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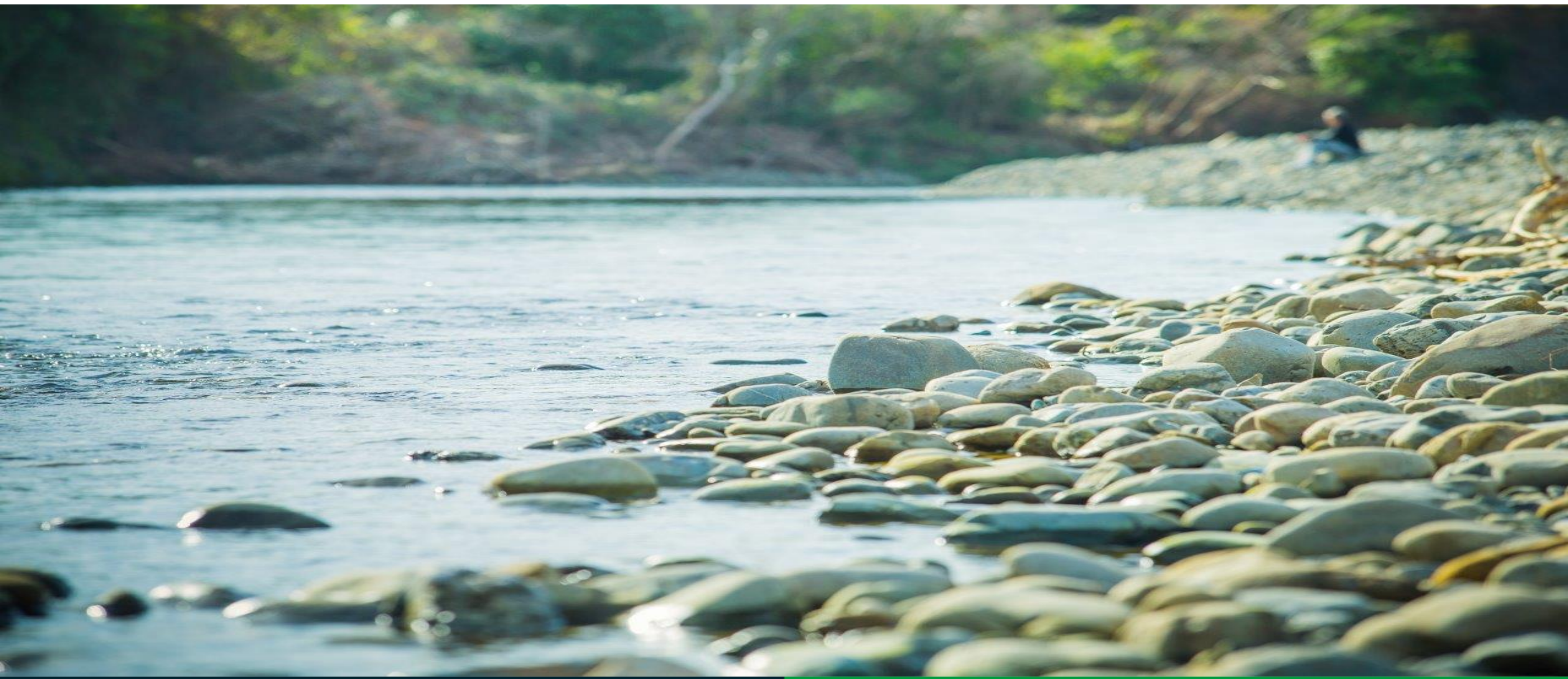

NATIONAL POLICY STATEMENT FOR FRESHWATER MANAGEMENT 2014

A Guide to Communicating and Managing Uncertainty

When Implementing the National Policy Statement for Freshwater Management 2014

New Zealand Government

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1 Introduction

1.1 Purpose of this guide

The National Policy Statement for Freshwater Management 2014 (NPS-FM) requires regional councils to integrate the management of fresh water with the management of land and the coastal environment. Councils must establish objectives for fresh water, and set water quantity and quality limits in their plans, following a prescribed, nationally consistent process. Tāngata whenua roles and interests must be provided for, and councils must develop monitoring plans to measure progress towards achieving the fresh water objectives, and accounting systems to better understand water takes and sources of contaminants, and to manage within limits.

In giving effect to councils' obligations under the NPS-FM, much of the required decision-making will be made based on uncertain information. This guide provides practical considerations, principles and methods aimed primarily at helping regional council staff identify, assess, communicate and manage uncertainty. It may also be useful for iwi and hapū or community participants in regional freshwater planning processes to better understand these issues.

1.2 Document structure and relationship to other guides

This guidance document is structured as follows:

Section 1 introduces the guidance and key terminology to be used.

Section 2 recommends and introduces the use of three stages in managing uncertainty.

Section 3 provides detail on Stage 1 – assessing and reducing uncertainty.

Section 4 provides detail on Stage 2 – communicating uncertainty and risk.

Section 5 provides detail on Stage 3 – making decisions under uncertainty.

Section 6 provides a summary of key messages.

This guide is part of a series of documents supporting implementation of the NPS-FM. This guide on uncertainty is relevant for all aspects of implementing the NPS-FM, but is particularly pertinent for the process of establishing fresh water objectives and setting limits, and especially when a collaborative process is used. While communicating uncertainty is important in all policy processes, it is even more challenging in collaborative processes because of the need for a wide range of participants to understand and weigh uncertain information.

1.3 What is uncertainty?

> "There are some things that you know to be true, and others that you know to be false; yet, despite this extensive knowledge that you have, there remain many things whose truth or falsity is not known to you. We say that you are uncertain about them. You are uncertain, to varying degrees, about everything in the future; much of the past is hidden from you; and there is a lot of the present about which you do not have full information. Uncertainty is everywhere and you cannot escape from it."[1]

Uncertainty is the situation involving imperfect and/or unknown information. It applies to physical measurements that are already made, to predictions of future events, and to the unknown. We are all, in our daily lives, frequently presented with situations where a decision must be made when we are uncertain of exactly how to proceed.

Uncertainty is a word used in subtly different ways in a number of technical fields. However most uncertainties fall into three broad types[2] that are useful in the context of the NPS-FM:

i. **Natural variability** refers to the natural variations in many aspects of the environment that we measure. For example, flows and contaminant concentrations in a river vary in time, and contaminant leaching rates vary in space. This variation is an inherent part of the environment and cannot be reduced by collecting more information. Assessments often deal with inherent variability, however, by presenting statistics such as the mean or median river flow or contaminant concentration. Such statistics are estimates of "true" values because they are always made from a limited number of samples and the more samples taken the better the estimate will be. The uncertainty associated with statistical estimates can be quantified, as well as reduced by gathering more data. This is described later. In other words, while natural variability in the environment cannot be reduced, our understanding of that variability can be improved.

ii. **Model and parameter uncertainty** includes uncertainty due to the limited scientific knowledge about the nature of models that link causes, environmental effects and mitigation actions, as well as uncertainty about model parameters. There may be disagreements about the model, such as which model is most appropriate for the purpose at hand, which variables should be included, the model's functional form (eg, whether the relationship being modelled is linear, exponential or some other form), and how much data collected in another context can be generalised to the problem at hand. Model and parameter uncertainty can sometimes be quantified and reduced through technical effort, as described later.

iii. **Deep uncertainty** is uncertainty about the fundamental processes or assumptions underlying an assessment, which is not likely to be reduced by additional technical work within the time period in which a decision must be made.[3] Typically deep uncertainty is present when:

    - underlying environmental processes are not understood
    - there is lack of consensus among scientists about the nature of an environmental process

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1 Lindley (2006).

2 For example as used in *Environmental decisions in the face of uncertainty* (IOM 2013).

3 Note that deep uncertainty is not necessarily unknowable; future work beyond the decision at hand may reduce it later.

- methods are not available to characterise the process.

Deep uncertainty also applies to future unknown changes in the social, economic and technological context of the decision.

For example, in a typical limit-setting project under the NPS-FM, a technical team will deal with:

- *natural variability* in river flows and water quality indicators from day to day and between seasons and years
- *modelling uncertainty* because of poor data for many of the small streams, and lack of clarity around the likely impact of changes to river flows and water quality on indicators of ecological and other values.

There is typically *deep uncertainty* about many things, including the long-term implications of climate change and future market conditions for particular land and water resource uses (eg, hydropower generation and dairy farming). There is also deep uncertainty about future advances in technology to mitigate adverse effects, and about some basic environmental processes such as recharge of deep groundwater resources and complex interactions between ground- and surface water.

1.4 Terminology around uncertainty and risk

It is useful, and indeed necessary, to establish some terminology around how uncertainty relates to risk, and to risk management. This terminology is necessary in order to follow the concepts and approaches suggested throughout the remainder of the guide.

While risk, like uncertainty, is a term used in subtly different ways across many fields, the Australian and New Zealand International Standard for risk management[4] provides definitions for a handful of terms that are useful in the context of implementing the NPS-FM. The following terms are taken from either the Standard or the Resource Management Act (RMA) (as identified in footnotes), and will be used consistently throughout this guide.

- **Uncertainty** is "the state, even partial, of deficiency of information related to understanding or knowledge of an event, its consequence, or likelihood".[5]
- **Risk** is the "effect of uncertainty on objectives"; "risk is often characterised by reference to potential events and consequences, or a combination of these"; and "risk is often expressed in terms of a combination of the consequences of an event and the associated likelihood [or probability] of occurrence."[6] In the context of the NPS-FM, the events and consequences we are typically interested in are, respectively, effects of resource use (see below) and attainment of (or failure to attain) outcomes (eg, fresh water objectives and other environmental, social, economic and cultural outcomes). Effects and outcomes may be of various magnitudes and/or significance.
- **Effects** under the RMA definition[7] include any positive or negative impact on social, cultural, economic or ecological values. They include temporary, permanent and cumulative effects, regardless of the scale. The RMA also specifically refers to the need to include consideration of

4 Standards New Zealand (2009).

5 Ibid.

6 Ibid.

7 Section 3 of the RMA.

any potential effect of high probability and any potential effect of low probability that has a high potential impact. The RMA thus implicitly requires consideration of risk when dealing with potential (ie, uncertain) effects.

- **Likelihood** is the "chance of something happening, whether defined, measured or determined objectively or subjectively, qualitatively or quantitatively, and described using general terms or mathematically (such as a probability)".[8] Likelihood is often used more narrowly as a qualitative description of probability, used when the chance of an event cannot be expressed numerically, and is thus used in qualitative risk assessment approaches.[9] Likelihood will be used with this qualitative meaning in this guide to distinguish it from probability (see below).

- **Probability** is "the chance of something happening … described mathematically".[10] Probability is a numerical measure and can be used in quantitative risk approaches.

- **Risk management** is "the application of management policies, procedures and practices to the activities of communicating, consulting, establishing the context, and identifying, analysing, evaluating, treating, monitoring and reviewing risk".[11] Risk can never be entirely eliminated, as all decisions involve risk; even deferring a decision involves risk. Risk management involves establishing the nature of a risk in terms of likelihood and consequence, and the context for management (eg, the socio-political setting and ability to respond), and then developing a strategy to manage the risk. It is an approach to set the best course of action under uncertainty by identifying, assessing, understanding, acting on and communicating risk.[12]

Three important points arise from the relationship between uncertainty and risk that will be built on throughout this guide. First, because "risk is the effect of uncertainty on objectives" the terms risk and uncertainty are inseparable – whenever the term uncertainty is used in this guide it is implicit that there will be risk, and vice versa.

Second, it is useful in the context of implementing the NPS-FM to express risk and uncertainty in terms of consequences and likelihood (or probability) of occurrence; that is, the standard approach to risk assessment is useful. A recurring theme in this guide will be the recommendation to predict effects and/or attainment of given outcomes (eg, fresh water objectives) in terms both of their likelihood (or probability), and their magnitude and/or significance (ie, the two key components of risk), under any particular limit-setting scenario being considered.

Third, it is rare in NPS-FM limit-setting processes to have sufficient information to confidently assign numeric probabilities to effects or attainment of outcomes, or to quantify the magnitude of, or identify, all possible effects. Giving effects and outcomes a level of significance requires value judgements about the relative significance of multiple, sometimes conflicting, effects and outcomes. These judgements may be informed by technical work, but are ultimately part of decision-making. Usually it is possible for technical teams supporting the limit-setting processes to estimate the nature of possible effects, describe their significance, and make qualitative or semi-quantitative assessments of their likelihood, based on community and technically informed analysis and expert judgement.

8 Standards New Zealand (2009).

9 For example see Environmental Risk Management Authority (2009).

10 Standards NZ (2009).

11 Ibid.

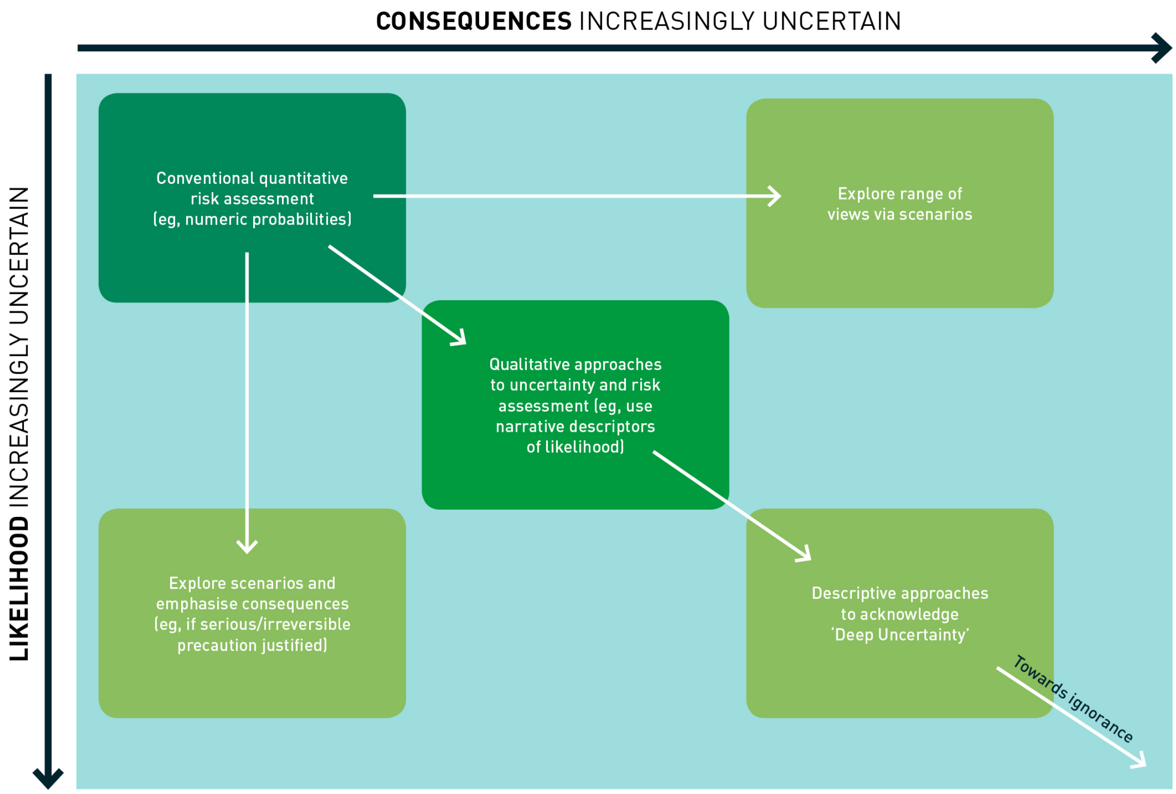
12 Cameron (2006).

What this means is that NPS-FM processes typically need a mix of quantitative and qualitative approaches to assess uncertainty and risk. Methods for doing this vary as uncertainty increases, as illustrated in figure 1, even to the point of complete ignorance (ie, unknown unknowns). The range of methods alluded to in figure 1 will be described in more detail throughout this guide.

Box 1 – Key messages about how uncertainty relates to risk

1. The terms ‘uncertainty’ and ‘risk’ are inseparable – wherever one term is used in this guide the other is also implied.
2. For limit-setting processes under the NPS-FM, it is useful to predict effects and/or achieving outcomes (eg, fresh water objectives) in terms of likelihood of this occurring and the magnitude and/or significance of the effect or outcome.
3. NPS-FM processes typically require a mix of quantitative and qualitative approaches to assess uncertainty and risk (eg, figure 1).

Figure 1: How methods for tackling uncertainty, and therefore risk, change as the degree of uncertainty about likelihood and consequence increases[13]



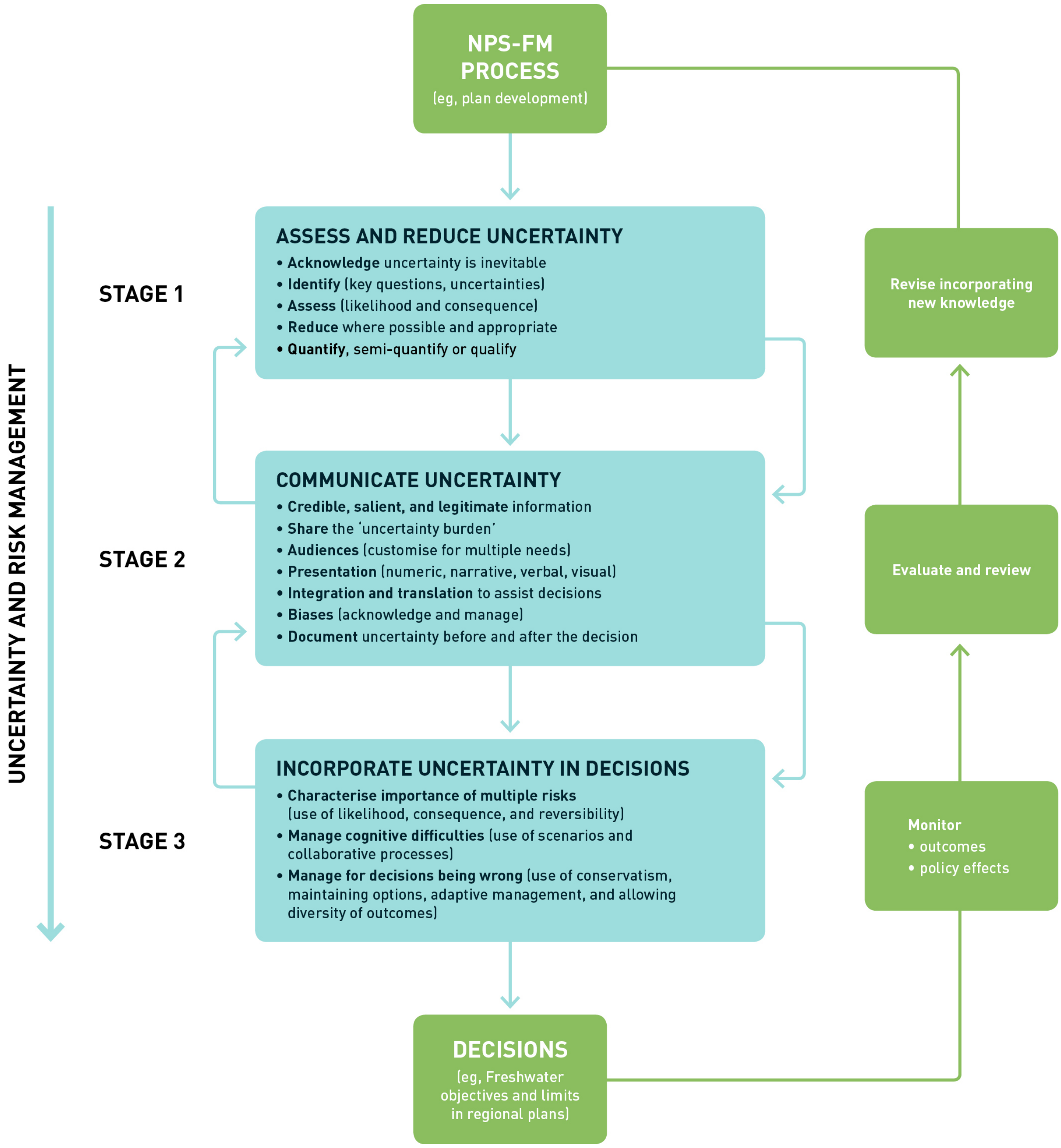
[13] Adapted from POST (2004).

2 Managing uncertainty in three stages

> "The big environmental problems of today make it difficult, and often impossible, to rely on science providing unequivocal 'facts' on which to base policies. Instead, we need to respond intelligently to the imperfections of science in forming policy decisions, but in a way that makes sensible use of the available scientific knowledge, in the context of other information… [An] approach proposes that we embrace uncertainty, work to reduce it where possible, incorporate uncertainty more transparently in the policy process and recognise the need to develop more sophisticated self-critical policy models in the process." (Parliamentary Commissioner for the Environment, 2004)

Developing policy for freshwater management under the National Policy Statement for Freshwater Management 2014 (NPS-FM) requires councils to form multidisciplinary teams with community participants. While there are many possible approaches to managing uncertainty and risk along the way, the most relevant and useful approaches for these teams can be organised into three stages, as illustrated in figure 2. This guide is structured to lead the reader through these three stages.

Figure 2: Three stage iterative process to manage uncertainty in NPS-FM processes



3 Stage 1: Assessing and reducing uncertainty

3.1 Identify and acknowledge sources of uncertainty

In any project under the National Policy Statement for Freshwater Management 2014 (NPS-FM), a critical step is to acknowledge that uncertainty is everywhere, is inevitable and is normal in natural resource management and planning. It is useful to identify the main sources of uncertainty that contribute to a particular problem, so that each source may be assessed, reduced, characterised, communicated and then incorporated appropriately into decision-making (see figure 2).

Identification of uncertainties begins at the outset of a project and should be continually revisited. Identifying key uncertainties early will strongly influence good project and process design. To do this it is important to develop a conceptual understanding of the catchment under consideration as a system, including the biophysical, social, cultural and economic components, and their linkages. Conceptual diagrams are a useful tool to help discuss and refine the conceptual understanding of the system and its parts (figure 3). They help to frame key technical questions in limit-setting projects, such as:

- How do water and contaminants move through the landscape?
- What are the main land and water resource use pressures and their effects on attributes and values?
- What types of limits to resource use are therefore required?
- What possible alternative futures (ie, scenarios) should be explored and what would be the consequences of each for environmental, social, cultural and economic values?[14]

Conceptual diagrams also help identify technical and other knowledge providers that will be needed as part of the team. It is then possible for the team to begin to address the key project questions, and identify the uncertainties of each part, the system as a whole, and outside influences. It is useful to seek alternative views, which may be based on local experience not known to technical experts, and discuss these. Consulting widely helps identify uncertainties that need attention early, saving difficulties later in a project if the conceptual understanding proves to be incorrect or contested.[15]

The process of identifying uncertainties carries on throughout a project. The later steps to assess, reduce, quantify and communicate uncertainty will be repeated as learning and understanding about the system and its interactions grows. This is illustrated by the feedback arrows in figure 2.

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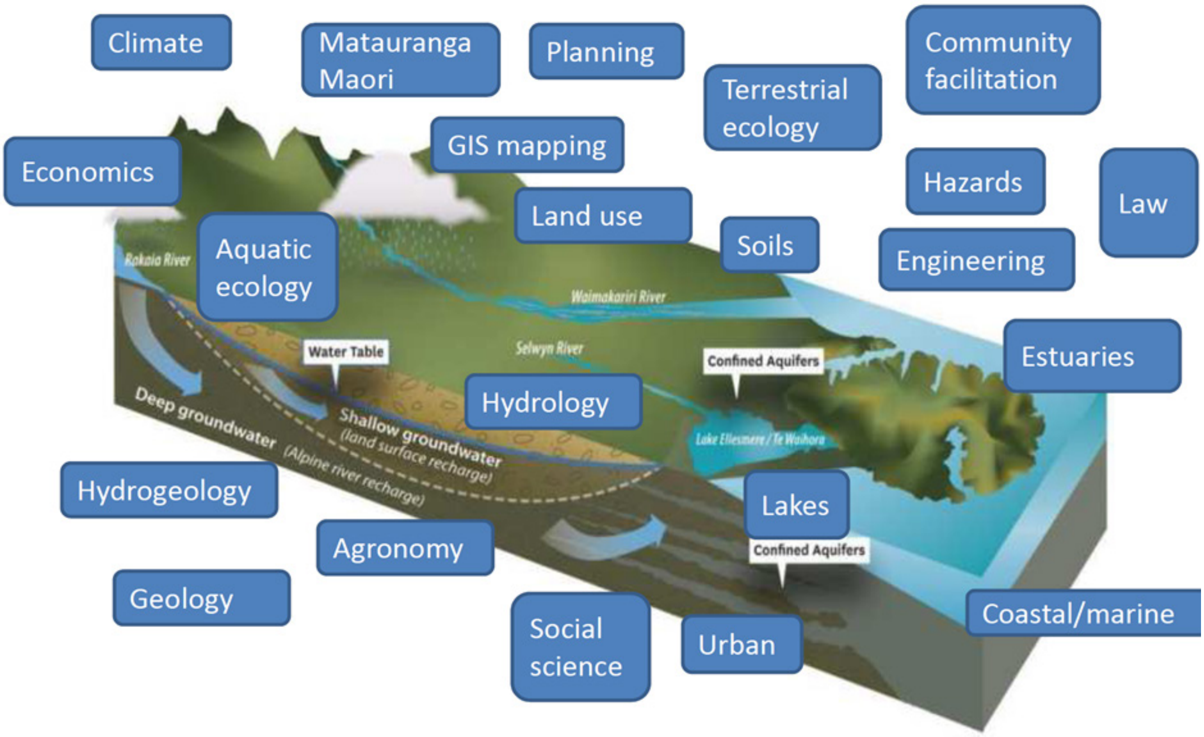
14 These examples are all important technical questions in addressing Part CA2 of the NPS-FM.

15 For example see Dodson (2015).

Figure 3: Conceptual illustration of typical system components to be considered



3.2 Assessing and reducing uncertainty

Assessing uncertainty involves:

- identifying whether the uncertainty is natural variability, model uncertainty, or deep uncertainty (as outlined in section 1.3), and therefore whether it can theoretically be reduced
- identifying how the uncertainty relates to risk (see section 1.4), ie, the uncertainty relating to a consequence (eg, the magnitude of an effect or outcome) and to the likelihood of that effect or outcome occurring[16] (this may help with the next step)
- prioritising the uncertainty's likely importance in the decision-making process and decision
- determining how much effort to put into reducing the uncertainty.

Deep uncertainties (see section 1.3) are, by definition unlikely to be able to be reduced during a project timeframe. These uncertainties must instead be acknowledged and made transparent through effective communication. This is not to say that all deep uncertainties are unknowable forever, because future work beyond the decision at hand may improve knowledge later. It is useful to acknowledge, however, what can and cannot be achieved in the timeframe. Most of the effort in reducing uncertainty must therefore focus on characterising inherent natural variability and model uncertainty.

16 For example as recommended in Environmental Risk Management Authority (2009).

The extent to which some uncertainties of these types can be reduced will depend on the time and budget resources available. In general, longer timeframes and larger budgets allow key project questions to be more thoroughly addressed, and uncertainty reduced. Judgements on the cost-effectiveness of extra effort are constantly needed, however. It is important not to use the search for more information to avoid dealing with uncertainty, or as a reason not to act at all.

Uncertainties associated with estimating natural variability are technically the simplest to reduce because it is usually a matter of more intensive measurement at more sites for longer time periods. For example, ecological and water quality sampling can be undertaken at more sites, in more rivers and lakes, more frequently and/or over longer time periods, to better characterise spatial and temporal variability in the measure of attributes used to describe freshwater objectives and limits.

Uncertainties associated with predictive models and their parameters may also be reduced by employing greater technical effort. This could involve:

- more relevant models
- greater calibration and validation effort
- more fundamental research
- more experienced and/or specialised experts
- more substantial peer review processes.

More complex models may or may not reduce uncertainty, and they usually make uncertainties less visible because complex assumptions and calculations are performed unseen inside the model. Employing more than one model to make independent parallel predictions can be useful for establishing converging lines of evidence, thus potentially increasing confidence (ie, reducing uncertainty) in predictions.

It is useful to regularly revisit the key project questions and assess whether further effort would be likely to alter the resource management decisions required. Logically, if the uncertainty is not expected to affect a decision, then no further analysis is required. For example, if a particular uncertainty mainly relates to risks that are not considered to be dominant compared to others in the project, then there may be little merit in exploring that uncertainty too far. It is useful to consider 'scale and significance'[17] of effects and uncertainties when prioritising and deciding on the effort required, as illustrated in figure 4. An example of this approach can be seen in the proposed draft national environmental standard for determining which methods, and so the level of effort and resulting uncertainty, to use for determining ecological flows.[18] Some degree of uncertainty is unavoidable, and efficient, effective decision-making relies on sound judgement of 'how much effort is enough'.[19]

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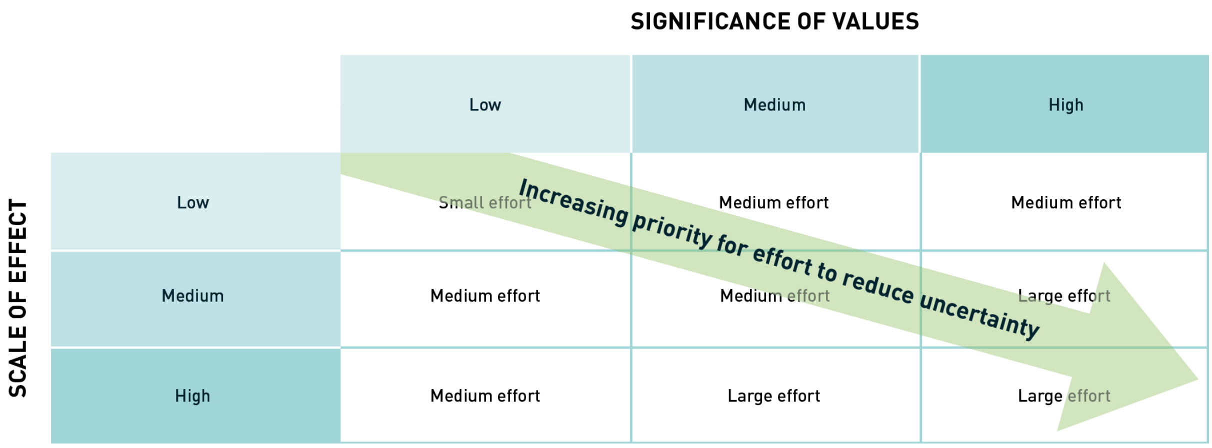
17 As used in several places in the RMA to guide judgements in situations where an appropriate level of detail or effort will vary according to a particular situation. That is, it implies this variable effort in information collection and assessment will assist decision making.

18 See Table A4.3 in Beca (2008).

19 Environmental Risk Management Authority (2009).

Figure 4: Consideration of 'scale and significance' in prioritising effort to reduce uncertainty



Box 2 – Summary of approaches for assessing and reducing uncertainty

- Assess the type and nature of uncertainties and associated risks.
- Assess priorities – which uncertainties justify the effort to reduce?
- Consider the merits and costs of gathering more data.
- Consider the pros and cons of using more sophisticated models.
- Consider more technical expertise, research, and/or peer review.
- Consider multiple parallel methods to produce converging lines of evidence.
- Making cost-effective decisions concerning effort to reduce uncertainty.

3.3 Quantifying uncertainty where possible

As a project progresses and uncertainties are reduced as much as possible with the time and resources available, it is useful to characterise the key remaining uncertainties:

- quantitatively (where possible)
- by semi-quantitative or qualitative means.

Estimating the likelihood and consequences of any effect can vary from providing full quantitative estimates (eg, numeric probabilities), to qualitative estimates (eg, use of narrative descriptors of likelihood), to weak descriptions where there is deep uncertainty, to complete ignorance about unknowns (see section 1.4, figure 1 for more information).

Typically in NPS-FM limit-setting processes there are some quantifiable parts of problems that can be expressed in numeric terms (eg, using probability density functions or confidence intervals), but very often the uncertainty cannot be assessed in this way. For example, when an assessment of whether a defined outcome (eg, a fresh water objective) will be achieved is produced by a long chain of analytical steps in which the final answer depends on many preceding estimates, all of which have uncertainty. While some analyses in the chain may have uncertainties that can be expressed as numeric probabilities, it is usually appropriate to communicate the overall uncertainty using narrative descriptors of likelihood, because using numeric probability may suggest greater confidence than is actually the case.

How much uncertainty can be quantified depends on the type of uncertainty and the technical resources available. Quantitative characterisation of uncertainties is diverse, varies across technical disciplines, and is in some cases very technical. Some simple examples are described below for each of the three types of uncertainty.

Uncertainties in estimating aspects of the environment that have '*natural variability*' can be shown by describing the average (mean) or median, and using a range of data (eg, maximum, minimum, quartiles etc) and the standard error of the mean.

Uncertainties in predictive '*models and their parameters'* can be expressed using a variety of methods that vary by technical discipline. For example, a typical modelling process will ideally use a subset of field data for calibrating the model, and a separate subset for running an independent validation. This will allow an estimate of model error; that is, where the predictions depart from actual measurement over the validation data period, and this can be used to calculate statistical errors (see example in box 3). Other technical methods that can be used to show model uncertainty include sensitivity analysis, probabilistic (Bayesian) analysis, and Monte Carlo analysis.

Box 3: Example – Quantifying uncertainty in a Lake Benmore water quality model[20]

A model was built to predict the consequences of increased nutrient loads (from intensification of land use) on water quality in Lake Benmore. Despite data covering only short time periods, quantitative estimates of uncertainties were produced by calculating absolute and normalised root-mean-square-errors, and comparing these with errors reported in other published studies for context.

Other methods were also used to provide converging lines of support for the model predictions, including comparing predicted variables with values in the literature, and using results from a purpose-designed, in-lake experiment. In this experiment, nutrients were artificially added to controlled mesocosms (enclosures) and the growth response of algae and colour of the water measured. All these methods helped quantify and describe uncertainty in the model predictions.

The Lake Benmore model outputs helped inform a series of irrigation consent hearings, and has since been refined and used to inform a collaborative community process to establish objectives and limits in the upper Waitaki catchment.

See: http:/ecan.govt.nz/publications/Reports/report-lake-benmore-water-quality-000809.pdf.

[20] Reported in Norton et al (2009).

Where it is not possible to quantify uncertainties (eg, using probability density functions or confidence intervals), qualitative estimates of the outcome being achieved should still be considered in making the decision. For example, expert judgement can be used to express the likelihood that a particular outcome will be achieved (eg, a fresh water objective defined by a threshold for an NPS-FM attribute), using narratives like those shown in table 1. This is useful and valid provided the basis for estimates is transparently communicated, and appropriately reviewed by peers, stakeholders and community.

In some situations it may be useful to guide technical experts in a team to make consistent narrative estimates of likelihood, by aligning the narrative likelihood descriptors with approximately equivalent probabilities (table 1). This can clarify the narrative descriptors so that experts in different technical disciplines treat them in the same way in a given project.[21] This allows the uncertainty of different assessments to be more easily integrated and compared, as discussed later in section 4.4.

Table 1: Probability scale and alternative narrative scales of likelihood[22]

Probability	Intergovernmental Panel on Climate Change (IPCC) scale[23]	Scale based on legal standards of proof[24]	Environmental Risk Management Authority (ERMA) scale[25]
100%	–	Beyond any doubt	–
>99%	Virtually certain	Beyond a reasonable doubt	Highly likely
90–99%	Very likely	Clear and convincing evidence	Highly likely
80–90%	Likely	Clear showing	Highly likely
67–80%	Likely	Substantial and credible evidence	Likely
50–67%	About as likely as not	Preponderance of evidence	Likely
33–50%	About as likely as not	Clear indication	Unlikely (occasional)
10–33%	Unlikely	Probable cause, reasonable belief	Very unlikely
1–10%	Very unlikely	Reasonable grounds for suspicion	Highly improbable
<1%	Exceptionally unlikely	No reasonable grounds for suspicion	Highly improbable
0%	–	Impossible	–

Note: Dashes (–) indicate that no equivalent point is provided in the IPCC and ERMA scales.

In addition to defining uncertainties in terms of the likelihood of effects or outcomes being achieved, decision-makers need to understand if the effects are reversible or irreversible, temporary or permanent, and whether there might be time lags before effects are observed. All of these things contribute to the context for risk management,[26] and they should be assessed and communicated.

21 For example, as used by IPCC in their climate change assessment reports. See Mastrandrea et al (2010).

22 Adapted from Weiss (2003), Environmental Risk Management Authority (2009), and Mastrandrea et al (2010).

23 Mastrandrea et al (2010).

24 Weiss (2003).

25 Environmental Risk Management Authority (2009).

26 See definition of risk management in section 1.4, including the 'context' of the risk.

'Deep uncertainties' by definition cannot be quantified within the project timeframe. It may not even be possible to qualitatively characterise these in the timeframe for the project. Some deep uncertainties may never be quantified. Nevertheless, these uncertainties (and processes giving rise to them) can be described, given context, and made transparent for decision-making.

Box 4 – Summary of methods and approaches for quantifying uncertainty

- Consider how much the uncertainty can be quantified.
- Use data ranges, standard errors and confidence intervals to quantify uncertainties associated with sample statistics such as the mean and median, where appropriate.
- Quantify uncertainty associated with model predictions where possible (eg, statistical errors, sensitivity analysis, Monte Carlo and other technical methods).
- Develop semi-quantitative or qualitative methods where full quantification is not possible, and express results using narrative descriptors of likelihood (eg, very likely, likely, about as likely as not, unlikely, very unlikely).
- Acknowledge limitations and ignorance.

4 Stage 2: Communicating uncertainty and risk

4.1 Communication is critical

Implementing the National Policy Statement for Freshwater Management 2014 (NPS-FM) requires values-based decisions, especially to set objectives and limits. The different values must be weighed, as well as the values and their associated assessment uncertainties. Communicating uncertainty to stakeholders and decision-makers is therefore a critical part of making decisions on limits.

New Zealand research into what the public thinks about science found that in general:[27]

- "New Zealanders are not inclined to take scientific claims on trust. They are likely to judge research as irrelevant or unconvincing if they do not understand the research methods and/or the meaning of evidence is not immediately apparent."
- "Openness about uncertainty is seen as evidence of honesty on the part of scientists. Open acknowledgement of areas of uncertainty and new questions are preferable to bland assurances of safety or predictability."

It is critical for effective communication that information for public policy development is credible, salient and legitimate.[28] To achieve this, active, iterative and inclusive communication is crucial between experts, the participants of a public process, and decision-makers.[29] It has also been shown that this communication builds social trust and broader acceptance of decisions in the community.[30]

Recent experience by regional councils implementing the NPS-FM is that communicating complex information and associated uncertainties is much easier said than done.[31] It is fundamental, however. Communicating uncertainty is not only a professional responsibility for technical contributors to policy development,[32] doing so shares the burden of uncertainty with the community and provides for more transparent decision-making (box 5).

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27 Parliamentary Commissioner for the Environment (2004).

28 'Credible' means the information is perceived by relevant stakeholders to be scientifically accurate and technically believable. 'Salient' means the assessment is relevant to the needs of policy and decision-makers. 'Legitimate' means the information is the outcome of a process that is seen as procedurally unbiased and fair (Cash et al, 2003; Parliamentary Commissioner for the Environment, 2004).

29 For example, Gallopin et al (2001).

30 For example see Institute of Medicine (2013) and Duncan (2008; 2013).

31 See Fenemor (2014), Macdonald et al (2014), Norton and Robson (2015), Rouse et al (2014), Henley (2014).

32 For example, Gluckman (2013).

Box 5 – A key message is: "Communicating uncertainty shares the burden"

- Scientists and other technical contributors to a public policy process have a responsibility to identify and communicate the uncertainties in their work.
- Acknowledging uncertainty can relieve the burden felt by scientists who are often unreasonably expected to have high confidence in their conclusions.
- When uncertainty is communicated its burden is shared amongst technical people, the community, and decision-makers, and decisions can be more transparent.
- Limit-setting decisions require weighing of values and their uncertainties. Communicating uncertainty is therefore critical for good decision-making.

4.2 Identify target audiences

Identifying target audiences is critical to tailoring communication techniques to their different needs. In a typical NPS-FM project or process there will be several different audiences to consider, including various community groups, iwi and hapū, and other stakeholders, scientists, planners, lawyers, technical peer reviewers, community decision-making committees, and ultimately plan hearing commissioners. All these require information communicated at different levels of detail.

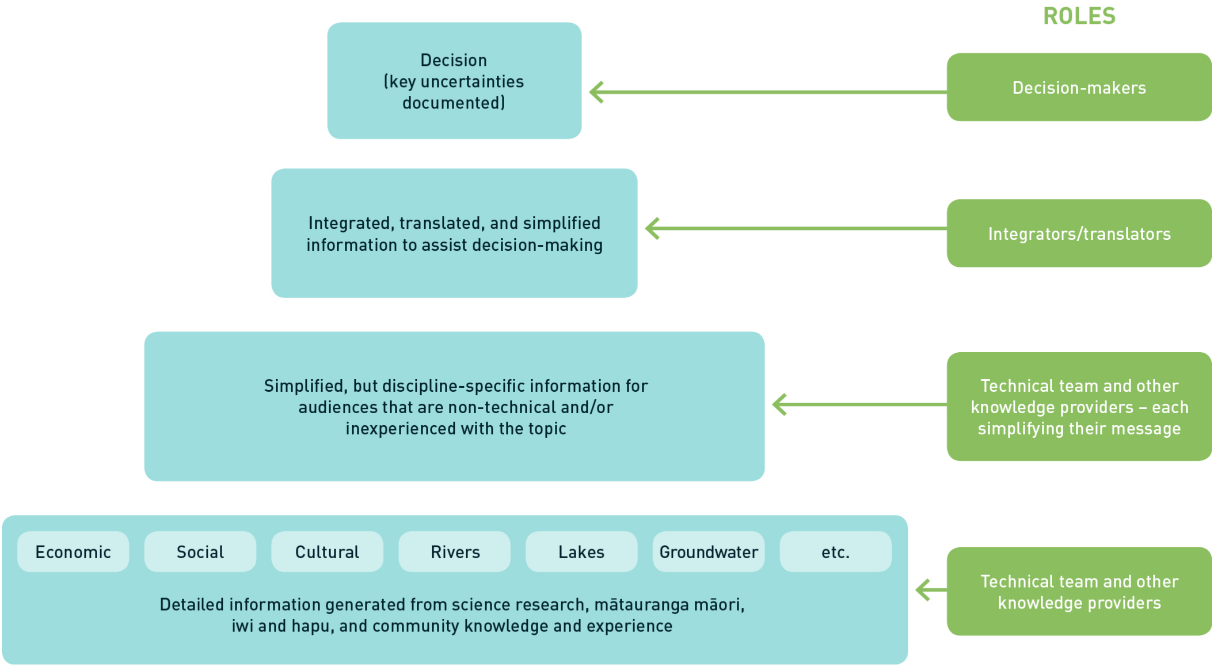
Limit-setting teams need to generate a wide range of information to assess the technical aspects of a typical system, like the one illustrated in figure 3. The information needs to be at a level of detail that will stand up to technical peer review in each discipline, and also be available for scrutiny of key aspects at hearings if required. This information can be visualised as the base of a 'pyramid' of information, which can then be summarised, integrated and translated at several simpler levels for the needs of different audiences (figure 5).

Detailed technical information overloads community discussions and risks 'paralysis by analysis'[33] in community decision-making processes. Technical providers in NPS-FM processes must find ways to simplify their messages (figure 5), and save the detail only for those who require it. Suggestions are provided in section 4.3.

While all technical contributors need to simplify their messages, there is also an important role to integrate and translate information from multiple technical disciplines into a form that is digestible for decision-making. This will be described further in section 4.4.

[33] As described by Jasonoff (2007).

Figure 5: Illustration of the 'pyramid' of information typically needed in NPS-FM processes



4.3 Presenting uncertainty – suggestions for the technical team

For the technical team presenting information to technical audiences (near the base of the pyramid shown in figure 5), more detailed and nuanced presentations of uncertainty are appropriate. Most community audiences will include people who are non-technical, or inexperienced with the topic however, and the message must be summarised and simplified. In NPS-FM limit-setting processes the message typically needs to include an assessment of the likelihood of attaining a given outcome or of an effect occurring, as well as a description of that outcome or effect. Such information can be presented numerically, narratively (or verbally), and graphically. Each approach has strengths and weaknesses, as shown in table 2. Examples of typical graphic presentations for technical audiences are shown in appendix 1.

Table 2: Strengths and weaknesses of different forms of presenting uncertainty[34]
(The strengths and weaknesses will vary depending on the stage of the decision, the purpose of the communication, and the audience)

STRENGTHS	WEAKNESSES
Numeric communication of probability (eg, probabilities, percentages, frequencies)	
• precise and potentially leads to more accurate perceptions of risk than use of verbal/narrative descriptors • conveys aura of scientific credibility • can be converted from one metric to another (eg, 10% = 1 out of 10) • can be verified for accuracy (assuming enough observations) • can be calculated but must be based on data (observations of the modelled response).	• people often have problems understanding and applying mathematical concepts • lacks sensitivity for adequately tapping into and expressing gut-level reactions and intuitions.
Verbal or narrative communication of likelihood (eg, unlikely, possible, almost, certain)	
• allows for fluidity in communication (is easy and natural to use) • expresses the level, source, and imprecision of uncertainty, encourages one to think of reasons why an event will or will not occur • unlike numbers, may better capture a person's emotions and intuitions.	• variability in interpretation may be a problem (eg, *likely* may be interpreted as a 60% chance by one person and as an 80% chance by another).
Visual (graphic) communication of likelihood (eg, pie charts, scatter plots, line graphs)	
• summarises a great deal of data and shows patterns in the data that would go undetected using other methods • useful for priming automatic mathematic operations (eg, subtraction in comparing the difference in height between two bars of a histogram) • can attract and hold people's attention because it displays data in concrete, visual terms • may be especially useful to help with visualisation of part-to-whole relationships.	• data patterns may discourage people from attending to details (eg, numbers) • poorly designed or complex graphs may not be well understood, and some people may lack the skills to interpret graphs • graphics can sometimes be challenging to prepare or require specialised technical programs • the design of graphics can mislead by calling attention to certain elements and away from others.

[34] The information in this table is adapted from Institute of Medicine (2013).

Uncertainties can be shown in narrative, numeric and graphical form in the same report, or presented sequentially during face-to-face presentations or workshop discussions. In a presentation or workshop discussion, it may be useful to work through the different forms with the whole group, or it may be appropriate to use different forms for particular audiences at different stages. While this takes time, the advantages include:

- the point is more likely to be noticed with repetition, and may result in a better understanding of the uncertainty when expressed in different ways
- the message will reach more individuals because many people have preferences for a specific form of presentation and may miss information reported in a less-preferred form.

An example of numeric, narrative and visual methods of communicating the likelihood of attaining a given outcome (eg, a fresh water objective) are shown in table 3 below.

Table 3: A simplified narrative scale of likelihood combined with a visual colour code[35]

Narrative descriptor[36]	Probability class	Description[37]	Colour code
Very likely	90–100%	Likely to occur even in extreme conditions	
Likely	67–90%	Expected to occur in normal conditions	
About as likely as not	33–67%	About an equal chance of occurring as not	
Unlikely	10–33%	Not expected to occur in normal conditions	
Very unlikely	0–10%	Not likely to occur even in extreme conditions	

4.4 Presenting uncertainty – suggestions for the integrator

The large range of assessments and their uncertainties that form the base of the pyramid in figure 5 need to be considered at the decision-making level at the top of the pyramid. There are significant cognitive difficulties in this, which are discussed further in section 5.2; however an integrator can support decision-making by bringing together and simplifying how uncertainty is presented with each of the different assessments. That is, they can bridge the bottom to the top of the pyramid (figure 5). The key steps include collation, integration and translation of all the information and associated uncertainties into a more easily digestible format (see box 6).

35 Adapted from Rouse and Norton (2010).

36 Simplified based on the Intergovernmental Panel on Climate Change (IPCC) scale (Mastrandrea et al, 2010) by merging each of the extreme ends of the scale (ie, >99 per cent merged into the 90–100 per cent class; and <1 percent merged into the 0–10 per cent class).

37 From Intergovernmental Panel on Climate Change (2005).

Box 6 – Integrate and translate the meaning of multiple uncertainties

1. **Collate**. Gather together the multiple assessments of uncertainty that will typically be expressed in a variety of ways by the multiple contributors of information to a project (eg, qualitative and quantitative descriptions, multiple technical disciplines and other information).
2. **Integrate**. Relate the uncertainties and associated risks to each other by considering questions such as which are:
   a. bigger
   b. smaller
   c. compounding
   d. cross-cancelling
   e. likely to influence decisions.

   Consider which need to have the highest priority for communication in the process in future.
3. **Translate**. What does it all mean in the context of the decisions required? How can the messages be simplified? What are the options to mitigate or otherwise manage the highest priority uncertainties?

The role of integrating and translating is distinctly different from that of each individual knowledge provider (see figure 5). In freshwater management, this integration role has been performed largely by planners. Councils are finding, however, that the technical complexity of limit setting under the NPS-FM, and the increased need for communication of technical issues to community audiences during collaborative or enhanced consultative processes, requires technical integrators to assist with this role, working closely alongside planners and community facilitators.[38]

One way of exploring what the known uncertainties mean for decision-making is to use the concept of risk, and its expression in terms of a combination of consequences and the associated likelihood of occurrence, as outlined in section 1.4. If we can clearly show that the consequence of an action is either achieving or failing to achieve particular outcomes (eg, fresh water objectives and other environmental, social, economic and cultural outcomes), and assess how likely we are to achieve those outcomes under a range of alternative scenarios, then we have the two components necessary to express the risk (ie, the effect of uncertainty on outcomes) of each scenario. If we also use narrative classes of likelihood, and the colour code presentation technique from table 3, we can apply this consistently across multiple assessments and to some extent present multiple assessment uncertainties in a common format.[39]

One example of this type of communication is the summary matrix used for several recent limit-setting processes in Canterbury.[40] The merits of various possible future scenarios are represented in

38 For example, Rouse et al (In press).

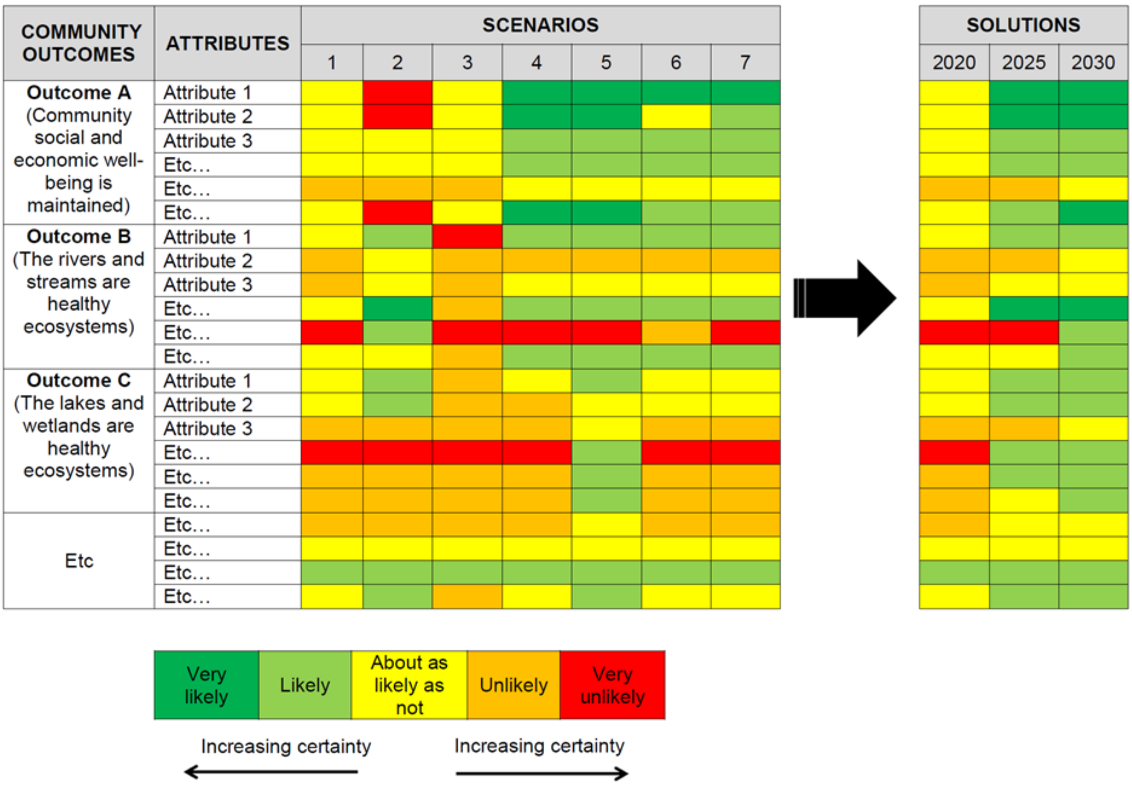
39 For example, similar to the method used by IPCC to generate standard language across multiple disciplines in their numerous climate change assessment reports. See Mastrandrea et al (2010).

40 Norton & Robson (2015).

a simple matrix showing the assessed likelihood that each scenario will achieve a series of outcomes desired by the community (figure 6). It is important to acknowledge the simplification involved in this type of communication, and to ensure that the underlying technical detail (the base of the pyramid in figure 5) is also available for audiences that want it. It is also important to be aware and manage the potential for framing bias to occur with this type of communication, as discussed in section 4.5.

While the matrix shows an estimate of the likelihood of defined outcomes occurring under given scenarios (ie, the coloured cells), and describes the nature of those outcomes (in the descriptions given in the first and second columns), there is no weighting of importance or significance given to the various outcomes (ie, the rows are not ranked or weighted). The process of weighing the relative significance or importance of each outcome and its associated uncertainties and risks is left to the decision-making process. Thus the role of integrator stops short of making value judgements, but does help inform subsequent discussion on values, and so assists decision-making. This leaves a very significant integration challenge for decision-makers, as will be described further in section 5.

Figure 6: Matrix summarising the assessed likelihood that various defined future scenarios will achieve a set of defined outcomes desired by the community



The five-point scale (green to red) summarises (and normalises) assessments made by multiple technical contributors. The matrix shows consequences of scenarios for multiple different outcomes, and trade-offs between conflicting outcomes. The matrix can be useful for debating options and exploring solutions, for example, how to recombine positive elements from different scenarios and use mitigations to turn ‘reds’ into ‘greens’ through time (see columns at right). Note that uncertainty is greatest at the centre of the likelihood scale (yellow) and decreases towards both ends of the scale.

4.5 Acknowledging and managing biases

Research has shown that different people and groups of people, including experts, non-experts and regulatory decision makers, have biases that can affect their interpretation of uncertainty.[41] For example, people tend to select and interpret information in order to support their existing worldview, and this is known as 'confirmation bias'. Information about probabilities in particular has been found to be susceptible to biases by both experts and non-experts. Other common biases include the availability bias, confidence bias, group bias and framing bias, and these are all described in appendix 2.

When people's judgements about a risk are biased, risk management and communication efforts may not be as effective as they would otherwise be. Communicators of information about uncertainty cannot eliminate these biases, but they should be aware of the potential for biases to influence the acceptance of, and reaction to, probabilistic information. They should also try to avoid being influenced by their own biases by striving to play the role of objective information provider to a policy process.[42]

4.6 Documenting uncertainty and managing communication risks

Documenting the nature and magnitude of uncertainty in a decision is not only important during the consideration process and at the time of the decision, but it is also important when a decision might be revisited or evaluated in the future. Documenting uncertainty may help target investigations to inform the next plan review cycle, and informs the development of monitoring requirements.

While the benefits of making uncertainty transparent are clear, however, it is also worth recognising and managing the process risk this creates. Recent experience by regional councils has shown that conscientious communication of uncertainties may be abused by some parties who use knowledge uncertainty for advocacy. For example, uncertainty can be easily used to cast doubt on evidence and is sometimes used by parties at hearings to discredit the basis for consensus decisions made earlier in a process. This risk reinforces the importance of documenting uncertainty as well as the process and decisions around prioritising effort to reduce it. It is also useful to document collaborative agreements made in acceptance of uncertainties along the way.

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41 For example, Kahneman (2011), Kloprogge et al (2007), Institute of Medicine (2013), and Duncan (2013).

42 As described for example by Gluckman (2013, 2014 and 2015) and Pielke (2007).

4.7 Summary

Box 7 – Key messages and approaches for communicating uncertainty

- Do "share the uncertainty burden" but don't mask the message – lead with the message and be clear about the level of uncertainty.
- Openness about uncertainty is seen as evidence of honesty on the part of scientists. Provide credible, salient, legitimate information. Be honest, frank and open. Listen to the audience and involve them as a legitimate partner in the process. Speak clearly and without defensiveness.
- Identify all of the stakeholders (or audiences) who need to receive information, as they may have different needs or learning preferences.
- Large quantities of technical information may need to be produced. It is important to simplify the messages to a digestible format for everyone involved.
- Developing a common language to discuss aspects of uncertainty can help with simplifying the messages (eg, very likely, likely, about as likely as not, unlikely etc).
- Use a range of different tools (conceptual diagrams, words or narrative statements, statistics, graphs) to illustrate uncertainties – all will have advantages and disadvantages. Repetition using different formats will help reinforce messages.
- An important challenge lies in collating, integrating and translating the main messages (and their associated risks) from all of the different technical work areas.
- It can be useful to summarise the main messages in a common format (eg, using a matrix to show the likelihood of achieving outcomes under different scenarios, and traffic light colours to describe aspects of the uncertainty).
- Acknowledge and manage the many biases to which the human mind is vulnerable.

5 Stage 3: Making decisions using uncertain information

There are three fundamental challenges when making decisions using uncertain information. These arise from the:

1. difficulty of defining the importance of a risk for one value, relative to risks for other values
2. fundamental cognitive difficulty humans have in incorporating probability and uncertainty into their thinking
3 difficulty of not knowing anything definite about the future.

The following sections address each of these challenges in turn, by discussing:

- practical methods for characterising and comparing multiple risks
- approaches that allow us to overcome the cognitive difficulties in thinking about probabilities and uncertainty
- ways to manage the fact that aspects of decisions will, over time, turn out to be wrong (eg, appropriate precaution, conservatism and adaptive management).

5.1 Characterising the relative importance of multiple risks

One of the key questions that decision-makers must deal with is how to define the importance of any particular risk or uncertainty relative to other risks and uncertainties in that decision. For example the matrix described in section 4.4 (figure 6) shows the assessed likelihood of achieving multiple different, unweighted outcomes, and leaves the weighing of the relative significance or importance of each outcome and its associated risks to decision-makers. This is not a simple task, because in addition to the two commonly expressed dimensions of risk (likelihood (or probability) and consequence (scale and significance of effect or outcome)) there are many other aspects that contribute to the "context"[43] for decision-making. Making a decision that integrates the different aspects requires value judgements to be made.

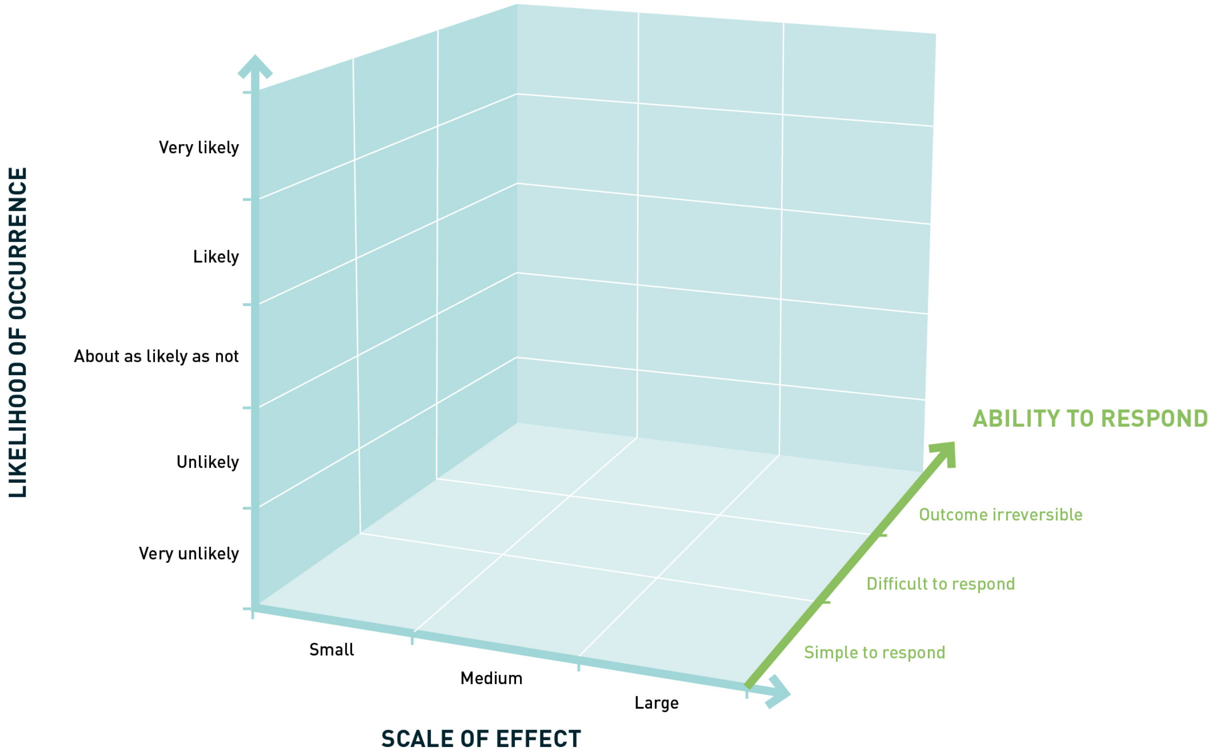
Among the many aspects that contribute to the context of risks, the ability to respond to a risk (irreversibility) is a particularly important and useful aspect to consider. The ability to respond to a risk can be illustrated conceptually on a three-dimensional diagram along with likelihood and scale of

43 For example the Australian and New Zealand Standard (AS/NZS, 2009) definitions include numerous aspects under the risk management "context" such as the cultural, social, political, legal, regulatory, financial, technological, economic, natural and competitive environment. For other discussions of numerous aspects that affect the context of risk see for example Environmental Risk Management Authority (2009), Institute of Medicine (2013), Cameron (2006), Parliamentary Commissioner for the Environment (2004) and Fietje (2001). The context may also include the "emotional/irrational dimension" (eg, Tersteeg & Elsen, 1999).

effect, as shown in figure 7. In the first two dimensions the relationship between likelihood and effect (ie, the risk) results in low likelihood/low effect events that are generally of little concern, but high likelihood/high effect events of great concern. When we add the concept of reversibility (the third dimension), events where the capacity to respond is high are of lesser concern than occurrences which are irreversible or very difficult to respond to.

It's valuable to consider these three dimensions in making decisions about uncertainty, as it helps decision-making to focus on the risks that are of greatest importance. Obviously the ability of decision-makers to understand and prioritise risks in this way relies on effective communication by the technical team of both dimensions of risk (eg, likelihood and consequence) and context, such as the ability to respond and irreversibility, as described in section 3.3.

Figure 7: Characterisation of risk in terms of likelihood, scale of effect, and reversibility



The teams informing limit setting need to judge carefully the appropriate level of technical work to use to characterise risk. Very detailed approaches to risk management are described in the literature that may be appropriate for some medical and structural engineering situations,[44] but for typical National Policy Statement for Freshwater Management 2014 (NPS-FM) processes the demands on stakeholders are already significant, and lay stakeholders in particular are often at or beyond their capacity to absorb the technical information they are presented with. Recent experience by regional councils suggests that broad scale integrated descriptions of uncertainty (described in section 4.4) may be an appropriate level of detail for most NPS-FM decision-making.

44 For example Institute of Medicine (2013).

Irreversibility requires particular attention, and should be a major driver in decisions on whether to employ a precautionary approach and/or adaptive management (described later). Irreversibility can occur in many environmental contexts, including:

- loss of biodiversity both at a species and habitat level
- tipping points in lake processes
- loss of habitat
- weed and pest invasion
- global climate processes.

Irreversibility also occurs with other values, however. Economic impacts on individuals may cause irreversible losses, communities can be lost, large scale infrastructure investment can be irreversible and result in similarly irreversible environmental effects, and values of cultural significance can be irreplaceably damaged.

5.2 Managing cognitive difficulties in uncertainty and risk

Human brains are evolutionarily designed to address problems in relation to survival and reproduction. The concepts of randomness, risk and probability are recent arrivals for our brain development, which means that we are not well equipped to make probability-based decisions. It has been known for some time that we use heuristics in making decisions on risk[45] – these are shortcuts that allow rapid judgements to be made with less cognitive effort. The advantage of heuristics can be seen in the example of the two Stone Age humans who come upon a lion. The one who uses the heuristic "see lion – run away" may not make a decision as outcome efficient as the one who stands and calculates the probability of being eaten, but by always running that human survived and passed their genes on.

Heuristics are therefore useful tools for decision-making, and are hard-wired into human brains. They also result in a number of biases in the way we make decisions (see section 4.5), however. Emotions also play an important role in how we view and respond to risk, with perceptions of high risk associated with feelings of dread, terror and the unknown.

It can be argued that decision-makers, as well as technical teams informing decision-makers, should try to remove these biases and non-rational influences from decision-making. Economists have developed a number of modelling approaches to do this, although these are generally for probabilities that can be quantitatively defined and managed rather than for situations involving deep uncertainty. Engineers and other professions have used multi-criteria analysis (MCA) as a quasi-quantitative approach to integrating multiple values and risks into a decision-making process.

The problem with approaches that attempt to eliminate cognitive biases from limit-setting decision-making, however, is that the decisions require value judgements.[46] For example, how can a decision-

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45 For example, Tversky & Kahneman (1974). The technical definition of 'heuristic' is "a simple procedure that helps find adequate, though often imperfect, answers to difficult questions", and may also be considered as "roughly, a rule of thumb" (Kahneman, 2011).

46 As discussed in section 5.1.

maker rationally compare a low probability but extremely high and irreversible impact risk to the environment (see figure 7), with a high probability but moderate impact risk to the economy, particularly where different stakeholders are unequally affected? Making decisions on the future, where important market and non-market values are at stake, requires decision-makers to move beyond rational analysis into a value judgement about what is important and how much risk is acceptable. To attempt quantitative, rational assessments in this context results in the value judgements being hidden.

There are two process tools that can help manage these cognitive difficulties with uncertainty. These are the use of scenarios, and use of collaborative processes for decision-making.

5.2.1 Scenarios

Scenarios, in the context of implementing the NPS-FM, are a description of a range of different states of the world that are used to explore what the future might look like.[47] Scenarios can be used to describe many factors that may be relevant to a decision, and can assist with several aspects in a decision-making process, including:

- providing coherence and integration to the technical analysis of problems
- allowing comparisons between assessments of different values and the uncertainties associated with those assessments
- assisting with learning and innovation to find solutions (as illustrated in figure 6).[48]

Scenarios also help show that there are multiple possible futures (with multiple possible outcomes for environmental, social, cultural and economic values) that could arise as a result of different ways of managing land and water resources. There are also multiple possible futures that could arise from a single resource management approach, caused by variation in factors that are beyond the control of the decision-making process (eg, world market conditions and other factors about which there is deep uncertainty). This can help to illustrate that no single future is definitive, and that multiple uncertainties are inherent. Scenarios help to explore possible futures in situations where definitive predictions are not possible because of a high degree of uncertainty and complexity (as illustrated in figure 1).

5.2.2 Collaborative approaches to decision making

Under the NPS-FM, councils may choose to prepare regional plans using collaborative processes, and some are already doing so. The international literature and recent experience by some regional councils suggests that collaborative processes are particularly useful in situations where the policy problem is characterised by:

- a lack of certainty in knowledge
- disagreement over norms and values (ie, a ‘wicked’ problem).[49]

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47 They may include a description of the sequence of events that led to that state of the world.

48 For example, Heinrichs et al (2010), Norton & Robson (2015) and Fenemor (2014).

49 For example, Berkett & Newton (2015), and Duncan (2013).

This is typically the case for many situations where limit setting is required under the NPS-FM. Some key features of collaborative processes that help with uncertainty are:

- Group decision-making: There is some evidence that groups of people are able to make better predictions than individuals,[50] and groups of people are used formally in predictive techniques such as the Delphi method or Human Swarming.[51] For highly complex, uncertain decisions it is possible that having a number of minds working interactively on a problem can reduce the impact of individual biases, and produce better answers than an individual.
- Acceptable versus optimum: The use of consensus tends to drive decisions towards "acceptable" rather than "optimal" outcomes. With uncertainty the decision becomes about what is an acceptable risk for a stakeholder to take in relation to their values. The decision therefore becomes a binary "acceptable" or "not acceptable" decision, which is a simpler cognitive task than assessing a continuum of probabilities. This also creates threshold types of decisions that are amenable to the high-level assessment and presentation of uncertainty described in section 4.4.
- Maintenance of options: Because we cannot reliably predict the future, we also do not know which particular viewpoint will produce a sustainable future. If we use the analogy of genes, then evolutionary biology tells us that a more diverse gene pool is more resilient to environmental shocks than a narrow gene pool. If we think of ideas about a sustainable future as being genes, then we will maximise our future resilience by ensuring as many ideas as possible of what is likely to be sustainable are included in our solution. This is achieved by collaborative decision-making, since if one stakeholder's viewpoint is not represented the solution is not likely to be acceptable to them and consensus is not achieved.

5.3 Managing the certainty of being wrong

The future is essentially an unknown world. The only certain thing that we can say about any complex prediction or decision that we make today under the NPS-FM is that it will be inaccurate or wrong – the extent to which it is wrong will vary in scale and importance, but we cannot know how it will vary or to what extent. This is not to say that a decision made at a given point in time is not the right one for the information available on the day; but it acknowledges the decision is made with imperfect information. It is useful to acknowledge this, because the paradigm of making decisions under uncertainty changes from one of trying to maximise the accuracy of the decision, to managing for the situation where aspects of the decision turn out, in time, to be wrong.

The key approach to managing imperfect decisions in the environmental context is the Precautionary Principle. The Precautionary Principle arose in the Rio Convention (1992), and an element of precaution or caution is mentioned in 14 of New Zealand's current laws.[52] Although it was originally intended as a way to allow decision-makers to take measured action even in the absence of full knowledge, the Precautionary Principle is now used in several different ways in environmental law and decision-making. This guide is non-specific about the meaning of the Precautionary Principle, and

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50 Surowiecki (2004).

51 Rosenberg (2015).

52 Gluckman (2015).

suggests that all its commonly used elements can be useful for managing uncertain situations. These are described below, and include:

- conservatism
- consideration of irreversibility
- adaptive management.

5.3.1 Conservatism

In the context of the NPS-FM, an example of conservatism would be to set limits at a point that is more protective of a particular value than the evidence suggests may be needed. Conservatism could be used in some circumstances to provide a buffer in case the technical analysis is inaccurate in the direction that affects the value. For example, to protect the ecology of a highly valued lake, we may set nutrient load limits at the lower end of the range that the modelling suggests is required, on the basis that if the analysis is inaccurate we will still be protecting those values. This approach is utilised extensively in the field of engineering, where factors of safety are built into any design, with the size of the factor reflecting the assessed risk (eg, threat to human life).

The need for conservatism is dependent on the analysis of risks (eg, figure 7), where for low impact events it is generally not needed, but for high impact events the need for conservatism will vary depending on whether the outcome is reversible, and its likelihood of occurrence.

Care must be taken with the use of conservatism, since it can be present in both the analysis and in the decision. Technical experts and models will often build conservative assumptions into their analysis, which if combined with conservatism in the decision will result in over-conservatism in the setting of limits. For this reason, if conservatism is to be used it is important for technical team members to communicate to decision-makers the nature and direction of any uncertainty in the analysis.

5.3.2 Irreversibility, options and the value of information

Option theory is well established in economics and finance, but it is the lesser known 'quasi option value' that is of particular interest in the management of uncertainty in environmental decisions. Quasi option value[53] says that there is a tangible value associated with improved information in the future. Its use says that if you can *delay making a decision that results in an irreversible loss, then there is tangible advantage to doing so.*

While there are theoretical approaches to calculating the value of information (VOI approaches) gained by delaying a decision, in practical terms quasi option value directs towards decisions that are more conservative initially, with allowance for adaptive management (see below). If a decision can be made in a way that irreversible consequences do not arise, then that decision can be revisited in the future as new information becomes available. Delaying a decision or initial conservatism also has costs, so there is a trade-off between the value of information and the cost of the delay, but where uncertainty is high this delay may be worthwhile.

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53 Pearce et al (2006).

It is important to note the distinction between no decision or inaction, and a decision or action that proceeds with caution, but prevents irreversible consequences across the values. The "proceed with caution" approach that this implies reflects the original intent of the Precautionary Principle.[54]

5.3.3 Adaptive management

Adaptive management is the classic tool for managing uncertainty, and allows for decisions that preserve options, avoid irreversible consequences, and provide for the avoidance or reversal of adverse outcomes. The adaptive management cycle involves decisions, implementation of change, monitoring, review and new changes. A key feature of adaptive management is the need to keep changes to the level where they are always reversible, since irreversible changes cannot be subject to review and adaptation. Adaptive management is built into the freshwater management process outlined in the NPS-FM, with monitoring and plan review allowing for the revision of limits and approaches to management via plan changes.

Adaptive management under conditions of high uncertainty and irreversibility involves incremental change, with the monitoring and review cycle used to reduce uncertainty and refinement of decisions. For example, an irrigation development may be staged to allow for monitoring of ecological outcomes to ensure that desired values are maintained. Alternatively, the decision on limits could include defined triggers; for example providing for a managed increase in nutrient loads if specific mitigation measures are put in place and/or if monitoring shows that outcomes are being achieved.

Adaptive management cannot always be employed, because some decisions can be difficult to reverse either for biophysical or socio-political reasons. For example, once intensification of land use has been allowed, it can be practically very difficult or impossible to return to the original pre-intensification situation because a set of stakeholders has been created with a strong interest in the new status quo. Therefore adaptive management is generally best combined with conservatism; for example, the limit becomes more permissive rather than less permissive over time.

5.3.4 Diversity of outcomes

Diversification is also highly developed in the economics and finance literature, where it is known as portfolio management. In that context, the aim is to create a set of non-correlated positions, the combination of which reduces the variability of the portfolio overall to less than the individual positions. Alternatively we can consider it as the more accessible concept, "don't put all your eggs in one basket".

The problem with a single set of outcomes for a group of resources is that if the limit is set in the wrong place, then the loss will be encountered everywhere, which is particularly problematic if the outcome is irreversible. If a diversity of limits is set across a set of resources, however, then being wrong means that while some values may be affected, the loss will not occur everywhere.

Diversity of outcomes also has benefits for an adaptive management approach, since the different approaches across catchments allow for comparison of monitoring data, and observation of how societies' values move in relation to each other over time.

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[54] For example, Gluckman (2015).

Allowing for diversity of outcomes is possible particularly where there are a range of different values represented across a region or group of resources. The ideal approach of treating catchments of similar value sets differently can be problematic if questions of fairness and equity arise for affected stakeholders. It is rare that catchments will be exactly alike, however, and provided decisions are made in a sufficiently broad geographic context there will normally be opportunities for decision-makers to create diversity in their approaches.

5.3 Summary

Box 8 – Key messages for making decisions under uncertainty

- Characterise the nature of risks and uncertainties through the technical informing process. These can be usefully described in terms of the likelihood of occurrence, the scale and significance of the effect or outcome, and reversibility.
- Particular attention should be paid to irreversibility of consequences across the range of values, since this will drive approaches to manage for the situation where the decision turns out, over time, to be wrong (eg, use of precaution, conservatism and adaptive management).
- Cognitive difficulties with making decisions under uncertainty place a considerable burden on decision-makers. Scenarios provide a useful tool for exposing and understanding uncertainties.
- Because NPS-FM decisions on limits involve value judgements, some level of stakeholder engagement is essential. Consensus-based collaborative processes are particularly useful in policy problems where there is uncertainty of knowledge and disagreement over norms and values (ie, in 'wicked' problems), as is typically the case with limit setting under the NPS-FM. Experience suggests collaborative processes also provide assistance with the cognitive difficulties of making decisions under uncertainty.
- It is useful to start from the premise that decisions will, in time, turn out to be wrong, although we cannot tell how wrong or in what respect. Approaches to managing this situation then become an essential part of the decision, and include conservatism, maintaining options, adaptive management, and allowing for a diversity of outcomes.

6 Summary of key messages

Managing uncertainty in National Policy Statement for Freshwater Management 2014 (NPS-FM) processes can be seen as a three-stage iterative process (as shown in figure 2). The process involves acknowledging, identifying, assessing, reducing, quantifying, communicating uncertainty, and then incorporating it into decision-making. Key messages and approaches for doing this are summarised below.

Terminology around uncertainty and risk

- It is useful to adopt some simple, but consistent terminology for handling uncertainty and associated risk in the context of NPS-FM processes; see the definitions in section 1.4.
- The terms 'uncertainty' and 'risk' are inseparable; wherever one term is used in this guide the other is also implied.
- It is useful to predict effects and/or attainment of outcomes (eg, fresh water objectives) in terms of both likelihood and the scale and/or significance of the effect or outcome.

Stage 1 – Assessing, reducing and quantifying uncertainty

- Assess the type and nature of uncertainties and associated risks.
- Assess priorities – which uncertainties justify the effort to reduce them?
- Consider the merits of gathering more data and/or using more sophisticated models.
- Consider the merits of more technical expertise, research, and/or peer review.
- Consider multiple parallel methods to produce converging lines of evidence.
- Consider 'scale and significance' and risk in making cost-effective choices on methods to reduce uncertainty.
- Consider the level of quantification of uncertainty that is possible.
- Use data ranges, standard errors and confidence intervals to quantify uncertainties associated with sample statistics such as the mean and median, where appropriate.
- Quantify uncertainty associated with model predictions where possible (eg, statistical errors, sensitivity analysis, Monte Carlo analysis and other technical methods).
- Develop semi-quantitative or qualitative methods where full quantification is not possible and express results using narrative descriptors of likelihood (eg, very likely, likely, about as likely as not, unlikely, very unlikely).
- Acknowledge limitations and ignorance.

Stage 2 – Communicating uncertainty and risk

- "Share the uncertainty burden" – when uncertainty is communicated, the burden is shared and decisions can be more transparent.
- Technical contributors to a public policy process have a responsibility to identify and communicate the uncertainties in their work. Don't mask the message, however. Lead with the message and be clear about the level of uncertainty.
- Acknowledging uncertainty can relieve the burden felt by scientists, who are often unreasonably expected to have high confidence in their conclusions.
- Openness about uncertainty is seen as evidence of honesty on the part of scientists. Provide credible, salient, legitimate information. Be honest, frank and open. Listen to the audience and involve them as a legitimate partner in the process. Speak clearly, and without defensiveness.
- Identify all of the stakeholders (or audiences) who need to receive information, as they may have different needs or learning preferences.
- Large quantities of technical information may need to be produced and a key requirement is to simplify the messages to a digestible format for everyone involved.
- Developing a common language to discuss aspects of uncertainty can help with simplifying the messages (eg, very likely, likely, about as likely as not, unlikely).
- Use a range of different tools (conceptual diagrams, words or narrative statements, statistics, graphs) to illustrate uncertainties; all will have advantages and disadvantages. Repetition using different formats will help reinforce messages.
- An important challenge lies in collating, integrating and translating the main messages (and their associated risks) from all of the different technical work areas.
- It can be useful to try and summarise the main messages in a common format (eg, using a matrix to show the likelihood of achieving outcomes under different scenarios and traffic light colours to describe aspects of the uncertainty).
- Acknowledge and manage the many biases to which the human mind is vulnerable.
- Document uncertainty during the process, but also at the time of the decision.
- Acknowledge and manage the risk that communication of uncertainty will be abused by some parties who will use it for advocacy.

Stage 3 – Making decisions under uncertainty

- Limit-setting decisions require weighing of values *and* their uncertainties. Therefore receiving information on the nature of uncertainty is critical for good decision-making.
- It is useful to receive information described in terms of the likelihood of occurrence, the scale and significance of the effect or outcome, and reversibility.
- Particular attention should be paid to irreversibility of consequences, since this will drive approaches to precaution, conservatism and adaptive management.

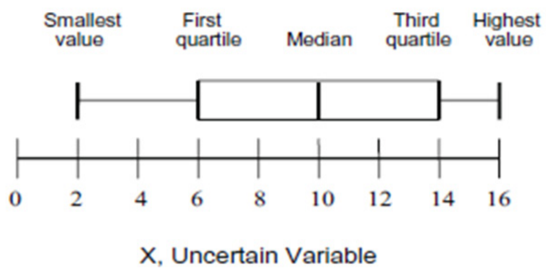
- The cognitive difficulties with making decisions under uncertainty are substantial. Use of collaborative processes and scenarios helps to expose and understand uncertainties.
- Consensus-based collaborative processes are particularly useful where there is uncertainty of knowledge and disagreement over norms and values (ie, ‘wicked’ problems), as is typically the case with limit setting under the NPS-FM.
- It may be useful to start from the premise that decisions on limits will be inaccurate or wrong. Approaches to managing this situation then form part of the decision, and include conservatism, maintaining options, adaptive management, and allowing for a diversity of outcomes.

Appendix 1: Examples of common graphical displays of uncertainty

Box-and-whisker plots

Box-and-whisker plots (figure A1) are effective in displaying summary statistics (medians, ranges, fractiles), but they provide no information about the shape of the data distribution except for the presence of asymmetry in the distribution. The first quartile (the left-hand side of the box) represents the median of the lower part of the data, the second quartile (the line through the middle of the box) is the median of all data, and the third quartile (the right-hand side of the box) is the median of the upper part of the data. The ends of the "whiskers" show the smallest and largest data points.

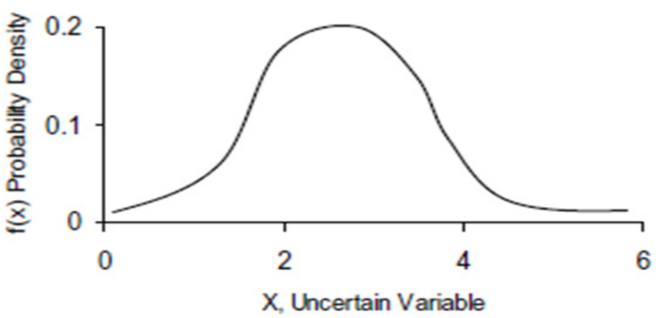
Figure A1: Example of a box-and-whisker plot



Probability density functions

Probability density functions show the probability of a given value (figure A2). Probability density functions represent a probability distribution in terms of the area under the curve and highlight the relative probabilities of values. The peak in the curve is the mode, and the shape of the curve indicates the shape of the distribution (that is, how skewed the data are).

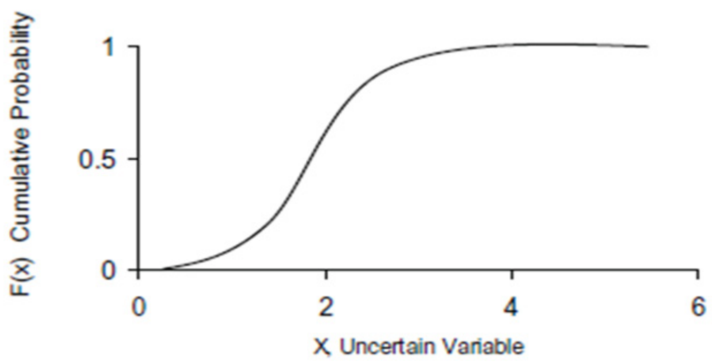
Figure A2: Example of a probability density function



Cumulative distribution function

Cumulative distribution functions show similar information as probability density functions, but with the Y axis showing cumulative probability. For example in figure A3 the probability that the uncertain variable X will be 2 or less is 0.5 or 50 per cent, and the probability that it will be 4 or less is 0.9 or 90 per cent. Cumulative distribution functions are calculated by taking the integral of the probability density function.

Figure A3: Example of a cumulative distribution function

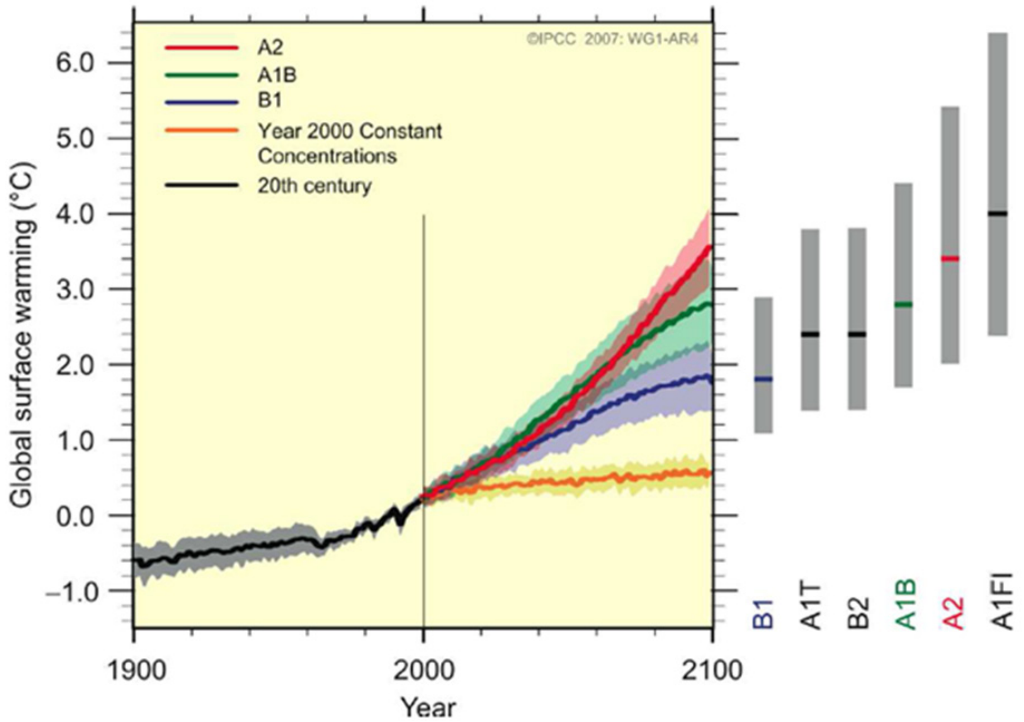


Displaying standard deviations and/or standard errors

In statistics the standard deviation is a measure that quantifes the amount of variation or dispersion of a set of data values. A standard deviation close to 0 indicates that the data points tend to be very close to the mean of the set, while a high standard deviation indicates that the data points are spread out over a wider range of values. The standard error of a sample mean is a measure of its uncertainty, and expresses the amount by which it is expected to fluctuate around the population mean.[55] Displaying standard deviations and/or standard errors graphically helps communicate uncertainty. The example in figure A4 shows standard deviation ranges of multiple individual model predictions.

55 Scientists use statistics, such as a mean derived from a sample, as an estimate of the population mean. The standard error of a sample mean is a measure of its uncertainty and expresses the amount by which it is expected to fluctuate around the population mean. Standard errors decrease as sample size increases, as indicated by the equation for the standard error of the mean ($SE = s/\sqrt{n}$) where s= sample standard deviation (ie, a measure of the inherent variability) and n=sample size.

Figure A4: Example of a graphical display of multiple model predictions that helps to communicate the uncertainty associated with predictions



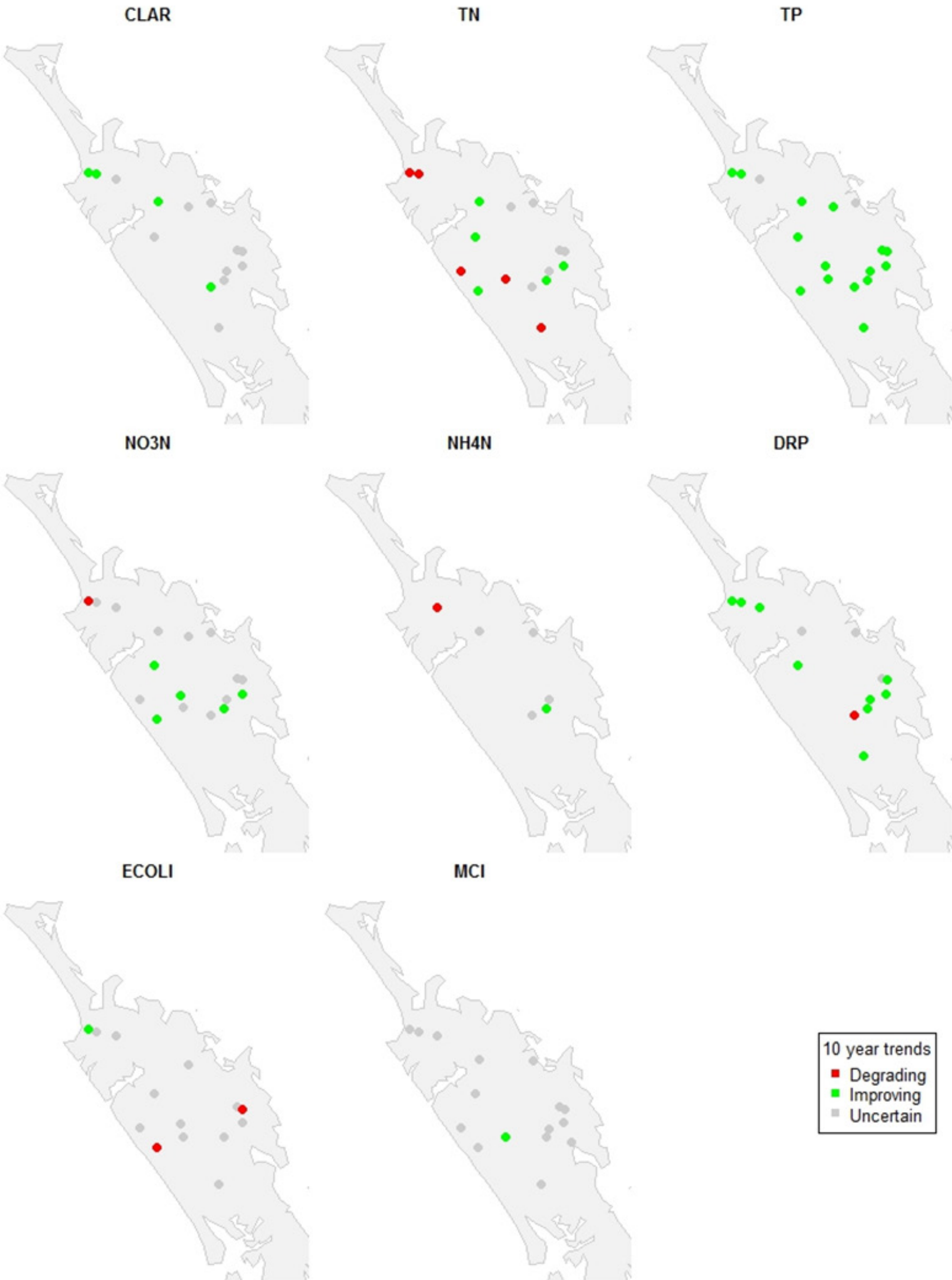
(Source: figure SPM-7, Intergovernmental Panel on Climate Change (2007))

Figure A4 shows global mean surface warming for a range of emissions scenarios and climate models. Solid lines are multi-model global averages of surface warming (relative to 1980–99) for the multiple scenarios (A2, A1B, B1 etc), shown as continuations of the 20th century simulations. Shading denotes the plus/minus one standard deviation range of individual model annual averages. The grey bars at right indicate the best estimate (solid coloured line within each bar) and the likely range of warming by 2100 assessed for the scenarios.

Displaying results of significance tests

Numerous statistical methods exist for testing the significance of trends and other data relationships. The results from these tests can be usefully presented graphically to indicate uncertainty, as shown in the example in figure A5.

Figure A5: Examples of maps showing trends in water quality indicators at monitoring sites



(Source: Snelder, 2015)

In figure A5, where the statistical trend tests were significant (ie, the Kendal test p-value < 0.05) the direction of the trend is indicated as improving or degrading. Where the statistical test was not significant the trend is indicated as "uncertain" (grey circles) meaning the test can be regarded as inconclusive concerning the direction of the trend.

Appendix 2: Common biases in communicating uncertainty

Several established types of bias to be aware of when communicating uncertainty include:[56]

Availability bias: People tend to judge events that are easily recalled as more risky or more likely to occur than events that are not readily available to memory. An event may have more availability if it occurred recently, if it was a high-profile event, or if it has some other significance for an individual or group. The overestimation of rare causes of death that have been sensationalised by the media is an example of availability bias. Thus the mere discussion of a possible event may increase its perceived riskiness, regardless of what the actual risk may be.

Confirmation bias: Confirmation bias refers to the filtering of new information to fit previously formed views. In particular, it is the tendency to accept as reliable new information that supports existing views, but to see as unreliable or erroneous and filter out new information that is contrary to current views. People may ignore or dismiss uncertainty information if it contradicts their current beliefs.

Confidence bias: People typically have too much confidence in their own judgements. This appears to affect almost all professions, as well as the lay public. The few exceptions are people who receive constant feedback on the accuracy of their predictions, such as weather forecasters. The psychological basis for this unwarranted certainty seems to be insensitivity to the weaknesses in assumptions on which judgements are based.

Group bias: The literature on public participation emphasises the importance of interaction among stakeholders as a way of minimising the cognitive biases that shape how people react to risk information. For example, the more homogeneous a group is with respect to knowledge and preferences, the more strongly the knowledge and preferences will affect a group decision. Uncertainty can be either amplified or downplayed, depending on a group's biases toward the evidence.

Framing bias: Different ways of framing probabilistic information can leave people with different impressions about a risk estimate and, consequently, the confidence in that estimate. For example, stating that "10 percent of bladder cancer deaths in the population can be attributed to arsenic in the water supply" may leave a different impression than stating that "90 per cent of bladder cancer deaths in the population can be attributed to factors other than arsenic in the water supply," even though both statements contain the same information. Choices based on presentations of a range of uncertainty will be similarly influenced by the way that information is presented.

Anchoring bias: Anchoring bias describes the common human tendency to rely too heavily on the first piece of information offered (the "anchor") when making decisions. During decision-making, anchoring occurs when individuals use an initial piece of information to make subsequent

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56 After Kloprogge et al (2007), Institute of Medicine (2013), and Kahneman (2011).

judgements. Once an anchor is set, other judgements are made by adjusting away from that anchor, and there is a bias toward interpreting other information around the anchor. For example, the initial price offered for a used car sets the standard for the rest of the negotiations, so that prices lower than the initial price seem more reasonable even if they are still higher than what the car is really worth.

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