Natural Hazards Commission Toka Tū Ake

Understanding and communicating uncertainty in natural hazard and risk information: a literature review

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Natural Hazards Commission
Toka Tū Ake

Executive summary

Uncertainty is inherent in natural hazard and risk information. It arises from the complexity of natural systems, limitations in data and models, and uncertainty about future environmental and societal change. Yet decisions about land use, infrastructure, emergency management, insurance and resilience still need to be made. This means uncertainty must be understood, managed and communicated in ways that support transparent and defensible decision-making.

This literature review supports the Natural Hazards Commission Toka Tū Ake (NHC Toka Tū Ake) in developing a methodology for assigning and communicating confidence levels to natural hazard and risk information. While not exhaustive, it draws together national and international literature on uncertainty, confidence, and risk communication, with a focus on what uncertainty is, why it matters, how it can be managed, and how it can be communicated effectively. The review finds that poorly understood or poorly communicated uncertainty can contribute to inaction, overly conservative responses, inappropriate risk-taking, and reduced trust in science and decision-making. By contrast, acknowledging and communicating uncertainty clearly can improve transparency, strengthen trust, and support more proportionate and adaptable decisions.

The review identifies several complementary approaches for managing and communicating uncertainty, including use of the best available information, improving data and modelling, applying adaptive and precautionary approaches, and using tools such as scenarios, Dynamic Adaptive Pathways Planning, qualitative confidence ratings, numerical ranges, and visual communication methods. A consistent finding is that there is no single best method; effective communication depends on the audience, decision context and type of uncertainty involved. Overall, the review supports development of a practical framework that clearly defines uncertainty, applies a structured confidence approach, aligns with New Zealand's legislative and policy context, and helps natural hazard information be used more confidently and consistently in decision-making.

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Introduction

Uncertainty is inherent in natural hazard risk information and decision-making. It arises from the complexity of natural systems, limitations in data and models, and unpredictable human and environmental factors (Bevan, 2022). In the context of natural hazard risk management, uncertainty can influence how information is interpreted, how individual and organisational decisions are made, and how risks are communicated to stakeholders.

This literature review underpins the development of a methodology to assign levels of confidence to natural hazard and risk information, so that uncertainties can be communicated. It explores the nature and types of uncertainty, their implications for risk tolerance and decision-making, and best-practice approaches for managing and communicating uncertainty. The review draws on national and international research, frameworks, and examples to provide an evidence base for understanding, managing and communicating uncertainty.

Why is the Natural Hazards Commission Toka Tū Ake interested in uncertainty?

The Natural Hazards Commission Toka Tū Ake (NHC Toka Tū Ake) is a Crown entity responsible for providing residential property owners (who have a current contract of fire insurance for their residential property) with insurance against damage from natural hazards covered by the Natural Hazards Insurance Act 2023 (NHI Act).

The functions of NHC Toka Tū Ake, as set out in the NHI Act, include to facilitate research and education, and contribute to the sharing of information, knowledge and expertise with the Crown, public and private entities, and the public generally, including in relation to:

- natural hazards and their impacts
- damage to residential buildings, residential land, and other property as a result of natural hazards, including how that damage might be prevented or reduced
- community resilience to natural hazards
- natural hazard risk management
- planning for, and recovering from, natural hazards.

Our Resilience Strategy for Natural Hazard Risk Reduction 2024–2029[1] outlines our goal to inform, enable and influence the choices and decisions that reduce vulnerability and the exposure of New Zealand's built environment to natural hazards. To support the delivery of this strategy, our Risk Reduction Strategy 2025–2029[2] delves deeper into this goal, aiming to inform, enable and influence evidence-based risk reduction decision-making and action. Together, these strategies outline our vision to have natural hazards resilience embedded into decision-making at all levels (local, regional, and national) and set out our intentions for delivering on our resilience mandate in the NHI Act. As uncertainty is intrinsically linked to natural hazards data and risk information, it is crucial that it can be understood, managed and communicated to facilitate risk-informed action and improved natural hazards resilience.

To deliver our resilience mandate and associated strategies, we deliver a range of work programmes associated with increasing the uptake of natural hazard risk information, including the Natural Hazards Portal, submissions, natural hazard scenarios, and guidance frameworks such as the Risk Tolerance and Pre-Event Land Use Planning methodologies. These initiatives provide us with insights to how uncertainty is understood, communicated and interpreted in practice. For example, through the submissions process we see that submitters are requesting evidence and provisions to be removed due to uncertainties in the science or data.

To increase confidence, understanding and use of natural hazard risk information, we need to clearly and consistently communicate uncertainty.

Scope

This literature review is aimed at any person or agency involved in hazard risk management. It is intended to provide a high-level overview of concepts associated with managing and communicating uncertainty to support the development of our methodology to assign levels of confidence to natural hazard and risk information.

1 https://www.naturalhazards.govt.nz/assets/Publications-Resources/Resilience-and-Research-Publications-/Resilience.strategy.risk.reduction-2024-2029-1-1.pdf

2 https://www.naturalhazards.govt.nz/assets/Publications-Resources/Resilience-and-Research-Publications-/Risk-Reduction-Strategy-2025-2029.pdf

Uncertainty is a broad concept with a vast amount of literature and guidance associated with it. The following areas are explored throughout this review:

- Defining uncertainty
- The importance of uncertainty
- Managing uncertainty
- Communicating uncertainty

Uncertainty is a cross-cutting theme across a range of disciplines, and it interfaces with many hazard risk management concepts, including risk and risk communication. While this review introduces key frameworks, classifications (e.g. Walker et al., 2003; Bevan, 2022) and techniques for managing uncertainty through communication, it does not attempt to catalogue all existing literature on uncertainty or its management options. Many of the topics included have been extensively reviewed elsewhere and are not addressed in detail. This review is intended to be read in conjunction with those existing reviews and research papers.

Methodology

This literature review was developed using publicly available, open-access information to ensure transparency, accessibility and relevance. The content was compiled through a mixed-methods approach that included:

- published journal articles from national and international sources, providing peer-reviewed evidence and theoretical foundations
- websites and reports from reputable organisations, including government agencies, research institutions and hazard risk management bodies
- subject matter expertise, drawing on practitioner insights and expert commentary to ensure practical relevance
- examples from both New Zealand and international contexts, to illustrate how uncertainty is managed across different systems, sectors and decision-making environments
- AI-generated summaries of academic literature to assist with synthesising concepts and identifying themes across large volumes of literature; where AI was used, references were cross-checked to ensure results were not AI 'hallucinated' references.

This approach enabled a comprehensive and balanced review of existing thinking, best practice, and emerging approaches to managing and communicating uncertainty in natural hazard risk management.

What is uncertainty?

Uncertainty broadly refers to a lack of, or incomplete, information (Fischhoff & Davis, 2014; Spiegelhalter, 2017). Exact definitions for uncertainty often change depending on discipline, context, perception and management approaches (Walker et al., 2003). Table 1 outlines common definitions for uncertainty.

Table 1. Summary table of definitions for uncertainty

Source	Definition
Health and Safety Executive, 2001	"... a state of knowledge in which, although the factors influencing the issue are identified, the likelihood of any adverse effects or the effects themselves cannot be precisely described".
Walker et al., 2003	"...any departure from the unachievable ideal of complete determinism".
Brown, 2004	"...our inability to resolve a unique, causal, world, either in principle or in practice...".
Brouwer and De Blois, 2008	"... limited (incomplete or imperfect) knowledge and information about current or future environmental, social, economic, technological, political and institutional conditions, states and outcomes and the implications or consequences of these current or future conditions, states and outcomes".
Brugnach et al., 2008	"...we consider uncertainty impinging on a decision situation has no meaning in itself, but acquires meaning through the relationships established between the decision maker and the socio-technical environmental system. [...] Uncertainty then becomes a property of how an individual in a social context relates to a system through certain practices and activities [...] involving knowledge of different types."
Sigel et al., 2010	"A person is uncertain if he/she lacks confidence about his/her knowledge relating to a concrete question".

Intergovernmental Panel on Climate Change (IPCC), 2022	"A state of incomplete knowledge that can result from a lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from imprecision in the data to ambiguously defined concepts or terminology, incomplete understanding of critical processes or uncertain projections of human behaviour. Uncertainty can therefore be represented by quantitative measures (e.g., a probability density function) or by qualitative statements (e.g., reflecting the judgement of a team of experts)"
ISO (International Organization for Standardization) 31000, 2009	"Uncertainty is the state, even partial, of deficiency of information related to, understanding or knowledge of an event, its consequence, or likelihood".

Each definition of uncertainty conceptualises it differently, often emphasising the cause or source of the uncertainty, the extent to which it can be quantified, or the context in which it occurs. Bevan (2022) summarises these differences in the following ways:

- **Where uncertainty comes from** – some people see uncertainty as something that naturally exists in the world (like unpredictable weather) (e.g. IPCC, 2022; Brown 2004). Others think it's about what's going on in our minds – how confident or unsure we feel (Sigel et al., 2010). Another view is that uncertainty is shaped by society and how we talk about or understand things (Brugnach et al., 2008).
- **What we compare it to** – uncertainty is often described in relation to an ideal situation where we know everything (e.g. Sigel et al., 2010; Brugnach et al., 2008). But what that "ideal" looks like can vary. It might mean having complete knowledge, knowing exactly what will happen, having enough information to make a decision, or simply feeling confident in what we know.
- **What the uncertainty is about** – uncertainty can relate to many things, such as what happened in the past, what's happening now, what might happen in the future, the results of models or predictions, the causes behind how systems behave, or the outcomes of decisions and how people feel about them (e.g. IPCC, 2022; Brouwer and De Blois, 2008).

Variation in how uncertainty is defined and conceptualised means that clarity is needed to avoid confusion (Fischhoff & Davis, 2014). Misalignment in how scientists, decision-makers and communities define and ultimately understand uncertainty can lead to confusion, mistrust and poor decisions (Kwakkel et al., 2010; Walker et al., 2003). Clearly articulating what type of uncertainty is being discussed (e.g. whether about what might happen or why it might happen) builds shared understanding, supports consistent communication, and enables more confident, informed decision-making (Fischhoff & Davis, 2014).

Managing and defining uncertainty within the context of hazard risk management has additional complexities. This is due to the definition of risk being closely associated with uncertainty and having its own variable definitions. The New Zealand Standard for Risk Management (ISO 31000:2018), defines risk as "the effect of uncertainty on objectives", with the effect being a deviation from the expected (either positive or negative), uncertainty referring to a lack of knowledge, and objectives being what is trying to be achieved. This definition therefore ties risk and uncertainty together by defining risk in the context of the ability for unknowns (or uncertainty) to change desired outcomes or goals.

In this literature review, we have chosen to adopt the Intergovernmental Panel on Climate Change (IPCC) definition for uncertainty (Table 1) for the following reasons:

- The IPCC definition has undergone a rigorous peer review process.
- It provides a clear distinction between risk and uncertainty. Managing uncertainty and decision-making in a hazard risk management context requires concepts to be distinguishable from each other to support clear communication and effective decision-making.
- The definition has been developed to suit an environmental context, which makes it suitable for uncertainty in the context of natural hazard risk management.

Distinguishing between probability and uncertainty

Probability and uncertainty are related but distinct concepts in natural hazards risk assessment. The probability, or likelihood, of a hazard event is derived from statistical analysis of historical data and other available evidence, describing the anticipated frequency with which a hazard of a given type or magnitude might occur. A 1-in-100-year flood, for example, does not mean the event will occur once a century, it means there is a 1% chance of that flood occurring in any given year.

Uncertainty, by contrast, reflects the limits of our knowledge and the degree of confidence we can place in the probability estimate. The level of uncertainty is linked to the quality of the input data used to generate the probability and arises from factors such as incomplete or short historical records, limitations in measurement, and the potential for future environmental changes − including climate change − to alter the underlying conditions that govern hazard behaviour. Where probability describes what we expect to happen, uncertainty describes how well we actually know that.

Degrees of uncertainty

Any data and information will have a certain amount of uncertainty associated with it. However, some data and information are better understood than others, and therefore the type, degree or sources of uncertainty may differ. Understanding the degree of uncertainty within data and information, and nature of the uncertainty, can support the correct and appropriate use of data and evidence. It can also help to determine how best to reduce and manage uncertainties (Fischhoff & Davis, 2014). This allows for decision-making to be supported by systematically identifying and prioritising data and evidence that should be used, and uncertainties that need to be reduced, managed and communicated.

The 'Rumsfeld Matrix'[3] (Figure 1) classifies knowledge in four different ways to understand where and to what degree uncertainties are present (Hald Mortensen, 2024):

- **Known knowns**: These are facts or variables that we're aware of and understand. They form the basis of our knowledge and provide the foundation for using data and evidence, and for communicating what is well established.
- **Known unknowns**: These are factors we know exist, but don't fully understand. They represent gaps in our knowledge that we must address through research, investigation or consultation with experts. Identifying and addressing known unknowns may clarify where uncertainty exists, what additional evidence may be needed, and in some cases may help reduce uncertainty.
- **Unknown knowns**: These are elements that we don't realise we know. Typically, they have been overlooked or dismissed as unimportant. Uncovering these insights can lead to breakthroughs in our understanding and a reduction of uncertainty. Identifying unknown knowns can also facilitate the effective and appropriate use of all data and information available.
- **Unknown unknowns**: These are factors that we're not aware of and can't predict. They can represent the most significant source of uncertainty as they cannot be specifically anticipated or planned for, and highlight the need for flexible, adaptive approaches that can respond as new information emerges.

3 The term 'Rumsfeld Matrix' was coined in 2002 after Donald Rumsfeld, the then-US Secretary of Defence, held a press conference about the Iraq war. Initially, his words were met with confusion, but over time, they have been adopted and expanded beyond military strategy (https://www.theuncertaintyproject.org/tools/rumsfeld-matrix).

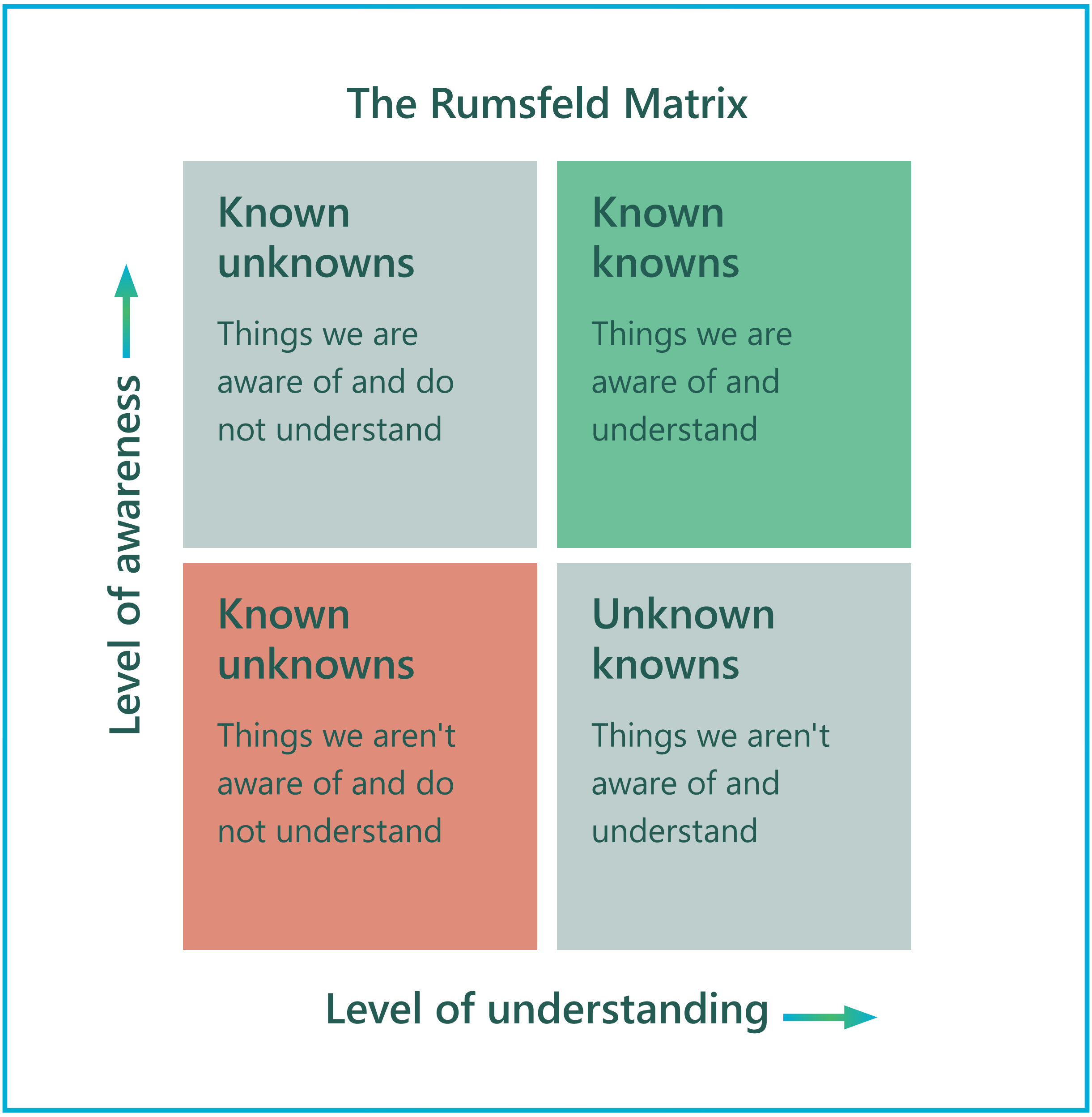


Figure 1. The Rumsfeld Matrix of uncertainty

Types of uncertainty

There are two commonly recognised types of uncertainty: aleatory, or stochastic, uncertainty and epistemic uncertainty (Doyle et al., 2023; Jenkins, 2019; van der Bles et al., 2019; Spiegelhalter, 2017; Doyle et al., 2014). Aleatory uncertainty results from the inherent randomness or variability within a system or process, while epistemic uncertainty results from incomplete data, information, methods, assumptions or knowledge about a topic. Model uncertainty, scenario uncertainty and data uncertainty can be understood as common sources or sub-categories of epistemic uncertainty, as they relate to limitations in how information is collected, interpreted, modelled or projected.

It is common for natural hazard information to contain multiple sources of epistemic uncertainty, alongside an element of aleatory uncertainty that cannot be eliminated, although it may be better characterised.

In some cases, uncertainty may also be shaped by differing values, objectives or preferences, particularly where there are different views about the desirability or acceptability of alternative outcomes. This is often relevant in situations of deep uncertainty, where uncertainty may relate not only to evidence, models or probabilities, but also to how outcomes are valued or prioritised (Marchau et al., 2019) (see subsection below for an explanation of deep uncertainty).

Within these broad types of uncertainty, more detailed sub-categories can be used to identify where uncertainty arises and how it may affect the interpretation and use of natural hazard information. These sub-categories can support clearer communication by making the sources of uncertainty more explicit, including whether uncertainty relates to data quality, model structure, assumptions, computational processes, or interpretation of outputs. For example, Bevan (2022) identifies 15 types of modelling uncertainty across six categories (Table 2).

Table 1. Summary table of definitions for uncertainty

Category	Type	Description
Conceptual	Model choice	The effect of choices made by modellers
	Modeller uncertainty	Difference in interpretation of the model problem
Conceptual/ mathematical	Structural uncertainty (conceptual)	Uncertainty in the correct relations between variables or mathematical forms. Sometimes this is just called model uncertainty.
	Model completeness	Whether all relevant variables are included
Mathematical	Model boundaries	Uncertainty due to selection of boundary conditions
	Parametric uncertainty	Uncertainty in setting or calibrating of parameters
	Model aggregation	Errors due to the aggregation of model elements
Technical implementation	Data uncertainty	Uncertainty in the data used in model construction, calibration and tuning, including descriptions of environment, etc
	Model implementation	Uncertainty introduced due to the computational implementation of a model, including numerical approximations

Category	Type	Description
Model driving	Initial conditions	The effect of varying initial conditions in model settings
	Model forcing/ scenario uncertainty	Assumptions about conditions external to the model system that drive behaviour
Interpretation of model	Internal variability of the model	Spontaneous fluctuations in the model condition due to complexity of relationships
	Internal variability of the system	Spontaneous fluctuations in the system under study due to natural randomness or unpredictability
	Model output interpretation	Difference in interpretation of processed model outputs
	Inter-model uncertainty	Difficulty in interpretation of results of alternative models

Identifying these sources of uncertainty supports more transparent communication between scientists, practitioners and decision-makers. It also enables targeted strategies for managing uncertainty, such as improving data inputs, refining models or adjusting decision frameworks.

Deep uncertainty

Deep uncertainty is a situation where people do not know, or cannot agree on, how a system works, what the future conditions will be, how likely different outcomes are, or what outcomes matter most. It is commonly used in fields like climate change adaptation, natural hazards, infrastructure planning, insurance, economics, and long-term public policy. Unlike situations where uncertainty can be reasonably estimated, deep uncertainty means deep uncertainty means the future cannot be reliably predicted using standard forecasting approaches.

Good uncertainty communication can incorporate deep uncertainty by explaining what is known, explaining what is uncertain, describing confidence levels, avoiding false precision, and supporting transparent decision-making (e.g. Lawrence et al, 2019).

Managing deep uncertainty successfully does not mean eliminating uncertainty. It means reducing vulnerability to surprise, avoiding irreversible mistakes, preserving future choices, improving resilience, and enabling adaptation to decisions over time.

Why are uncertainties important?

Legislative requirements

In New Zealand, legislation requires decision-making even when there is uncertainty. However, there is no consistency across the statutes, policies or guidance on what constitutes uncertainty, how it is assessed, or how it is managed. For example, the management of uncertainty in natural hazard risk management is implicit in the Resource Management Act 1991, but explicit in the New Zealand Coastal Policy Statement, the National Policy Statement – Natural Hazards, and coastal hazard and climate change guidance. Managing uncertainty is explicit in the Civil Defence and Emergency Management Act 2002 and, at the time of publication, both the Planning Bill and the Natural Environment Bill explicitly refer to uncertainty. Examples of how uncertainty is incorporated into New Zealand statutes is summarised in Appendix 1.

Implications for decision-making and risk tolerance

Uncertainty, and how it is communicated, can affect whether decisions are made, how decisions are made, and how much weight is placed on uncertain information. These effects can then influence how risks are interpreted, managed and tolerated by individuals, organisations and communities. Inaction, decision-making processes, and adaptable decision-making approaches are three important implications of uncertainty:

- **Inaction**. Uncertainty can prevent decision-making because it is often perceived as being synonymous with a lack of, or poor quality, information (Jenkins, 2019; van der Bles et al., 2019). When decision-makers are faced with high levels of uncertainty, particularly deep or difficult-to-quantify uncertainty, they may delay action while waiting for more information or avoid action altogether (Meyer & Kunreuther, 2017; Slovic, 2016).

- **Changing how decisions are made**. The presence of uncertainty can influence whether an analytical approach to decision-making is applied, where significant time and information is used to make a decision (Saaty, 2008), or whether a rapid decision-making process is applied, where a decision is made quickly with less deliberate consideration (Evans & Stonovich, 2013). A rapid approach can lead to uncertainties being overlooked, or to decisions being based on assumptions rather than clearly understood evidence. This can affect the appropriateness of decisions for the level and type of uncertainty present, and may also affect trust in science and risk information (van der Bles et al., 2019; Jenkins, 2019; Becker et al., 2020; Doyle et al., 2014).
- **Potential to enable more adaptable decision-making**. When uncertainty is clearly communicated, it can support more effective and adaptable decision-making by helping decision-makers understand what is known, what is uncertain, what assumptions have been made, and what limitations should be considered. This can allow for more flexibility and support multiple decision pathways.

Uncertainty plays a critical role in shaping how individuals, organisations and communities perceive, tolerate and manage risk. These effects on decision-making can influence how risk is interpreted and managed. Uncertainty can affect decision-making in two main ways:

- **Risk-averse responses**. Decision-makers are faced with high levels of uncertainty, particularly deep or unquantifiable uncertainty, so they may become more cautious and have a lower tolerance for taking on or experiencing risk. This may lead to conservative planning responses, particularly where uncertainty is poorly understood or difficult to quantify (Meyer & Kunreuther, 2017; Slovic, 2016).
- **Risk-taking responses**. In contrast, some decision-makers may accept higher levels of risk when uncertainty is present or perceived as unavoidable. This can occur even after efforts to reduce uncertainty or adapt decision-making styles in response to uncertainty. As a result, levels of risk may be tolerated that are not appropriate for the nature of the risk or the level and type of uncertainty present (Meyer & Kunreuther, 2017; Slovic, 2016).

The degree to which decision-making is affected by uncertainty can vary according to the individual and the decision being made. For example, scientists are more likely to adjust to an analytical decision-making approach and work to reduce uncertainties, whereas non-scientists may be more likely to switch to a rapid decision-making approach (Doyle et al., 2014). Decision-making style can also influence how willing an individual is to engage with and seek out information on uncertainty (Martin et al., 1997; Lipshitz et al., 2001; Dhungana et al, 2025).

As uncertainty changes over time (for example, through new evidence, improved modelling or better understanding), risk tolerance may also change in response. Effectively managing and communicating uncertainty can therefore mitigate negative implications associated with uncertainty and support more transparent, adaptable and proportionate decision-making.

Implications for perception of science

How uncertainty is managed and communicated can affect public trust in science and the decisions that science underpins, including the following:

- **Erosion of public trust in science**. When uncertainty is poorly communicated or perceived solely as a sign of unreliability, it can reduce public confidence in science and, by extension, in the decisions and advice that science informs (van der Bles et al., 2019; Jenkins, 2019; Becker et al., 2020; Doyle et al., 2014). Maintaining public trust therefore depends on honest and transparent communication of what is and is not known.
- **The association of uncertainty with poor-quality science**. This can discourage scientists from communicating it openly, for fear of being seen as incompetent (van der Bles et al., 2019; Becker et al., 2020; Doyle et al., 2014). This creates a risk that uncertainty is underreported, further compounding the issues above. Addressing this barrier requires clear guidance on how uncertainty can be communicated effectively in ways that are honest and accessible without undermining confidence in the underlying science. When done well, effective uncertainty communication supports more informed decision-making, sustains public trust, and strengthens broader understanding of risk (Dhungana, 2025).
- **Risk of misinformation and loss of critical detail**. Where the complexities of uncertainty are oversimplified or omitted – often because they are difficult to explain – essential nuance can be lost, increasing the risk that incorrect or incomplete information shapes decisions (van der Bles et al., 2019).
- **A driver of new knowledge**. Uncertainty has an important positive role: by identifying gaps in understanding, it can prompt further research and innovation, ultimately strengthening the evidence base (Doyle et al., 2025; Clegg, 2010; Hollermann & Evers, 2015).

Managing uncertainty

Why and when does uncertainty need to be managed?

Effectively managing uncertainty can reduce negative outcomes, such as decisions based on assumptions, inaction and distrust in science (Spiegelhalter, 2017; Fischhoff & Davis, 2014). One of the most significant benefits from effectively managing uncertainty is increased confidence in decision-making, enabling more informed, timely and transparent decisions, despite uncertainty. Rather than waiting for perfect information, decision-makers can manage the uncertainties using iterative approaches, adaptative planning and precautionary principles to avoid decision paralysis and support resilient and flexible outcomes.

The degree to which uncertainty needs to be managed will depend on the nature of the decision being made (U.S. Department of Health and Human Services, 2021). Decision importance can be assessed by considering factors such as the potential consequences of getting the decision wrong, whether the decision can be reversed or adjusted later, and the scale of its societal, environmental, cultural or economic impacts (National Aeronautics and Space Administration (NASA), 2023; National Research Council, 2014). These factors can inform how uncertainty is managed, support the effective use of resources, and enable more robust and defensible decision-making.

Comprehensive uncertainty assessments demand significant time, data and technical expertise, meaning the effective use of resources is essential. Decisions involving deep uncertainty, or long-term or irreversible consequences (such as infrastructure development in floodplains, coastal adaptation planning, or land-use rezoning) may require detailed uncertainty assessments (Marchau et al., 2019).

The following section provides a summary of different techniques for managing uncertainty, along with an assessment of their relative effectiveness. These examples can be used in combination with each other.

Using best available information

Using best available information is a useful approach for managing uncertainty (Ministry for the Environment, 2023). This includes ensuring data and evidence is supported by multiple model runs, sensitivity testing, and the most up-to-date data and inputs. Requiring best-available information to be used can prevent inaction by ensuring timely decision-making, even where data are uncertain or imperfect. This is particularly relevant for natural hazard risk management as natural hazard data will always contain some degree of uncertainty. As a result, the use of best-available information is commonly embedded in policy, including district policies and the National Policy Statement – Natural Hazards (NPS-NH).

The principle of best-available information may be limited if there is no guidance as to what constitutes best-available information (Weichselgartner & Pigeon, 2015). With no guidance, there will be limited consistency in the data used across the country. There may also be increased instances of data being misused or implemented in a context that it is not suitable for. An example of what constitutes best-available information is from the NPS-NH Implementation Guide (MfE, 2026), which states that:

As a guide, applying best information available involves the following:

- *Use complete and scientifically robust data where possible.*
- *Best available information may also include information obtained from modelling, as well as partial data and information obtained from other sources.*
- *When using information that is uncertain or incomplete, give preference to sources of information that provide the greatest level of certainty, while taking all practicable steps to reduce uncertainty.*
- *If the information is uncertain, including when considering future conditions under climate change, interpret it in a way that gives effect to the proportionate risk-based approach required by the NPS-NH.*

Reducing uncertainty

Investing in scientific studies, data collection, research and modelling can improve understanding of a system and help reduce some epistemic uncertainties (Doyle et al., 2025; Clegg, 2010). However, generating new knowledge does not always reduce uncertainty. Research may reveal additional complexities, relationships or unknowns, increasing awareness of uncertainty even as understanding improves. Rather than eliminating uncertainty, these activities can help decision-makers better characterise, bound and navigate uncertainty (Janssen et al., 2005; Hollermann & Evers, 2015).

This improved understanding can help decision-makers select an appropriate response to uncertainty, whether that involves reducing it where possible, acknowledging and monitoring it, or designing plans that remain effective despite it (Doyle, 2014; Lipshitz & Strauss, 1997). Where uncertainty reduction is pursued, clear expectations and decision thresholds should be established to avoid unnecessary delays in decision-making and recognise the practical limits of further investigation.

Communicating uncertainty

Effectively communicating uncertainty by applying best-practice principles and plain language techniques can improve interpretation of data and information and contribute to effective decision-making. Clear communication helps ensure decision-makers grasp the full range of unknowns and limitations, so they can select a management strategy or outcome that matches the situation and the level of confidence in the available data (Doyle et al., 2014; Fischhoff & Davis, 2014). Communicating uncertainty also builds trust and contributes to a transparent decision-making process (Doyle et al., 2025). Being transparent requires presenting data and evidence alongside any assumptions, limitations and uncertainties (Ministry for the Environment, 2023). This supports a robust decision-making process by ensuring all those who are involved or affected understand the decisions made, reasons for decisions, and other options that were considered (Ministry for the Environment, 2023).

Implementing adaptable approaches

Adaptable approaches to decision-making can be implemented to account for uncertainty and the variation of outcomes that are possible (Marchau et al., 2019). These approaches can manage uncertainty by building different options into decision-making to ensure there is adaptability for ‘known unknowns’. For example, Dynamic Adaptive Pathways Planning (DAPP) manages uncertainty by providing a range of different options for progressing under uncertain conditions (Haasnoot et al., 2013). Further guidance on decision-making under deep uncertainty, including which approaches may be appropriate in different contexts, is provided by Marchau et al. (2019) and Curran et al. (2025).

Scenarios are also widely used adaptive approaches (Alexander, 2000; Robinson et al., 2014). Scenarios (discussed in more detail below) enable different outcomes or options to be explored across a range of plausible futures (Alexander, 2000; Bishop et al., 2007; Butler et al., 2016; Duinker & Greig, 2007).

Scenarios

A natural hazard scenario is a credible, but often simplified, description of a natural hazard event which is possible or plausible. Scenarios are not predictions. Instead, they provide a structured way to explore uncertainty, test assumptions, and understand how different decisions or interventions may perform under a range of plausible futures.

Different types of scenarios include back-casting, and effects-based and event-based scenarios. Back-casting involves creating a scenario that reveals a desired future state and then working back to understand what actions may be required to reach the desired state. Effects-based scenarios focus on the impacts from an event, such as infrastructure and building damage from an earthquake.[4] Event-based scenarios explore hazard characteristics, such as rainfall intensity or earthquake magnitude (Davies, 2019; Duinker & Greig, 2007). An example in New Zealand is where scenarios have been used to explore possible hazards and impacts associated with events such as a Wellington Fault Mw 7.5 earthquake.

Natural hazard event scenarios often focus on the 'maximum credible event' approach as, in theory, if stakeholders can understand and prepare for the 'worst case' they can respond to lesser events (Davies, 2019). However, a range of other classifications of scenarios can be used, as summarised in Table 3.

Table 3. Scenario classifications and their descriptions. From National Emergency Management Agency, 2023

Scenario scale	Description
Outlier event	Considered to be a statistical outlier that cannot reliably be predicted, these are extremely rare and could have catastrophic consequences that would be unmanageable, or even difficult to comprehend (e.g. a large meteor strikes a major city). Due to the limited ability to predict extreme events, they are unlikely to be useful for risk-assessment purposes.
Maximum credible event (MCE)	Possible, worst-case events likely to be associated with significant consequences. Events must be realistic, even if highly unlikely, and be underpinned by a degree of expert knowledge on what magnitude of event is possible, e.g. for Taranaki volcanic hazard, a large and prolonged volcanic eruption including a collapse of the cone. These types of scenarios are recommended for CDEM Group risk assessments.

4 Effects-based and events-based scenarios are common within natural hazard risk management, because they are versatile and can be used for a range of resilience-based activities, such as business continuity planning or assessing mitigation options for risk reduction (Davies, 2019; Alexander, 2000; Duinker & Greig, 2007; Hayes et al., 2018).

Scenario scale	Description
Most likely/mid-range event	Describes an event or series of events that have a higher likelihood of occurrence than the MCE and are likely to require a coordinated response by the CDEM Group, e.g. a localised but disruptive rainstorm which results in flooding of an urban area, evacuations, school closures and multiple, small landslides and temporary road closures throughout a region.
Routine or regular events	Frequently occurring events that are managed as a 'business as usual' or routine activity and result in largely negligible consequences, e.g. earthquakes that people feel but which cause no damage. Unlikely to require CDEM Group consideration or planning.

Scenarios are valuable for communicating uncertainty because they help to establish a better, shared understanding of existing and emerging risks, clarify assumptions, and explore how different combinations of hazard, exposure, vulnerability and response may affect outcomes (Alexander, 2000; Bishop et al., 2007; Butler et al., 2016; Duinker & Greig, 2007). However, scenarios also need to be communicated carefully. A risk is that a scenario may be interpreted as a prediction or treated as the future that planning should be designed around. This can lead to decisions being tailored to one representation of the future, rather than being robust across a range of plausible futures. To avoid this, scenarios should be clearly described as exploratory tools, with their assumptions, limitations and purpose made explicit.

Scenarios are most useful when they are used to test decisions, interventions or planning options across multiple plausible futures. This can help identify which options are robust under different conditions, which assumptions matter most, and where further information may be needed. For example, scenarios can be used to test whether a land-use planning response, infrastructure investment or adaptation pathways remain effective under different assumptions about hazard magnitude, exposure, vulnerability, climate change, or development patterns.

The process of developing and applying scenarios can also help identify and prioritise uncertainties (including deep uncertainty, see Curran et al., 2025). By examining how changes to scenario components affect outcomes, decision-makers can better understand which uncertainties are most influential and where further research or monitoring would be most useful (Alexander, 2000). For example, Robinson et al. (2018) found that changing earthquake magnitude within a certain range resulted in limited changes to modelled fatalities, highlighting that uncertainties related to impacts may be more important to reduce than uncertainties related to the hazard itself.

When scenarios are co-created with communities, practitioners, academics and decision-makers, they can support shared understanding of uncertainty and improve how risk information is interpreted and used (Butler et al., 2016). For example, Project AF8 has supported engagement around the potential impacts of a Mw8+ Alpine Fault rupture (Orchiston et al., 2018), while Auckland Volcanic Field eruption scenarios developed through the DEVORA research programme helped identify areas for future research, including infrastructure impacts and gas dispersion modelling (Deligne et al., 2017; Hayes et al., 2018).

Overall, scenarios are a tool that can be used to communicate and explore uncertainty. Their value lies in helping decision-makers understand plausible conditions, test options, identify important assumptions, and consider whether decisions are sufficiently flexible or robust across a range of futures.

Applying the precautionary approach

The precautionary principle describes an approach for addressing natural hazards subject to high scientific uncertainty and rules out lack of scientific certainty as a reason for not taking preventive action.

It has been defined by the United Nations Conference on the Environment and Development (1992) as: "where there are threats of serious or irreversible environmental damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent degradation". Although originally formulated in the context of environmental protection, the precautionary principle has been applied more widely (Health and Safety Executive, 2001).

The Health and Safety Executive (2001) recommends that the precautionary principle should be invoked where:

- there is good reason, based on empirical evidence or plausible causal hypothesis, to believe that serious harm might occur, even if the likelihood of harm is remote; and
- the scientific information collected at this point is so uncertain that we can't confidently judge what might happen next or continue with the risk assessment process.

Much like the requirement for best-available information, using the precautionary principle is often included in policy and legislation. For example, the Civil Defence and Emergency Management Act, NPS-NH, and New Zealand Coastal Policy Statement all require the precautionary approach to be applied when there is uncertainty but the potential for adverse effects.

Communicating uncertainty

Clear communication of uncertainty enhances transparency and fosters trust among scientists, decision-makers and communities. It is also essential for addressing knowledge gaps across disciplines (Doyle et al., 2025; Clegg, 2010). Users of information, decision-makers and scientists should ensure uncertainties are communicated effectively to all relevant audiences.

There is a range of literature and guidance documents dedicated to best-practice methods for communicating uncertainty (e.g. Das et al., 2025; Charlton et al., 2025). Below is a summary of these approaches.

High-level themes for communicating uncertainty

Clarity and openness

Communicating uncertainty clearly and openly should be central to both scientific communication and decision-making (Lofstedt, 2010). Despite some thinking that communicating uncertainty should be avoided because it can lead to negative perceptions of credibility, research has found that the public and decision-makers are often more comfortable with uncertainty than scientists may realise (Doyle et al., 2024; 2025). This highlights the importance of communicating uncertainty. Many people anticipate that uncertainty will be present within science, particularly in the context of natural hazards, and so expect that uncertainties will be communicated to them. The expectation that uncertainties will be present, but are not clearly communicated and acknowledged, can create mistrust of science and scientists (Doyle et al., 2023; 2024).

Communicating uncertainties should be focussed on explaining what types of uncertainties are present and why (Doyle et al., 2019; van der Sluijs et al., 2011; Walker et al., 2003; Kloprogge et al., 2011; Moss, 2011). This may include explaining limitations in data, models, methods, sources, assumptions or known unknowns. Explaining why uncertainty is present may require acknowledging broader factors that shape the evidence base, such as disciplinary differences, funding opportunities, or policy and political priorities. These factors can mean that some hazards, locations or impacts are better studied and understood than others (Doyle et al., 2023).

Being open about uncertainty can also reduce misunderstanding if, or when, outputs or outcomes differ in the future (Doyle et al., 2025). Further research and the availability of more information over time can mean that assumptions change, the level of uncertainty changes, and this can influence what decisions are made. For example, the probability of an Alpine Fault rupture changed in 2021 following additional and more sophisticated research (Howarth et al., 2021). This change has the potential to impact how the risk is managed and the general public's perception of science. Providing clear explanations of uncertainty can reduce confusion and mistrust when changes in information occur.

Prioritise audience needs

Approaches used to communicate uncertainty must be appropriate for the audience receiving the information. This includes considering the audience's level of risk literacy, technical expertise, familiarity with natural hazard information, and understanding of how science handles uncertainty. Non-scientific audiences may not be familiar with technical terminology, scientific processes, or the way scientific conclusions are developed and expressed under uncertainty. They may also have different expectations about the role of science, what constitutes evidence, and how much confidence can be placed in scientific findings (Doyle et al., 2023).

How much detail is shared depends on the situation and the time available to make decisions. In urgent or crisis situations, messages to decision-makers, including information about uncertainty, should be kept short and focused (Doyle et al., 2014; Martin et al., 1997; Lipshitz et al., 2001). These situations require timely decision-making by those who have limited time or capacity to process information. Whereas, in non-crisis situations there is considerably more time and capacity, meaning detail and nuance can be translated. Therefore, the level of uncertainty conveyed should vary from focused details in a high-pressure urgent crisis through to depth, analysis and nuanced discussion in non-time-critical situations (Eppler & Mengis, 2004; Endsley, 2000; Doyle & Becker, 2022).

Engage collaboratively

Where possible, a collaborative approach to engagement should be used to develop structured and accessible approaches to communicate uncertainty, supporting a shared understanding (Kasperson, 2014; Renn, 2014; French & Maule, 2010; Frewer, 2004; Bauer et al., 2007). This is in line with research that shows misunderstandings are more likely to be caused by a lack of shared terminology and language, rather than a lack of ability to understand information about uncertainty and other complex topics (Doyle et al., 2015).

Scenarios and tabletop exercises should be used as part of engagement to establish shared uncertainty terminology, existing levels of trust, prior experiences with uncertainty and/or risk, and potential disciplinary differences (Doyle & Becker, 2022; Keeney & von Winterfeldt, 1986; Doyle et al., 2019; Patt, 2009; Fischhoff & Davis, 2014). Establishing this information through engagement can assist in creating a shared responsibility, prioritising audience needs and developing suitable communication products (Frewer, 2004; Hudson-Doyle & Johnston, 2018).

Approaches to communicating uncertainty

There are three main approaches for communicating uncertainty: through text, numerically, and visually (or a combination of). When considering these approaches, each method has its own strengths and limitations. The literature provides no single 'best' approach for communicating uncertainty (Spiegelhalter, 2017; Charlton et al., 2025). Instead, the most effective approach depends on the needs and priorities of your audience.

Using words and text

Written descriptions of uncertainty can take many forms, from detailed explanations to brief disclaimers or qualitative descriptions. Text-based communication is often accessible to a wide range of audiences and provides a straightforward way for scientists and decision-makers to convey uncertainty (Spiegelhalter, 2017). However, textual descriptions can be prone to misinterpretation, which may influence risk tolerance and decision-making. The following section outlines several approaches for using text to communicate uncertainty.

Qualitive descriptions of uncertainty and confidence

A common technique for communicating uncertainty is to use qualitative descriptions, such as low, medium or high confidence. Unlike qualitative descriptions of likelihood, which describe the chance of an event occurring, confidence descriptions communicate the level of trust that can be placed in an assessment or conclusion. This distinction is important because qualitative likelihood terms, such as unlikely, likely or extremely likely, can be interpreted inconsistently by different audiences and may not align with intended numerical meanings (Doyle et al., 2014; Becker et al., 2020; Spiegelhalter, 2017).

The IPCC confidence scale provides one example of a structured approach for communicating confidence. It assesses confidence by considering both the strength of the evidence, including the type, amount, quality and consistency of evidence, and the level of agreement (IPCC, 2022; Risbey & Kandlikar, 2007).

Where evidence is robust and agreement is high, confidence is also high. Where evidence is limited or agreement is low, confidence is lower. This approach helps communicate uncertainty by making clear whether a conclusion is well supported, contested or based on limited evidence.

Qualitative confidence descriptions can be useful because they are accessible to non-expert and non-technical audiences (Spiegelhalter, 2017; Becker et al., 2020; Doyle et al., 2014). However, they should be clearly defined and applied consistently, as audiences may interpret terms such as low, medium or high confidence differently. Where possible, qualitative descriptions should be supported by an explanation of what the confidence rating is based on, including evidence quality, expert agreement, assumptions, and limitations. Care should also be taken to ensure these confidence ratings are not interpreted as the likelihood of an event outcome (Clive et al, 2023).

Structured approaches

A structured approach is a predetermined framework that aligns with communication principles. It often involves scientists, decision-makers and those affected by a decision working together to come up with an approach for identifying and communicating uncertainty (Janssen et al., 2005; Doyle et al., 2019). Structured approaches are commonly associated with models, as there are many different, potentially uncertain components, such as the problem definition, computational issues, inaccuracies in input data, and verification (Doyle et al., 2019). Structured approaches are a useful communication technique for natural hazard risk management as models are common within risk assessments, such as hazard models or models for building footprints (Doyle et al., 2019; Dhungana et al, 2025).

Walker et al. (2003) developed a structured approach that identifies and describes elements of uncertainty, including the location, level and nature. The location refers to the components of the model that are creating uncertainty, the level refers to the degree or severity of uncertainty, and nature of uncertainty is whether it is aleatory or epistemic.

Kwakkel et al. (2010) (Table 4) further developed the Walker et al. (2003) approach by establishing four levels (levels 1-4) to describe uncertainty (shallow, medium, and deep uncertainty, and recognised ignorance) rather than categories proposed by Walker et al. (2003) (i.e. statistical, scenario, and recognised ignorance). This change was implemented because it can reduce misinterpretation or differences across disciplines, where the language and words associated with uncertainty can differ.

Table 4. Kwakkel et al., 2010 matrix for communicating uncertainty

Location		Level				Nature		
		Level 1: shallow uncertainty	Level 2: medium uncertainty	Level 3: deep uncertainty	Level 4: recognised ignorance	Ambiguity	Epistemology	Ontology
System boundary								
Conceptual model								
Computer model	Model structure							
	Parameters inside the model							
	Input parameters to the model							
Input data								
Model implementation								
Processes output data								

Consensus and dissensus

When uncertainty is caused by scientific disagreement, for example, experts interpreting the same data differently, it is important to communicate both the areas of agreement (consensus) and disagreement (dissensus). When dissensus is emphasised, it can lead to people being more distrustful of scientific information, which can result in decision-making being delayed and creating a barrier for action. This is because people tend to be more comfortable with processing ambiguity in scientific information rather than conflict (Doyle et al., 2019).

In situations of deep uncertainty, the aim may not be to resolve all disagreements about assumptions, models or probabilities before a decision is made. Instead, communication can help identify where agreement exists, where disagreement remains, and whether decisions or interventions are robust across a range of plausible assumptions or futures (Kalra et al., 2014).

Table 5 provides an example of statements where consensus is emphasised (highlighting ambiguity) compared to dissensus (highlighting conflicting information).

Table 5. Examples of statements that emphasise ambiguity and conflict. Adapted from: Smithson, 1999

Type of statement	Example
Ambiguity	Forecasts A and B both predict that the cyclone is most likely to hit either Town X or Town Y.
Conflict	Forecast A predicts the cyclone is most likely to hit Town X. Forecast B predicts it is most likely to hit Town Y.

In line with clear and transparent communication, where dissensus is present the reasons for the disagreement should be clearly explained (Markon & Lemyre, 2013; Doyle et al., 2019). Shifting the focus from the disagreement itself to the underlying rationale helps the audience understand whether the disagreement materially affects the decision, and to make informed judgments.

Numerical approaches

Numerical approaches can be used to communicate uncertainty by showing the range, variability, confidence or sensitivity associated with data, models, assumptions or conclusions. Unlike probabilities and likelihoods, numerical uncertainty information helps explain how much confidence can be placed in an estimate, how much variation exists, or how sensitive results are to changes in assumptions or inputs.

Numerical uncertainty information can be communicated in several ways.

Ranges, confidence intervals and probability distributions

These methods can be used to communicate the spread of plausible values or outcomes. Ranges and confidence intervals provide a concise way to show bounds around an estimate, while probability distributions can provide additional information about whether some values within that range are more plausible than others. However, ranges can be misinterpreted, as audiences may assume that all values within the range are equally likely, even where the underlying distribution is not uniform. Clear explanation of the relevant assumptions, limitations, and what the range represents is therefore needed to support appropriate interpretation (Spiegelhalter, 2017).

Ensemble methods

Ensemble approaches use multiple model runs, datasets, assumptions or model structures to show how outputs vary under different conditions. They can help distinguish robust differences between scenarios or models from variation that may reflect natural variability (Kalra et al., 2017; Spiegelhalter, 2017). However, ensemble spread should not be treated as the full range of uncertainty, as models may share common assumptions, methods or biases. Communication should therefore explain what the ensemble does and does not represent, and whether decisions remain robust beyond the modelled range (Kalra et al., 2017).

Sensitivity analysis

Sensitivity analysis can be used to show how changes in assumptions, parameters or inputs affect results. This helps identify which uncertainties have the greatest influence on outcomes and where further investigation, monitoring or communication may be needed. However, sensitivity analysis should not be treated as fully exploring all plausible future conditions, particularly under deep uncertainty. Its value for communication is in making influential assumptions explicit and supporting discussion about whether decisions or interventions remain robust across a wider range of conditions (Kalra et al., 2017).

Structured expert judgement

Where data are limited or uncertainty is difficult to quantify, structured expert judgement can provide a transparent process for eliciting and documenting expert assessments. This can support more consistent communication of uncertainty by making clear the evidence considered, assumptions made, areas of agreement or disagreement, and confidence placed in the assessment. Moss (2011) highlights the importance of systematic expert judgement, calibrated uncertainty terms, and a traceable account of the evidence used to support major findings.

Bayesian methods

Bayesian methods are approaches that update estimates, probabilities or beliefs as new evidence becomes available, allowing uncertainty and changing knowledge to be incorporated explicitly into decision-making. Where used, communication should explain the prior assumptions, new evidence incorporated, and how the assessment of uncertainty has changed, consistent with broader guidance on systematic and transparent uncertainty reporting (Moss, 2011).

Approaches to communicating uncertainty

Visual communication of uncertainty is usually through diagrams, graphs and maps. There is no one 'best approach'. Instead, it needs to be tailored to audience needs and the information being communicated.

Maps

Maps can be used to display uncertainty information using an adjacent or integrated approach. Adjacent mapping is where two maps are produced, one showing the data and information, and the other the level of uncertainty (Figure 2). An integrated map shows the data and uncertainty on the same map (Figure 3). Adjacent maps are considered more appropriate when communicating to technical audiences, and integrated maps are better for the public (Charlton et al., 2025). Maps should always be uncluttered and display simple information to increase understanding, regardless of whether uncertainty is being communicated in an adjacent or integrated map.

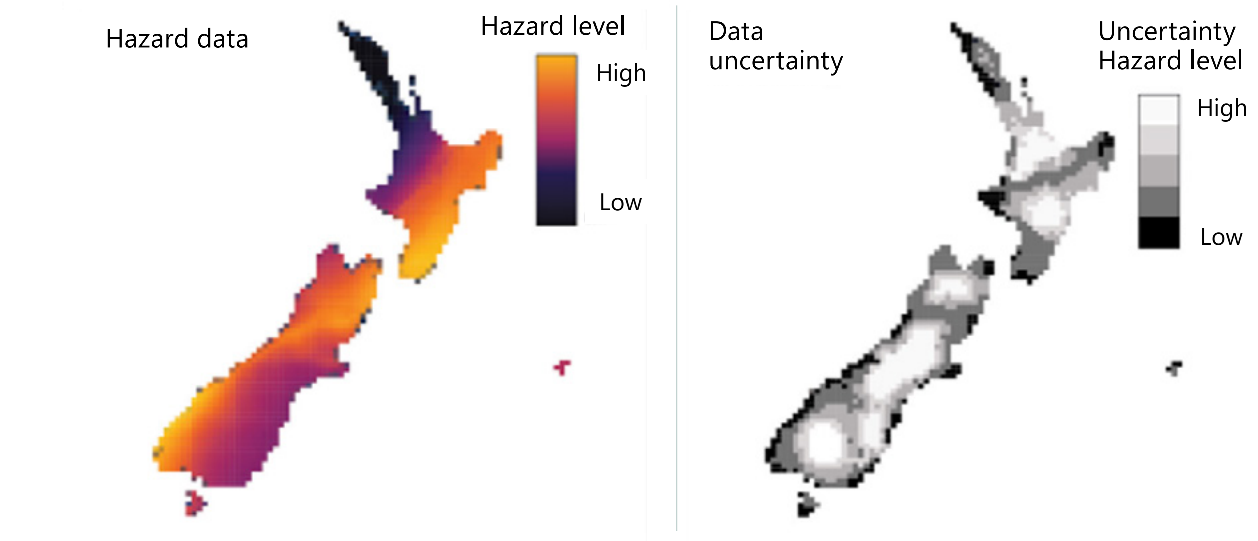


Figure 2. Adjacent maps, where uncertainty is shown on a separate map from the main data. From Charlton et al., 2025

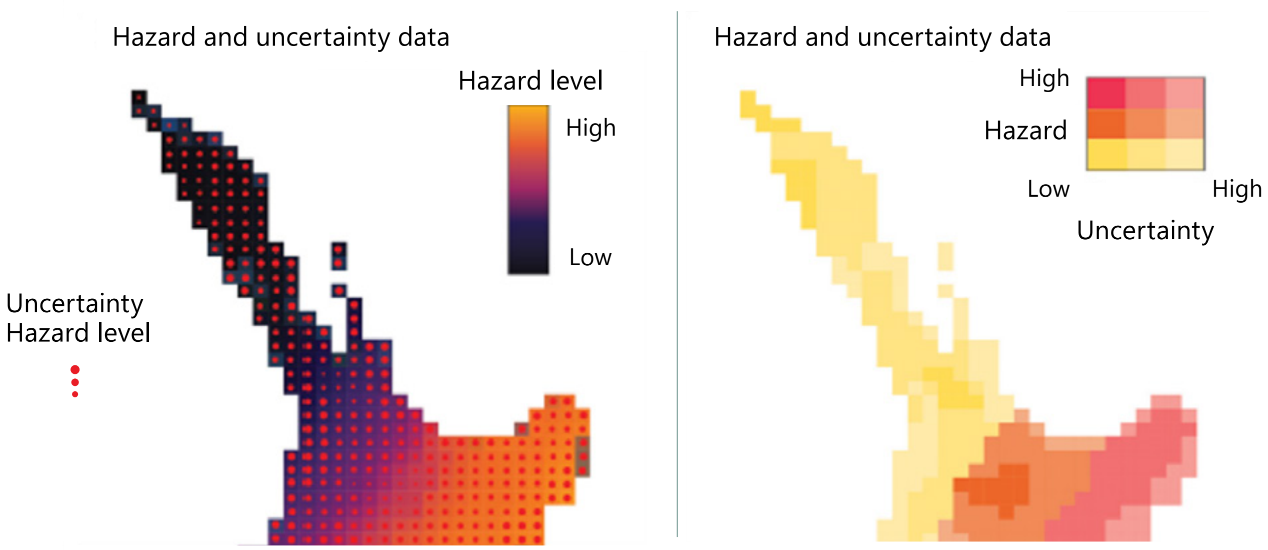


Figure 3. Integrated maps, where uncertainty is shown on the same map as the main data. From Charlton et al., 2025

Visual variables and symbology

Visual variables and symbology include colour hues, transparency, size and sketchiness. These variables can be applied across all forms of visual communication (maps, graphs and diagrams) and should be understood for how they can affect the interpretation and understanding of uncertainty (Charlton et al., 2025). Figure 4 summarises the visual variables and how they are associated with levels of uncertainty. It is important to be aware of these differences when presenting information visually as it can change how people interpret uncertainty and how they use the information. For example, dashed lines will be perceived as less certain information, regardless of whether this is intended when presenting information. This could result in applying the precautionary principle when it isn't necessary.

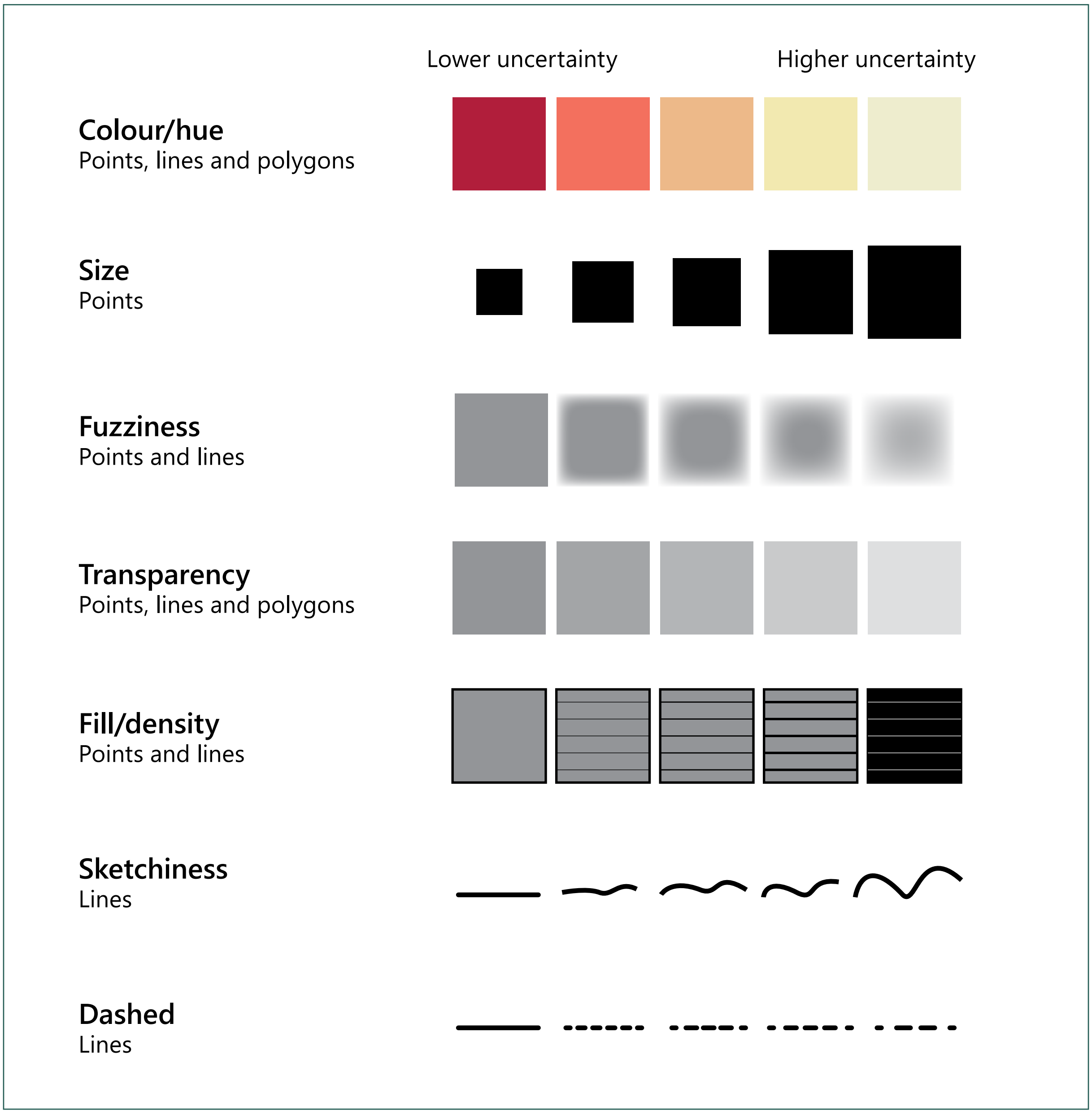


Figure 4. Various visual variables and how they influence the perception of uncertainty. From Charlton et al., 2025

Confidence scores and ratings

A confidence rating or score can be used to mark the degree of reliability or uncertainty of information (IPCC, 2022). It helps decision-makers and those consuming information understand how much trust they can place in the information being used (Van der Sluijs et al., 2005). A confidence score typically reflects the quality of the evidence base (e.g. how robust, consistent or recent it is), the level of agreement or consensus among experts, and the clarity of the underlying assumptions or models (Risbey & Kandlikar, 2007). Confidence scores or ratings are typically provided in two different formats: qualitative scoring system or as a matrix. Examples of each are provided below.

Qualitative scoring system

Qualitative scoring systems use descriptive terms (e.g. high, medium, low) to express how confident experts are in a particular piece of information or conclusion. These systems are especially useful when communicating with non-technical audiences or when numerical precision is not feasible (Spiegelhalter, 2017). An example of a qualitive confidence system is from Public Safety Canada (2012) Risk Assessment Methodology Guidelines (Table 6). This requires experts to assign a confidence measure to any estimations that they use. Low confidence levels can then signal to decision-makers where caution in the interpretation of results is required, and high confidence levels can encourage immediate action.

Table 6. Qualitative confidence scoring system. From Public Safety Canada, 2012

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

Matrix confidence scores

A matrix confidence scoring system is a structured method for expressing uncertainty by combining two or more dimensions, typically evidence quality and level of agreement, to assign an overall confidence level (Van der Sluijs et al., 2005). This approach is widely used because it provides a simple way to communicate uncertainty while also reconciling many of the components that can contribute to uncertainty.

As part of the third assessment report the IPCC developed guidance for applying a confidence rating to their information (Risbey & Kandlikar, 2007). This approach requires the evidence (including the type, amount, quality and consistency) and the level of consensus to be assessed together to give an overview of the level of confidence (Figure 5).

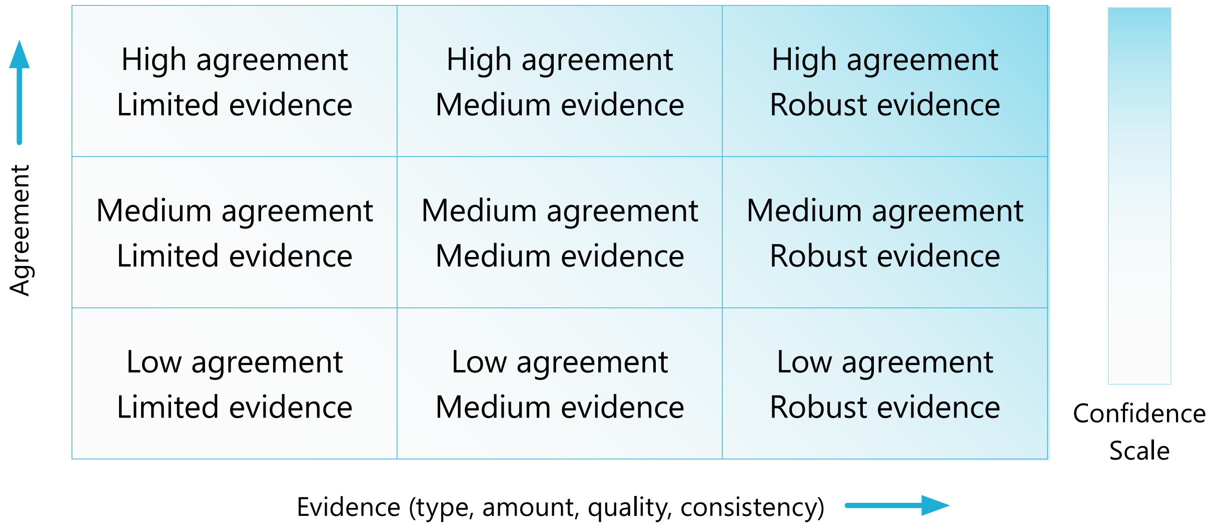


Figure 5. IPCC confidence matrix (IPCC, 2010)

The National Emergency Management Agency's Director's guidelines for CDEM Group Planning recommends assessing the supporting evidence, expertise, and participant agreement to determine a confidence level (Table 7). Incorporating the level of expertise is a useful addition compared to the IPCC approach because it allows specialist judgements to be prioritised and assessed, which can increase the certainty in information even if there is no historical evidence of an event occurring.

Table 7. Confidence matrix for CDEM risk assessment. From National Emergency Management Agency, 2023

	Supporting evidence	Expertise	Participant agreement
Lowest	• No historical events • No scientific model • Anecdotal information of historical events	No expertise is available	Fundamental disagreement of assessment
Low	Scientific model which could be applied with significant modification	Expertise is available	Disagreement of major aspects of assessment
Moderate	• Historic event of similar magnitude in a comparable community of interest • Relevant scientific model available	Relevant expertise is used to make decision	Disagreement of minor aspects of assessment
High	• Recent historical event of similar magnitude in a directly comparable community of interest • Good scientific model available	Relevant expertise is highly influential in the decision	Agreement of assessment
Highest	• Recent historical event of similar magnitude to that being assessed in the community of interest • Highest quality scientific model	Relevant and demonstrated expertise available and highly influential in making the decision	Strong agreement of assessment

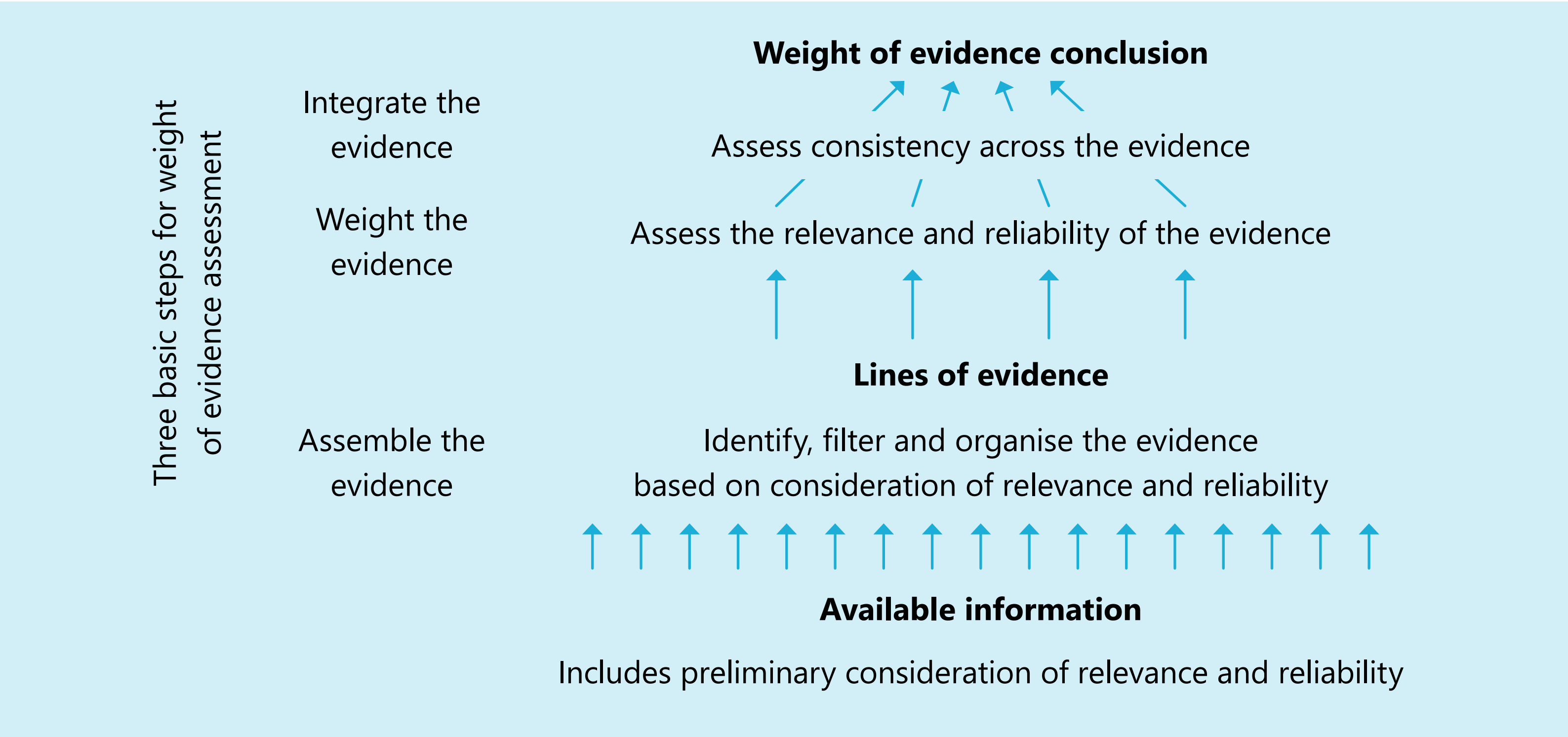
Confidence matrices can be a useful way to communicate uncertainty, but care is needed when confidence is reported alongside likelihood or probability (Risbey & Kandlikar, 2007). Although likelihood and confidence are conceptually different (as outlined earlier), presenting them together can create internal consistency challenges if the distinction is not clearly explained. For instance, assigning a high likelihood to an event while expressing low confidence in that estimate may appear contradictory. This is because likelihood describes the assessed chance of an event occurring, whereas confidence describes the level of trust that can be placed in that assessment, based on the strength of evidence, level of agreement, assumptions and limitations. This potential for confusion must be weighed against the benefits of communicating uncertainty. It is therefore important to clearly distinguish between the likelihood of an event occurring and the confidence in the data and evidence that underpins the assessment.

Bias within confidence scores and ratings

The process of assigning confidence ratings can introduce subjective bias. As Doyle et al. (2019) note, evaluating the quality of evidence and the level of expert consensus often involves judgment calls that may reflect individual or disciplinary biases. While some degree of subjectivity is unavoidable, it is essential that such assessments follow a transparent and well-documented methodology to minimise bias and enhance credibility.

The European Food Safety Authority (Hardy et al., 2017) has provided guidance for assessing evidence, which could be applied to a confidence matrix. There are three main steps to assess the evidence being used to reach a conclusion: 1) assemble the evidence, 2) weight the evidence, 3) integrate the evidence (Figure 6). The reliability, relevance, and consistency of evidence should be evaluated to determine its suitability for the question at hand, its overall quality, and its alignment with other available evidence. The consensus among experts also needs a rigorous process to avoid biases about who is being considered an 'expert'. The process for establishing expert consensus needs to be transparently documented and chosen in the context of the decision and uncertainties present (e.g. timeframe and decision importance) (Hardy et al., 2017).

Figure 6. The interaction between assessing the reliability, relevance, and consistency of evidence, with the steps for weighing the evidence. From Hardy et al., 2017



Conclusion

This literature review outlines concepts related to uncertainty, including definitions, approaches to manage and communicate it, and its inherent presence within data and information related to natural hazard risk management. By reviewing literature related to these concepts, three clear conclusions can be drawn; 1) uncertainty can lead to negative impacts on decision-making, 2) there is a clear need to communicate, and where appropriate, manage uncertainty, and 3) that uncertainty is highly complex.

Each of these conclusions are discussed in more detail below.

Uncertainty can lead to negative impacts on decision-making

When uncertainty is not effectively managed and communicated, it can negatively affect judgement, decision-making, risk tolerance, and perception of science. When uncertainty is present it can result in inaction, where decision-makers view uncertainty as indicating poor-quality information and delay or avoid decision-making in response. This can have particularly severe implications for hazard risk management where natural hazard data and information is inherently uncertain.

Conversely, high levels of uncertainty can lead decision-makers to take uninformed risks and adopt rapid decision-making approaches based on assumptions. Oversimplification of uncertainty can lead to erosion of public trust in science, misinformation and critical information being omitted, potentially impacting the quality of decisions.

Clear need to communicate uncertainty

Many of the negative impacts associated with uncertainty can be reduced through clear, consistent and transparent communication. Communicating uncertainty effectively can support confidence in the use of natural hazard information by helping decision-makers understand what is known, what remains uncertain, what assumptions have been made, and what limitations should be considered.

In many instances, acknowledging and communicating uncertainty can support a more flexible approach, including identifying where further information may be needed, where uncertainty should be monitored, and where judgement or decisions may need to remain adaptable as new evidence emerges. This is especially relevant in the context of climate change and natural hazard risk management, where uncertainty cannot be eliminated. Communicating uncertainty can also help identify areas that are less well understood, supporting future research, monitoring and knowledge development.

Uncertainty is complex

While the previous conclusions highlight the importance of identifying and effectively managing and communicating uncertainty, this conclusion acknowledges that doing so can be extremely challenging. The literature does not identify one clear best-practice approach for managing or communicating uncertainty. Instead, the approach depends on the target audience, type of decision being made, outcomes sought, and type of uncertainty.

This is because there are many differing types and degrees of uncertainty, disciplinary differences in how uncertainty is understood and perceived, and a range of contexts that require decision-making under uncertain conditions. There is a substantial body of literature and guidance on uncertainty; however, the volume of available material can make it challenging for non-experts to access and determine which approach they should take.

Recommendations

Following a detailed review of the literature summarised in this report, two recommendations can be made. First, the development of a structured methodology to assess uncertainty across natural hazards data and information and subsequently apply a confidence rating to support communicating uncertainties. Based on the conclusion drawn from this review, a methodology should reflect the following:

- A clear definition of uncertainty
- Apply a confidence scoring system that expresses reliability of information
- Focused on practical application of communicating uncertainty rather than focusing on academic or theoretical approaches to uncertainty
- Aligned to existing New Zealand legislative requirements and policy guidance for managing uncertainty

- Adaptable to audience needs and different purposes – this includes decision-makers and scientists, as well as crisis and non-crisis situations
- Compatible with other techniques for managing uncertainty, including precautionary principle, scenarios, and best-available information

Secondly, establishing a process for monitoring, reviewing, and evaluating how uncertainties are being communicated and managed. This will ensure continuous improvement, alignment with legislative requirements, and adaptability to evolving contexts. Processes for monitoring, evaluating and reviewing how uncertainty is managed should be embedded within organisational systems and revisited regularly to assess the effectiveness of uncertainty frameworks, communication strategies, and engagement practices:

- Monitoring should focus on identifying where uncertainty is being acknowledged, how it is classified and communicated, and whether it is influencing decision-making in a transparent and proportionate way.
- Evaluating should assess whether the chosen approaches are fit for purpose, aligned with legislative requirements, and responsive to stakeholder needs. This includes reviewing the use of tools such as confidence scoring systems, scenario planning and adaptive pathways.
- Reviewing should identify gaps in knowledge, inconsistencies in application, and opportunities for improvement.

These processes must be supported by clear documentation, feedback loops, and stakeholder engagement to ensure continuous learning and adaptation. By institutionalising these practices, organisations can build trust, improve decision quality, and enhance resilience in the face of complex and evolving natural hazard risks.

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Appendix 1 Legislative and policy requirements

There are legislative requirements that mandate decision-making even when there is uncertainty. These are wide ranging across numerous statutes, with examples summarised in Table A1.1 below (emphasis added).

Table A1.1 Legislative and policy requirements to consider uncertainties (emphasis added)

Legislation	Provisions
Natural Environment Bill	Section 166 (1): When deciding whether to grant or refuse an application for a natural resource permit, **a permit authority must favour caution** and environmental protection if the information available to determine the application is **uncertain or inadequate**. (2): However, if applying subsection (1) means that the application is likely to be refused, the permit authority must consider whether including a condition that requires, or conditions that form, an adaptive management approach would address the **concerns arising from the uncertainty or inadequacy** of the information. Section 167 (3): In determining the use of an adaptive management approach, the permit authority must consider— (a) whether there is adequate evidence that using an adaptive management approach will— (i) **sufficiently reduce uncertainty about the effects of the activity**; and (ii) adequately manage any remaining risk; and (d) **the degree of uncertainty about the effects of the activity**; and (e) whether and the extent to which the adaptive management approach will **sufficiently diminish the risk and the uncertainty**.

Legislation	Provisions
Planning Bill	Section 31(c): an activity should be classified as a discretionary activity if (ii) the adverse effects of the activity are **unknown or uncertain** Section 149(3): (3) In determining the use of an adaptive management approach, the consent authority must consider— (a) whether there is adequate evidence that using an adaptive management approach will— (i) **sufficiently reduce uncertainty** about the effects of the activity; and (ii) adequately manage any remaining risk; and (b) the extent of any environmental risk (including the consequences if the risk is realised); and (c) the importance of the activity for which the consent relates; and (d) **the degree of uncertainty about the effects of the activity**; and (e) whether and the extent to which the adaptive management approach will **sufficiently diminish the risk and the uncertainty**. (4) A consent authority may decide that an adaptive management approach sufficiently diminishes the risk and uncertainty if it is satisfied that Part 1 Contents of regional spatial plans Section 4(2): The spatial plan committee **must not use an uncertainty or inadequacy in the available information as a reason to omit content** from its regional spatial plan if the committee considers that including the content is necessary to meet the requirements of clause 2 or 3. (3) If the spatial plan committee is using information that is uncertain or inadequate, the committee must have regard to— (a) **the extent of the uncertainty or inadequacy**;
Building Act 2004	Primarily managed through a combination of performance-based standards, compliance pathways, and regulatory oversight mechanisms.
Resource Management Act 1991	Section 32 Requirements for preparing and publishing evaluation reports (2) An assessment under (1)(b)(ii) must (c) assess the risk of acting or not acting if there is **uncertain or insufficient information** about the subject matter of the provisions. Subpart 1AB Restrictions on section 128 reviews of conditions of extended coastal permits S165ZFHHA (3) In subsection (2), an adaptive management approach— (a) means a systematic and iterative process of decision making that **aims to reduce and manage uncertainty** about the environmental effects of an activity over time through—...

Civil Defence and Emergency Management Act 2002	Section 7: All persons exercising functions in relation to the development and implementation of civil defence emergency management plans under this Act may **be cautious in managing risks even if there is scientific and technical uncertainty about those risks**
National CDEM Plan Order 2015	Section 88 Principles The principles underlying risk reduction are to - (f) take a **precautionary approach** to managing hazards and risks where there is (i) **scientific or technical uncertainty about a hazard or risk**; or (ii) potential for cumulative or cascading risks to arise.
Local Government Act 2002	Section 101B Infrastructure strategy (4) The infrastructure strategy must outline the most likely scenario for the management of the local authority's infrastructure assets over the period of the strategy and, in that context, must— (c) include the following assumptions on which the scenario is based: (i) the assumptions of the local authority about the life cycle of significant infrastructure assets: (ii) the assumptions of the local authority about growth or decline in the demand for relevant services: (iii) the assumptions of the local authority about increases or decreases in relevant levels of service; and (d) **if assumptions referred to in paragraph (c) involve a high level of uncertainty,—** **(i) identify the nature of that uncertainty; and** **(ii) include an outline of the potential effects of that uncertainty.**
Policy	
New Zealand Coastal Policy Statement (s58 RMA)	Policy 3 - 1. Adopt a **precautionary approach** towards proposed activities whose effects on the coastal environment are **uncertain, unknown, or little understood, but potentially significantly adverse**. 2. In particular, adopt a **precautionary approach** to use and management of coastal resources potentially vulnerable to effects from climate change, so that: a. avoidable social and economic loss and harm to communities does not occur; b. natural adjustments for coastal processes, natural defences, ecosystems, habitat and species are allowed to occur; and c. the natural character, public access, amenity and other values of the coastal environment meet the needs of future generations.

Legislation	Provisions
National Policy Statement - Natural Hazards (s45A RMA)	Policy 5: Natural hazard risk assessment and decisions must be based on the best available information and must be made even when that information is **uncertain or incomplete** Clause 3.4 (2) When information is **uncertain or incomplete**, decision-makers must continue to undertake risk assessments and make decisions using the best available information and **not delay making decisions solely because of uncertainty about the quality or quantity of the information available**.
Guidance	
NZCPS 2010 Guidance Note -Policy 3: Precautionary approach	Guidance for the implementation of the precautionary approach in the NZCPS. Contains guidance on related objectives and policies, implementation, case law, example provisions, and a glossary of terms and explanations.
MFE Coastal Hazards & Climate Change	Advocates for uncertainty to be assessed and considered in decision making. For example: “Making decisions under uncertain conditions will always involve judgements based on the available knowledge and appraisal of a range of projections. Not acting in the face of deepening uncertainty also involves considerable risk. Instead, **uncertainty needs to be accounted for** by considering a wide range of plausible future conditions in developing an adaptive planning strategy” (p26).
NZSEE, SESOC & NZGS Earthquake Design for Uncertainty - Advisory, 2022	The purpose of this guidance is to reiterate the importance of designing buildings so that they behave in a predictable, desirable manner when subject to earthquake shaking, which mitigates the risks of uncertain demands. The principles outlined in the advisory describe fundamentally good structural engineering practice that is effective at reducing risk irrespective of whether codified seismic hazard is considered stable or not.

Natural Hazards Commission
Toka Tū Ake