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ORIGINAL PAPER

The relationship between adaptation and mitigation in managing climate change risks: a regional response from North Central Victoria, Australia

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Abstract This two-part paper considers the complementarity between adaptation and mitigation in managing the risks associated with the enhanced greenhouse effect. Part one reviews the application of risk management methods to climate change assessments. Formal investigations of the enhanced greenhouse effect have produced three generations of risk assessment. The first led to the United Nations Intergovernmental Panel on Climate Change (IPCC), First Assessment Report and subsequent drafting of the United Nations Framework Convention on Climate Change. The second investigated the impacts of unmitigated climate change in the Second and Third IPCC Assessment Reports. The third generation, currently underway, is investigating how risk management options can be prioritised and implemented. Mitigation and adaptation have two main areas of complementarity. Firstly, they each manage different components of future climate-related risk. Mitigation reduces the number and magnitude of potential climate hazards, reducing the most severe changes first. Adaptation increases the ability to cope with climate hazards by reducing system sensitivity or by reducing the consequent level of harm. Secondly, they manage risks at different extremes of the potential range of future climate change. Adaptation works best with changes of lesser magnitude at the lower end of the potential range. Where there is sufficient adaptive capacity, adaptation improves the ability of a system to cope with increasingly larger changes over time. By moving from uncontrolled

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emissions towards stabilisation of greenhouse gases in the atmosphere, mitigation limits the upper part of the range. Different activities have various blends of adaptive and mitigative capacity. In some cases, high sensitivity and low adaptive capacity may lead to large residual climate risks; in other cases, a large adaptive capacity may mean that residual risks are small or non-existent. Mitigative and adaptive capacity do not share the same scale: adaptive capacity is expressed locally, whereas mitigative capacity is different for each activity and location but needs to be aggregated at the global scale to properly assess its potential benefits in reducing climate hazards. This can be seen as a demand for mitigation, which can be exercised at the local scale through exercising mitigative capacity. Part two of the paper deals with the situation where regional bodies aim to maximise the benefits of managing climate risks by integrating adaptation and mitigation measures at their various scales of operation. In north central Victoria, Australia, adaptation and mitigation are being jointly managed by a greenhouse consortium and a catchment management authority. Several related studies investigating large-scale revegetation are used to show how climate change impacts and sequestration measures affect soil, salt and carbon fluxes in the landscape. These studies show that trade-offs between these interactions will have to be carefully managed to maximise their relative benefits. The paper concludes that when managing climate change risks, there are many instances where adaptation and mitigation can be integrated at the operational level. However, significant gaps between our understanding of the benefits of adaptation and mitigation between local and global scales remain. Some of these may be addressed by matching demands for mitigation (for activities and locations where adaptive capacity will be exceeded) with the ability to supply that demand through localised mitigative capacity by means of globally integrated mechanisms.

Keywords Adaptation · Climate change risks · Integration · Mitigation · Risk management · Tradeoffs

1 Introduction

The two principal methods of managing the risks associated with the enhanced greenhouse effect are the mitigation of greenhouse gases and adaptation to climate change (IPCC 2001; Smit et al. 1999). To date, most work on adaptation and mitigation has dealt with each separately, leaving any potential links between the two relatively unexplored. Adaptation has largely been overlooked until recently for reasons pertaining to perceived policy weaknesses (e.g., Burton 1994; Pielke 1998), and for scientific and technical reasons. In particular, there are large differences between adaptation and mitigation on spatial, temporal and socio-economic scales with respect to how they reduce climate change risks (Wilbanks and Kates 1999; Adger 2001; Corfee-Morlot and Agrawala 2004). Some of the questions that are now guiding approaches that explore synergies between adaptation and mitigation include:

- Context—''In what context are adaptation and mitigation measures most appropriate?''
- Timing—''When should adaptation or mitigation measures be implemented?''
- Activity—''How do we relate adaptation and mitigation for specific activities?''
- Location and scale—''Who should implement adaptation and mitigation measures?''

Spatially, adaptation works best at the local scale because the biophysical and social characteristics of each location, along with anticipated climate change and the resultant impacts on specific activities, are sufficiently diverse to ensure that generic approaches are usually inappropriate, or at least need to be modified to account for local factors (e.g. Smit et al. 1999; Wilbanks and Kates 1999). Temporally, the benefits of adaptation can be almost immediate if implemented in response to current climate risks and can also provide future benefits over a range of time scales (UNDP 2005). Anticipatory adaptation will be guided by planning horizons for particular activities, with the benefits in avoided damage to changing exposure to climate hazards over time. Ancillary benefits may provide earlier benefits for anticipatory adaptations and may accompany reactive adaptations (e.g., Callaway 2004).

The mitigation of greenhouse gases has benefits at the scale of avoided damages, which range from the global to the local. However, it does not matter where greenhouse gases are reduced because they rapidly become well-mixed in the atmosphere, with global reductions in radiative forcing acting on climate (Corfee-Morlot and Agrawala 2004). The benefits of mitigation in terms of avoided damage also contain a temporal delay that ranges from decades in the atmosphere to centuries in the oceans (IPCC 2001). Ancillary benefits can also provide appreciable returns on investment (time, money and effort) prior to realising the benefits of avoided damages (Davis et al. 2000; Corfee-Morlot and Höhne 2003).

Much of the work relating adaptation and mitigation has utilised single scenarios of change. However, we would argue that if one looks across the entire range of plausible outcomes, a very different pattern emerges (Jones 2004b; Mastrandrea and Schneider 2004). It is impossible to respond to outcomes in a single scenario because one never knows exactly what damages will arise from a given amount of emissions. Methods that explore the benefits of mitigation, are often required to do so in the knowledge of what the ensuing damages will be (e.g., application of the RICE (Regional dynamic Integrated model of Climate and the Economy) model—Nordhaus and Boyer 2000), and those that apply adaptations often respond to changing risks as they are experienced. Both mitigation and adaptation measures need to be appropriate for a wide range of potential outcomes, and the best way to do this is in a risk management framework (Kane and Shogren 2000; Jones 2004a).

In this paper, we briefly describe how environmental risk management frameworks suit the aims of the United Nations Framework Convention on Climate Change (UNFCCC) Article 2. Adaptation and mitigation are complementary methods of risk management, managing different aspects of climate risk over both space and time (Jones 2003). However, when it comes to the implementation of adaptation and mitigation, the fact that they manage different aspects of climate risk may not matter to stakeholders who have decided to act on climate change; in part because the benefits of adaptation and mitigation will be experienced locally (Tol 2003) though perhaps not at the same time. In this paper we examine how the planning and implementation of climate risk affects other forms of environmental management at the regional scale, using North Central Victoria, Australia as an example.

The first half of the paper outlines the complementary links between adaptation and mitigation under risk management from a global perspective. The second half summarises these issues as they affect north central Victoria, then trace the pathways that are being developed to reduce regional greenhouse gas emissions to zero while sustainably managing the human and natural resources of the region.

2 Risk management approaches for climate change

2.1 Risk management frameworks

Risk management is a structured process that aims to limit harm in an environment of uncertainty (AS/NZS 2004). Risk can be broadly understood as the likelihood of an event and its consequences (e.g. Schneider 2002; Patwardhan et al. 2003). The structure of risk can differ depending on the overall activity, but generally involves one or more hazards with outcomes being measured according to criteria representing specific levels of harm. Risk treatment aims to reduce the likelihood of a harmful event, its consequences, or both.

The process of assessing greenhouse gas-induced climate change which has led to the development of the UNFCCC can be viewed as a major risk management exercise (Beer 1997). Climate change falls within the broad area of environmental risk assessment, but has a number of specific features that require specialised management. For example, the Australian/New Zealand Standard for Risk Management (AS/NZS 2004) is similar in scope to the United Nations Development Program (UNDP) Adaptation Policy Framework (UNDP 2005), although specialised tools for developing and utilising climate scenarios and analysing climate risks feature in the latter. These frameworks are similar to many other national frameworks, although the language and details differ (Power and McCarty 1998, 2002; Beer 2003). For example, the terms risk assessment and risk management can variously mean part or all of an assessment (Beer 2003). Here, we use risk management for the whole process, risk analysis for quantifying unmanaged risk and risk evaluation and treatment for the evaluation, and treatment (or mitigation) of risk. The term mitigation of risk is generally not used when dealing with climate change because it refers specifically to the mitigation of climate change through greenhouse gas reductions.

Steps that should be carried out in any risk assessment include characterisation of the problem, derivation of the criteria for the measurement and reduction of harmful outcomes, assessment of unmanaged risk, assessment and prioritisation of risk management options, implementation of those options and monitoring and review. Stakeholders are vital to the process, as is communication and consultation, as will be discussed later. Specific frameworks for assessing climate change risks needing management through adaptation have been prepared by Jones (2001), Willows and Connell (2003) and UNDP (2005).

2.2 Applying risk to climate change

While a certain amount of attention has been given to the analysis of climate change risks, less attention has been placed on evaluation and implementation of treatment options. In this section we focus on five areas where progress can be made; in some cases, just raising issues and in others suggesting where improvements lie. In all areas, the links between adaptation and mitigation are crucial. These areas are:

The research/policy interface, where academic-based research and policy formulation are concerned with different aspects of risk (and view them very differently)

- Inappropriate framing of the problem
- Improving methods of risk analysis
- The delay between cause and effect
- The relationship between adaptation and mitigation as tools for managing risk

2.2.1 *The research/policy interface*

Two types of risk associated with climate change are the risks associated with climate change itself, and risks associated with the implementation of policy. Risks directly associated with climate change are assessed by the IPCC through formal assessment and technical reports. The IPCC's remit is to assess climate risks in a manner that is useful for policy development without being policy prescriptive. The research aspects of climate change include the risks associated with human-induced climate change and research into methods to reduce these risks.

A different set of risks is linked to decision-making on policy (e.g., economic risks associated with reducing greenhouse gas emissions). Within the UNFCCC, the Subsidiary Bodies for Scientific and Technical Advice, and Implementation, develop and provide guidance for policy-makers on managing risk, but do not advocate particular decisions. Policy-making itself takes place in a less structured and more political environment, where structured decision analytic frameworks are less often applied. This has variously been described as a ''policy mess'' where decisions can be ad hoc and short-term (e.g., Turnpenny et al. 2005), often having little impact on the initial problem of climate change.

These two areas are dealt with quite differently with regard to risk management, and are poorly integrated. While this lack of integration may be due to good reasons, mainly to do with not mixing science and policy, it remains problematic for risk management, where it is generally recommended that the steps in risk management be assimilated into a single (though possibly many layered and diverse) process (McCarty and Power 2000; AS/NZS 2004). However, the central issue is not to intervene in the policy-making process but is to bridge the gap between the primary risk and those associated with various policy options. The principal advantage of risk management in this regard is that policy (normative) options can be proposed and tested in a non-prescriptive manner (Patwardhan et al. 2003). However, dependable methods for doing this still need to be developed (McCarty and Power 2000) so that stakeholders can have confidence in the process and results.

Areas where improvements can be made include a more appropriate framing of the problem, improvements in risk analysis methods, more attention being placed on changes over time, better management of uncertainty, improvements in risk communication and a better understanding of the relationship between adaptation and mitigation over a variety of temporal, spatial and institutional scales.

2.2.2 *Inappropriate framing of the problem*

Climate change is presented as a causal chain of consequences starting from greenhouse gas emissions that alter the atmosphere's radiative balance, changing climate and leading to impacts that range from the biophysical through to the socio-economic. While this is true, this is not how climate change should be laid out within a decision analytic framework. Although that sequence will be the way events play out, large uncertainties mean that several iterations of potential futures need to be explored: those where no action is taken to manage climate change and those where alternative responses are explored. Three generations of risk management can be identified.

The first generation endeavoured to establish whether greenhouse gas emissions pose a sufficient risk to warrant detailed investigation. This was achieved through the release of the IPCC First Assessment Report in 1990, followed by the drafting of the UNFCCC in 1992 and its subsequent ratification by 193 countries.

The second generation endeavoured to quantify the level of risk under a future where climate change risks are not being actively managed. Within the IPCC, this has seen the development of two generations of greenhouse gas scenarios—the IS92a–f scenarios (Pepper et al. 1992) and the SRES A1, A2, B1 and B2 family (Nakiçenovic and Swart 2000). The ability to undertake coupled ocean–atmosphere climate modeling and regional climate modeling has provided knowledge of how climate may change and climate change projections. Impact assessments have provided knowledge of how natural and systems may respond to a range of potential changes. Risk can be measured from the current baseline, or under future baselines projecting change (e.g., demography, land-use, technology, economy) without climate change.

The third generation is examining how to manage risk through mitigation and adaptation with the aim of reducing future climate risks by reducing the magnitude of climate change and responses to those changes. Two issues are being explored: 1) what residual risk remains after various management options have been exercised (including critical levels of risk)? And 2) how can the transition from today to a future world where dangerous climate change has been avoided be managed? In short-hand, these two issues translate to assessments of targets and pathways. This area of assessment is in its early stages, and has been addressed so far by the development of stabilisation greenhouse gas scenarios, integrated assessment models and sustainable development scenarios.

Therefore, a comprehensive understanding of climate change risks requires more than a single pass through the causal chain outlined above. A single pass may be sufficient for understanding individual impacts, but if the aim is to avoid widespread critical damage, then outcomes with, and without, risk treatment options need to be assessed. However, the stated expectations of many policy-makers and critics of climate science suggest they view the issue of climate change as a simple, causal chain. This raises the expectation that sufficient information about future climate change can be determined from a specified emission scenario, then a clear pathway that will avoid ‘‘dangerous’’ climate change with a high ‘‘scientific’’ certainty be developed at negligible or manageable risk to the current economy. What the underlying level of scientific certainty should be is never clearly articulated and there is a significant possibility that the information required to fulfil this model will come too late for action to be taken (especially if this information can only be gained through hindsight).

2.2.3 Improving methods of risk analysis

The comments in the previous section suggest that the specialised methods developed to assess climate change do not meet the needs of comprehensive risk assessment. However, those methods can be usefully employed within a larger framework. Also needed are all the tools available to all risk assessments, such as the use of uncertainty management, risk communication, exploratory and normative scenarios, vulnerability analysis, the involvement of stakeholders and learning-by-doing approaches that involve ongoing monitoring and assessment.

The context and framing of risk (as in likelihood × consequence) are also important. Results reported in the IPCC Third Assessment Report (e.g., Smith et al. 2001) show that as global mean temperature increases, so do the number of risks and their relative magnitudes. Jones (2003, 2004b) shows that this structure can be expressed probabilistically as the likelihood of threshold exceedance in a way that links top down (global down to local) and bottom up (local up to global) assessments. Mastrandrea and Schneider (2004) have assessed the likelihood of exceeding global thresholds of ''dangerous'' climate change, and Patwardhan et al. (2003) discuss methods for doing so. By utilising quantified ranges of global warming that incorporate a range of input uncertainties, rather than single scenarios, this structure also allows risks to be compared under varying ranges of global warming where different mitigation strategies are employed. Most importantly, unlike the investigation of linear stress–response frameworks, risk management is designed to operate in environments of high uncertainty.

A range of recent work aims to address these concerns. The incorporation of probabilities into climate change risk assessments is discussed by Schneider (2002), Webster et al. (2003), Jones (2001, 2003), Dessai and Hulme (2003), Mastrandrea and Schneider (2004) and Wigley (2004a, b). Heuristics affecting the communication of climate change risks are discussed by Morgan et al. (2001) and Patt and Dessai (2004). Stakeholder led approaches are discussed by Morgan and Keith (1995), Morgan et al. (2001) and Conde and Lonsdale (2005). Comprehensive risk assessments for dealing with adaptation to climate change have been developed by UNDP (2005). The implementation of climate policy and its associated risks is discussed by Corfee-Morlot and Höhne (2003).

2.2.4 Delay between cause and effect

The delay between cause and effect in terms of the timing of emissions and the resultant atmospheric and oceanic responses, which separates the up-front costs of mitigation from the deferred benefits of ameliorated climate change, is the largest problem facing greenhouse gas mitigation. This problem is central to climate change and has been widely discussed in terms of both science and policy (IPCC 2001).

Less often discussed is the relationship between mitigation and adaptation in managing risk over time. Recent moves to link adaptation to both current and future climate risks have the potential to provide short- and long-term benefits. The co-benefits of mitigation can also be short-term, e.g., the reduction of air pollution associated with the use of fossil fuels. Theoretically, the coincidence of short-term direct or ancillary benefits of adaptation and mitigation provides the opportunity for sustained benefits over time, even if the source of those benefits may change.

Assessing the benefits of climate policy over time is difficult but the following points are relevant to managing climate risk with respect to action and response:

- Investments in mitigating greenhouse gases (including carbon sequestration) will take some time to be realised in terms of the benefits of avoided damage;
- Investments in mitigation made in one location will not be realised in terms of benefits of avoided damage in that location but will contribute to benefits across the globe;
- The benefits of adaptation will be felt locally but depend on when anticipated climate change/variability occurs;
- Co-benefits of actions may be realised on quite different timescales to the climate-related benefits.

These points are very relevant to the relationship between adaptation and mitigation in Part II of this paper.

2.2.5 The relationship between adaptation and mitigation

Adaptation and mitigation are complementary with regard to the components of risk that they manage (e.g., Wheaton and MacIver 1999; Kane and Shogren 2000; Adger 2001; Dang et al. 2003; Jones 2003). By mitigating the rate and magnitude of global warming and attendant climate changes, reduced emissions of greenhouse gases diminish the frequency and magnitude of climate hazards. This increases the possibility that the remaining 'unavoidable' climate change can be adapted to, and that the sum of those adaptations may be positive. Adaptation increases the ability of a system to cope with a given range of climate variability, including extreme events. Adaptations of biological systems are largely autonomous, whereas adaptations in socio-economic systems can be autonomous or planned. Planned adaptation can also recognise and take advantage of autonomous adaptation, which on its own is value neutral.

Adaptation and mitigation also influence different parts of the projected range of mean global warming at any given time in the future. This relationship also carries through to sea level rise and some regional ranges of change (Jones 2003). Because mitigation will progressively reduce the likelihood of the highest plausible levels of atmospheric greenhouse gases from occurring, it also reduces the upper limit of global warming and other related changes. If we assume that one tonne of carbon dioxide mitigated will produce a marginal benefit of the equivalent of one tonne equivalent less damage, each tonne of reduced CO_2 (or equivalent) if sustained over time will produce a slightly reduced marginal benefit in terms of avoided damage. (The assumption of a marginal benefit is sustained unless a threshold of catastrophic change is avoided, in which case the benefit is ''infinite'' (Yohe 2003))

Adaptation increases the ability to cope measured from a baseline or reference which can be described as the current coping range (Jones and Boer 2005). Adaptation may increase the ability to cope incrementally or produce one or more step changes. Therefore, adaptation is path dependent, beginning with the ability to cope with current climate risks, aiming to manage changing climate risks under progressively warmer conditions over time. Larger climate change will require more and faster adaptations, which will be more expensive and less likely to be successful.

Figure 1 shows these relationships as they relate to global warming. The temperature envelope encompasses the IPCC (2001) projected range of mean global warming for the SRES scenarios during the course of this century. The SRES scenarios refer to futures where there are no specific policies to reduce greenhouse gas emissions, but the lower scenarios can be accepted as proxies for such reductions compared to the higher emissions (e.g. Swart et al. 2002). The figure shows how adaptation allows activities to cope with successively greater warmings over time. These temperatures have a very high to high probability of being exceeded. In particular, those outcomes where current climate risks are appreciable and likely to get worse, and where critical levels of impacts are likely to be met with only small changes in climate (Jones 2003).

Ensuring that high emission futures do not occur by introducing greenhouse gas mitigation measures will reduce temperatures from the uppermost possibilities of the unmitigated range. In this way, adaptation allows us to manage those climate risks that are highly likely, while mitigation reduces the likelihood of the severest consequences. Therefore in terms of the potential range of climate change, for example a global warming of 1.4 to 5.8°C by 2100, mitigation can reduce the upper limit to substantially less than 5°C whereas adaptation will most likely have to cope with warmings above 1.4°C. Various approaches to estimate the median warming, each based on different input assumptions but

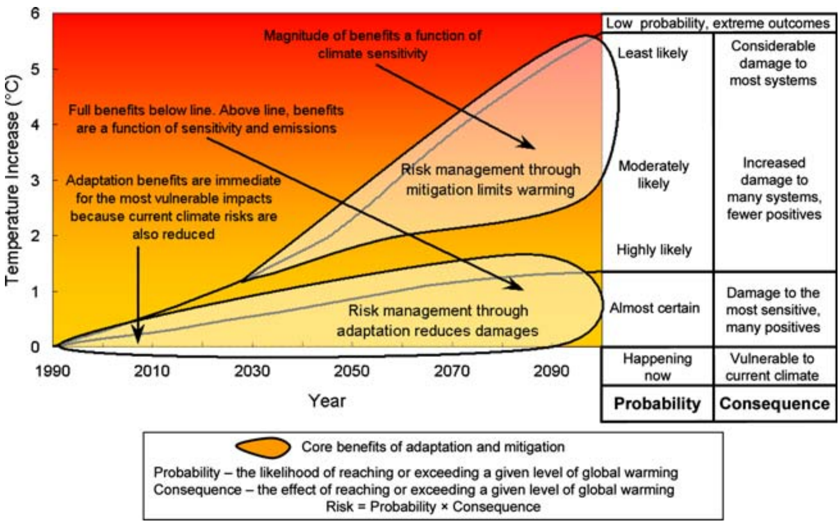

Fig. 1 Relationship between adaptation, mitigation and the projected range of global warming from (IPCC 2001). (Reproduced from Jones 2003)

using similar statistical methods, put the median warming for the SRES-dependent climate change at about 2.5–3.5°C by 2100 (Wigley and Raper 2001; Schneider 2001; Webster et al. 2003; Wigley 2004a).

In this way, adaptation and mitigation work from the bottom up and top down of the range of global warming, respectively. Adaptation reduces risks from the most sensitive impacts on the one hand and mitigation the risks of the largest impacts on the other. There remains a large area of uncertainty within the range of possibilities that need to be explored through ongoing investigations but it is possible to implement robust risk treatment measures under the current state of knowledge. This is the basis of the tolerable windows approach where adaptation and mitigation can both work towards a safe level of climate change (e.g., Petschel-Held et al. 1999; Yohe and Toth 2000). The structure in Fig. 1 shows that it is possible to move forward without explicit targets. To date, only relatively small but noticeable climate changes have already occurred, and where mitigation is in its early stages, confident with the knowledge that adaptation will reduce both current and future consequences of climate risks and mitigation actions will reduce future climate risks, even if we do not yet know by how much.

This complementary relationship can be seen in Figs. 2, 3 where both warming, climate-related hazards and impacts increase from left to right across the page. The green area on the left denotes a range of climate that a given activity can cope with—most usually, current climate with a certain range of extra variability before an activity becomes critical. The yellow area denotes an area where adaptive capacity (Put briefly, the potential to develop and implement adaptations (Brooks and Adger 2005)) can be developed to increase the coping range. The red area denotes a zone where mitigative capacity exists within that particular activity or sector. Reduction of greenhouse gases in the atmosphere will reduce climate-related hazards by progressively reducing the possible upper range of global warming and related changes. The orange area denotes an area of potential residual risk where adaptation is insufficient to cope with that magnitude of change and a global

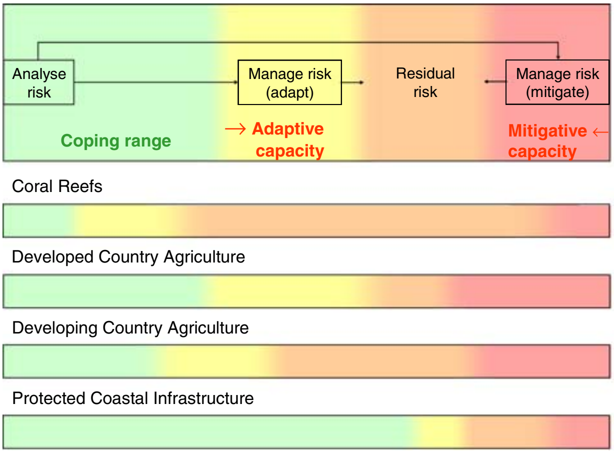

Fig. 2 Coping range, zones of adaptive and mitigative capacity and residual risk. Both temperature and damages increase from left to right, but the likelihood of exceeding a given temperature or associated critical threshold decreases. Below are some schematics showing the relevant coping ranges and zone of adaptive and mitigative capacity for several different activities. Fuzzy boundaries denote high uncertainty

capacity to mitigate will be required. From left to right denotes increasing damage but a decreasing likelihood of exceeding thresholds associated with successively higher magnitudes of change.

Also shown are several activities showing nominal ranges for the relevant coping ranges and zones of adaptive and mitigative capacity. Coral reefs threatened by thermal coral bleaching are thought to have a small adaptive capacity within the timescale of global warming, so require a relatively large mitigative effort for reefs to remain close to their coping ranges (e.g. Hoegh-Guldberg 2004) but have a limited capacity to fix further carbon. Agriculture in developed countries typically shows a larger coping range than in developing countries (Gitay et al. 2001) and has a significant mitigative capacity through improved soil, vegetation and livestock management. The final example of protected coastal infrastructure denotes an area that has a large coping range but very low adaptive capacity (e.g., where very expensive protection is required) inviting the risk of catastrophic failure above a given threshold.

In Fig. 2, the scale mismatch between the mitigative capacity of a particular activity and its demand for reduced greenhouse gases becomes apparent. There are two ways to view mitigative capacity: the first is what mitigative capacity does a particular activity hold (Yohe 2001)? And the second is what mitigative capacity at the global scale does an activity require, given its potential to adapt to a changing climate? One way to view this mismatch is to see it in terms of supply and demand. Mitigative capacity gives some idea of the ability to supply greenhouse gas reductions available for each activity to reduce its residual risks after adaptation, but the market is global, so this supply must be aggregated at the global scale to supply reduced climate hazards at the local scale. Therefore, local supply of mitigative capacity does not directly meet local demand. This is an issue that needs to be addressed by organisations working at local to national scales.

Figure 3 deals with adaptive and mitigative capacity on an aggregate scale. This can be viewed as the range of capacities that may be present over a region, a nation or the world. At the initial level, we can nominate a set of generic capacities that can take place

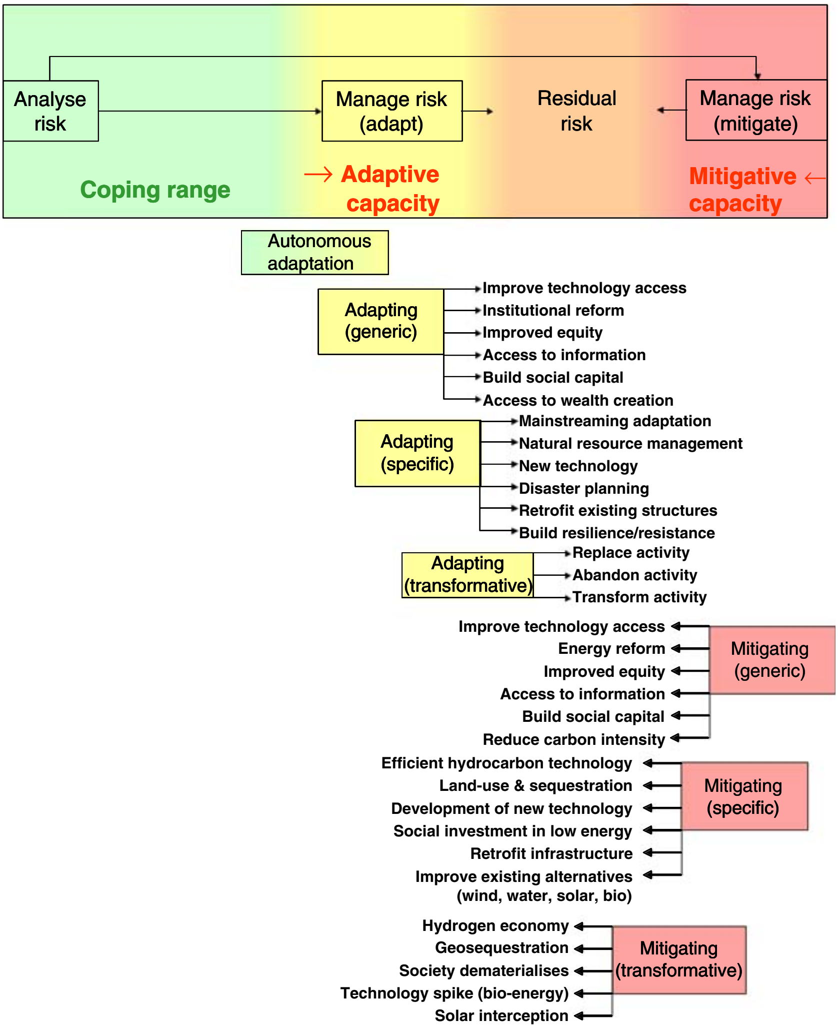

Fig. 3 Coping range and zones of adaptive and mitigative capacity shown with examples of generic, specific and transformative adaptation and mitigation options

irrespective of context-specific needs of each. These are comparatively easy to undertake, generally inexpensive and have a number of co-benefits. The second level denotes context-specific adaptation and mitigation options that are implemented specifically to manage climate risks. They may also require a further investment in research and development. These can also be thought of extending or evolving current paradigms. The third set is transformative and involves new technologies, new paradigms or both. Each set is assumed to be more difficult to implement but provides a more substantial level of risk management.

Therefore, the relationship between adaptation and mitigation as it manages the risk of global warming is complementary and with the two not being interchangeable. However, despite this complementarity at the global scale, a single region is not able to meet supply and demand for both mitigation and adaptation at the domestic scale. The demand for adaptation can be met locally but the demand for mitigation, though supplied locally, needs to be integrated within a global market. In Part 3, we look at how one region is attempting to come to grips with this challenge.

3 Regional approaches to managing climate risk

Part 3 looks at a regional approach to managing climate change risk being taken by organisations in Central Victoria, Australia. The Central Victorian Greenhouse Alliance (CVGA) is a coalition of regional groups that aims to reduce greenhouse gas emissions. The North Central Catchment Management Authority (NCCMA) is a statutory authority charged with the sustainable management of four central Victorian catchments. The CVGA covers the area of the NCCMA and several adjacent local government areas.

The NCCMA oversees the management of the region's most important natural resource—water—while providing an integrated planning framework for the management of land, water and biodiversity. It has recognised the importance of adapting to climate change in its 2003–2007 strategy (NCCMA 2003). Both organisations have concluded that the risks of climate change are sufficiently high to require the management of climate risks through both mitigation and adaptation. Together, they are working out how to manage these risks within a regional planning framework.

3.1 Framing the issues

The North Central region comprises an area of almost three million hectares (ha), approximately 13% of the State of Victoria. The region extends from the Great Dividing Range in the south to the River Murray in the north, a distance of up to 280 km and is around 150 km wide (Fig. 4). The regional population covered by the CVGA is approximately 300,000, with over half living in the two largest centres of Bendigo and Ballarat.

The North Central CMA includes four major river catchments—those of the Campaspe, Loddon, Avoca and Avon-Richardson rivers. The Campaspe and Loddon rivers flow directly into the River Murray. The Avoca River flows into a series of lakes and wetlands but during flood events, may drain to the River Murray and via effluent stream channels to a further series of terminal lakes. The Avon-Richardson catchment is internally drained.

3.1.1 Environment

The region has a largely Mediterranean climate, with cool, moist winters and warm, dry summers. The north and west of the region is substantially warmer and drier than the south and east. Rainfall ranges between about 350 mm per year in the northwest to over 1,200 mm per year in the far southeast with a very high interannual variability. Average daily temperatures in the north–west range between 15°C and 31°C in January and 4°C and 14°C in July. In the far south of the region, they range between 11°C and 27°C in January and 2°C and 10°C in July.

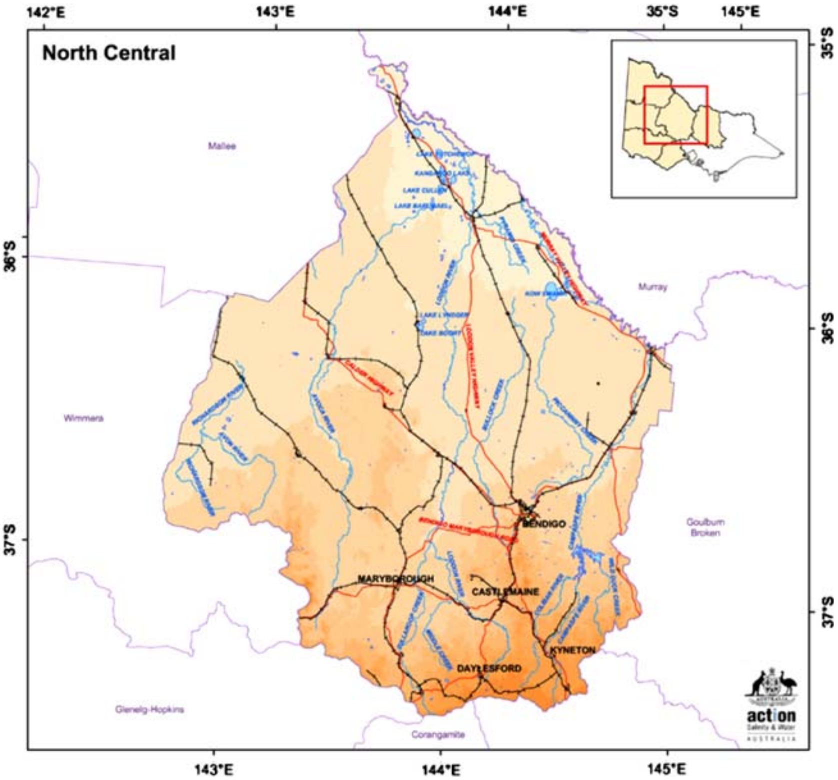

Fig. 4 Map of the North Central CMA and location in Victoria, Australia. The CVGA also takes in areas to the southwest west and south. (Natural Resource Management Ministerial Council 2004)

Both surface and groundwater resources are heavily used in the region, which has substantial irrigated agriculture and horticulture, mainly in the north. Water use is 1,425,000 ML yr^{-1} for irrigation and 40,000 ML yr^{-1} for industrial and domestic use. There are three major surface water storages within the region that meet about 25% of demand. The remaining surface water supplies are drawn from the Murray and Goulburn systems of the Murray–Darling Basin.

Agriculture consists mainly of horticulture, dairying, cropping and grazing for meat and wool with a large number of smaller, niche activities. Economic output in 2001 was A$785 million, with horticulture growing rapidly by >6% yr^{-1}, substantially higher than the rate of inflation, dairying and grazing at growing slightly in real terms and cropping declining slightly in real terms (1.2% nominally).

Thirteen percent of the region is public land, with forestry and plantations occurring in the south. Extensive Ramsar gazetted wetlands occur in the north. Eight bioregions are represented within the region but native vegetation is poorly represented in all but two bioregions. Although 12.7% of the region retains native vegetation coverage, many ecological communities retain less than 1% of their original distribution. Woodlands and grassy woodlands, which occupied the areas most readily developed for agriculture, are especially poorly represented.

3.1.2 Institutional structures

The Central Victorian Greenhouse Alliance has as members: thirteen local government bodies, a university, a regional bank, an energy generation and distribution company, two state government bodies, a social service organisation a healthcare group and the NCCMA. They have as their central aim *''to reduce Central Victorian Greenhouse Gas Emissions by 30 per cent below 2000 levels by 2010 reducing still further to zero net emissions by 2020''* (CVGA 2004). At present, the alliance is trialling and investigating a number of energy saving strategies and technologies using local government bodies and schools. The alliance has three strategic priorities: energy efficiency, renewable energy and biosequestration (CVGA 2004). Trials have so far investigated low emissions street lighting, diesel fuel additives, low emission strategies and collecting baseline data on greenhouse gas emissions by sector and local government area.

All local government members are members of the Cities for Climate Protection Programme (CCP). In Australia, this programme has been developed in conjunction with the Australian Greenhouse Office (AGO). The CCP programme empowers local government to reduce greenhouse gas emissions by adopting a 'Milestone Framework' process. The CCP Australia programme invites all members to pledge to reduce greenhouse gas emissions and to improve the energy efficiency in their local communities by agreeing to a five-step milestone process involving:

- Inventory and forecast—conducting a base year emissions analysis and forecast of municipal and community-wide greenhouse gas emissions (corporate and community);
- Set reduction targets—developing a local action plan that spells out a greenhouse gas reduction target and the policies and measures that will achieve that target;
- Plan implementation—active implementation of the climate protection measures contained in the local action plan; and
- Measure progress—monitoring and verification of progress in achieving emission reductions.

The North Central Catchment Management Authority develops and implements a regional catchment strategy aiming for sustainable land and water use, improvement of ecosystem health and productive primary industries. Climate is seen as one of the region's five primary assets and as part of the specific management actions and targets (Table 2) the NCCMA is seeking to ''mainstream'' climate issues into regional strategies, especially through a Land Use Change and Revegetation in North Central Victoria (Climate Change Response) Strategy. The climate change response itself aims to *''respond to the challenge of climate change by helping the North Central region to take responsibility for net greenhouse gas emissions, by developing an improved understanding of the impacts of climate change and thereby enabling actions that improve the resilience of natural systems and primary industry in the face of climate change.''* (NCCMA 2003). The NCCMA has adopted the emission-reduction targets of the CVGA.

3.1.3 Climate change risks

Regional projections of climate change produced by CSIRO (2001) suggest that the region will become warmer and drier, with an increased incidence of drought and higher potential evaporation, leading to reductions in runoff and water supply (Table 1). These changes are for climate change without mitigation, based on the SRES greenhouse gas emission

Table 1 Regional projections of climate change for the north central region of Victoria

Season	Change in 2030	Change in 2070
Summer	Warmer by 0.3 to 1.6°C	Warmer by 0.8 to 5.0°C
	Drier by 0 to 20%	Drier by 5 to 60%
Autumn	Warmer by 0.3 to 1.6°C	Warmer by 0.8 to 5.0°C
	Precipitation change of +10 to –15%	Precipitation change of +20 to –40%
Winter	Warmer by 0.2 to 1.4°C	Warmer by 0.7 to 4.3°C
	Precipitation decrease likely (+3 to −10%)	Precipitation decrease likely (+10 to –25%)
Spring	Warmer by 0.2 to 1.4°C	Warmer by 0.7 to 4.3°C
	Precipitation decrease likely (+3 to −10%)	Precipitation decrease likely (+10 to −25%)
Annual	Warmer by 0.3 to 1.6°C	Warmer by 0.8 to 5.0°C
	Hot summer days increase 10 to 50% (over 35°C)	Hot summer days increase 30 to 300% (over 35°C)
	Frost days decrease 0 to 70%	Frost days decrease 50 to 100%
	Precipitation decreases likely (+3 to −15%)	Precipitation decreases likely (+10 to −40%)

scenarios and projections of global warming from IPCC (2001). Regional patterns were obtained from a range of climate models using methods described in Whetton et al. (2002).

Three major themes within the catchment where adaptation and mitigation issues are expected to coincide are:

- **Agriculture**: agriculture is one of the largest sources of greenhouse gases within the region and is also expected to be affected by climate change, largely through increased temperatures, increased atmospheric CO_2 and reduced rainfall. The mitigative capacity of the regional agriculture and agricultural soils is unexplored but may be substantial when compared to emissions.
- **Built environment**: Warmer temperatures will increase demands for cooling through the use of air conditioners that then raise emissions, greatly increasing peak energy demand as a proportion of baseload demand. The provision of standing energy becomes more expensive because of the need to provide the capacity to supply a large peak load relative to baseload. Joint measures to ameliorate building temperatures while lowering energy demand will reduce the demands for capital if peak and baseload energy supplies can be kept within limits. Overhead transmission of electricity also becomes less efficient in warmer climates, increasing the benefits of a local capacity for power generation compared to remote sources.
- **Carbon sequestration** through revegetation: Revegetation is seen as providing a suite of benefits for biodiversity, salinity amelioration and timber production, but it is also realised that long-term plantings will be affected by climate change as will flora and fauna, land and water degradation from salinity and rates of timber production.

The latter theme of carbon sequestration is the one we concentrate on in this paper because it provides the strongest link between the activities of the CVGA and NCCMA.

The CVGA have so far mainly focussed on the mitigation of greenhouse gases. CVGA (2004) estimates regional emissions to be 4 million tonnes in CO_2 equivalent terms for 2002–03 resulting from manufacturing, agriculture, retailing, transport and construction activities (CVGA 2004). The emission reduction targets are 30% by 2010 and 100% by

Table 2 Emission reduction targets proposed by the CVGA (CVGA 2004)

Target date	Reduction in net regional greenhouse emissions (%)	Energy efficiency measures (%)	Energy derived from renewable sources (%)	Sequestration of residual emissions (%)
2010	30	15	20	10
2020	100	30	80	20

2020. Table 2 shows areas from which those reductions are intended come. The 15% and 30% reductions included in energy efficiency measures are listed but not incorporated into the target, allowing some leeway.

Risks to achieving the three targets have briefly been assessed by the CVGA (2004):

- Energy efficiency—Energy efficiency gains could be outstripped by energy consumption. Demand for energy in Victoria is currently growing at a rate of 1.9% per year, and if this trend cannot be slowed or reversed, energy consumption will be 14% higher by 2010 than for 2003, and 38% higher in 2020 (at compound rates of growth). Therefore, to meet its targeted energy efficiency improvements of 15% by 2010 and 30% by 2020, the CVGA may need to almost double current efficiency by 2020.
- Renewable Energy—the renewable energy target of 20% by 2010 and 80% by 2020 may be impossible to achieve. Only about 3.5% of the State of Victoria's total electricity supply was generated from renewable sources in 2001 and the State Government is targeting an increase of no more than 10% by 2010. Therefore, the most cost-effective of the renewables (solar hot water, wind and bioenergy) will need to be targeted. However, matching the intermittent output of sun and wind to grid demand is difficult beyond about 20% of total supply, so to reach the 80% renewable by 2020 goal, new technologies will be required.
- Carbon sequestration—Unless the current 2% per annum regional increase in energy demand can be curtailed, a 20% sequestration rate will require annual plantings of more than 2,500 hectares annually to continue until 2020. Australia's refusal to enter into the Kyoto agreement means that international trade mechanisms for carbon sequestration will not be accessible, requiring a totally domestic market or for bilateral agreements to be set up with individual organisations.

The NCCMA is faced with planning adaptation to the climate changes summarised above and is jointly involved in sequestration planning with the CVGA and other regional bodies. In its regional strategy, the NCCMA assessed all the perceived risks facing catchment management, in order to prioritise their thirty implementation packages. The climate change package is placed as a fourth-ranked priority out of five priority bands. However, many of the top-ranked priorities relating to both land and water management require the management of both the up- and down-side of climate risks. As the following case studies show, both climate change and management of the ensuing risks will affect carbon stocks, salinity, water supply and quality and biodiversity. The climate package is summarised in Table 3. It covers both adaptation and mitigation but the detail as to what measures need to be identified and implemented is the subject of ongoing work.

The following case studies are relevant to achieving the carbon sequestration targets of the CVGA (Table 2) and the implementation of the climate package of the NCCMA (Table 3).

Table 3 Management actions and targets for climate for the NCCMA Strategy

Management actions and targets	Key Implementation Agency(s)	Referring plan(s)
Finalise the Regional Response to Climate Change Action Plan by 2004 and implement key actions by 2008	NCCMA	Climate Change Action Plan
Develop understanding of implications of climate change scenarios for management of dryland and irrigated land and associated assets and services by 2008	Dept. Primary Industry	
Develop farming systems and management practices that increase resilience in the face of climate variability and climate change by 2008	Dept. Primary Industry	
Conduct a second comprehensive greenhouse gas emissions audit for the North Central region during 2005	NCCMA	Climate Change Action Plan
Develop greenhouse gas emissions audit tool for use by individual landholders/primary producers	NCCMA	
Assess the implications for climate change scenarios for flooding, water way management and riparian and wetland health and develop management response by 2008	NCCMA, Dept. Sustainability & Environment	
Coordinate community participation in climate change activities to increase regional awareness of climate change	NCCMA, Local government, CVGA stakeholders	Climate Change Action Plan, Municipal Greenhouse Action Plans

3.2 Regional case studies—assessing the risks to water, carbon and salinity stocks and flows under climate change

Two of the most important resources in the region are water and carbon. Water provides significant agricultural yield and maintains important wetlands. Carbon stocks in both soil and vegetation reflect the health of both the surface and subsurface environment. Salinity is one of the most serious regional land degradation issues. Vegetation clearing during the past 150 years has contributed to a substantial dryland salinity problem as well as leaving a number of ecological vegetation classes at well below sustainable levels for maintaining ecosystem heath and biodiversity (NCCMA 2003). Loss of biodiversity is seen as the cause of many of regions natural resource management problems, reducing landscape resilience and capacity for regeneration.

Carbon sequestration through greenhouse-related conservation plantings is being planned as part of the activities of the CVGA. Co-benefits of such plantings are expected to come from added biodiversity and amelioration of dryland salinity (NCCMA 2003). Joint assessments of climate change and revegetation show that replacing grasslands with forest will contribute to future reductions in runoff (Herron et al. 2002). This implies that the joint management of adaptation and mitigation as part of land-use management will involve trade-offs between carbon and water.

These relationships have been established by several lines of evidence:

- Quantification of the limits of climate change impacts on regional runoff.
- Assessment of water and salt fluxes in response to climate change and reafforestation.

- Estimation of the area of offset plantings required to meet regional targets for the sequestration of CO_2.
- A spatial assessment of the joint benefits of revegetation on biodiversity, salinity and sequestration/commercial forestry.

3.2.1 Climate change impacts on regional runoff

Here we estimate the potential range of change to mean runoff to the four major catchments, and from adjacent catchments supplying water for irrigation. Hydrological model sensitivity to climate change can be defined as the response of a particular hydrological model to a known quantum of climate change (Jones et al. 2006). Hydrological sensitivity is measured here as the percentage change in mean annual runoff occurring in response to a change in mean annual rainfall and potential evaporation (Jones and Page 2001). A simple model constructed from sensitivity analyses run for 22 catchments over Australia using two hydrological models, was used to estimate the potential range of change in mean annual runoff (Jones et al. 2006). These catchments are unimpaired thus representing a fairly natural hydrological cycle, and occur over a wide range of climates.

The model was constructed to estimate changes based on the inputs of percent change in mean annual rainfall and areal potential evaporation and percent runoff as a proportion of mean annual rainfall. The model takes the form:

$$\delta Q = \mathrm{C}\frac{Q}{P}\delta P + \mathrm{D}\frac{Q}{P}\delta Ep$$

where Q is mean annual runoff, P is mean annual rainfall, Ep is mean annual areal evapotranspiration, and C and D are constants.

The results for the four major catchments within the NCCMA and the adjacent Goulburn and Upper Murray catchments are shown in Table 4. They show that by 2030, decreases range from a few percent to 20% to 25% in the upper Murray and Goulburn catchments and from 1/3rd to 40% north central Victoria. In 2070, the decreases are much larger, ranging from around 5% to greater than 50% (this model becomes unreliable for large changes, due to non-linear behaviour that is not well represented by two simple parameters).

Table 4 Estimate range of changes in mean annual runoff from a simple hydrological sensitivity model for 2030 and 2070

Catchment	Area	Runoff (ML)	Developed Yield (ML)	Development Category	2030 low	2030 high	2070 low	2070 high
Upper Murray	10,150	2,803,000	837,950	Fully Allocated	−1	−21	−3	> −50
Goulburn	16,858	3,366,000	1,943,000	Fully Allocated	−2	−24	−4	> −50
Campaspe	4,048	305,000	121,000	Fully Allocated	−3	−33	−5	> −50
Loddon	15,658	415,000	109,000	Fully Allocated	−3	−37	−6	> −50
Avoco	14,211	136,200	3,380	Fully Allocated	−3	−40	−7	> −50

The Upper Murray and Goulburn catchments supply water to the NCCMA region, the other three catchments are within the region. With this model, changes of over 50% are too uncertain to be quantified further

3.2.2 *Water and salt fluxes in the Bet Bet Creek catchment*

This case study used a simple vegetation, water and salt balance model, Biophysical Capacity to Change (BC2C) to estimate water and salt fluxes under both climate and land-use change, in the Bet Bet catchment (Zhang et al. 2005). Bet Bet Creek is a tributary of the Loddon River, in the extreme southwest of the Loddon River catchment. The catchment covers 1,075 km^2. Annual average rainfall ranges from 500 mm in the north to 700 mm in the south with winter rainfall being dominant. Current tree cover is 23% of the catchment, calculated using a 20% crown-cover threshold, mostly as forest or wooded pasture.

The BC2C model links changes in land-use to changes in stream flow volume and salt yield (Dowling et al. 2004; Evans et al. 2004). When combined with the groundwater and surface water fluxes of salt, BC2C allows the estimation of the impacts of revegetation and climate change on catchment scale water and salt balances. Changes in runoff are related to proportional changes in annual rainfall and potential evapotranspiration.

The BC2C model undertakes the following steps:

1. Perform a water balance based on mean annual rainfall and tree cover using the water balance model of Zhang et al. (2001) to calculate total excess water. Perturbing rainfall, evapotranspiration and tree cover alters runoff.
2. Model salt mobilisation. The surface water is assumed to carry all the salt that falls in rainfall to the stream each year. Groundwater recharge mixes deep below the ground surface and can discharge slowly to the stream over decades or centuries, carrying with it the salt it gains in transit.
3. Convert water and salt loads to stream salinity, allowing both water yield and quality to be assessed.

The model was run under baseline conditions, then perturbed by three scenarios: two climate change scenarios were based on the CSIRO DARLAM 125 km model which had minimal changes in rainfall and the CSIRO Cubic Conformal model, a drier model. The third scenario re-treed all cleared land; this is not considered plausible, and was set to consider the maximum possible effect of revegetation. Climate change scenarios were run with and without altered vegetation cover for 2030 and 2070.

The baseline mean annual water yield varies between 20 mm to 150 mm across the catchment. The impact of climate change alone reduces water yield by between 10% to 20%, reduces the generation of salt by up to 3% in 2030 and 10% in 2070 and increases instream salinity by up to 15% in 2030 and 33% in 2070 (Table 5). The equivalent data for combined climate and vegetation change were not quoted by Zhang et al. (2005) due to the unrealistic nature of the revegetation scenario, however spatial changes show that revegetation of all cleared land alone reduced water yield by a minimum of 10% at some sites, with most of the catchment experiencing water yield reduction greater than 50%. When climate change and revegetation impacts are combined, the decreases in water yield are larger. Decreases in salt yield are roughly twice those of climate alone in the revegetated parts of the catchment. This leads to substantial increases in instream salinity with only ~10% of catchment area showing a salinity benefit by 2030. The area showing a salinity benefit is about ~1% by 2070.

Compared to revegetation under current climate, climate change reduces the area experiencing a salinity benefit and magnifies salinity damage. Despite a reduced salt flux because of decreased groundwater discharge, reductions in streamflow lead to increased in-stream salinity (Zhang et al. 2005).

Table 5 (Upper rows) Climate scenarios for the two climate models showing annual average change in percent for rainfall and potential evapotranspiration for Bet Bet Creek

Climate model	CSIRO DARLAM 125 km (DAR125)			CSIRO Cubic Conformal (CC50)		
Year	2030	2070		2030	2070	
Global Warming (°C)	0.85	2.30		0.85	2.30	
Precipitation (%)	0.0	−0.1		−7.2	−19.4	
Potential Evaporation (%)	5.6	15.3		6.4	17.2	
	2030			2070		
	Water Yield % change	Salt Generation % change	EC % change	Water Yield % change	Salt Generation % change	EC % change
Current climate	0	0	0	0	0	0
D125	−7	−1	6	−18	−4	14
CC50	−19	−3	15	−45	−10	33

(Lower rows) Impact of climate change on water, salt fluxes and in-stream salinity in Bet Bet Creek. ''Current vegetation'' fixes the current 23% tree cover and looks at climate change alone (from Zhang et al. 2005)

3.2.3 Benefits of revegetation for meeting sequestration targets

Current emissions in terms of CO_2 equivalent greenhouse gases among all members of the CVGA are estimated to be about 4 million tonnes in 2003 (CVGA 2004). The energy footprint of these emissions expressed locally, i.e. all the land required to offset these emissions, is substantial. Estimated rates of CO_2 sequestration subject to regional climate and generally poor soils range from between 2 tonnes and 5 tonnes per hectare per year (Rogers 2002). To offset these emissions would require planting an area of between 800,000 and 2 million hectares, the latter being over half the total area of the member local governments of the CVGA.

However, much higher figures are available as indicative sequestration rates for forestry over Australia (AGO and MDB 2001). Estimated thirty-year average rates (AGO and MDB 2001) are 10, 13 and 15 tonnes per hectare per year for medium–low, medium and medium–high growth rates, respectively. The medium–low rates are relevant in the northern part of the region and the medium–high rates in the south. At these sequestration rates the entire CVGA target becomes more manageable, ranging from 80,000 ha to 100,000 ha in 2010 and double that in 2020 (assuming no further growth in emission rates, which would require larger areas). At these sequestration rates, much lower areas of planting would be required than those quoted surveyed by Rogers (2002).

The establishment date of these planting is also important, because growth rates peak 10 to 15 years from planting, then gradually decline towards maturity (AGO and MDB 2001). In a business plan to offset local government emissions, Dettmann (2004) uses figures for the medium–low, medium and medium–high growth rates to estimate the offset potential of current and proposed Kyoto-compliant plantations. For example, current corporate emissions for the City of Greater Bendigo are 14,808 tonnes CO_2 equivalent (Dettmann

2004). Planned agroforestry projects covering 360 ha are projected to sequester at up to 12.5 tonnes CO_2 per year for a total of 3,930 tonnes of CO_2 by 2010 (Dettmann 2004). These and continuing forward projections will more than account for the council's emissions targets in the future, even with planned harvesting. The other councils are undertaking similar planning and analysis but are at a much earlier stage.

Several revegetation models are being considered. Forestry and agroforestry with some harvesting for sawlogs or pulp; standing plantations for shelterbelts, biodiversity and dryland salinity amelioration; and planting of salt tolerant vegetation in saline discharge areas (NCCMA 2003). The only specific measure in the NCCMA 2003–2007 catchment strategy that quantifies revegetation targets, aims to increase the area of native vegetation coverage from <13% to 20% by 2030, an area of about 200,000 ha. In most cases, this would involve an increase in carbon stocks as degraded areas are made more biodiverse but cannot as yet be reliably quantified. Increased areas of revegetation are included in the NCCMA strategy packages on dryland salinity and climate but targets have not been nominated (NCCMA 2003). Developing plans to quantify these targets, subject to levels of funding from both government and private investment, is part of the strategy. However, as noted above, uncertainties as to sequestration rates make planning difficult requiring that carbon accounting be an important part of ongoing monitoring programmes.

3.2.4 Balancing salinity, biodiversity and sequestration benefits

Along with estimating the areas of land required for offset plantings, the identification of locations and purpose are critically important for feasibility studies to be undertaken. Work by the NCCMA has assessed the spatial benefits of revegetation on carbon sequestration, salinity benefits and biodiversity using Geographical Information Software (GIS). A simple rule-based system looking at core areas of benefit for commercial forestry, biodiversity and dryland salinity amelioration found that the three rarely coincided in one place, and that most potential revegetation sites only managed to maximise benefits for one or two aims. In this case, sequestration maximises with forestry, the high-rainfall areas being those where CO_2 is sequestered fastest.

Commercial forestry is best suited to high-rainfall areas in the south of the catchment or to irrigated agroforestry. Salinity benefits are highest in the middle slopes of the catchments where high recharge areas for local and regional aquifers have been identified. Water losses in terms of reduced runoff are also less in these zones compared to grassland-forest conversion for commercial forestry likely to be located in upper catchments (Herron et al. 2003). Biodiversity benefits are high in riparian zones, areas of former box-ironbark forest, mallee and native perennial grassland and grassy woodlands, where sequestration rates and storage values may be much lower. However, the planned future use of the revegetation area is also important. Riparian zones were the areas where all benefits were closest to optimal and, because of their importance for water quality and aquatic habitat are high priority, but these zones only cover a limited area. Commercial plantations are likely to accumulate CO_2 fastest, but are also the most likely to be harvested, so may ultimately stabilise at lower levels of sequestered CO_2 than permanent plantations in lower rainfall areas. This suggests that high rainfall plantings will give the best short-term benefits but that slower growing plantings subject to minimal harvesting may take over as good long-term sinks for CO_2.

3.3 Managing risks to regional water, carbon and salinity stocks and flows

These case studies brings together several lines of research concerning the management of climate change risks through sequestration in central Victoria and how they may impact on natural resource use and land management. They show that although the areas required to meet offset planting targets of the CVGA are also shared by plans to enhance biodiversity and dryland salinity, impacts on salinity, water supply and water quality also need to be taken into account. However, the most important natural resource of the Catchment Management Authority, water, faces significant risks under both do-nothing and risk treatment scenarios. Treating some forms of environmental risks, e.g. revegetation to sequester carbon and ameliorate dryland salinity can exacerbate other forms of risk, such as reduced water supply and quality.

The work leads to the following conclusions:

- Climate change will reduce runoff, streamflow and ultimately, water supply, due to lower rainfall and higher evaporation. Even where rainfall does not change significantly, higher potential evaporation will still contribute to net decreases in runoff.
- Revegetation will reduce runoff independently of climate change, but will add to the losses caused by climate change.
- Salt fluxes will decrease in absolute terms but in-stream salt concentrations may increase. This is counter to the conclusions for the entire Murray Darling Basin of Beare and Heaney (2002) who conclude that reduced rainfall will reduce the salt flux sufficiently for water quality to improve by 2070. These different conclusions may be due to differences in models, location and scale, and require further investigation.
- Areal screening shows that the benefits of revegetation for biodiversity, commercial forestry and dryland salinity rarely coincide in any one place. More often there are benefits for two out of three, indicating that trade-offs are needed.
- The spatial distribution of positive and negative changes and of interactions between the different fluxes shows that solutions need to take account of biophysical heterogeneity. However, we are not yet able to quantify the interactions between the three fluxes of water, salt and carbon under climate change at the local or catchment scale.

These interactions are shown in Fig. 5. Trade-offs between these different processes will need to be managed if the different risks: climate-related, loss of biodiversity, salinity and agricultural are to be managed successfully. Although regional emissions are targeted to decrease, this is not guaranteed and global emissions and concentrations of CO_2 will increase in any case. Climate change will reduce water supply, as will sequestration and allied revegetation efforts. Changes in water supply will need to be adapted to. Reduced rainfall and revegetation will also lead to reduced salt discharge to the surface but the net impact on water quality remains uncertain. Revegetation is expected to enhance biodiversity.

In terms of combining mitigation and adaptation as they affect sequestration, the following issues have not yet been dealt with:

- Fire and drought—drier climates and increased fuel loads will promote fire, placing sequestered carbon in vegetation at risk. Currently that risk is borne by the owner of the carbon, and financial instruments are not yet in place to insure against that risk.

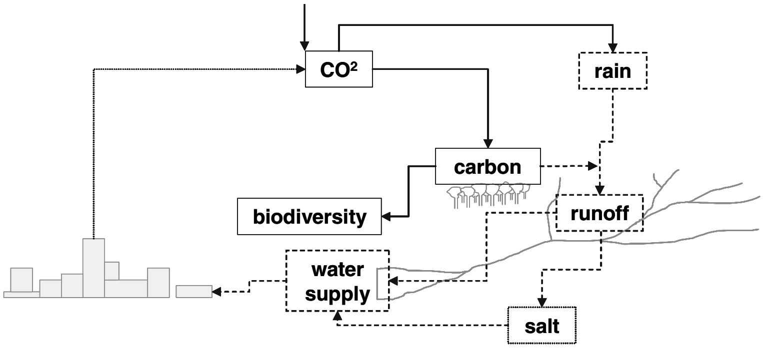

Fig. 5 Schematic diagram of stock and flows of CO_2, carbon, water, salt and biodiversity as affected by climate change and mitigation activities. Solid lines and boxes denote increases in stocks and flows, dashed lines denote decreases and dotted lines changes in either direction

- CO_2 fertilisation—increases in atmospheric carbon dioxide will increase the growth rates of vegetation unless offset by substantial reductions in rainfall and frequent drought. Vegetation will also become more drought tolerant. There is also some evidence that more efficient shallow-rooted vegetation will increase deep infiltration rates when soil moisture is high, contributing to salinity. On the other hand, deep-rooted and biodiverse vegetation should be able to make use of increased soil moisture in higher growth rates.
- Reduced water supply—the purchase of water rights may be required before plantations can be established, to compensate for the loss of water elsewhere in the catchment. This would provide a cost that may partially or wholly counterbalance the financial benefits of selling carbon.
- Species selection—large changes in climate may affect the choice of species to be planted or may send existing vegetation into decline, meaning that it acts as a source rather than as a sink. Key plant species may also need to be established in specific locations to anticipate the migration of animal species or other plants under climate change.
- Weeds and pests—changing patterns of weed and pest invasion may also affect tree survival. At present a whole cohort of Forest Red Gum, *Eucalyptus blakeleyi*, is dying throughout central and eastern Victoria, ostensibly through insect attack (Gibbons and Boak 2002) but a warming climate and persistent drought conditions may be an underlying cause.

The various policy and economic instruments available also affect the viability of sequestration options. A number of programmes are addressed in NCCMA (2003), and many of the national and state strategies affecting natural resource management are being implemented through the NCCMA, who are required to integrate these with their regional strategies. This will serve to maximise the benefits of these programmes if their aims are supported by underpinning science that can help address some of the different trade-offs shown in Fig. 5.

Financial and social instruments also need to be investigated further as does risk communication so that these issues are more widely understood within the community. Socio-economic change is also a factor. For example, the trend is to smaller farms engaged in so-called lifestyle farming. These farms increase the number of dams in the catchment also leading to reductions in regional runoff, provide benefits in terms of outside income from commuters, who emit more greenhouse gases travelling to town and work but also plant trees.

Although there are clear links between adaptation and mitigation as it affects the carbon sequestration, an integrated approach is needed—not just to integrate adaptation and mitigation—but to integrate a broad range of issues affecting natural resource management under climate change.

4 Discussion and conclusions

In this paper, we have combined two lines of investigation with regard to managing the risks of the enhanced greenhouse effect. Part 2 contains a theoretical investigation of the link between adaptation and mitigation with regard to managing the risk of climate change. The complementarity between adaptation and mitigation is critical. Exercising adaptive capacity (adapting) allows an activity to cope with successively larger changes produced by successively higher levels of global warming. Exercising mitigative capacity (mitigating) reduces the risk of climate hazards from the upper end of the projected range of change (Figs. 1–3).

Mitigation and adaptation can also be linked at the regional scale as shown in Part 3. Here, the example of sequestering carbon through revegetation requires both adaptation and mitigation issues to be dealt with, offering climate-related, salinity, biodiversity and commercial (agriculture, forestry) benefits. An integrated approach using trade-offs to maximise those benefits and minimise negative outcomes will be required. Similar approaches are likely to be required for other activities where adaptation and mitigation issues are significant, such as for agriculture and peak energy demand (Dang et al. 2003).

However, there is a discontinuity between the local and global scale that can be expressed as the difference between mitigative capacity and the demand for mitigation for a particular activity at a given time and place. The capacity to mitigate is not related to the mitigative demand for each activity, instead being related to its adaptive capacity and whether exercising this capacity is sufficient to cope with serious impacts likely to be encountered at a given level of change. Where adaptive capacity can be exercised locally, the benefits are also felt locally. Demand for mitigation will be highest when and where adaptive capacity is exceeded. The supply of mitigative capacity is local, as is the demand, but that demand is for a global good. This is the largest hurdle facing the institutions of north central Victoria. While it makes good sense to exercise both adaptive and mitigative capacity, as outlined in Part 2, mitigation needs to be integrated within a global market to meet a host of demands at the local scale.

The one available instrument to carry this out is the Kyoto Protocol, although the market is restricted to Annex 1 countries, rather than being global. The refusal of the Australian Government to sign the Protocol has prevented the north central Victorian region from accessing financial instruments under the protocol to offset carbon emissions through Kyoto-compliant revegetation. Bilateral agreements are being sought with urban local government who do not have access to land for revegetation and with industries who also wish to offset emissions (CVGA 2004). The CVGA is developing a prospectus for regional investment in permanent plantings that, in addition to providing an emission offset, would provide a range of co-benefits for biodiversity and salinity (the latter carefully managed taking account of the research described above; Dettmann 2004). The policy framework for revegetation at the state and federal level includes conservation policy regarding depleted box-ironbark forests, dryland salinity policy and funding and carbon trading frameworks (e.g., NCCMA 2003).

The implementation of adaptation and mitigation such activities may also take place at very different scales to the scales on which policy is made. Most policy affecting adaptation and mitigation is likely to be ''top down'', instituted at state, provincial or national level, while actions facilitated by those policies may be much more local. For instance, central governments are often interested in ''big ticket'' items where single investments in mitigation produce large, easy to see outcomes. This suits mitigation options for large power generation systems where there are a limited number of companies and power generators and for large-scale industrial processes. However, many of the power needs in northern Victoria may be addressed by niche generators involving both renewable energy and cogeneration.

Agriculture is similar. Despite the opportunity for mitigation of large amounts of greenhouse gases and the sequestration of carbon in vegetation and soils, there are thousands of separate enterprises to deal with and only a small amount of capacity in each enterprise. It makes sense to deal with mitigation and adaptation together on the farm scale, not least because climate will have an impact on both. Exploring on-farm mitigation options is one of the measures of the NCCAM in Table 3.

The activities of the CVGA have greatly influenced the evolution of the NCCMA five-year strategy (NCCMA 2003). Following submissions by the CVGA, the NCCMA formally adopted climate as an asset and set targets for the sequestration of CO_2 consistent with those of the CVGA. The CMA is now the most progressive of all the catchment management authorities in the states of New South Wales and Victoria with regard to climate change.

Part 2 of this paper was presented as a rationale for integrating adaptation and mitigation when managing climate change risks. This rationale has been presented to both the NCCMA and CVGA in presentations and both organisations are undertaking to apply these principles to their own particular portfolio of activities. Both groups recognise that the regional reductions in greenhouse gases will not provide direct benefits at the local level. They recognise that mitigation contributes to the atmosphere as part of the global commons, reducing climate hazards in a widely distributed benefit. They also believe that the region will receive economic benefits by being an early adopter of new technologies and measures. The need to adapt is also recognised by both bodies, as is the need to consider trade-offs between adaptation and mitigation measures in achieving the best possible outcome.

Because they have concluded that warming is inevitable, the NCCMA and CVGA believe that the advantages of investing in innovative approaches are greater (risk tolerant behaviour) than the advantages of avoidance (risk averse behaviour). A great deal of planning has gone into exploring how such investments can be made involving a broad range of actors and potential actors. It will remain to see whether this comprehensive regional approach results in a greater public awareness and an increased regional involvement in managing the risks of climate change. However, it is clear that mechanisms which can allow mitigative capacity to supply demands for mitigation at the global scale need to be developed, so that investments in adaptation and mitigation can be better integrated at the local scale.

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References

Adger WN (2001) Scales of governance and environmental justice for adaptation and mitigation of climate change. J Int Develop 13:921–931

AGO, MDB (2001) The contribution of mid to low rainfall forestry and agroforestry to greenhouse and natural resource management outcomes. Australian Greenhouse Office and the Murray Darling Basin, Canberra

AS/NZS (2004) Risk management, Australian/New Zealand standard for risk management, AS/NZS, vol. 4360. Standards Australia, Canberra

Beare S, Heaney A (2002) Climate change and water resources in the Murray Darling Basin, Australia; impacts and adaptation. ABARE Conference Paper 02.11, p 33. Available from www.abareconomics.com <http://www.abareconomics.com>

Beer T (1997) Strategic Risk Management: a case study of climate change. World Resour Rev 9:151–164

Beer T (2003) Environmental risk and sustainability. In: Beer T, Ismail-Zadeh A (eds) Risk science and sustainability: science for reduction of risk and sustainable development for society. NATO Science Series. Series II, Mathematics, Physics, and Chemistry 112. Kluwer Academic, Dordrecht, pp 39–61

Brooks N, Adger N (2005) Assessing and enhancing adaptive capacity, In: Lim B, Spanger-Siegfried E, Burton I, Malone E, Huq S (eds) Adaptation policy frameworks for climate change: developing strategies, policies and measures. Cambridge University Press, Cambridge and New York, pp 165–82

Burton I (1994) Deconstructing adaptation ... and reconstructing. Delta 5:14–15

Callaway J (2004) Adaptation benefits and costs: are they important in the global policy picture and how can we estimate them? Global Environ Change 14:273–282

Conde C, Lonsdale K (2005) Engaging Stakeholders in the Adaptation Process. In: Lim B, Spanger-Siegfried E, Burton I, Malone E, Huq S (eds) Adaptation policy frameworks for climate change: developing strategies, policies and measures. Cambridge University Press, Cambridge and New York, pp 47–66

Corfee-Morlot J, Agrawala S (2004) The benefits of climate policy. Global Environ Change Vol 14:197–199

Corfee-Morlot J, Höhne N (2003) Climate change: long-term targets and short-term commitments. Global Environ Change 13:277–293

CSIRO (2001) Climate change projections for Australia. CSIRO Atmospheric Research, Australia, p 8

CVGA (2004) Zero net emissions by 2020: leading by example. unpublished business plan. Central Victorian Greenhouse Alliance, Bendigo Australia

Dang HH, Michaelowa A, Tuan DD (2003) Synergy of adaptation and mitigation strategies in the context of sustainable development: the case of Vietnam. Climate Policy 3:S81–S96

Davis DL, Krupnick A, McGlynn (2000) Ancillary benefits and costs of mitigation: an overview, OECD Paper prepared for the Workshop on Assessing the Ancillary Benefits and Costs of GHG Mitigation Strategies held on 27–29 March 2000, OECD, Paris

Dessai S, Hulme M (2003) Does climate policy need probabilities? Tyndall centre working paper no. 34. Tyndall Centre for Climate Change Research, Norwich UK, p 42

Dettmann P (2004) City of Greater Bendigo case study. In Growing trees for geenhouse sinks in north central Victoria, an investment guide for landholders and purchasers. Central Victorian Greenhouse Alliance, Bendigo

Dowling T, Dawes WR, Evans R, Dyson P, Walker GR (2004) Prioritising upland catchments in the Murray–Darling Basin with respect to salinity benefits from afforestation. CSIRO Land and Water Technical Report 15/04, CSIRO, Canberra

Evans R, Gilfedder G, Austin J (2004) Application of the biophysical capacity to change (BC2C) model to the Little River (NSW). CSIRO Land and Water Technical Report 15/04, CSIRO, Canberra

Gibbons P, Boak M (2002) The value of paddock trees for regional conservation in an agricultural landscape. Ecol Manage Restor 3:205–210

Gitay, H, Brown S, Easterling W, Jallow B (2001) Ecosystems and their goods and services. In: McCarthy JJ, Canziani OF, Leary NA, Dokken DJ, White KS (eds) Climate change 2001: impacts, adaptation,

and vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, pp 235–342
Herron N, Davis R, Jones R (2002) The effects of large-scale afforestation and climate change on water allocation in the Macquarie River Catchment, NSW, Australia. J Environ Manage 65:369–381
Herron N, Davis R, Dawes W, Evans R (2003) Modelling the impacts of strategic tree plantings on salt loads and flows in the Macquarie River Catchment, NSW, Australia. J Environ Manage 68:37–50
Hoegh-Guldberg O (2004) Coral reefs in a century of rapid environmental change. Symbiosis 37:1–31
IPCC (2001) Climate change 2001: synthesis report. In: Watson RT, Albritton DL, Barker T, Bashmakov IA, Canziani O, Christ R, Cubasch U, Davidson O, Gitay H, Griggs D, Houghton J, House J, Kundzewicz Z, Lal M, Leary N, Magadza C, McCarthy JJ, Mitchell JFB, Moreira JR, Munasinghe M, Noble I, Pachauri R, Pittock AB, Prather M, Richels RG, Robinson JB, Sathaye J, Schneider SH, Scholes R, Stocker T, Sundararaman N, Swart R, Taniguchi T, Zhou D (eds) Cambridge University Press, Cambridge, p 397
Jones RN (2001) An environmental risk assessment/management framework for climate change. Natural Hazards 23:197–230
Jones RN (2003) Managing the risk of climate change. Paper prepared for the OECD Project on the Benefits of Climate Policy. 12–13 December 2002, Paris, ENV/EPOC/GSP(2003)22/FINAL
Jones RN (2004a) Incorporating agency into climate change risk assessments—an editorial comment. Climatic Change 67:13–36
Jones R (2004b) Managing climate change risks. In: Corfee Morlot J, Agrawala S (eds) The benefits of climate change policies: analytical and framework issues. Organisation for Economic Co-operation and Development, Paris, pp 251–297
Jones RN, Page CM (2001) Assessing the risk of climate change on the water resources of the Macquarie River Catchment. In: Ghassemi F, Whetton P, Little R, Littleboy M (eds) Integrating models for natural resources management across disciplines, issues and scales (Part 2), Modsim 2001. International Congress on Modelling and Simulation, Modelling and Simulation Society of Australia and New Zealand, Canberra, pp 673–678
Jones RN, Boer R (2005) Assessing current climate risks. In: Lim B, Spanger-Siegfried E, Burton I, Malone E, Huq S (eds) Adaptation policy frameworks for climate change: developing strategies, policies and measures. Cambridge University Press, Cambridge and New York, pp 91–118
Jones RN, Chiew FHS, Boughton WB, Zhang L (2006) Estimating the sensitivity of mean annual runoff to climate change using selected hydrological models. Adv Water Resour 29:1419–1429
Kane S, Shogren JF (2000) Linking adaptation and mitigation in climate change policy, Climatic Change 45:75–102
McCarty LS, Power M (2000) Approaches to developing risk management objectives: an analysis of international strategies. Environ Sci Policy 3:311–319
Morgan MG, Fischhoff B, Bostrom A, Atman CJ (2001) Risk communication: a mental models approach. Cambridge University Press, Cambridge, p 366
Morgan MG, Keith D (1995) Subjective judgments by climate experts. Environ Sci Technol 29(10):468–476
Mastrandrea MD, Schneider SH (2004) Probabilistic integrated assessment of ''dangerous'' climate change. Science 304:571–575
Nakiçenovic N, Swart R (eds) (2000) Emissions scenarios: special report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge UK, p 570
Natural Resource Management Ministerial Council (2004) National action plan for salinity and water quality: annual report 2002–03. Departments of Agriculture, Fisheries and Forestry and the Environment and Heritage, Canberra, p 227
NCCMA (2003) North central regional catchment strategy, 2003–2007. NCCMA, Huntly Australia, <http://www.nccma.vic.gov.au>
Nordhaus WD, Boyer J (2000) Warming the world: economic models of global warming. MIT Press, Cambridge, USA
Patt A, Dessai S (2004) Communicating uncertainty: lessons learned and suggestions for climate change assessment. Comptes Redus Geosci 337:425–441
Patwardhan A, Schneider SH, Semenov SM (2003) Assessing the science to address UNFCCC Article 2: a concept paper relating to cross cutting theme number four. Intergovernmental Panel on Climate Change, Geneva, p 13, <http://www.ipcc.ch/activity/cct3.pdf>
Petschel-Held G, Bruckner T, Schellnhuber HJ, Toth F, Hasselmann K (1999) The tolerable windows approach: theoretical and methodological foundations. Climatic Change 31:301–331
Pepper W, Leggett J, Swart R, Wasson J, Edmonds J, Mintzer I (1992) Emission scenarios for the ipcc, an update, assumptions, methodology and results. Prepared for the Intergovernmental Panel on Climate Change, Working Group I, p 115

Pielke RA Jr (1998) Rethinking the role of adaptation in climate policy. Global Environ Change 8:159–170
Power M, McCarty LS (1998) A comparative analysis of environmental risk assessment/risk management frameworks. Environ Sci Technol 32:224A–231A
Power M, McCarty LS (2002) Trends in the development of ecological risk assessment and management frameworks. Human Ecol Risk Assessment 8:7–18
Rogers M (2002) The energy footprint for north central Victoria: an initial step toward addressing climate change. LaTrobe University, Bendigo, p 12
Schneider SH (2002). Can we estimate the likelihood of climatic changes at 2100? Climatic Change 52:441–451
Smit B, Burton I, Klein RJT, Street R (1999) The science of adaptation: a framework for assessment. Mitigation Adaptation Strat Global Change 4:199–213
Smith JB, Schellnhuber J-J, Mirza MMQ (2001) Vulnerability to climate change and reason for concern: a synthesis. In: McCarthy JJ, Canziani OF, Leary NA, Dokken DJ, White KS (eds) Climate change 2001: impacts, adaptation, and vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, pp 913–967
Swart R, Mitchell J, Morita T, Raper S (2002) Stabilisation scenarios for climate impact assessment. Global Environ Change 12:155–166
Tol RSJ (2003) Adaptation and mitigation: trade-offs in substance and methods, Working paper FNU-33. Centre for Marine and Climate Research, Hamburg University, Hamburg <http://www.uni-hamburg.de/Wiss/FB/15/Sustainability/essen.pdf>
Turnpenny J, Haxeltine A, Lorenzoni I, O'Riordan T, Jones M (2005) Mapping actors involved in climate change policy networks in the UK. Tyndall Centre Working Paper 66. Tyndall Centre, University of East Anglia, Norwich UK
UNDP (2005) Adaptation policy frameworks for climate change: developing strategies, policies and measures. In: Lim B, Spanger-Siegfried E, Burton I, Malone E, Huq S (eds) Cambridge University Press, Cambridge and New York, p 266
Webster MD, Forest CE, Reilly J, Babiker M, Kicklighter D, Mayer M, Prinn R, Sarofim M, Sokolov AP, Stone P, Wang C (2003) Uncertainty analysis of climate change and policy responses. Climatic Change 61:295–320
Wheaton EE, MacIver DC (1999) A framework and key questions for adapting to climate variability and change. Mitigation Adaptation Strat 4:215–225
Whetton PH, Suppiah R, McInnes KL, Hennessy KJ, Jones RN (2002) Climate change in Victoria: high resolution regional assessment of climate change impacts. Department of Natural Resources and Environment, Melbourne, p 44
Wigley TML (2004a) Choosing a stabilisation target for CO_2. Climatic Change 67:1–11
Wigley TML (2004b) Modelling climate change under no-policy and policy emissions pathways. In: Corfee Morlot J, Agrawala S (eds) The benefits of climate change policies: analytical and framework issues. Organisation for Economic Co-operation and Development, Paris, pp 221–248
Wigley TML, Raper SCB (2001) Interpretation of high projections for global mean warming. Science 293:451–454
Wilbanks TJ, Kates RW (1999) Global change in local places: how scale matters. Climatic Change 43:601–628
Willows RI, Connell RK (eds) (2003) Climate adaptation: risk, uncertainty and decision-making. UKCIP Technical Report. UKCIP, Oxford. <http://www.ukcip.org.uk/risk_uncert/risk_uncert.html>
Yohe GW (2001) Mitigative capacity—the mirror image of adaptive capacity on the emissions side. Climatic Change 49:247–262
Yohe GW (2003) More trouble for cost-benefit analysis. Climatic Change 56:235–244
Yohe G, Toth FL (2000) Adaptation and the guardrail approach to tolerable climate change. Climatic Change 45:103–128
Zhang L, Austin J, Dawes W, Hairsine P, Durack P, Jones RN (2005) Implications of climate change for natural resources management: a preliminary assessment of the impact of climate change on catchment salt and water balances for selected catchments in Victoria. CSIRO Report to the Australian Greenhouse Office, CSIRO, Canberra
Zhang L, Dawes WR, Walker GR (2001) The response of mean annual evapotranspiration to vegetation changes at catchment scale. Water Resour Res 37:701–708