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Making decisions in the face of uncertainty: Understanding risk

Part 1
May 2016

Available for download at **http://www.pmsca.org.nz**
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Acknowledgments

The first draft of this paper was prepared by Dr Anne Bardsley of the Office of the PMCSA. Other members of the Office also provided input. Early drafts were reviewed by staff of the Ministry of Civil Defence and Emergency Management. The final draft was reviewed by the Committee of Departmental Science Advisors.

We specifically acknowledge the valuable input of the following reviewers:

Mark Ferguson, *Science Foundation Ireland, Chief Science Advisor to the Government of Ireland*
David Mair, *Joint Research Centre, European Commission*
Sarah-Jayne McCurrach, *Ministry of Civil Defence and Emergency Management*
Kim Wright, *Ministry of Civil Defence and Emergency Management*
Murray Sherwin, *New Zealand Productivity Commission, Chair Strategic Risk and Resilience Panel*
David Johnston, *Joint Centre for Disaster Research, Massey University, and GNS Science*
Sarb Johal, *Joint Centre for Disaster Research, Massey University,* and *GNS Science*
Emma Hudson-Doyle, *Joint Centre for Disaster Research, Massey University,* and *GNS Science*
Richard Bedford, *Royal Society of New Zealand* and *Auckland University of Technology*
Aidan Gilligan*, SciCom – Making Sense of Science, Brussels*

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Forward – About this series

As the Prime Minister's Chief Science Advisor (PMCSA), part of my terms of reference is to promote the use of science-based evidence to support public policy making, both within traditional policy domains and also relating to questions of new and emerging technologies. Increasingly, this work requires explaining to government and publics how science can assist and what science can tell us about decision-making when knowledge is incomplete. This includes consideration of concepts of risk, uncertainty, probability and precaution. Few if any decisions can be made with absolute certainty of outcome. The consequence of this reality is that some decisions appear to take too much risk and others not enough, the latter often leading to a sense of inaction. Indeed no innovation is possible without some level of uncertainty, so an absolute sense of precaution leads to stasis.

The assessment of virtually every hazard and risk has a scientific dimension. This is particularly so in the cases of technology assessment and in considering the responses to potential natural hazard events and other crises. Scientific advice in such situations includes identifying risks and opportunities and managing them effectively. For instance, providing scientific scrutiny of governmental risk assessments helps to inform a better understanding of the possible outcomes, and thus to assist government decision-making.

The term 'risk' itself implies some uncertainty of outcome, which can be either positive or negative. Dealing with the negative effects of a risk or a decision – the downside of uncertainty – involves managing and minimising potential damaging effects to ourselves and our communities, economy, and environment. This requires proactively understanding these effects and adequately planning and being prepared. However, for societies to progress, we must also consider the positive effects of risk – the upside of uncertainty in decision-making – where potential benefits can be realised. Management then entails minimising potential negative impacts while maximising the opportunities.

As such, it is important to determine whether the potential positive effects (benefits) of a decision made in the face of uncertainty are likely to outweigh the potential harms. To do this we use risk assessments to better inform our knowledge and our perceptions of the risk. However, there are many reasons why perceptions of risk vary between people and between communities and societies, and it is that variation in perception that can make some people appear risk averse and others foolhardy. That variation is based on many innate biases and on our different worldviews.[†] In the public arena this is often reflected in the political process.

In a democracy and in our own lives, understanding risk is everyone's responsibility, from the individual to communities, and our government. Therefore integrity of the information we assess, and collaboration in our assessment of this information, are key to enabling an informed decision to be made when taking or facing risks. In many cases peer reviewed scientific evidence is central to this process, but a key message of this series of papers is that science cannot have all the answers.

[†] A worldview is a particular philosophy, or collection of beliefs, about life and the universe that is held by an individual or a group. We use the term to indicate the overall perspective from which one sees and interprets the world.

Science is an iterative, self-correcting process that gradually leads toward a general consensus of scientific views based on the consistency, volume and weight of evidence on a particular issue. However, the pace of change occurring today, and the increasingly complex risks we face both individually and as a society often require choices to be made and action to be taken before all of the desired evidence can be gathered. We frequently want to know more than science can produce. Given that there is nearly always a degree of uncertainty in any decision, even if scientifically informed, levels of judgement have to be made both in our own choices and in those that policy makers make on our behalf.

The intention of this series of discussion papers is to enable the reader to understand what risk means to individuals, their communities and government; to promote awareness and understanding of the many aspects of risk assessment, communication and management; and to consider the long-term risks in New Zealand and how we might make decisions optimally when the outcomes are uncertain.

Part 1 in the series is designed to provide a general understanding of risk and its associated concepts. It will introduce the reader to basic principles of risk management including risk assessment, the translation of science into risk communication, and how we use our beliefs and values when making risk-based decisions. A greater understanding of the concepts of risk, hazard, potential impact (consequences), vulnerability and exposure, and the limits of scientific knowledge surrounding them, provides a basis for individuals and communities to better consider the complex trade-offs between risks and benefits, allowing them to formulate their own responses to many situations that will challenge us in the twenty first century. The first paper will serve as an introduction for the more in-depth discussion of concepts and issues in the rest of the series.

Part 2 will consider in further detail the concepts of risk perception and risk management – in other words, how we think about risk and how we attempt to manage it or live with it. This leads to a discussion of values, biases, beliefs and worldviews that influence how we see and deal with risk, both individually and as a society. In a rapidly changing world we now face many societal decisions we have never faced before. For example, there are risks relating to changing and emerging technologies that had not been contemplated a generation ago. The rapid pace of technological change means that our society is more connected than ever, making our new way of life increasingly vulnerable to disruption. Similarly, we need to think hard about how to sustain and improve our economy, while also protecting our environment and distinctive biological heritage that makes New Zealand a uniquely, great place to live. This means making decisions and considering the trade-offs involved in preparing for, and adapting to, our changing environment. Understanding the factors that can affect our interpretation and acceptance or rejection of scientific evidence, and the trust we place in various sources of information, is critical to our success in this regard. But none of this is simple.

Part 3 will tackle the longer-term trends that may affect New Zealand and discuss the role of government in risk management. Building on the first two papers, it will introduce risks, including global risks, that have system wide effects – for example climate change, demographic change and disruptive technologies. Understanding the information at hand, scientific or otherwise, is essential for policy makers and government officials who have to decide what 'is best' on the basis of available evidence, while bearing the responsibility of protecting our most valuable assets. Usually this means having to make a decision without all the answers, but it also means being adaptive and being willing to change policy responses in the light of new information. It also requires being clear with risk communication so that all stakeholders including the public understand the basis of decision making. As societal approaches will be needed, the importance of collective consensus in risk management cannot be underestimated.

The stories used to illustrate this series of papers are chosen to demonstrate the complexities of decisions involving risk and uncertainty. They show how values come into play, and how different perceptions of risk, precaution and our various distinct worldviews affect our decision-making. They also highlight essential differences between voluntary and involuntary risks (those we take versus those we face).

The second and third papers in this series will be released later this year. The goal of these discussion papers is to help improve the quality of the public understanding of the many risks that confront New Zealand; be it in terms of how we address the balance between economic growth and resource use, how we use and/or control new disruptive technologies, how we make decisions about initiatives aimed at enhancing our quality of life or addressing natural hazards or threats to our national security. All governments must constantly address societal and economic risks over which scientific knowledge, and both societal and personally-held values may be contested. The discussion that follows will attempt to address some of these issues, particularly within the New Zealand context.

Sir Peter Gluckman
Prime Minister's Chief Science Advisor

Part 1: About risk

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Part 1: About risk

Aim and Scope

This paper is Part 1 in a series of three discussion papers that aims to provide a broad frame of reference for discussion of risk in the New Zealand context. The over-arching theme of the series is ‘decision-making under uncertainty’, because some degree of uncertainty underlies virtually all choices we make, both as individuals and collectively as a society.

This first paper deals with the fundamental problem of defining and interpreting ‘risk’ itself, and how it is understood and assessed from both scientific and popular perspectives. The objective is not to analyse any particular risk or type of risk, but rather to clarify the conceptual frameworks and processes that allow decisions to be made when outcomes are not completely knowable at the time. A greater understanding of the concepts of risk, hazard, potential impact (consequences), vulnerability and exposure, and the value, but also the limits of scientific knowledge, provides a basis for individuals and communities to better consider the trade-offs between risks and benefits, allowing them to formulate responses to many decisions that we must make as individuals and as a society, and in particular in relationship to many core issues that challenge New Zealand society.

Box 1

Our everyday risks: the morning commute

Mary has two choices about how to get to and from work each day, and most of the time she chooses to take the bus over driving her car. She makes this decision for a number of reasons that reflect her values, perceptions, her worldview and her analysis of the situation each day. One consideration is her concern for the environment, which favours the public transport option. But by taking the bus she risks being held up by a sometimes unpredictable timetable, rather than feeling in control of her own travel if she takes her car. On the other hand, she knows that if she drives, she will almost inevitably have to deal with heavy traffic on the motorway, and have little chance of finding a car park near her office. She doesn't consciously calculate the statistical probability of these different scenarios, rather she makes an informed and rather automatic guess based on her own experience, biases and beliefs. On this basis, Mary chooses to take the bus most days.

Mary's perception is that the risk of driving has a high probability of a bad outcome in terms of traffic and parking, and that this outweighs the benefit of driving her car to work. She is not even thinking about the fact that the physical risk of injury is much higher as the driver of a car than as a passenger on a bus, which (if she was very analytical) might further sway her decision.

Getting off the bus across the road from her office presents another decision; one she makes every day, and does so mostly subconsciously. The road is busy and she needs to cross it. Cars and buses come around the corner at speed, and the road is wide. It is more than a matter of a few steps to the other side. She could walk about 100 metres down to the crossing and wait for the lights – but this increases the distance she has to travel and the time it will take – or she could dash across from where she disembarks, taking the shortest path to her office door. She is not the only one making this choice, and most who are heading in the same direction choose the direct path – they jaywalk across the road. This behaviour by others is a social cue that is likely to influence her decision, particularly if she sees someone she knows (and trusts) doing the same. Her behaviour will also be affected by her past experience on this road – she has done this many times before and is reasonably confident about the dynamics of the hazards around her. She believes in her own ability to judge the speed and distance of the approaching vehicles and to get across the road fast enough between spurts of traffic.

Mary's choice and behaviour in crossing the road are influenced by the value she places on saving time versus risking injury. The risk itself might be modified by other factors, some of which are out of her control, such as the road surface conditions (e.g. wet surface, unobserved tripping hazards), the sometimes unpredictable behaviour of drivers, as well as the margin of safety she allows in the timing and speed of her crossing – reflecting her appetite for risk. She makes the dash rather than heading for the crossing.

Introduction

As Mary's story (Box 1) illustrates, we all make numerous choices on a daily basis, some conscious and some unconscious, that involve varying degrees of risk and uncertainty. We face them from the moment we get out of bed. Some risks will be under our control, and some will not be. From dodging the obstacles in our path to the shower, to what we do in the kitchen (think of all the hazards in the kitchen), to our mode of transport to work and the people we interact with along the way, our choices will affect the outcome of our day in both obvious and inconspicuous ways. Our food choices can carry health risks – both in the long term (leading to obesity and heart disease) and sometimes acutely (risking food poisoning), as do the tools we use to prepare it, depending on the actions of ourselves and others. Traveling by any means from home to work involves risks and uncertainties, but we must choose a way to get there.

Similarly, virtually every decision that governments must make on our behalf involves some level of uncertainty. Unintended consequences are common in our private choices and certainly are so in policy-making, and yet decisions by governments often cannot wait. Indeed a decision not to do anything is still a decision with consequences.

Increasingly we must, as societies, make decisions with regard to new technologies. When should we adopt them? When should we control them? Indeed the history of human innovation – from the invention of fire to advances in molecular biology – demonstrates that every technology has both benefits and downsides. The pace of development of new technologies such as the "internet of things"[‡], machine learning and artificial intelligence, brain-machine interfaces, gene editing and driverless cars, to name but a few – will all bring this complex equation of decision making by societies into sharp focus. Without some risk taking innovation is impossible, because every innovation involves some level of uncertainty as to its effects. When the automobile was first invented no one would have foreseen its impacts for good (mass transport) and bad (pollution, injuries, etc.) on society. The same can be said of technologies such as the internet – it has made our lives much easier but it has also changed the way we communicated and learn, changed concepts of privacy and personal space, and it has exposed young people to cyberbullying, sexting and pornography. Its long-term effects on brain-development are uncertain. Even concepts such as the nation-state and the representative nature of democracy might be threatened.

Some degree of risk is present in everything we do. Successful entrepreneurs and military leaders are successful often because they have taken risks; but equally, failed entrepreneurs and generals may have failed either because they have been too risk-averse or have taken too great a risk. As individuals and as a society, we take risks to achieve benefits, and we avoid risks to protect ourselves from harm. We constantly make decisions that carry some level of risk, often with incomplete knowledge of possible outcomes, and in situations where we cannot wait for a definitive answer before a decision must be taken. We can prepare to the best of our ability and still be negatively affected. Or we can take a carefree attitude towards the hazards and risks we face and get away with it, at least some of the time – though we can never know for sure that we will. The future is inherently uncertain.

The intent of the following discussion is not to shape any particular risk assessment or decision; rather it is to assist individuals, communities, policy makers and politicians to better understand what risk is and the various way it is approached, so as to enable constructive discourse on complex matters where decisions cannot wait, but factors remain uncertain and the values associated with the decision may well be in dispute.

1. What is Risk?

This may seem like a simple question, but there is no straightforward answer. The term 'risk' has a wide range of connotations, but all imply that the outcome of an action or event is uncertain – it can be a negative threat or a positive opportunity, with

[‡] The Internet of Things (IoT) describes the system of interconnected 'things' via the internet. Each device has a unique identifier (numeric or alphanumeric codes) allowing interactions across the network. The 'things' could be computing devices, digital or mechanical machines (e.g. cars with sensors), objects, animals (e.g. implanted with a biochip transponder) or people (e.g. with a heart monitor).

consequences affecting something of value (referred to as 'assets'). 'Risk' is often defined as the combination of the likelihood of occurrence and the consequence of exposure of assets to a 'hazard'. The magnitude of the risk is influenced by the level or frequency of exposure and the vulnerability of the assets, the characteristics of the hazard, and how likely an event is to occur.

A key emphasis of this series is that although risk can be defined in a concise and technical way[§] (see Box 2), the perception of risk is a broader concept that is ultimately dependent on social and individual values. Sometimes taking risks (voluntarily) can lead to greater rewards, as in the case of the successful investor, but in other situations it can lead the same people to substantial losses. The investment outcome will be in part determined by how the investor weighs up and makes choices in the face of uncertainty, but also by externalities beyond his or her control (for example the New Zealand economy could be greatly affected by unanticipated decisions made by a major economic power). In other situations there is no choice but to face risks (involuntarily), and prepare for the possible consequences. For example, to live nearly anywhere in New Zealand carries with it the risk of being exposed to one or more natural hazards including volcanoes, earthquakes and floods. Our

Box 2

Some important definitions

Asset: anything of human value; includes people/populations, systems, communities, the built domain, the natural domain, economic activities and services, trust and reputation

Exposure: People, property, systems, or other assets present in hazard zones or exposed to hazards that are thereby subject to potential losses.

Hazard: any source of potential harm, including loss of life or injury, property damage, social and economic disruption or environmental degradation.

Resilience: being shock-ready, and having the ability to resist, survive, adapt and/or even thrive in response to shocks and stresses. Resilience can be defined in terms of societal, economic, infrastructure, environmental, cultural capital, social capital, and/or governance components.

Risk: a combination of the *likelihood* of occurrence and the *magnitude* of impact (consequences) of a hazard event on people or things that they value (assets). Risk is modified by the extent of exposure of an asset to a hazard, and the vulnerability of the asset to the harmful consequences of the hazard. The Australian and New Zealand Risk Management Guidelines define risk as *the effect of uncertainty on objectives.*

Shock: a sudden, disruptive event with an important and often negative impact on a system/s and its assets

Stress: a long term, chronic issue with an important and often negative impact on a system/s and its parts

Vulnerability: the characteristics and circumstances of an asset that make it susceptible to, or protected from, the impacts of a hazard

§ The Australian and New Zealand Standard Risk Management Guidelines define risk as *the effect of uncertainty on objectives.* The 'effect' implied here can be either positive or negative – it is a deviation from what is expected in terms of financial, environmental, health and safety, or other goals ('objectives'). [1]

approach to risk obviously differs between these different situations, both individually and as a society and nation.

1.1 Hazards, shocks and stresses

To understand risk, we must first understand 'hazards' (see Box 2). The term hazard refers to any source of potential harm, including loss of life or injury, property damage, social and economic disruption or environmental degradation. What makes something a hazard is the fact that by being exposed to it there is a possibility for something to go wrong. A hazard has no impact and does not create a risk unless there is exposure to it. Potential hazards are everywhere – in the kitchen drawer, the foods we eat, the consumer products we rely on, our modes of transport, where we choose to live, and the activities we pursue in work and leisure.

Hazards can be naturally occurring (e.g. geological or biological hazards such as fault lines or infectious agents) or can be induced by human activity (e.g. technological or sociological hazards such as industrial chemicals or terrorism). A disruptive, hazard-related event may be referred to as a 'shock'. The extent of harm or impact resulting from such an event can sometimes be measured quantitatively and expressed in monetary value, number of lives lost, etc., but many consequences can only be expressed descriptively, in terms of other emotional, environmental and/or social impacts.

Long-term, chronic conditions or trends (also known as 'stresses') that have important, often negative impacts can become or contribute to future shocks. For example, the slowly rising sea levels, associated with climate change, is a stress that if combined with a low-pressure weather system contribute to the storm to create a greater shock.

1.2 Exposure, vulnerability and resilience

In order to be at risk, people and/or things of value (assets) have to be exposed to a hazard. In addition to human lives and health, assets can include our built or natural environment, our communities and economic activities, and even our national or personal reputation. A hazard to which people or assets are not exposed does not create a risk, but could have the potential to create a risk in the future. For example, a tsunami that only reaches shore on a deserted island is not a risk, because no assets are exposed to it, but if the island is later occupied by humans, they and their communities will be exposed to the risk of future tsunamis. Similarly, if one never opens the kitchen drawer where the meat cleaver is stored, the meat cleaver cannot cause harm, but used carelessly the risk of injury can be significant. If a gun is locked in a safe it cannot create a risk and is not a hazard, but left loaded in a backyard where children are playing it is a major hazard and risk has been created.

The degree to which we (or our assets) are negatively affected by exposure to a hazard is influenced by our vulnerability (or that of our assets) and our resilience to that hazard. The effect of exposure to hazards on our risk profile is evident when we think about the potential for disasters to occur. The impacts of natural disasters are increasing both in New Zealand and globally, but generally not because there are more hazards around us (although climate change may be increasing the frequency of shocks). Rather the main driver of our increased risk is that our overall *exposure* is increasing, as for example, more and more people are living in regions prone to flooding and coastal erosion. Thus there are more assets, people, interconnected services and critical infrastructure being exposed to risks than ever before (see Box 3).

Vulnerability refers to characteristics and circumstances that make an asset susceptible to the potentially damaging impacts of a hazard. The degree of vulnerability is influenced by physical, social, economic, and environmental factors. While exposure itself creates vulnerability, poorly constructed buildings, inadequate or poorly maintained infrastructure, and high population density further exacerbate community vulnerability. Conversely, it is possible to be exposed to a hazard but to have reduced vulnerability if the community has the capacity to mitigate possible losses by improving building design and infrastructure.

Box 3

The risk equation

Disaster risk is increasing mainly as a result of an increasing number of exposed and interconnected (and more vulnerable) assets. Increasing resilience can decrease the impacts of risk.

Thus the concept of vulnerability conveys the understanding that the impacts of a hazard event are partially a function of the preventive and preparatory measures that are employed to reduce the risk, but also of the inherent qualities that make one asset experience greater harm than another when exposed to the same shock or stress. For example, buildings or infrastructure may be more vulnerable to earthquake damage if made of brittle and/or weak materials rather than flexible and/or strong ones. Factors such as low income, immobility, poor physical condition or lack of social support may make some people more vulnerable than others to the effects of a shock.

In many cases it is not possible to completely eliminate exposure, so we live with a level of residual, 'tolerable' risk (see section 6) and must be prepared for the possibility of a disruptive event. For example, many communities in New Zealand reside in earthquake-prone zones, and we try to anticipate the possibility of an event through building codes and disaster preparedness. The more prepared we are, the less vulnerable – and less negatively affected – we will be in the face of such shocks and stresses. However if we are not aware of the risks, we cannot prepare for them.

Resilience is in some ways the counter to vulnerability. It is defined as being shock-ready, and having the ability to resist, survive, adapt and/or even thrive in response to shocks and stresses. Resilience encompasses societal, economic, infrastructure and environmental components, as well as cultural capital, social capital, and governance. Individuals and communities who know how to limit their exposure to hazards or decrease their vulnerability and are prepared for a disruptive event will tend to be more resilient in the face of challenges. This requires knowledge of the hazards, and having the skills needed to anticipate and cope with the demands and changing circumstances they may encounter.

Resilience is not merely the ability to recover and start life ‘as normal’ following a shock. We live in a changing world in which adaptability is key, and this can provide another route to greater resilience. Adaptable communities and individuals are able to respond to a shock by moving to an improved state in which they can progress and prosper in the changed environment. They can use their own resources to build coping capacity for shocks and stresses, rather than focusing on their vulnerability and needs.

2. Risks we take vs risks we face

The way we think about and perceive risks affects the way we deal with them. There are *risks we take* (choosing an action in the view that the benefit outweighs possible harm), and there are *risks we face* (those we don’t choose but have to deal with). When *facing* risks we try to protect ourselves; when *taking* risks we look for advantage, but also need to prepare for possible failure – as does a prudent investor. These considerations operate both at an individual level and at a societal/national level. Individuals differ greatly in their risk-taking or risk aversion behaviour, as do different cultures and sectors of society. And the way scientists, actuaries, experts and regulators think about risk can differ significantly from how the public thinks, particularly in the way that human and societal values are taken into account.

2.1 Taking risks: voluntary action

For those risks that we take willingly (known as *voluntary risk*), we use our judgment to conclude that the benefits we stand to gain outweigh the likelihood or magnitude of possible harm from our exposure to the hazards (as in the surfing story described in Box 4). When we feel that we have personal choice and control, we can make what we consider to be informed and calculated decisions about taking risks, even in some cases where the evidence would clearly point to a different course of action (regarding smoking or the consumption of sugary foods, for instance).

Box 4

Surfing the unpredictable sea

Tane is a big-wave surfer, and takes any opportunity to get out into the waves. It is a dangerous pastime. It is unpredictable, like the sea. He likes the adrenalin rush that comes with confronting a fear of the unknown, and has learned to trust his abilities. There is always a risk that the next big wave will crush him, but he also knows that risk and opportunity go hand-in-hand. He might hesitate and miss a wave – caught by another surfer with a bigger appetite for the risk. Catching a wave is the risk payoff: the hard work, the wipeouts, and the pain are all worth it when he gets that perfect ride. The more waves he goes for, the more risk he takes, but the more perfect waves he will catch.

There are other risks too – should Tane worry about sharks? Despite the relatively high incidence of shark attacks in New Zealand waters compared with some other coastlines, the absolute risk is low. Fatal shark attacks occur in New Zealand at an approximate frequency of once every 13 years. The average person has little to fear from sharks.[i] Surfers like Tane, however, place themselves in the domain of sharks more frequently, because the biggest waves he wants to surf are on a coastline where great whites are frequently seen. Is it worth the risk? Tane thinks so.

Tane is among those who feel great pleasure in voluntary risk taking. He enjoys opportunities and the challenge of being out of his ‘comfort zone’, to push himself and conquer fear. His risk appetite is fundamentally associated with his emotions. Life for Tane is dull without risk – nothing ventured, nothing gained.

An appetite for taking voluntary risks is based in part on personality and in part on one's worldview. We have personal views on what is an acceptable level of risk for ourselves, which may be different from that of society as a whole. We also have different views about balancing costs and benefits that will affect us today versus those that will affect us later in life (think of our very different views about smoking or building up savings for retirement). As a society we make decisions that involve some uncertainty, and therefore risk, in order to advance and improve societal function and our quality of life, but as individuals we all have different ways of perceiving and estimating risk and thus we interpret the benefits and costs of those decisions differently. Indeed the implied cost-benefit analyses will often be different for a society as a whole and for us as individuals. This is one reason why politicians can make decisions on our behalf that we personally do not like.

2.2 Facing risks: involuntary exposure

We all face risks that are not of our choosing, and that may be outside of our control: these are referred to as *involuntary risks*. Some are associated with natural hazards and others are human-made. Some of these risks can be mitigated by preparation to reduce our exposure or vulnerability to their potential adverse effects. For natural hazards such as tsunamis, floods and earthquakes, we have warning systems and evacuation plans, and regulations around where homes can be built and the standards that must be met in order to reduce the impact of such events. However, some exposures cannot be avoided, and there are other risks that we have far less ability to mitigate. We may perceive these risks as being particularly high because we have less control over them, and the possible outcomes may be unwanted or unknown (see Box 5). Often when the issues are contentious, stakeholders with vested interests or those holding particularly strong opposing worldviews may promote confusing or misleading information that can further affect our own assessment of the risk.

3. Individual risks vs societal risks

The scenarios described above touch on how an individual's risk perception influences choices and behaviours. But the societal perspective on the same types of behaviours can be very different. An activity that is acceptable to us personally (for example smoking marijuana or breaking the speed limit) may not be acceptable for the whole population, or conversely, an activity or choice that the majority of people agree with (e.g. abortion rights), may not be agreeable to an individual who holds a particular opposing worldview.

Box 5

Involuntary exposures - Agricultural spray drift

New Zealand's horticultural sector has long relied on the use of pesticides and herbicides to control invasive pests and weeds that threaten to choke crops. Although biotechnological approaches (based on genetic approaches) are emerging, society has not deemed these acceptable in New Zealand. Farmers must choose among available options – typically the long-used agrichemical solutions – to produce the best crop yield in the most acceptable manner. It is a risk-based decision, and the farmer's choice to spray crops on his or her own land can have consequences beyond the farm gate. Droplets of spray can drift in the wind and end up in neighbouring properties, or even at significant distances from the target site, potentially exposing people and animals to harmful substances.

Affected neighbours may view their rights not to be exposed to pesticides as being overridden by the farmer's rights regarding how he chooses to use his land. The perception of risk by neighbours can be high, and exposed groups may attribute symptoms or diseases that they experience to the chemical sprays, *whether or not an association can be identified* by epidemiologists. Because the risk is involuntary, and they personally may see no benefit, they are unlikely to see eye-to-eye with the pesticide-using farmers, no matter how justified the farmers' arguments are in the decisions they have made to use them.

We often make risky choices that affect ourselves alone, but sometimes the risks we take affect others, and questions arise over personal interest versus the common good. In some situations we are prohibited from taking too great a risk, such as excess alcohol drinking, speeding or using handheld mobile phones while driving. This is because such personal risk taking can easily affect others or create problems and costs for society.

As a society we apply safeguards to reduce or mitigate risks where possible, and where it is deemed justifiable on a societal and fiscal basis. But even though we exercise precaution, we do not try to remove every risk we face. This is a complex judgment process for both local and central government and for individuals. It leads us to fence swimming pools to prevent accidental drownings but not to place shark nets on our beaches for the much rarer but equally tragic shark attacks. We mitigate the risk associated with road crossings by installing traffic lights and pedestrian signals at busy intersections, so that the chance of injury or death for any single road-crossing is low. But the more we expose ourselves to the hazard (and the more people who are exposed), the higher the risk; the more chance we have to be injured. Each individual's small risk adds up to a reasonably high risk over a lifetime, and high societal cost. Hundreds of millions of dollars per year are spent as a result of road crashes involving pedestrians ($405 million in 2014 [2]) in addition to the large but intangible emotional and social costs of these fatalities and injuries.

3.1 Collective decision-making

Our individual behavior patterns and responses are often very different in situations where we decide to do something compared to when someone else makes a decision that will affect us. But a characteristic of an organised democratic society is that decisions are constantly being made by others on our behalf. In a representative democracy, we hope that such decisions will reflect the best possible assessment of risk, cost and benefit, but an 'objective' analysis may not always align with public perception or opinion. Popular opinion and electoral consequences are likely to be a consideration in any government's assessment of and response to risk. No matter what the decision is, some people in the community will feel that they are being exposed to risks over which they have no control. This type of decision-making is necessary for a society to function, but will always generate some level of conflict. Even if we have a personal appetite for risk, we may oppose a risky decision that is taken for society's benefit, either because we are less in control of it, we have insufficient knowledge of the uncertainties, or we have differing values regarding the possible outcomes and our chances of personal benefit. In these situations, a *risk we take* as a society is perceived as a *risk we face* as an individual.

The fluoridation of water is an example. Where we have reticulated water, decisions are effectively made on our behalf by an authority as to whether to fluoridate it. Robust evidence from the public health and scientific community points to major beneficial effects of fluoridation of water that has a low natural fluoride content. But others reject this decision, citing a variety of objections – some of a philosophical nature and some because their reading or interpretation of the available data leads them to believe it creates an unacceptable risk. Governments take different approaches to handling this type of irreconcilable conflict, but increasingly realise that formal scientific assessment is important to assisting decision making in such situations.

In our daily lives we frequently make choices that have uncertain consequences. But in the face of uncertainty and conflicting values, how do societies make rational and responsible choices? How do we set our priorities? How do we determine the relative merits of outcomes? What value system should we use? These are important questions that constantly challenge those tasked with evaluating risks in order to make policy decisions on our behalf. In an effort to be as objective as possible, policymakers use the methodologies of scientific risk assessment as a starting point.

4. Calculating risk

On an individual basis, we tend to use 'rules of thumb' (sometimes called heuristics) in making risk judgments based on our familiarity with the risk, how easily the possible negative consequences come to mind, and how much control we have over them. The road-crossing scenario described in Box

1 illustrates how we make subconscious decisions about accepting risk in everyday life. Most people are unlikely to go through a conscious and complex decision-making process every time they cross a road. Rather, we each have general tendencies to make relatively safe or unsafe choices, supported or reinforced by our past experience, beliefs and attitudes. In the road-crossing situation, car speed and distance present an objective hazard. Our own judgment of them may or may not be accurate. We make predictions of the probable outcome that reflect our personal judgment or 'best guess' (sometimes called our 'subjective probability') of safety based on past experience, intuition, and opinion and not on mathematical calculations. Our judgment can change as our knowledge of the hazard increases.

In some situations, the risk (in the road crossing example, the risk of injury or death) can be estimated as an objective probability – a statistical calculation based on the frequency of observed events. On average more than ten pedestrians per week are injured on New Zealand roads, and in urban areas pedestrians make up over a quarter of all road fatalities. The vast majority (90%) of pedestrian fatalities occur when crossing a road (rather than walking on a footpath), and most occur when a pedestrian is jay-walking. When trying to cross away from controlled crossings, the pedestrian has to make more risk-based choices – where, when and how to cross – and the objective probability of harm is elevated, regardless of the individual's subjective analysis.

4.1 Quantitative risk assessment

Scientists generally think about risk in a more formal way, relying on apparently objective probabilities and impacts wherever possible. But they also make judgments that are unavoidably subjective to varying degrees, because scientific processes can at best provide estimates, rather than certainty, about possible outcomes.

Risk assessment is the process of evaluating the likelihood and consequence of a hazardous event. Quantitative risk assessment aims to describe, and where possible, quantify risk as accurately as possible using standardised processes that allow for comparison of different kinds of risks. It involves hazard identification and characterisation of possible consequences, a calculated estimation of the likelihood of occurrence of an event, and assessment of exposure and vulnerability that influence the potential extent and magnitude of an event's impact. This leads to an assignment of a score that represents the seriousness (and therefore the tolerability or otherwise) of the risks.

The basic questions posed in a risk assessment process address the main components of the risk equation:

- Hazard identification: What could cause harm?
- Risk characterisation: What could go wrong?
- Likelihood/probability estimation: How likely is it to happen?
- Consequence analysis: How bad will it be? What levels of vulnerability and resilience exist?

On a national level, risk assessments are often undertaken to identify and evaluate significant risks, not only to improve our awareness and anticipation of the risks, but also to provide policymakers with information to choose risk management activities and resources (e.g. investments in monitoring or structural measures to minimise risk or reduce exposure). This type of analysis focuses the risk debate on technical factors, so as to decide on risk issues as 'rationally' as possible, and to identify a level of 'acceptable' risk (see section 6).

4.1.1 Identifying hazards and risks

Some of the risks we face are obvious; for example, living near natural hazards (e.g. on a major fault line, on an unstable cliff, or close to an active volcano) or when our work or leisure involves dangerous activities. We may know that these hazards exist, but if we have not experienced shocks associated with them, we may underestimate or consciously downplay the danger. Scientific study can tell us about the nature and extent of the potential risk, and natural hazard monitoring can identify changes that may signal impending harm, bringing the risk to our attention. For example, science warns of an increasing frequency and intensity of weather-associated natural disasters in the Asia-Pacific region over the next several decades due to climate change, and the factors exacerbating them, including poor urban planning and increased urbanization and poor land management. [3]

Other risks are essentially undetectable without scientific investigation, particularly those with potential impacts that are not clearly tied to their point of origin (e.g. solar flare, radiation and some chemical exposures), or for which there is a long time between exposure and effect (e.g. excessive sun-tanning and exposure to asbestos both increase the risk of developing cancer some decades later). Still other risks, like those relating to new technologies or problems specific to our modern world, require forward thinking to imagine possible scenarios for which history has no record.

(for example the risk of a flood damaging your property may depend on the combined effect of the weather, the state of flood banks and on decisions made by a dam manager upstream, and whether you have heeded forecasts and sandbagged your property or not).

The work of identifying and labelling something as a hazard can be a matter of judgment, though scientific methods can provide guidance for many categories of risk. However it is not simply based on mathematical assessments, but a process that involves human values. Despite the intended objectivity of statistical risk calculations, they can still be contested because judgement and values are inevitably involved in the underlying estimates (see Box 6).

Box 6

Mapping coastal hazards zones

New Zealanders have always had strong emotional, spiritual, cultural, economic, and professional connections to the coast. But whether or not we have recognised it, our coastline has always been under a degree of threat. Early coastal settlements were located too close to the sea to allow for natural environmental changes such as erosion and coastal inundation that result from severe weather, tsunamis, and extreme tidal events. Human activity has also changed the coastal dynamics along much of the New Zealand seashore. [4] Climate change and rising sea levels have added a significant dimension to the risk. Recently, efforts have been made to reduce the risk of natural disasters and erosion by scientific evaluation and mapping coastal hazard zones. [5] But designating safety margins and setting restrictions on development has met opposition from homeowners and local communities, who view the exercise as potentially decreasing their property values. The question becomes one of safety and sustainability versus the values of private property and the protection of individual and community interests.

Faced with a receding coastline, the options are to intervene and 'protect' the coast, accept or adapt to the changes, or manage a community retreat from the hazard zones. When assets are threatened (e.g. private property, popular beaches, community assets) the community demands action from local government to defend their interests, such as building sea walls or reinstating sand on beaches - a 'hold the line,' protection-based approach. But there is still a matter of risk, cost and benefit: Who will benefit by building structures to protect coastal properties? The property owners themselves will, but beachgoers will gradually sea their natural beach eroded even more quickly because of the seawall. And why should other ratepayers pay when they will get no obvious benefit?

The mapped hazard zones will thus become contested between individual and broader interests. The question becomes whether the value of the defended infrastructure or property outweighs the cost of its defence. Either way, it is a matter of values, and they are likely to be in conflict.

There are many different types of potential risks (e.g. health-related, social, economic, reputational, environmental) to which internal and external factors both contribute, and variability in either can affect their likelihood and consequence

4.1.2 Likelihood estimations

Once hazards have been defined, risk assessment involves an evaluation of the likelihood (probability) of the hazard event occurring, and of their potential impact (the severity of consequences to life and health, property and infrastructure, and the environment). Interpreted in the statistical sense, probability measures the relative frequency of an event, usually assessed from historical data, to produce an estimate of the underlying likelihood. Where historical data are unavailable or incomplete, scenarios, judgment, models and/or simulations are often used to produce an estimate of likelihood. Qualitative expert judgment is applied using a standardised terminology for communicating likelihoods, ranging from 'rare' (or 'exceptionally unlikely') to 'almost certain' (or 'virtually certain'). In formal risk analyses these become defined terms relating to the predicted frequency of occurrence or calculated probability. Probability translation tables such as those shown in the Appendix provide a link between numerical probabilities and verbal descriptors of those probabilities. The translation of numerical probability ranges to qualitative terms is meant to reflect most people's perception of what the terms mean (see Appendix Tables A1, A2, A3).[**]

4.1.3 Impact/consequence analysis

The other part of the risk equation is the assessment of the impact or consequences resulting from a shock. Consequences can be expressed in terms of economic, environmental, or social criteria, and are assessed on an impact scale from insignificant through to extreme. In some cases the impact can be estimated quantitatively by event modeling or using past data, measured in, for example, numbers of fatalities/injuries, monetary cost, or extent of area affected. Other situations require qualitative descriptors corresponding to levels of impact on other types of assets (e.g. emotional costs, cultural costs, reputational damage etc). The formal impact criteria definitions are also outlined in the Appendix (Table A4).

An overall risk score can then be derived as an estimate of relative risk by combining the predicted severity of the consequences of a hazard event with an estimate of its likelihood. In making this calculation it is necessary to consider the multiple possible consequences and varying degrees of severity of each.

[**] These terms correspond to numerical scores for input into the 'risk = likelihood × consequence' equation.

4.2 Acknowledging uncertainty

Where there is sufficient experience with a particular hazard to estimate probabilities, a quantitative approach to risk assessment is the commonly accepted way to deal with the situation. Such quantitative assessments are very useful, but they can also suggest a level of accuracy that can be misleading. [6] The problem is that providing numerical estimates conveys a level of precision, while the concept of risk itself necessarily implies inherent uncertainty. Further, the language used can also mislead if not carefully applied. Words such as 'negligible' and 'unlikely' have connotations in everyday language that can be interpreted variably, so these need to be used carefully when attempting to convey objective scientific criteria. Although the discussion above (and in the Appendix) shows how these terms can be related to numeric consequence and likelihood scores, these meanings and uncertainties need to be addressed as explicitly as possible in risk communication.

The quantification of risk may be based on available data or calculated via a model, both of which may contain uncertainties, inaccuracies, and limitations that must be acknowledged and reduced as much as possible. The amount of uncertainty regarding a specific risk varies depending on the type of hazard, and on our historical knowledge of its frequency of occurrence and potential impact. This may depend on the quality of the available scientific evidence, and estimates may change as greater knowledge emerges. The likelihood of some events can be estimated in advance based on the observation of trends, while others, including very rare but severe disasters are only minimally predictable. 'Black swan' events (see Box 7) are by nature improbable and incalculable – but consequences may be so severe that they eclipse more probable events – and if ignored, it may be at our peril.

Box 7

Black Swans

Black swans are a common sight on New Zealand lakes, but at one time Europeans did not think they existed. In 1697, the surprising discovery by Dutch explorers of large numbers of black swans in Western Australia defied previous assumptions (derived from a distinctly Northern Hemisphere perspective) that all swans were white. The term “Black Swan event” thus refers to an event or phenomenon that is unprecedented or unexpected in human history at the time it occurs. It is something that we don’t see coming, because nothing in our past experience suggests the possibility of its occurrence.

“Black Swan Theory” was introduced by Nassim Nicholas Taleb in his 2007 book ‘The Black Swan’, [8] about rare but high-impact events. Such a catastrophic event is unpredictable because there is no previous historical record to go by. Like a million-to-one chance, it may be thought of as impossible, but it can happen – and when it does, we may be very unprepared. The September 11th, 2001 terrorist attacks in the US fit the bill. Many see the global financial crisis of 2008 as a Black Swan event.

As for risks associated with new technologies, we have little or no experience of the possible outcomes, and need forward-looking approaches that consider plausible future developments (simulations, probabilistic calculations, projections, and scenarios). The uncertainties may be numerous and extensive, but scientific methods can help reduce them. Innovation is simply not possible without accepting some degree of uncertainty – if no risks are accepted or if there is excessive precaution, then no innovation can occur. [7]

There are always uncertainties surrounding formal risk estimates. In the real world, probability data can be ambiguous and/or incomplete, affecting the reliability of the risk information. Statistical logic is not the whole story – some subjectivity in assigning probabilities is unavoidable. Because of this, indications of the degree of confidence in the estimate are important (see section 4.2.4 – Confidence measures).

4.2.1 Complex risks and uncertainty

The discussion thus far has focused on identifying and comparing individual risks, so that they can be prioritised for management. But we are becoming increasingly aware that there can be unprecedented consequences of single events, relating to the interconnectedness of systems. A black swan event is one that cannot be predicted (see Box 7). Such events may have a singular cause (for example an asteroid impact), but more often the seemingly unimaginable occurs because a less severe initial event triggers an unforeseen cascade of failures that leads to crisis.

Catastrophic events often arise from interconnected risk factors rather than from a single cause. Each risk factor alone might not provoke major disaster but in combination they can become critical. This compounding of factors is often seen in major transport disasters such as plane crashes. The 2011 Fukushima disaster in Japan exemplifies the concept of complex risk factors and cascading impacts (see Box 8)

Events such as Fukushima and even the Christchurch earthquakes have highlighted the need to go beyond linear approaches to risk management. Preparing for and building resilience to known disaster risks may overlook harder to predict, cascading effects. They can result from hidden interdependencies in the complex systems that connect lifeline utilities, communications, and community and government activities. For example, a simple transformer failure can lead to a power failure, which causes an air traffic problem when a backup system fails. Failure of a part of the system can thus escalate into catastrophic, multi-system failure. This added uncertainty affects the processes, policies, and plans that form the framework of preparedness and response. The potential for cascading impacts is inherently difficult to deal with, and scientific claims in these situations need to acknowledge that we cannot know all possible consequences – predictions can be erroneous or incomplete.

can be reduced, but not eliminated, by further

Box 8

The East Japan disaster

On the 11th of March 2011, the unthinkable happened. Despite the hazard and associated risks being known about, a magnitude 9.0 earthquake struck off the east coast of Japan, leading to a cascade of complex problems that shook the nation to its core and reverberated around the world.

The submarine earthquake triggered a massive tsunami that completely wiped out coastal communities – despite well-developed coastal defenses – claiming the lives of more than 15,000 people. The forceful seismic tremors also damaged structures and transmission lines, cutting off power, and the tsunami flooded and destroyed emergency power generators at the nearby Fukushima Daiichi Nuclear Power station. This power failure extinguished the cooling capacity of the reactors and the overheating caused widespread radioactive fallout. The radiation threat compounded the uncertainty of the already chaotic situation and amplified public anxiety, increasing the climate of fear.

The official report of the Fukushima Nuclear Accident Independent Investigation Commission [9] concluded that the nuclear disaster, though triggered by natural events, was manmade and could have been avoided – that it was a consequence of negligence, cultural issues, and flawed policies. Up to that point, Japan had relied heavily on its nuclear industry, which produced nearly one third of the nation's power. In fact the industry had been viewed as a mark of technological progress and a source of national pride.

The reaction to the accident was to shut down all nuclear power plants to conduct 'stress tests', and the country was forced to rely on imported fossil fuels – at high cost both financially and in terms of increased greenhouse gas emissions. One reactor in Sendai was reopened in August 2015 despite widespread public anxiety. All said and done, having been assured that a nuclear accident couldn't happen it had, and public confidence was profoundly shaken.

Although a number of countries including the United States, France, the United Kingdom, China, India and South Korea have continued to pursue nuclear power, the events at Fukushima lead to rapid decisions in Germany and Switzerland to phase it out, and public opposition in Italy quashed plans to build new nuclear power plants to generate a quarter of the nation's electricity. Such choices leave these countries with substantial challenges in providing affordable power and in meeting their carbon emissions reduction goals. The risks, and the choices that different countries make, are indeed complex.

study. Even so, science can play an important role in establishing the level of preparedness that is needed by using probability estimates to deal with these uncertainties.

4.2.2 Not all uncertainty is created equal

Some things we don't know

Uncertainty is inherent in risk assessments. There will often be incomplete or insufficient scientific understanding of the hazard and risk scenarios – in other words, situations where we *don't know* the most likely outcome – this is also known as *epistemic uncertainty*. [10] This can include uncertainty about the probability, consequences, and/or magnitude of a hazard event; data uncertainty due to limitations in the accuracy and precision of measurement; or insufficient historical data for calculating probabilities. This type of uncertainty

Uncertainty does not become an excuse for inaction. We can view climate change in this context. While anthropogenic climate change is clearly upon us, the rate of rise in sea levels and in global temperatures, and the impacts on local climate are still highly uncertain. The climate system is inherently complex and a wide variety of factors, each with their own uncertainties, have to be considered. Some factors (e.g. the effects of clouds) are less understood than others (e.g. the rise in atmospheric carbon dioxide). Further there is no clarity as to how effective global mitigation efforts will be. But this does not mean that there is not a scientific consensus about the risks ahead, and policy makers around the world are responding accordingly.

Some things we can't know

Another type of uncertainty is *statistical* (or objective) uncertainty, which arises out of the natural variability of the hazard, or the differing inherent sensitivities (vulnerabilities) to the hazard within the population. For example, there is an inherent randomness in volcanic activity, and multiple factors influence when a period of unrest will result in eruption, making prediction of future events subject to considerable statistical uncertainty. Similarly, the movement of tectonic plates is not regular, and while scientists can measure the strain in the rock, they can only forecast general probabilities with regard to earthquake prediction. Because the uncertainty is intrinsic to the hazard, it may not be reduced simply by further study; rather it can only be represented by a statistical range of possible values.

Regarding sensitivities (vulnerabilities), effects of different levels of exposure to a chemical or a medicine, for example, can be estimated based on average responses within a population, but there will be inter-individual variations that mean the probable effect must be expressed as a range, and there may be outliers who are very sensitive to lower exposures, or rather insensitive to higher ones. This type of unavoidable unpredictability means that we *can't know* the outcome with complete certainty. [10]

4.2.3 At risk of being wrong: Probabilistic uncertainty and types of error

Because complete certainty is unattainable in scientific risk assessment, it will always carry some possibility of error. When basing decisions on outcomes of statistical risk calculations, we need to be aware of two possible and distinct types of error – false positives and false negatives.

In medical testing, a false positive error occurs when a test erroneously indicates the presence of a disease or condition when none exists – this is also called a 'false alarm'. A false negative is the opposite – the test erroneously indicates the absence of a disease when one actually exists. Most medical diagnostics have, by their very nature, both false negative and false positive rates and both doctors and their patients need to understand these when tests are interpreted. Indeed this is one reason why it is often important to repeat a test, as technical issues can be one reason for a false result in either direction.[††]

In risk evaluations, false-positive associations convey the impression that the risk is higher than it actually is, which tends to promote unduly cautious behavior. In informing policy, therefore, false positives lead to erroneous action to avoid risk, and this is not without consequences. In health screening programmes, a high false-positive error rate can be costly if it results in unnecessary preventive interventions when no disease would have developed, and in some cases this may actually cause harm (see Box 9). On the other hand, a high false-negative rate can greatly diminish the diagnostic value of the test and can lead to serious disease being missed.

False positive errors in risk assessment can lead to over-cautious behaviour that prevents the benefits that might flow from taking a risk (e.g. leading to overly stringent regulation or prohibition of an activity or technology that might otherwise be very beneficial). In short, the complexities of such situations can end up in the development of policies that are not necessary, based on the size of the risk.

False negatives, on the other hand, can lead to erroneous inaction, or the failure to implement a policy that would reduce the consequences or ensure avoidance of a real risk. They convey that risk is low when it is not; for example, when early warnings of a technical issue are treated as false alarms rather than signals of impending danger (see Box 10).

The traditional methods of scientific inquiry are focused more on avoiding false positive error than on avoiding false negative error, because accepting a false positive result is equivalent to accepting a false scientific hypothesis. This asymmetrical and

[††] In terms of formal statistical approaches, these errors can be thought of as acceptance of a false hypothesis (in the case of a false positive error) or rejection of a true hypothesis (a false negative).

Box 9

The impact of false positives

A goal of much modern public health is to shift the focus from treatment of established disease towards prevention, early detection, and modification of risk factors. Part of this effort involves programmes that screen asymptomatic people to assess the probability that they have sub-clinical disease rather than waiting for appearance of disease symptoms, when it may be too late for effective treatment. Demonstration that early detection can be beneficial for some diseases has given rise to the expectation that this should be done for others. However, screening comes with costs, and risks.

With the introduction of screening programmes for prostate cancer using the Prostate-Specific Antigen (PSA) test, medicine has moved from late diagnosis – where the disease was not recognised until it had progressed to an advanced and aggressive state – to over-diagnosis, and over-treatment of disease that in many cases is inconsequential. This is because prostate cancer is complex; in some cases it is very aggressive and in others it is effectively benign, and both forms can give positive PSA test results. This effectively means that the test generates a high rate of false-positive results (suggesting severe disease when none exists). Among 1000 men screened for PSA, only 1 would avoid a premature death due to prostate cancer because of the screening, and 5 would experience a serious complication from the surgical procedures that might follow from a false-positive test. Overstating the insights gained, and thus the health benefits of a particular test, is a risk not to be taken lightly. Efforts to find better screening tests or to redefine how to use the PSA test are therefore ongoing.

conservative academic approach does not always fit with real-world risk decisions for which there can be consequences both for taking unnecessary action or for taking no action. [11] Because statistical tests by their very nature are designed to minimize one or another type of error (and not both), the choice of test used is influenced by subjective judgment of which type of error is less costly in terms of potential harm. In other words, risk evaluators must choose the option for which the risk of being wrong (signaling incorrect action or incorrect inaction) is the least damaging.

4.2.4 Confidence measures

There are various points at which uncertainty enters into risk calculations and where expert judgment must be used. A single numerical score derived through traditional methods of risk assessment does not optimally convey the reliability status of the overall risk estimation, which can lead to flawed decision-making. [6, 12] Establishing a standardised qualitative scale of confidence levels – from very low to very high confidence – is a useful way of demonstrating how reliable the likelihood and consequence data are, and conveying how much uncertainty surrounds a particular risk assessment (see Appendix, table A5).

Communicating uncertainty and levels of confidence in risk assessment is important, though it highlights the extent to which judgments must inevitably be made, even by experts, when calculating risk levels. It is easy to see how acknowledging the presence of uncertainty and subjective values can create skepticism and make the use of risk assessment particularly challenging in the policy context, where unlike in science, there may be less comfort with the realities of uncertainty. [13]

We have seen elements of this globally in the 'debate' around climate change. Because of different worldviews and perceptions of cost and benefit, some stakeholders have manufactured an even greater sense of uncertainty by exploiting and inflating ambiguities in data and downplaying consistent trends that lead to a widespread and strong scientific consensus.

Nevertheless, though the methods of science are designed to limit the influence of personal values,

Box 10

False negative errors – unheeded warnings

In 2004, the U.S. automobile company General Motors (GM) released the Chevrolet Cobalt - a relatively low-budget car that was produced on slim margins. Even before its release - as early as 2002 - it was recognised that the ignition switch in the Cobalt was problematic, occasionally being jostled out of the 'run' position, causing the engine to shut off while the car was being driven. By 2004 the company had received many reports of engines stalling while the car was moving, but GM engineers considered it more of an inconvenience to customers than a matter of safety, and the circumstances under which it would occur were perceived to be rare. They had failed to realise that if the switch was not in the 'run' position, the airbags would also be disabled, leaving the driver with no airbag protection in the event of a crash.

This diagnostic error was recognised in 2007 by outside investigators, who identified a clear link between ignition switch failure and airbag non-deployment. This should have been considered a real risk by the car manufacturer, and earlier complacency should have been acknowledged for what it was – a false-negative error.

Cost considerations at GM slowed efforts to correct the problem. It was not until 2014, after at least 54 accidents and 13 deaths had occurred, that a vehicle recall was issued. Had the risk been fully appreciated and attention been paid to the faulty ignition switches early on, the costs to repair it would have been insignificant compared with those that were ultimately incurred from the recall and compensation, not to mention the human costs incurred and reputational damage to the company. [14]

it is clear that judgments still need to be made. For both scientists and policy makers, judgment is needed when deciding whether there is enough appropriate evidence on which to base an assessment, while considering the possible impacts of being wrong. [15]

A key background principle is that science by its very nature can absolutely disprove many things but in general, science is not able to absolutely prove most things. The processes of science are designed on this basis. The finding of a black swan disproved the conclusion of the 17th century European that all swans were white. There was then and still is no way to design an experiment to prove that all swans are black or white – the potential for there to be swans of other colours cannot be formally excluded unless you could be certain *every* swan on the planet had been sighted. Similarly, a drug can be proved to be unsafe but no drug can ever be proved to be totally safe. There must always be the possibility of a very rare side effect – one that could conceivably affect only one individual on the planet. At some point the weight of evidence can be judged sufficient to allow a conclusion to be made - on drug safety, on swan colours, or another issue under scientific scrutiny. The expression of confidence in that conclusion will depend on just how weighty the evidence is.

5. Translating science to communicate risk

Risk communication is an exchange of information aimed at equipping people to act appropriately in response to an identified risk. It should encompass the probability of the risk occurring, the importance of the adverse event being described, and the effect of the event on the individual or society. Ineffective risk communication can lead to either underestimating or overestimating risks.

Good risk communication provides a balanced evidence-based summary of risks and harms, but in reality there is no value-free way of framing a risk issue. As this series of papers highlights, actuarial risk assessment and public risk perception are not always aligned on the level of risk associated with a specific hazard. This can generate controversy if risk communication and management decisions do not take public concerns into account. The elements of good risk communication will be expanded upon in the third paper in this series.

5.1 Conveying technical information

For risks to be properly understood, statistical and scientific knowledge needs to be put in context and translated into a common language that is readily grasped by a non-technical audience. The scales described above (sections 4.1.2, 4.1.3 and 4.2.4) and detailed in the Appendix apply qualitative descriptors to levels of risk in terms of likelihood, consequence, and confidence in the data. Such scales are used not only in risk assessments but are also often applied in risk communication. The scales and descriptors are not meant to instruct people and organisations on how to react to risk, but to provide information for them to make their own decisions.

Care must be taken in how risks are framed and probabilities presented. For example, stating that a certain level of exposure to a substance results in a doubling of the risk of developing a disease sounds on its surface like a cause for serious concern. But if the absolute risk of the disease is extremely small, the increase resulting from the exposure will be insignificant. The media often ignores this basic fact. If the baseline risk of developing a rare cancer is 1 in a million, and a chemical exposure increases that risk to 1 in 500,000, it is less informative to talk about a doubling of risk than to point out that the risk remains minimal. On the other hand if the baseline risk was 1 in a 100 and chemical exposure increased the risk to 1 in 10, clearly there are grounds for banning the chemical. The point is it is always important to use absolute numbers and to focus on degrees of safety rather than to characterise exposures as safe or dangerous – risk is not black and white. We recognise that most activities and decisions involve some risk, however small it may be, and that individuals and societies must decide how much risk they are willing to tolerate.

5.2 Statistical misunderstandings

There are numerous ways in which probability information can be misinterpreted. The numerical format used for expressing a risk likelihood influences how the brain processes the information, and thus can affect a person's understanding of the magnitude of the risk in question. [16, 17] For example, people often believe that the chance of something happening is higher if it is expressed as an absolute number (e.g. 10 times out of 100; known as a 'frequency format') than if it is expressed as a percentage (10% chance - a 'probability format') even those these are exactly the same. However, frequency formats can result in errors in risk comparisons because of a tendency to think about the numerator of the equation (e.g. the 10 in the '10 times out of 100') as the absolute number of people affected. This can lead, for example, to perceiving a frequency of 4 in 100 as being higher than 1 in 20 when of course it is lower. [18] However, some may question the reliability of data if a low denominator is used, erroneously believing that it is representative of a small sample size. [16]

Similarly, the framing of a probability can affect how its magnitude is interpreted, and therefore the choices made. For example, being told there is a "70% chance of success" (a positive framing) will often provoke a different action to hearing there is a "30% chance of failure" (negative framing).

These errors in interpretation of numerical data reflect unconscious biases in our perceptions that occur when we think and react quickly to a situation or risk. In general, people judge probabilities by their plausibility, which is biased by or whether or not they can envisage the outcome. Our thinking tends to be biased towards perceiving a risk is high if the outcome is plausible to us, and conversely we tend to perceive risks as low if we find them hard to imagine. With frequency formats expressing absolute numbers (e.g. 1 in 10), people are sometimes prone to 'optimistic bias' ("it can't happen to me"), attributing risk to others and considering themselves more likely to be among the unaffected group. Biases affecting risk perception will be discussed in further detail in the next paper of this series.

6. Deciding when risk is 'acceptable'

Risk is part of our everyday lives; some risks we want to take, some we tolerate and some we do our best to avoid. How do we decide which risks are acceptable? Our views on the acceptability of risk depend on how much we value what is at stake.

For *voluntary* risks – those that we undertake by choice (e.g. driving a car, flying in an airplane, surfing, motorcycle riding, alpine skiing, rock climbing, eating certain foods etc) - we use our own judgments to decide if the risk is acceptable by considering whether we value the reward (benefit) enough to take on the risk of harm (see Box 4).

If a risk is *involuntary*, people tend to expect a much higher perceived benefit for the risk to be deemed acceptable. One way to consider the acceptability of risk is to use cost-benefit analysis to assign monetary value to the possible consequences,[‡‡] but clearly we cannot assign monetary values to all types of costs and outcomes, or put a numerical value on all the potential positive and negative consequences of taking a risk.

When dealing with hazards, the goal is to reduce the magnitude of impact and the likelihood of events occurring, to lower the risk to an acceptable level. We do not attempt to remove all hazards from daily life; to enjoy benefits (for example, of living in a beautiful setting that might also be prone to natural hazards, or using X-rays for medical imaging, or exposing ourselves to X-Rays as when we take a long distance flight) we must live with them and do what we can to lower the risk. It is impossible to reduce risk to zero - we must decide on a level that we can tolerate in order to guide our risk-taking decisions.

A common aim is to reduce risk to levels that are 'as low as reasonably practicable' (ALARP). The ALARP principle is essentially a trade-off (or 'balancing act') between the cost associated with the potential consequences of a risk and the cost of mitigating against them. It aims to reduce risks as far as possible "without cost expenditure that is disproportionate to the benefit gained, or where the solution is impractical to implement." [19] This approach is meant to ensure that mitigation activities are apportioned according to the level of risk. From this perspective, a risk would be considered acceptable if the cost of reducing it would far exceed the costs saved (or the benefits gained) by doing so. The ALARP principle is often used by regulators and policymakers to decide on acceptable risk levels, but can also be viewed from an individual perspective. The 'cost' of risk reduction is generally broader than its monetary value – it could be the expense of effort, relative priority, or a compromise to personal values, freedoms, or other factors (see Box 11).

Regardless of how risks and acceptability criteria are calibrated, it is clear that what constitutes an acceptable risk varies between individuals and across communities and different sectors of society and across societies. This makes it difficult to aggregate risk preferences and assign levels of risk that are unanimously acceptable for policy decisions. The concept of acceptable risk is also dynamic - opinions do and should change in response to new challenges and evolving knowledge. The perceived risk of flying in a plane in 1915 was very different to that of getting on a plane in 2016. Perception and actions also change in response to experiencing hazardous events – for example if you have had a relative or friend who was in plane crash.

Yet for all the difficulties, we still need to make decisions and find ways to establish trust in the risk assessment processes. For particularly contested issues such as adopting some new technologies, it is necessary to understand what makes individuals and groups view risks differently in the first place. This is essential if there is to be progress towards a convergence of views that will allow advances to be made for the benefit of society as a whole. This emphasises the need for risk communication as a multi-way exchange of information, knowledge, and values that helps individuals and communities to identify, prepare and respond to uncertain outcomes from the hazards and risks we face in our lives.

[‡‡] An influential 1969 study on societal benefit and technological risk [19] claimed that the acceptability of an involuntary risk requires about 1,000 times the economic benefit associated with a voluntary risk

Box 11

Risk reduction - how far can you go?

As Low as Reasonably Practicable (ALARP)

There is no such thing as zero risk. But the inevitability of risk in our lives does not mean that nothing can be done. When hazards are identified and their associated risks are known, it makes sense to do what we can to reduce the possible negative impacts.

Emily bought a house in what she believed was a relatively safe neighbourhood. There was an alarm system in the house but she had never used it because the previous owner did not leave her the alarm code and she assumed that it was not in working order. Although Emily always locked the doors when she left the house, she didn't think much about the possibility of a burglary… until it happened to her.

Fortunately Emily had homeowner's insurance, for which she paid a higher premium because her house was not protected by an alarm. The insurance company paid to replace her computer and other items, but that didn't take away Emily's worry and apprehension - she was aware now that this could happen again.

What should she do to reduce her risk? For a start, she decided it was time to get the alarm fixed. She no longer left the downstairs windows cracked open using the 'safety' catches, because it was clear that these could be jimmied open, as that is how the burglars had gained entry to her house. She was more careful about not leaving valuable items easily visible through the windows.

Should she have gone further? She could install bars on her windows and extra locks on her doors. Perhaps she could erect a high fence that would be difficult to climb. She could pay for security service to monitor her home when she is away. These measures would be costly, not just in terms of monetary expense, but would affect the aesthetics of her property and make her feel somewhat imprisoned in her own home. Although she has not reduced her risk to zero, in Emily's view, the risk reduction measures she has already undertaken have reduced the risk to 'as low as reasonably practicable' for her.

7. Precaution and decision-making in the policy setting

Policymakers must frequently make decisions about accepting risk, managing it, or avoiding it, and often without the luxury of waiting for all of the answers, even if they were attainable. Furthermore, their frame of reference includes additional factors in their consideration of the multiple dimensions and impacts of any decision. Politicians will inevitably consider that some decisions they make involve tradeoffs between different sectoral interests and thus can have electoral consequences. For them risk in the ballot box is real – it is the driving force of democracy. Yet under a democratic system they are accountable for balancing many different objectives, including economic growth, human health, social values and environmental protection. These issues of complex decision making will be discussed further in the third paper in this series.

We can sometimes reliably identify possible outcomes and likelihood from quantitative risk assessment (section 4.1), but as we have discussed, there is often uncertainty around levels of impact, and/or the assignment of probabilities. This is particular true for complex environmental risks, or those posed by new technologies for which experience is insufficient for us to be very confident about possible future effects or scenarios. In such cases the issue of what level of precaution is desirable in decision-making becomes relevant.

The *Precautionary Principle* arose as a policy guideline to deal with uncertainty in environmental risk assessment and decision-making. In general, the principle provides guidance in responding to uncertainty, allowing action to be taken to avert risk of irreversible harm to environment or health in absence of scientific certainty about the risk. It is meant to be a form of *active* management of uncertainty, such that appropriate measures might be put in place until greater knowledge allows these to be tightened or loosened. But it has also been misused to prevent some activities (including the use of new technologies) until absolute safety of the activities can be proven, which is actually and scientifically impossible. Here the call for implementation of the Precautionary Principle can reflect a distrust in the ability of regulators to apply the ALARP principle to reduce risks.

While in many cases it is logical and reasonable to apply action to anticipate and avert harm in advance or without clear demonstration that the action is necessary, making an automatic link between any possible and remote (but uncertain) source of harm and specific management responses (e.g. totally banning an activity or new technology) is not always justified on precautionary grounds. Shifting the balance towards prudent and informed foresight is, however, a rational goal.

Several versions of the Precautionary Principle have been promoted, varying from weak recommendations enabling or authorising action, to strongly worded doctrine demanding no action until there is absolute certainty of outcome (which is impossible). Among these there is wide latitude for its interpretation. [20] This issue will be elaborated further in Part 2 and Part 3 in this series, which deepen the discussion about how policy decisions can be made when the choice is between strategies that each carry risks, and how we think about trading off competing values when science can't provide all the answers.

8. Conclusion

The concepts of risk and uncertainty can be defined and understood in both technical and non-technical terms. No matter how they are described, their meanings resonate differently depending on the background, experience, culture and values of the individual or group. Likewise, scientific methods can be applied to the assessment of specific hazards and risks, but their 'acceptability' will be weighed on more than scientific evidence alone. These factors must be considered when decisions are made to manage risks and accept new opportunities. Parts 2 and 3 of this series will delve further into these concepts and what they mean for New Zealand.

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Appendix: Formal risk analysis

Risk assessment entails the combinatorial analysis of the likelihood (*probability*) of the occurrence of a hazard event, and of the potential impact (the severity of *consequences*) on exposed assets.To convey the probability of an event, standardised qualitative terminology is used to relate a numeric likelihood range to a qualitative classification term. Different risk analyses may use different categories, as shown in tables A1 and A2 but all analyses must include their definition of terms used. The qualitative terminology used to describe levels of impact (severity) is shown in table A4.

Likelihood terminology

Table A1. Classification of likelihood (as used by New Zealand Government for risk assessment). Classifications are based on Public Safety Canada's *All hazards risk assessment: Methodology guidelines 2012-2013* [21]

Classification	**Likelihood**
Rare	May occur only in exceptional circumstances; Once every 1000 or more years.
Unlikely	Is not expected to occur; and/or no recorded incidents or anecdotal evidence; and/or very few incidents in comparable organisations worldwide; and/or little opportunity, reason or means to occur. May occur once every 100-1000 years.
Possible	May occur at some time; few, infrequent, random recorded incidents or little anecdotal evidence; some incidents in associated or comparable organisations worldwide; some opportunity, reason or means to occur; may occur once per 10-50 years.
Likely	Likely to or may occur; regular recorded incidents and strong anecdotal evidence and will probably occur once per 1-9 years.
Almost certain	Very likely to occur. Based on high level of recorded incidents and/or strong anecdotal evidence. Will probably occur annually.

Another example of a qualitative scale used to convey probabilistically-quantified likelihoods is that of the Intergovernmental Panel on Climate Change (IPCC), [21] which ranks probability from "exceptionally unlikely" (0-1% probability) to virtually certain (99-100% probability), as shown in table A2. In their reports, the IPCC clearly distinguishes these qualitative descriptors of *likelihood* (frequentist probability) from descriptors indicating the *level of confidence* in the information (the degree of understanding/consensus among experts; see table A5).

Table A2. Standard terms used to define likelihood in the IPCC Fifth Assessment Report. [21]

Term	Likelihood of outcome
Virtually certain	>99% probability
Extremely likely	>95% probability
Very likely	>90% probability
Likely	>66% probability
More likely than not	>50% probability
About as likely as not	33 to 66% probability
Unlikely	<33% probability
Extremely unlikely	<5% probability
Exceptionally unlikely	<1% probability

Since September 2015, GeoNet and GNS Science have introduced a probability table similar to that of the IPCC,

Table A3. GeoNet Probability Translation Table, v. 2.0, used from 1 September 2015. [22]

Verbal likelihood term	Probability of outcome
Extremely likely	Greater than 99%
Very likely	80% to 99%
Likely	60% to 80%
About as likely as not	40% to 60%
Unlikely	15% to 40%
Very unlikely	1% to 15%
Extremely unlikely	Less than 1%

Consequence terminology

Table A4. Classification of impact (as used in New Zealand government for risk assessment). Classifications are based on Public Safety Canada's *All hazards risk assessment: Methodology guidelines 2012-2013* [21]

Classification	Impact
Insignificant	No impact or some local, general response required, but no specialised response. No injuries, little damage, low financial
Minor	Some local, specialised response, and surveillance and monitoring from regional authorities. First aid treatment, minor building damage.
Moderate	Significant local, specialised response, and multi-regional general response, and notification from national authorities. Medical treatment, moderate building damage
Major	Multi-functional, multi-regional specialised response and mobilisation from national authorities and notification from international authorities. Extensive injuries, high level of building/infrastructure damage
Extreme	Multi-functional, national and international, specialised response. Deaths, large-scale structural damage and infrastructure failure

Confidence measures

Table A5. IPCC rating levels used to indicate the degree of confidence (reflecting the degree of understanding/consensus among experts) in the information being provided in risk assessment [23]

Confidence measure	Description
A	Very high confidence in judgment based on thorough knowledge of the hazard, the very large quantity and quality of the relevant data and consistent relevant
B	High confidence in judgment based on a very large body of knowledge on the hazard, the large quantity and quality of relevant data and very consistent relevant assessments
C	Moderate confidence in judgment based on a considerable body of knowledge on the hazard, the considerable quantity and quality of relevant data and consistent relevant assessments
D	Low confidence in the judgment based on a relatively small body of knowledge on the hazard, the relatively small quantity and quality of relevant data and somewhat consistent relevant assessments
E	Very low confidence in judgment based on small to insignificant body of knowledge on the hazard, quantity and quality of relevant data and/or inconsistent relevant assessments

The IPCC also uses a similar qualitative scale to describe levels of confidence based on the quality and quantity of the available evidence and the level of agreement (consistency) of that evidence, as shown in figure A1.

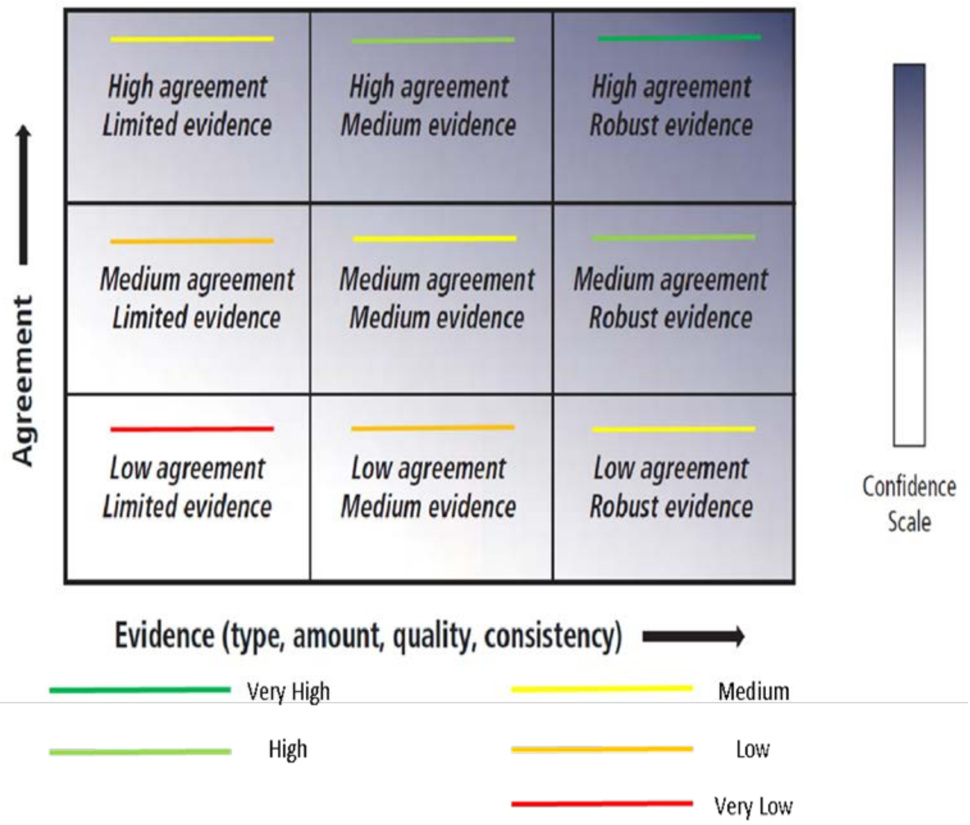

Figure A1. Confidence levels depicted as a combination of evidence and agreement. The five levels of confidence (indicated by different colours) roughly correspond to the confidence measures shown in table A4. (from [24])

Terms and definitions

This section contains definitions and explanations of the key terms and concepts

Consequence/impact

The outcome of an event that may result from a hazard. Impact may be expressed quantitatively (e.g. monetary value), by category (e.g. high, medium, low) or descriptively in terms of human, environmental, and political/social impacts.

Decisions under risk/decisions under uncertainty

These two terms are used in some sectors: 'decisions under risk' assumes that the probabilities of outcomes are knowable to some extent, whereas 'decisions under uncertainty' occur when the probabilities, and possibly the outcomes themselves, are unknowable.

Exposure

People, property, systems, or other assets present in hazard zones or exposed to hazards that are thereby subject to potential losses.

Hazard

An intrinsic capacity to cause harm.
A hazard can be an event, entity, phenomenon or human activity, and can be single, sequential or combined with other hazards in its origin and effects. Each hazard is characterised by its timing, location, intensity and probability.

The origin of hazards can be natural (geological, hydro-meteorological and biological) or induced by human activity (environmental degradation and technological hazards), and include latent conditions or trends that may represent future threats. [25]

Lifeline utilities

Companies and publicly owned entities delivering infrastructure services in energy, telecommunications, transport and water / sewerage.

Probability (Likelihood)

Probability is defined as the likelihood of a hazard occurring or the chance of a hazard happening. Probability is usually described quantitatively as a ratio (e.g. 1 in 10), percentage (e.g. 10%) or value between 0 and 1 (e.g. 0.1), or qualitatively using defined and agreed terms such as unlikely, almost certain, possible etc.

Risk

Risk is defined as the likelihood and consequences of a hazard. Risk can also be described as the effect of uncertainty on objectives (Risk Management Standard ISO31000

Risk reduction

Risk reduction refers to efforts to decrease in risk through risk avoidance, risk control, or risk transfer – can be accomplished by reducing vulnerability and/or consequences [26]

Residual risk

The risk that remains after risk treatment has been applied to reduce the potential consequences.

Resilience

Resilience means being shock-ready, and having the ability to resist, survive, adapt and/or even thrive in response to shocks and stresses. Resilience can be defined in terms of societal, economic, infrastructure, environmental, cultural capital, social capital, and/or governance components.

Shock

The term ‘shock’ is used (in the NRR) to denote a sudden, disruptive event with an important and often negative impact on a system/s and its assets.

Stress

A stress is a long term, chronic issue with an important and often negative impact on a system/s and its parts.

System

A system is defined as set of things working together as parts of an interconnecting network; a complex whole e.g. society (individual, community, nation), the environment and physical entities (e.g. infrastructure).

System Trends

System trends are long-term factors that indirectly, positively or negatively influence risks (e.g. demographic changes that may influence vulnerability).

Threat

A threat is a potentially damaging physical event, phenomenon or activity of an intentional/malicious character. It is a man-made occurrence, individual, entity, or action that has the potential to harm life, information, operations, the environment, and/or property [27]

Vulnerability

The characteristics and circumstances of an asset (populations, systems, communities, the built domain, the natural domain, economic activities and services, trust and reputation) that make it susceptible to, or protected from, the impacts of a hazard

Worldview

The overall perspective from which one sees and interprets the world. A particular philosophy (collection of beliefs) on life held by an individual or a group.