Chapter 6 Application of climate projections in impact and risk assessments

Risk management is an iterative process, where a process of scoping and risk identification usually takes place before more detailed assessments are carried out. Care must be exercised when using the projections from Chapter 5 in any risk assessment, particularly when selecting climate variables, determining temporal and/or spatial resolution, and dealing with uncertainty.

Detailed risk assessments generally require purpose-built climate projections, including time series, or probabilistic representations of future climate. Various tools have been developed which represent different methods for enhancing the delivery of climate information to stakeholders both for education and for risk assessment and management. Nevertheless, significant challenges remain for communicating climate risk in ways that can be effectively used in risk management.

The major purpose behind constructing and using climate change projections is to aid decision-making in an environment of uncertainty. There are subtle but important differences between the development of climate change projections and the use of such information for impact and risk assessment.

The context of an assessment determines the information required and how it can best be used: who it is for, what it is about, where it is located and how the results are to be used. Specific methods for treating uncertainty are largely dictated by context and the needs of stakeholders. Such needs also include the development and sharing of a conceptual framework, i.e. sharing the researchers' and stakeholders' understanding of how the system in question operates, creating a viable assessment process, and communicating assumptions and confidence levels as part of the assessment process.

Climate change risk assessment and management is an emerging and inherently inter-disciplinary science. New approaches and methods for incorporating information about future climates into assessments are constantly being developed. Appropriate methods and tools are largely dictated by an assessment's context, rather than through a 'best practice' set of recipes. This chapter summarises the use of climate information to inform impact assessment and risk management.

6.1 Climate change and risk management

Climate risk is the product of the *consequences* of climate change and the *likelihood* of those consequences (Jones 2001; ISO 2002; Figure 6.1). In the past, climate change impact assessment has been dominated by analysis of the consequence component of climate change risk, especially in testing the consequences of unmitigated climate change. The estimation of impacts independently of likelihood continues to be a mainstream research activity. However, as questions regarding risk have become more sophisticated, such as 'how much climate change needs to be adapted to by when', more decision-makers are seeing climate change as a risk management issue. This development is increasing the need to assess the likelihood of specific risks. However, great care is warranted because likelihoods need to be developed appropriately: all relevant uncertainties need to be managed carefully and underlying assumptions clearly stated to avoid under- or over-confidence, incorrect framing of the problem or misapplication of the results.

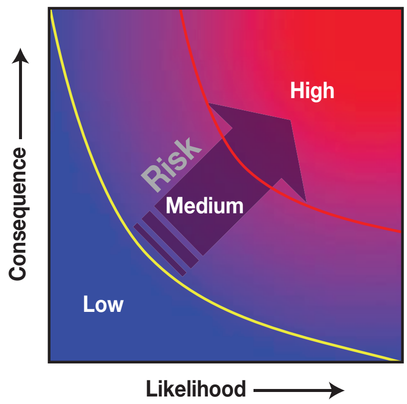


Figure 6.1: Conceptual model of the likelihood – consequence relationship

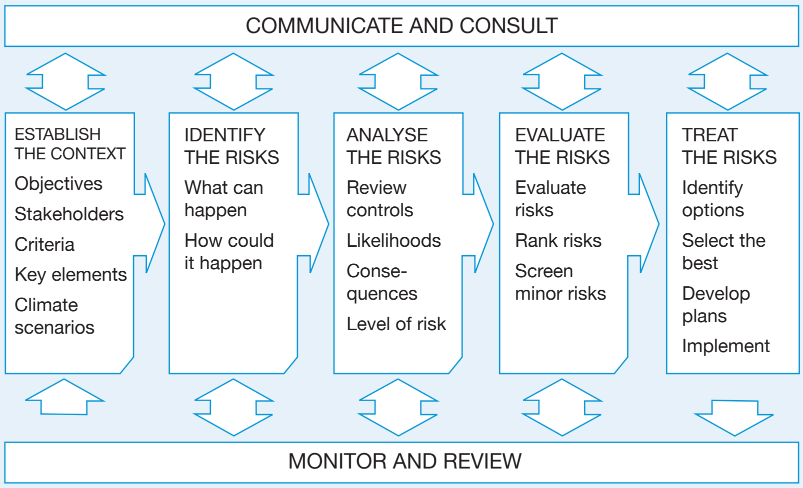
Risk management applies scientific and technical analyses to estimate the likelihood of different outcomes. The process is often conceptualised as a series of steps, which identify the context, characterise the hazards and/or potential consequences, assess the likelihood of different outcomes, evaluate risk, and, ultimately, implement appropriate method(s) for reducing risk (Box 6.1).

Box 6.1 A risk management framework

A number of frameworks exist that provide guidance on applying the principles of risk assessment and management in decision-making. In Australia, the principal framework is the Australia/New Zealand Risk Management Standard (Australian Standards 2004), which has recently been adapted to provide guidance specific to managing climate risk (AGO 2006a). The Risk Management Standard divides the process of risk management into five steps:

1. **Establish the context** – identification of the decision-making event and the associated challenges, establishment of the approach to risk management that is to be used as well as the information and data requirements (including climate projections);
2. **Risk identification** – identification of the potential climate hazards and downstream consequences of concern to stakeholders;
3. **Risk analysis** – qualitative or quantitative analysis of the likelihood of different outcomes, including the probability of exceeding stakeholder-identified thresholds;
4. **Risk evaluation** – assessment of whether risks are tolerable, prioritisation of multiple risks (if present), and judgment regarding whether risks require treatment; and
5. **Risk treatment** – selection and implementation of risk management actions (e.g. through methods such as stakeholder forums, multi-criteria analysis, cost-effectiveness).

In addition, communication and consultation with stakeholders occurs throughout the entire process. Clarity and transparency surrounding underlying concepts and assumptions is required. All participants need to understand the different ways in which the system is conceptualised and used by various stakeholders. Monitoring and review ensures that a learning-by-doing ethos is developed and communicated among all parties. Risk management should not be a one-off event, but a process that is engaged over time and updated with changing information and stakeholder preferences.



The two main strategies for managing climate risk are: *mitigation* of climate change via the abatement and sequestration of greenhouse gas emissions and *adaptation* to climate impacts emanating from the unmitigated component of climate change (IPCC 2007b,c). For each there are myriad specific policies and measures that could be implemented. Combined with the uncertainties associated with future climate change, they form a complex decision-making environment. Both public and private institutions need to navigate this complexity to manage climate risk, whether it is in assessing the benefits of avoided damages via mitigation (Preston and Jones 2006; Jones and Preston 2006) or the potential for adaptation options to reduce societal vulnerability. This has increased the demand for climate information.

Climate risks can be divided into two broad categories (Sarewitz *et al*. 2003):

1. **Event risk** – The risk of occurrence of natural hazards such as sea level rise, storm surge, or extreme rainfall events. *Consequence* is expressed as the occurrence of a discreet event of a particular size or duration and may be integrated with *likelihood* through the quantification of an event return period. For example, the identification of a 1-in-100 year storm event communicates the frequency or likelihood (once every hundred years) of an event as well as its magnitude (in terms of wind speeds or rainfall totals). Event risk is often quantified as hazard times likelihood and is typical of assessments carried out by the natural disaster and insurance communities.
2. **Outcome risk** – Risks associated with environmental or societal outcomes of climatic changes such as species extinctions, loss of agricultural productivity or heat-related human mortality. *Consequences* are expressed as impacts for one or more scenarios of climate change, and may be integrated with *likelihood* through uncertainty analysis (e.g. generation of a probability distribution) or the quantification of the likelihood of exceeding a vulnerability threshold (Jones 2001). Outcomes may also incorporate risk from non-climatic sources, allowing climate change to be assessed in a broader social and environmental context.

Both types of risk are useful to stakeholders for risk management, their choice depending on how rigorously they can be quantified and the form in which that information can be produced, subject to requirements. Risk management is iterative, where a process of scoping and risk identification usually takes place before more detailed assessments are carried out to manage specific risks identified by those initial assessments.

National to regional scale climate projections provide valuable information at this initial stage, which helps establish the context for risk management and scope the potential consequences (Box 6.1). Quantification of event risk is typically a first step in a risk analysis, which requires integrating information on climate events into impact models that predict the resulting system responses. Outcome risks, or clear links between event risks and outcomes, are generally preferred for assessing adaptation needs. Most adaptation measures are designed to reduce negative or enhance positive consequences.

More detailed risk assessments generally require purpose-built climate scenarios or probabilistic representations of future climate. These are discussed in sections 6.2 and 6.3.

When assessing climate risk, caution must be exercised to avoid over-investment in analytical precision. Due to uncertainties associated with climate change and limits to time, expertise, system knowledge, or funding, it may be difficult to derive robust estimates of risks, especially outcome risks, which may also be heavily influenced by the evolution of future adaptive capacity (Patt *et al.* 2005). In such situations, effort may be best-invested in identifying least-cost strategies for achieving risk reduction, rather than exhaustive attempts to reduce uncertainty or to rigorously quantify the risk itself. Identifying and reducing existing system vulnerabilities to climate variability may also help to manage future climate risks (Sarewitz *et al*. 2003; Allen Consulting 2005), especially where risks under current climate are consistent with future risks identified during scoping exercises.

6.1.1 Framing climate risks

A range of different assessments of climate risk can be carried out, such as:

- Impact assessments of unmitigated climate change, testing what may happen if no specific climate policies are enacted; this covers most of the assessments within the IPCC Working Group II contribution to the Fourth Assessment Report (IPCC 2007b);
- Assessing the benefits of greenhouse gas emission policies through avoided damages measured as the difference in climate-related risks associated with a reference emissions scenario (e.g. the unmitigated SRES scenarios) and those associated with a mitigation policy scenario (e.g. Jones and Preston 2006); integrated assessments will consider benefits from both adaptation and mitigation (e.g. Stern *et al*. 2007);

- Assessing adaptation needs over a range of policy and planning horizons for specific activities and regions;
- Assessing how specific development pathways or policies may be affected by climate change and developing adaptation options to make them more sustainable. Integrating adaptation options into ongoing plans and activities, especially into current risk management activities, is referred to as *mainstreaming*.

In general, the benefits of mitigation are longer-term (decades) and the benefits of adaptation are shorter term (years to decades), but not exclusively so (Figure 6.3). Key to assessing adaptation needs is planning horizons: what is the rate and magnitude of change anticipated within a given planning horizon that needs to be adapted to?

When assessing adaptation, it is important to take a whole of climate approach by representing *both* human-induced climate change and background climate variability. The change may be linear, graduated non-linear, or a step change. Many subsequent risks will follow a similar pattern. Background variability may also alter in response to climate change but this possibility needs to be investigated on a case-by-case basis.

Planning horizons mark how far into the future adaptation measures may be needed. Timing is informed by both operational and aspirational goals. Aspirational goals relate to what is desired (e.g. sustainable operations, profitability) or should be avoided (e.g. critical levels of harm, system failure). Operational goals relate to the pathway that is taken to achieve that goal.

Incremental adaptation allows a learning-by-doing approach to be taken, informing the process along the way and allowing it to adjust to new information. Up-front responses, or the need to anticipate outcomes in advance, are most relevant to adaptations that require large initial planning and investment, those with a long operational life (and where retrofitting is too expensive) or if the damage to be avoided is irreversible and/or unacceptable. The 'wait and see' response is thought in most cases to be the most expensive option and will not cope with irreversible impacts.

Figure 6.3 shows a sample of planning horizons for different activities (lower scale) and operational pathways towards achieving a specific goal (upper scale). These are not intended to represent a complete set of pathways – many paths are possible depending on circumstance. The process for deciding which adaptation(s) to implement may also assess which type of adaptation pathway is most suitable. If aspirational targets are some decades away, the capacity to carry out an assessment over a range of timescales may be needed to test variable timing of responses. This is a far more sophisticated requirement than is being applied in most existing assessments.

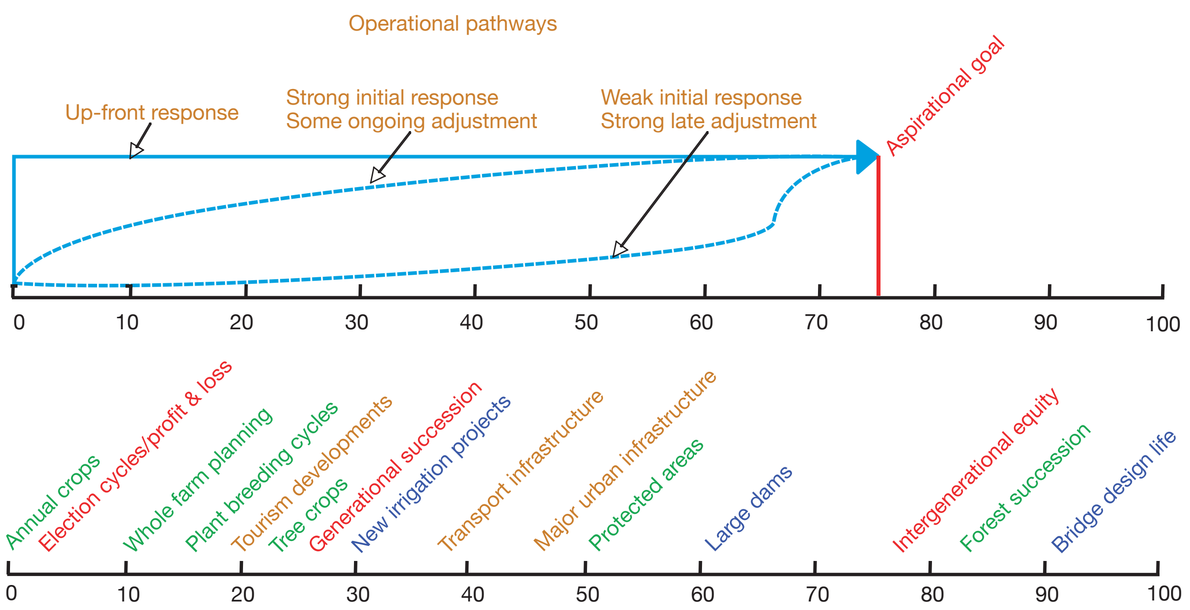


Figure 6.3: Relationship between goals and pathways for adaptation (upper diagram), related to a number of planning horizons of different timescales (lower diagram). The horizontal scale is in years.

6.2. Key issues in applying climate information

The choice of which climate information may be required for use in any impact or risk assessment is determined by the:

1. climate variable(s) of interest
2. spatial and temporal scale of the assessment
3. management of uncertainty

The first two factors, properly applied, will establish the plausibility of any resulting climate information and the third factor will establish confidence in the results.

Most projections, such as those detailed in this report, are not forecasts but are conditional upon the assumptions incorporated into the input data and model that produced those projections. Many of the assessments listed in section 6.1.1 do not require forecasts. For example, scenarios used in an assessment of unmitigated climate change risks would aim to be physically plausible under the forcing conditions consistent with that change, but would not necessarily be expected to occur. Analyses testing the sensitivity of impacts to specific climate change likewise do not require forecasts.

When assessing adaptation needs over the short to medium term, the aim should be to come as close to the anticipated range of plausible climate change as possible. However, because a whole of climate focus is taken, combining Australia's substantial ongoing climate variability with the uncertainties of climate change, uncertainties will be substantial. Assigning likelihoods to specific outcomes is becoming increasingly possible with model improvements and more sophisticated approaches and methods. However, the large inherent uncertainties remain a reason as to why off-the-shelf estimates and the uncritical use of climate projections are not advised.

6.2.1 Climate variables

A major task in any assessment is to identify the relevant climate variables, either associated with event risk or those that drive subsequent responses of societal and environmental systems (Table 6.1). Although the projections developed for this report span a broad range of variables, for any given application or risk of concern often only a subset of these is required. A robust physical relationship between the selected variables and the outcome of interest should be ensured. Appropriate variables may be identified by stakeholders, conceptual models of the system of interest, or through the use of more detailed process models where prior research and experience has elucidated the key climate drivers of the system.

The form of a selected variable will differ from system to system; for example:

- Species richness in the wet tropics is a function of maximum and minimum temperatures and rainfall during summer and winter seasons as well as intra-annual variability in temperature, rainfall and radiation (Williams *et al.* 2003).
- Maximum average January temperature is the most sensitive indicator of grape quality for a number of varieties (Webb 2006).
- Changes in alpine snow conditions depend on daily precipitation and temperature (Hennessy *et al*. 2003).

Although most event-based risks will be in response to changes in extreme conditions (IPCC 2007b), it is often difficult to provide reliable estimates of such changes. Instead, changes to mean conditions have most often been relied upon. For example, while past assessments of coastal impacts applied average sea level change in Bruun Rule-like algorithms (CIU 1992; Zhang *et al*. 2004), the interaction of higher sea levels with extreme tides resulting from natural climatic variability and/or anthropogenic climate changes are more realistic (McInnes *et al*. 2003, 2005a,b). Similarly, projections of changes in extreme rainfall events are central to understanding flood risk (Hennessy *et al.* 2004; Abbs *et al*. 2006), extreme heat for understanding heat-related mortality (McMichael *et al*. 2002), and fire weather for understanding bushfire risk (Hennessy *et al*. 2005).

To develop meaningful estimates of the risk of such climatic events, simulations using low-resolution climate models to derive average changes in climatic conditions are not sufficient. Instead, high-resolution modelling through statistical or dynamical downscaling and nested modelling techniques is often required to simulate such events (Abbs *et al.* 2006). However, there is a trade-off between the application of simple and easy to apply methods and the time, money and effort needed to provide more realistic detail that each assessment must confront. Ideally, scenarios should be constructed using the simplest information required to make the decision under consideration, but this is not always an easy task.

When identifying climate variables and selecting the relevant climate models used for generating climate scenarios, each scenario used in a risk assessment should be internally consistent. For example, all projections of rainfall and temperature changes applied in an agricultural impact model should be incorporated under a consistent set of assumptions, including the choice of global climate models, time period, and greenhouse gas emissions scenario. Arbitrary mixing-and-matching of projections degrades the realism of the outcome and limits comparability of different impact and risk assessments (Box 6.2).

Table 6.1: Common climate variables used in impact and risk assessment

Impact area	Impact	Climate variables	Examples
Agriculture	• Dryland wheat production • Grape quality	• Temperature • Rainfall	• Howden *et al*. (1999) • Howden and Jones (2001) • Luo *et al*. (2005) • Webb (2006)
Water resources	• Stream flows • Storage inflows	• Rainfall • Evaporation	• Jones and Page (2001) • Jones and Durack (2005)
Coasts	• Sustainable yields • Storm surge return periods and area inundated	• Sea level rise • Winds • Pressure	• Kirono *et al*. (2007) • CIU (1992) • Cowell *et al*. (2006) • McInnes *et al*. (2003) • McInnes *et al*. (2006)
Infrastructure	• Impacts to buildings • Road maintenance costs • Energy production	• Temperature • Rainfall • Radiation • Winds • Sea level rise	• Amitrano *et al*. (2007) • Austroads (2004) • PIA (2004) • PB Associates (2007) • Victorian Government (2007)
Terrestrial biodiversity	• Primary production • Population extinctions	• Temperature • Rainfall • Radiation	• Pickering *et al*. (2004) • Williams *et al*. (2003)
Marine biodiversity	• Coral bleaching and mortality	• Sea surface temperature	• Hoegh-Guldberg (1999) • Done *et al*. (2003)
Health impacts	• Heat-related mortality • Infectious disease	• Temperature • Rainfall • Humidity	• McMichael *et al*. (2002) • Woodruff *et al*. (2005)
Fire weather	• Fire intensity & frequency • Length of fire season • Period suitable for controlled burning	• Precipitation • Temperature • Relative humidity • Wind	• Hennessy *et al*. (2005)
Alpine snow conditions	• Snow cover • Snow depth • Snow duration	• Precipitation • Temperature	• Hennessy *et al*. (2003)

Box 6.2 Applying internally consistent climate change scenarios

Because different global and regional climate models display marked differences with respect to future climate projections, multiple models are often used to generate climate scenarios for impact assessment. This enables the uncertainty in future climate conditions to be reflected in estimates of impact and risk assessments, often by identifying of potential 'best' and 'worst' case impact scenarios. Care must be exercised to preserve the internal consistency of a model's projections of different climate variables. Variables such as temperature, rainfall, evaporation, and humidity are highly interactive, meaning a change in one variable has an effect on other variables. As such, mixing variables from different models in a single scenario may result in physically implausible (or impossible) combinations.

For example, to identify the worst possible outcome from an impact model, it may be tempting to identify the most pessimistic rainfall projection from any climate model and pair that scenario with the most pessimistic temperature projection (Figure 6.4a). However, because the projections for the variables were derived from different climate models, they may be physically inconsistent, providing a spurious estimate of future impacts. The magnitude of projected impacts would therefore be larger than that derived from internally consistent projections.

Instead, estimates of impacts should first be calculated independently for each climate model under consideration (Figure 6.4b). This results in a range of impact estimates that are representative of plausible climate futures which can then be ranked according to their relative impact. Low, high and/or intermediate outcomes, or combinations of those in probability distributions, can be selected for further application.

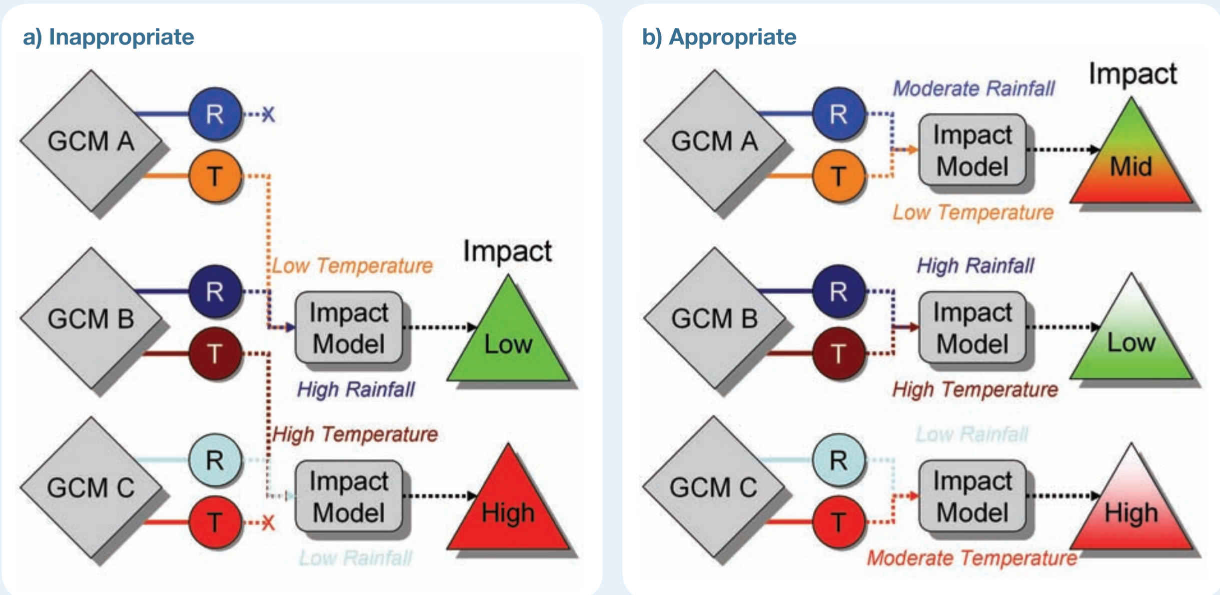


Figure 6.4. Example of appropriate and inappropriate use of climate model projections in impact assessment. For both of the above figures, rainfall (R) and temperature (T) projections from three different global climate models (GCMs) are applied in a hypothetical impact model. In **(a)**, each pair of global climate model scenarios is applied independently to the impact assessment model, resulting in a range of different climate impacts. In **(b)**, projections of rainfall and temperature from different models are paired to yield extreme scenarios of climate change, which are then applied to the impact model.

6.2.2 Spatial and temporal scales

Each assessment needs to decide the temporal and spatial scales over which that assessment will be conducted by considering the following aspects:

- the time horizon for the projected climate change or impact
- future time slice or transient time series
- the temporal resolution of the projection or assessment
- single point, multiple points or geographic areas
- the spatial resolution of the projection.

6.2.2.1 The time horizon for the projected climate change or impact

By convention, most of the climate change projections and estimated impacts developed internationally have employed time horizons of approximately one century (e.g. out to 2100), as illustrated by IPCC global temperature and sea level projections (IPCC 2001, 2007a). This reflects the limit of most greenhouse gas scenarios and climate model simulations. Australian climate projections and estimates of impacts often extend to the late 21st century (i.e. 2070) although more immediate time horizons are also routinely employed (e.g. 2025, 2030 or 2050). However, the stakeholder focus groups conducted for this report reflected the growing demand for time horizons more consistent with planning horizons for many industries and sectors, ranging anywhere from 1 to 25 years.

6.2.2.2 Fixed time or transient time series

The CSIRO (2001) projections of Australian climate change and a wide variety of impact assessments relied upon time slices centred on 2030 and 2070 (Whetton *et al*. 2005). Many specific applications, for example, both hydrological and crop models require the use of long time series to adequately capture a realistic response due to climate variability. These can be used as time slice (a changed climate for a number of decades centred on a given year) or transient inputs (a gradually changing climate spanning the present to future). Because some systems (particularly natural ecosystems and biodiversity) are affected as much by the rate of climate change as the magnitude (IPCC 2004), transient projections may be required to estimate rates of climate changes over various time periods.

6.2.2.3 Temporal resolution

Climate projections may be developed on annual, seasonal, monthly, weekly, or daily time steps. Sometimes seasonal to annual information is sufficient to develop a general understanding of future trends and dynamics. However, many complex processes, such as specific hydrological or agricultural systems, may require daily time series data as input, even though the results may be aggregated to seasonal to annual values. Preparation of high resolution data is often resource intensive. Daily data from climate models is available from a limited number of models and time periods, but this situation has improved with the latest set of climate models. Methods for preparing scenarios incorporating daily data include dynamic and statistical downscaling and perturbation of historical time series by monthly or annual change factors, the most common method used to date (Chiew 2006).

6.2.2.4 Single point, multiple points, or geographic areas

Climate projections require data presented in a range of spatial forms. For example, agricultural crop models are often location-specific and hydrological models may require information for specific nodes within the surface water system. In such instances, climate projections at specific geographic locations (grid-cells) are necessary to drive impact assessment models for one or more locations. Howden *et al*. (1999) used climate model projections to simulate climate change impacts on dryland wheat production for 11 point locations throughout the Australia wheatbelt but aggregated the result to assess national impacts. Kirono *et al.* (2007), used climate projections for the Lismore region in northern New South Wales to drive hydrological modelling of the Richmond River catchment. Hennessy *et al*. (2005) projected changes in fire weather for 17 sites in south-east Australia. Other impact assessment applications have simulated impacts over an entire region or landscape (e.g., Hennessy *et al*. 2003; Williams *et al*. 2003; Jones *et al*. 2007), thereby capturing spatial heterogeneities. For such applications, climate projections that reflect the spatial variability in future changes are needed, often as gridded data sets of varying geographic and temporal resolutions.

6.2.2.5 The spatial resolution of the projection

The spatial resolution of climate information is a core challenge for development of climate projections. Climate model output is often produced on a geographic grid of 300–400 km, yet underlying climatological gradients and land surface heterogeneity lie within these spatial scales. Capturing events such as thunderstorms or tropical cyclones requires much finer resolution (e.g. 1–5 km; Abbs *et al*. 2006). Quantifying the impacts of climate change at relevant scales is also important for decision-making. Although climate projections are often provided at coarse resolution, many of the datasets for baseline climate, soil, runoff, topography and land use in Australia that are useful for supporting risk assessment research are available at resolutions from 1–5 km (e.g. spatial datasets generated for the 2001 National Land and Water Resources Audit) while remote sensing may allow the built environment to be resolved with centimetre-scale precision. However, if it can be shown that coarse resolution climate changes overlaid on higher resolution baseline data provide realistic simulations of change, the spatially explicit modelling of impacts can be accomplished even with coarse projections.

6.3 Treatment of uncertainty

While the role of science is to improve our understanding of how systems work, research does not always reduce uncertainty. For example, when a poorly known process becomes better quantified and added to other known uncertainties, the total quantified range may increase, fuelling the perception that uncertainty has increased. However, a qualified uncertainty has merely been quantified. For example, the addition of carbon cycle uncertainties to the range of global average warming in IPCC (2007a) have led to a greater range of global warming than in IPCC (2001). Examples of uncertainties that were reduced in the Fourth Assessment Report include the thermal component of sea level rise, the 'likely' range of climate sensitivity (IPCC 2007a) and ranges of warming for selected regions (Fig 2.6 in Carter *et al*. 2007). Advances in scientific research pertaining to current climate and projections of regional climate change for Australia are discussed in Chapters 2 to 5.

The main methods for managing the resulting uncertainties contained within climate projections research in impact and risk assessments can be grouped into contextual and statistical approaches. Contextual approaches, which reduce structural uncertainties described in section 4.2.4, are discussed in section 6.1, and statistical approaches, which reduce value uncertainties, are described below.

Some of the key uncertainties associated with climate projections, include:

- Future emissions of greenhouse gases and aerosols
- Climate sensitivity
- Regional expressions of global climate change.

Additional uncertainties arise during the impact assessment process, namely:

- System sensitivity to climatic changes
- System adaptive capacity.

These key climate uncertainties translate into an uncertainty space bounded by plausible parameters for climate sensitivity, future greenhouse gas emissions, and regional patterns of change. (These are not the only uncertainties that may need to be managed during a risk assessment – for example, environmental and socio-economic factors may both contribute to risk as stressors and modifiers of impact and resulting consequences. However, space only permits a discussion of the major climate-related uncertainties.)

This uncertainty space can be explored using a range of statistical methods that include various sampling strategies. Because of the many contributing uncertainties and possible contexts for assessment, there is no completely objective way of applying these statistical methods to manage uncertainties. Instead a hierarchy of approaches is used – these range from multi-model studies that produce probability distributions, various sampling methods applied to quantified ranges of uncertainty, and expert judgement through to the exploration of 'what if' scenarios and sensitivity studies (Box 1.1 in Chapter 1). Sometimes, an assessment will combine several of the above approaches in scenario construction.

All approaches used need to be clearly described, transparent (i.e. assumptions are clearly stated) and reproducible. Credibility with stakeholders is an important part of whether the results are ultimately accepted. One major test to determine whether a specific uncertainty, and how it is constructed, is important to a result is to gauge its robustness under different assumptions (e.g. Jones and Page 2001; Dessai and Hulme 2007). If the result is insensitive to changes in the underlying uncertainty then that particular source of uncertainty can be overlooked. If the result is sensitive, then confidence in how well that particular aspect of uncertainty has been represented, and how it contributes to the total uncertainty, will influence how the results are interpreted and taken up. In this context, the sensitivity testing of methods and assumptions becomes an extension of more conventional sensitivity assessments, such as those that test sensitivity to changing inputs. However, such work does require the expenditure of resources, which may compete with the resources required to construct physically plausible scenarios discussed in section 6.2. Trade-offs between uncertainty management and scenario detail (e.g. spatial and temporal downscaling) in an assessment may be required.

The following descriptions portray how climate change uncertainties have been represented in a range of assessments conducted in Australia over the past decade. They are presented in a hierarchical order ranging from the use of simple scenarios through to methods that fully explore the plausible range of uncertainty.

6.3.1 Representing climate uncertainties

Most often, bounded estimates of climate change are used rather than the total uncertainty as portrayed in Figure 4.4 of Chapter 4. Figure 6.5 shows three representations of sampling within an uncertainty space. A single model, with a single emissions scenario, and low, medium, and high climate sensitivities results in three different estimates of future change, confined to one region of the uncertainty space. When additional emissions scenarios are included, a broader range of futures becomes apparent. With the inclusion of additional models, the range of potential changes becomes even wider. However, by combining uncertainties for climate sensitivity, emissions, and regional climate patterns the resulting projections can be represent the plausible uncertainty space of judged climate change (section 4.2.4).

The lower series in Figure 6.5 describes the current state of play. This report describes a range of climate models, greenhouse gas emission scenarios and climate sensitivities that can be used to represent both biophysical and socio-economic uncertainties. The difference between the sample of 144 projections compared to the sample of three projections in Figure 6.5 emphasises that any likelihoods and associated statistical measures (e.g. mean, median or standard deviation), will differ substantially depending on the assumptions and method used to characterise uncertainty (Lopez *et al*. 2006).

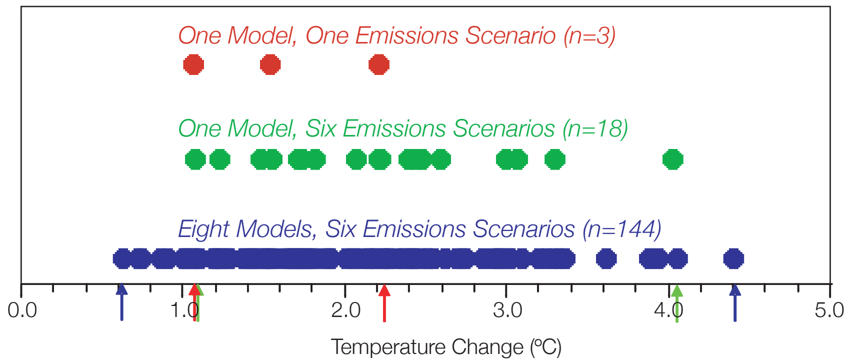


Figure 6.5: Projected changes in annual mean temperature in Canberra in 2070 based on simulations with the OzClim scenario generator (www.csiro.au/ozclim; Page and Jones 2001). Results are presented for temperature changes using one model (CSIRO Mark 3.0) with one emissions scenario (A1) and three climate sensitivities (red); one model (CSIRO Mark 3.0) with the six IPCC illustrative scenarios (green); and eight models with the six IPCC scenarios (blue). Coloured arrows on the axis identify the minimum and maximum results for each ensemble of results.

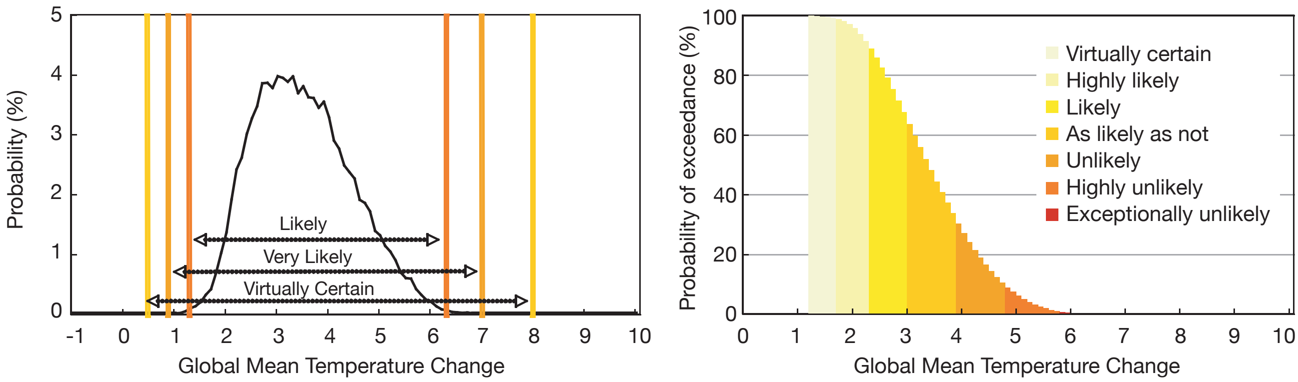


Figure 6.6: Likelihood of global average warming in 2100 consistent with the climate sensitivity, carbon cycle uncertainties and range of SRES emissions scenarios summarised in IPCC (2007a). The left hand panel shows the conditional probability of occurrence along with the likelihood that the 'real' answer (given the underlying assumptions are considered realistic) will lie within the stated range. The right hand panel shows the likelihood of exceeding a given level of change.

Other strategies include continuous random sampling of the uncertainty space (e.g. Monte Carlo and bootstrap sampling techniques), structured sampling and model weighting according to representativeness or skill as discussed in Chapter 4.

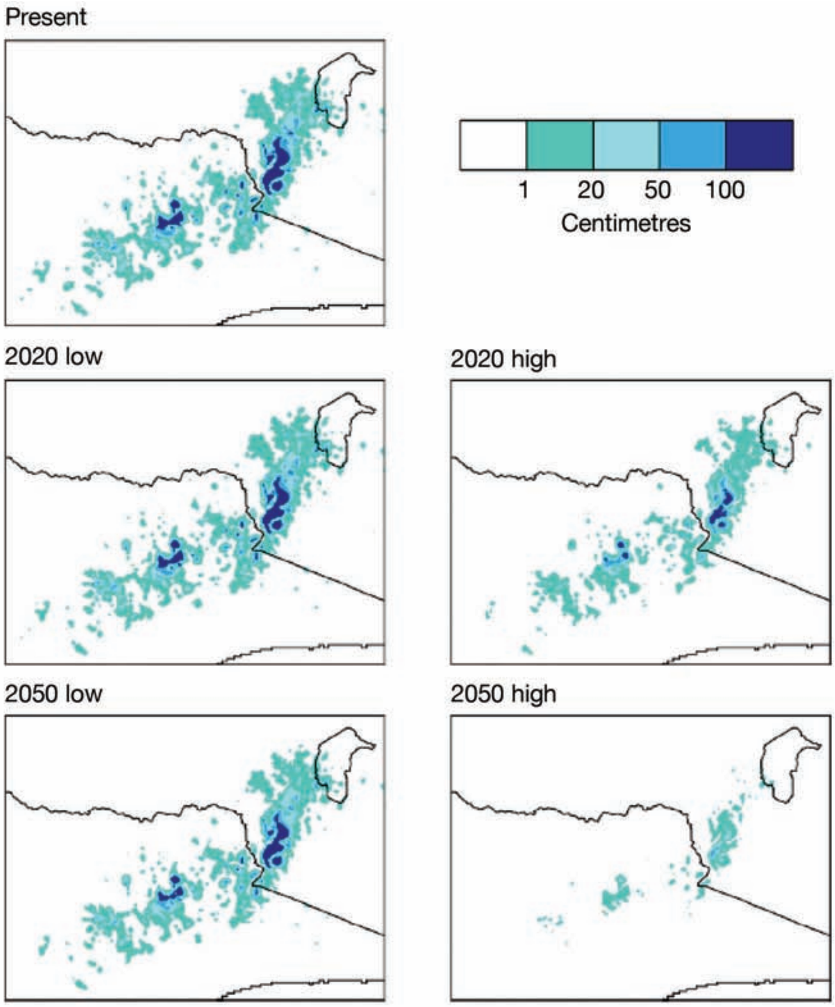
Probabilities can be expressed in two ways. One is as a probability density function as shown in Figure 4.6, where several sources of uncertainty, or a suite of model results may combine in a probability density function where the central tendencies are more likely than the extremes. This is a predictive framework that estimates conditional likelihoods of specific outcomes, often event-based risks. The other is as a cumulative distribution function that measures the likelihood of exceeding a given limit or threshold, and is more suited to the assessment of outcome risk. The first gives the conditional probability of occurrence and the second the conditional probability of exceedance (Figure 6.6). The key advantages in using cumulative probability functions, or assessing the likelihood of exceedance, are that it measures risk from a baseline and is much less sensitive to underlying uncertainties than the probability density function (Jones 2004).

6.3.2 Examples of uncertainty management in impact and risk assessments

A single projection of future climate conditions may be sufficient to illustrate the type of changes that can occur and the potential sensitivity of impacts to that change, or to test a particular method of downscaling. However, for most other purposes, it is better to apply a larger number of projections that represent a larger portion of the uncertainty space.

One commonly used approach is to apply widely divergent estimates of future changes, such as a 'best case' and a 'worst case', for example by constructing two projections combining a higher climate sensitivity (commonly yielding higher temperatures) with drier conditions, and a lower climate sensitivity with wetter conditions (e.g. NAST 2000; Hayhoe *et al*. 2004; Edmonds and Rosenberg 2005). The use of disparate emissions scenarios can further accentuate the difference in projected futures. However, while both may be plausible, they represent limited uncertainty and it is difficult to determine which, if either, might be more likely.

Alternatively, investigators can examine a broad range of climate projections from multiple climate models to identify 'low' and 'high' projections that are more reflective of the full range of uncertainty (AGO 2006a,b). For example, Figure 6.7 shows low and high projections of climate change impacts to snow conditions in the Australian Alps (Hennessy *et al*. 2003). This approach has the advantage of representing the range of uncertainty in future conditions, while communicating this information in a relatively simple manner. As discussed in Box 6.2, when applying such projections in impact assessment models, care must be taken to ensure projections are internally consistent.



Scenario (Year)	Projected Change in Temperature (°C)	Projected Change in Precipitation (%)
Low impact (2020)	+0.2	+0.9
High Impact (2020)	+1.0	-8.3
Low impact (2050)	+0.6	+2.3
High impact (2050)	+2.9	-24.0

Figure 6.7: Projected 'low' and 'high' changes in alpine temperature and precipitation for 2020 and 2050, relative to 1990 (bottom) and associated simulated annual average maximum snow depth (cm) (top).

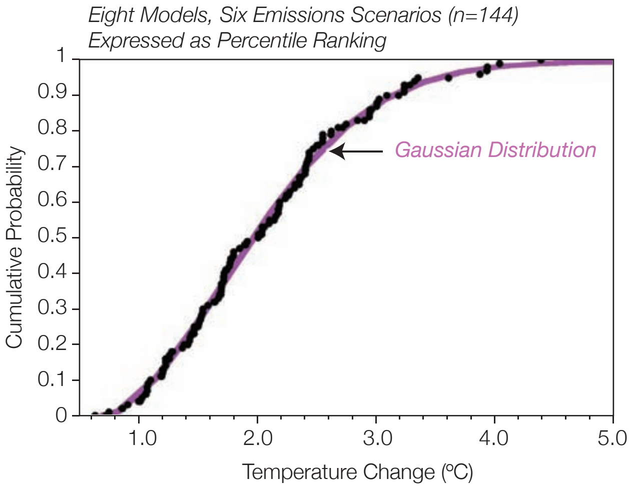


Figure 6.8: Cumulative probability distribution for annual mean temperature change in Canberra in 2070. Black circles represent 144 projections from eight climate models with three climate sensitivities and the six illustrative emissions scenarios of the IPCC. Purple curve represents a Gaussian distribution fit to the data.

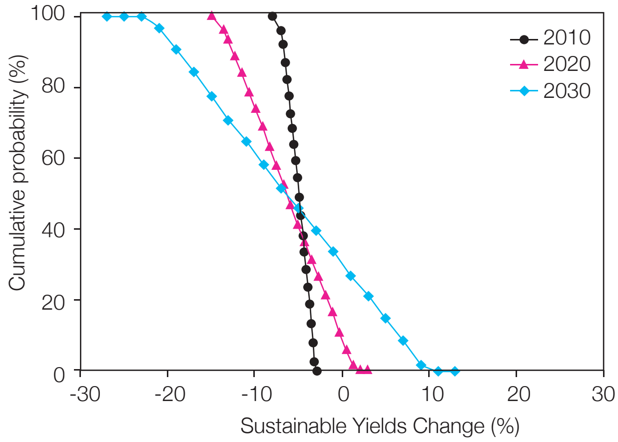


Figure 6.9: Cumulative probability distributions for changes in sustainable yields of a regional water utility. Distributions were based upon the applications of a suite of climate projections to a statistical relationship between rainfall, evaporation and yield, based upon simulations with the IQQM hydrological model (Kirono *et al*. 2007).

If information is needed on the likelihood of different changes or impacts, estimates of probability can be generated by applying frequency statistics. Results can be treated as a sample of the population of actual climate change or impacts, and probabilities can be calculated to compare the relative likelihood of different outcomes in the sample (Figure 6.8). More advanced statistical methods can be used to generate probability density functions or cumulative probability distributions from a sample of projections or impact results. These can be applied in impact assessment using Monte Carlo methods to estimate the probability of different outcomes (Kirono *et al*. 2007; Figure 6.9)

Downscaling of extreme events from model simulations can also assess the likelihood of exceeding specific extremes, such as extreme rainfall events (Figure 6.10). This frequentist analysis tests many instances of an event-based risk downscaled from a baseline and climate change simulation of the same model, consistent with the analysis of historical events. Using ensembles of models will increase the confidence in such analyses.

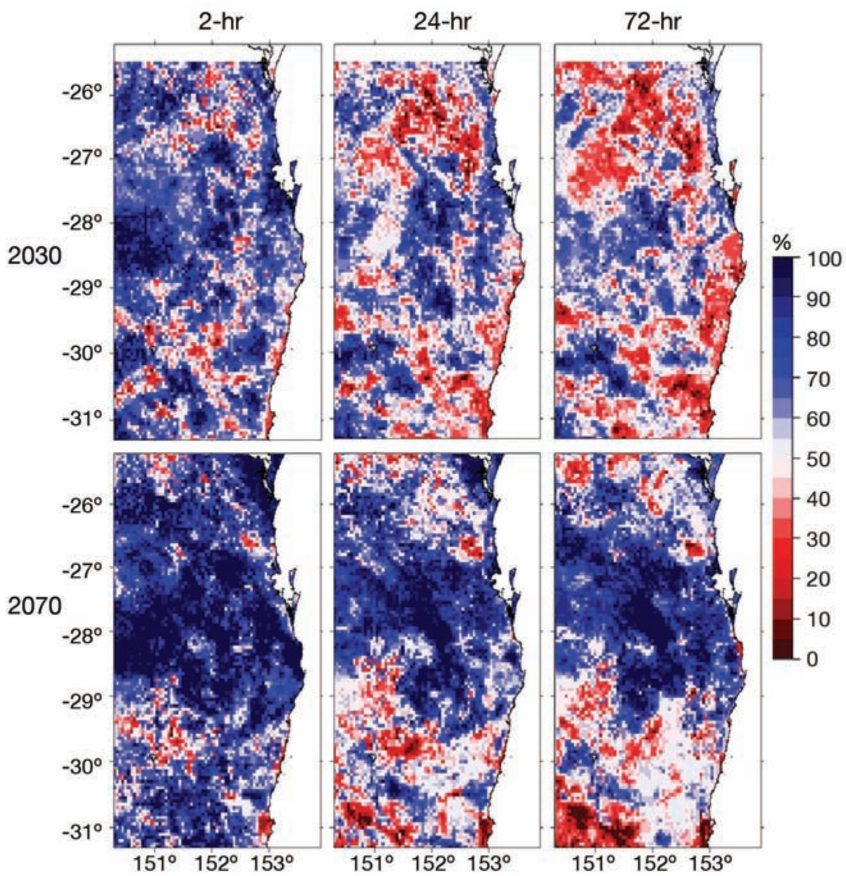


Figure 6.10: Probability of increases in extreme rainfall events in central coastal New South Wales. Probabilities are expressed as a percentage of model simulations that indicate increases in extreme rainfall (Hennessy *et al*. 2004).

A range of assessments have been carried out that combine the SRES greenhouse gas emission scenarios and model-based projections of climate change derived from those scenarios to ask 'what if' questions about impact-related risks. These assessments have applied ensembles of change and/or Monte Carlo methods to develop more robust statistical estimates of the probability of exceeding thresholds. Chapter 5 presents probabilities of exceeding different temperature and rainfall thresholds across Australia. Such techniques have been used to assess the likelihood of exceeding different impact thresholds, such as reductions in agricultural productivity or dam inflows (Howden and Jones 2001; Jones and Page 2001; Kirono *et al*. 2007). A number of studies have also examined the likelihood of exceeding thresholds for 'dangerous interference' with the global climate system (Hare and Meinshausen 2004; Jones 2004; Mastrandrea and Schneider 2004; Jones and Preston 2006). Damages avoided through mitigation can be contrasted by comparing outcomes associated with high emissions with those from a low emissions, or stabilisation scenario.

The application of methods for likelihood estimation is highly dependent upon sample size and potentially on how those underlying uncertainties are managed. Generally, as the sample size increases, estimates of the distribution become more robust. The need for a healthy sample is a challenge for some impact applications. Crop models, hydrological models and ecosystem models all tend to be complex, physically-based process models. Iterative simulations with such models with a broad range of scenarios may be prohibitive, given the time and resources involved. This challenge has been addressed in two different ways:

1. Prior screening of a population of climate scenarios to identify the 'most-likely' future climatic conditions (Jones and Mearns 2005). This projection is then used in impact assessment, yielding a 'most likely' impact.

2. Prior sensitivity analysis of the impact model of interest with a relatively small number of arbitrary projections. The population of impact outcomes can subsequently be used to generate a simple statistical impact response function that can then be comprehensively interrogated with a larger population of global climate model estimates. For example, Jones and Howden (2001) used a similar approach with APSIM in a national risk assessment. This technique has also seen several applications in hydrology (Jones and Page 2001; CSIRO and Melbourne Water 2005; Jones and Durack 2005; Kirono *et al*. 2007; Figure 6.9).

Finally, the projections presented in this document signal a further advance in estimating climate change likelihoods. Applying these techniques to impact and risk assessment should help constrain uncertainties by providing tighter 'most likely' outcomes. However, because there are a number of realistic alternatives in how such likelihoods can be applied, these alternatives can be tested in impact assessments to determine whether the results are robust or sensitive to the input assumptions (Jones and Page 2001; Dessai and Hulme 2007). This information will improve our understanding of which risks are sensitive to what variables, and also feed back into modelling studies in terms of where improvements are needed most. For example, Jones *et al*. (2005) tested water yield in the Fitzroy Basin under the assumption that regional ranges of rainfall variability were uniform, or grouped according to the distribution of model patterns of change (Figure 6.11). The resulting analysis showed that the shapes of the input uncertainties were critical and that rainfall changes over only three months of the wet season comprised 75% of the uncertainty in total catchment water yield. Such exercises, expanded to a larger range of impact types, could be used to test model-weighting schemes.

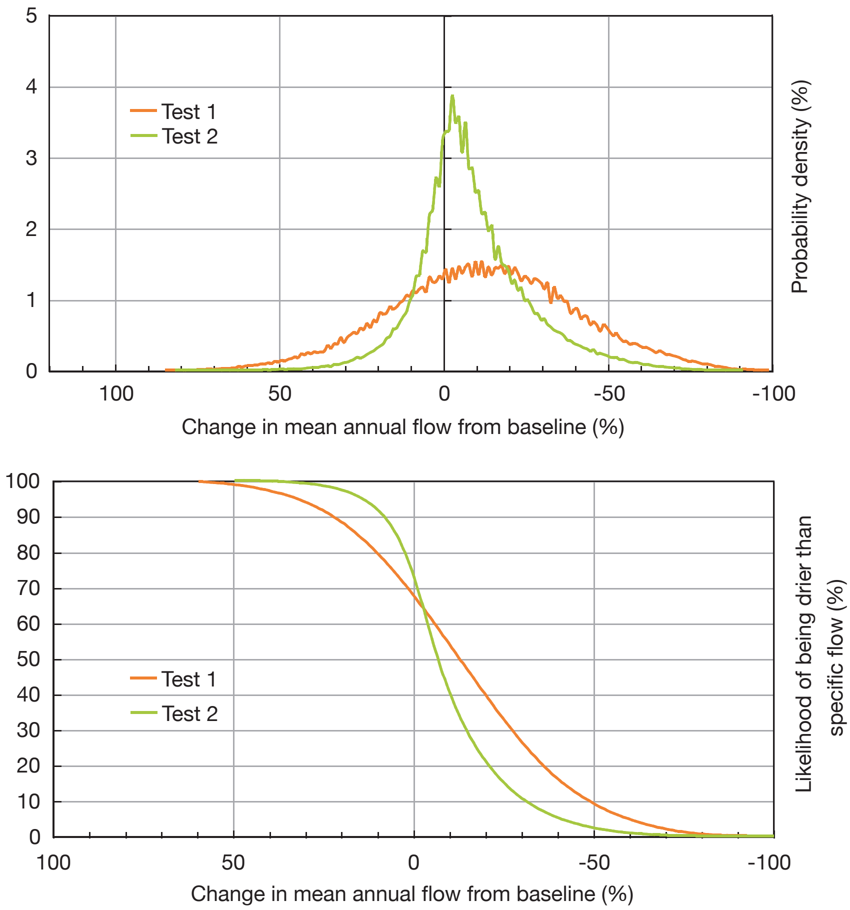


Figure 6.11: Comparison of probability distributions for change in mean annual flow for the Fitzroy River in 2030 comparing uniform sampling of rainfall changes (Test 1) with non-uniform sampling based on the climate model distribution (Test 2). The top chart shows probability density, the bottom chart shows the probability of mean annual flow being drier than a specific change (as measured from the x-axis).

6.4 Delivering climate projections to end-users and stakeholders

As the demand for climate projections has grown, various tools have been developed which represent different methods for enhancing the delivery of climate information to the public and stakeholders both for education and for risk assessment and management.

Australia's primary platform for distributing climate projections is the OzClim scenario generator. OzClim enables users to generate their own projections of average climate change for different time periods in the future, drawing from various climate models and assumptions about climate sensitivity and future greenhouse gas emissions. It also enables projection data to be exported in various file formats for subsequent use in other computing environments. MAGICC/SCENGEN can be used to explore potential climate changes at the global to regional scale under a similar range of assumptions. SimCLIM is an open-framework modelling system for integrated hazard and climate impact analysis.

In the United States, the Consortium for Atlantic Regional Assessment was recently developed as an internet-based tool providing information on historical and future climate and land-use (Dempsey and Fisher 2005). The United Kingdom (UK) Climate Impacts Programme's Adaptation Wizard is a simple on-line tool that leads users through the process of understanding climate change through to making decisions about adaptation, while the Scenario Gateway provides online access to UK climate scenarios. Together with appropriate risk assessment and management frameworks, these tools enhance the capacity for stakeholders to access climate projections, begin assessing risk and identifying risk management decisions.

The availability of climate data through such tools does not ensure that such information will be used for managing climate risk. Recent work on climate change communication has identified challenges in delivering messages to the public regarding climate change and its consequences (Table 6.2). Unless overcome, these challenges diminish perceptions of climate risk, reduce incentives for taking risk management actions and limit understanding of what actions may be useful or appropriate.

Many of these challenges were also identified in stakeholder focus groups conducted as a part of the development of the projections in this report. Stakeholder consultation was undertaken in November 2006 through focus groups in Adelaide, Perth, Brisbane Melbourne and Sydney, and through an online survey. There were 64 participants in the focus groups, and 230 responses to the survey.

Stakeholder messages regarding climate projections highlighted:

- the need for different data among diverse stakeholders.
- the need for simplicity and transparency in communication of information.
- the limited ability by stakeholders to distinguish between weather forecasts, seasonal climate forecasts and multi-decadal climate projections.
- confusion by stakeholders in managing information on climate change as new research becomes available, such as successive generations of climate change projections, and the use of different climate models, emissions scenarios and model resolutions.
- conflicting messages from different communicators.
- the need for information on how to respond to projected changes.
- the potential for demands for information to exceed available resources and technical capacity.

Such sentiments reflect two issues that exist in conflict:

1. an intense demand for increasingly detailed information, and
2. challenges in meeting demand as well as in interpreting and using that information which is available.

In addition, stakeholders identified a number of barriers to obtaining and applying climate projections, such as the ability to locate information on the internet (the most popular vehicle for obtaining information) or even the colour scheme used in graphics.

Perhaps the most effective mechanism for overcoming the challenges to using climate information in decision-making is to couple the provision of information about climate change and impacts with a particular decision-making event (CSIRO and Melbourne Water 2005; Kirono *et al*. 2007). This ensures that climate projections are developed that are relevant to the endpoint or risk of concern, and stakeholders have more intimate knowledge of the methods by which they were developed. It also ensures that uncertainty in climate projections and impacts are treated in a manner relevant to and preferred by stakeholders charged with a decision-making event. Such an approach provides the best chance that the information will be relevant to stakeholders, appropriately interpreted and effectively used.

Table 6.2: Challenges in communicating climate change projections and risk

Challenge	Solution
Diverse communicators (e.g. scientists, policy-makers, the media) with varying agendas and credibility (Boykoff and Boykoff 2004; Cameron 2005).	Emphasise the scientific confidence in climate projections; ensure transparency and consistency in communications.
Confusion about how the climate system works (Sterman and Sweeney 2002).	Provide the public with information not only regarding what climate changes are projected, but also why such changes are anticipated and how they were derived.
Difficulty in identifying specific and salient threats associated with climate change (Ohe and Ikeda 2005).	Link climate change projections with social and environmental impacts. Increase focus on projections of climate extremes where the consequences are more self-evident.
Low prioritisation of climate change relative to more immediate concerns (Moser and Dilling 2004).	Link climate change to other sustainability issues, such as energy, natural resource management, regional security and public health.
Limited understanding of how individuals' actions can reduce risk (CCSA 2005).	Link projections of climate change and impacts with risk management strategies relevant to the audience (e.g. greenhouse gas mitigation and adaptation measures).
Perceptions of the likelihood of climate projections and impacts vary by individual, population, and impact of interest (Patt and Schragg 2003; Patt and Dessai 2005)	Isolate consequence and probability in the communication of risk to minimise subjective interpretations (Manning 2003).
Poor uptake and use of existing tools for climate projections and impact assessment by stakeholders (Demeritt and Langdon 2004; Dempsey and Fisher 2005).	Better marketing of available tools and services to stakeholders as well as demonstrations of prior use and value; easy to access and use methods and tools.
Existing information on climate change is inappropriate for a particular decision-event.	Target projection development to the needs of end users and develop alternative, yet internally consistent, methods for presenting projections.