Benefit	stock	x	x					Possibly monetise through direct - survey methods on willingness to pay for avoided impacts) or indirect methods through lost market benefits (e.g. lost income through death)	All	
Social - households - stress symptoms (indirect)	number people (	Benefit	stock	x	x					None	All	
Economic - private - households - housing damaged or destroyed (direct)	$	Benefit	stock				x		x	-	All	
Economic - private - households - loss of wages, purchasing power (indirect)	$	Benefit	Flow							-	All	

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Economic - private - households - increase in poverty (indirect)	-	Benefit	flow							-	All	
Economic - public sector - education, health, water, sewage, electricity, transport, emergency services - assets damaged or destroyed (direct)	$	Benefit	Stock				x		x	-	All	
Economic - public sector - education, health, water, sewage, electricity, transport, emergency services - loss of infrastructure services (indirect)	$	Benefit	Flow						x	-	All	
Economic - private sector - agriculture, industry, commerce, services - assets damaged or destroyed (direct)	$	Benefit	Stock				x		x	-	All	
Economic - private sector - agriculture, industry, commerce, services - alosses due to reduced production (indirect)	$	Benefit	Flow						x	-	All	
Environmental - loss of natural habitats	-	Benefit	Stock					x		-	All	
Environmental -effects on bio-diversity	-	Benefit	Flow					x		-	All	
Damage to buildings	$	Benefit	stock				x			Based on historic data	All	Deloitte Access Economics. (2013). *Building our nation's resilience to natural disasters*.
Damage to infrastructure	$	Benefit	stock				x			Based on historic data	All	
Damage to crops and livestock.	$	Benefit	stock					x		Historical data on value of production of land OR costs per head of stock / area of land / length of fence	All	
Emergency response costs	$	Benefit	flow						x	Historical data	All	
Household costs	$	Benefit	flow						x	Costs of clean-up and evacuation	All	
Commercial costs	$	Benefit	flow						x	Costs of clean-up and evacuation	All	
Loss of production.	-	Benefit	flow						x	Not included due to transferability	All	
Death	$	Benefit	stock		x					Office of Best Practice Regulation (OBPR) Estimate of the financial value society places on reducing the average number of deaths by one ($3.5m)	All	
Injury	$	Benefit	stock		x					Office of Best Practice Regulation (OBPR. Number of injuries based on historical data	All	
Personal items and memorabilia	-	Benefit	stock	x		x				Qualitative	All	
Psychological	-	Benefit	flow	x	x					Qualitative	All	
Inconvenience and stress.	-	Benefit	flow	x	x					Qualitative	All	